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 beverage vending machine equipment was analyzed using a variant of National Energy Modeling System (NEMS) model, called NEMS-Building Technology (BT). The U.S. Department of Energy (DOE) Energy Information Administration (EIA) approves the name NEMS to describe only an official version of the model without any modification of the code or data. Because the analysis of beverage vending machine energy conservation standards entails some minor code modifications and the model is run under variations of DOE/EIA assumption policy scenarios, the name NEMS-BT refers to the model as used here. Because the magnitude of national energy savings as a result of the proposed standards is very small relative to total electric generation, the 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 (chapter 11 of the TSD) for each trial standard level (TSL). The electricity savings increase over time as various categories of beverage vending machine equipment are replaced with more efficient equipment meeting the energy conservation standards in today's final rule.

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. Lacking sales information for beverage vending machine equipment by census division, an allocation of savings was made on the basis of population. 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.

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

Census Division	Share %
New England	11.2
Middle Atlantic	14.1
East North Central	16.0
West North Central	6.8
South Atlantic	18.4
East South Central	6.0
West South Central	11.2
Mountain	6.5
Pacific	16.0

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 (maximum technologically feasible efficiency level or max tech) for both classes of beverage vending machine equipment considered in this rulemaking. Max tech is TSL 7 for Class A equipment and TSL 6 for Class B equipment.

The preliminary estimated savings from these two equipment types in 2030 was 0.76 terawatt-hours (TWh) or 2.59 trillion British thermal units (Btu) in site energy terms. Based upon a previous rulemaking that also affected electricity use for refrigeration (DOE 2008), NEMS-BT was run using the projected time series of savings that were multiplied by a series of factors that ranged from 10–60 (designated here with a suffix X). Thus, for example, the 2030 beverage vending machine savings imposed upon the commercial module in NEMS-BT in the 30X case was 30 × 2.59 TWh = 22.8 TWh.

Based on the graphical output and a comparison of trends among the output variables, the numerical noise from the model appeared to overwhelm the impact of the savings decrement for the smaller multiplier factors (*i.e.*, less than 20X). The numerical noise stems in part from a precise balancing between the demand and supply sides of NEMS that is not always achieved, given the iterative nature of the solution process. 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 the Energy Information Administration’s (EIA’s) *Updated Annual Energy Outlook 2009* (*AEO2009*) reference case.[1]

The values of the multipliers used are solely dependent on the initial (and arbitrary) choice of Class A and Class B vending machines and a specific TSL for those machines. The NEMS-BT simulations were performed prior to the final engineering analysis and selection of TSLs and so the 1X multiplier does not correspond to any specific TSL for in previous sections of the report. However, it was judged that the savings decrements (in TWh) tested in NEMS-BT (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 Beverage Vending Machine Electricity Savings with Different Multipliers with Total Generation by Year

Multiplier	Electricity Savings	2015	2020	2025	2030
1X	Savings, *TWh*	0.29	0.64	0.76	0.76
	% of total generation	0.01	0.01	0.02	0.02
20X	Savings, *TWh*	5.79	12.81	15.20	15.20
	% of total generation	0.13	0.28	0.31	0.30
30X	Savings, *TWh*	8.69	19.22	22.79	22.79
	% of total generation	0.20	0.42	0.47	0.45
40X	Savings, *TWh*	11.58	25.63	30.39	30.39
	% of total generation	0.27	0.56	0.63	0.60

Based on this analysis, a decision was made to use the multipliers in the range of 20X through 40X. While these multipliers are greater than 1, they still do not yield large perturbations to the base case simulation. For example, as Table K.2.1 indicates, even at 40X in 2025, the total savings decrement applied to the model represents only about 0.6 percent of total electricity generation.

Final Implied Multipliers by TSL for All Beverage Vending Machine Equipment

Subsequent to the production of the NEMS simulations described earlier, 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 beverage vending machines, Class A and Class B equipment are distinguished. To adjust for these changes, the difference between the final savings estimate (by TSL) 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 was2.06 TWh at TSL 5 for Class A equipment, as compared to the actual value used as the 1X case in NEMS-BT of 2.59 TWh. Thus, the scale factor for TSL 5 is 2.06/2.59 = 0.796. 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 final implied multipliers by TSL are presented in Table K.2.2. The first column in Table K.2.2 displays the scale factors for each TSL. 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 “20X” case in the original set of simulations were interpolated to be a value of 4, then the impact for TSL 5 for all refrigeration equipment would be $(1/20) \times 1.16 \times 4 = 0.232$. The remaining columns in Table K.2.2 show the implied multipliers from the three simulations performed with NEMS-BT (using their designations of 20X, 30X, and 40X). For example, the actual final multipliers used for TSL 4 for Class A beverage vending machine equipment were 29.7, 44.5, and 59.4. 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).

Table K.2.2 Final Implied Multipliers by Trial Standard Level–Beverage Vending Machines

Equipment Type	Scale Factor	NEMS-BT Implied Multipliers		
		20X	30X	40X
Class A Equipment				
TSL 1	0.041	484.6	726.9	969.2
TSL 2	0.197	101.3	152.0	202.6
TSL 3	0.437	45.8	68.7	91.5
TSL 4	0.674	29.7	44.5	59.4
TSL 5	0.796	25.1	37.7	50.2
TSL 6	0.878	22.8	34.2	45.6
TSL 7	1.068	18.7	28.1	37.5
Class B Equipment				
TSL 1	0.017	1,199.9	1,799.9	2,399.8
TSL 2	0.025	808.6	1,212.8	1,617.1
TSL 3	0.124	161.0	241.6	322.1
TSL 4	0.142	140.8	211.2	281.6
TSL 5	0.382	52.3	78.5	104.6
TSL 6	0.426	47.0	70.5	93.9

K.3 REGRESSION SMOOTHING OF NEMS-BT OUTPUTS

Even at the selected multiplier levels shown in Table K.2.2, 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:

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

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, and
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 year the standard goes into effect (2012). By forcing the impact to be zero in 2011, this procedure generates estimated impacts that typically could be expected to change in a systematic fashion beginning in 2012.

Figure K.3.1 illustrates this procedure for the differences in total installed capacity and the three types of fossil fuel-fired generating plant capacity. The particular case shown is for beverage vending machine equipment at the "30X" level of savings (or 28.1X relative to TSL-7 for Class A beverage vending machine equipment). 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.)

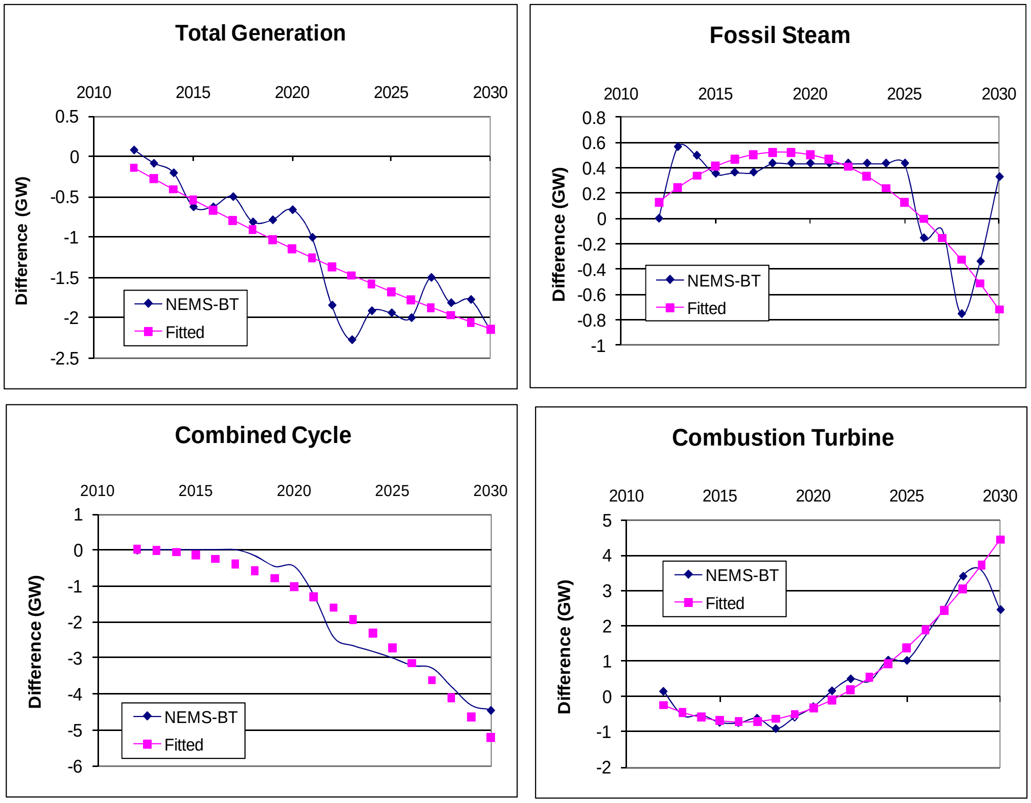

Figure K.3.1 Example of Regression Smoothing Fits for Fossil-Fuel Power Plants and Total Installed Capacity (30X case)

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 facilities using fossil steam technologies. In these cases, the model produces significant deviations from trend for up to 5 years throughout the forecast period. In this particular case, NEMS-BT appears to show some anomalous behavior in the last year or two of the simulation period, especially for fossil steam. The regression smoothing approach provides a means of generating more plausible predictions in these instances. In some cases, a single particularly anomalous year was not used in regression fitting procedure.

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.

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 (20X, 30X, and 40X). A subsequent linear regression was performed using 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 2030. The results shown are based on the three simulations selected for beverage vending machine equipment (20X, 30X, and 40X as described above). The fitted 2030 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 20X, 30X, and 40X savings multipliers.

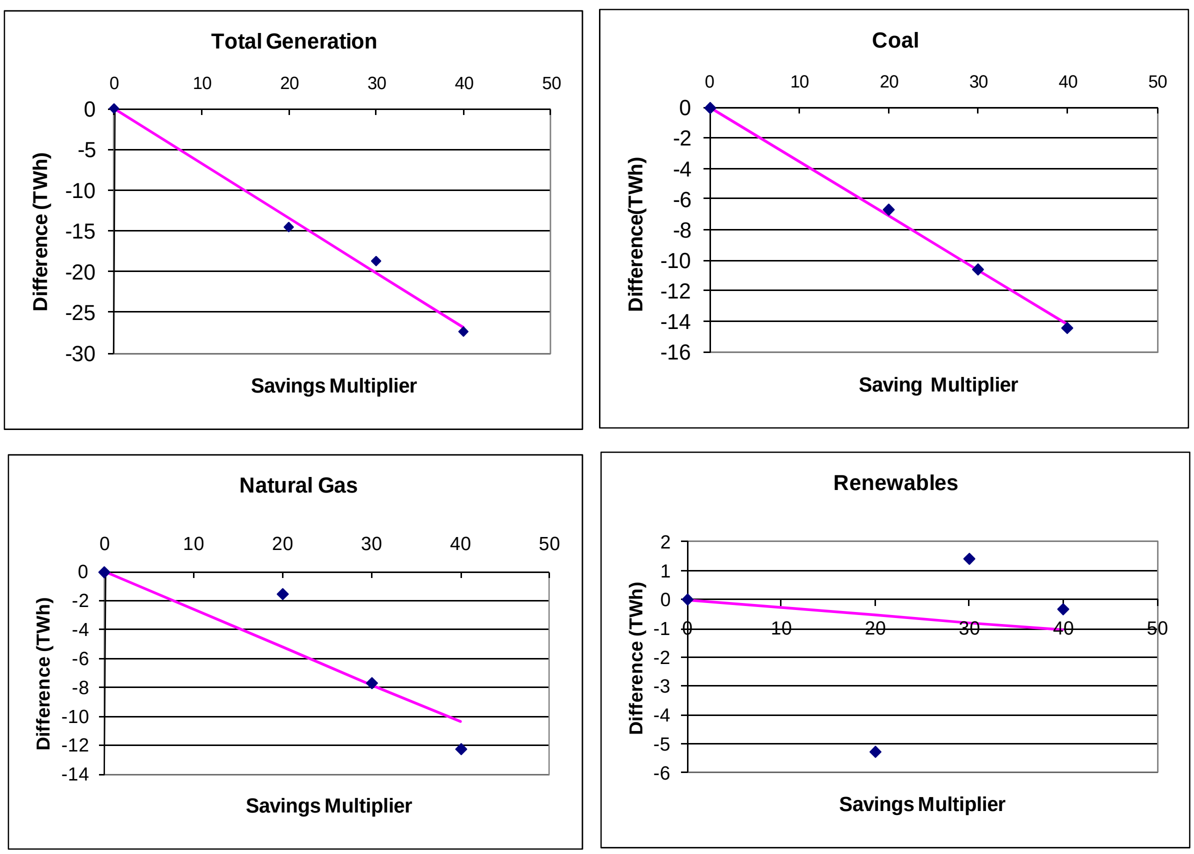

Figure K.4.1 Response (Interpolating) Functions for Selected Generation Outputs for 2025

Within this range of savings, the graph demonstrates that 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 renewables, the response at the 20X is proportionately greater than either the 30X or 40X levels. The approach 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.2.2. Thus, for example, the scale factor associated with TSL 4 for Class A equipment is 0.674. For total electricity generation in 2030, the estimated response coefficient is -0.260 (*e.g*., the slope of regression line in the top left panel of Figure K.4.1). Thus, the estimated impact on total generation in 2030 from this specific TSL would be 0.674 × -0.260 = -0.269 TWh.

K.5 ENVIRONMENTAL IMPACTS

The general approach for estimating the impacts on the utility sector was used to develop an environmental assessment in terms of changes in emissions. Annual values of the emissions for oxides of nitrogen (NO_x), mercury (Hg), and carbon dioxide (CO_2) were extracted from the relevant tables produced by NEMS. Similar to examples shown in Figure K.3.1, the projections of emissions 2012–2030 were smoothed using the quadratic function in time discussed above. Response functions were then estimated at 5-year intervals between 2015–2030.

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 30X case shows a somewhat greater response than the 20X and 40X cases in 2030. But 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 2015–2030 reflects the increasing reduction in emissions over selected years. There is little change in the slopes from 2025–2030, reflecting a distinct slowdown in the rate of increase of savings. By the middle part of the next decade, most beverage vending machine equipment will have already been replaced by more efficient equipment mandated by today's standards. Moreover, reduction in nuclear and renewable generation prompted by today's standards have the effect of retarding further reductions in CO_2 emissions toward the end of the period.

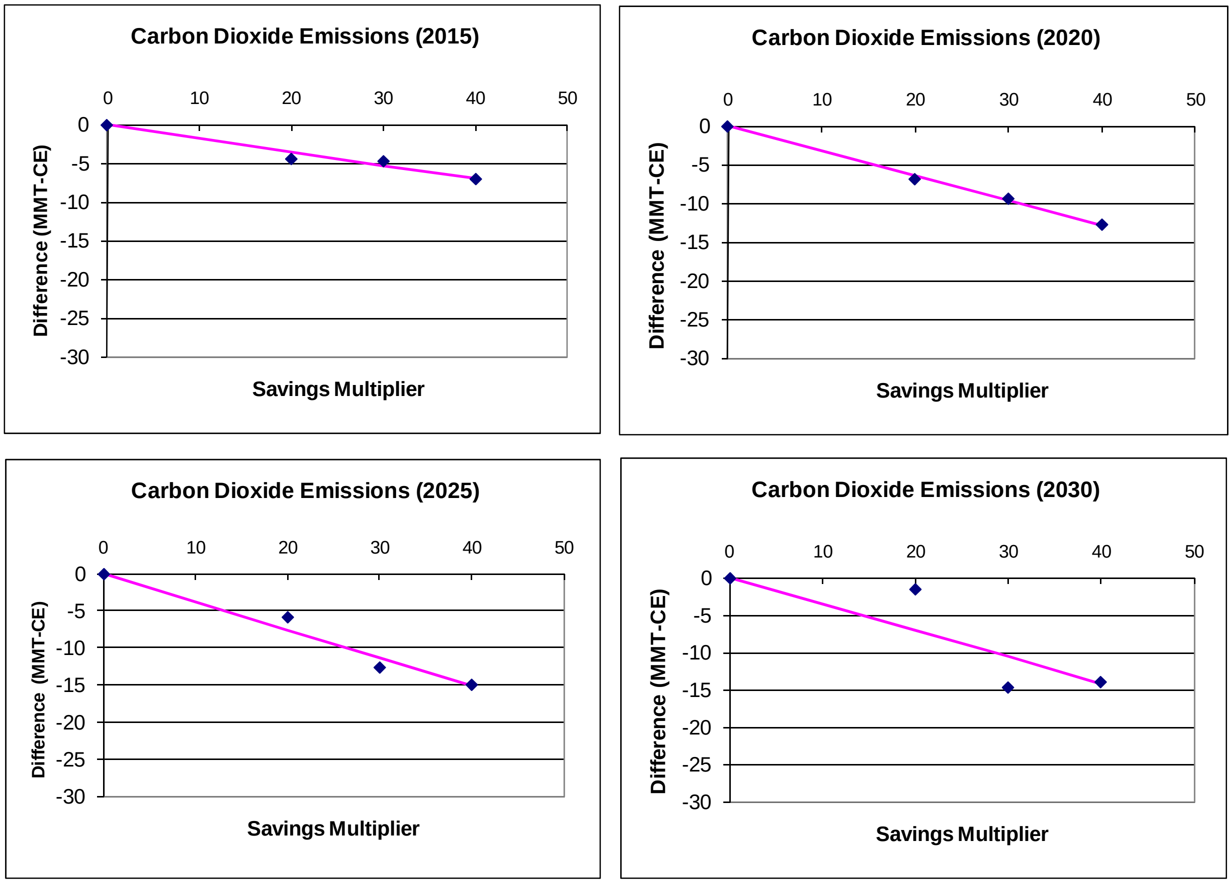

Figure K.5.1 Response (Interpolating) Functions for Carbon Dioxide for 2015, 2020, 2025, and 2030

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