Pacific Northwest NATIONAL LABORATORY

PNNL-33251

Impacts of Model Building Energy Codes

November 2023

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Executive Summary

The Department of Energy (DOE) Building Energy Codes Program (BECP) periodically evaluates national and state-level impacts associated with energy codes in residential and commercial buildings. Pacific Northwest National Laboratory (PNNL), funded by DOE, conducted an assessment of the prospective impacts of national model building energy codes from 2010 through 2040. A previous PNNL study evaluated the impact of the Building Energy Codes Program[1]. A 2016 study[2] looked more broadly at overall code impacts and this report describes the methodology used for the assessment and presents the impacts in terms of energy savings, consumer cost savings, and reduced greenhouse gases and other emissions at the state level and at aggregated levels. In 2021, DOE conducted an interim and limited update to its 2016 study to evaluate potential building code updates using the 2016 methodology[3]. That interim update includes estimated savings resulting from updates to the model energy codes, including the ANSI/ASHRAE/IES Standard 90.1-2016 (ASHRAE 90.1-2016) and 2019 editions, as well as the 2018 and 2021 International Energy Conservation Code (IECC). This current version is a fully updated report that includes the recent code updates (ASHRAE 90.1-2019 and 2021 IECC), as well as additional enhancements and updates, including updated energy prices, annual floorspace additions, state code adoption dates, and emission factors, among others.

Energy codes follow a three-phase cycle that starts with the development of a new model code, proceeds with the adoption of the new code by states and local jurisdictions, and finishes when the new code is implemented and builders, architects, and engineers are required to comply with the new provisions. The development of new model code editions creates the potential for increased energy savings. After a new model code is adopted, potential savings are realized in the field when new buildings (or additions and alterations) are constructed to comply with the new code. The contributions of all three phases are crucial to the overall impact of codes and are considered in this assessment. Figure ES.1 schematically describes the analysis framework. Energy savings are expressed in terms of energy use intensity (EUI) in the figure.

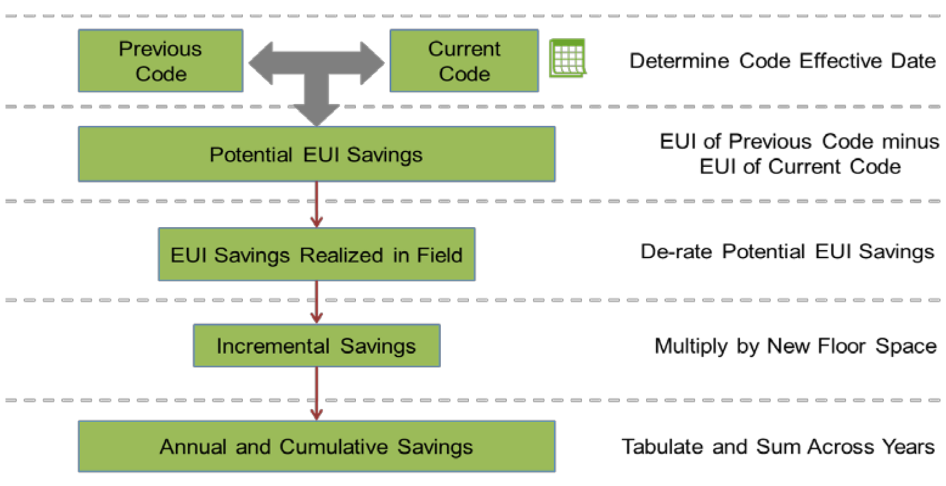

Figure ES.1. Codes Impact Analysis Framework

[1] Building Energy Codes Program: National Benefits Assessment, 1992-2040. Available at: https://www.energycodes.gov/sites/default/files/2021-07/BenefitsReport_Final_March20142.pdf

[2] Impacts of Model Energy Codes. Available at: https://www.energycodes.gov/sites/default/files/2019-09/Impacts_Of_Model_Energy_Codes.pdf

[3] Impacts of Model Building Energy Codes – Interim Update. Available at: https://www.energycodes.gov/sites/default/files/2021-07/Impacts_of_Model_Energy_Codes_2010-2040_Interim_Update_07182021.pdf

Determine Code Effective Date. The years in which each state adopted various code editions must be known to calculate savings. PNNL collected data on the years in which various code editions were adopted by each state and verified the accuracy of the adoption data. In states with no state-wide code but with significant adoption and code activities in local jurisdictions (Arizona, Colorado, and Wyoming), the code effective in populous jurisdictions is used as a surrogate for the state-wide code.

Historical adoption data is used to project the rate at which each state will adopt codes in the future, i.e., from 2023 through 2040. States are classified as aggressive, moderate, or slow adopters of energy codes, which then determines how fast a state will adopt a new code in the future. The following states are excluded from the analysis because they do not have a state-wide code and energy codes are not enforced state-wide: Alaska, Kansas, Missouri, Mississippi, North Dakota, and South Dakota.

Calculate Potential EUI Savings. Once the adoption years of various code editions are known, it is possible to calculate savings from one code to the next. All code-to-code savings are counted towards the impact of energy codes; savings from beyond-code programs that may be active in the states are not counted towards energy codes. Code savings are calculated by first determining the EUI of each code edition. DOE's Determination analyses of the prior cycles of commercial and residential codes, conducted by PNNL[1], are used to develop these EUIs. Savings resulting from improvements in equipment efficiency due to federally mandated requirements are not included in this analysis. EUIs of future code editions are based on projected improvements in various building technologies (envelope, heating, ventilating, air conditioning, lighting, and water heating). California and Washington are excluded from the assessment because their energy codes are significantly different from the model codes for which EUIs are developed using the Determination analyses.

De-Rate Potential EUI Savings. To capture the impact of code requirements not being met, potential savings from a new code are de-rated by a realization rate, defined as the fraction of total potential energy savings achieved in the field. Data from DOE's residential field study[2] are used to determine residential code realization rates. The savings realization rate in the first year after a residential code is adopted is 80%, increasing each year and ending at 100% after 10 years. For commercial codes, a literature review found that past compliance studies were insufficient to make statistically valid judgements on savings realization rates for entire states. Past studies also did not report the fraction of potential energy savings realized in the field. In the absence of defensible data, a conservative realization rate of 50% was chosen for the first year after a code is adopted, increasing each year, and ending at 80% after 10 years.

Incremental Savings. Having calculated savings based on individual code EUIs, the adoption scenarios in each state, and realization rates, the EUI savings are then multiplied by new floor space to calculate the incremental savings for each state. New floor space estimates for commercial and residential buildings developed in a previous analysis[3] were updated using data from Annual Energy Outlook 2022.[4] New floor space added each year includes new construction, additions, and, for commercial buildings only, alterations.

Annual and Cumulative Savings. Projected impacts are reported in terms of annual savings each year, as well as cumulative savings for different periods. The terms annual and cumulative are described in greater detail in Section 2.2.

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1 Determination analyses: https://www.energycodes.gov/determinations.

2 DOE residential field study: https://www.energycodes.gov/compliance/residential-energy-code-field-study.

3 Building Energy Codes Program: National Benefits Assessment, 1992-2040. Available at: https://www.energycodes.gov/sites/default/files/2021-07/BenefitsReport_Final_March20142.pdf.

4 Energy Information Administration's Annual Energy Outlook projects new floor space added in the future. Accessed at: https://www.eia.gov/outlooks/aeo/.

Table ES.1 summarizes the impact of energy codes beginning in 2010 and ending in 2040 for all states included in the analysis. The results include savings from electricity, natural gas, and fuel oil (residential only) and are reported separately for residential and commercial codes. The cumulative FFC energy savings from 2010 through 2040 are 17.00 quads. In terms of financial benefits to consumers from reduced utility bills, energy codes are expected to save $182 billion dollars from 2010 through 2040.

These energy and energy cost savings are higher than those reported in the 2021 interim update. For example, the cumulative 2010 to 2040 savings of $182 billion is higher than the $138 billion savings reported in the interim update. Updates to the methodology, such as energy prices, annual floorspace additions, and state code adoption dates, help account for this increase.

Table ES.1. Summary of Energy Codes Impact on Energy and Energy Cost

Sector	Site Energy Savings (Quads)	Primary Energy Savings (Quads)	Full-Fuel-Cycle Savings (Quads)	Energy Cost Savings (2021 $ billion)*
Commercial				
Annual 2030	0.15	0.36	0.38	3.59
Annual 2040	0.17	0.40	0.42	3.82
Cumulative 2010-2030	1.72	3.93	4.14	40.97
Cumulative 2010-2040	3.37	7.75	8.16	78.22
3% discount rate	—	—	—	79.88
7% discount rate	—	—	—	76.78
Residential				
Annual 2030	0.21	0.39	0.41	4.82
Annual 2040	0.23	0.43	0.45	5.08
Cumulative 2010-2030	2.32	4.22	4.50	54.14
Cumulative 2010-2040	4.56	8.31	8.85	103.9
3% discount rate	—	—	—	106.2
7% discount rate	—	—	—	101.9
Total				
Annual 2030	0.37	0.75	0.79	8.41
Annual 2040	0.40	0.83	0.87	8.90
Cumulative 2010-2030	4.05	8.15	8.63	95.11
Cumulative 2010-2040	7.93	16.06	17.00	182.1
3% discount rate	—	—	—	186.0
7% discount rate	—	—	—	178.7

* Energy cost savings discounted at a 5% rate unless otherwise noted.

Table ES.2 summarizes the impact of energy codes beginning in 2010 and ending in 2040 for all states included in the analysis. The results include savings from electricity, natural gas, and fuel oil (residential only) and are reported separately for residential and commercial codes. The cumulative energy savings from 2010 through 2040 equates to a reduction of 840 million metric tons (MMT) of carbon dioxide (CO2), 314 thousand tons of sulfur dioxide (SO2), 1,314 thousand tons of nitrogen oxides (NOX), 1.60 tons of mercury (Hg), 7.4 thousand tons of nitrous oxide (N2O), and 5,858 thousand tons of methane (CH_4).

The emissions reductions are lower than those reported in the 2021 interim update. For example, the cumulative 2010 to 2040 CO_2 reduction of 840 MMT is less than the 901 MMT reduction reported in the interim update. Updated electricity and gas emissions factors help account for this decrease. These factors are now lower than before, and the net effect is reduced emissions savings compared to projected earlier savings. Despite the fact that this updated report showed higher energy savings, the reduced emissions factors more than offset the higher energy savings to result in lower total emissions savings.

Table ES.2. Summary of Energy Codes Impact on Emissions

Sector	CO_2 Reduction (MMT)	SO_2 Reduction (thousand tons)	NO_X Reduction (thousand tons)	Hg Reduction (tons)	N_2O Reduction (thousand tons)	CH_4 Reduction (thousand tons)
Commercial						
Annual 2030	17	7.0	25.5	0.037	0.17	115
Annual 2040	19	7.6	28.5	0.041	0.18	128
Cumulative 2010-2030	192	75	285	0.41	1.8	1,297
Cumulative 2010-2040	375	148	557	0.80	3.6	2,522
Residential						
Annual 2030	22	7.8	35.3	0.038	0.18	156
Annual 2040	23	8.5	38.4	0.041	0.19	168
Cumulative 2010-2030	239	84	386	0.41	2.0	1,709
Cumulative 2010-2040	466	166	757	0.81	3.8	3,336
Total						
Annual 2030	39	15	61	0.075	0.35	271
Annual 2040	42	16	67	0.081	0.38	296
Cumulative 2010-2030	431	158	671	0.82	3.8	3,006
Cumulative 2010-2040	840	314	1,314	1.60	7.4	5,858

Social Cost of Greenhouse Gases. Table ES.3 presents the results of a social cost of greenhouse gases analysis. Unrounded values by year of present value per metric ton of avoided CO_2, CH_4, and N_2O are used in this analysis. The range of results is shown below.[1]

Table ES.3. Present Social Value of Climate and Health Benefits for Energy Codes by Discount Rate (2021 $ million)

Climate Benefits	5.0%_Avg	3.0%_Avg	2.5%_Avg	3% 95th Pct.
Commercial				
Annual 2030	452	1,330	1,890	3,940
Annual 2040	656	1,760	2,430	5,280
Cumulative 2010-2030	4,210	13,100	19,000	38,500
Cumulative 2010-2040	9,840	28,800	40,900	85,200
Residential				
Annual 2030	578	1,690	2,400	5,000
Annual 2040	822	2,190	3,030	6,580
Cumulative 2010-2030	5,310	16,500	23,800	48,300
Cumulative 2010-2040	12,400	36,100	51,300	107,000
Health Benefits	**Low, 7.0%**	**Low, 3.0%**	**High, 7%**	**High, 3%**
Commercial				
Annual 2030	37	42	38	43
Annual 2040	23	25	23	26
Cumulative 2010-2030	1,510	1,690	1,530	1,710
Cumulative 2010-2040	1,740	1,950	1,770	1,970
Residential				
Annual 2030	78	87	80	89
Annual 2040	33	37	34	38
Cumulative 2010-2030	3,430	3,830	3,490	3,900
Cumulative 2010-2040	3,770	4,210	3,840	4,290

[1] Interagency Working Group on Social Cost of Carbon. 2021. *Social Cost of Carbon, Methane, and Nitrous Oxide. Interim Estimates under Executive Order 13990*. United States Government. Available at https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf.

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Acronyms and Abbreviations

AEO	Annual Energy Outlook
AIA	American Institute of Architects
BECP	Building Energy Codes Program
BTO	Building Technologies Office
Btu	British Thermal Unit
DHW	Domestic Hot Water
DOE	Department of Energy
ECPA	Energy Conservation and Production Act
EIA	Energy Information Administration
EUI	Energy Use Intensity
FFC	Full-Fuel Cycle
ICC	International Code Council
IECC	International Energy Conservation Code
LEED	Leadership in Energy and Environmental Design
MMT	Million Metric Tons
NEMS	National Energy Modeling System
NIA	National Impact Analysis
NOMAD	Naturally Occurring Market Adoption
PNNL	Pacific Northwest National Laboratory
SWH	Service Water Heating

Contents

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1.0 Introduction

Building energy codes regulate the energy efficiency of new construction and major renovations of buildings. Energy codes have been in place in one form or another since the 1970s and became part of official federal policy in 1992 with the amendment[1] of the Energy Conservation and Production Act (ECPA). The Department of Energy's (DOE's) Building Energy Codes Program (BECP) was created in response to congressional direction in ECPA to promote energy efficiency in buildings through energy codes. Since then, BECP has supported the development and adoption of model energy codes and encouraged compliance with those codes through various educational and tool-development activities.

Model codes are codes developed by a national consensus process and made available for adoption by states and local jurisdictions. The model codes of interest in this report are the International Energy Conservation Code (IECC)[2] for residential and ANSI/ASHRAE/IES Standard 90.1 (ASHRAE 90.1)[3] for commercial as these are explicitly referenced in the amended provisions of ECPA and are the basis for most U.S. state codes.

Recent editions of the IECC and ASHRAE 90.1 have the potential to generate a nearly 40% reduction in energy use compared to earlier codes.[4] Together with this rapid progress of codes in the recent past, the President's executive actions on climate change and the recently passed Bipartisan Infrastructure Law and Inflation Reduction Act have generated increased interest in understanding the magnitude of the impact of energy code activities.

To respond to this interest, PNNL, funded by DOE's Building Energy Codes Program, assessed the national impact of building energy codes from 2010–2040. This report describes the methodology and presents the results of the assessment. The starting point of 2010 is chosen because it coincides with the start year for the goals established in the DOE Building Technologies Office's (BTO) Multi-Year Program Plan (BTO 2016). The current assessment builds upon previous analysis, through which PNNL evaluated the historical impacts of buildings energy codes from 1992 through 2010 (Livingston et al. 2014).

The start year of the analysis is a sensitive input. Codes have been in existence since the 1970s and the BECP has been in existence since 1992. Buildings constructed earlier than 2010 and complying with earlier codes have been generating savings and will continue to generate savings in the future. By picking the start year as 2010, savings from the previous years are not reflected in this assessment. If the start year were 1992, for example, savings shown in 2010 and future years would increase significantly. Thus, the overall impact of energy codes in this assessment can be considered conservative. This is also true because the analysis does not include potential savings from states whose energy codes are fundamentally different from the national model energy codes and states that have neither a state-wide code nor state-wide adoption and enforcement.

Section 2.0 of this report describes the overall technical approach. Results are presented in Section 3.0. Appendix A provides details on the inputs used in the assessment.

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[1] Energy Conservation and Production Act (Pub. L. No. 94-385), as amended by the Energy Policy Act of 1992 (Pub. L. No. 102-486).

[2] See www.iccsafe.org.

[3] See www.ashrae.org.

[4] For example Standard 90.1-2019 compared to 90.1-2001 and IECC 2021 compared to 2003 per https://public.tableau.com/app/profile/doebecp/viz/HistoricalModelEnergyCodeImprovement/CombinedHistoricalCodeImprovement_1

2.0 Methodology

Model energy codes follow a three-phase cycle that starts with the development of a new model code, continues with the adoption of the new code by states and local jurisdictions, and finishes the new code is implemented and builders, architects, and engineers are required to comply with the new provisions. The contribution of all three phases on the overall impact of the code is considered in this assessment. Once a new model code is developed, states need to take action to formally adopt the new code. After the new code is adopted, savings are realized in the field only when new buildings (or additions and alterations) are constructed to comply with the new code. Delayed adoption of a new model code and incomplete compliance with all the code's requirements can erode potential savings.

This analysis uses a rolling baseline in which savings are based on the difference in energy efficiency between a new code and its immediate predecessor. When a new code is adopted, the version it replaced becomes the baseline against which savings are calculated. This changes with each new code, thus a rolling baseline. A detailed discussion about the rolling baseline can be found in Section 2.1.2.

In this analysis, potential savings between one code and its successor do not include savings resulting from improvements in equipment efficiency mandated by federal rulemakings. DOE rulemakings set minimum efficiency levels for certain heating, ventilating, and air conditioning (HVAC), and service water heating (SWH) equipment. These improvements in equipment efficiency would result regardless of whether a new code is enforced and are therefore not attributable to the energy code.

There are many beyond-code programs, such as utility incentive programs, Energy Star, and LEED, as well as other locally- and state-funded programs that promote energy efficiency in buildings. Such programs have an impact on the energy efficiency of the building stock that can be considered separate from the code impact. For example, the first phase of the DOE residential field study (BECP 2016a) showed that windows installed in new homes consistently and significantly exceeded code requirements in all participating states. This higher level of window performance might be driven by certain beyond-code programs, but it can be difficult to separate the impact of these programs from the impact of codes. Energy codes remain the primary mechanism through which improvements in energy efficiency are enforced on most of the building stock. This trend may change as state and local Building Performance Standards (BPS) gain traction and require existing buildings to meet performance targets. In this analysis, improvement between successive codes is based on the requirements found in the new code. No credit is taken for improvements beyond the requirements within the energy code.

2.1 Analysis Framework

This section describes the analytical framework of the assessment and provides further detail on how the savings calculation is structured. Figure 1 provides a schematic overview of the framework. The assessment begins with the adoption of codes at the state level starting in 2010. In each year, potential savings are calculated by subtracting the energy use intensity (EUI) of the current code from the EUI of the previous code. Next, potential savings are de-rated by realization rate to determine savings realized in the field. Finally, the de-rated savings are multiplied by the floor space added in a given year to calculate the incremental savings in that year (Figure 2). These incremental savings are captured in the annual savings during later years. The process repeats each year starting with the evaluation of the code currently in place and the code that was in place before. Annual and cumulative savings are calculated from incremental savings to determine the overall impact. More details on the calculation are provided in the following sections.

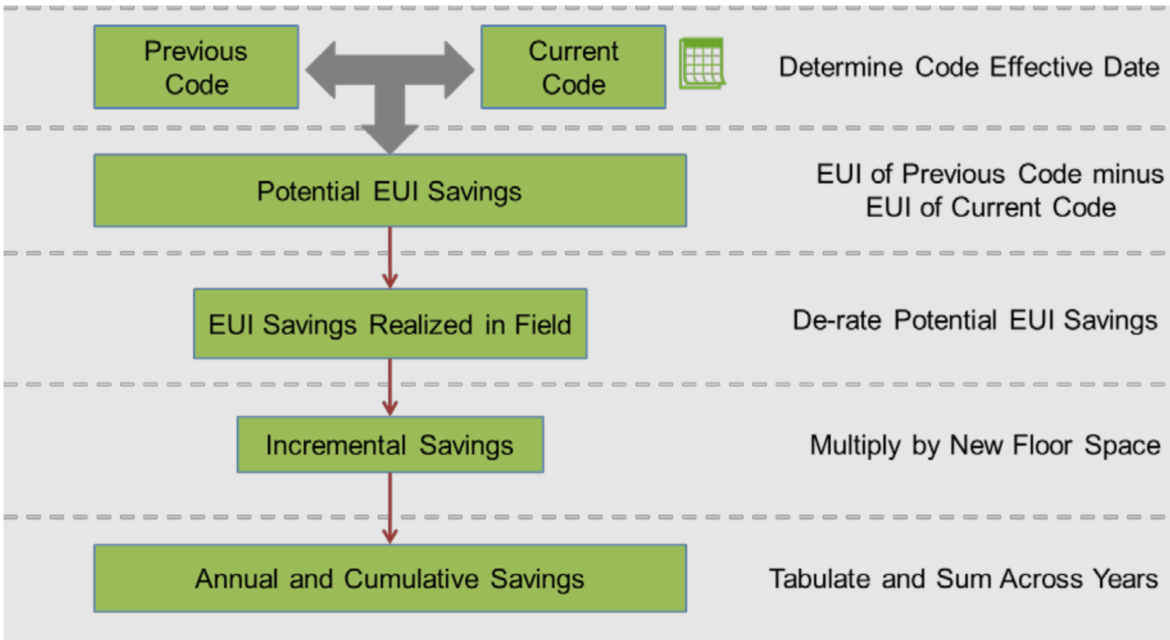

Figure 1. Codes Impact Analysis Framework

Incremental Savings = Potential EUI Savings × Savings Realization Rate × Floor space

Figure 2. Incremental Savings Calculation

2.1.1 Scope of Analysis

This cannot be considered a full national analysis because several states were excluded for one of two reasons:

1. They do not adopt a code at the state level, or a state-wide code exists but it is not mandatory or there are special restrictions on enforcement. States in this category are Alaska,[1] Kansas, Missouri, Mississippi, North Dakota, and South Dakota. Conversely, Arizona, Colorado, and Wyoming do not enforce state-wide codes, but their largest jurisdictions have adopted recent energy codes, so they are included and treated as if they have state-wide codes in this study. Table 1 provides details on the treatment of states with no mandatory state-wide codes or enforcement. Detailed information on adoption inputs can be found in Appendix A.

2. They have energy codes significantly different in format and content than ASHRAE 90.1 or the IECC model codes, so the EUIs developed for this analysis could not be applied to their energy codes. Developing custom EUIs for these states was beyond the scope of this analysis. California and Washington are in this category.

[1] Commercial: only buildings in the transportation, public facilities, and education department are regulated. Residential: Must comply with state code if state financial assistance is used in construction.

Table 1. States With No Mandatory State-wide Code or Enforcement Restrictions

State	Mandatory Enforcement of State-wide Code	Use of Populous Jurisdictions or Cities as Surrogate for State-wide Code
Alaska	Yes	No
Arizona	No	Yes (Phoenix, Tucson)
Colorado	No	Yes (Denver, Aurora, and Boulder County)
Kansas	No	No
Missouri	No	No
Mississippi	No	No
North Dakota	No	No
South Dakota	No	No
Wyoming	No	Yes (Jackson and Cheyenne Counties)

Developing associated savings estimates for these states would require evaluating EUIs that do not currently exist, and as a result, these states have been excluded from the report. Taken together, the excluded states represent a sizeable amount of the U.S. new building stock, accounting for 18% of new commercial floor space and 20% of new residential floor space projected to be constructed between 2011 and 2040 in the United States. If it were possible to consider the impacts of these excluded states as part of the overall national impact analysis, the values would likely be substantially higher than the results reported in this study.

2.1.2 Rolling Baseline Approach

The rolling baseline used in this study assumes the predecessor code of each newly adopted code as the baseline for savings analysis. Alternatively, a fixed baseline would assume that the first code in the study period – the one in place in a state in 2010 in this study – was the baseline for all future codes.

Since this study uses the difference between the baseline EUI and the current code EUI to determine incremental savings for new construction, it is clear that the rolling baseline results in much smaller, more conservative savings estimates. On the other hand, the fixed baseline approach was rejected as overly optimistic because it implicitly assumes that building efficiency never increases in the absence of changes to the energy code. Given a variety of market drivers for efficiency that are known to exist (product competition, utility rebates, federal tax credits, above-code programs, etc.) that assumption was deemed insupportable.

A third approach, used in some past analyses from BECP as well as other organizations' code impact studies, is to assume an increasingly efficient baseline intended to represent "normally occurring market adoption" (NOMAD) of efficiency in the absence of codes improvements. Assumptions about NOMAD levels are typically based on expert opinion and are thus inherently subjective, ranging from high to low depending on individual beliefs about how much efficiency will improve over time.

More important for the current study, a NOMAD baseline is unrelated to code development and adoption that have actually occurred. Code adoption, code-to-code savings, and compliance rates in the presence of codes are known in many cases. Relying on what is known for developing the baseline makes the analysis more robust and defensible. At the same time, all assumptions about future code levels are ultimately subjective; in the absence of a perfect way to predict the future, this study opted for the approach most closely tied to the development/adoption/implementation cycle.

It should be noted that an inherent consequence of choosing the predecessor code as the baseline is that a state that adopts codes in a timely fashion could save less energy than a state that delays new code adoption if the new code edition saves less than the previous code. This effect is discussed in greater detail in Section 3.0.

2.1.3 Code Effective Date

For this analysis, savings are generated for the first time when a state adopts a code newer than the one in place in 2010, and assuming states will follow historical adoption trends in making future code updates. A code was considered to be in place in a given year if the code was effective on or before July 1st of that year. For future code adoptions, states are classified into four categories based on their historical rate of adoption:

Aggressive: State adopts new code within one code cycle. Future adoption lag = 1 year.

Moderate: State adopts new code within two code cycles. Future adoption lag = 4 years.

Slow: State adopts new code after two code cycles. Future adoption lag = 7 years.

Not Applicable: States with no state-wide code, no code enforced in jurisdictions within the state or with minimal relationship to the national model codes.

Based on the above classification, the year in which a state is expected to adopt a future code depends on the adoption lag and the code year. For example, Illinois, classified as aggressive, is anticipated to adopt the 2021 IECC in the year 2022 (a one-year lag). The code year for both residential and commercial is the IECC year (and not the year in which the code book is published). For example, the code year for the 2015 IECC is 2015 even though the 2015 IECC was published in 2014. The commercial code year is based on the IECC and not on ASHRAE 90.1 because most states adopt the IECC (to which ASHRAE 90.1 is an alternate compliance path).

2.1.4 Code-to-Code Savings

Once the code in place in a given year for each state is known or assigned, code-to-code savings can be calculated by subtracting the EUI of the new code from that of the previous code. The delta between the code EUIs is used in determining the potential EUI savings in Figure 2. Code EUIs are developed using the process established by DOE for its statutorily directed "Determinations" that indicates whether a new code will improve energy efficiency in buildings. The most recent commercial and residential determinations and their associated technical reports describe the process in greater detail (DOE 2021, Salcido et al. 2021). The Determination process excludes savings from improvements in equipment efficiency due to federally mandated requirements. Further detail on how commercial and residential EUIs are developed is provided below.

Commercial Code EUIs. There are six editions of ASHRAE 90.1—2004, 2007, 2010, 2013, 2016 and 2019—for which PNNL calculated EUIs. Simulations were performed for each climate zone in every state and the results were weighted by forecasted new construction area to produce state-level EUIs. These results are used in this analysis.

Earlier Determination analyses for ASHRAE 90.1-2007 and 90.1-2004 could not be used directly to obtain EUIs for those Standards because when those analyses were performed, the federally mandated equipment efficiencies differed from how the Determination analyses for ASHRAE 90.1 were conducted. To correctly calculate the EUIs for ASHRAE 90.1-2007, for example, savings percentages between ASHRAE 90.1-2010 and 90.1-2007 calculated in the Determination analysis of 90.1-2010 are applied to the state-level EUIs of 90.1-2010. A similar process is followed to determine EUIs for ASHRAE 90.1-

2004. This process of using savings percentages ensures that the EUIs of the six ASHRAE 90.1 editions (2004 through 2019) are consistent with each other in terms of the published Determination savings. EUIs for codes older than ASHRAE 90.1-2004 are calculated using a historical index of commercial code improvements developed by PNNL (BTO 2016).

To develop EUIs for future code editions, PNNL examined BTO's Technology Roadmap reports for envelope, lighting, HVAC, and SWH (BTO 2015, 2014a,b,c). PNNL also reviewed AIA's 2030 Goal (AIA 2030) and the goals set by the ASHRAE 90.1 development committee for each edition. Appendix A provides additional discussion of future code EUIs.

Different reduction percentages are applied to different end-uses depending on the projected technological progress. The plug and process end-use is conservatively projected to see no reduction at all in future code editions. The impact of renewable technologies is not included in future code editions. Detailed inputs for historical and future code edition efficiency levels can be found in Appendix A.

States can adopt either the commercial IECC or the corresponding ASHRAE 90.1– both are updated every three years. Each edition of the IECC has historically allowed the corresponding ASHRAE 90.1 edition as an alternate compliance path, and it is assumed that practice will continue. In this analysis, the EUIs developed for ASHRAE 90.1 are used to represent corresponding editions of ASHRAE 90.1 and the commercial IECC, because developing state-level EUIs for the commercial IECC is beyond the scope of this analysis. For example, ASHRAE 90.1-2019 and 2021 IECC are represented by a single state-level EUI. The codes are substantially similar enough to have comparable energy savings between code editions.[1]

States often amend certain sections of the IECC or ASHRAE 90.1 when adopting the code. Such amendments to commercial codes are not factored into the EUIs used in this analysis.

Residential Code EUIs. PNNL used the EUIs developed for six editions of the residential IECC— 2006, 2009, 2012, 2015, 2018 and 2021. EUIs from the past analyses are used in the current assessment. The impact of state-specific code amendments was not incorporated into the EUI analysis because amended code EUIs were not available for all code editions adopted by a particular state. Plug loads are not currently regulated by residential codes and are therefore not included in the analysis.

As with the commercial codes, EUIs of future editions of residential codes are determined by reviewing BTO's Technology Roadmaps. The recent history of energy savings includes:

The 2021 IECC saved 9.4% site energy relative to the 2018 version (Salcido et al. 2021).

The 2018 IECC saved 1.7% site energy relative to the 2015 version (DOE 2019).

The 2015 IECC saved 1% site energy relative to the 2012 version (Mendon et al. 2015)

The 2012 IECC saved 24% site energy relative to the 2009 version (Lucas et al. 2013, DOE 2012).

The 2009 IECC saved 11% site energy relative to the 2006 (Lucas et al. 2013, DOE 2012).

For future code editions, different reduction percentages are applied to different end-uses depending on the projected technological progress. Further details on the historical and future code edition efficiency levels can be found in Appendix A.

[1] A comparison between Standard 90.1-2019 and 2021 IECC is available in Appendix B in this report: https://www.energycodes.gov/sites/default/files/2022-09/2021_IECC_Commercial_Analysis_Final_2022_09_02.pdf

2.1.5 Savings Realized in the Field

Energy code compliance is crucial to realizing the savings potential embedded within code requirements. While many past studies have attempted to quantify compliance with residential and commercial codes, a literature survey of past commercial compliance studies (Bartlett et al. 2016) found several problems including too-small sample sizes, sample bias, difficulty in accessing compliance documentation, and most importantly in the context of this analysis, the lack of a uniform definition of compliance. Past field studies measured the percent of requirements complied with relative to the total number of requirements, a metric aligned with how building officials see compliance but not tied to energy savings. The current analysis defines compliance as a savings realization rate equal to the fraction of the total potential savings that is achieved in the field. The savings realization rate determined in this manner is used to calculate the incremental savings in a given year, as shown in Figure 2.

Results from a series of residential field studies show that investment in building energy code education, training, and outreach can produce a significant and measurable improvement in residential building energy savings realized in the field (Blanding et al. 2022). This field study considers the sample size required to make statistically significant statements about the energy savings potential realized in the field at the state level. One of the study outcomes is a comparison of the observed EUI for an entire state with that of a hypothetical sample that fully complies with the code. Using these results, it is possible to determine the fraction of EUI savings realized in the field.

The results from the first phase of the residential field study show that states commonly realized more than 100% of expected savings (exceeded code requirements) for codes that had been adopted at least two years after they had been published. Of the eight states in the field study, the seven with 2012 IECC or 2009 IECC had savings realization rates over 100%. Only one state had adopted the 2015 IECC, which was published just one year prior to adoption and measurement in the field study, and its realization rate was 89%. Based on the limited data in the field study, PNNL hypothesized that a relationship could be established between the publication date of the code and the savings realization rate—the longer the delay in adopting a code, the higher the realization rate. For example, if a state adopted the 2009 IECC in the year 2015, the realization rate in 2015 would be very close to 100%. However, if a state adopted the 2015 IECC in 2016, the realization rate would be lower. The underlying theory is that the savings realized in the field seem to depend more on the time that has passed since the code was published than on the time passed since the code was adopted. Based on this hypothesis, a realization rate of 80% was chosen as a conservative estimate in the first year after the code is published. The realization rate was then increased asymptotically every year, approaching 100% at the end of 10 years. When a new code becomes effective, for example five years after the previous code, the realization rate is reset to 80% for Year 1 of the new code. This approach was applied to all residential codes and states.

Similar data for savings realized in the field in commercial buildings is not available. DOE finalized a commercial codes field study in 2023 to better understand the potential energy and energy cost savings realized from codes in commercial buildings. Only four of 230 total buildings were fully compliant with the energy code. The lost energy cost savings as found during the field study was $189 per thousand square feet, with present value of $2,868 per thousand square feet, on average across all the buildings (Tyler et al. 2023). A pilot study conducted by PNNL (Rosenberg et al. 2016) analyzed lost energy savings from a sample of nine small office buildings in the Pacific Northwest. The study found the maximum fraction of lost energy savings to be approximately 12%, or in other words, the lowest savings realization rate was 88%. For the current analysis, a conservative realization rate of 50% is chosen for the first year after the commercial code is published, i.e., only 50% of the potential savings are realized in the first year. For example, aggressive adopting states with a future adoption time lag of one year will realize only 50% of the savings from the new code in the first year. The realization rate then increases asymptotically every year, approaching 80% in year 10. This approach is applied to all commercial codes and states.

2.1.6 Floor Space Multiplier

The incremental savings depend upon the amount of new floor space in the state that is built to the code. New floor space constructed in a given year is used to determine the incremental savings in a given year, as shown in Figure 2. Estimates of new residential and commercial floor space constructed each year were developed from the National Energy Modeling System (NEMS) output files from the Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2022 reference case. This data is reported at the Census Bureau division level. State-level census population estimates are used to split the AEO Census Bureau division level floor space values among states within each division.

Shrinkage of savings over time because of floor space demolition is not included in the analysis because it is assumed that the average lifespan of a building is longer than this analysis period.

2.2 Calculation of Incremental, Annual, and Cumulative Savings

Savings from code adoptions are generated throughout a building's life because in the absence of a new code, the building would have been built to an older, less energy efficient code and would have consumed more energy every year of its life. Thus, buildings built to better codes after 2010 are still generating savings today. Savings from new code construction are added to savings from past code adoptions in each year, as described above in Figure 1 and Figure 2. In this analysis, three different types of savings are calculated and tabulated for each year in the study:

Incremental savings: Savings accruing only from new floor space added in a given year. These savings are simply a product of the code-to-code savings in a given year and the floor space added in that year.

Annual savings: Savings accruing from not only new floor space added in the given year but also from previous code adoptions and new floor space construction that occurred in the study period up to that year. Annual savings account for code actions that affected floor space added in previous years, and that continues to generate savings in the current year.

Cumulative savings: The sum of annual savings over all the years in the study period.

Savings reduction occurring from degradation of energy saving features over time is ignored for this analysis. For example, lighting occupancy sensor control savings could reduce over time because of degrading electronic components (relays, sensors, control mismanagement, etc.) or there may be an increase in infiltration due to wear and tear of the envelope. These effects are ignored in the analysis because they will equally affect the new code and the baseline, thus having a negligible net effect on the savings. A sample calculation in the next section explains the savings calculation for a single state.

2.3 Sample Calculation

Table 2 provides an example of how incremental, annual, and cumulative savings are calculated in this analysis. The calculation is performed for energy savings only for a single state for the period beginning in 2010 and ending in 2020. For simplicity, generic values are chosen for code-to-code savings, savings realization rates, and the amount of floor space added each year. In the actual analysis, this calculation is performed separately for residential and commercial buildings for each state.

2.3.1 Explanation of Calculation Table Rows

Row 1 indicates the code edition. The calculation starts with code edition 1 in place in 2010. In 2011, a new code is adopted giving rise, for the first time, to energy savings indicated in row 2. Likewise, a new code is adopted in 2014 and 2018. The code-to-code energy savings arise from the fact that code edition 2 has an improved efficiency compared to code edition 1. These savings are incremental over the prior edition. Row 3 shows the savings realization rate. Note that it improves each year a code is in place and then gets lower whenever a new code is adopted. Row 4 shows the realized savings, calculated as code-to-code savings (Row 2) times the realization rate (Row 3). Row 5 shows the floor space added in a given year, which, for this example, is assumed to be a million square feet (sf) every year.

Table 2. Example Calculation of Incremental, Annual, and Cumulative Savings for One State

Row	Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1	Code Edition	1	2	2	2	3	3	3	3	4	4	4
2	Code-to-Code Savings, kBtu/sf	-	7.0	7.0	7.0	6.0	6.0	6.0	6.0	5.0	5.0	5.0
3	Realization Rate	-	0.7	0.8	0.9	0.7	0.8	0.9	0.95	0.7	0.8	0.9
4	Realized Savings, kBtu/sf	-	4.9	5.6	6.3	4.2	4.8	5.4	5.7	3.5	4.0	4.5
5	New floor space added, thousand sf	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
							Savings, billion Btu					
	Year of accounted savings →	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	↓ Year floor space is added											
6	2010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	2011	0.0	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
8	2012	0.0	0.0	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
9	2013	0.0	0.0	0.0	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
10	2014	0.0	0.0	0.0	0.0	4.2	4.2	4.2	4.2	4.2	4.2	4.2
11	2015	0.0	0.0	0.0	0.0	0.0	4.8	4.8	4.8	4.8	4.8	4.8
12	2016	0.0	0.0	0.0	0.0	0.0	0.0	5.4	5.4	5.4	5.4	5.4
13	2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	5.7	5.7	5.7
14	2018	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	3.5	3.5
15	2019	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0
16	2020	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5
17	Incremental	0.0	4.9	5.6	6.3	4.2	4.8	5.4	5.7	3.5	4.0	4.5
18	Annual	0.0	4.9	10.5	16.8	21.0	25.8	31.2	36.9	40.4	44.4	48.9
19	Cumulative (sum of Annual Savings from 2010 through 2020)											280.8

Note: Generic values are used in this table to demonstrate the calculation.

Rows 6 through 16 calculate the incremental savings in each year, i.e., the realized savings (Row 4) times the floor space added in that year (Row 5). There are no incremental savings in 2010 because the code in place did not change. In 2011, however, a new code is adopted, and incremental savings will be generated. In 2012, there are both, incremental savings from new floor space added in that year, and savings from buildings constructed in 2011 will continue into 2012 and beyond. These continuing savings can be seen in Rows 7-15 of Table 2 where the initial savings number in each row is repeated each year. On Row 8, for example, buildings built in 2012 deliver 5.6 MMBtu of savings the first year. They continue to deliver this same 5.6 MMBtu of savings in all subsequent years (moving horizontally to the right across the row).

2.3.2 Incremental vs. Annual Savings

Row 17 in Table 2 shows the incremental savings in every year and Row 18 shows the annual savings in every year. For 2011 the incremental and annual savings are the same, but for 2012, the annual savings are larger because they are the sum of the previous year's annual savings and the current year's incremental savings. Annual savings at the end of the study period are much larger than at the beginning of the study period. For example, the annual savings in year 2020 are much larger than in 2015 because the floor space added each year in the intervening period (2016-2020) generates savings that will become part of the annual savings in 2020. Finally, Row 19 shows the cumulative savings for the entire period, a sum of the annual savings (Row 18) from 2010 through 2020.

The example results are shown graphically in Figure 3.

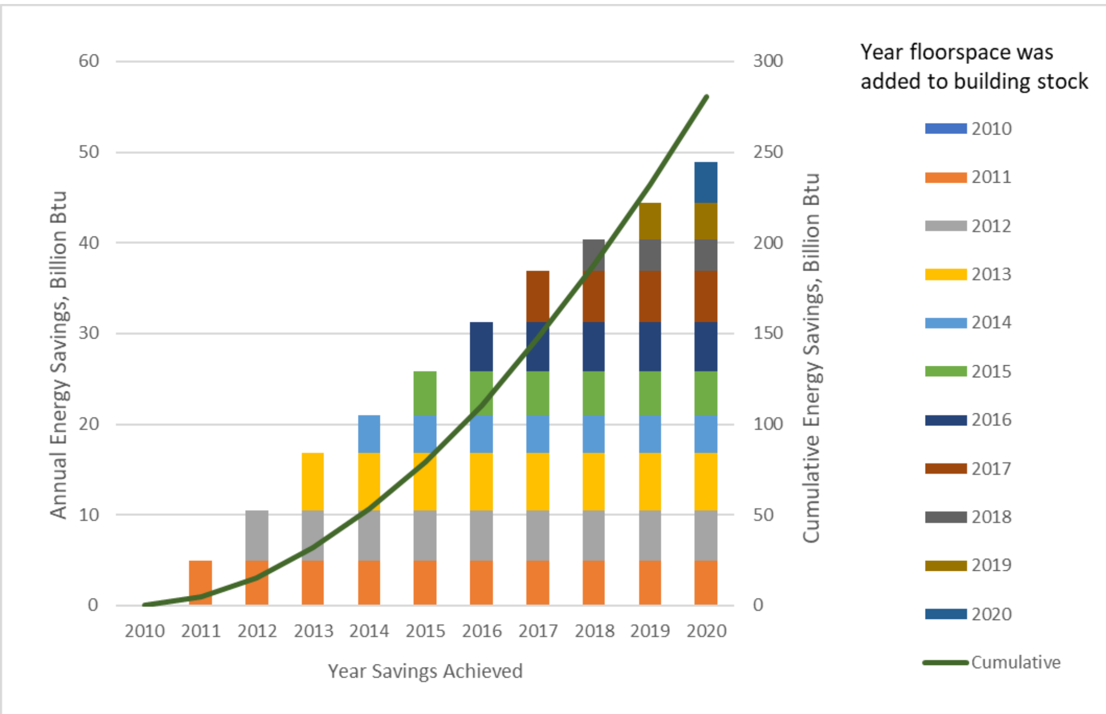

Figure 3. Annual and Cumulative Savings from Energy Codes – Example

2.4 Impact of Energy Codes on Emissions

This analysis considers the impact of energy codes on avoided greenhouse gases and other emissions including estimates of the monetized benefits of the reductions in emissions.

2.4.1 Emissions Analysis

The conversion from site energy savings to emissions reductions is performed by applying environmental conversion factors developed through DOE's Appliance and Equipment Standards Program[1] as summarized here and described in Appendix B. The emissions analysis estimates the effect of energy codes on the power sector and the site (where applicable) combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2), and mercury (Hg). The analysis also estimates the impacts of

1 http://energy.gov/eere/buildings/appliance-and-equipment-standards-program

energy codes on emissions of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), as well as the reductions to emissions of other gases due to upstream activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion.

The analysis of power sector emissions of CO_2, NO_X, SO_2, and Hg uses marginal emissions factors that were derived from data in AEO 2022 (EIA 2022a). Power sector combustion emissions of CH_4 and N_2O are derived using Emission Factors for Greenhouse Gas Inventories published by the EPA, as are site combustion emissions of CO_2, CH_4 and N_2O.[1] The FFC upstream emissions are estimated based on the methodology described in Appendix B and in Coughlin (2013). The upstream emissions include emissions from fuel combustion during extraction, processing, and transportation of fuels, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2. Each annual version of the AEO incorporates the projected impacts of existing air quality regulations on emissions. The AEO generally represents current Federal and State legislation and final implementation regulations in place as at the time of its preparation. For details, see Summary of Legislation and Regulations Included in the AEO 2021, Appendix, Electric power sector.[2] The emissions intensity factors are expressed in terms of physical units per megawatt-hour (MWh) or million British thermal units (MMBtu) of site energy savings. Total emissions reductions are estimated by multiplying the emissions intensity factor by the energy savings calculated during this analysis. The emissions factors used in the calculations are provided in Appendix B. For power sector emissions, the factors depend on the sector and end use.

2.4.2 Social Cost of Carbon, Methane, and Nitrous Oxide

DOE estimated the climate benefits of CO_2, CH_4, and N_2O (*i.e.,* SC-GHGs) reductions using the estimates presented in the *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates* under EO 13990 published in February 2021 by the Interagency Working Group on the Social Cost of Greenhouse Gases (February 2021 TSD).[3] The SC-GHGs is the monetary value of the net harm to society associated with a marginal increase in emissions in a given year, or the benefit of avoiding that increase. In principle, SC-GHGs includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk and natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-GHGs reflects the societal value of reducing or increasing emissions of the gas in question by 1 metric ton (MT). The SC-GHGs is the theoretically appropriate value to use in conducting benefit-cost analyses of policies that affect CO_2, N_2O, and CH_4 emissions.

While the IWG works to assess how best to incorporate the latest, peer reviewed science to develop an updated set of SC-GHG estimates, it set the interim estimates to be the most recent estimates developed by the IWG prior to the group being disbanded in 2017. The estimates rely on the same models and

[1] https://www.epa.gov/sites/default/files/2021-04/documents/emission-factors_apr2021.pdf.

[2] https://www.eia.gov/outlooks/aeo/assumptions/pdf/summary.pdf

[3] On March 16, 2022, the Fifth Circuit Court of Appeals (No. 22-30087) granted the federal government's emergency motion for stay pending appeal of the February 11, 2022, preliminary injunction issued in Louisiana v. Biden, No. 21-cv-1074-JDC-KK (W.D. La.). As a result of the Fifth Circuit's order, the preliminary injunction is no longer in effect, pending resolution of the federal government's appeal of that injunction or a further court order. Among other things, the preliminary injunction enjoined the defendants in that case from "adopting, employing, treating as binding, or relying upon" the interim estimates of the social cost of greenhouse gases—which were issued by the Interagency Working Group on the Social Cost of Greenhouse Gases on February 26, 2021—to monetize the benefits of reducing greenhouse gas emissions. In the absence of further intervening court orders, DOE will revert to its approach prior to the injunction and present monetized benefits where appropriate and permissible under law.

harmonized inputs and are calculated using a range of discount rates. As explained in the February 2021 SC-GHG TSD, the IWG has recommended that agencies to revert to the same set of four values derived from the SC-GHG distributions based on three discount rates as were used in regulatory analyses between 2010 and 2016 and subject to public comment. For each discount rate, the IWG combined the distributions across models and socioeconomic emissions scenarios (applying equal weight to each) and then selected a set of four values recommended for use in benefit-cost analyses: an average value resulting from the model runs for each of three discount rates (2.5 percent, 3 percent, and 5 percent), plus a fourth value, selected as the 95th percentile of estimates based on a 3 percent discount rate. The fourth value was included to provide information on potentially higher-than-expected economic impacts from climate change.

This analysis estimated the climate benefits of CO_2, CH_4, and N_2O reductions (i.e., SC-GHGs) using the values published in February 2021 by the IWG on Social Cost of Greenhouse Gases (February 2021 TSD). Table 3 shows the SC-CO_2 and Table 4 shows the four sets of SC-CH_4 and SC-N_2O values in 5-year increments from 2025 to 2040. For purposes of capturing the uncertainties involved in this type of analysis, all four sets of SC-CO_2 values are included, as recommended by the IWG.[1]

Table 3. Annual SC-CO_2 Values from 2021 Interagency Update, 2025–2040 (2021$ per Metric Ton CO_2)

Year	Discount Rate			
	5%	3%	2.5%	3%
	Average	Average	Average	95th percentile
2025	18	59	86	180
2030	20	64	93	190
2035	23	70	100	210
2040	26	76	110	230

The SC-CO_2, SC-CH_4, and SC-N_2O emissions reduction estimated for each year are multiplied by the SC-CO_2, SC-CH_4, and SC-N_2O value for that year in each of the four cases to estimate the monetized benefit of emissions savings occurring in that year. To calculate a present value of the stream of monetized savings over the analysis period, the analysis discounts the values in each of the four cases using the specific discount rate that had been used to obtain the SC-GHG values in each case.

Table 4. Annual SC-CH_4 and SC-N_2O Values from 2021 Interagency Update, 2025–2040 (2021$ per metric ton)

Year	SC-CH_4				SC-N_2O			
	Discount Rate and Statistic				Discount Rate and Statistic			
	5%	3%	2.5%	3%	5%	3%	2.5 %	3%
	Average	Average	Average	95th percentile	Average	Average	Average	95th Percentile
2025	835	1,790	2,320	4,740	7,071	21,450	31,160	56,550
2030	977	2,040	2,610	5,410	8,123	23,720	34,060	62,840
2035	1,160	2,320	2,940	6,210	9,413	26,280	37,240	69,920
2040	1,330	2,610	3,280	7,010	10,700	28,850	40,420	76,990

[1] For example, the February 2021 TSD discusses how the understanding of discounting approaches suggests that discount rates appropriate for intergenerational analysis in the context of climate change are likely to be less than 3 percent.

2.4.3 Social Cost of Sulfur Dioxide and Nitrous Oxide

Building energy codes would reduce SO_2 and NO_X emissions from electricity generation in those 22 states that are not affected by caps. Caps refers to regulatory limits on emissions of certain pollutants, specifically SO_2 and NO_X, that are imposed on power plants or other sources of electricity generation in some states. States that are affected by caps have specific emission limits set by the government or regulatory authorities. These caps restrict the maximum amount of SO_2 and NO_X that can be emitted into the atmosphere from power plants within those areas. On the other hand, states that are not affected by caps do not have such specific limits set by the government. As a result, implementing building energy codes in these states would help reduce SO_2 and NO_X emissions from electricity generation by promoting more energy-efficient practices and technologies in buildings, even though there are no specific caps in place.

DOE estimated monetized values of NO_X and SO_2 emissions reductions from electricity generation using the latest benefit-per-ton estimates for that sector from the EPA's Benefits Mapping and Analysis Program.[1] DOE used EPA's values for $PM_{2.5}$-related benefits associated with NO_X and SO_2 and for ozone-related benefits associated with NO_X for 2025, 2030, 2035 and 2040, calculated with discount rates of 3 percent and 7 percent. DOE used linear interpolation to define values for the years not given in the 2025 to 2040 period; for years beyond 2040 the values are held constant.

The ozone-related benefits associated with NO_X occur only in the ozone-season (May to September). EPA data indicate that ozone-season NO_X emissions from electricity generation are slightly less than half of all-year NO_X emissions. DOE accounted for this characteristic in its methodology.

DOE combined the EPA data with data from AEO2022 to estimate benefit-per-ton values by sector. Appendix C provides methodological details and values that DOE used. The results presented in the Results section use benefit-per-ton values for the residential and commercial sectors. DOE multiplied the emissions reduction (in tons) in each year by the associated $/ton values, and then discounted each series using discount rates of 3 percent and 7 percent as appropriate.

Building energy codes also reduce NOx and SO_2 emissions from combustion at the home or commercial building. To monetize the value of these emissions reductions, DOE used benefit-per-ton estimates from the Benefits Mapping and Analysis Program's 2018 report Technical Support Document Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors.[2] Although none of the sectors refers specifically to residential and commercial buildings, the sector called "Area sources" would be a reasonable proxy for residential and commercial buildings. "Area sources" represents all emission sources for which states do not have exact (point) locations in their emissions inventories. Because exact locations would tend to be associated with larger sources, "area sources" would be fairly representative of small, dispersed sources like homes and businesses.[3]

The EPA document provides high and low estimates for 2025 and 2030 at 3 and 7 percent discount rates (see Table 5). DOE converted the values to 2021$ using the implicit price deflator for gross domestic product ("GDP") from the Bureau of Economic Analysis and interpolated and extrapolated values as described previously.

[1] Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 21 Sectors. https://www.epa.gov/benmap/estimating-benefit-ton-reducing-directly-emitted-pm25-pm25-precursors-and-ozoneprecursors

[2] Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors. https://www.epa.gov/benmap/estimating-benefit-ton-reducing-pm25-precursors-17-sectors.

[3] The sector "Area sources" was not used in the EPA's most recent analysis that DOE used for the electricity generation sector.

Table 5. Summary of the Total Dollar Value (mortality and morbidity) per Ton of Directly Emitted $PM_{2.5}$ Precursor Reduced by Area Sources (2021$)

Year of Emission	Low		High	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
	NO_X			
2025	9,700	8,800	22,000	20,000
2030	11,000	9,500	24,000	21,000
	SO_2			
2025	61,000	55,000	140,000	120,000
2030	67,000	60,000	150,000	140,000

3.0 Results

This section presents the results of the assessment in terms of site energy savings, primary energy savings (including transmission, delivery, and generation losses), full-fuel cycle (FFC) savings[1], financial benefits to consumers (utility bill savings), and avoided greenhouse gases and other emissions.

Financial benefits are calculated by applying historical and future fuel prices to site energy savings and by discounting future savings to 2021 dollars. Historical fuel prices are obtained from EIA (EIA 2022b,c). Future fuel prices are obtained from EIA's AEO 2022 dataset (EIA 2022a). A real discount factor of 5% is applied to discount future energy cost savings. In addition, boundary discount factors of 3% and 7% are provided for savings in a 2010-2040 time frame. Further details on savings conversions can be found in Appendix A.

Table 6 below summarizes the impact of energy codes aggregated across all the states included in this analysis. Savings are combined from all fuel types (electricity, natural gas, and fuel oil). Annual savings, as defined in Section 2.2, are shown for 2030 and 2040, and cumulative savings are shown for 2010 through 2030 and also 2010 through 2040. Savings are further broken out into residential and commercial codes. Energy codes are estimated to save 17.00 quads of FFC energy and $182 billion dollars in consumer cost on a cumulative basis from 2010 through 2040. Primary energy savings are split between commercial and residential buildings, with energy cost savings roughly 5% higher in residential than commercial. As described in Section 2.1.1, the results shown here are lower than the total potential savings from energy codes in the entire U.S. because several states were not included.

The energy and energy cost savings are higher than those reported in the 2021 interim update. For example, the cumulative 2010 to 2040 savings of $182 billion is higher than the $138 billion savings reported in the interim update. Updates to the methodology, such as energy prices, annual floorspace additions, and state code adoption dates, help account for this increase. Electricity prices from 2010 through 2040 are 18% higher on average for residential buildings and 14% higher on average for commercial buildings compared with the interim update. The floorspace additions from 2010 through 2040 are 7% higher for residential buildings and 2% higher for commercial buildings compared with the 2021 interim update.

As explained in Section 2.1.2 the rolling baseline approach uses the previous code in place as the baseline. This can give rise to non-intuitive results, such as states that adopt codes in a timely manner saving less energy on a cumulative basis than states that adopt codes at a moderate or slow pace (given equal floor space and same starting code editions). For example, Illinois is an aggressive adopter of new codes, and Michigan adopts codes at a moderate pace. Comparing the residential cumulative primary energy savings between these states shows that Illinois saves 0.13 quads and Michigan saves 0.38 quads. Michigan's savings is much higher despite a projected 20% lower new construction floor area during the analysis period.

The higher savings from Michigan result from two main differences:

In the analysis start year (2010), Michigan has the 2003 IECC and Illinois has the 2009 IECC. Per square foot of residential construction floorspace, Michigan has greater potential to save energy from code adoption solely due to the code in place in 2010.

Michigan adopts 2009 IECC in 2011 and 2015 IECC in 2016 (skipping 2012 IECC) and stays on the 2015 IECC until 2022. The predecessor for the 2009 IECC for Michigan is the 2003 IECC, and later, the predecessor for the 2015 IECC is the 2009 IECC. Illinois adopts 2012 IECC in 2013 and then 2015 IECC

[1] This includes fuel extraction, processing, conveyance to the retail distribution center, and delivery to power plant.

in 2016. The predecessor for the 2012 IECC is 2009 IECC for Illinois, and for the 2015 IECC it is the 2012 IECC. These combinations will result in much higher savings for Michigan compared to Illinois.

Similarly, other states that are moderate and slow adopters of codes are likely to accumulate higher savings per unit of floor space.

Table 6. Summary of Energy Codes Impact on Energy and Energy Cost

Sector	Site Energy Savings (Quads)	Primary Energy Savings (Quads)	Full-Fuel-Cycle Savings (Quads)	Energy Cost Savings (2021 $ billion)*
Commercial				
Annual 2030	0.15	0.36	0.38	3.59
Annual 2040	0.17	0.40	0.42	3.82
Cumulative 2010-2030	1.72	3.93	4.14	40.97
Cumulative 2010-2040	3.37	7.75	8.16	78.22
3% discount rate	—	—	—	79.88
7% discount rate	—	—	—	76.78
Residential				
Annual 2030	0.21	0.39	0.41	4.82
Annual 2040	0.23	0.43	0.45	5.08
Cumulative 2010-2030	2.32	4.22	4.50	54.14
Cumulative 2010-2040	4.56	8.31	8.85	103.9
3% discount rate	—	—	—	106.2
7% discount rate	—	—	—	101.9
Total				
Annual 2030	0.37	0.75	0.79	8.41
Annual 2040	0.40	0.83	0.87	8.90
Cumulative 2010-2030	4.05	8.15	8.63	95.11
Cumulative 2010-2040	7.93	16.06	17.00	182.1
3% discount rate	—	—	—	186.0
7% discount rate	—	—	—	178.7

* Energy cost savings discounted at a 5% rate unless otherwise noted.

Table 7 summarizes the impact of energy codes on greenhouse gases and other emissions, aggregated across all the states included in this analysis. The cumulative energy savings from 2010 through 2040 equates to a reduction of 840 million metric tons (MMT) of CO_2, 314 thousand tons of SO_2, 1,314 thousand tons of NOx, 1.60 tons of Hg, 7.4 thousand tons of N_2O, and 5,858 thousand tons of CH_4.

The emissions reductions are lower than those reported in the 2021 interim update. For example, the cumulative 2010 to 2040 CO_2 reduction of 840 MMT is lower than the 901 MMT reduction reported in the interim update. Updated electricity and gas emissions factors help account for this decrease. These factors are now lower than before, and the net effect is lower CO_2 savings now compared to projected earlier. Despite the fact that this updated report showed higher energy savings, the reduced emissions factors more than offset the higher energy savings to result in lower total emissions savings. Emissions factors will likely continue to vary over time due to changing assumptions about the future development of the electric grid, such as the current shift away from coal generation and toward renewable sources.

Table 7. Summary of Energy Codes Impact on Emissions

Sector	CO_2 Reduction (MMT)	SO_2 Reduction (thousand tons)	NO_X Reduction (thousand tons)	Hg Reduction (tons)	N_2O Reduction (thousand tons)	CH_4 Reduction (thousand tons)
Commercial						
Annual 2030	17	7.0	25.5	0.037	0.17	115
Annual 2040	19	7.6	28.5	0.041	0.18	128
Cumulative 2010-2030	192	75	285	0.41	1.8	1,297
Cumulative 2010-2040	375	148	557	0.80	3.6	2,522
Residential						
Annual 2030	22	7.8	35.3	0.038	0.18	156
Annual 2040	23	8.5	38.4	0.041	0.19	168
Cumulative 2010-2030	239	84	386	0.41	2.0	1,709
Cumulative 2010-2040	466	166	757	0.81	3.8	3,336
Total						
Annual 2030	39	15	61	0.075	0.35	271
Annual 2040	42	16	67	0.081	0.38	296
Cumulative 2010-2030	431	158	671	0.82	3.8	3,006
Cumulative 2010-2040	840	314	1,314	1.60	7.4	5,858

Table 8 presents the results of the analysis of the present social value of carbon savings from codes. The results are shown in terms of the present value of the avoided emissions, in 2021$, for various discount rates. Table 9 through Table 12 show similar present social value results for CH_4, N_2O, NO_X, and SO_2.

Table 8. Present Social Value of CO_2 Emissions Reduction for Energy Codes by Discount Rate (2021 $ million)

Sector	5.0%_Avg CO_2	3.0%_Avg CO_2	2.5%_Avg CO_2	3% 95th Pct. CO_2
Commercial				
Annual 2030	349	1,112	1,612	3,363
Annual 2040	499	1,449	2,041	4,451
Cumulative 2010-2030	3,263	11,052	16,314	33,052
Cumulative 2010-2040	7,564	24,012	34,777	72,616
Residential				
Annual 2030	438	1,398	2,026	4,227
Annual 2040	616	1,789	2,521	5,499
Cumulative 2010-2030	4,058	13,743	20,285	41,102
Cumulative 2010-2040	9,408	29,865	43,254	90,318
Total				
Annual 2030	787	2,511	3,637	7,589
Annual 2040	1,115	3,238	4,561	9,950
Cumulative 2010-2030	7,321	24,795	36,599	74,155
Cumulative 2010-2040	16,973	53,876	78,031	162,935

Table 9. Present Social Value of CH_4 Emissions Reduction for Energy Codes by Discount Rate (2021 $ million)

Sector	5.0%_Avg CH_4	3.0%_Avg CH_4	2.5%_Avg CH_4	3% 95th Pct. CH_4
Commercial				
Annual 2030	102	213	274	567
Annual 2040	156	304	382	816
Cumulative 2010-2030	938	2,038	2,654	5,380
Cumulative 2010-2040	2,249	4,663	5,976	12,396
Residential				
Annual 2030	138	288	369	765
Annual 2040	204	400	501	1,072
Cumulative 2010-2030	1,242	2,694	3,508	7,113

Sector	5.0%_Avg CH_4	3.0%_Avg CH_4	2.5%_Avg CH_4	3% 95th Pct. CH_4
Cumulative 2010-2040	2,982	6,181	7,919	16,429
Total				
Annual 2030	241	501	643	1,331
Annual 2040	360	704	883	1,889
Cumulative 2010-2030	2,180	4,732	6,162	12,493
Cumulative 2010-2040	5,230	10,844	13,895	28,825

Table 10. Present Social Value of N_2O Emissions Reduction for Energy Codes by Discount Rate (2021 $ million)

Sector	5.0%_Avg N_2O	3.0%_Avg N_2O	2.5%_Avg N_2O	3% 95th Pct. N_2O
Commercial				
Annual 2030	1	4	5	10
Annual 2040	2	5	7	13
Cumulative 2010-2030	11	35	51	91
Cumulative 2010-2040	27	77	111	204
Residential				
Annual 2030	1	4	6	10
Annual 2040	2	5	7	14
Cumulative 2010-2030	12	37	54	98
Cumulative 2010-2040	28	82	118	218
Total				
Annual 2030	3	7	11	20
Annual 2040	4	10	14	26
Cumulative 2010-2030	23	72	105	189
Cumulative 2010-2040	55	160	229	423

Table 11. Present Social Value of NO_X Emissions Reduction for Energy Codes by Discount Rate (2021 $ million)

Sector	Low, 7.0%	Low, 3.0%	High, 7%	High, 3%
Commercial				
Annual 2030	29	33	30	33
Annual 2040	19	21	19	21
Cumulative 2010-2030	1,169	1,306	1,190	1,330

Cumulative 2010-2040	1,356	1,515	1,382	1,544
Residential				
Annual 2030	69	77	70	78
Annual 2040	30	33	30	34
Cumulative 2010-2030	3,122	3,488	3,183	3,557
Cumulative 2010-2040	3,428	3,829	3,496	3,906
Total				
Annual 2030	98	109	100	112
Annual 2040	48	54	50	55
Cumulative 2010-2030	4,291	4,794	4,373	4,887
Cumulative 2010-2040	4,784	5,344	4,878	5,450

Table 12. Present Social Value of SO_2 Emissions Reduction for Energy Codes by Discount Rate (2021 $ million)

Sector	Low, 7.0%	Low, 3.0%	High, 7%	High, 3%
Commercial				
Annual 2030	8	9	8	9
Annual 2040	4	4	4	4
Cumulative 2010-2030	343	384	343	384
Cumulative 2010-2040	386	431	386	431
Residential				
Annual 2030	10	11	10	11
Annual 2040	3	4	3	4
Cumulative 2010-2030	308	345	310	347
Cumulative 2010-2040	341	381	344	384
Total				
Annual 2030	18	20	18	20
Annual 2040	7	8	7	8
Cumulative 2010-2030	652	728	654	731
Cumulative 2010-2040	727	812	729	815

Table 13 through Table 17 show the energy and environmental impacts for each state. Site, primary, and FFC energy savings (Quads), energy cost savings (billion $ 2021), and CO_2 reduction (MMT) are shown in the tables for each state. Commercial and residential savings are shown separately. Certain states, such as Arizona, Florida, Texas, and a few others, have much higher total savings than other states reflecting their relatively higher past and projected new floor space construction. The additive nature of code savings gives rise to significantly higher cumulative savings for these states at the end of the study period.

Table 13. Site Energy Savings (quads)

State	Commercial				Residential				Total			
	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040
Alabama	0.01	0.01	0.05	0.11	0.00	0.00	0.04	0.09	0.01	0.01	0.10	0.19
Arizona	0.01	0.01	0.14	0.26	0.01	0.01	0.09	0.16	0.02	0.02	0.23	0.42
Arkansas	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.03	0.00	0.00	0.03	0.06
Colorado	0.01	0.01	0.08	0.16	0.01	0.01	0.10	0.19	0.02	0.02	0.19	0.35
Connecticut	0.00	0.00	0.02	0.03	0.00	0.00	0.03	0.06	0.00	0.00	0.04	0.09
Delaware	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.03
District of Columbia	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02
Florida	0.01	0.01	0.09	0.18	0.01	0.01	0.08	0.17	0.02	0.02	0.17	0.35
Georgia	0.01	0.01	0.07	0.15	0.01	0.01	0.09	0.19	0.02	0.02	0.16	0.34
Hawaii	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02
Idaho	0.00	0.00	0.02	0.03	0.00	0.00	0.02	0.04	0.00	0.00	0.04	0.07
Illinois	0.00	0.00	0.04	0.08	0.00	0.00	0.05	0.09	0.01	0.01	0.09	0.16
Indiana	0.00	0.00	0.02	0.06	0.01	0.01	0.07	0.15	0.01	0.01	0.09	0.21
Iowa	0.00	0.00	0.03	0.06	0.00	0.01	0.06	0.11	0.01	0.01	0.09	0.17
Kentucky	0.00	0.00	0.04	0.09	0.00	0.01	0.04	0.09	0.01	0.01	0.08	0.18
Louisiana	0.00	0.00	0.02	0.03	0.00	0.00	0.02	0.05	0.00	0.00	0.04	0.08
Maine	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.02
Maryland	0.00	0.00	0.02	0.04	0.00	0.00	0.02	0.04	0.00	0.00	0.04	0.08
Massachusetts	0.00	0.00	0.02	0.04	0.00	0.00	0.05	0.09	0.01	0.01	0.07	0.13
Michigan	0.01	0.01	0.13	0.23	0.01	0.01	0.15	0.28	0.02	0.02	0.27	0.51
Minnesota	0.00	0.00	0.05	0.09	0.02	0.02	0.18	0.35	0.02	0.02	0.22	0.44
Montana	0.00	0.00	0.02	0.03	0.00	0.00	0.03	0.05	0.00	0.00	0.04	0.08
Nebraska	0.00	0.00	0.02	0.04	0.00	0.00	0.03	0.07	0.01	0.01	0.05	0.11
Nevada	0.00	0.00	0.03	0.06	0.00	0.00	0.05	0.10	0.01	0.01	0.08	0.16
New Hampshire	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.03
New Jersey	0.00	0.00	0.03	0.05	0.00	0.00	0.05	0.09	0.01	0.01	0.08	0.14
New Mexico	0.00	0.00	0.03	0.08	0.00	0.00	0.04	0.09	0.01	0.01	0.07	0.17
New York	0.00	0.00	0.05	0.09	0.01	0.01	0.08	0.15	0.01	0.01	0.13	0.24
North Carolina	0.01	0.01	0.09	0.18	0.01	0.01	0.14	0.25	0.02	0.02	0.23	0.43
Ohio	0.01	0.01	0.08	0.17	0.01	0.01	0.09	0.19	0.02	0.02	0.17	0.36
Oklahoma	0.00	0.00	0.02	0.04	0.00	0.01	0.05	0.10	0.01	0.01	0.07	0.14
Oregon	0.00	0.00	0.01	0.02	0.00	0.00	0.03	0.06	0.00	0.00	0.04	0.08
Pennsylvania	0.00	0.00	0.04	0.09	0.01	0.01	0.08	0.17	0.01	0.01	0.12	0.25
Rhode Island	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.03
South Carolina	0.00	0.00	0.03	0.07	0.00	0.00	0.03	0.07	0.01	0.01	0.06	0.14
Tennessee	0.01	0.01	0.06	0.12	0.01	0.01	0.05	0.10	0.01	0.01	0.11	0.22
Texas	0.02	0.02	0.19	0.35	0.02	0.02	0.26	0.51	0.04	0.04	0.46	0.86

State	Commercial Annual 2030	Commercial Annual 2040	Commercial Cumulative 2010-2030	Commercial Cumulative 2010-2040	Residential Annual 2030	Residential Annual 2040	Residential Cumulative 2010-2030	Residential Cumulative 2010-2040	Total Annual 2030	Total Annual 2040	Total Cumulative 2010-2030	Total Cumulative 2010-2040
Utah	0.00	0.00	0.02	0.03	0.00	0.00	0.02	0.04	0.00	0.00	0.03	0.07
Vermont	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.02
Virginia	0.00	0.00	0.04	0.08	0.01	0.01	0.07	0.12	0.01	0.01	0.11	0.20
West Virginia	0.00	0.00	0.01	0.03	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.05
Wisconsin	0.00	0.00	0.04	0.09	0.00	0.00	0.04	0.08	0.01	0.01	0.09	0.17
Wyoming	0.00	0.00	0.01	0.03	0.00	0.00	0.02	0.04	0.00	0.00	0.04	0.07

Table 14. Primary Energy Savings (quads)

State	Commercial Annual 2030	Commercial Annual 2040	Commercial Cumulative 2010-2030	Commercial Cumulative 2010-2040	Residential Annual 2030	Residential Annual 2040	Residential Cumulative 2010-2030	Residential Cumulative 2010-2040	Total Annual 2030	Total Annual 2040	Total Cumulative 2010-2030	Total Cumulative 2010-2040
Alabama	0.01	0.01	0.14	0.27	0.01	0.01	0.10	0.19	0.02	0.02	0.23	0.46
Arizona	0.03	0.03	0.36	0.66	0.02	0.02	0.20	0.39	0.05	0.05	0.57	1.05
Arkansas	0.00	0.00	0.03	0.06	0.00	0.00	0.03	0.07	0.01	0.01	0.06	0.12
Colorado	0.01	0.02	0.18	0.34	0.01	0.01	0.14	0.27	0.03	0.03	0.32	0.61
Connecticut	0.00	0.00	0.03	0.06	0.00	0.00	0.03	0.07	0.01	0.01	0.07	0.14
Delaware	0.00	0.00	0.02	0.03	0.00	0.00	0.02	0.04	0.00	0.00	0.04	0.08
District of Columbia	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.04
Florida	0.02	0.03	0.24	0.47	0.02	0.02	0.21	0.43	0.04	0.05	0.45	0.90
Georgia	0.02	0.02	0.16	0.36	0.02	0.02	0.22	0.45	0.04	0.04	0.39	0.81
Hawaii	0.00	0.00	0.02	0.04	0.00	0.00	0.01	0.02	0.00	0.00	0.03	0.07
Idaho	0.00	0.00	0.04	0.07	0.00	0.00	0.03	0.06	0.01	0.01	0.07	0.13
Illinois	0.01	0.01	0.08	0.16	0.01	0.01	0.07	0.13	0.01	0.02	0.15	0.29
Indiana	0.01	0.01	0.05	0.13	0.01	0.01	0.11	0.22	0.02	0.02	0.15	0.36
Iowa	0.01	0.01	0.06	0.13	0.01	0.01	0.09	0.18	0.01	0.02	0.16	0.31
Kentucky	0.01	0.01	0.10	0.20	0.01	0.01	0.09	0.20	0.02	0.02	0.19	0.40
Louisiana	0.00	0.00	0.04	0.08	0.01	0.01	0.05	0.11	0.01	0.01	0.09	0.19
Maine	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.03
Maryland	0.00	0.00	0.05	0.09	0.00	0.01	0.05	0.10	0.01	0.01	0.10	0.18
Massachusetts	0.00	0.00	0.04	0.08	0.00	0.01	0.06	0.11	0.01	0.01	0.10	0.19
Michigan	0.02	0.02	0.25	0.47	0.02	0.02	0.20	0.38	0.04	0.04	0.45	0.84
Minnesota	0.01	0.01	0.08	0.16	0.03	0.03	0.29	0.58	0.04	0.04	0.37	0.74
Montana	0.00	0.00	0.03	0.06	0.00	0.00	0.03	0.06	0.01	0.01	0.07	0.13
Nebraska	0.01	0.01	0.04	0.10	0.01	0.01	0.05	0.11	0.01	0.01	0.10	0.21
Nevada	0.01	0.01	0.08	0.15	0.01	0.01	0.09	0.16	0.01	0.02	0.16	0.31
New Hampshire	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.03	0.00	0.00	0.02	0.05
New Jersey	0.00	0.00	0.06	0.10	0.01	0.01	0.07	0.13	0.01	0.01	0.13	0.23
New Mexico	0.01	0.01	0.08	0.19	0.01	0.01	0.06	0.12	0.02	0.02	0.14	0.31
New York	0.01	0.01	0.10	0.18	0.01	0.01	0.12	0.22	0.02	0.02	0.21	0.41
North Carolina	0.02	0.02	0.21	0.42	0.03	0.03	0.32	0.59	0.05	0.05	0.54	1.01
Ohio	0.02	0.02	0.17	0.36	0.01	0.02	0.13	0.28	0.03	0.04	0.30	0.64
Oklahoma	0.00	0.00	0.05	0.09	0.01	0.01	0.09	0.19	0.01	0.01	0.14	0.28
Oregon	0.00	0.00	0.03	0.05	0.00	0.00	0.05	0.09	0.01	0.01	0.07	0.14
Pennsylvania	0.01	0.01	0.09	0.19	0.01	0.01	0.11	0.24	0.02	0.02	0.21	0.43
Rhode Island	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.04
South Carolina	0.01	0.01	0.07	0.16	0.01	0.01	0.08	0.16	0.02	0.02	0.15	0.32

State	Commercial Annual 2030	Commercial Annual 2040	Commercial Cumulative 2010-2030	Commercial Cumulative 2010-2040	Residential Annual 2030	Residential Annual 2040	Residential Cumulative 2010-2030	Residential Cumulative 2010-2040	Total Annual 2030	Total Annual 2040	Total Cumulative 2010-2030	Total Cumulative 2010-2040
Tennessee	0.01	0.01	0.15	0.29	0.01	0.01	0.10	0.22	0.02	0.03	0.25	0.50
Texas	0.04	0.04	0.48	0.89	0.05	0.05	0.56	1.06	0.09	0.09	1.04	1.95
Utah	0.00	0.00	0.04	0.08	0.00	0.00	0.03	0.06	0.01	0.01	0.07	0.14
Vermont	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.02
Virginia	0.01	0.01	0.10	0.19	0.01	0.01	0.15	0.29	0.02	0.02	0.25	0.48
West Virginia	0.00	0.00	0.03	0.06	0.00	0.00	0.03	0.06	0.01	0.01	0.05	0.11
Wisconsin	0.01	0.01	0.09	0.18	0.01	0.01	0.06	0.12	0.01	0.02	0.14	0.29
Wyoming	0.00	0.00	0.03	0.06	0.00	0.00	0.03	0.05	0.01	0.01	0.06	0.11

Table 15. FFC Energy Savings (quads)

State	Commercial				Residential				Total			
	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040
Alabama	0.01	0.01	0.14	0.28	0.01	0.01	0.10	0.20	0.02	0.03	0.24	0.49
Arizona	0.03	0.03	0.38	0.69	0.02	0.02	0.22	0.41	0.05	0.05	0.60	1.10
Arkansas	0.00	0.00	0.03	0.06	0.00	0.00	0.03	0.07	0.01	0.01	0.06	0.13
Colorado	0.02	0.02	0.19	0.35	0.01	0.01	0.15	0.29	0.03	0.03	0.34	0.65
Connecticut	0.00	0.00	0.03	0.07	0.00	0.00	0.04	0.08	0.01	0.01	0.07	0.15
Delaware	0.00	0.00	0.02	0.04	0.00	0.00	0.03	0.05	0.00	0.00	0.04	0.08
District of Columbia	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.04
Florida	0.02	0.03	0.25	0.50	0.02	0.02	0.22	0.45	0.04	0.05	0.48	0.95
Georgia	0.02	0.02	0.17	0.38	0.02	0.02	0.23	0.47	0.04	0.05	0.41	0.85
Hawaii	0.00	0.00	0.02	0.04	0.00	0.00	0.01	0.03	0.00	0.00	0.03	0.07
Idaho	0.00	0.00	0.04	0.07	0.00	0.00	0.04	0.07	0.01	0.01	0.07	0.14
Illinois	0.01	0.01	0.09	0.17	0.01	0.01	0.07	0.14	0.01	0.02	0.16	0.31
Indiana	0.01	0.01	0.05	0.14	0.01	0.01	0.12	0.24	0.02	0.02	0.16	0.38
Iowa	0.01	0.01	0.07	0.14	0.01	0.01	0.10	0.19	0.02	0.02	0.17	0.33
Kentucky	0.01	0.01	0.10	0.21	0.01	0.01	0.10	0.21	0.02	0.02	0.20	0.42
Louisiana	0.00	0.00	0.04	0.08	0.01	0.01	0.05	0.12	0.01	0.01	0.09	0.20
Maine	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.03
Maryland	0.00	0.00	0.05	0.09	0.00	0.01	0.05	0.10	0.01	0.01	0.10	0.19
Massachusetts	0.00	0.00	0.05	0.09	0.01	0.01	0.06	0.12	0.01	0.01	0.11	0.21
Michigan	0.02	0.02	0.26	0.49	0.02	0.02	0.22	0.41	0.04	0.04	0.48	0.90
Minnesota	0.01	0.01	0.09	0.17	0.03	0.03	0.31	0.62	0.04	0.04	0.40	0.79
Montana	0.00	0.00	0.03	0.07	0.00	0.00	0.04	0.07	0.01	0.01	0.07	0.13
Nebraska	0.01	0.01	0.04	0.10	0.01	0.01	0.06	0.12	0.01	0.01	0.10	0.22
Nevada	0.01	0.01	0.08	0.16	0.01	0.01	0.09	0.17	0.01	0.02	0.17	0.33
New Hampshire	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.03	0.00	0.00	0.02	0.05
New Jersey	0.00	0.01	0.06	0.11	0.01	0.01	0.08	0.14	0.01	0.01	0.14	0.25
New Mexico	0.01	0.01	0.08	0.20	0.01	0.01	0.06	0.13	0.02	0.02	0.14	0.33
New York	0.01	0.01	0.10	0.20	0.01	0.01	0.13	0.24	0.02	0.02	0.23	0.44
North Carolina	0.02	0.02	0.22	0.44	0.03	0.03	0.34	0.62	0.05	0.05	0.56	1.06
Ohio	0.02	0.02	0.18	0.38	0.02	0.02	0.14	0.30	0.03	0.04	0.32	0.68
Oklahoma	0.00	0.01	0.05	0.10	0.01	0.01	0.10	0.20	0.01	0.02	0.15	0.30
Oregon	0.00	0.00	0.03	0.05	0.00	0.00	0.05	0.09	0.01	0.01	0.08	0.15
Pennsylvania	0.01	0.01	0.10	0.20	0.01	0.01	0.12	0.26	0.02	0.03	0.22	0.46
Rhode Island	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.05
South Carolina	0.01	0.01	0.07	0.17	0.01	0.01	0.08	0.17	0.02	0.02	0.15	0.34

State	Commercial				Residential				Total			
	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040
Tennessee	0.01	0.01	0.16	0.30	0.01	0.01	0.10	0.23	0.03	0.03	0.26	0.53
Texas	0.04	0.04	0.50	0.94	0.05	0.05	0.59	1.12	0.09	0.10	1.09	2.06
Utah	0.00	0.00	0.04	0.08	0.00	0.00	0.03	0.06	0.01	0.01	0.07	0.14
Vermont	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.03
Virginia	0.01	0.01	0.10	0.20	0.01	0.02	0.16	0.31	0.02	0.03	0.26	0.50
West Virginia	0.00	0.00	0.03	0.06	0.00	0.00	0.03	0.06	0.01	0.01	0.06	0.12
Wisconsin	0.01	0.01	0.09	0.19	0.01	0.01	0.06	0.12	0.01	0.02	0.15	0.31
Wyoming	0.00	0.00	0.03	0.07	0.00	0.00	0.03	0.05	0.01	0.01	0.06	0.12

Table 16. Discounted Consumer Energy Cost Savings (Billion $ 2021)

State	Commercial				Residential				Total			
	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040
Alabama	0.15	0.16	1.68	3.23	0.13	0.13	1.34	2.62	0.28	0.29	3.02	5.85
Arizona	0.30	0.32	3.98	7.09	0.22	0.24	2.76	5.08	0.53	0.55	6.75	12.16
Arkansas	0.02	0.03	0.24	0.49	0.04	0.04	0.41	0.80	0.06	0.07	0.66	1.29
Colorado	0.15	0.16	1.89	3.44	0.13	0.14	1.55	2.92	0.28	0.30	3.43	6.37
Connecticut	0.05	0.05	0.50	0.97	0.06	0.06	0.59	1.21	0.10	0.11	1.09	2.18
Delaware	0.02	0.02	0.19	0.35	0.03	0.03	0.34	0.61	0.04	0.04	0.53	0.96
District of Columbia	0.01	0.01	0.10	0.19	0.01	0.01	0.15	0.29	0.02	0.02	0.24	0.48
Florida	0.20	0.22	2.45	4.60	0.24	0.26	2.65	5.15	0.44	0.48	5.10	9.75
Georgia	0.19	0.20	1.73	3.65	0.28	0.29	2.97	5.84	0.47	0.49	4.70	9.49
Hawaii	0.06	0.06	0.66	1.28	0.04	0.04	0.40	0.79	0.10	0.10	1.06	2.07
Idaho	0.02	0.03	0.28	0.53	0.02	0.03	0.31	0.55	0.05	0.05	0.59	1.08
Illinois	0.06	0.07	0.80	1.46	0.07	0.08	0.78	1.52	0.13	0.15	1.58	2.98
Indiana	0.07	0.08	0.43	1.20	0.13	0.13	1.26	2.58	0.20	0.21	1.69	3.77
Iowa	0.06	0.06	0.64	1.26	0.10	0.10	1.16	2.19	0.16	0.17	1.80	3.45
Kentucky	0.10	0.10	1.06	2.07	0.12	0.12	1.04	2.24	0.22	0.22	2.10	4.31
Louisiana	0.03	0.03	0.37	0.69	0.06	0.06	0.53	1.16	0.09	0.10	0.90	1.85
Maine	0.01	0.01	0.08	0.19	0.01	0.01	0.11	0.25	0.02	0.03	0.19	0.43
Maryland	0.04	0.04	0.53	0.96	0.05	0.06	0.69	1.26	0.09	0.11	1.22	2.23
Massachusetts	0.06	0.06	0.70	1.29	0.08	0.09	1.01	1.86	0.14	0.15	1.71	3.16
Michigan	0.23	0.24	2.82	5.17	0.21	0.22	2.53	4.73	0.44	0.46	5.35	9.90
Minnesota	0.07	0.08	0.87	1.62	0.34	0.34	3.51	6.91	0.41	0.42	4.38	8.53
Montana	0.03	0.03	0.35	0.66	0.03	0.03	0.32	0.60	0.06	0.06	0.68	1.26
Nebraska	0.04	0.04	0.35	0.76	0.06	0.06	0.60	1.22	0.10	0.10	0.96	1.98
Nevada	0.06	0.06	0.66	1.24	0.08	0.09	1.01	1.85	0.14	0.15	1.66	3.09
New Hampshire	0.02	0.02	0.18	0.38	0.02	0.02	0.21	0.45	0.04	0.04	0.39	0.82
New Jersey	0.05	0.06	0.72	1.28	0.07	0.08	1.00	1.77	0.13	0.14	1.71	3.06
New Mexico	0.10	0.10	0.76	1.74	0.07	0.08	0.66	1.43	0.17	0.18	1.42	3.17
New York	0.11	0.12	1.38	2.57	0.17	0.18	2.04	3.81	0.28	0.31	3.42	6.37
North Carolina	0.17	0.18	1.96	3.69	0.30	0.31	3.89	6.91	0.46	0.48	5.85	10.60
Ohio	0.16	0.17	1.61	3.27	0.18	0.19	1.74	3.59	0.34	0.36	3.35	6.86
Oklahoma	0.04	0.04	0.38	0.75	0.11	0.11	1.10	2.19	0.14	0.15	1.48	2.94
Oregon	0.02	0.02	0.25	0.46	0.04	0.05	0.55	1.00	0.06	0.07	0.81	1.46
Pennsylvania	0.08	0.09	0.88	1.76	0.17	0.17	1.64	3.35	0.25	0.27	2.52	5.11
Rhode Island	0.01	0.02	0.19	0.34	0.01	0.02	0.18	0.34	0.03	0.03	0.37	0.68
South Carolina	0.08	0.09	0.66	1.52	0.10	0.11	1.14	2.17	0.18	0.19	1.80	3.70

State	Commercial				Residential				Total			
	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040
Tennessee	0.14	0.15	1.68	3.10	0.12	0.13	1.19	2.47	0.26	0.28	2.86	5.57
Texas	0.34	0.35	4.27	7.77	0.61	0.63	7.09	13.29	0.95	0.98	11.36	21.06
Utah	0.03	0.03	0.35	0.66	0.02	0.03	0.29	0.56	0.05	0.06	0.65	1.22
Vermont	0.01	0.01	0.08	0.14	0.01	0.01	0.16	0.27	0.02	0.02	0.23	0.40
Virginia	0.07	0.07	0.84	1.53	0.15	0.16	1.85	3.43	0.22	0.23	2.69	4.96
West Virginia	0.02	0.03	0.26	0.52	0.03	0.04	0.36	0.70	0.06	0.06	0.62	1.22
Wisconsin	0.09	0.09	0.88	1.77	0.07	0.07	0.71	1.40	0.15	0.16	1.59	3.17
Wyoming	0.03	0.03	0.29	0.57	0.02	0.03	0.30	0.56	0.05	0.05	0.59	1.13

Table 17. Avoided CO_2 Emissions (MMT)

State	Commercial Annual 2030	Commercial Annual 2040	Commercial Cumulative 2010-2030	Commercial Cumulative 2010-2040	Residential Annual 2030	Residential Annual 2040	Residential Cumulative 2010-2030	Residential Cumulative 2010-2040	Total Annual 2030	Total Annual 2040	Total Cumulative 2010-2030	Total Cumulative 2010-2040
Alabama	0.61	0.64	6.52	12.81	0.51	0.54	5.32	10.63	1.12	1.19	11.84	23.44
Arizona	1.37	1.45	17.50	31.65	0.95	1.02	11.34	21.23	2.31	2.48	28.83	52.88
Arkansas	0.14	0.15	1.33	2.77	0.17	0.19	1.84	3.63	0.30	0.34	3.17	6.41
Colorado	0.72	0.79	8.93	16.50	0.70	0.77	8.13	15.50	1.42	1.55	17.06	32.00
Connecticut	0.14	0.16	1.58	3.11	0.22	0.24	2.20	4.55	0.37	0.41	3.78	7.66
Delaware	0.07	0.08	0.87	1.66	0.10	0.11	1.33	2.44	0.18	0.20	2.20	4.09
District of Columbia	0.03	0.04	0.37	0.74	0.06	0.06	0.61	1.23	0.10	0.10	0.98	1.97
Florida	0.98	1.15	11.52	22.27	1.09	1.22	11.72	23.31	2.07	2.37	23.24	45.58
Georgia	0.88	0.95	7.98	17.19	1.18	1.25	12.26	24.49	2.06	2.21	20.24	41.68
Hawaii	0.09	0.10	0.98	1.94	0.06	0.07	0.65	1.33	0.15	0.17	1.63	3.27
Idaho	0.15	0.17	1.71	3.29	0.15	0.17	1.94	3.58	0.30	0.34	3.66	6.87
Illinois	0.33	0.39	4.18	7.79	0.34	0.40	3.89	7.60	0.66	0.78	8.07	15.39
Indiana	0.39	0.44	2.22	6.38	0.64	0.68	6.18	12.81	1.03	1.12	8.40	19.19
Iowa	0.31	0.33	3.18	6.40	0.46	0.49	5.36	10.15	0.77	0.82	8.54	16.54
Kentucky	0.47	0.50	4.86	9.71	0.58	0.61	4.97	10.98	1.05	1.11	9.83	20.68
Louisiana	0.16	0.18	1.87	3.62	0.31	0.34	2.67	5.97	0.48	0.53	4.54	9.59
Maine	0.04	0.05	0.30	0.73	0.05	0.06	0.42	0.99	0.09	0.11	0.72	1.72
Maryland	0.18	0.21	2.30	4.28	0.22	0.27	2.73	5.22	0.40	0.48	5.03	9.50
Massachusetts	0.18	0.20	2.21	4.12	0.30	0.34	3.71	6.93	0.48	0.54	5.92	11.06
Michigan	1.02	1.09	12.55	23.18	0.98	1.05	11.59	21.78	2.00	2.14	24.14	44.96
Minnesota	0.36	0.40	4.30	8.10	1.61	1.66	16.49	32.86	1.96	2.06	20.78	40.96
Montana	0.14	0.16	1.64	3.12	0.16	0.17	1.92	3.57	0.30	0.33	3.55	6.69
Nebraska	0.24	0.26	2.09	4.64	0.32	0.34	3.10	6.39	0.56	0.60	5.19	11.02
Nevada	0.33	0.37	3.69	7.22	0.40	0.43	4.85	9.06	0.74	0.80	8.54	16.28
New Hampshire	0.06	0.06	0.52	1.13	0.08	0.09	0.77	1.65	0.14	0.16	1.29	2.78
New Jersey	0.21	0.24	2.76	5.02	0.31	0.34	4.14	7.45	0.52	0.58	6.90	12.47
New Mexico	0.49	0.53	3.87	9.01	0.37	0.40	3.20	7.08	0.87	0.93	7.06	16.09
New York	0.39	0.46	4.89	9.17	0.57	0.63	6.83	12.88	0.96	1.09	11.73	22.05
North Carolina	0.93	1.01	10.36	20.11	1.40	1.47	17.75	32.18	2.33	2.48	28.10	52.29
Ohio	0.89	0.96	8.48	17.75	0.79	0.86	7.56	15.88	1.68	1.82	16.03	33.63
Oklahoma	0.21	0.23	2.26	4.51	0.51	0.54	5.17	10.43	0.72	0.77	7.43	14.93
Oregon	0.11	0.12	1.31	2.45	0.22	0.24	2.73	5.02	0.32	0.36	4.04	7.47
Pennsylvania	0.44	0.50	4.52	9.28	0.69	0.74	6.63	13.80	1.13	1.24	11.15	23.08
Rhode Island	0.05	0.05	0.59	1.08	0.06	0.06	0.66	1.26	0.10	0.11	1.26	2.34
South Carolina	0.42	0.46	3.18	7.61	0.40	0.44	4.45	8.64	0.82	0.90	7.63	16.25

State	Commercial				Residential				Total			
	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040	Annual 2030	Annual 2040	Cumulative 2010-2030	Cumulative 2010-2040
Tennessee	0.63	0.67	7.28	13.84	0.61	0.65	5.51	11.85	1.23	1.33	12.80	25.68
Texas	1.90	2.00	23.15	42.69	2.69	2.84	31.02	58.75	4.59	4.84	54.17	101.44
Utah	0.16	0.19	1.89	3.69	0.14	0.18	1.64	3.27	0.30	0.37	3.53	6.96
Vermont	0.02	0.02	0.27	0.48	0.03	0.04	0.50	0.87	0.05	0.06	0.77	1.35
Virginia	0.38	0.44	4.79	8.96	0.72	0.78	8.48	15.98	1.10	1.22	13.27	24.95
West Virginia	0.13	0.15	1.33	2.74	0.14	0.16	1.53	3.08	0.28	0.31	2.86	5.82
Wisconsin	0.42	0.46	4.30	8.75	0.31	0.35	3.28	6.62	0.73	0.82	7.58	15.37
Wyoming	0.15	0.16	1.54	3.10	0.12	0.14	1.58	2.92	0.27	0.30	3.12	6.02

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Appendix A – Model Inputs

This appendix provides detailed information on the inputs used for adoption and code-to-code savings.

A.1 Adoption

Table A.1 and Table A.2 show the year in which various code editions were adopted by each state, as well as the projected future rate of adoption (based on the aggressive, moderate, and slow classifications) for each state for commercial and residential codes. The actual adoption year for the various code editions are shown where they are known, while future adoption years were estimated by adding the adoption time lag of the state to the year of the published code. In terms of older codes, only ASHRAE 90.1-2001 is shown for commercial and 2003 IECC for residential because all states in the analysis had adopted these codes by 2010—the starting point for the analysis—and thus, there is no need to assess codes older than ASHRAE 90.1-2001 and 2003 IECC. The term “start” indicates the code edition in place at the start of the analysis in 2010. Blanks indicate code editions that were skipped and never adopted.

Table A.1. Commercial Codes Adoption Classification by State

State	Adoption Classification	Adoption Lag Years	90.1-2001	90.1-2004	90.1-2007	90.1-2010	90.1-2013	90.1-2016	90.1-2019	90.1-2022	90.1-2025	90.1-2028	90.1-2031	90.1-2034	90.1-2037
Code Year			*2000*	*2006*	*2009*	*2012*	*2015*	*2018*	*2021*	*2024*	*2027*	*2030*	*2033*	*2036*	*2039*
Alabama	Slow	7	start		2013		2016		2024	2031	2034	2037	2040	2043	2046
Arizona	Moderate	4	start			2013		2019	2025	2028	2031	2034	2037	2040	2043
Arkansas	Slow	7	start	2013	2015	2019	2022		2025	2031	2034	2037	2040	2043	2046
Colorado	Moderate	4	start		2012	2017		2020	2024	2028	2031	2034	2037	2040	2043
Connecticut	Moderate	4		start	2012	2016	2018		2022	2028	2031	2034	2037	2040	2043
Delaware	Moderate	4			start	2014		2020	2024	2028	2031	2034	2037	2040	2043
District of Columbia	Moderate	4			start	2014	2020		2024	2028	2031	2034	2037	2040	2043
Florida	Moderate	4		start	2012	2015	2018	2021	2024	2028	2031	2034	2037	2040	2043
Georgia	Slow	7		start	2011		2020	2025	2030	2031	2034	2037	2040	2043	2046
Hawaii	Moderate	4		start	2013		2017	2023	2026	2028	2031	2034	2037	2040	2043
Idaho	Moderate	4		start	2011	2015	2018	2021	2025	2028	2031	2034	2037	2040	2043
Illinois	Aggressive	1			start	2013	2016	2019	2022	2025	2028	2031	2034	2037	2040
Indiana	Slow	7			start			2023	2028	2031	2034	2037	2040	2043	2046
Iowa	Slow	7			start	2014		2023	2028	2031	2034	2037	2040	2043	2046
Kentucky	Slow	7		start	2011	2014		2025	2028	2031	2034	2037	2040	2043	2046
Louisiana	Slow	7		start	2011	2015	2018	2025	2028	2031	2034	2037	2040	2043	2046
Maine	Moderate	4			start		2021	2023	2025	2028	2031	2034	2037	2040	2043
Maryland	Aggressive	1			start	2012	2015	2019	2023	2025	2028	2031	2034	2037	2040
Massachusetts	Aggressive	1			start	2014	2017	2020	2022	2025	2028	2031	2034	2037	2040
Michigan	Moderate	4	start		2011		2017		2023	2028	2031	2034	2037	2040	2043
Minnesota	Moderate	4		start		2015		2020	2023	2028	2031	2034	2037	2040	2043
Montana	Moderate	4			start	2014		2021	2023	2028	2031	2034	2037	2040	2043
Nebraska	Slow	7	start		2011			2020	2028	2031	2034	2037	2040	2043	2046
Nevada	Moderate	4		start	2012	2015		2021	2024	2028	2031	2034	2037	2040	2043
New Hampshire	Moderate	4			start		2019	2023	2026	2028	2031	2034	2037	2040	2043
New Jersey	Aggressive	1		start	2011	2013	2016	2020	2023	2025	2028	2031	2034	2037	2040
New Mexico	Slow	7		start	2012			2021	2028	2031	2034	2037	2040	2043	2046
New York	Aggressive	1		start	2011	2015	2016	2020	2022	2025	2028	2031	2034	2037	2040
North Carolina	Slow	7		start		2012	2019		2025	2031	2034	2037	2040	2043	2046
Ohio	Moderate	4		start	2013	2017		2023		2028	2031	2034	2037	2040	2043

State	Adoption Classification	Adoption Lag Years	90.1-2001	90.1-2004	90.1-2007	90.1-2010	90.1-2013	90.1-2016	90.1-2019	90.1-2022	90.1-2025	90.1-2028	90.1-2031	90.1-2034	90.1-2037
Oklahoma	Slow	7	start	2012	2016	2019		2023	2028	2031	2034	2037	2040	2043	2046
Oregon	Aggressive	1			start	2014	2017	2019	2023	2025	2028	2031	2034	2037	2040
Pennsylvania	Moderate	4			start		2018	2022	2025	2028	2031	2034	2037	2040	2043
Rhode Island	Moderate	4			start	2013	2019	2022	2024	2028	2031	2034	2037	2040	2043
South Carolina	Slow	7		start	2013			2025	2028	2031	2034	2037	2040	2043	2046
Tennessee	Slow	7	start	2011		2016		2020	2028	2031	2034	2037	2040	2043	2046
Texas	Moderate	4	start		2011		2016		2024	2028	2031	2034	2037	2040	2043
Utah	Aggressive	1			start	2014	2016	2019	2023	2025	2028	2031	2034	2037	2040
Vermont	Aggressive	1		start		2012	2015	2020	2023	2025	2028	2031	2034	2037	2040
Virginia	Moderate	4		start	2011	2014	2018	2021	2023	2028	2031	2034	2037	2040	2043
West Virginia	Slow	7	start		2013	2019	2022	2025	2028	2031	2034	2037	2040	2043	2046
Wisconsin	Slow	7		start	2011		2018		2023	2031	2034	2037	2040	2043	2046
Wyoming	Slow	7	start		2011	2016	2025	2028		2031	2034	2037	2040	2043	2046

Table A.2. Residential Codes Adoption Classification by State

State	Adoption Classification	Adoption Lag Years	IECC 2003	IECC 2006	IECC 2009	IECC 2012	IECC 2015	IECC 2018	IECC 2021	IECC 2024	IECC 2027	IECC 2030	IECC 2033	IECC 2036	IECC 2039
Code Year			*2003*	*2006*	*2009*	*2012*	*2015*	*2018*	*2021*	*2024*	*2027*	*2030*	*2033*	*2036*	*2039*
Alabama	Slow	7		start	2013		2016		2024	2031	2034	2037	2040	2043	2046
Arizona	Moderate	4				start		2019	2025	2028	2031	2034	2037	2040	2043
Arkansas	Slow	7	start			2019	2022	2025	2028	2031	2034	2037	2040	2043	2046
Colorado	Moderate	4		start	2012	2017		2020	2024	2028	2031	2034	2037	2040	2043
Connecticut	Moderate	4		start	2012	2016	2018		2022	2028	2031	2034	2037	2040	2043
Delaware	Moderate	4			start	2014		2020	2024	2028	2031	2034	2037	2040	2043
District of Columbia	Moderate	4			start	2014	2020		2024	2028	2031	2034	2037	2040	2043
Florida	Moderate	4	start		2012	2015	2018	2021	2024	2028	2031	2034	2037	2040	2043
Georgia	Slow	7		start	2011		2020	2025	2030	2031	2034	2037	2040	2043	2046
Hawaii	Moderate	4		start	2013		2017	2023	2026	2028	2031	2034	2037	2040	2043
Idaho	Moderate	4		start	2011	2015	2018	2021	2025	2028	2031	2034	2037	2040	2043
Illinois	Aggressive	1			start	2013	2016	2019	2022	2025	2028	2031	2034	2037	2040
Indiana	Slow	7	start		2012			2020	2028	2031	2034	2037	2040	2043	2046
Iowa	Slow	7			start	2014		2023	2028	2031	2034	2037	2040	2043	2046
Kentucky	Slow	7		start	2011			2025	2028	2031	2034	2037	2040	2043	2046
Louisiana	Slow	7		start	2015			2025	2028	2031	2034	2037	2040	2043	2046
Maine	Moderate	4			start		2021	2023	2025	2028	2031	2034	2037	2040	2043
Maryland	Aggressive	1			start	2012	2015	2019	2023	2025	2028	2031	2034	2037	2040
Massachusetts	Aggressive	1			start	2014	2017	2020	2022	2025	2028	2031	2034	2037	2040
Michigan	Moderate	4	start		2011		2016		2023	2028	2031	2034	2037	2040	2043
Minnesota	Slow	7		start		2015			2025	2031	2034	2037	2040	2043	2046
Montana	Moderate	4			start	2014		2021	2023	2028	2031	2034	2037	2040	2043
Nebraska	Slow	7	start		2011			2020	2028	2031	2034	2037	2040	2043	2046
Nevada	Moderate	4		start	2012	2015		2021	2024	2028	2031	2034	2037	2040	2043
New Hampshire	Moderate	4			start		2019	2023	2026	2028	2031	2034	2037	2040	2043
New Jersey	Aggressive	1		start	2011	2014	2016	2020	2023	2025	2028	2031	2034	2037	2040
New Mexico	Slow	7		start	2012			2021	2028	2031	2034	2037	2040	2043	2046
New York	Aggressive	1	start		2011	2015	2016	2020	2022	2025	2028	2031	2034	2037	2040
North Carolina	Slow	7		start		2012	2019		2025	2031	2034	2037	2040	2043	2046
Ohio	Slow	7		start	2013			2019	2025	2031	2034	2037	2040	2043	2046
Oklahoma	Slow	7	start		2012			2025	2028	2031	2034	2037	2040	2043	2046
Oregon	Aggressive	1		start	2011	2014	2017	2019	2023	2025	2028	2031	2034	2037	2040

Pennsylvania	Moderate	4			start		2018	2022	2025	2028	2031	2034	2037	2040	2043
Rhode Island	Moderate	4			start	2013	2019	2022	2024	2028	2031	2034	2037	2040	2043
South Carolina	Slow	7		start	2013	2019	2022	2025	2028	2031	2034	2037	2040	2043	2046
Tennessee	Slow	7	start	2011	2017	2019		2025	2028	2031	2034	2037	2040	2043	2046
Texas	Moderate	4	start	2011	2012		2016		2024	2028	2031	2034	2037	2040	2043
Utah	Aggressive	1			start	2014	2016	2019	2023	2025	2028	2031	2034	2037	2040
Vermont	Aggressive	1	start			2012	2015	2020	2023	2025	2028	2031	2034	2037	2040
Virginia	Moderate	4		start	2011	2014	2018	2021	2023	2028	2031	2034	2037	2040	2043
West Virginia	Slow	7	start		2013	2019	2022	2025	2028	2031	2034	2037	2040	2043	2046
Wisconsin	Slow	7		start	2016	2019	2022	2025	2028	2031	2034	2037	2040	2043	2046
Wyoming	Slow	7	start		2011	2016	2025	2028	2031	2031	2034	2037	2040	2043	2046

A.2 Code-to-Code Savings

As described in Section 2.1.4, code-to-code savings are calculated by using the Determination process. Previous Determinations issued by DOE and the supporting quantitative analysis reports can be found on the BECP website[a]. These reports include detailed information on EUIs for commercial and residential code editions. For codes older than ASHRAE 90.1-2004 and 2006 IECC, a historical EUI index developed by PNNL is used. This index is anchored with a value of 1.0 for the EUI of ASHRAE 90.1-2004 for commercial and 2006 IECC for residential. Going back one edition of codes (because one cycle is all that is needed for this analysis), the EUI index for 90.1-2001 is 1.141, and for 2003 IECC is 1.012.

Future code EUIs are developed based off the determination-based EUI of ASHRAE 90.1-2019 for commercial and 2021 IECC for residential. For future residential and commercial code editions, plug and process loads are not affected. Similarly, the DHW consumption for residential buildings is not affected by code improvements in the future. Energy reduction factors are developed for future code editions as explained in Section 2.1.4. These factors are shown in Table A.3 for commercial and Table A.4 for residential.

The technological progress is not constant through time, which is accounted for in the energy reduction factors. The factors vary for different end-uses and depend upon the future potential for improvement for the end-use category. The envelope technology improvements are reflected in the HVAC end-use category.

Table A.3. Commercial Future Code Edition Energy Reduction Factors (90.1-2019 = 1.00)

End-Use	90.1-2022	90.1-2025	90.1-2028	90.1-2031	90.1-2034	90.1-2037	90.1-2040
Electricity – HVAC	0.94	0.88	0.83	0.78	0.73	0.69	0.65
Electricity – Lighting	0.92	0.86	0.80	0.72	0.64	0.56	0.48
NG – HVAC	0.94	0.88	0.83	0.78	0.73	0.69	0.65
NG – Plug and Process	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Electricity – Plug and Process	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table A.4. Residential Future Code Edition Energy Reduction Factors (2021 IECC = 1.00)

End-Use	IECC 2024	IECC 2027	IECC 2030	IECC 2033	IECC 2036	IECC 2039	IECC 2042
Electricity – HVAC	0.95	0.90	0.86	0.81	0.77	0.74	0.70
Electricity – Lighting	0.94	0.92	0.88	0.80	0.72	0.64	0.56
Electricity – DHW	1.00	1.00	1.00	1.00	1.00	1.00	1.00
NG – HVAC	0.95	0.90	0.86	0.81	0.77	0.74	0.70
NG – DHW	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Oil – HVAC	0.95	0.90	0.86	0.81	0.77	0.74	0.70
Oil – DHW	1.00	1.00	1.00	1.00	1.00	1.00	1.00

[a] Determinations on BECP website: https://www.energycodes.gov/determinations

Appendix B – Emissions Analysis Methodology

B.1 Introduction

The emissions analysis consists of two components. The first component estimates the effect of energy codes on power sector and site combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and mercury (Hg). The second component estimates the impacts of energy codes on emissions of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), as well as the reductions to emissions of all species due to "upstream" activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions. Together, these emissions account for the full-fuel-cycle (FFC), in accordance with DOE's FFC Statement of Policy. 76 FR 51282 (Aug. 18, 2011).

The analysis of power sector emissions uses marginal emissions intensity factors calculated by DOE. DOE's methodology is based on results published with the most recent edition of the Annual Energy Outlook (AEO) which is published by the Energy Information Agency (EIA). For this analysis DOE used AEO 2022.[1] DOE developed end-use specific emissions intensity coefficients, in units of mass of pollutant per kWh of site (grid) electricity, for each pollutant. The methodology is based on the more general approach used for all the utility sector impacts calculations, which is described in the report "Utility Sector Impacts of Reduced Electricity Demand" (Coughlin, 2014; Coughlin, 2019).[2,3] This appendix describes the methodology used to estimate the upstream emissions factors, and presents the values used for all emissions factors.

B.2 Power Sector and Site Emissions Factors

Power sector marginal emissions factors are calculated by looking at the difference, over the full analysis period, in fuel consumption and emissions across a variety of cases published with the AEO. The analysis produces a set of emissions intensity factors that quantify the reduction in emissions of a given pollutant per unit reduction of fuel used in (grid) electricity generation for each of the primary fossil fuel types (coal, natural gas and oil). These factors are combined with estimates of the fraction of generation allocated to each fuel type, also calculated from AEO 2022 data, for each sector and end-use. The result is a set of end-use specific marginal emissions intensity factors, summarized in the tables below. Total emissions reductions are estimated by multiplying the intensity factors times the energy savings. Power sector emissions factors are presented in Table B.2 through Table B.7

Site combustion of fossil fuels in buildings (for example in water-heating, space-heating or cooking applications) also produces emissions of CO_2 and other pollutants. To quantify the reduction in these emissions from energy codes, DOE used emissions intensity factors from Environmental Protection Agency (EPA) publications.[4] These factors, presented in Table B.1, are constant in time. The EPA defines SO_2 emissions in terms of a formula that depends on the sulfur content of the fuel. The typical use of petroleum-based fuels in buildings if for heating, and a typical sulfur content for heating oils is a few hundred parts-per-million (ppm). The value provided in Table B.1 corresponds to a sulfur content of approximately 100 ppm.

B.3 Upstream Factors

The FFC upstream emissions are estimated based on the methodology developed by Coughlin (2013).[5] The upstream emissions include both emissions from fuel combustion during extraction, processing and transportation of fuel, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

The FFC accounting approach is described briefly in Coughlin (2013). [5] When demand for a particular fuel is reduced, there is a corresponding reduction in the upstream activities associated with production of that fuel (mining, refining etc.) These upstream activities also consume energy and therefore produce combustion emissions. The FFC accounting estimates the total consumption of electricity, natural gas and petroleum-based fuels in these upstream activities. The relevant combustion emissions factors are then applied to this fuel use to determine the total upstream emissions intensities from combustion, per unit of fuel delivered to the consumer.

In addition to combustion emissions, extraction and processing of fossil fuels also produces fugitive emissions of CO_2 and CH_4. Fugitive emissions of CO_2 are small relative to combustion emissions, comprising about 2-3 percent of total CO_2 emissions for natural gas and 1-2 percent for petroleum fuels. In contrast, the fugitive emissions of methane from fossil fuel production are relatively large compared to combustion emissions of CH_4. Hence, fugitive emissions make up over 99 percent of total methane emissions for natural gas, about 95 percent for coal, and 93 percent for petroleum fuels.

Fugitive emissions factors for CO_2 and methane from coal mining and natural gas production were estimated based on a review of recent studies compiled by Burnham (2011).[6] This review includes estimates of the difference between fugitive emissions factors for conventional production of natural vs. unconventional (shale or tight gas). These estimates rely in turn on data gathered by EPA under new GHG reporting requirements for the petroleum and natural gas industries.[7,8] The value for methane, if it were translated to a leakage rate, would be equivalent to 1.3%. Actual leakage rates of methane at various stages of the production process are highly variable and the subject of ongoing research. In a comprehensive review of the literature, Brandt et al. (2014)[8] find that, while regional studies with very high emissions rates may not be representative of typical natural gas systems, it is also true that official inventories have most likely underestimated methane emissions. As more data are made available, DOE will continue to update these estimated emissions factors.

Upstream emissions factors account for both fugitive emissions and combustion emissions in extraction, processing, and transport of primary fuels. For ease of application in its analysis, DOE developed all of the emissions factors using site (point of use) energy savings in the denominator. Table B.8 presents the electricity upstream emissions factors for selected years. The caps that apply to power sector NO_X emissions do not apply to upstream combustion sources, so some components of the upstream fuel cycle (particularly off-road mobile engines) can contribute significantly to the upstream NO_X emissions factors.

B.4 Data Tables

Summary tables of all the emissions factor data used by DOE for analysis using AEO 2022 are presented in the tables below. Table B.1 provides combustion emissions factors for fuels commonly used in buildings. Table B.2 to Table B.7 present the marginal power sector emissions factors as a function of sector and end use for a selected set of years. Table B.8 to Table B.10 provide the upstream emissions factors for all pollutants, for site electricity, natural gas and petroleum fuels. In all cases, the emissions factors are defined relative to the site electricity supplied from the grid and site use of the fuel.

Table B.1. Site Combustion Emissions Factors

Species	Natural Gas g/mcf	Distillate Oil g/bbl
CH_4	1.03E+00	1.33E+01
CO_2	5.47E+04	4.46E+05
N_2O	1.03E-01	8.65E+00
NO_X	4.36E+01	3.62E+02
SO_2	2.73E-01	2.20E+02

Table B.2. Power Sector Emissions Factors for CO_2 (Million Short Tons (MMsT)/Quad of Site Electricity Use)

	2025	2030	2035	2040
Residential Sector				
Clothes Dryers	1.40E+02	1.22E+02	1.08E+02	9.99E+01
Cooking	1.38E+02	1.21E+02	1.07E+02	9.89E+01
Freezers	1.42E+02	1.24E+02	1.10E+02	1.02E+02
Lighting	1.42E+02	1.24E+02	1.10E+02	1.01E+02
Refrigeration	1.42E+02	1.24E+02	1.10E+02	1.02E+02
Space Cooling	1.34E+02	1.17E+02	1.05E+02	9.76E+01
Space Heating	1.44E+02	1.26E+02	1.11E+02	1.02E+02
Water Heating	1.40E+02	1.22E+02	1.08E+02	9.98E+01
Other Users	1.40E+02	1.22E+02	1.08E+02	9.97E+01
Commercial Sector				
Cooking	1.29E+02	1.12E+02	9.97E+01	9.25E+01
Lighting	1.32E+02	1.15E+02	1.02E+02	9.43E+01
Office Equipment (Non-PC)	1.25E+02	1.08E+02	9.66E+01	9.00E+01
Office Equipment (PC)	1.25E+02	1.08E+02	9.66E+01	9.00E+01
Refrigeration	1.38E+02	1.21E+02	1.07E+02	9.89E+01
Space Cooling	1.32E+02	1.15E+02	1.03E+02	9.62E+01
Space Heating	1.45E+02	1.27E+02	1.12E+02	1.03E+02
Ventilation	1.39E+02	1.21E+02	1.07E+02	9.90E+01
Water Heating	1.29E+02	1.12E+02	9.93E+01	9.22E+01
Other Uses	1.27E+02	1.10E+02	9.80E+01	9.11E+01
Industrial				
All Uses	1.27E+02	1.10E+02	9.80E+01	9.11E+01

Table B.3. Power Sector Emissions Factors for CH_4 (Million Short Tons (MMsT)/Quad of Site Electricity Use)

	2025	2030	2035	2040
Residential Sector				
Clothes Dryers	1.09E-02	9.61E-03	8.27E-03	7.33E-03
Cooking	1.07E-02	9.39E-03	8.08E-03	7.16E-03
Freezers	1.13E-02	9.91E-03	8.52E-03	7.56E-03
Lighting	1.14E-02	1.00E-02	8.61E-03	7.63E-03
Refrigeration	1.13E-02	9.89E-03	8.51E-03	7.54E-03
Space Cooling	9.66E-03	8.47E-03	7.30E-03	6.49E-03
Space Heating	1.17E-02	1.03E-02	8.82E-03	7.82E-03
Water Heating	1.10E-02	9.69E-03	8.33E-03	7.39E-03
Other Users	1.09E-02	9.59E-03	8.25E-03	7.32E-03
Commercial Sector				
Cooking	9.30E-03	8.14E-03	7.00E-03	6.21E-03
Lighting	9.68E-03	8.48E-03	7.29E-03	6.47E-03
Office Equipment (Non-PC)	8.61E-03	7.53E-03	6.47E-03	5.75E-03
Office Equipment (PC)	8.61E-03	7.53E-03	6.47E-03	5.75E-03
Refrigeration	1.07E-02	9.42E-03	8.10E-03	7.19E-03
Space Cooling	9.29E-03	8.14E-03	7.02E-03	6.24E-03
Space Heating	1.18E-02	1.04E-02	8.93E-03	7.91E-03
Ventilation	1.08E-02	9.46E-03	8.14E-03	7.21E-03
Water Heating	9.26E-03	8.10E-03	6.97E-03	6.19E-03
Other Uses	8.91E-03	7.79E-03	6.70E-03	5.95E-03
Industrial				
All Uses	8.91E-03	7.79E-03	6.70E-03	5.95E-03

Table B.4. Power Sector Emissions Factors for Hg (Million Short Tons (MMsT)/Quad of Site Electricity Use)

	2025	2030	2035	2040
Residential Sector				
Clothes Dryers	3.54E-01	3.13E-01	2.91E-01	2.80E-01
Cooking	3.44E-01	3.04E-01	2.83E-01	2.72E-01
Freezers	3.66E-01	3.23E-01	3.01E-01	2.90E-01
Lighting	3.71E-01	3.28E-01	3.06E-01	2.94E-01
Refrigeration	3.65E-01	3.23E-01	3.01E-01	2.89E-01
Space Cooling	3.03E-01	2.67E-01	2.48E-01	2.38E-01
Space Heating	3.82E-01	3.38E-01	3.15E-01	3.03E-01
Water Heating	3.58E-01	3.16E-01	2.94E-01	2.83E-01
Other Users	3.53E-01	3.12E-01	2.91E-01	2.79E-01
Commercial Sector				
Cooking	2.92E-01	2.57E-01	2.39E-01	2.29E-01
Lighting	3.06E-01	2.70E-01	2.51E-01	2.41E-01
Office Equipment (Non-PC)	2.66E-01	2.34E-01	2.17E-01	2.08E-01
Office Equipment (PC)	2.66E-01	2.34E-01	2.17E-01	2.08E-01
Refrigeration	3.46E-01	3.06E-01	2.85E-01	2.74E-01
Space Cooling	2.88E-01	2.54E-01	2.36E-01	2.26E-01

Space Heating	3.87E-01	3.43E-01	3.20E-01	3.07E-01
Ventilation	3.48E-01	3.07E-01	2.86E-01	2.75E-01
Water Heating	2.91E-01	2.56E-01	2.38E-01	2.28E-01
Other Uses	2.77E-01	2.44E-01	2.26E-01	2.17E-01
Industrial				
All Uses	2.77E-01	2.44E-01	2.26E-01	2.17E-01

Table B.5. Power Sector Emissions Factors for N_2O (Million Short Tons (MMsT)/Quad of Site Electricity Use)

	2025	2030	2035	2040
Residential Sector				
Clothes Dryers	1.55E-03	1.36E-03	1.17E-03	1.03E-03
Cooking	1.51E-03	1.33E-03	1.14E-03	1.00E-03
Freezers	1.60E-03	1.40E-03	1.20E-03	1.06E-03
Lighting	1.61E-03	1.42E-03	1.22E-03	1.07E-03
Refrigeration	1.59E-03	1.40E-03	1.20E-03	1.06E-03
Space Cooling	1.36E-03	1.19E-03	1.02E-03	9.04E-04
Space Heating	1.65E-03	1.45E-03	1.25E-03	1.10E-03
Water Heating	1.56E-03	1.37E-03	1.17E-03	1.04E-03
Other Users	1.54E-03	1.36E-03	1.16E-03	1.03E-03
Commercial Sector				
Cooking	1.30E-03	1.14E-03	9.79E-04	8.64E-04
Lighting	1.36E-03	1.19E-03	1.02E-03	9.03E-04
Office Equipment (Non-PC)	1.20E-03	1.05E-03	9.02E-04	7.97E-04
Office Equipment (PC)	1.20E-03	1.05E-03	9.02E-04	7.97E-04
Refrigeration	1.52E-03	1.33E-03	1.14E-03	1.01E-03
Space Cooling	1.30E-03	1.14E-03	9.80E-04	8.66E-04
Space Heating	1.68E-03	1.47E-03	1.26E-03	1.12E-03
Ventilation	1.52E-03	1.34E-03	1.15E-03	1.01E-03
Water Heating	1.30E-03	1.14E-03	9.74E-04	8.61E-04
Other Uses	1.25E-03	1.09E-03	9.35E-04	8.26E-04
Industrial				
All Uses	1.25E-03	1.09E-03	9.35E-04	8.26E-04

Table B.6. Power Sector Emissions Factors for NO_X (Million Short Tons (MMsT)/Quad of Site Electricity Use)

	2025	2030	2035	2040
Residential Sector				
Clothes Dryers	5.44E-02	6.48E-02	5.44E-02	4.89E-02
Cooking	5.36E-02	6.37E-02	5.35E-02	4.81E-02
Freezers	5.57E-02	6.64E-02	5.58E-02	5.00E-02
Lighting	5.59E-02	6.66E-02	5.58E-02	5.00E-02
Refrigeration	5.56E-02	6.63E-02	5.57E-02	4.99E-02
Space Cooling	5.07E-02	6.04E-02	5.11E-02	4.61E-02
Space Heating	5.68E-02	6.77E-02	5.67E-02	5.08E-02
Water Heating	5.46E-02	6.50E-02	5.46E-02	4.89E-02

Other Users	5.43E-02	6.47E-02	5.43E-02	4.88E-02
Commercial Sector				
Cooking	4.85E-02	5.76E-02	4.84E-02	4.36E-02
Lighting	4.99E-02	5.93E-02	4.99E-02	4.49E-02
Office Equipment (Non-PC)	4.62E-02	5.47E-02	4.61E-02	4.17E-02
Office Equipment (PC)	4.62E-02	5.47E-02	4.61E-02	4.17E-02
Refrigeration	5.37E-02	6.39E-02	5.36E-02	4.82E-02
Space Cooling	4.94E-02	5.88E-02	4.98E-02	4.50E-02
Space Heating	5.73E-02	6.83E-02	5.72E-02	5.13E-02
Ventilation	5.38E-02	6.40E-02	5.38E-02	4.83E-02
Water Heating	4.83E-02	5.73E-02	4.82E-02	4.35E-02
Other Uses	4.72E-02	5.60E-02	4.71E-02	4.25E-02
Industrial				
All Uses	4.72E-02	5.60E-02	4.71E-02	4.25E-02

Table B.7. Power Sector Emissions Factors for SO_2 (Million Short Tons (MMsT)/Quad of Site Electricity Use)

	2025	2030	2035	2040
Residential Sector				
Clothes Dryers	7.88E-02	6.35E-02	4.95E-02	4.32E-02
Cooking	7.69E-02	6.18E-02	4.82E-02	4.21E-02
Freezers	8.16E-02	6.57E-02	5.13E-02	4.48E-02
Lighting	8.23E-02	6.64E-02	5.18E-02	4.53E-02
Refrigeration	8.14E-02	6.55E-02	5.12E-02	4.47E-02
Space Cooling	6.92E-02	5.54E-02	4.31E-02	3.75E-02
Space Heating	8.45E-02	6.82E-02	5.32E-02	4.65E-02
Water Heating	7.94E-02	6.40E-02	4.99E-02	4.36E-02
Other Users	7.87E-02	6.33E-02	4.94E-02	4.31E-02
Commercial Sector				
Cooking	6.56E-02	5.26E-02	4.09E-02	3.56E-02
Lighting	6.87E-02	5.51E-02	4.29E-02	3.74E-02
Office Equipment (Non-PC)	6.01E-02	4.81E-02	3.74E-02	3.25E-02
Office Equipment (PC)	6.01E-02	4.81E-02	3.74E-02	3.25E-02
Refrigeration	7.71E-02	6.21E-02	4.84E-02	4.23E-02
Space Cooling	6.62E-02	5.30E-02	4.12E-02	3.58E-02
Space Heating	8.57E-02	6.91E-02	5.40E-02	4.72E-02
Ventilation	7.75E-02	6.23E-02	4.86E-02	4.24E-02
Water Heating	6.52E-02	5.23E-02	4.07E-02	3.55E-02
Other Uses	6.25E-02	5.01E-02	3.89E-02	3.39E-02
Industrial				
All Uses	6.25E-02	5.01E-02	3.89E-02	3.39E-02

Table B.8. Electricity Upstream Emissions Factors

Species	Unit	2025	2030	2035	2040
CO_2	kg/MWh	27.12	24.82	23.29	22.76
CH_4	g/MWh	2,233	2,072	1,960	1,937
Hg	g/MWh	5.407E-06	4.696E-06	3.900E-06	3.312E-06
N_2O	g/MWh	0.1521	0.1359	0.1205	0.1097
NO_X	g/MWh	363.0	334.7	317.0	311.7
SO_2	g/MWh	2.422	2.051	1.751	1.554

Table B.9. Natural Gas Upstream Emissions Factors

Species	Unit	2025	2030	2035	2040
CO_2	kg/MMcf	7.096	7.107	7.162	7.172
CH_4	g/MMcf	691.1	692.9	694.2	694.2
Hg	g/MMcf	0	0	0	0
N_2O	g/MMcf	0.0111	0.0111	0.0112	0.0112
NO_X	g/MMcf	100.3	100.5	101.5	101.7
SO_2	g/MMcf	0.0301	0.0301	0.0304	0.0305

Table B.10. Petroleum Fuel Upstream Emissions Factors

Species	Unit	2025	2030	2035	2040
CO_2	kg/bbl	69.71	69.83	70.27	71.62
CH_4	g/bbl	950.3	944.3	943.6	960.6
Hg	g/bbl	4.650E-06	4.688E-06	4.379E-06	4.071E-06
N_2O	g/bbl	0.5819	0.5873	0.5964	0.6051
NO_X	g/bbl	762.3	770.8	785.5	799.3
SO_2	g/bbl	13.76	13.85	14.05	14.21

B.5 References

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Appendix C - Benefit-Per-Ton Values for NO_X and SO_2 Emissions from Electricity Generation

C.1 Introduction

This appendix describes the analytical methodology DOE uses to incorporate regional and end use sector variability in NO_X and SO_2 valuations into the emissions monetization. The regional values assigned to these emissions are based on benefit-per-ton estimates published by EPA for a variety of sectors, including electricity generation. EPA provides high and low estimates of benefit-per-ton of NO_X and SO_2 emissions reductions in forty regions of the continental USA. DOE combined these data with regional information on electricity consumption and emissions to define weighted-average national values for NO_X and SO_2 as a function of sector.

DOE's methodology uses results associated with the most recent edition of the Annual Energy Outlook (AEO) published by the Energy Information Agency (EIA). For this analysis DOE used the Reference case from AEO2022.[1] The AEO data are used to define two sets of factors that enter into the calculation: the distribution of sectoral electricity consumption by region, and the magnitude of NO_X and SO_2 emissions in each region.

C.2 Methodology

C.2.1 EPA Data

In 2022 EPA published an updated Technical Support Document (TSD) describing an approach for estimating the average avoided human health impacts and monetized benefits related to emissions of $PM_{2.5}$ and ozone precursors including NO_X and SO_2 from 21 sectors.[a] The EPA TSD includes estimates of the present value of the benefits of NO_X and SO_2 emissions reductions (benefit-per-ton estimates or BPT) for 2025, 2030, 2035 and 2040. For NO_X, EPA provides values for $PM_{2.5}$ –related benefits and for ozone-related benefits. Because the pollutants associated with NO_X as $PM_{2.5}$ and SO_2 emissions persist in the atmosphere over a period of years, reductions in any given year will have benefits in subsequent years. These future benefits are discounted and summed to provide a single value for the reduction of one ton of emissions in the emissions year.

For Electricity generating units, EPA estimated a benefit per-ton for each of the 48 contiguous continental states. Some states are aggregated into larger regions (CT-RI, DE-NJ, IDOR-WA, ME-MA-NH-VT, and ND-SD), resulting in separate BPT estimates for forty regions. BPT values for NO_X and SO_2 as precursors to $PM_{2.5}$ include high and low impact scenarios; BPT values for NO_X as a precursor to ozone include short and long-term impacts. For all data two rates of discounting (3% and 7%) are provided.

DOE used linear interpolation to define values for the years between 2025 and 2030, 2030 and 2035, and 2035 and 2040. DOE defined the total value of NO_X emissions reductions as the sum of the BPT value for $PM_{2.5}$ plus one half of the BPT value for ozone; the factor of one-half accounts for the fact that ozone is primarily produced during the May-September period, so approximately half of NO_X emissions will produce ozone emissions.

C.2.2 AEO Data

For this calculation DOE used the total annual emissions of NO_X and SO_2 for each of the AEO's 25 Electricity Market Module (EMM) regions,[2] and data tables published with the NEMS code package.[b] The latter are used to map EPA regions to EMM regions, and to calculate the contribution of each utility customer sector (residential, commercial and industrial) to total pollutant emissions in each EMM region. The data are then combined to create time series of BPT values for each end use sector.

C.2.3 Equations and Results

Consistent with its treatment of other utility and environmental impacts, DOE defines a times series of national average estimates of NO_X and SO_2 values.

The same methodology is applied to each pollutant type and EPA scenario (low-7%, low3%, etc.). The notation is:

- y is the analysis year,

[a] U.S. Environmental Protection Agency. Estimating the Benefit per Ton of Reducing Directly-Emitted $PM_{2.5}$, $PM_{2.5}$ Precursors and Ozone Precursors from 21 Sectors. January 2022. https://www.epa.gov/system/files/documents/2021-10/source-apportionment-tsd-oct-2021_0.pdf

[b] The NEMS package can be downloaded at https://www.eia.gov/outlooks/aeo/info_nems_archive.php. Once installed, the file path to the data files is aeo2022\reference\input\emm_db.zip. The data files are EMMCNTL_RDB.xlsx and LDSMSTR_RDB.xlsx

- z is a label for the EOA region,
- w(z,m) is a matrix that maps EPA regions to EMM regions; it is defined as the fraction of total electricity sales within m to region z; $\sum z$ w(z,m) = 1 for all m,
- p(z,y) is the BPT estimate in EPA region z and year y,
- s is a label for the customer sector (commercial, residential, industrial),
- v(s, m) is the weight of sector s in EMM region m, defined as the fraction of total electricity sales within m to sector s; $\sum s$ v(s,m) = 1 for all m,
- M(m,y) is total pollutant emissions in EMM region m and year y.

The calculation proceeds in four steps:

1. Pollutant emissions are allocated to sector:

$$M1(m, s, y) = M(m, y) * v(s, m)$$

2. Sectoral pollutant emissions are mapped from EMM regions to EPA regions:

$$M2(z, s, y) = \sum m\ M1(m, s, y) * w(z, m)$$

3. A weight is defined for EPA region z and sector s, based on pollutant emissions:

$$u(z, s, y) = M2(z, s, y)/[\ \sum z\ M2(z, s, y)\ ]$$

4. The regional weights are used to define a national average BPT value for each sector:

$$P(s, y) = \sum z\ u(z, s, y) * p(z, y)$$

The results of this calculation are provided in Table C.1 for NO_X and in Table C.2 for SO_2. DOE's prices are not significantly different than the EPA estimate of the US average.

Table C.1. NO_X Benefit-per-ton Values by Sector (2021$/ Short Ton)

Sector	High, 3% Discount Rate			High, 7% Discount Rate		
	2025	2030	2040	2025	2030	2040
Commercial	62,140	69,070	84,240	55,550	61,670	75,240
Residential	62,020	68,880	83,920	55,660	61,840	75,530
Sector	**Low, 3% Discount Rate**			**Low, 7% Discount Rate**		
	2025	**2030**	**2040**	**2025**	**2030**	**2040**
Commercial	62,010	68,750	83,510	55,550	61,560	74,880
Residential	61,890	68,570	83,230	55,440	61,400	74,620

Table C.2. SO_2 Benefit-per-ton Values by Sector (2021$/ Short Ton)

Sector	High, 3% Discount Rate			High, 7% Discount Rate		
	2025	2030	2040	2025	2030	2040
Commercial	62,140	69,070	84,240	55,550	61,670	75,240
Residential	62,020	68,880	83,920	55,660	61,840	75,530
Sector	**Low, 3% Discount Rate**			**Low, 7% Discount Rate**		
	2025	**2030**	**2040**	**2025**	**2030**	**2040**
Commercial	62,010	68,750	83,510	55,550	61,560	74,880
Residential	61,890	68,570	83,230	55,440	61,400	74,620

C.3 References

1. U.S. Energy Information Administration. *Annual Energy Outlook 2022 with Projections to 2050*. 2022. Washington, D.C. (Last accessed September 8, 2022.) https://www.eia.gov/outlooks/aeo/.

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