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Technical Appendix: The Clean Power Plan and Beyond

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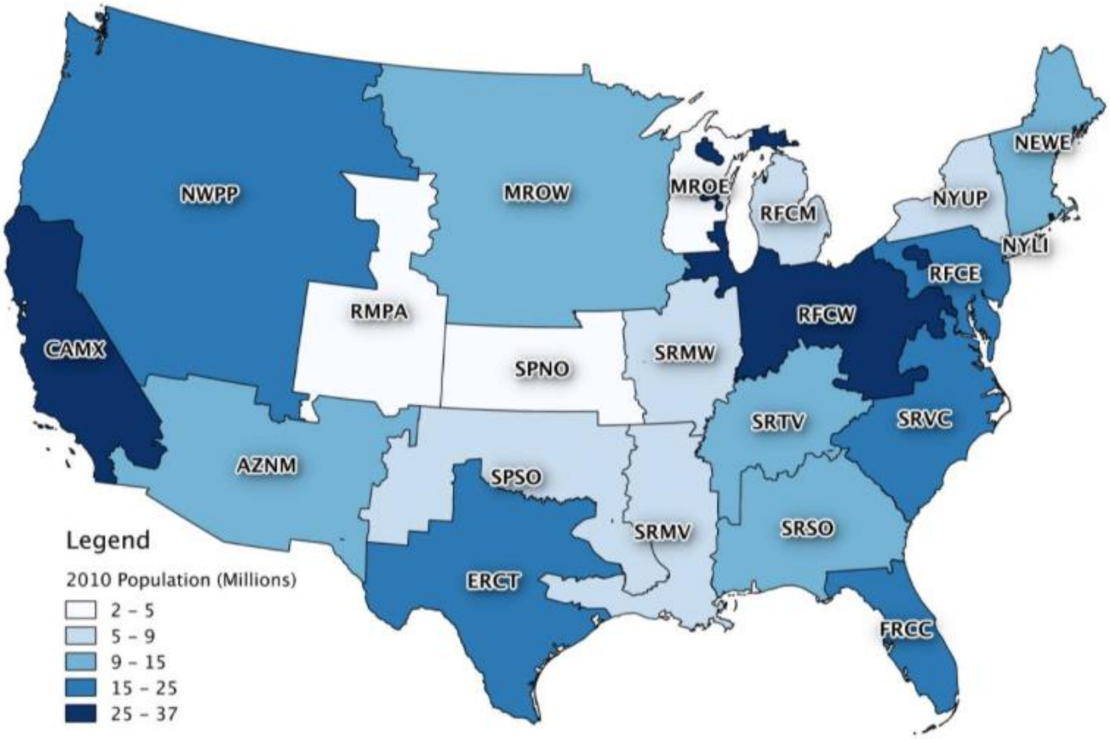
A TECHNICAL BACKGROUND ON MODELING CPP CONSTRAINTS

A.1 Modeling CPP Goals

In the electric power sector, the CPP constraints on statewide emissions intensities and state-level mass emissions are modeled through direct constraints in the GT-NEMS Electricity Market Module (EMM). Constraints at the state level are aggregated into the 22 NERC regions used for electric power modeling in the EMM weighted via a matrix of state-to-NERC-region generation.

Figure A.1. The Electricity Market Module's NERC Regions and Their Populations In 2010



(Source: Benjamin Staver, Georgia Institute of Technology)

For rate-based goals, GT-NEMS totals the emissions (lbs CO_2) from units covered by the CPP and the generation (MWh) from both covered units and units eligible for generation of Emissions Reduction Credits (ERCs). Our modeling makes use of the statewide-blend rate-based goals from the final CPP rule. For the ERC-generating units, such as wind and solar, special methodological steps are made to ensure that GT-NEMS properly accounts for the eligibility criteria defined by the CPP. First, GT-NEMS variables are used to identify ERC-generating units that are forecast to be constructed and have not yet been publicly announced by generation-owning firms – "unplanned" units. Generation from these unplanned ERC-generating units is included in the denominator of the compliance calculation for rate-based goals. Second, estimations of the ERCs available from units that have announced construction dates on or after January 1st, 2013 are made; the estimated ERCs are added to the denominator of each NERC region's compliance calculation for rate-based goals. The steps described here are necessary to reconcile the fundamental difference between the CPP's definition of "incremental generation" (generation from new capacity added after 2012) and GT-NEMS' definition of "incremental generation" (generation from unplanned units). Overall, through these steps, GT-NEMS fully accounts for ERCs in its computation of compliance with the rate-based goals.

For the mass-based goals, no special computational steps are necessary. Our modeling makes use of the mass-based goals for existing plants only defined in the final CPP rule. By default, GT-NEMS fully accounts for the benefits of low-carbon generation under the mass-based goal in its optimization of the power sector's decisions.

A.2 Definition of Affected Units

According to the CPP final rule, affected units are defined by several criteria. First, the units must be in operation or under construction on or before January 8, 2014, since that date is when EPA first proposed to regulate CO_2 emissions from existing power generation units. Second, the units must provide power to an electric service provider (e.g. a power plant) that supplies 25MW or more to the grid. Third, the units must be categorized as either (A) coal-fired or oil-fired with a single-cycle prime mover, or (B) natural-gas-fired with a combined-cycle prime mover. Natural-gas-fired units with a single-cycle prime mover are excluded, as they generally have small capacity factors and therefore small contributions to power sector CO_2 emissions.

The CPP also defines eligibility criteria for ERC-generating units. Generally, ERC-generating units must be connected to the bulk grid in some way; for example, a rooftop solar power unit that sells power to the grid would be eligible to generate ERCs, but a disconnected solar unit would not. ERC-generating units generally produce electricity without emitting CO_2, although waste-recycling options such as solid waste combustion and CO_2-storing options such as biomass burning are eligible for ERC generation. Combined heat and power units (CHP, also called "co-generation) are also allowed to generate ERCs. Units that store energy, such as pumped storage units, are not allowed to generate ERCs because storage units require power generated by existing units that may well be fossil-fired affected units from which the CPP intends to reduce CO_2 emissions.

A.3 The CPP Goals Modeled at the Regional Level

The annual trajectory of rate goals for each state, provided in Appendix 1-5 for EPA's Technical Support Document on calculating the state goals, form the foundation of the goals modeled in GT-NEMS.

The code and parameters for controlling the CPP modeling assumptions are in the main electricity module control file, EMMCNTL. There are a variety of switches to control the kind of goal to be modeled: rate versus mass, existing vs. existing + new, and the phasing of the goals (a start date and an end date). The code allows for one goal per region per year. In addition to coding the goals at the level of the EMM region, the code allows users to input the goals at the state level, and then GT-NEMS aggregates the state goals into regional goals using a state-region matrix of 2012 generation.

Table A.1 lists the resulting regional rate goal trajectories for the compliance period, 2022-2030.

Table A.1. Annual Emissions Rate Goals for Each EMM Region Modeled in GT-NEMS (Lbs-CO_2/kWh)

Region	2022	2023	2024	2025	2026	2027	2028	2029	2030
1 Tex	1325	1285	1228	1195	1163	1129	1100	1070	1041
2 Fla	1131	1099	1059	1032	1006	979	959	938	918
3 MW-east	1537	1486	1413	1374	1335	1294	1255	1215	1175
4 MW-west	1673	1615	1532	1489	1444	1399	1354	1308	1262
5 NEP-ne	903	881	856	836	816	796	785	773	763
6 NEP-nyc	1112	1081	1042	1017	991	964	945	926	906
7 NEP-li	1129	1097	1057	1031	1004	977	957	937	917
8 NEP-ups	1129	1097	1057	1031	1004	977	957	937	917
9 RF-east	1338	1297	1240	1208	1174	1140	1111	1080	1050
10 RF-mich	1525	1475	1403	1365	1325	1285	1247	1207	1168
11 RF-west	1596	1543	1465	1424	1383	1341	1299	1256	1214
12 SERC-mv	1407	1363	1301	1265	1230	1194	1161	1127	1094
13 SERC-mw	1663	1607	1524	1480	1437	1392	1347	1302	1256
14 SERC-s	1299	1259	1205	1174	1142	1109	1082	1053	1025
15 SERC-tv	1545	1494	1420	1381	1341	1300	1261	1221	1181
16 SERC-vc	1418	1372	1309	1274	1238	1202	1168	1134	1100
17 SWPP-n	1710	1650	1564	1519	1474	1428	1381	1333	1285
18 SWPP-s	1381	1338	1278	1244	1209	1174	1142	1109	1077
19 WEC-sw	1294	1254	1201	1170	1138	1106	1078	1050	1022
20 WEC-cal	1017	991	960	937	915	891	876	861	846
21 WEC-nw	1300	1261	1207	1175	1143	1111	1083	1054	1026
22 WEC-roc	1586	1532	1455	1416	1374	1332	1291	1248	1207
Total	**30018**	**29077**	**27776**	**27037**	**26286**	**25520**	**24839**	**24139**	**23450**

GT-NEMS uses the same process for aggregating the mass goals as used for aggregating the rate goals. Table A.2 lists the resulting regional mass goal trajectories for the compliance period for a policy that affects only existing units. The EIA CPP distribution requires the mass-based goals to be input in terms of million metric tons (because these were the units of the proposed-CPP's mass-based equivalents).

Table A.2. Annual Emissions Mass Goals for EMM Regions Modeled in GT-NEMS (Million Short Tons); Existing Units Only

Region	2022	2023	2024	2025	2026	2027	2028	2029	2030
1 Tex	214	207	198	194	190	185	182	180	177
2 Fla	118	115	111	109	107	104	103	102	101
3 MW-east	15	14	13	13	13	12	12	12	12
4 MW-west	117	113	107	105	102	99	97	95	93
5 NEP-ne	32	31	31	30	30	29	29	29	29
6 NEP-nyc	12	12	12	11	11	11	11	11	11
7 NEP-li	3	3	3	3	3	3	3	3	3
8 NEP-ups	22	22	21	20	20	20	19	19	19
9 RF-east	118	114	109	107	105	102	100	99	97
10 RF-mich	48	46	44	43	42	41	40	39	38
11 RF-west	371	357	340	332	325	315	309	303	295
12 SERC-mv	85	82	78	77	75	73	72	71	69
13 SERC-mw	63	60	57	56	55	53	52	51	50
14 SERC-s	117	113	108	106	104	101	100	98	97
15 SERC-tv	159	153	146	143	139	135	133	130	127
16 SERC-vc	134	129	124	121	119	115	113	112	109
17 SWPP-n	47	45	43	42	41	40	39	38	37
18 SWPP-s	92	89	85	83	81	79	78	77	75
19 WEC-sw	66	64	62	60	59	58	57	56	55
20 WEC-cal	61	60	58	57	56	54	54	54	53
21 WEC-nw	88	85	81	79	77	75	74	73	71
22 WEC-roc	52	50	48	47	46	44	44	43	42
Total:	2034	1964	1879	1838	1800	1748	1721	1695	1660

Table A.3 lists the resulting regional mass goal trajectories for the compliance period for a CPP compliance that affects existing and new units.

Table A.3. Annual Emissions Mass Goals for Each EMM Region Modeled in GT-NEMS (Million Short Tons): Existing and New Units

Region	2022	2023	2024	2025	2026	2027	2028	2029	2030
1 Tex	202	196	188	184	180	175	173	170	168
2 Fla	120	116	112	110	108	105	104	104	102
3 MW-east	15	14	14	13	13	13	12	12	12
4 MW-west	117	113	108	106	103	100	98	96	94
5 NEP-ne	33	32	31	31	30	29	29	29	29
6 NEP-nyc	13	12	12	12	11	11	11	11	11
7 NEP-li	3	3	3	3	3	3	3	3	3
8 NEP-ups	22	22	21	21	20	20	20	19	19
9 RF-east	119	115	110	108	106	103	102	100	98
10 RF-mich	48	46	44	43	42	41	40	40	39
11 RF-west	369	356	339	332	324	315	309	303	296
12 SERC-mv	86	83	79	78	76	74	73	72	70
13 SERC-mw	63	61	58	57	55	54	53	51	50
14 SERC-s	118	114	109	107	105	102	101	99	98
15 SERC-tv	111	107	102	100	98	95	94	92	90
16 SERC-vc	135	130	125	122	120	117	115	113	111
17 SWPP-n	100	96	91	89	87	85	83	81	79
18 SWPP-s	93	90	87	85	83	81	80	78	77
19 WEC-sw	71	69	66	65	63	62	61	60	59
20 WEC-cal	67	65	63	62	61	59	59	58	58
21 WEC-nw	93	90	86	84	82	80	79	78	76
22 WEC-roc	55	53	51	50	48	47	46	45	44
Total	2053	1983	1899	1862	1818	1771	1745	1714	1683

There is an array of switches for controlling if a region complies with a rate- or mass-based goal. We focus on mass-based goals, but also take advantage of the goal heterogeneity that GT-NEMS affords, in our “hybrid” case where the South is assumed to adopt rate-based goals, while the rest of the nation adopts mass-based goals. GT-NEMS also has switches that identify the types of EGUs that are defined as “affected” units and the types of EGUs that are allowed to generated ERCs under a rate-based goal. The default switches for affected units matched the EPA rules and so were not changed.

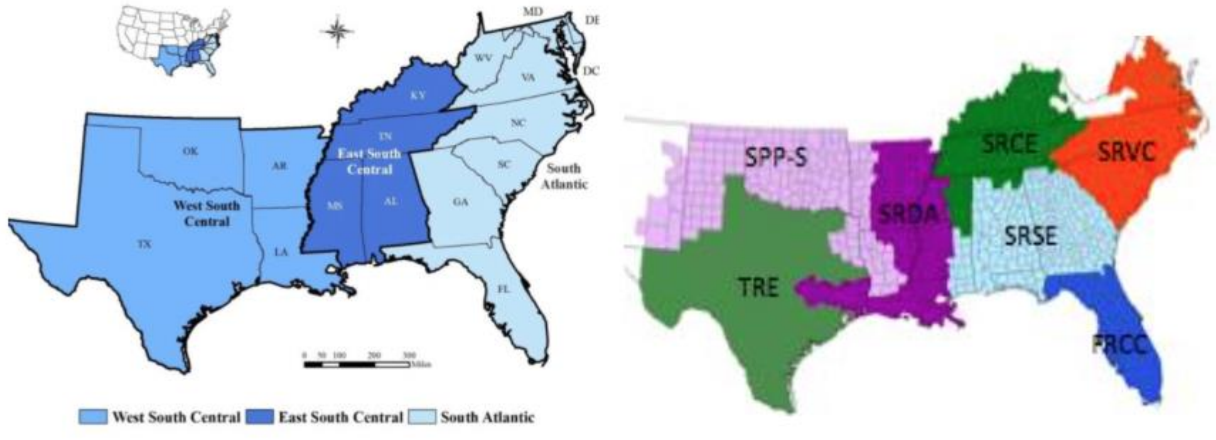
GT-NEMS allows trading under either mass- or rate-based goals, trading either emission allowances or ERCs. We turned off the trading options, disallowing inter-regional trading, because the trading features were designed to meet the proposed CPP rule specifications and might not be applicable to the final CPP rule. By turning trading off, there is no trading across regions, but to the extent that NERC regions span multiple states, there is implicitly trading across states within regions.

A.4 Modeling the CPP Goals in the South

GT-NEMS uses the 22 regions defined by the North American Electric Reliability Corporation (NERC) to forecast electricity supply and demand (Figure A.2). Seven NERC regions are used in this study to define the South. These include four divisions of the Southeast Reliability Council (SRDA, SRCE, SRSE, and SRVC), the Southern Power Pool-South (SPP-S), the Texas Reliability Entity (TRE), and the Florida Reliability Coordinating Council (FRCC). The NERC sub region names are shown in Table A.4.

The demand-side modules of GT-NEMS are based on data for nine Census Divisions, including three that cover 16 states in the South and the District of Columbia (DC).

Figure A.2. Census Division and NERC Regions in The South



Census Divisions in the South

NERC Regions in the South

Table A.4. NERC Regions in the South: Names and Appreviations

Abbreviation	NERC Sub Region Name	Geographic Name
1. TRE	Texas Regional Entity	Texas
2. FRCC	Florida Reliability Coordinating Council	Florida
12. SRDA	SERC Reliability Corporation - Delta	Mississippi Delta
14. SRSE	SERC - Southeast	Georgia & Alabama

15. SRCE	SERC – Central	Tennessee Valley
16. SRVC	SERC – Virginia & Carolinas	Virginia & Carolinas
18. SPPS	Southwest Power Pool South	Southern Plains

A.5 Modeling a Price on Carbon

Modeling of CO_2 emissions reduction policies beyond the Clean Power Plan appears at several points within the working paper and is rationally achieved through the introduction of carbon pricing in certain GT-NEMS scenarios. The working paper explores the impacts of, on the one hand, forward-looking CO_2 emissions reduction policies that are implemented in tandem with the Clean Power Plan, and on the other hand, CO_2 emissions reduction policies implemented post-2030. The working paper makes no assumptions about the particular form such policies might take, e.g., renewable portfolio standards, energy-efficiency resource standards, CO_2-intensity-based standards, or a cap-and-trade scheme. Instead, certain scenarios in the working paper attempt to reveal how a policy that is effective at reducing CO_2 emissions beyond the requirements of the Clean Power Plan would impact cost-minimizing behavior in the electric power sector. To model a CO_2 emissions-reducing policy beyond the Clean Power Plan, the working paper uses a carbon pricing mechanism.

Several grounds justify the use of carbon pricing as a model CO_2 emissions-reducing policy. A carbon pricing model provides explication of the shadow price of carbon introduced by a CO_2 emissions reduction policy beyond the Clean Power Plan, providing a transparent communication of the stringency of the policy. Carbon pricing allows cost-minimizing power sector behavior to engage all mechanisms for CO_2 emissions reductions, including renewable energy deployment, fossil plant heat rate improvement, and energy efficiency resources

AEO 2014 includes two side cases with \$10 or \$25 carbon allowance fee per metric ton of CO_2 emissions (in 2012 dollars). Using the same modeling methods, we applied \$20/metric ton of CO_2 emission tax in electric power sector.

A carbon tax (or carbon allowance fee) can be modeled using two input files—EPMDATA and EPMCNTL. EPMDATA allows us to assign a year-by-year value to carbon dioxide emissions as a proxy for policies to mitigate CO2 emissions. EPMCNTL provides option flags to select affected end-use sectors. By switching an electric power sector flag from False to True, we can set the carbon tax applies to electric power sector only.

EPMDATA is designed using a unit of 1987 dollar/KG of carbon. To model \$20/ton of CO_2 (in 2012 dollars) starting from 2022 with no escalation through 2050, we followed unit conversion steps as following:

\$20/metric ton of CO_2 in 2012 dollars

- Convert to in 2022 dollars using Consumer Price Index (CPI) projection by Oregon State University (download available at http://liberalarts.oregonstate.edu/spp/polisci/faculty-staff/robert-sahr/inflation-conversion-factors-years-1774-estimated-2024-dollars-recent-years/individual-year-conversion-factor-table-0)
  For example, CPI factor converting from 2012 to 2022 is 1.233.

- Convert to $/KG of CO_2 in 2022 dollars (multiplier 0.001)
- Convert to $/KG of CO_2 in 1987 dollars (CPI factor from 1987 to 2022 is 2.490)[1] [2]
- Convert to $/KG of carbon in 1987 dollars (multiplier 44/12=3.667)

As a result, $0.036317/KG of carbon in 1987 dollars is assigned in EPMDATA from 2022 through 2050.

Specifications for the “CO2fee5 after2022, no escalation rate (111(d)) Case” are as follows:

20	$/metric ton CO_2 in 2012 dollars
24.66	$/metric ton CO_2 in 2022 dollars
0.02466	$/KG CO_2 in 2022 dollars
0.009904593	$/KG CO_2 in 1987 dollars

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[1] http://oregonstate.edu/cla/polisci/download-conversion-factors

[2] http://liberalarts.oregonstate.edu/spp/polisci/faculty-staff/robert-sahr/inflation-conversion-factors-years-1774-estimated-2024-dollars-recent-years/individual-year-conversion-factor-table-0

B Modeling Distributed and Utility-Scale Photovoltaics

This appendix documents the modeling assumptions for distributed and utility-scale photovoltaics used in the “EE+Solar” scenario that supports Georgia Tech’s analysis of the Clean Power Plan (CPP). In addition to updating the cost assumptions of distributed and utility-scale solar, we also model the updated tax extenders (for solar and wind power) and the Clean Energy Incentive Program.

B.1 Distributed Solar Photovoltaics

The “EE+Solar” scenario updates the cost assumptions of distributed solar in the residential and commercial sector and utility-scale solar in GT-NEMS using data from three major sources.

- Annual Energy Outlook (AEO) 2015 (EIA, 2015a)
- Photovoltaic System Pricing Trends: Historical, Recent, and Near-Term Projections (Feldman et.al., 2015)
- U.S. Solar Market Insight Report. (GTM/SEIA, Q1 and Q2 2015)

A literature review of future system-installed costs using these sources is conducted to cover the range of cost projections. The median and average values are then calculated and they become the base of GT-NEMS CPP solar PV cost updates.

Tracking the Sun VIII (Barbose et. al., 2015) and Utility-scale Solar 2014 (Bolinger et. al., 2015) produced by Laurence Berkeley National Laboratory were also examined. However, because they focus on analyzing historical cost trends rather than making projections about future costs, they are used as reality checks for the characterization of current costs.

For distributed solar, AEO 2015, compared to AEO 2014, adjusted the system-installed costs of residential and commercial solar PV downward to reflect falling solar PV system costs. However, the costs are still too high compared to evidence collected by Tracking the Sun VIII (LBNL, 2015). As a result, lowering the AEO cost assumption by 20% produces a second AEO-related data point.

By October 2015, GTM/SEIA had issued two quarterly reports analyzing the 2015 U.S. solar PV cost trends, including system costs. They become part of the data used to update the 2015 costs.

The Photovoltaic System Pricing Trends: Historical, Recent, and Near-Term Projections (Feldman et.al, 2015) report conducted by the National Renewable Energy Laboratory (NREL) includes both historical cost analysis based on LBNL’s Tracking the Sun VIII and cost projections from Bloomberg New Energy Finance (BNEF) and Deutsche Bank.

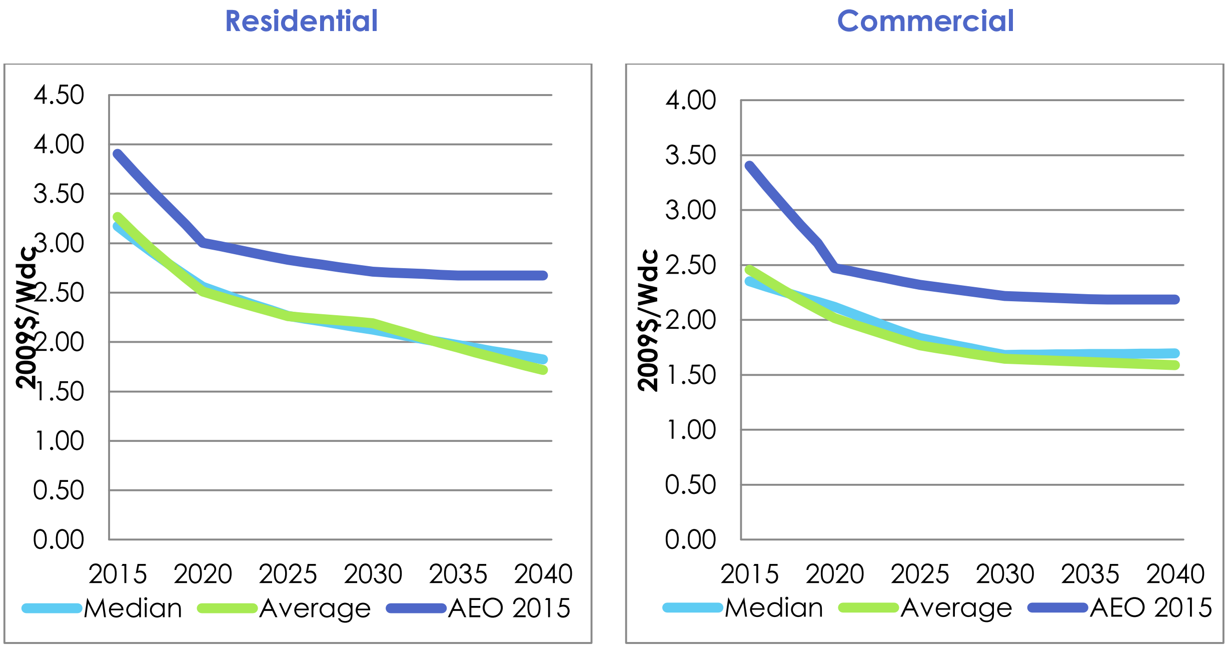
Because of the challenging nature of cost forecasting, many sources used in this study do not extend their projections beyond 2020. The two sources that have long-term cost projections are AEO 2015 and BNEF.

Table B.1 summarizes the data points used to update the residential and commercial distributed solar PV cost assumptions. All values are converted to 2009 dollar per W-dc, suitable for GT-NEMS. Median and mean costs for 2015, 2020, 2025, 2030 and 2035 are calculated, and linear cost reduction is assumed between major years. Figure B-1 and B-2 illustrate the new cost trajectories, in comparison to the AEO 2015 assumptions. The median and mean costs track closely to each other. This study uses the median cost trajectory to generate the new distributed solar modeling assumptions. The new assumptions are imported to kgentk and rsgentk to replace the default AEO 2015 reference case cost assumptions for commercial and residential solar PV system, respectively.

Table B.1. Data Sources Used by GT-CPP Distributed Solar Assumption Updates

Installed Cost (2009$/Wdc)	2015		2020		2025		2030		2035	
	Residential	Commercial	Residential	Commercial	Residential	Commercial	Residential	Commercial	Residential	Commercial
AEO 2015	3.91	3.58	3.00	2.47	2.83	2.32	2.71	2.22	2.66	2.18
AEO 2015 w. 20% CR	3.12	2.73	2.40	1.98	2.27	1.86	2.16	1.78	2.13	1.75
GTM/SEIA Q1	3.25	1.98								
GTM/SEIA Q2	3.17	1.93								
BNEF High	3.62	2.72	2.81	2.27	2.27	1.81	1.81	1.59	1.81	1.63
BNEF Low	2.72	1.81	1.99	1.36	1.68	1.09	2.08	1.00	1.18	0.91
Deutsche Bank: Solar City	3.17		2.72							
Deutsche Bank: Vivint Solar	3.17		1.72							
BNEF US High	3.81		3.17							
BNEF US Low	2.72		2.27							
Median	**3.17**	**2.35**	**2.56**	**2.12**	**2.27**	**1.83**	**2.12**	**1.68**	**1.97**	**1.69**
Mean	**3.27**	**2.46**	**2.51**	**2.02**	**2.26**	**1.77**	**2.19**	**1.65**	**1.94**	**1.62**

Figure B.1. Residential and Commercial Solar PV Cost Updates



B.2 Utility-Scale Solar

Similarly for utility-scale solar, a review of the three major sources produced a range of utility-scale solar PV costs for 2016, as summarized in Table B.2. Unlike distributed solar, GT-NEMS does not explicitly assumes an annual solar system cost trajectory. Instead, a learning function calculates the PV system cost based on the first of its kind PV cost in 1999 and learning rates.

As indicated in Table B.2, the new median value produced by the literature review is 29% lower than the AEO 2015 assumption. This study then applies the same amount of cost reduction to the 1999 utility PV system cost, reducing it from $2,070/kW to $1,468/kW (in 1987$). This value becomes the new input to the ECPDATX file, which controls the utility-scale solar PV cost assumption in GT-NEMS. The learning rates used in GT-NEMS is inline with the literature, and as a result, no update is made to it.

Table B.2. Data Sources Used by GT-NEMS CPP Utility-scale Solar Assumption Update

2013$/W-ac	2016 Utility-scale Solar Cost
AEO 2015	3.12
AEO 2015 w. 20% CR	2.50
Duetche Bank- First Solar	1.87
Duetche Bank- SunEdison	2.12
BNEF US High	2.21
BNEF US Low	1.48
LBNL/NREL	3.05
Median	2.21
Mean	2.33

This study assumes the same learning rates used in AEO 2015. A three-stage learning function is used to project the future cost of solar PV. Table B-3 summarizes the learning rate and number of PV installed capacity doublings assumed in each stage.

Table B.3. Three-Stage Learning Used in AEO 2015

	Number of Doublings in Stage 1	Number of Doublings in Stage 2	Number of Doublings in Stage 3	Stage 1 Learning Rate	Stage 2 Learning Rate	Stage 3 Learning Rate
PV Module	1	5	500	0.2	0.1	0.01
BOS	1	5	500	0.2	0.1	0.01

BOS = Balance of System

B.3 ITC and PTC Extension

On December 18, 2015, both chambers of the U.S. Congress passed an omnibus spending bill that included a provision to extend the investment tax credits (ITC) for commercial and residential solar and the expired production tax credit (PTC) for wind.

PTC is extended at its current 2.3¢/kWh rate, and presumably remains indexed to inflation, but adjusted down at the following schedule consistent with DOE's description of the Renewable Electricity Production Tax Credit.:[3]

- 2015 and 2016: 100% of current tax credit rate
- 2017: 80% of current rate
- 2018: 60% of current rate
- 2019: 40% of current rate
- 2020: phase out

The newly extended ITC is scheduled as following for both utility-scale and distributed (commercial and residential) solar PV (we do not apply the ITC to solar thermal systems because of their negligible anticipated deployment during the CPP compliance period). The ITC subsidies decline as follows:

- 2017 – 30%
- 2018 – 30%
- 2019 – 30%
- 2020 – 26%
- 2021 – 22%
- Utility-scale solar stays at 10% after 2021
- No ITC for distributed solar after 2021

This study uses three GT-NEMS input files to model the tax credit extensions.

Kgentk in the GT-NEMS commercial sub-module governs the distributed energy sources in the commercial sector, including solar and wind. In particular, the "Tax Credit Pct" variable controls the

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[3] http://energy.gov/savings/renewable-electricity-production-tax-credit-ptc

percentage of ITC granted to different distributed energy sources on an annual basis. This study updates the "Tax Credit Pct" variable for solar according to the scale above to reflect the newly extended ITC schedule. Although kgentk does not have a variable for production tax credit that is in the ¢/kWh term, it does allow ITC to be used as a proxy for PTC. Therefore, a 30% ITC is used as a proxy of the 2.3¢/kWh PTC for wind, and the percentage declines following the same schedule of wind PTC.

Rsgentk in the GT-NEMS residential sub-module has identical functions to kgentk. A similar exercise was carried out to update the ITC and PTC schedule for commercial solar as well as residential solar and wind.

Utility wind also receives an extended PTC at the exact same schedule as distributed wind. In ecpdat.x, a NEMS input file in the electricity sub-module that controls various type of electricity generation including wind, the default PTC is modeled through variable "%PTCSUB" as a constant value that ends on 2015. To reflect the latest wind PTC, this study instead switches to an annual PTC modeling approach by turning "YRSW%" variable from 0 to 1 for wind, and changed the last year of subsidy, i.e. the "UPGSYL" variable, from 2015 to 2019. The actual PTC values for the time period between 2016 and 2019 are set to 1.83¢/kWh, 1.46¢/kWh, 1.1¢/kWh, and 0.73¢/kWh, respectively, in 2004$.

For utility-scale solar, ITCSUB variable in the ECPDATX file allows the model to specify a certain level of ITC for a list of technologies, including utility-scale solar. The default assumption is that a 10% ITC will be in place from 2017 onward. This study applies the newly extended ITC schedule for solar at the higher levels listed above, through the ITCSUB in order to model its impact on solar deployment and carbon emission reductions.

B.4 Clean Energy Incentive Program (CEIP) via Solar and Wind

In the official ruling of the Clean Power Plant, a Clean Energy Incentive Program is established to incentivize early adoption, specifically in 2020 and 2021, of clean energy in the form of energy efficiency for low-income communities and renewable energy. The goal is to achieve 300 million short tons of CO_2 emission reduction between 2020 and 2021. This study assumes that the incentivizing effect of CEIP is equivalent to an even longer and more robust ITC and PTC program. In particular, this study assumes that instead of sliding down from 30% in 2019 to 26% in 2020 and 22% in 2021, the solar ITC would remain at 30% for the two years concerned by CEIP for both utility-scale and distributed solar. For utility and distributed wind, rather than phasing out in 2020, a PTC equivalent to 60% of the 2015 value would stay for 2020 and 2021. The prolonged and strengthened solar ITC and wind PTC are expected to emulate the CEIP program and drive more growth in solar and wind adoption in 2020 and 2021, which would contribute to the CO_2 reduction goal of CEIP.

Ideally, utility solar and wind should also be an integral part of the CEIP program; however, due to modeling difficulties with inserting additional tax credits to the ECPDATX file in NEMS, they were not modeled in this study.

B.5 Solar PV System Results

The projected solar electricity generation would increase significantly from the 2012 level under both the Solar PV Cost Adjustment scenario and the scenario with the ITC, PTC and the CEIP. The results shown in the following tables, figures, and text do not properly reflect the impact of the tax extenders because of modeling difficulties that were identified and then fixed as a result of the analysis that follows. The cost adjustments were properly modeled and are accurately described below.

In the Solar Cost Adjustment scenario, the residential sector would have the largest increase in solar electricity generation across all three sectors, marking a 981% increase from the 2012 level. In terms of the absolute amount of electricity generated, the utility sector leads with a 33.12 TWh generation in 2030. However, in the Solar PV Cost Adjustment + ITC/PTC Extension + CEIP scenario, the residential sector would have both the largest solar electricity generation as well as the greatest increase from the 2012 level.

Figures B.1 to B.3 show the comparison between the two modeled scenarios and the AEO 2015 reference case, respectively. The common theme is that solar electricity generation would increase significantly from the reference case, although the change in the utility sector would come later in the time period.

Table B.4. Solar Electricity Generation in GT-CPP Solar Scenarios

	Solar PV Cost Adjustment					
	Residential		Commercial		Utility	
	Generation (TWh)	% Increase	Generation (TWh)	% Increase	Generation (TWh)	% Increase
Solar PV Cost Adjustment Scenario						
2012	2.45	--	4.61	--	3.30	--
2015	6.85	180%	7.14	55%	19.68	496%
2020	11.34	363%	9.12	98%	29.60	796%
2025	17.98	634%	13.90	202%	30.38	820%
2030	26.48	981%	20.93	354%	33.12	903%
2035	36.43	1387%	28.67	522%	40.42	1124%
2040	48.00	1860%	36.99	703%	57.35	1637%
Solar PV Cost Adjustment + ITC/PTC Extension + CEIP						
2012	2.45	--	4.61	--	3.30	--
2015	6.85	180%	7.14	55%	19.68	496%
2020	19.85	711%	10.59	130%	29.57	796%
2025	28.33	1057%	15.35	233%	30.34	819%
2030	36.71	1399%	22.15	381%	33.96	928%
2035	46.49	1798%	29.67	544%	42.20	1178%
2040	57.85	2262%	37.82	721%	63.33	1818%

Figure B.2. Solar Electricity Generation in the Residential Sector

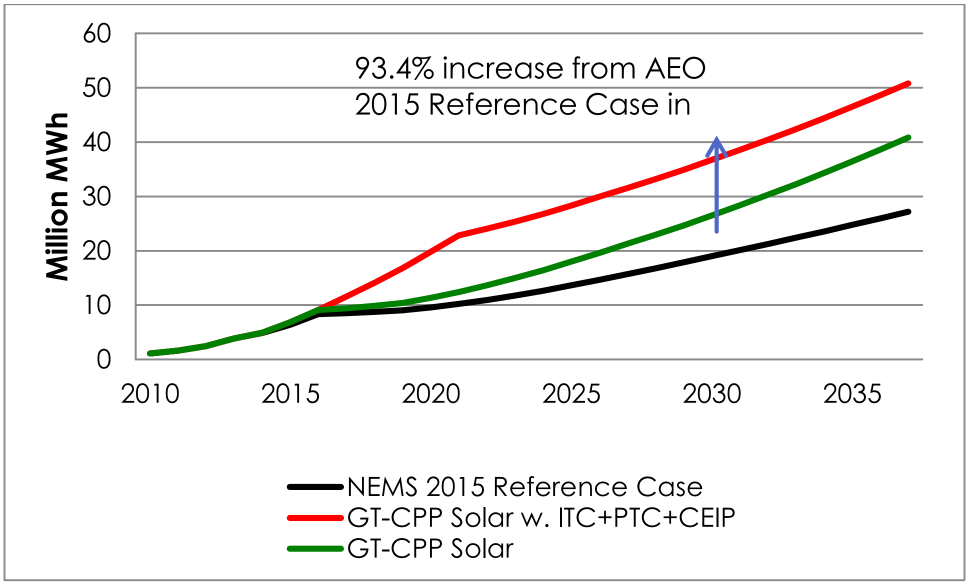
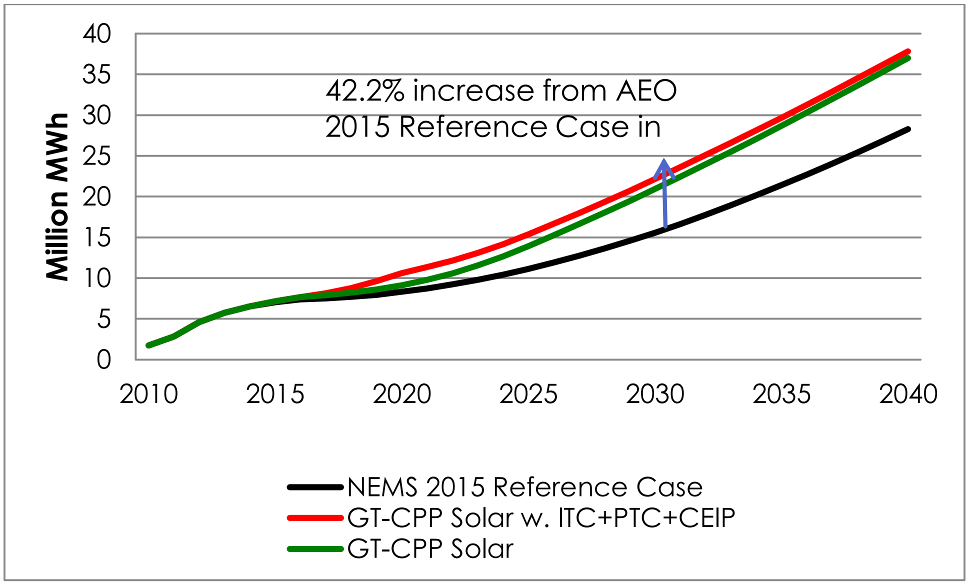


Figure B.3. Solar Electricity Generation in the Commercial Sector



Electricity rates would be higher for all three end-use sectors under both modeled scenarios, and there is no statistically significant difference between the two scenarios (Table B.5). The rate hike relative to the Reference case would reach its peak between 2025 and 2030 (ranging from 2.6 to 2.7% above the Reference case in 2030) and then begin to fall. By 2040, both modeled scenarios show less than 1% rate increase from the Reference case. Compared to 2012, electricity prices for all three end-use sectors would continue to rise regardless of the scenario.

Figure B.4. Solar Electricity Generation in the Utility Sector

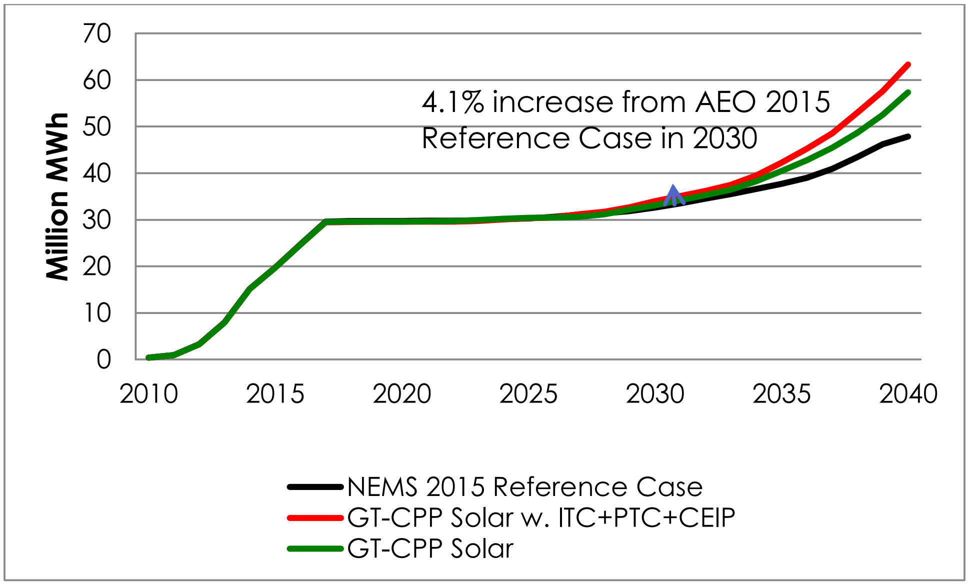


Table B.5. Electricity Rate Impacts of Solar Scenarios

	Residential		Commercial		Industrial	
	Rate (¢/kWh)	% Increase	Rate (¢/kWh)	% Increase	Rate (¢/kWh)	% Increase
Solar PV Cost Adjustment Scenario						
2012	12.06	0%	10.24	0%	6.75	0%
2015	12.30	1.4%	10.30	1.3%	7.17	1.1%
2020	13.23	2.6%	10.90	2.5%	7.40	2.1%
2025	13.89	2.7%	11.34	2.3%	7.79	2.1%
2030	13.97	2.9%	11.34	2.7%	7.85	2.6%
2035	14.20	2.0%	11.48	1.6%	8.05	1.4%
2040	14.65	0.9%	11.88	0.5%	8.64	0.2%
Solar PV Cost Adjustment + ITC/PTC Extension + CEIP						
2012	12.06	0%	10.24	0%	6.75	0%
2015	12.30	1.4%	10.30	1.3%	7.17	1.1%
2020	13.25	2.6%	10.90	2.5%	7.40	2.2%
2025	13.89	2.8%	11.36	2.5%	7.80	2.2%
2030	13.97	2.9%	11.35	2.7%	7.85	2.6%
2035	14.20	2.0%	11.48	1.6%	8.06	1.5%
2040	14.65	0.7%	11.86	0.4%	8.45	0.0%

With the updated solar PV cost, extended ITC and PTC for wind and solar, as well as the CEIP, CO_2 emissions from the residential, commercial, and utility sector would decrease in the next 25 years compared to the reference case (Figure B.6). However, solar and wind alone are not enough to dampen the overall increase of CO_2 emission in the commercial and utility sector in the next 25 years. Emissions would increase by around 7% for these two sectors by 2030, compared to the 2012 level. Nevertheless, a more positive sign can be seen in the residential sector, where the CO_2 emissions under the two modeled scenarios would not only decrease from the Reference case but they would also be slightly lower than the 2012 level. CEIP alone would contribute 47 million short tons of CO_2 savings in 2020 and 2021.

Table B.6. CO_2 Emission Reductions Under the Solar Scenarios

	Residential CO_2 Emission		Commercial CO_2 Emission		Utility CO_2 Emission	
	Emission (Mil MMT CO_2eq)	% Change vs. Reference Case	Emission (Mil MMT CO_2eq)	% Change vs. Reference Case	Emission (Mil MMT CO_2eq)	% Change vs. Reference Case
Solar PV Cost Adjustment Scenario						
2012	1044	--	933	--	2035	--
2015	1082	3.7%	968	3.8%	2047	0.6%
2020	1055	1.1%	971	4.1%	2108	3.6%
2025	1040	-0.4%	981	5.2%	2161	6.2%
2030	1041	-0.3%	1000	7.2%	2183	7.3%
2035	1037	-0.6%	1021	9.4%	2187	7.5%
2040	1031	-1.2%	1042	11.8%	2189	7.5%
Solar PV Cost Adjustment + ITC/PTC Extension + CEIP						
2012	1044	--	933	--	2035	--
2015	1083	3.7%	969	3.8%	2047	0.6%
2020	1051	0.7%	971	4.1%	2104	3.4%
2025	1035	-0.9%	980	5.1%	2157	6.0%
2030	1034	-0.9%	998	7.0%	2174	6.8%
2035	1030	-1.3%	1018	9.2%	2176	6.9%
2040	1023	-1.9%	1039	11.4%	2177	7.0%

Electricity bills for the residential, commercial, and industrial sector would be higher under both solar scenarios compared to the Reference case, except for the late 2030s in the residential and commercial sector (Table B.4). Electricity consumption would decline in the residential and commercial sector from 2019 onward, however the decrease is small – at most a 1.5% decline for the residential sector and 1.1% for the commercial sector – compared to the increase in electricity rates. As a result, consumers from both sectors would have to pay higher electricity bills. Electricity consumption would increase for the industrial sector under both solar scenarios, which leads to even higher electricity bills.

Table B.7. Impacts of Solar Scenarios on Electricity Bills

	Residential		Commercial		Industrial	
	Electricity Bill (Billion 2013$)	% Change	Electricity Bill (Billion 2013$)	% Change	Electricity Bill (Billion 2013$)	% Change
Solar PV Cost Adjustment Scenario						
2012	56.5	0.0%	46.4	0.0%	22.7	0.0%
2015	59.2	1.6%	47.9	1.2%	23.7	1.1%
2020	63.9	2.0%	52.3	2.0%	28.3	4.3%
2025	67.6	1.7%	56.1	1.4%	32.6	7.5%
2030	70.0	1.5%	58.3	1.4%	33.6	8.6%
2035	73.2	0.4%	61.3	0.4%	34.3	6.7%
2040	78.0	-0.8%	66.5	-0.6%	36.3	4.4%
Solar PV Cost Adjustment + ITC/PTC Extension + CEIP						
2012	56.5	0.0%	46.4	0.0%	22.7	0.0%
2015	59.2	1.6%	47.9	1.2%	23.7	1.1%
2020	64.3	2.6%	52.3	2.0%	28.3	4.3%
2025	68.0	2.4%	56.1	1.4%	32.6	7.5%
2030	70.5	2.3%	58.3	1.5%	33.6	8.6%
2035	73.7	1.2%	61.4	0.5%	34.3	6.7%
2040	78.6	0.0%	66.6	-0.5%	36.3	4.5%

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C Residential Energy-Efficiency Scenario

C.1 Modeling the Energy Efficiency of Residential Buildings

In the residential sector, we strengthen the representation of appliance standards in NEMS. The U.S. is among the earliest adopters of a nation-wide appliance standards program. The policy design involves an incremental, consensus-oriented process, generally involving key stakeholders, namely manufacturers, consumer advocates, experts, and non-profit organizations (Sachs, 2012). During the open process, manufacturers negotiate with environmental groups and other stakeholders to reach consensus agreements, which usually become the precursors of new standards. The Department of Energy (DOE) applies engineering-economics analysis to the proposed new rule, weighing the benefits and costs, including the trade-off between the increased capital costs and decreased energy costs of the more efficient appliances. The analysis process usually takes about three years before DOE issues the final rule. There is another 3-5 years before mandatory compliance so that the market has some time for adjustment (Desroches, Garbesi, Kantner, Buskirk, & Yang, 2013; Lee, Groshans, Gurin, Cook, & Walker, 2012)

Evidence has shown that appliance standards are effective in expanding energy-efficiency adoption and achieving energy savings. Some of the existing state and federal standards have significantly improved efficiencies for gas furnaces, central air conditioners, and refrigerators (Desroches et al., 2013). Motivated by both R&D and regulations limiting energy use, the annual energy consumption of refrigerators has declined by 70%, along with decreasing retail prices, increased capacity, and the addition of premium features (Desroches, Hafemeister, Kammen, Levi, and Schwartz, 2011). Other appliances regulated by standards have also seen significant improvement in their energy efficiency.

In NEMS, the Residential Demand Module (RDM) contains energy efficiency and cost characterizations across three groups of residential technologies—appliances/equipment, lightings, and miscellaneous electronics. Three input files, rsmeqp, rsmlgt, and rsmels, provide equipment cost and performance technology "menus" that provide available options for the three groups of major end uses. In 2015, the EIA updated cost/efficiency characteristics for residential building technologies, following their publication, "Technology Forecast Updates" (Navigant Consulting, Inc. 2014), which provides baseline and projected cost and efficiency characteristics for the business-as-usual and advanced cases. We draw most of our assumed appliance standards from those modeled in the AE02014 "Integrated High Demand Technology" side case, which represent generally modest improvements in efficiency and lower costs over the 25-year planning horizon (EIA, 2014, p. E-8). In addition, we compared the 2015 NEMS updates to the AEO 2014 High Tech side case, and applied more aggressive efficiency and lower costs to our modeling.

Table C.1 shows assumptions for efficiency improvements and cost reductions. These assumptions are strengthened in several targeted areas: (1) including room AC units, refrigerators, freezers, where we see significant improvements in appliance standards (2) geothermal heat pump, electric water heater, dishwasher, and clothes dryer, where we see the 2015 NEMS's updates are more aggressive and (3) lighting and miscellaneous electric uses, where we rely on High Tech assumptions for costs and efficiency.

In Table C.1, energy efficiency is defined in different ways. Space heaters and coolers are described in terms of heat per unit energy (Coefficient of Performance (COP) or annual fuel utilization efficiency

(AFUE)). Water heaters are described by their Energy Factor (EF). Most of cooking, clothes washing, and refrigeration are described by a unit energy consumption (UEC) typically in units of kWh per year).

Table C.1. Efficiency Improvements and Capital Costs for Residential Appliances and Equipment*

End-Use Equipment (Efficiency Metrics)	Type	Available Year		Energy Efficiency	Installed Capital Cost for New Home ($2010 per unit)	Retail Capital Cost for Replacement ($2010 per unit)
Space Heating						
Electric Furnace	1	2010	2013	1	1900	1620
(COP)	1	2014	2050	1	1900	1620
Electric Heat Pump	2	2010	2014	2.26	2400	3110
(COP)	2	2015	2050	2.4	2475	3185
	3	2010	2014	2.4	3225	4235
	3	2015	2050	2.58	3425	4435
	4	2010	2019	2.49	3575	4725
	4	2020	2029	2.78	3750	5050
	4	2030	2050	2.8	3750	5050
	5	2010	2013	3.14	4000	5300
	5	2014	2029	3.22	4125	5495
	5	2030	2050	3.52	3500	4800
Natural Gas Furnace	6	2010	2012	0.78	2500	1800
(AFUE)	6	2013	2050	0.8	2500	1800
	7	2010	2012	0.8	2500	1800
	7	2013	2013	0.8	2500	1800
	7	2014	2050	0.8	2500	1800
	8	2010	2010	0.9	1925	1835
	8	2011	2050	0.9	2750	2330
	9	2010	2050	0.95	3200	2800
	10	2010	2050	0.98	3750	3330
Natural Gas Radiator	11	2010	2012	0.8	3300	2540
(AFUE)	11	2013	2050	0.82	3500	2740
	12	2010	2050	0.85	4250	3470
	13	2010	2013	0.98	4000	3600
	13	2014	2050	0.99	4000	3600

Kerosene Furnace	14	2010	2012	0.8	3250	2790
(AFUE)	14	2013	2050	0.83	3500	3020
	15	2010	2050	0.85	3750	3250
	16	2010	2050	0.98	4750	4250
LPG Furnace	17	2010	2012	0.78	2500	1800
(AFUE)	17	2013	2050	0.8	2500	1800
	19	2010	2050	0.9	2750	2330
	20	2010	2050	0.95	3200	2800
	21	2010	2050	0.98	3750	3330
Distillate Furnace	22	2010	2012	0.8	3250	2790
(AFUE)	22	2013	2050	0.83	3500	3020
	23	2010	2050	0.85	4750	4250
	24	2010	2050	0.98	4750	4250
Distillate Radiator	25	2010	2012	0.8	3300	2540
(AFUE)	25	2013	2050	0.82	3500	2740
	26	2010	2050	0.85	4250	3470
	27	2010	2013	0.98	4000	3600
	27	2014	2050	0.99	4000	3600
Wood Heaters (COP)	28	2010	2050	1	4500	4100
Geothermal Heat Pump	29	2010	2016	3.3	5000	5000
(COP)	29	2017	2019	3.5	5000	5000
	29	2020	2050	3.7	5000	5000
	30	2010	2050	5	6500	7100
NG Heat Pump	31	2010	2019	1.3	4500	5100
(COP)	31	2020	2050	1.5	4250	4600
Space Cooling						
Room Air Conditioners	1	2010	2013	2.87	275	275
(COP)	1	2014	2050	3.22	295	295
	2	2010	2013	3.17	290	290
	2	2014	2029	3.22	295	295
	2	2030	2050	3.52	455	455
	3	2010	2019	3.37	565	465
	3	2020	2024	3.57	632.8	520.8
	3	2025	2029	3.77	694.95	571.95

	3	2030	2050	4.31	830.55	683.55
Central Air Conditioning	4	2010	2050	4.02	3200	2880
(COP)	5	2010	2019	4.02	3200	2880
	5	2020	2050	4.1	3550	3230
	6	2010	2019	4.69	3850	3310
	6	2020	2050	4.69	3200	2720
	7	2010	2010	6.15	4500	4300
	7	2011	2019	7.03	6000	5200
	7	2020	2050	7.62	6000	5200
Electric Heat Pump	8	2010	2014	3.81	2400	0
(COP)_	8	2015	2050	4.1	2475	0
	9	2010	2050	4.4	3475	0
	10	2010	2011	4.69	3600	0
	10	2012	2050	4.84	3600	0
	11	2010	2019	6.45	3975	0
	11	2020	2029	6.74	4025	0
	11	2030	2034	7.03	4125	0
	11	2035	2050	7.33	4125	0
Geothermal Heat Pump	12	2010	2016	14.1	5000	0
(Energy Efficiency Ratio (EER))	12	2017	2019	16.1	5000	0
	12	2020	2029	17.1	5000	0
	12	2030	2050	21	5000	0
	13	2010	2019	28	6500	0
	13	2020	2050	46	6500	0
NG Heat Pump	14	2010	2019	0.6	4500	0
(EER)	14	2020	2050	0.75	4250	0
Water Heating						
Natural Gas	1	2010	2014	0.59	900	720
(EF)	1	2015	2050	0.62	920	740
	2	2010	2013	0.67	1250	1070
	2	2014	2029	0.67	1100	920
	2	2030	2050	0.85	1600	1400
	3	2010	2029	0.82	2200	2000
	3	2030	2050	0.85	2500	2400
	4	2010	2029	0.85	1600	1400
	4	2030	2050	1.4	3500	3000
Electric	5	2010	2014	0.9	600	480

(EF)	5	2015	2050	0.95	675	555
	6	2010	2014	0.91	625	505
	6	2015	2050	0.95	675	555
	7	2010	2050	0.96	725	605
	8	2010	2013	2	1850	1730
	8	2014	2019	2.1	1950	1830
	8	2020	2050	2.5	2500	2300
	9	2010	2013	2.45	2050	1930
	9	2014	2019	2.75	2050	1930
	9	2020	2029	3.6	2750	2630
	9	2030	2050	3.6	3000	2800
Distillate Oil	10	2010	2014	0.53	1900	1660
(EF)	10	2015	2050	0.62	2100	1860
	12	2010	2050	0.68	2250	2010
LPG	13	2010	2014	0.59	900	720
(EF)	13	2015	2050	0.62	920	740
	14	2010	2013	0.67	1250	1070
	14	2014	2029	0.67	1100	920
	14	2030	2050	0.85	1600	1400
	15	2010	2029	0.82	2200	2000
	15	2030	2050	0.85	2500	2400
	16	2010	2029	0.85	1600	1400
	16	2030	2050	1.4	3500	3000
Solar Thermal	17	2010	2016	1	7840	6214
(EF)	17	2017	2019	1	7590	5964
	17	2020	2029	1	7270	5632
	17	2030	2050	1	6850	5200
Dishwashing						
(EF)	1	2010	2050	0.7	715	395
	2	2010	2050	0.73	770	450
	3	2010	2013	1.2	790	470
	3	2014	2019	1.23	790	470
	3	2020	2029	1.3	790	470
	3	2030	2050	1.38	790	470
Clothes Washing						
kWh/cycle (motor)	1	2010	2014	0.198	500	400
	1	2015	2017	0.13	750	650
	1	2018	2050	0.111	850	750
	2	2010	2014	0.12	700	600

	2	2015	2050	0.109	725	625
	3	2010	2010	0.111	950	850
	3	2011	2050	0.092	950	850
Cooking						
Natural Gas	1	2010	2050	0.399	400	350
Thermal Efficiency (But Out/Btu In)	2	2010	2050	0.42	500	450
Electric (kWh/yr)	5	2010	2050	601	400	350
LPG	3	2010	2050	0.399	400	350
Thermal Efficiency (But Out/Btu In)	4	2010	2050	0.42	500	450
Clothes Drying						
Natural Gas	1	2010	2014	3.14	450	350
(EF)	1	2015	2050	3.3	500	400
	2	2010	2014	3.35	500	400
	2	2015	2050	3.61	575	475
Electric	3	2010	2014	3.55	400	300
(EF)	3	2015	2050	3.81	430	330
	4	2010	2014	3.81	430	330
	4	2015	2050	5.42	750	650
Refrigeration						
Bottom-mounted freezer	6	2010	2013	680	1450	1400
(kWh/yr)	6	2014	2050	672	1450	1400
	7	2010	2013	526	1050	1000
	7	2014	2019	457	1176	1120
	7	2020	2024	394.5	1312.5	1250
	7	2025	2050	315.6	1575	1500
Side-mounted freezer	4	2010	2013	813	1450	1400
(kWh/yr)	4	2014	2050	716	1650	1600
	5	2010	2013	632	1220	1170
	5	2014	2019	509	1366.4	1310.4
	5	2020	2024	474	1525	1462.5
	5	2025	2050	379.2	1830	1755

Top-mounted freezer	1	2010	2013	511	500	450
(kWh/yr)	1	2014	2050	408	525	475
	2	2010	2013	408	575	525
	2	2014	2050	342	600	550
	3	2010	2011	376	850	800
	3	2012	2013	349	930	880
	3	2014	2019	311	1041.6	985.6
	3	2020	2024	261.75	1162.5	1100
	3	2025	2050	209.4	1395	1320
Freezing						
Chest Freezer	1	2010	2013	397	450	400
(kWh/yr)	1	2014	2050	298	600	550
	2	2010	2013	311	475	425
	2	2014	2019	273.68	532	476
	2	2020	2024	233.25	593.75	531.25
	2	2025	2050	186.6	712.5	637.5
Upright Freezer	3	2010	2013	758	550	500
(kWh/yr)	3	2014	2050	533	700	650
	4	2010	2013	497	710	660
	4	2014	2019	437.36	795.2	739.2
	4	2020	2024	372.75	887.5	825
	4	2025	2050	298.2	1065	990

Table C.2. Efficiency Improvements and Capital Costs for Residential Lighting

Application	**Bulb Type**	**Available Year**		**Cost**	**EE (Lumens/Watt)**	**Watts**
General Service	Incandescent	2005	2012	0.33	14.5	57
		2013	2013	0.74	16.1	52.5
		2014	2019	1.71	19.8	42
		2020	2050	99	99	99
	CFL	2009	2010	3.07	67.2	13
		2011	2019	2.33	67.2	13
		2020	2029	2.27	69	13
		2030	2039	2.21	70.7	13
		2040	2050	2.16	72.5	13
	LED	2005	2010	66.58	44	18
		2011	2011	25.85	60	13
		2012	2012	19.07	66.8	11.7

		2013	2013	14.07	74.3	10.5
		2014	2014	9.48	82.7	8.6
		2015	2015	6.78	92	7.5
		2016	2016	5.37	102.4	6.6
		2017	2017	4.26	113.9	5.7
		2018	2018	3.37	126.8	5
		2019	2019	2.67	141.1	4.4
		2020	2024	2.11	157	3.8
		2025	2029	1.61	179.5	3.7
		2030	2039	1.1	202	3.6
		2040	2050	0.78	202	3.5
Reflector	Incandescent	2005	2019	3.31	9.7	65
		2020	2029	3.23	9.8	65
		2030	2039	3.14	9.9	65
		2040	2050	3.06	10	65
	CFL	2005	2019	6.23	48	15
		2020	2029	6.07	50.4	15
		2030	2039	5.92	52.9	15
		2040	2050	5.77	55.6	15
	Halogen	2005	2019	5.99	12.6	50
		2020	2029	5.85	13.2	50
		2030	2039	5.7	13.9	50
		2040	2050	5.55	14.6	50
	LED	2005	2010	160.58	36	28
		2011	2011	49.93	50	20
		2012	2012	40.05	56.8	17.5
		2013	2013	32.12	64.5	15.3
		2014	2014	18.75	73.2	13.4
		2015	2015	13.53	83.1	11.7
		2016	2016	9.76	94.4	10.2
		2017	2017	7.04	107.2	9
		2018	2018	5.08	121.8	7.8
		2019	2019	3.66	138.3	6.9
		2020	2024	2.64	157	6
		2025	2029	2.01	180	5.5
		2030	2039	1.37	202	5
		2040	2050	0.98	202	5
Linear Fluorescent	T12	2005	2019	5.79	63.1	35
		2020	2050	96.9	99	99
	T-8	2005	2019	2.61	73.8	33
		2020	2029	2.66	77	33
		2030	2039	2.57	77.7	33
		2040	2050	2.48	77.7	33
	LED	2005	2012	99	50	25

		2013	2013	60	107	19
		2014	2019	34.07	107	19
		2020	2029	5.46	157	15
		2030	2050	2.88	157	15
Torchiere	Incandescent	2005	2012	3.21	12.27	57.3
		2013	2013	3.35	12.8	55.8
		2014	2019	3.67	14.03	52.3
		2020	2029	4.54	11.5	57.5
		2030	2039	4.43	11.9	57.5
		2040	2050	4.31	12.3	57.5
	CFL	2005	2019	6.23	48	15
		2020	2029	6.07	50.4	15
		2030	2039	5.92	52.9	15
		2040	2050	5.77	55.6	15
	Halogen	2005	2019	15	92.8	70
		2020	2050	10	92.8	70
	LED	2005	2010	192.69	36	28
		2011	2011	59.92	50	20
		2012	2012	48.06	56.8	17.5
		2013	2013	38.54	64.5	15.3
		2014	2014	22.5	73.2	13.4
		2015	2015	16.23	83.1	11.7
		2016	2016	11.71	94.4	10.2
		2017	2017	8.45	107.2	9
		2018	2018	6.1	121.8	7.8
		2019	2019	4.4	138.3	6.9
		2020	2024	3.17	157	6
		2025	2029	2.41	180	5.5
		2030	2039	1.64	202	5
		2040	2050	1.17	202	5

**These changes are highlighted with shading.*

Table C.3. Efficiency Improvements of Miscellaneous Residential Uses: Reference Case vs CPP Scenario*

	2015	2020	2025	2030	2035	2040
Televisions	-4.7%	130.1%	136.8%	134.8%	128.8%	124.1%
Set Top Boxes (STB)	-3.4%	33.5%	37.3%	40.9%	41.7%	40.9%
Home Theater Systems (HTS)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
DVD Players	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Video Game Consoles (VGC)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Desktop PCs (DPC)	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Laptop PCs (LPC)	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Monitors	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Modems & Routers (NET)	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Non PC Rechargeable Electronics	-3.4%	46.5%	46.1%	57.1%	62.3%	56.5%
Ceiling Fans (CFN)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Coffee Machines (COF)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Dehumidifiers (DEH)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
External Power Supplies (EPS)	41.7%	60.5%	61.6%	67.3%	70.4%	69.4%
Microwaves (MCO)	-3.9%	4.3%	8.3%	12.5%	13.8%	13.3%
Pool Heaters & Pumps	-0.1%	-0.5%	-0.4%	-0.1%	0.1%	0.0%
Home Security Systems (SEC)	0.1%	0.2%	0.1%	0.0%	0.0%	0.0%

**The changes are highlighted with shading. Some of these appliances had negative efficiency improvements in the Reference case, which were converted to zeros.*

In this study, we assume the same saturation level for all residential miscellaneous uses but strengthen their energy performance using the AEO 2014 High Tech scenario as the blueprint. The per-unit energy consumption levels from the High Tech scenario are adopted for all but four end-uses. They lead to concrete efficiency improvement above the reference case, ranging from to 12.5% for microwaves to 134.8% for television in 2030.[4] For home theater systems, celling fans, coffee machines, and dehumidifiers, the Reference case assumptions of unit energy consumption remain in order to remove the small decreases in energy efficiency assumed in the High Tech case.

Finally, we use the High Tech side case assumptions for building code compliance and building shell efficiency. Specifically, "For new residential construction, building code compliance is assumed to improve after 2013, and building shell efficiencies are assumed to meet Energy Star requirements by 2023. Existing residential building shells exhibit 50% more improvement than in the Reference case after 2013." (EIA, 2014, p. E-8).

C.2 Results of the Residential Energy-Efficiency Scenario

This residential energy-efficiency scenario reduces residential electricity consumption by 6.7 percent in 2030 and by 9.5 percent in 2040 below the Reference case projections. The electricity savings are projected in different ranges by residential end-uses. As we see charts in Table C.2, some end-uses, such as lighting (-46.3%), water heating (-35.3%), dishwashers (-20.5%), clothes dryers (-15.5%), and space cooling (-15.1%) are expected to bring relatively larger percent reductions of electricity consumption. In terms of the size of electricity use, lighting and HVAC are important target residential technologies. In our modeling, water heating is expected to bring the largest savings by 0.96 quadrillion Btu (QBtu) in 2030, and lighting is expected to save 0.47 QBtu, space cooling is 0.40 QBtu, and space heating is 0.26 QBtu. Following the CEIP initiatives, these residential appliances

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[4] The percentage of relative improvement refers to how much more the improvement is greater than the improvement in the reference case. For example, the 60% improvement in TVs compared to the base is not that TVs are using 60% less than the base case, but that the improvement seen in the base case at the given year is increased by 60%.

could play a key role in improving demand-side energy efficiency, especially for low-income communities.

The residential energy-efficiency improvements would result in increases in residential electricity prices, by 2.3% in 2030, while electricity prices in commercial and industrial sectors are slightly decreased (Table C.3). The national CO_2 emissions in electric power sector reduce by 3.1% in 2030, which is 67 million metric tons of CO_2 reductions compared to the Reference case.

Table C.4. Energy Consumption in GT-CPP Residential Energy-Efficiency Scenario

	Residential Energy Consumption (QBtu)	% Increase above 2012	% Decrease below Reference Case
2012	19.85	0.0%	0.0%
2015	20.48	3.2%	-1.1%
2020	19.13	-3.6%	-6.1%
2025	18.28	-7.9%	-9.7%
2030	18.24	-8.1%	-10.9%
2035	18.38	-7.4%	-11.1%
2040	18.54	-6.6%	-11.3%

Figure C.1. Energy Consumption in the Residential Sector

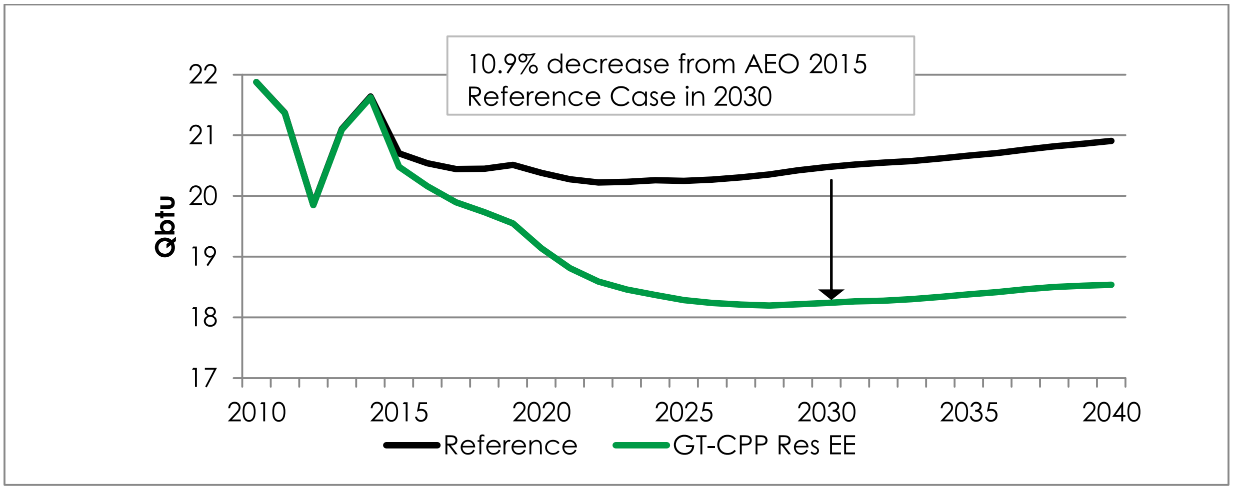
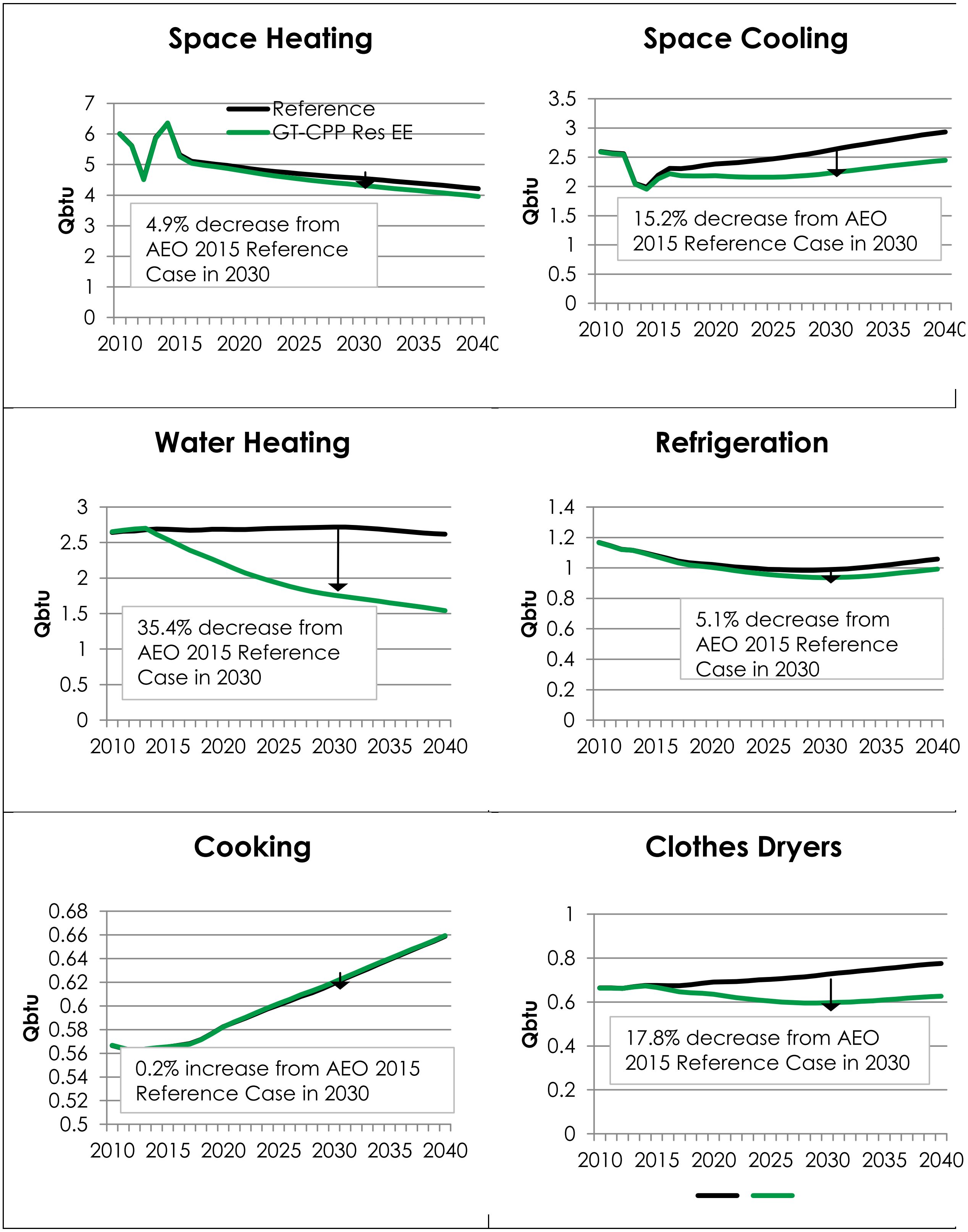


Figure C.2. Energy Consumption by Residential End-Uses



Space Heating

4.9% decrease from AEO 2015 Reference Case in 2030

Space Cooling

15.2% decrease from AEO 2015 Reference Case in 2030

Water Heating

35.4% decrease from AEO 2015 Reference Case in 2030

Refrigeration

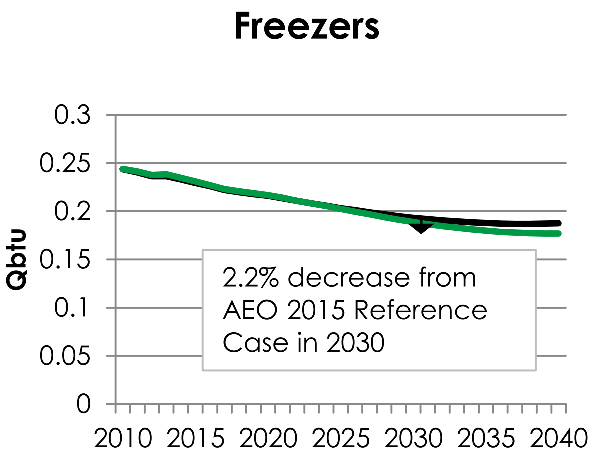
5.1% decrease from AEO 2015 Reference Case in 2030

Cooking

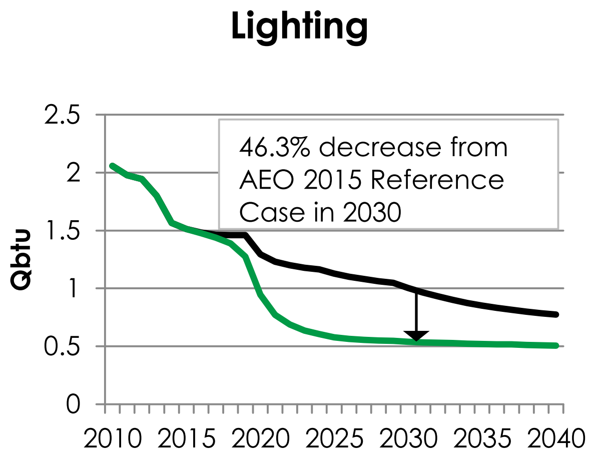
0.2% increase from AEO 2015 Reference Case in 2030

Clothes Dryers

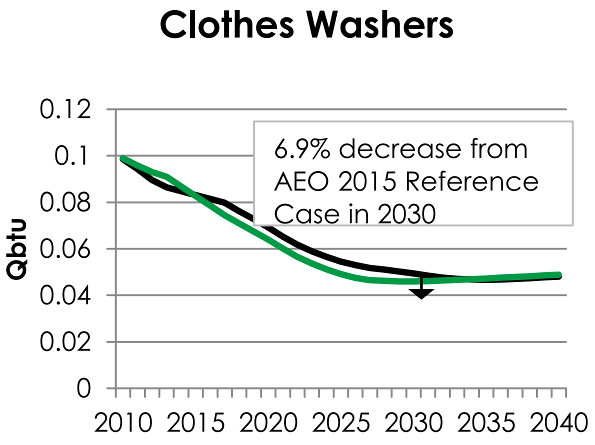
17.8% decrease from AEO 2015 Reference Case in 2030


Freezers

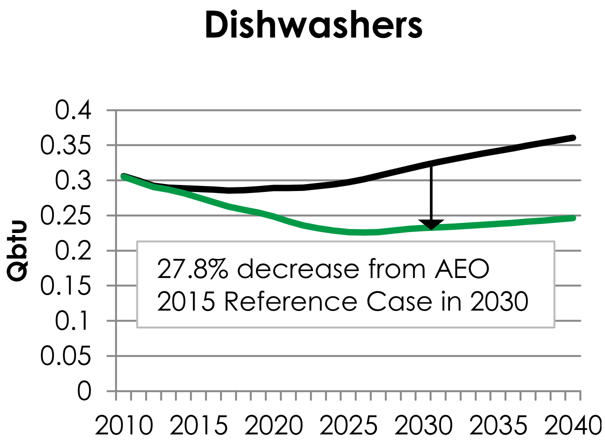
2.2% decrease from AEO 2015 Reference Case in 2030


Lighting

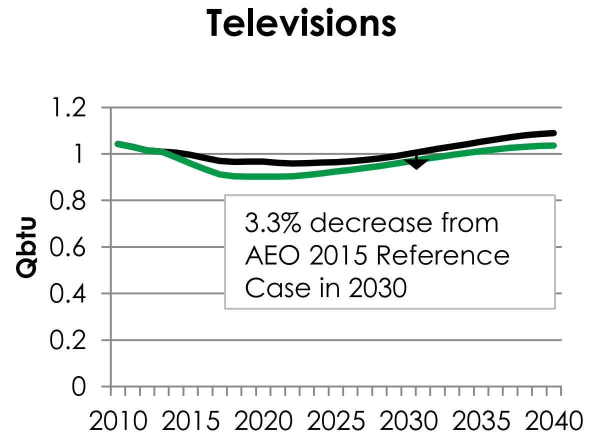
46.3% decrease from AEO 2015 Reference Case in 2030


Clothes Washers

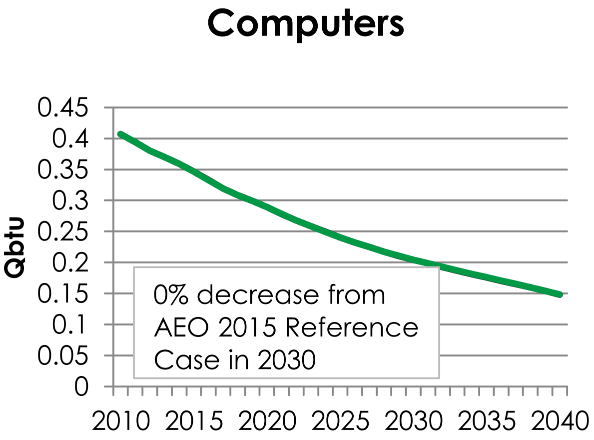
6.9% decrease from AEO 2015 Reference Case in 2030


Dishwashers

27.8% decrease from AEO 2015 Reference Case in 2030


Televisions

3.3% decrease from AEO 2015 Reference Case in 2030


Computers

0% decrease from AEO 2015 Reference Case in 2030

As shown in Table C.5, residential electricity rates would rise with the increased energy efficiency – by 2.8% in 2030 compares to the Reference case. In contrast, rates would decrease in the residential and industrial sectors by 1.5% and 1.3%, in 2030, respectively.

Table C.5. Electricity Rates by Sector

	Residential			Commercial			Industrial		
	Rate (cent/kWh)		% Difference	Rate (cent/kWh)		% Difference	Rate (cent/kWh)		% Difference
	Reference	GT-CPP Residential EE		Reference	GT-CPP Residential EE		Reference	GT-CPP Residential EE	
2012	12.1	12.1	0.0%	10.24	10.24	0.0%	6.75	6.75	0.0%
2015	12.1	12.1	-0.1%	10.16	10.15	-0.1%	7.09	7.08	-0.2%
2020	12.9	13.0	0.6%	10.63	10.42	-2.0%	7.25	7.09	-2.2%
2025	13.5	13.8	2.1%	10.63	10.42	-2.0%	7.63	7.47	-2.1%
2030	13.6	13.9	2.8%	11.09	10.92	-1.5%	7.65	7.55	-1.3%
2035	13.9	14.1	1.7%	11.29	12.29	8.9%	7.93	7.77	-2.1%
2040	14.5	14.8	1.6%	11.82	11.66	-1.3%	8.45	8.32	-1.5%

Because consumption of electricity decreases with these efficiency upgrades, residential electricity bills would fall, despite the higher rates. In particular, residential electricity bills would be 12% in 2030 (Table C.6).

Table C.6. Electricity Bill Savings in Residential Sector

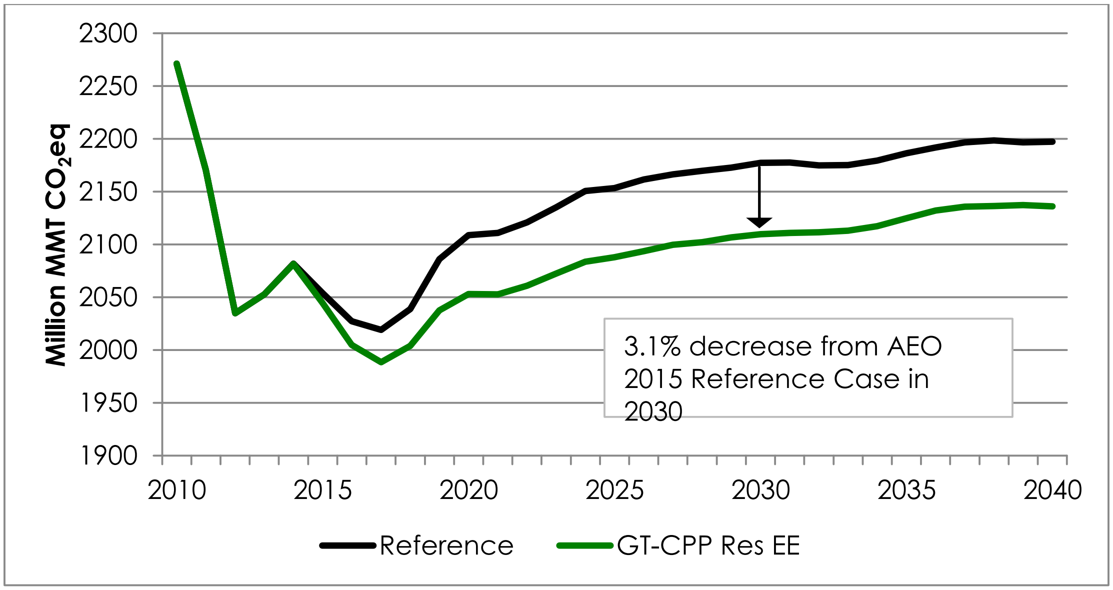
(2013$ Million)	Reference	GT-CPP Residential EE	Difference
2012	595,508	595,304	-204
2015	616,381	608,931	-7,451
2020	634,956	584,379	-50,577
2025	657,885	584,972	-72,912
2030	662,914	584,414	-78,500
2035	683,742	597,849	-85,892
2040	723,908	633,306	-90,602

On their own- in the absence of other policies- these residential energy-efficiency improvements would reduce U.S. CO_2 electric sector emissions by 3.1% in 2030 relative to the Reference case forecast (Table C.7). Over time the differential drops to 2.8% in 2040, as demand continues to rise and the High Tech technologies advance at a slower pace.

Table C.7. CO_2 Emissions in the Electric Power Sector

CO_2 Emission in Electric Power Sector		
	Emission (Mil MMT CO_2eq)	% Decrease compared to AEO 2015 Reference Case
2012	2035	0.0%
2015	2045	-0.4%
2020	2053	-2.7%
2025	2088	-3.1%
2030	2110	-3.1%
2035	2125	-2.8%
2040	2136	-2.8%

Figure C.3. CO_2 Emission in Electric Power Sector



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D Commercial Energy-Efficiency Scenario

D.1 Modeling the Energy Efficiency of Commercial Buildings

Five types of changes are made to the NEMS 2015 Reference Case. First, two new high-efficiency rooftop air source heat pump technologies are added to the array of commercial HVAC options. Second, the GT-NEMS 2015 CPP version of ktek file includes all the high-efficiency space heating and cooling technologies that are part of the GT-NEMS 2014 High Tech case. Fourth, we lower the discount rates used in the 2015 NEMS Reference Case for two types of end-use technologies in the commercial sector: space cooling and lighting. Fifth, stronger state building codes and other state energy efficiency policies are proxied by strengthening the envelope efficiency of new buildings and by using the AE02014 High Technology "side case" assumptions. Each of these alterations are described below.

Two new high-efficiency rooftop air source heat pump technologies. Commercial air conditioners, also known as rooftop units, are commonly used in low-rise buildings such as schools, restaurants, big-box stores and small office buildings. They cool about half of the total commercial floor space in the United States. We add two innovative in air source heat pumps (ASHPs) into the GT-NEMS 2015 technology menu to reflect new HVAC units recently introduced into the U.S. marketplace: the Daikin Rebel and the Carrier Corporation's Weather Expert. Both of these technologies were winners of DOE's Rooftop Unit Challenge, which incentivized manufacturers of rooftop AC unit to develop products with Integrated Energy Efficiency Rating (IEER) higher than 18. This challenge was modeled out of the increasingly popular X-prize approach.

The 7.5-ton Rebel was the first to win the rooftop challenge. With a variable speed heat pump and other improvements, it achieves an IEER of 20.6 and a Coefficient of Performance (COP) of 5.89. The ASHP serves space cooling and heating, as well as water heating demands. Based on a survey of installers, the cost of a 7.5-ton Rebel is approximately $24,000 (including $10,000 for installation).

The 8.5-ton version of Carrier Corporation's Weather Expert gas/electric unit is another winner of the DOE Rooftop Unit Challenge Award. It has an IEER of 20.8 and a COP of 6.10. Communication with the retailer indicates that Weather Expert (48LC09) costs $9,700, including installation cost, which is significantly lower than the cost of the Daikin Rebel. Following identification of the winners, DOE facilitates the demonstration of winning units in big-box retailer stores, thereby lowering adoption hurdles and spurring the market adoption of high efficient rooftop air-conditioners.

To model the cost reduction, we introduce both Daikin Rebel and Carrier Weather Expert in 2015 and assume that they are nascent technologies that will benefit from economies of scale. In particular, we introduce an exogenous learning effect that is consistent with Weiss (2010), which found a 18% learning rate for high-efficiency appliances and Desroches (2013), which found a 30% learning rate for HVAC equipment. Specifically, we implement a step-wise cost decline combined with a cost trend function of 30% for the first doubling of service demand, which happens in 2020 and 20% for the second doubling which, happens in 2035. We further assume that the Daikin Rebel and Carrier Weather Expert are subject to continuous cost reduction, so that between the periods when service demand is doubled, costs fall each year, eventually converging on the cost reductions with each doubling. The performance of these two new technologies relative to other technologies included in the NEMS commercial module's ktek file is shown in Table D.1.

Table D.1. Characteristics of Rooftop Space Cooling Technologies, Including Two New High-Efficiency Units and the New Rooftop AC Standard

Technology Vintage	Capital Cost ($/kBtu/hr)	COP (Btu-out /Btu-in)	Available Years: Reference Case	Reference Case	COP (Btu-out /Btu-in)	Available Years: CPP Scenario	CPP Scenario
	Rooftop AC						
2003 installed base	62.22	2.70	2003-03	√	2.70	2003-03	√
2007 installed base	70.56	2.96	2003-09	√	2.96	2003-09	√
2010 typical	88.89	3.28	2003-52	√	3.28	**2003-17**	√
2010 mid-range	105.56	3.52	2003-52	√	**4.27**	**2023-52**	√
2010 high	255.56	4.07	2010-52	√	4.07	**2010-17**	√
2020 typical	88.89	3.37	2020-52	√	**3.71**	**2018-22**	√
2020 high	242.22	4.07	2020-52	√	4.07	2020-52	√
	Rooftop Air-source Heat Pump						
2003 installed base	63.89	2.73	2003-03	√	2.73	2003-03	√
2007 installed base	72.78	2.87	2007-09	√	2.87	2007-09	√
2010 typical	76.67	3.22	2003-52	√	3.22	**2003-17**	√
2010 high	96.67	3.52	2003-52	√	3.52	**2003-17**	√
Rebel 2014	365.75	5.89	2020-52		5.89	2020-52	√
WE 2014	95.10	6.10	2020-52		6.10	2020-52	√
2020 typical	76.67	3.22	2020-52	√	**3.70**	**2018-22**	√
2020 high	93.33	3.81	2020-52		**4.26**	**2023-52**	√
Rebel 2020	256.03	5.89	2020-52		5.89	**2018-52**	√
WE 2020	66.6	6.10	2020-52		6.10	**2018-52**	√
2030 high	103.33	4.40	2025-52		4.40	**2023-52**	√
2035 high	102.22	4.40	2030-52		4.40	**2025-52**	√
Rebel 2035	204.82	5.89	2035-52		5.89	2035-52	√
WE 2035	53.3	6.10	2035-52		6.10	2035-52	√

High Tech Option. In addition to adding two high-efficiency ASHPs, this study also compares the commercial building technology options between the newly developed GT-NEMS 2015 CPP case and the GT-NEMS 2014 High Tech case. Two high-efficient rooftop ASHP technologies that will become available in 2030 and 2035 are added to the former as a result of the comparison. In so doing, the GT-NEMS 2015 CPP version of ktek file includes all the high-efficiency space heating and cooling technologies that are part of the GT-NEMS 2014 High Tech case as well as the DOE Rooftop Challenge award winners.

New efficiency standards for commercial air conditioners and furnaces. The two new ASHP technologies and the High Tech equipment will benefit from the recent promulgation of what has been called an historic new efficiency standards for commercial air conditioners and furnaces, which may be the largest energy-saving standard in U.S. history.[5] This new standard is to be implemented in two phase: in 2018 they will deliver a 13% improvement in the energy efficiency of products, and in 2023, an additional 15% efficiency improvement will be required for new commercial units. The assumed efficiency levels, retail prices, installation and maintenance costs, and other equipment assumptions by size of unit and year can be found on the DOE docket website.[6]

We model the new standard by eliminating the "2010 typical" rooftop AC and ASHP in 2018 and the "2020 typical" AC unit in 2023. In their place, we make a number of higher efficiency space cooling technologies available several years earlier as shown in Table D.1. The available years for different technology vintages as modified in the CPP scenario are described in Table D.1.

Lower discount rates. We lower the discount rates used in the 2015 NEMS Reference Case for two technologies in the commercial sector: space cooling and lighting. In NEMS, discount rates are separated by end use, including space heating, space cooling, ventilation, lighting, water heating, cooking, and refrigeration, and they are divided into seven population segments for each end use. Each population segment is capable of using a different discount rate with regard to the end use in question each year. The proportion of consumers in each premium category includes consumers facing all decision types, i.e., new construction, replacement of worn-out equipment, and potential economic retrofit of working equipment.

In the 2015 NEMS Reference Case, these discount rates are higher than suggested by the bulk of the existing research. In the 2015 NEMS Reference Case, or example, approximately half of the consumer choices in lighting and space cooling are assigned discount rates greater than 100% and less than 2% of the population uses discount rates under 15% (Table D.2).

This problem has been recognized for some time in energy forecasting models. An extensive literature review spanning four decades is summarized in Cox, Brown and Sun (2013). That review uncovered more than two-dozen studies estimating implicit discount rates for commercial consumers across the GT-NEMS series of appliances. The mean discount rates in this literature ranged was 17% for space cooling and 36% for lighting. The SIMulation and Econometrics To Analyze Risk (SIMETAR)[7] tool was used to develop continuous probability distribution functions for each end use, applying the GRKS distributions for both space cooling and lighting. The results are shown in Table D.2. We only adjust the discount rates for these two end uses. The other end

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[5] http://energy.gov/articles/energy-department-announces-largest-energy-efficiency-standard-history

[6] https://www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0007-0106

[7] SIMETAR: http://www.njf.nu/filebank/files/20070101$194034$fil$T0GTzTCKEgEZBdBS1jll.pdf

uses also warrant adjustment, which would increase the rate of penetration of energy-efficient technologies in those categories.

Table D.2. Commercial Consumer Discount Rate Assumptions: 2015-2040

NEMS 2015 Reference Case Assumptions			**GT-NEMS CPP-All EE+Solar Assumptions**		
	Percentage of commercial consumers using a particular discount rate			**Commercial Consumers' Discount Rate**	
Commercial Consumers' Time Preference Premium to the Risk-Free Interest Rate	Space Cooling	Lighting	Percentage of commercial consumers using a particular discount rate	Space Cooling	Lighting
1000%	26.5%	26.4%	14.3%	20.2%	57.3%
100%	22.6%	22.5%	14.3%	15.2%	40.8%
45%	19.6%	19.3%	14.3%	13.7%	36.5%
25%	19.2%	19.2%	14.3%	13.0%	33.0%
15%	10.5%	10.6%	14.3%	11.6%	30.4%
6.50%	1.3%	1.6%	14.3%	9.4%	26.9%
0.00%	0.3%	0.4%	14.3%	7.2%	21.7%
Sources: EIA, 2013; Koomey, 1990.			Source: Cox, Brown, and Sun, 2013.		

More efficient building envelopes. Finally, parameters were changed to accelerate improvements in the thermal integrity of commercial building envelopes, representing advances in ceiling, wall, and foundation insulation and window technologies that have occurred in recent years and that are anticipated to result from stronger state building codes and other state energy efficiency policies. Specifically, the average shell efficiencies of the existing and new building stocks in 2040 are made 25% more efficient in the GT-NEMS 2015 CPP scenario following the assumption of High Demand Technology scenario AEO 2014 (EIA, 2014, p. E-10).

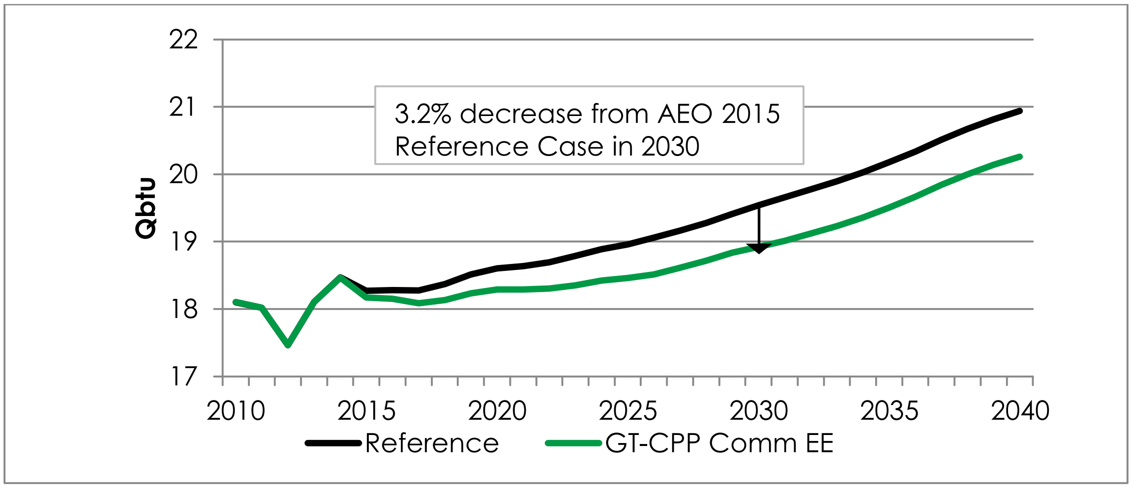
D.2 Results of Commercial Energy-Efficiency Scenario

The GT-CPP commercial energy-efficiency scenario reduces commercial energy consumption by 3.2% in 2030, and 2040, relative to the Reference case. This is the most rapidly growing electricity demand sector in the Reference case, which means that the sector's energy consumption in 2030 and 2040 are both greater than in 2012, but the growth has been reduced to 8.3% more than in 2012 (Table D.3). This table and the following figures do not reflect the impact of reduced discount rates because that change was made late in the model development period.

Table D.3. Energy Consumption in GT-CPP Commercial Energy-Efficiency Scenario

	Commercial Energy Consumption (QBtu)	% Increase Above 2012	% Decrease Below Reference Case
2012	17.47	0.0%	0.0%
2015	18.17	4.0%	-0.6%
2020	18.29	4.7%	-1.7%
2025	18.46	5.7%	-2.6%
2030	18.92	8.3%	-3.2%
2035	19.51	11.7%	-3.3%
2040	20.26	16.0%	-3.2%

Figure D.1. Electricity Consumption in Commercial Sector



Electricity rates generally rise modestly across all three customer classes (Table D.4). However, electricity bills in the commercial sector will decrease relative to the Reference case forecast because of the reduced electricity consumption enabled by the energy-efficiency improvements. The consumption reductions are modest, in part, because the highly competitive Daikin and Weather Expert HVAC systems cause a shift from gas to electric heat, in many states where heat pumps can operate effectively.

Table D.4. Electricity Rates in the Commercial Energy-Efficiency Scenario

	Residential			Commercial			Industrial		
	Rate (cent/kWh)		% Difference	Rate (cent/kWh)		% Difference	Rate (cent/kWh)		% Difference
	Reference	Commercial EE		Reference	Commercial EE		Reference	Commercial EE	
2012	12.1	12.1	0.0%	10.2	10.2	0.0%	6.8	6.8	0.0%
2015	12.1	12.3	1.4%	10.2	10.3	1.3%	7.1	7.2	1.1%
2020	12.9	13.2	2.4%	10.6	10.8	2.0%	7.2	7.4	2.0%
2025	13.5	13.9	2.6%	10.6	10.8	2.0%	7.6	7.8	2.1%
2030	13.6	13.9	2.8%	11.1	11.3	1.8%	7.6	7.8	2.6%
2035	13.9	14.1	1.7%	11.3	12.3	8.9%	7.9	8.0	1.3%
2040	14.5	14.6	0.7%	11.8	11.8	-0.2%	8.4	8.5	0.2%

The fuel shifting phenomenon also moderates the CO_2-reduction potential of the commercial energy-efficiency scenario. This will be the case as long as the carbon-intensity of power generation exceeds the CO_2 emissions of gas-heat (Table D.5).

Table D.5. CO_2 Emission in Electric Power Sector

	CO_2 Emission in Electric Power Sector	
	Emission (Mil MMT CO_2eq)	% Decrease compared to AEO 2015 Reference Case
2012	2035	0.0%
2015	2046	-0.4%
2020	2107	-0.1%
2025	2163	0.4%
2030	2185	0.4%
2035	2192	0.2%
2040	2193	-0.2%

References

Cox, Matt, Marilyn A. Brown, and Xiaojing Sun. 2013. "Energy Benchmarking of Commercial Buildings: A Low-cost Pathway for Urban Sustainability," *Environmental Research Letters,* Vol. 8 (3), pp. 1-12, http://iopscience.iop.org/1748-9326/8/3/035018/pdf/1748-9326_8_3_035018.pdf.

Koomey, Jonathan G., "Energy Efficiency Choices in New Office Buildings: An Investigation of Market Failures and Corrective Policies," dissertation, University of California at Berkeley, 1990.

EIA, 2013, *Commercial Demand Module of the National Energy Modeling System: Model Documentation 2013*, Table E-1, p. 220.

U.S. Energy Information Administration (EIA). (2014). *Annual Energy Outlook 2014.* Washington, DC: U.S. Energy Information Administration.

E Industrial Energy-Efficiency Scenario

E.1 Modeling the Industrial Energy-Efficiency Scenario

In the industrial sector, stronger energy-efficiency policies are modeled by including additional energy-efficiency assumptions related to combined heat and power (CHP) and electric motors, and by technical efficiency improvements in five manufacturing subsectors.

The scenario assumes that investment tax credits for CHP are extended through 2040 and raised to 30%. This accelerates the rate of decline for CHP system costs. In addition, EIA's High Technology assumptions are used, to characterize the speed of cost declines for CHP systems. The High Tech case is also used to define improved electric motor efficiencies. Unlike the EIA's High Tech case, we did not change the biomass supply curve.

Further, we assume that policies encourage manufacturers in five industrial subsectors to reduce their unit energy consumption (UEC) below Reference Case projections. These produce energy-consumption reductions in 2030 that range from 18% for bulk chemicals, 23% for cement and refining, 40% for pulp and paper, and 57% for iron and steel, modeled after Brown, Cox, and Cortes, (2010), which summarizes a study for the National Research Council.

In the NEMS Industrial Demand Module, the future improvements in UEC are modeled by using the Technology Possibility Curves (TPCs). TPCs reflect UEC in the initial year and annual energy intensity declines over time. For example, the following equation shows how the TPC is defined in the period between 2010 and 2040, for a certain industrial sector.

$$UEC(2010)*(TPCRate+1)^\wedge(2040-2010)=UEC(2040)$$

An input file, *ITECH,* delivers UECs in initial and final years and TPC Rates, which are annual percent improvements, by industrial subsector and by fuel type. The TPC Rates were estimated for existing (retrofit) and new facilities. Table E.1 shows estimated percent improvements for five industrial sectors.

Table E.1. Increased Energy Efficiency and Estimated Coefficients for Technology Possibility Curves by Scenario in Five Manufacturing Subsectors

	Bulk Chemicals	Refining	Pulp and Paper	Iron and Steel	Cement
Projected Energy Consumption (Quads)	6.08	6.07	2.15	1.38	0.44
Energy Consumption with Max Efficiency (Quads)	4.98	4.67	1.3	0.59	0.34
% Change	-18.09%	-23.06%	-39.53%	-57.25%	-22.73%
- Existing Equipment	-14.47%	-18.45%	-31.63%	-45.80%	-18.18%
- New Equipment	-21.71%	-27.68%	-47.44%	-68.70%	-27.27%
Annual Percent Improvement (TPC Rates, or Coefficients for TPCs)					
- Existing Equipment	-1.32%	-1.68%	-2.88%	-4.16%	-1.65%
- New Equipment	-1.97%	-2.52%	-4.31%	-6.25%	-2.48%

For illustrative purposes, Table E.2 shows the initial UECs for the pulp and paper industrial subsectors. The table also compares the TPC rates across scenarios.

Table E.2. Coefficients for Technology Possibility Curves by Scenario – Paper and Allied Products Sectors

Industry/Process Unit	Existing Facilities TPC(%)				New Facilities TPC(%)			
	UECs in 2010 $^{1)}$	Coefficients of TPC $^{2)}$			UECs in 2010	Coefficients of TPC		
		Reference	High Tech	CPP-Ind EE		Reference	High Tech	CPP-Ind EE
Paper and Allied Products								
Wood Preparation	0.230	-0.802	-0.033	-0.029	0.203	-0.790	0.386	-0.043
Waste Pulping-Electricity	1.149	-0.228	-0.161	-0.029	1.076	0.000	-0.228	-0.043
Waste Pulping-Steam	1.110	-0.456	-0.322	-0.029	1.039	0.000	-0.456	-0.043
Mechanical Pulping-Electricity	4.581	-0.767	0.021	-0.029	4.263	-1.380	0.893	-0.043
Mechanical Pulping-Steam	0.397	-1.533	0.043	-0.029	0.370	-2.760	1.787	-0.043
Semi-Chemical-Electricity	1.235	-0.173	-0.025	-0.029	1.199	-0.149	-0.052	-0.043
Semi-Chemical-Steam	4.270	-0.346	-0.051	-0.029	4.146	-0.297	-0.105	-0.043
Kraft, Sulfite, Misc. Chemicals	1.235	-0.519	-0.249	-0.029	1.128	-0.415	-0.502	-0.043
Kraft, Sulfite, Misc. Chemicals-Steam	9.172	-1.037	-0.498	-0.029	8.382	-0.830	-1.004	-0.043
Bleaching-Electricity	0.255	-0.853	-0.252	-0.029	0.224	-0.878	0.129	-0.043
Bleaching-Steam	4.505	-1.706	-0.504	-0.029	3.956	-1.756	0.259	-0.043
Paper Making	1.413	-0.485	-0.621	-0.029	1.251	-0.132	-1.376	-0.043
Paper Making-Steam	5.381	-0.969	-0.621	-0.029	4.763	-0.264	-1.376	-0.043

* Sources: 1) UECs in 2010 – NEMS 2014 Itech; 2) Reference Case – EIA (2013, Table B.14, p.152), High Tech side case – Table B.17 (p.156).

The GT-CPP industrial energy-efficiency scenario reduces industrial energy consumption by 7.1% in 2030 and by 9.1% in 2040 relative to the Reference case (Table E.3). As shown in Figure E.1, industrial energy consumption does not return to 2012 levels, but it stabilizes at about 34.5 quads by 2030.

E.2 Results of the Industrial Energy-Efficiency Scenario

Table E.3. Energy Consumption in GT-CPP Industrial Energy-Efficiency Scenario

	Industrial Energy Consumption (QBtu)	% Increase above 2012	% Decrease below Reference Case
2012	30.84	0.0%	0.0%
2015	31.98	3.7%	0.0%
2020	33.94	10.1%	-2.9%
2025	34.57	12.1%	-5.3%
2030	34.42	11.6%	-7.1%
2035	34.14	10.7%	-8.2%
2040	34.31	11.3%	-9.1%

Figure E.1. Energy Consumption in Industrial Sector

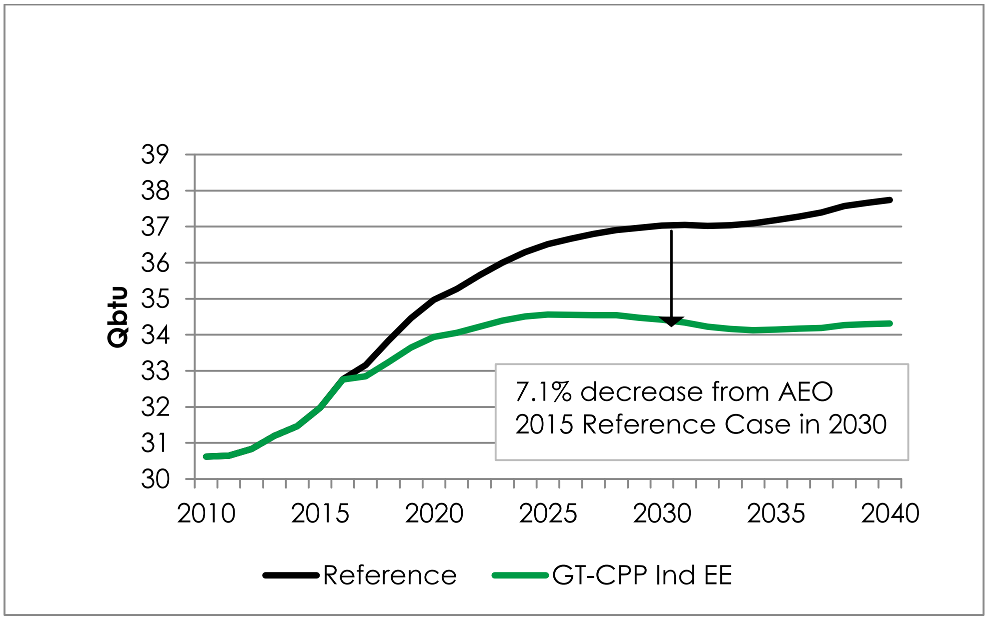


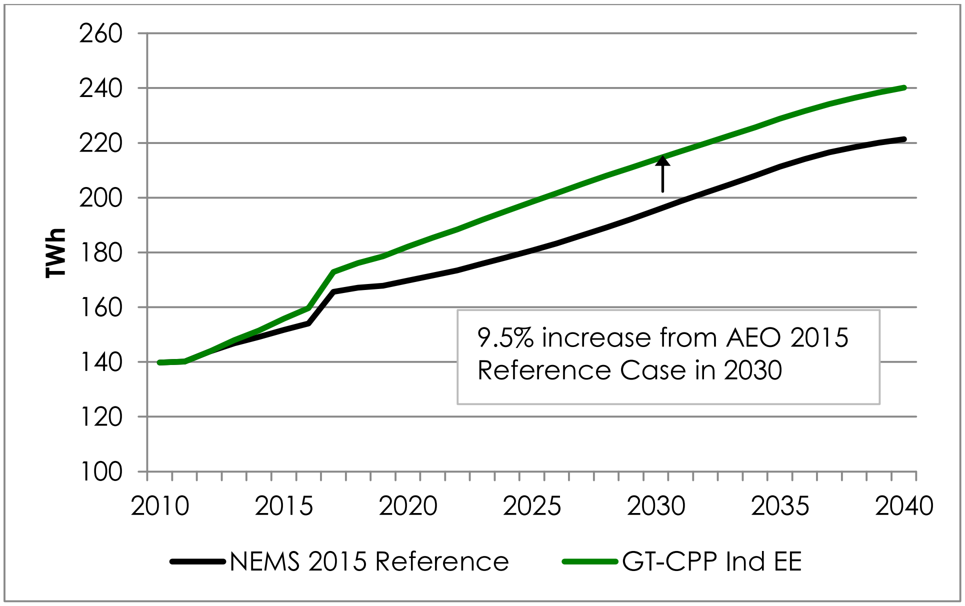
Figure E.2. Industrial Energy Consumption in Policy Scenario vs Reference Case

Electricity generation from industrial CHP systems grows in the Reference case and even more in the GT-CPP industrial energy-efficiency scenario, growing by nearly 50% more CHP generated electricity in 2030 than in 2012 (Table E.4, Figure E.2).

Table E.4. Industrial CHP Electricity Generation in GT-CPP Industrial EE Scenario

	Generation (TWh)	% Increase above 2012	% Decrease below Reference Case
2012	143.79	0.0%	0.0%
2015	155.78	8.3%	2.7%
2020	182.05	26.6%	7.3%
2025	198.44	38.0%	9.8%
2030	213.96	48.8%	9.5%
2035	228.78	59.1%	8.3%
2040	240.12	67.0%	8.5%

Figure E.2. CHP Electricity Generation in the Industrial Sector



The highly efficient industrial CHP systems cause significant reductions in electricity prices (Table E.5). These price effects spill into other sectors, benefitting households and businesses as well. This "demand reduction included price effect" (DRIPE) has been documented by others (Baer, Brown, and Kim, 2015).

Table E.5. Electricity Rates in the GT-CPP Commercial Energy-Efficiency Scenario

	Residential			Commercial			Industrial		
	Rate (cent/kWh)		% Difference	Rate (cent/kWh)		% Difference	Rate (cent/kWh)		% Difference
	Reference	GT-CPP Industrial EE		Reference	GT-CPP Industrial EE		Reference	GT-CPP Industrial EE	
2012	12.06	12.06	0.0%	10.23	10.23	0.0%	6.75	6.75	0.0%
2015	12.12	12.12	0.0%	10.16	10.16	0.0%	7.09	7.09	0.0%
2020	12.90	12.80	-0.8%	10.63	10.56	-0.7%	7.25	7.21	-0.6%
2025	13.52	13.28	-1.7%	11.09	10.90	-1.7%	7.63	7.51	-1.5%
2030	13.57	13.42	-1.0%	11.05	10.97	-0.7%	7.65	7.63	-0.2%
2035	13.91	13.66	-1.8%	11.29	11.12	-1.5%	7.93	7.84	-1.1%
2040	14.52	14.28	-1.7%	11.81	11.65	-1.4%	8.45	8.38	-0.8%

Electricity bills in the industrial sector would decrease as a result of the GT-CPP scenario of industrial energy efficiency (Table E.6), saving industry $60 billion (in $2013) in 2030, rising to $91 billion in 2040. In addition, cogeneration at industrial plants would create a new source of revenue for U.S. manufacturing that could strengthen its global competitiveness.

Table E.6. Electricity Bill Savings in Industrial Sector

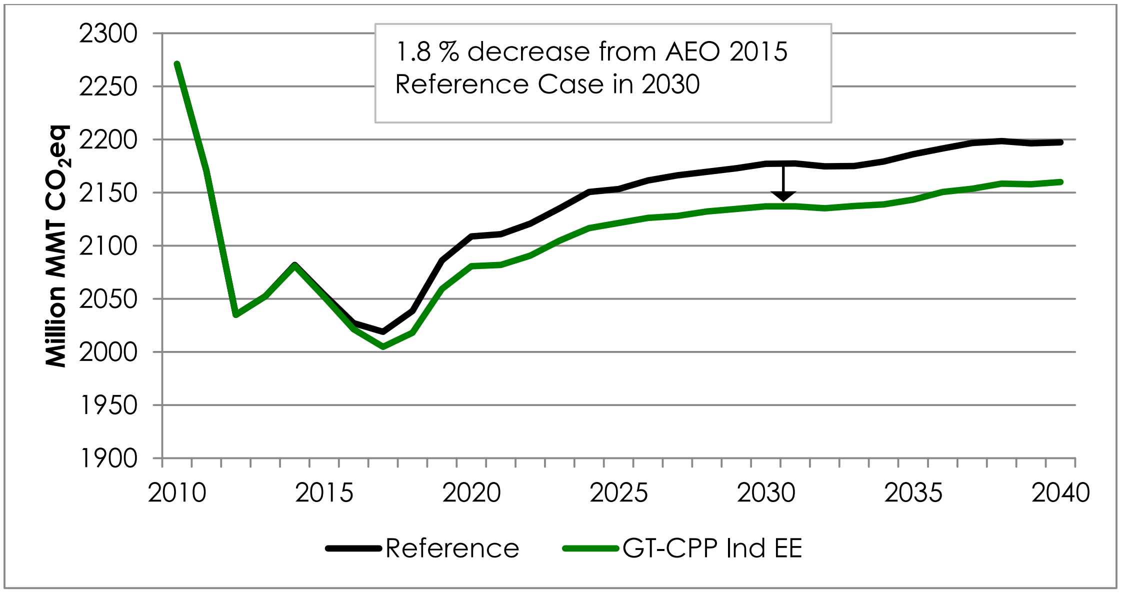
(2013$ Million)	Reference	GT-CPP Industrial EE	Difference
2012	610,135	610,135	-
2015	664,778	664,464	-314
2020	742,503	716,731	-25,772
2025	816,183	761,157	-55,026
2030	829,821	769,782	-60,038
2035	864,105	784,829	-79,276
2040	934,097	842,587	-91,509

The energy-efficiency improvements could have a significant effect on CO_2 emissions in the electric power sector (Table E.7 and Figure E.3).

Table E.7. CO_2 Emission Reductions in Electric Power Sector

National CO_2 Emission in Electric Power Sector		
	Emission (Mil MMT CO_2eq)	**% Decrease compared to AEO 2015 Reference Case**
2012	2035	0.0%
2015	2052	-0.1%
2020	2081	-1.3%
2025	2122	-1.5%
2030	2137	-1.8%
2035	2143	-2.0%
2040	2160	-1.7%

Figure E.3. CO_2 Emission in Electric Power Sector



References

Baer, Paul, Marilyn A. Brown, and Gyungwon Kim. 2015. "The Job Generation Impacts of Expanding Industrial Cogeneration," *Ecological Economics,* 110 (2015) 141–153.

Brown, Marilyn A, Matt Cox, and Rodrigo Cortes. 2010. "Transforming Industrial Energy Efficiency," *The Bridge* (Washington, DC: National Academy of Engineering), Fall, pp. 22-30.

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F Summary

The following list has the names and locations of all of the NEMS files that were changed to create the scenarios modelled in *The Clean Power Plan and Beyond.*

Electricity Sector:

-EMMCNTL
--M:/nemshome/as3/Input/CPP_Distribution/CPP_Dist_Default/emmcntl.CPP2015_all_pltsw_stdqt.txt
--M:/nemshome/as3/Input/CPP_Distribution/CPP_Dist_Default/emmcntl.CPP2015_ex_pltsw_stdqt.txt

-EPMDATA
--M:\nemshome\as3\Input\CPP_Distribution\CPP_Dist_Default\epmdata_20fee_2022.txt
--M:\nemshome\as3\Input\CPP_Distribution\CPP_Dist_Default\epmdata_20fee_2031.txt

Residential Sector:

-RSGENTKN
--M:/nemshome/xjs/inputs/rsgentk.v1.cpp_CEIP.txt

-RSMELSN
--M:/nemshome/gwk/111d/2015CPP/rsmels.highcpp.txt

-RSMEQPN
--M:/nemshome/gwk/111d/2015CPP/rsmeqp.highcpp.revised1.txt

-RSMSHLN
--M:/nemshome/gwk/111d/2015CPP/rsmshl.highcpp1.tx

-RSMLGTN
--M:/nemshome/gwk/111d/2015CPP/rsmlgt.highcpp1.txt

Commercial Sector:

-KTEK
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-KPREM
--M:/nemshome/as3/Input/CPP_Distribution/CPP_Dist_Default/kprem.v1.GTCPP2.txt

-ECPDATX
--M:/nemshome/xjs/inputs/ecpdatx_ref
--M:/nemshome/xjs/inputs/ecpdatx_cpp

-KGENTK
--M:/nemshome/xjs/inputs/kgentk.v2.cpp_CEIP.txt

-KSHEFFN
--M:/nemshome/xjs/inputs/ksheff.v1.cpphf.txt

Industrial Sector:

-INDCOGENN
--M:/nemshome/gwk/111d/2015CPP/indcogen.xml

-ITECHN
--M:/nemshome/gwk/111d/2015CPP/itech.txt

-INDRUNN
--M:/nemshome/gwk/111d/2015CPP/indrun.txt