APPENDIX K. ESTIMATION OF UTILITY AND ENVIRONMENTAL RESULTS FROM NEMS-BT OUTPUT

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APPENDIX K. ESTIMATION OF UTILITY AND ENVIRONMENTAL RESULTS FROM NEMS-BT OUTPUT

The effects of proposed energy conservation standards for commercial refrigeration equipment was analyzed using a variant of National Energy Modeling System (NEMS) model, called NEMS-BT.[1a] Because the magnitude of national energy savings as a result of the proposed standards is very small relative to total electric generation, the U.S. Department of Energy (DOE) used an estimation method involving regression smoothing and interpolation. This appendix describes the major elements of this method.

To run a simulation in NEMS-BT model, the refrigeration load in the commercial building module is reduced annually according to the electricity savings estimated by the National Energy Savings (NES) spreadsheet model (see Chapter 10 of the TSD) for each trial standard level (TSL). The electricity savings increase over time as various types of commercial refrigeration equipment are replaced with more efficient equipment meeting the proposed conservation standards.

The magnitude of the electricity decrement that would be required for NEMS-BT to produce stable results out of the range of numerical noise is greater than the highest TSL under consideration. Therefore, to estimate results for the TSLs evaluated here, a series of NEMS-BT simulations is performed using higher values for the input electricity savings. These simulations establish the relationship between the NEMS-BT output variables (electricity generation by fuel, installed electricity generation capacity, and emissions) and the electricity savings inputs. For each output variable, a regression model is estimated to represent an average response across the series of simulations. Impacts are obtained using predicted values from the regression models corresponding to the (smaller) levels of savings corresponding to TSLs.

K.1 Allocation of Input Electricity Savings by Census Division and End Use

Although the utility and environmental impacts are national in scope, the NEMS-BT model operates at a census division level. An allocation of savings was made on the basis of estimated sales distributions to various categories of buildings (supermarkets, convenience and specialty stores, gas stations with convenience stores, and multi-line retail stores). The shares used to distribute the savings across census divisions are shown in Table K.1.1. The shares are held constant for the forecast period through 2030.

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[a] DOE's EIA approves of the name NEMS to describe only an official version of the model without any modification of the code or data. Because the analysis of commercial refrigeration energy conservation standards entails some minor code modifications and the model is run under policy scenarios that are variations of DOE/EIA assumptions, the name NEMS-BT refers to the model as used here. (The Building Technologies [BT] program is one of the major program offices within DOE's Office of Energy Efficiency and Renewable Energy. The Building Technologies program is responsible for promulgating energy efficiency standards for the buildings sector mandated under the 2005 Energy Policy Act and earlier federal legislation.)

Table K.1.1 Shares of National Savings by Census Division Used in NEMS-BT

Census Division	Share (%)
New England	5.9%
Middle Atlantic	13.8%
East North Central	14.7%
West North Central	6.6%
South Atlantic	19.4%
East South Central	5.6%
West South Central	10.8%
Mountain	6.7%
Pacific	16.6%

K.2 Choice of Impact Multipliers

To gain some understanding of the how NEMS-BT would respond to various magnitudes of savings, a "reference" time series of savings was initially selected from a preliminary version of the NES spreadsheet model. This reference series was selected as the savings that would result from the most stringent TSL ("max technologically feasible) for all refrigeration equipment considered in this rulemaking (TSL 5). The estimated savings from this particular equipment type in 2030 was 6.0 terrawatt-hours (TWh) or 20.5 Trillion Btu (in site energy terms). NEMS-BT was run using the projected time series of savings pertaining to this case as well as for higher multipliers (designated here with a suffix X), including 1X, 2X, 4X, 6X, and 8X. (Thus, for example, the 2030 refrigeration savings imposed upon the commercial module in NEMS-BT in the 4X case was 41.0 TWh.)

It was judged, on the basis of graphical output and comparison of trends among the output variables, that the numerical noise from the model was overwhelming the impact of the savings decrement for the smaller multiplier factors less than 2X.[b] Table K.2.1 compares the savings decrement applied to the model under various multipliers and how the magnitude of the savings compares with total electricity generation in EIA's Annual Energy Outlook (AEO2007) reference case.[2c]

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[b] The numerical noise stems, in part, from the fact that a precise balancing between the demand and supply sides of NEMS is not always achieved, given the iterative nature of the solution process.

[c] The reader should note that the values of the multipliers used here are solely dependent on the initial (and arbitrary) choice of a particular refrigeration product and a specific trial standard level (TSL) for that product. The NEMS-BT simulations were performed prior to the final selection of TSLs and so the 1X multiplier does *not* correspond to any specific TSL for a product category in previous sections of the report. However, it was judged that the savings decrements (in TWh) tested in NEMS-BT, shown in lower portion of Table K.2.1, were in the relevant range of magnitudes to yield stable and robust predictions by the model and so additional runs using different multipliers were deemed unnecessary. For use in the predicting the impacts from the set of final TSLs, the savings decrement from any TSL was converted into an appropriate multiplier by scaling in proportion to the values shown in the first row of Table K.2.1.

Table K.2.1 Comparison of Refrigeration Electricity Savings with Different Multipliers with Total Generation

		2015	2020	2025	2030
1X	Savings (TWh)	1.44	3.64	5.66	5.99
	% of total generation	0.03%	0.08%	0.11%	0.11%
2X	Savings (TWh)	2.89	7.29	11.31	11.99
	% of total generation	0.06%	0.15%	0.23%	0.23%
4X	Savings (TWh)	5.77	14.57	22.63	23.98
	% of total generation	0.13%	0.31%	0.46%	0.46%
6X	Savings (TWh)	8.66	21.86	33.94	35.97
	% of total generation	0.19%	0.46%	0.68%	0.69%
8X	Savings (TWh)	11.54	29.14	45.26	47.95
	% of total generation	0.26%	0.62%	0.91%	0.92%

Based on this testing, a decision was made to use the multipliers in the range of 2X through 6X. While these multipliers are greater than 1, they still do not yield large perturbations to the base case simulation. For example, as Table K.1.1 indicates, even at 6X in the year 2025, the total savings decrement applied to the model represents only about 0.7 percent of total electricity generation.

Final Implied Multipliers by Trial Standard Level for All Refrigeration Equipment

Subsequent to the production of the NEMS simulations described in the previous section, some revisions were made to the final set of energy savings estimates for the final rule. In addition, for purposes of reporting utility and environmental impacts for refrigeration, *all 15* types of refrigeration equipment were aggregated. To adjust for these changes, the difference between the final savings estimate (by trial standard level) and the savings from the initial "reference" time series was represented as a scale factor. (For example, the energy savings for the final version of the energy standard was 5.28 TWh at TSL-5, as compared to the actual value used as the 1X case in NEMS-BT of 5.99 TWh. Thus, the scale factor for TSL-5 is 5.28/5.99 = 0.881). The scale factor essentially adjusts the savings from all refrigeration equipment for a specific TSL to be consistent with the reference series and, thus, be consistent with the interpolation procedure described above.

The first column in Table K.2.2 displays the scale factors for each TSL.[d] The remaining columns display the implied multipliers from the three simulations performed with NEMS-BT (using their designations of 2X, 4X, and 6X). For example, after *combining* all the refrigeration equipment, the *actual* final multipliers used for TSL-4 were 2.8, 5.7, and 8.5. Because the savings for TSL-1 through TSL-3 are smaller than those for TSL-4, the implied multipliers are larger than those for TSL-4 (and *vice versa* for TSL-5).

[d] The scale factors can also be viewed as interpolating values relative to the set of NEMS-BT impact runs. Thus, for example, if an impact upon a particular variable from the "2X" case in the original set of simulations was interpolated to be a value of, say, 0.10, then the impact for TSL-4 for all refrigeration equipment would be ½ x 0.703 x 0.10 = 0.035.

Table K.2.2 Final Implied Multipliers by Trial Standard Level – All Refrigeration Equipment

	Scale Factor	Implied Multipliers NEMS-BT ("2X")	NEMS-BT ("4X")	NEMS-BT ("6X")
All Refrigeration Equipment				
TSL – 1	0.114	17.6	35.1	52.7
TSL – 2	0.438	4.6	9.1	13.7
TSL – 3	0.678	3.0	5.9	8.9
TSL – 4	0.703	2.8	5.7	8.5
TSL – 5	0.881	2.3	4.5	6.8

K.3 Regression Smoothing of NEMS-BT Outputs

Even at the selected multiplier levels shown in Table K.1.1, the simulations with NEMS-BT produces considerable year-to-year variation that appears to be caused by numerical noise from the model solution. This variation appears to affect the outputs related to specific generation fuel and technologies more so than total generation or total installed capacity. For the utility impact assessment, it is more important to identify distinct trends in the utility sector adjustment process rather than year-to-year variation that may be spurious results from the model solution process.

To reduce the potential effect of numerical noise from NEMS-BT simulation, a smoothing regression was estimated for each of the model output variables. The output variables are measured as the differences between the (AEO) reference case and the energy efficiency standards case. The formulation of the smoothing regression was a simple quadratic function of time (in years) with the following form:

$$Y(T) = a_1 \text{ x } T + a_2 \text{ x } T^2 + u \qquad \textbf{Eq. K.1}$$

where

Y	=	Output variable for time period T (difference from reference case)
T	=	Time in years, T = 0 in 2012, T = 1 in 2013, etc.
a_1, a_2	=	estimated regression coefficients
u	=	random disturbance term.

The regression specification is such that the fitted (predicted) value of the variable is forced through the origin in the year prior to the implementation of the standard (2012). By forcing the impact to be zero in 2012, this procedure generates estimated impacts that typically could be expected to change in a systematic fashion beginning in 2013.

Figure K.3.1 illustrates this procedure for the differences in total installed capacity and the three types of fossil fuel capacity. The particular case shown is for commercial refrigeration equipment at the "4X" level of savings (or 5.7X relative TSL-4 for all commercial refrigeration equipment—see Table K.2.2). Clearly, NEMS-BT indicates a very smooth path of differences in total generation capacity as shown in the top left panel of the figure. (In this case, the regression smoothing would not be necessary.)

For plants using specific fuels or technologies, the differences in particular years from a smooth trend line are more substantial. The deviations from the fitted trend line are most pronounced for combustion turbines. In this case, the model produces a significant negative deviation from trend in the years between 2020 and 2027.[e]

Nevertheless, over the entire forecast period, the long-term trends in the capacity of all of these types of plants are apparent from the graphs. The approach in this analysis is to abstract these short-term deviations from what appear to be long-term trends.

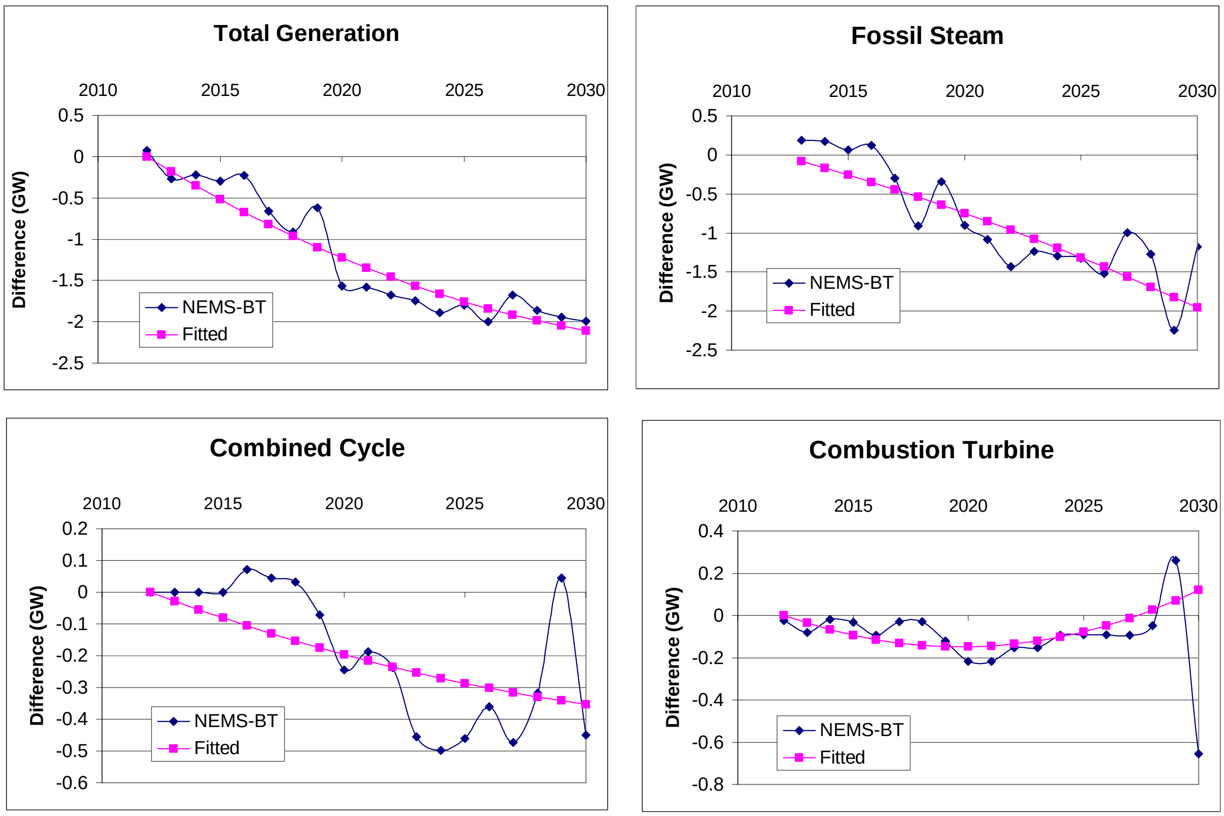

Figure K.3.1 Example of Regression Smoothing Fits for Fossil-Fired and Total Installed Capacity (4X case)

K.4 Estimation of Interpolating Functions from Savings Multipliers

The development of utility and environmental impacts focused on specific years from the NEMS-BT simulations: 2015, 2020, 2025, and 2030. For each output variable (e.g., coal-fired electricity generation), the predicted values from the trend regression were extracted for each savings multiplier level (2X, 4X, and 6X). A subsequent linear regression was performed using

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[e] In this particular case, NEMS-BT appears to show some anomalous behavior in the last several years of the simulation period, especially for combined cycle and combustion turbines. The regression smoothing approach provides a means of generating more plausible predictions in these instances. In some cases, the last year or two of the projection was not used in regression fitting procedure.

these values for the dependent variable and the values of the saving multiplier as the independent or explanatory variable. The y-intercept of this regression is forced through the origin. This restriction ensures that the predicted value of a NEMS-BT output variable is zero when the savings multiplier is zero. Predicted values for non-zero multipliers are calculated by taking the estimated regression coefficient (slope) times the value of the savings multiplier.

Figure K.4.1 shows several examples of this estimation approach. The magnitude of the energy savings multiplier is plotted on the x-axis against the total reduction in generation capacity for the year 2025. The results shown are based on the three simulations selected for commercial refrigeration equipment (2X, 4X, and 6X as described above). The fitted 2025 values from the smoothing regression of the NEMS-BT output are shown in the large solid (black) diamonds. In the case of total generation capacity, the linear regression line is closely aligned to the three points corresponding to the 2X, 4X, and 6X savings multipliers.

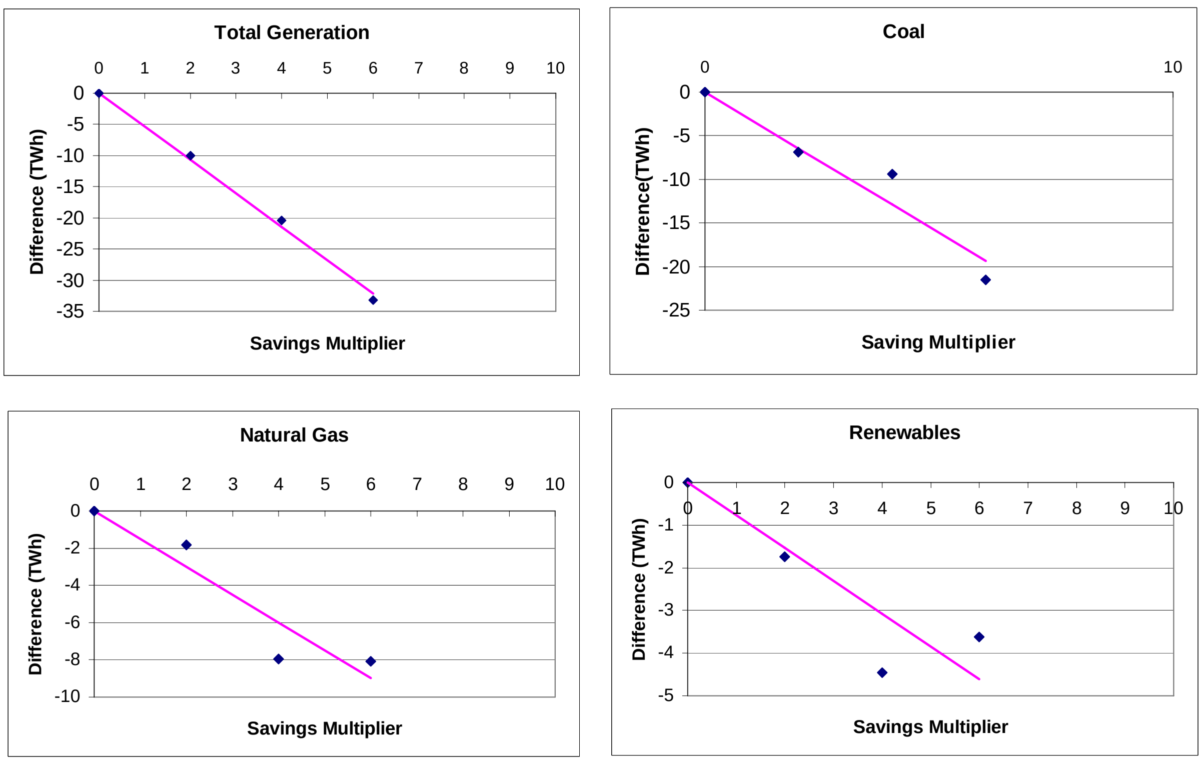

Figure K.4.1 Response (Interpolating) Functions for Selected Generation Outputs for 2025

Within this range of savings, the graph demonstrates the impact on total capacity predicted by the model is proportional to the magnitude of the refrigeration electricity savings.

For the other generation types shown in Figure K.4.1, the responses deviate from strict proportionality. For example, for coal, the response at the 4X is proportionately less than either the 2X or 4X levels. The approach taken here essentially produces a weighted average of the responses across these various savings multipliers.

The predicted value of a NEMS-BT output variable for a given standards level is interpolated along the regression line estimated for that variable. The computation of savings from a particular standards case first takes into account the scale factors shown in the first column in Table K.2.1. Thus, for example, the scale factor associated with Trial Standard Level 4 is 0.703. For total electricity *generation* in 2025, the estimated response coefficient is -5.36 (e.g., the slope of regression line in the top left panel Figure K.4.1). Thus, the estimated impact on total generation in 2025 from this specific trial standard level would be 0.703 x -5.36 = -3.77 TWh.

K.5 Environmental Impacts

The general approach for estimating the impacts on the utility sector was also used to develop an environmental assessment in terms of changes in emissions. Annual values of the emissions for NO_x, mercury, and carbon dioxide were extracted from the relevant tables produced by NEMS.

Similar to examples shown in Figure K.3.1, the projections of emissions from 2012 through 2030 were smoothed using the quadratic function in time discussed above. Response functions were then estimated at 5-year intervals between 2015 and 2030.

Figure K.5.1 shows the estimated response (or interpolating) functions for carbon dioxide emissions. There is very little disparity in the magnitudes of carbon dioxide emissions across the three multipliers selected. However, the 4X case shows a somewhat smaller response than the 2X and 6X cases. However, the regression-based average takes all three cases into account, leading to strong indication of a reduction in carbon dioxide emissions.

The scale of the y-axis is held constant for each of the plots and so the clockwise rotation of the slopes across the years 2015 through 2030 reflects the increasing reduction in emissions over selected years. There is little change in the slopes between 2025 and 2030, reflecting some slowdown in the rate of increase of savings. By the middle part of the next decade, most refrigeration equipment will have already been replaced by more efficient equipment mandated by the standards. Moreover, increases in coal generation toward the end of the forecast period have the effect of retarding further reductions in carbon dioxide emissions.

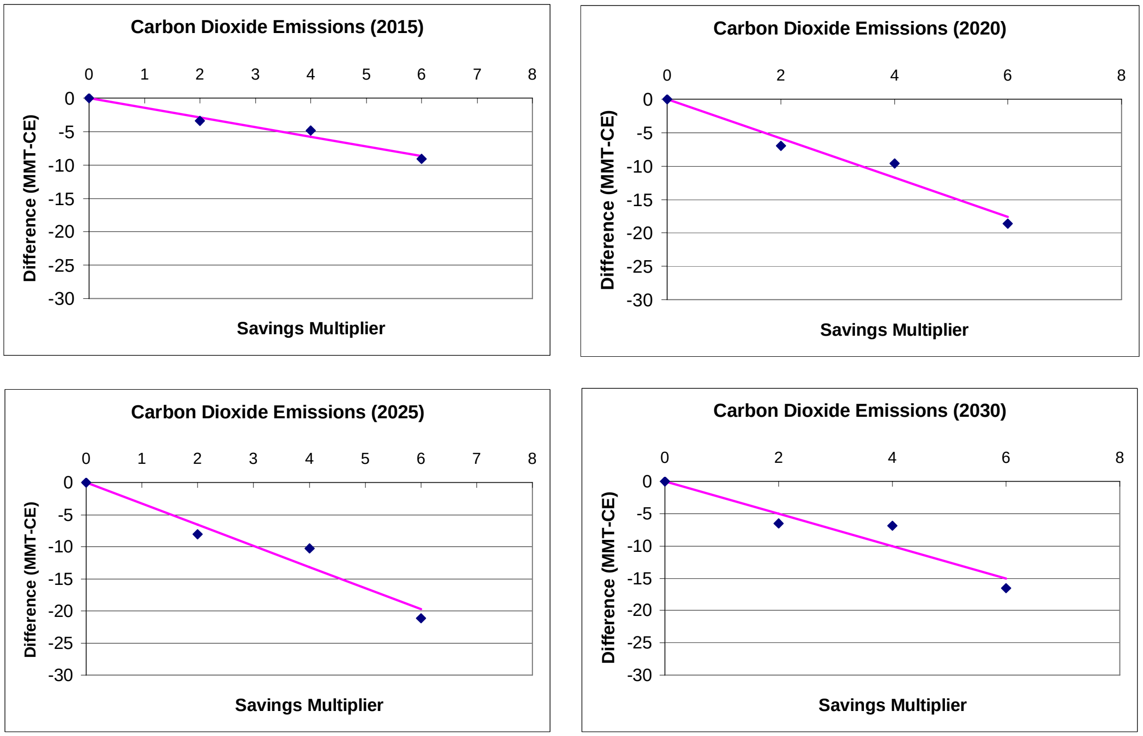

Figure K.5.1 **Response (Interpolating) Functions for Carbon Dioxide for Years 2015, 2020, 2025 and 2030.**

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