CHAPTER 10. NATIONAL IMPACT ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 10: NATIONAL IMPACT ANALYSIS

10.1 INTRODUCTION

The Energy Policy and Conservation Act (EPCA) states that any new or amended standard must be chosen so as to achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. In determining whether economic justification exists, the Department of Energy (DOE) must determine that the benefits of the trial standard level exceed its burdens to the greatest extent practicable. Key factors in this decision are: the total projected amount of energy savings likely to result directly from the imposition of the standard, and the savings in operating costs throughout the estimated average life of the covered product in the type (or class) compared to any increase in the price of, or in the initial charges for or maintenance expenses of, the covered products which are likely to result from the imposition of the standard.

To satisfy this EPCA requirement and to more fully understand the national impact of potential efficiency regulations for distribution transformers, the Department conducted a national impact analysis. This analysis assessed future national energy savings (NES) from trial transformer standards as well as the national economic impact using the net present value (NPV) metric.

The NES is the cumulative incremental energy savings from a transformer efficiency standard, relative to a base case scenario of no national standard, over a forecast period. The Department calculated NES for each trial standard level in units of quadrillion British thermal units (quads) for standards that it assumed will be implemented in the year 2010.

The NPV is the net present value of the incremental economic impact on consumers from a trial standard level. The Department calculated the NPV using a method similar to the NES, except that it estimated incremental costs and benefits instead of energy, and discounted the net benefits rather than calculating them as an un-discounted sum. The Department discounted purchases, expenses, and operating costs for transformers using a national average discount factor. It calculated the NPV impact from transformers that are purchased between 2010 through 2038 to calculate the total NPV impact from purchases during the forecast period.

The Department developed a Microsoft Excel spreadsheet, the National Impact Spreadsheet, to implement the calculations described above. The spreadsheet calculates capacity and operating cost savings associated with each of the trial standard levels. The NES analysis considers cumulative energy savings through the year 2038, while the NPV considers capacity and operating cost savings through the year 2073[a] for transformers purchased in the period 2010 to 2038. By taking the annual difference between the base case scenario and trial standard levels and summing the discounted annual results, the spreadsheet calculates an NPV for each trial standard level relative to the base case.

10.1.1 National Impact Analysis Spreadsheet Flowchart

Figure 10.1.1 presents a graphical flow diagram of the distribution transformer national impact analysis (NES and NPV) model and spreadsheet. In the diagram, the arrows show the direction of information flow of the calculation. The information begins with inputs (shown as parallelograms). As information flows from these inputs, it may be integrated into intermediate results (shown as rectangles) or through integrating sums or differences (shown as circles) into major outputs (shown as boxes with curved bottom edges). Note that the shipments model portion of the flow diagram (shaded) is discussed in Chapter 9.

[a] The Department maintains the same time period for NPV as it did in the ANOPR.

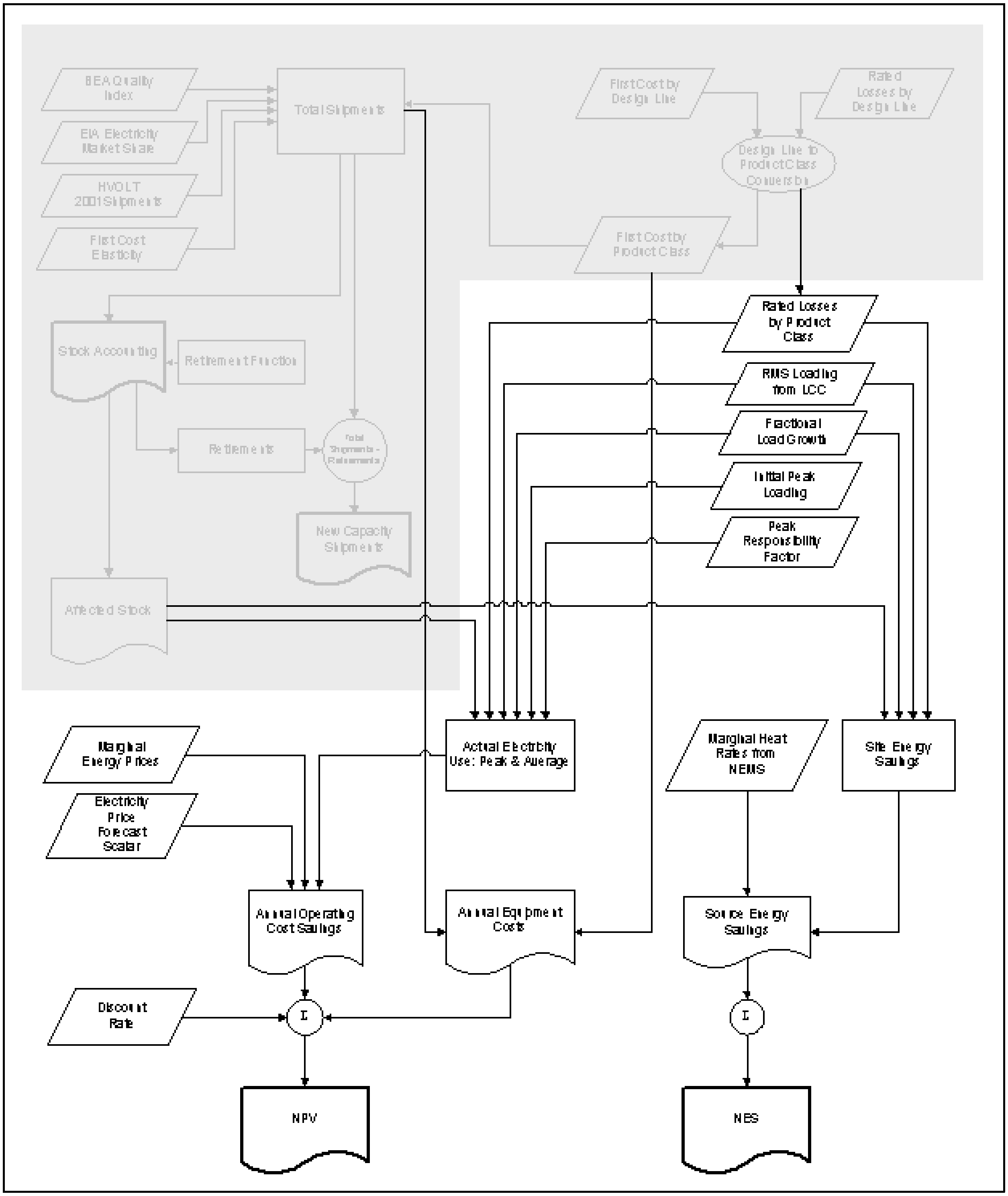

Figure 10.1.1 National Impact Analysis Flowchart

The calculation starts with the shipments model (described in Chapter 9), which integrates the inputs of 2001 shipments estimates from the Department's contractor,[1] the U.S. Bureau of Economic Analysis (BEA) transformer quantity index,[2] electricity market shares from DOE's Energy Information Administration (EIA),[3, 4] and equipment price estimates from the life-cycle cost (LCC) analysis, to produce a backcast and a forecast of total shipments. The Department used the total shipments and a retirement function to produce an accounting of in-service transformers (stocks), enabling DOE to estimate the stock that is affected by trial standards and transformer retirements. Total transformer capacity shipments minus transformer capacity retirements in new capacity shipments, which are those transformers made to supply new electrical capacity, i.e. growth in transformer capacity.

After the shipments calculation, the NES and NPV calculations begin. Key inputs from the LCC analysis are the average rated losses for both no-load and load losses, and the cost of transformers, including installation. The Department adjusts the losses and the equipment costs for transformer size and product class, to convert the data from representative design lines to average product class information. Additional inputs on average and peak losses—including root mean square (RMS) loading, peak loading, and peak responsibility factor—allow DOE to convert rated losses into actual losses. At this point, the information flow for the NES and NPV calculation splits into two paths.

On one path, the NES calculation sums the watt-hours of energy consumed by the affected stock, and takes the difference between the base case and standards scenario to calculate site energy savings. Marginal heat rates from the National Energy Modeling System (NEMS)[5] then convert the site energy savings to energy savings at the source (i.e., at the power plant). The marginal heat rates from NEMS include the transmission and distribution losses. (The Department performed a sensitivity analysis to analyze an improvement in the heat rate as a result of the efficiency improvement in the standards scenario; the impact was not significant.) The sum of annual energy savings for the forecast period through 2038 then provides the final NES result.

On the other path, the NPV calculation brings in marginal price inputs from the LCC analysis for both energy costs and capacity costs and for both load losses and no-load losses. The marginal prices, when combined with the actual peak and average losses, provide the estimate of the operating cost. Meanwhile, the adjusted equipment installed cost times the annual shipments provides the estimate of the total annual equipment costs. The Department calculated three differences to calculate the net impact of the trial standard. The first difference was between the trial standards scenario equipment costs and the base case equipment costs, to obtain the net equipment cost increase from a trial standard. The second difference was between the base case scenario operating cost and the trial standards scenario operating cost, to obtain the net operating cost savings from a trial standard. The third difference was between the net operating cost savings and the net equipment cost increase, to get the net expense/savings for each year. The Department then discounted the net expenses/savings to 2004 and summed them over the years 2010–2073 for transformers purchased during or before 2038, to provide the NPV impact of a trial standard.

The Department provided a detailed technical description of the shipments model in Chapter 9 of this TSD; similar descriptions of the other two models are provided below—the NES model in section 10.2, and the NPV model in section 10.3. Each technical description begins with a summary of the model. It then provides a descriptive overview of how the Department performs each model's calculations, and follows with a summary of the inputs. The final subsections of each technical description describe each of the major input and computation steps in detail and with equations, when appropriate. After the technical model descriptions, the Department presents the results of the national impact analysis calculations.

10.2 NATIONAL ENERGY SAVINGS

The Department developed the NES model to estimate the total national energy savings using the results from the shipments model, combined with information from the LCC on energy savings. The savings shown in the NES reflect decreased energy losses resulting from the installation of new, more efficient transformer units nationwide, in comparison to a base case with no national standards. Positive values of NES correspond to net energy savings, i.e., a decrease in energy consumption with standards in comparison to the energy consumption in the base case scenario.

10.2.1 National Energy Savings Overview

The Department calculated the cumulative incremental energy savings from a trial transformer efficiency standard, relative to a base case scenario of no standard, over the forecast period. It calculated NES for each trial standard level, in units of quads, for standards that it assumed will be implemented in the year 2010. The NES calculation started with estimates of transformer shipments and stocks (in-service transformers), which are outputs of the shipments model (Chapter 9). The Department then obtained estimates of transformer losses from the LCC analysis (Chapter 8), and calculated the total energy use by the stock of transformers for each year, for both a base case and a standards case. Over time, in the standards case, more-efficient transformers gradually replace less-efficient ones. Thus, the energy per unit capacity used by the stock of transformers gradually decreases in the standards case relative to the base case. The Department converted energy used by the transformers into the amount of energy consumed at the source of electricity generation (the source energy) with a site-to-source conversion factor. The site-to-source factor accounts for transmission, distribution, and generation losses. For each year analyzed, the difference in source energy use between the base case and the standards scenario is the annual energy savings. The Department summed the annual energy savings from 2010 through 2038 to calculate the total NES for the forecast period.

In calculating the NES, the Department did not assume any trends in transformer name-plate efficiency besides the incremental efficiency improvement indicated by the LCC calculation. The Department examined proprietary shipments data provided by the industry and found that the data lacked conclusive trends in efficiency improvement. Therefore, the Department felt that future efficiency trends were generally indeterminate and chose to use a fixed baseline efficiency. The Department also assumed that the efficiency of transformers does not degrade over time. This means the annual energy savings can be described in terms of an affected stock (see Equation 10.1), as described in section 9.3.10 in the shipments chapter:

$$AES(y) = (UEC_{Base} - UEC_{Std}) \times Aff\_Stock(y) \quad \textbf{Eq. 10.1}$$

where:

$AES(y)$	=	the annual energy savings in year y,
UEC_{Base}	=	the site unit energy consumption for the base case,
UEC_{Std}	=	the site unit energy consumption for the standards case, and
$Aff\_Stock(y)$	=	stock of transformers of all vintages that are operational in year y.

Then, given the annual energy savings, the NES can be calculated as a simple sum:

$$NES = \sum_{y=Std\_year}^{2038} SiteToSource(y) \times AEC(y) \quad \textbf{Eq. 10.2}$$

where:

Std_year	=	the year standards come into effect,
$SiteToSource(y)$	=	the site-to-source conversion factor in year y, and
AEC	=	the annual energy consumption.

Once the shipments model provides the estimate for the affected stock, the key to the NES calculation is in calculating UEC_{Base} and UEC_{Std}, using the input from the LCC analysis and including the site-to-source conversion factor. In the next section, the inputs necessary for the NES calculation are summarized and then presented individually.

10.2.2 National Energy Savings Inputs

The NES model inputs fall into three broad categories: (1) those that help convert the data from the LCC into data for the product classes and transformer size distributions used in the NES; (2) those that help calculate the unit energy consumption; and (3) the site-to-source conversion factor, which enables the calculation of source energy consumption from site energy use. The specific list of NES model inputs is as follows:

1. Size Scaling of Losses and Costs

2. Mapping of LCC Design Line Data to Product Classes

3. Mapping of Candidate Standard Levels to Trial Standard Levels

4. Root Mean Square Loading

5. Load Growth

6. Affected Stock

7. Effective Date of Standard

8. Unit Energy Consumption

9. Electricity Site-to-Source Conversion

10.2.2.1 Size Scaling of Losses and Costs

The Department used a scaling relationship, or equation, to project the economic results from one transformer design line to similar transformers of different sizes. This relationship is a key element in adjusting losses and costs from a representative transformer in the LCC to a distribution of transformer sizes represented in the NES calculation. To be consistent across trial standard levels, the Department used the same scaling for the National Electrical Manufacturers Association (NEMA)'s TP1 standard level as it did for the other levels. NEMA's scaling was apparently based on a different set of representative units than was used by the Department. As a result, for transformers other than the representative units, which were keyed to NEMA TP1 efficiencies, there is a slight difference in efficiency level between NEMA's TP 1 and the Department's TP 1, as used to calculate national impacts.

As described in the engineering analysis, the Department applied the 0.75 power scaling rule (the "0.75 scaling rule") for projecting losses and costs from one design line to transformers of other sizes. In the NES analysis, shipments are calculated in terms of installed capacity. The losses associated with a stock of transformers, and the costs associated with a capacity shipped, are estimated by multiplying the relevant capacity times the average losses, or costs per unit capacity. Before applying the 0.75 scaling rule, the Department calculated the losses and costs per unit of installed capacity within a given engineering design line. Then it calculated an adjustment factor using the 0.75 scaling rule to account for the fact that the representative design line unit used in the engineering analysis is not exactly the "average" transformer size for the set of transformers that the design line represents. This adjustment factor is given by the following equation:

$$AdjFactor = \sum_i \left[Ship_i \times Cap_i^{\,0.75} \right] / \left(Cap_{DL}^{\,0.75} \times \sum_i Ship_i \right) \qquad \textbf{Eq. 10.3}$$

where:

$AdjFactor$ = adjustment factor that gives the shipments-weighted losses or costs per transformer when multiplied by the design line losses or costs,
$Ship_i$ = shipments in the *i*-th size category,
Cap_i = the rated capacity for the transformers in the *i*-th size category, and
Cap_{DL} = the rated capacity of representative unit of the design line.

The Department also used the shipment-weighted average size of transformers represented by a particular design line to calculate the average loss per capacity ($AvgLossPerCap_{DL}$), as described in the following equation:

$$AvgLossPerCap_{DL} = LossPerCap_{DL} \times AdjFactor \times Cap_{DL} \,/\, Cap_{avg} \qquad \textbf{Eq. 10.4}$$

where:

$LossPerCap_{DL}$ = the loss, or cost per unit capacity, for the design line unit from the LCC analysis, and
Cap_{avg} = the shipment-weighted average size of transformers represented by a particular design line.

Once the losses and costs from the LCC represent the correct size distribution, they need a further adjustment so that they represent the appropriate product classes, as described in the next section.

10.2.2.2 Mapping Life-Cycle Cost Design Line Data to Product Classes

The NES and NPV calculations use the LCC calculations as the source of most input data. The Department performed the LCC calculations by design line, whereas any eventual standard would be promulgated by product class. As a first step, therefore, the NES calculation aggregates the LCC design line data into product classes. This design-line-to-product-class aggregation was the process by which the Department took the results from an economic analysis of engineering design lines and combined them to provide estimates of economic impact by product class.

To represent the variety of designs in some product classes, the Department analyzed up to three different design lines per product class. Specifically, product class 1 (single-phase, medium-voltage, liquid-immersed transformers) is represented by three design lines and product class 2 (three-phase, medium-voltage, liquid-immersed transformers) is represented by two design lines. The Department did not specifically examine single-phase, dry-type design lines. For single-phase product classes 5 and 9, the Department used the appropriate three-phase design lines divided by three. Table 10.2.1 presents the mapping of design line (DL) to product class (PC).

Table 10.2.1 Mapping of Design Line to Product Class

Product Class	**BIL*** ***kV****	**Capacity** ***kVA******	**Mapping**
PC 1, Liquid-Immersed, MV,† Single-Phase	Any	10-833	DL 1 + DL 2 + DL 3
PC 2, Liquid-Immersed, MV, Three-Phase	Any	15-2500	DL 4 + DL 5
PC 5, Dry-Type, MV, Single-Phase	20-45	15-833	(DL 9 ÷ 3) + (DL 10 ÷ 3)
PC 6, Dry-Type, MV, Three-Phase	20-45	15-2500	DL 9 + DL 10
PC 7, Dry-Type, MV, Single-Phase	46-95	15-833	(DL 11 ÷ 3) + (DL 12 ÷ 3)
PC 8, Dry-Type, MV, Three-Phase	46-95	15-2500	DL 11 + DL 12
PC 9, Dry-Type, MV, Single-Phase	≥ 96	75-833	DL 13 ÷ 3
PC 10, Dry-Type, MV, Three-Phase	≥ 96	225-2500	DL 13

* BIL = Basic impulse insulation level
** kV = kilovolt
*** kVA = kilovolt-ampere
† MV = medium-voltage

To aggregate losses from more than one design line, the Department took a shipments-capacity-weighted average of the per-kVA transformer characteristics from the economic analysis of the design lines and applied the average per-capacity values to the estimated capacity shipped for each product class. The Department's contractor[1] provided the capacity shipped for each design line (and each product class), the LCC analysis provided the economic results for each design line, and DOE used the 0.75 rule to estimate the re-scaled cost and loss estimates for each size category represented by each design line. Equation 10.5 provides the average loss per unit capacity of product class ($AvgLossPerCap_{PC}$), as derived from the average loss per unit capacity for a design line:

$$AvgLossPerCap_{PC} = \sum_{DL}\left[AvgLossPerCap_{DL} \times MS_{DL}\right] / \sum_{DL} MS_{DL} \qquad \textbf{Eq. 10.5}$$

where:

$AvgLossPerCap_{DL}$ = the average loss per unit capacity for the design line, and
MS_{DL} = the capacity market share of the design line.

Equation 10.5 sums those design lines that constitute a product class.

The $AvgLossPerCap_{PC}$ represents the average loss per unit capacity of the transformer load. For no-load losses, no more adjustment is needed; for load losses, however, the losses at rated load need to be converted to losses at actual loading. The RMS loading is a key factor in estimating load losses at actual loading. The next section describes the RMS loading input.

10.2.2.3 Mapping Candidate Standard Level to Trial Standard Level

The Department conducted the LCC analysis for six alternate efficiency levels, i.e., candidate standard levels (CSLs), for each representative unit in the 13 design lines. The Department selected the CSL efficiency levels for each design line by applying a set of common economic criteria to intermediate LCC analyses as discussed in Chapter 8, resulting in unique sets of CSL efficiencies for each design line. It mapped these LCC analysis results to trial standard levels (TSLs) for the 10 product classes. All CSLs directly map to their corresponding TSLs, with the exception of design lines 1 and 4. Constraints on material selection combinations within product classes resulted in illogical combinations of materials for DL 4. Additionally, because the representative units in design lines 1 and 2 are quite close in size, overlaps occurred in the scaled analysis which cause inconsistent results. The Department resolved both issues with relatively minor remapping of CSL to TSL for design line 1 and design line 4, as shown in Table 10.2.2.

Table 10.2.2 Mapping of Candidate Standard Levels to Trial Standard Levels

	DL1	DL2	DL3	DL4	DL5	DL9	DL10	DL11	DL12	DL13
TSL1	CSL1	CSL1	CSL1	CSL1	CSL1	CSL1	CSL1	CSL1	CSL1	CSL1
TSL2	CSL1	CSL2	CSL2	CSL2	CSL2	CSL2	CSL2	CSL2	CSL2	CSL2
TSL3	CSL1	CSL3	CSL3	CSL3	CSL3	CSL3	CSL3	CSL3	CSL3	CSL3
TSL4	CSL2	CSL4	CSL4	CSL3	CSL4	CSL4	CSL4	CSL4	CSL4	CSL4
TSL5	CSL3	CSL5	CSL5	CSL5	CSL5	CSL5	CSL5	CSL5	CSL5	CSL5
TSL6	CSL6	CSL6	CSL6	CSL6	CSL6	CSL6	CSL6	CSL6	CSL6	CSL6

10.2.2.4 Root Mean Square Loading

Energy losses in transformers follow the RMS load, not the arithmetic average load. The Department calculated the RMS loading as the root mean square of the transformer load, divided by the transformer rated capacity, times the power factor. (As explained in Chapter 6, while the Department's method for analysis can derive results for varying power factors, for the analysis presented here the Department set the power factor to the value of one.) The Department used the average national RMS loading for each design line as calculated in the LCC analysis. These values range between 30.5 percent and 59.1 percent for the different design lines.

10.2.2.5 Load Growth

The fractional load growth is the fraction by which the load has increased since a transformer was installed. Load growth occurs when new equipment, new appliances, or additional activities increase the energy loads on the circuits served by distribution transformers.

Load growth has the impact of increasing the load losses relative to the losses that the Department estimated to have occurred during the first year of installation.

The Department calculated the fractional load growth from an estimated load growth rate that it used as an input to the LCC analysis. There is a maximum load growth, *LGRMax,* which is set by the Department at 50 percent for liquid-immersed transformers. The 50 percent value represents the approximate amount of growth in load that can occur without overloading the transformer beyond a reasonable point. When overloading does occur, the transformer is assumed to be relocated and installed in a new location with the same initial peak loading as when originally installed.[6] See Institute of Electrical and Electronics Engineers, Inc. (IEEE) Std C57.91-1995[7] for details on permissible overloading of mineral-oil immersed transformers. Since IEEE does not report data on permissible overloading of dry-type units, the Department used the same values for both liquid-immersed and dry-type transformers. The age of the transformer at which the load switches to initial peak load is given by Equation 10.6:

$$age_{Max} = \frac{ln(1+LGRMax)}{ln(1+LGR)} \qquad \textbf{Eq. 10.6}$$

where:

age_{Max}	=	the maximum age of transformer after which time the load switches to initial peak load (years), and
LGR	=	the annual load growth rate (%).

Thus, the equation for the load growth as a function of the age of the transformer is as follows:

$$LGrwth(age) = (1 - LGR)^{(age)} - 1 \qquad \textbf{Eq. 10.7}$$

for $age < age_{Max}$, and

$$LGrwth(age) = (1 - LGR)^{(age - age_{Max})} - 1 \qquad \textbf{Eq. 10.8}$$

for $age >= age_{Max}$

where:

LGrwth (age)	=	the fractional load growth, and
age	=	the age of the transformer (years).

The Department then used the load growth to adjust the RMS loading estimate for the affected stock. The mathematical equation for this adjustment is as follows:

$$LAdjust(y) = \sqrt{\sum_{age=1}^{y-Std\_year}\left[Stock(y,age) \times (1 + LGrwth(age))^2\right] / Aff\_Stock(y)} \quad \textbf{Eq. 10.9}$$

where *LAdjust(y)* is the load adjustment factor in year *y*. All other variables have been defined in previous equations.

The Department used a load adjustment factor to calculate an adjusted RMS loading that incorporates load growth into the unit energy consumption, as described in section 10.2.2.7.

10.2.2.6 Affected Stock

The affected stock is an output of the shipments model (Chapter 9) and a key input for the NES and NPV calculations. The affected stock represents that portion of the transformer stock that is potentially impacted by a trial standard. It therefore consists of those transformers in the stock that are purchased in or after the year the trial standard has taken effect, as described by the following equation:

$$Aff\_Stock(y) = Ship(y) + \sum_{age=1}^{y-Std\_year} Stock(age) \quad \textbf{Eq. 10.10}$$

where:

Aff_Stock(y)	=	stock of affected transformers of all vintages that are operational in year *y*,
Ship(y)	=	shipment of new transformers in year *y*,
Std_year	=	year the standard becomes effective, and
Stock(age)	=	age in years of the stock of transformers.

10.2.2.7 Unit Energy Consumption

One of the final quantities the Department calculated for the NES estimate was the unit energy consumption for affected stock. The unit energy consumption times the capacity shipped and the site-to-source conversion factor equals the annual energy consumption from which DOE derived total national energy savings.

Annual unit energy consumption (*UEC(y)*) for affected stock is the annual energy consumption per unit capacity for transformers shipped after the effective date of a standard. The Department calculated the losses per transformer as the sum of no-load losses plus the load losses. It calculated the load losses as the rated load loss times the square of RMS loading, adjusted for load growth. Average energy consumed per unit capacity for affected stock varies from year to year due to load growth effects.

The annual unit energy consumption for distribution transformers for affected stock is given by Equation 10.11:

$$UEC(y) = E_{NL} + E_{LL} \times [RMS \times LAdjust(y)]^2 \qquad \textbf{Eq. 10.11}$$

where:

E_{NL}	=	rated no-load losses per kVA capacity,
E_{LL}	=	rated load losses per kVA capacity,
RMS	=	root mean square, and
Ladjust(y)	=	loading adjustment factor for year *y*.

Once the unit energy consumption for affected stock was defined, only one more input was necessary to complete the NES calculation: the site-to-source conversion factor.

10.2.2.8 Electricity Site-to-Source Conversion

The site-to-source conversion factor for electricity is the factor by which site energy (in kWh) is multiplied to obtain primary (source) energy (in Btu). Since the NES estimates the change in energy use of the resource (e.g., the power plant), this conversion factor is necessary to account for losses in generation, transmission, and distribution. After calculating energy consumption at the site of its use (i.e., the installed transformer), the Department multiplied it by the conversion factor to obtain primary energy consumption, expressed in quads (quadrillion Btus). This conversion permitted comparison across (source) fuels by taking into account the heat content of different fuels and the efficiency of different energy conversion processes. The annual values are the U.S. average conversion factors for electricity generation for both peak and base load reduction. The Department used marginal heat rates corresponding to base load for no-load losses (or core losses) and marginal heat rates corresponding to peak load for load losses (or coil losses). It used these different rates because load losses are higher during transformer peak loads while no-load losses occur at all times. The Department obtained these conversion factors using a variant of the NEMS, called NEMS-BT.[a] Table 10.2.3 presents the average annual conversion factors the Department used.

[a] For more information on NEMS, refer to the Department's EIA documentation. A useful summary is *National Energy Modeling System: An Overview 2003*.[5] DOE/EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because the analysis entails some minor code modifications and the model is run under policy scenarios that are variations on DOE/EIA assumptions, the name NEMS-BT refers to the model as used here (BT is DOE's Building Technologies Program, under whose aegis this work was performed).

Table 10.2.3 Average Site-to-Source Conversion Factors for No-Load Losses and Load Losses

Year	For No-Load Losses	For Load Losses
2010	2.699	2.931
2011	2.699	2.931
2012	2.699	2.931
2013	2.568	2.809
2014	2.390	2.578
2015	2.390	2.458
2016	2.390	2.345
2017	2.390	2.283
2018	2.390	2.222
2019–38	2.390	2.180

The Department used a time-series projection of conversion factors, changing from year to year, which it calculated as follows:

1. Start with an integrated projection of electricity supply and demand (e.g., the *Annual Energy Outlook* (*AEO2005)* reference case)[4] and extract the source energy consumption.

2. Estimate projected energy savings due to possible standards for each year (e.g., using the NES spreadsheet model).

3. Feed these energy savings back to the NEMS-BT model as a new scenario, specifically a deviation from the reference case, to obtain the corresponding source energy consumption.

4. Obtain the difference in source energy consumption between this trial standard level scenario and the reference case.

5. Divide the source energy savings, in Btu, adjusted for load-specific transmission and distribution losses, by the site energy savings, in kWh, to provide the time series of conversion factors in Btu per kWh.

The conversion factors change over time and account for the displacement of generating sources. The NES spreadsheet model includes the conversion factors for each year of the projection. The Department and stakeholders can examine the effects of alternative assumptions by revising this column of numbers.

The conversion of site energy savings to source energy savings and the summation of energy savings over the forecast period complete the NES calculations—the results section of this chapter (section 10.4) presents the output from the NES model. The next section (section 10.3) describes the technical details of the NPV calculation.

10.3 NET PRESENT VALUE

The Department estimated the national financial impact on consumers from the imposition of new energy-efficiency standards using a national NPV accounting component in the national impact spreadsheet. The Department combined output of the shipments model with energy savings and financial data from the LCC to calculate an annual stream of costs and benefits resulting from trial distribution transformer energy-efficiency standards. It discounted this time series to the year 2004 and summed the result, yielding the national NPV.

10.3.1 Net Present Value Overview

The NPV is the present value of the incremental economic impact of a trial standard level. Like the NES, the NPV calculation started with transformer shipments and transformer stocks, estimates of which are outputs from the shipments model. The Department then obtained estimates of transformer first costs, losses, and average marginal electricity costs from the LCC analysis. It calculated the amount spent on transformer purchases and installation, and then calculated the corresponding operating costs by applying the marginal prices to the energy (both energy and electricity system capacity) used by the stock of transformers for each year, for both a base case and a standards case. Over time in the standards case, more-expensive, but more-efficient transformers gradually replace less-efficient transformers. Thus, the operating cost per unit capacity used by the stock of transformers gradually decreases in the standards case relative to the base case, while the equipment costs increase.

The Department discounted purchases, expenses, and operating costs for transformers using a simple national average discount factor. The discount factor converts a future expense or benefit to a present value. The difference in present value of all expenses and benefits between the base case and standards scenario is the national NPV impact. The Department calculated the NPV impact from transformers that were purchased between the effective date of the standard and 2038, inclusive, to calculate the total NPV impact from purchases during the forecast period.

Mathematically, NPV is the value in the present time of a time series of costs and savings, described by the equation:

$$NPV = PVS - PVC \qquad \textbf{Eq. 10.12}$$

where:

PVS = the present value of electricity savings, and

PVC = the present value of equipment costs including installation.

PVS and *PVC* are determined according to the following expressions:

$$PVS = \sum_{y=Std\_year}^{2073} \left[\frac{OC_{Base}}{Cap}(y) - \frac{OC_{Std}}{Cap}(y) \right] \times Aff\_Stock(y) \times Discount\ Factor(y) \quad \textbf{Eq. 10.13}$$

where:

OC_{Base}/Cap(y) = operating cost per unit capacity of transformer for the base case in year *y*,
Aff_Stock(y) = stock of transformers of all vintages that are operational in year *y*,
y = the year (from effective date of the trial standard to the year when units purchased in 2038 retire), and
Discount Factor(y) = discount factor for the year *y,* defined in Eq. 10.14.

$$Discount\ Factor(y) = \frac{1}{(1 + Discount\ Rate)^{(y - reference\ year)}} \quad \textbf{Eq. 10.14}$$

where:

reference year = year 2004, and
discount rate = the rate of discount as described in section 10.3.2.7.

$$PVC = \sum_{y=Std\_year}^{2073} \left[\frac{FC_{Std}}{Cap}(y) - \frac{FC_{Base}}{Cap}(y) \right] \times Ship(y) \times Discount\ Factor(y) \quad \textbf{Eq. 10.15}$$

where:

FC_{Std}/Cap (y) = first cost of the transformer per unit of capacity for a trial standard level S*td* in year *y.* First cost is defined in Eq. 10.16 and described in section 10.3.2.1.
Std_year = the year standards come into effect, and
Ship (y) = shipments of transformers in year *y* for the standards case.

The Department calculated NPV using its projections of national expenditures for distribution transformers, including purchase price (equipment and installation price) and operating costs (electricity and maintenance costs). It calculated costs and savings as the difference between a trial standards case and a base case scenario without national standards. It discounted future costs and savings to the present.

The Department calculated a discount factor from the discount rate and the number of years between the year to which the sum is being discounted (2004) and the year in which the costs and savings occur. The NPV is the sum over time (2010–2073) of the discounted net financial savings.

The following sections describe the inputs specific to the NPV calculation.

10.3.2 Net Present Value Inputs

The NPV model inputs include cost inputs, inputs important for detailing electricity capacity costs, and several of the inputs used by the NES calculation. This section provides details on those inputs that have not yet been described as part of the NES and shipments models. The specific list of inputs for the NPV is as follows:

1. First Cost
2. Operating Cost
3. Peak Responsibility Factor
4. Initial Peak Load
5. Electricity Price Forecast Scalar
6. Marginal Electricity Costs
7. Discount Rate

10.3.2.1 First Cost

The first cost includes all of the initial costs that are incurred with the installation of a transformer. The Department expresses first cost in terms of cost per unit capacity. Specifically, it defines the first cost of acquiring a transformer with the following equation:

$$FC/Cap = (P + Install)/Cap \qquad \textbf{Eq. 10.16}$$

where:

FC = the first cost,
Cap = the rated capacity of the transformer,
P = the price of the transformer including shipping and taxes, and
$Install$ = the installation cost of the transformer.

In the NPV calculation, these values are obtained from the LCC calculation as the averages for specific design lines. The Department applied an adjustment factor to convert the first cost of a representative design to an estimated average first cost for a distribution of sizes within a particular product class. The adjustment incorporates the 0.75 scaling rule and the design-line-to-product-class mapping. This adjustment factor is explained in detail in sections 10.2.2.1 and 10.2.2.2. The costs are expressed in units of 2004$ per kVA of rated transformer capacity.

Table 10.3.1 shows the resulting mean first costs per kVA for distribution transformers by TSL and product class.

Table 10.3.1 First Cost of Distribution Transformers by Trial Standard Level and Product Class (2004$/kVA)

Product Class	Base	TSL 1* (TP 1)	TSL 2	TSL 3	TSL 4	TSL 5	TSL 6
PC 1, Liquid-Immersed, MV, Single-Phase	61.85	62.46	62.67	62.85	63.79	69.43	106.66
PC 2, Liquid-Immersed, MV, Three-Phase	20.48	21.04	22.12	24.37	24.99	35.82	37.87
PC 5, Dry-Type, MV, Single-Phase	27.58	28.24	28.82	30.15	33.70	44.65	44.64
PC 6, Dry-Type, MV, Three-Phase	22.36	23.18	23.72	24.79	26.79	35.37	35.36
PC 7, Dry-Type, MV, Single-Phase	32.61	33.36	33.97	35.31	38.12	47.16	47.17
PC 8, Dry-Type, MV, Three-Phase	23.43	23.80	24.05	24.65	26.41	36.30	36.31
PC 9, Dry-Type, MV, Single-Phase	28.90	29.10	29.50	30.37	34.92	47.60	47.61
PC 10, Dry-Type, MV, Three-Phase	22.46	22.62	22.92	23.60	27.14	36.99	36.99

*TSL = Trial Standard Level

10.3.2.2 Operating Cost

Transformer operating cost is the annual cost of transformer losses. Operating costs are a complex, yet essential, part of calculating the national economic impact of a trial distribution transformer standard. The Department used 11 distinct inputs to calculate operating costs. This large number of inputs was necessary because transformers have both no-load and load losses, and because electricity has both energy and capacity costs. The combination of distinct losses and distinct capacity and energy costs creates the necessity for four price and two loss coefficients. Potential load growth requires a load growth adjustment factor. Peak loading, peak load coincidence, and average loading require three additional factors to characterize load losses. Finally, the Department used an electricity price forecast scalar to characterize future trends in electricity prices consistent with the *AEO2005* forecast.

The Department assumed zero maintenance cost in calculating the transformer operating costs. It calculated annual operating costs using the following formula to capture the diversity of potential factors that can affect these costs:

$$OC/Cap = EPFS(y) \times (E_{NL} \times (NLLMCC + 8760 \times NLLMEC) + E_{LL} \times (LAdjust(y))^2 \times (PRF \times PL^2 \times LLMCC + 8760 \times RMS^2 \times LLMEC))/Cap \quad \textbf{Eq. 10.17}$$

where:

OC	=	the operating cost,
Cap	=	the rated capacity of the transformer,
$EPFS(y)$	=	the electricity price forecast scalar for year y,
E_{NL}	=	the no-load losses at rated load,
$NLLMCC$	=	the no-load loss marginal cost of capacity,

NLLMEC	=	the no-load loss marginal energy cost,
E_{LL}	=	the load losses at rated load,
LAdjust(y)	=	the load growth adjustment factor in year *y*,
PRF	=	the peak responsibility factor,
PL	=	the initial peak load,
LLMCC	=	the load loss marginal cost of capacity,
RMS	=	the root mean square loading of the transformer, and
LLMEC	=	the load loss marginal energy cost.

The Department expressed the operating costs in units of 2004$ per kVA of rated capacity. As in the NES calculation (see sections 10.2.2.1 and 10.2.2.2), the Department also applied an adjustment factor to incorporate the 0.75 scaling rule to E_{NL} and E_{LL}, to convert from design line data to product class estimates.

The following four sections explain the inputs of the operating cost equation that are not explained in the NES section.

10.3.2.3 Peak Responsibility Factor

The transformer peak responsibility factor (PRF) is the fraction of the transformer peak that is coincident with the system peak, calculated by taking the square of the ratio of the transformer load at the time of the customer peak load to the transformer peak load. In combination with the initial peak loading, the PRF is necessary for estimating the capacity cost impacts of transformer load losses. The Department used the average PRF from the hourly and monthly load analysis for the liquid-immersed and dry-type transformers, respectively, as reported in the LCC analysis. Table 10.3.2 presents the PRFs used in the analysis for the 10 product classes.

Table 10.3.2 Peak Responsibility Factors by Product Class

	PC 1	PC 2	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10
PRF	0.35	0.61	0.52	0.53	0.53	0.54	0.54	0.54

10.3.2.4 Initial Peak Load

The initial peak loading is the annual per-unit peak load on the transformer during the first year of operation. This factor, in combination with the PRF, is necessary for calculating capacity cost impacts from transformer load losses. The initial peak load is estimated as a percentage of the rated peak load of the transformer. The IEEE's *Draft Guide for Distribution Transformer Loss Evaluation*[6] defines a similar but different measure of peak transformer loading called an "Equivalent Annual Peak Load" that accounts for changes in peak load over the life of the transformer. Rather than use the equivalent annual peak load method, the Department characterized a range of possible initial peak loads by defining a distribution of initial peak loads.

Chapter 6, section 6.3.4, provides further description of DOE's method. Table 10.3.3 presents the initial peak loadings used in the analysis for the 10 product classes.

Table 10.3.3 Initial Peak Loading by Product Class

	PC 1	PC 2	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10
Initial Peak Loading	0.87	0.86	0.75	0.75	0.75	0.75	0.75	0.75

10.3.2.5 Electricity Price Forecast Scalar

The electricity price forecast scalar converts current electricity costs into forecasted costs for the period 2004–2073. The electricity price forecast scalar is the ratio of the unit cost of electricity in real dollars in a given year to the real cost of electricity in the year 2004. The Department used *AEO2005*[4] forecasts to obtain the electricity price forecast scalar. For the period beyond 2025, the Department used the BEA real dollar price trend from 2015 to 2025 to extrapolate the electricity price scalar.

10.3.2.6 Marginal Electricity Costs

The characterization of four distinct marginal electricity costs is necessary to calculate the operating costs of transformers and the financial impact of transformer efficiency standards. The four types of marginal costs are: no-load loss marginal capacity cost (*NLLMCC*), load loss marginal capacity cost (*LLMCC*), no-load loss marginal energy cost (*NLLMEC*), and load loss marginal energy cost (*LLMEC*). In an electricity system, there are both energy costs and capacity costs. Depending on the load shape of a particular load, the average value of capacity costs and energy costs are different. Since no-load losses and load losses have distinct load shapes, and since different customers have different load shapes, costs vary both by loss type and by the product class of the transformer. The Department therefore used distinct marginal energy and capacity costs for no-load losses and load losses for each transformer product class. No transformer size scaling is necessary for the marginal costs, although DOE needed to apply the design-line-to-product-class mapping described in section 10.2.2.2 to convert the design line output from the LCC to product class information for the NPV calculation. The Department calculated capacity costs in units of 2004$/kW/year, and energy costs in units of 2004$/kWh. Table 10.3.4 summarizes the four marginal costs for the 10 product classes.

Table 10.3.4 Marginal Energy and Demand Costs by Product Class

Marginal Energy Cost by Product Class *($/kWh)*								
	PC 1	**PC 2**	**PC 5**	**PC 6**	**PC 7**	**PC 8**	**PC 9**	**PC 10**
NLL	0.027	0.026	0.051	0.051	0.051	0.051	0.050	0.050
LL	0.037	0.034	0.054	0.053	0.054	0.053	0.053	0.053
Marginal Demand Cost by Product Class ***($/kW/year)***								
	PC 1	**PC 2**	**PC 5**	**PC 6**	**PC 7**	**PC 8**	**PC 9**	**PC 10**

NLL	103.05	106.42	92.19	93.50	92.06	93.32	93.99	93.99
LL	55.72	56.80	70.62	72.44	70.66	72.47	74.10	74.10

10.3.2.7 Discount Rate

The discount rate expresses the time value of money and is the final input to the NPV calculation. The Department used real discount rates of 3.0 and 7.0 percent, as established by the U.S. Office of Management and Budget (OMB) guidelines on regulatory analysis.[8] The discount rates the Department used in the LCC are distinct from those it used in the NPV calculations, in that the NPV discount rates represent the societal rate of return on capital, whereas LCC discount rates reflect the owner cost of capital and the financial environment of electric utilities and commercial and industrial entities.

10.4 RESULTS

10.4.1 National Energy Savings and Net Present Value from Trial Standard Levels

The NES and NPV results from the NES Spreadsheet Model for TSL 1 through TSL 6 are shown in Table 10.4.1. It should be reiterated that, currently, the NES Spreadsheet Model uses discrete point-values rather than a distribution of values for all inputs. Savings for the dry-type units are significantly different from the estimates in the advance notice of proposed rulemaking (ANOPR) analysis.[9] The difference in savings originates predominantly from the exclusion of dry-type, low-voltage transformers from the notice of proposed rulemaking (NOPR) stage of this analysis, since these types of transformers were regulated by the Energy Policy Act of 2005, enacted on August 8, 2005.

Table 10.4.1 Summary of Cumulative National Energy Savings (2010–2038) and Net Present Value (2010–2073) Impact

Distribution Transformers	Analysis	Discount Rate %	Trial Standard Level					
			TSL 1 (TP 1)	TSL 2	TSL 3	TSL 4	TSL 5	TSL 6
Liquid-Immersed	NES *quads*		1.70	2.28	2.99	3.38	6.51	9.38
	NPV *billion 2004$*	3	7.02	8.78	9.20	9.83	9.94	-10.31
		7	2.02	2.31	2.01	1.92	-1.14	-14.10
Dry-Type	NES *quads*		0.07	0.11	0.16	0.25	0.39	0.39
	NPV *billion 2004$*	3	0.44	0.68	0.95	1.29	1.05	1.05
		7	0.13	0.21	0.28	0.34	0.03	0.03

10.4.1.1 Liquid-Immersed Results

Tables 10.4.2 and 10.4.3 present the NES and NPV results for liquid-immersed transformers by product class. Figure 10.4.1 illustrates the typical pattern of primary energy savings and costs resulting from standards for liquid-immersed transformers over time. The figure shows the nature of net savings for all six TSLs relative to the base case.

Table 10.4.2 Cumulative Primary Energy Savings During 2010–2038: Liquid-Immersed Transformers by Product Class

Product Class	Cumulative Primary Energy Savings *quads*					
	TSL 1 (TP 1)	TSL 2	TSL 3	TSL 4	TSL 5	TSL 6
1. Liquid-Immersed, MV, Single-Phase	0.81	0.86	0.90	1.06	1.77	4.49
2. Liquid-Immersed, MV, Three-Phase	0.90	1.42	2.10	2.32	4.74	4.88
Total	1.70	2.28	2.99	3.38	6.51	9.38

Table 10.4.3 Net Present Value During 2010–2073: Liquid-Immersed Transformers by Product Class

Product Class	Net Present Value *$billion*											
	Discount Rate: 3%						Discount Rate: 7%					
	TSL 1 (TP 1)	TSL 2	TSL 3	TSL 4	TSL 5	TSL 6	TSL 1 (TP 1)	TSL 2	TSL 3	TSL 4	TSL 5	TSL 6
1. Liquid-Immersed, MV, Single-Phase	2.95	3.03	3.13	3.31	2.14	-16.91	0.87	0.86	0.85	0.75	-0.59	-12.76
2. Liquid-Immersed, MV, Three-Phase	4.07	5.76	6.08	6.52	7.80	6.60	1.16	1.46	1.16	1.18	-0.55	-1.34
Total	7.02	8.78	9.20	9.83	9.94	-10.31	2.02	2.31	2.01	1.92	-1.14	-14.10

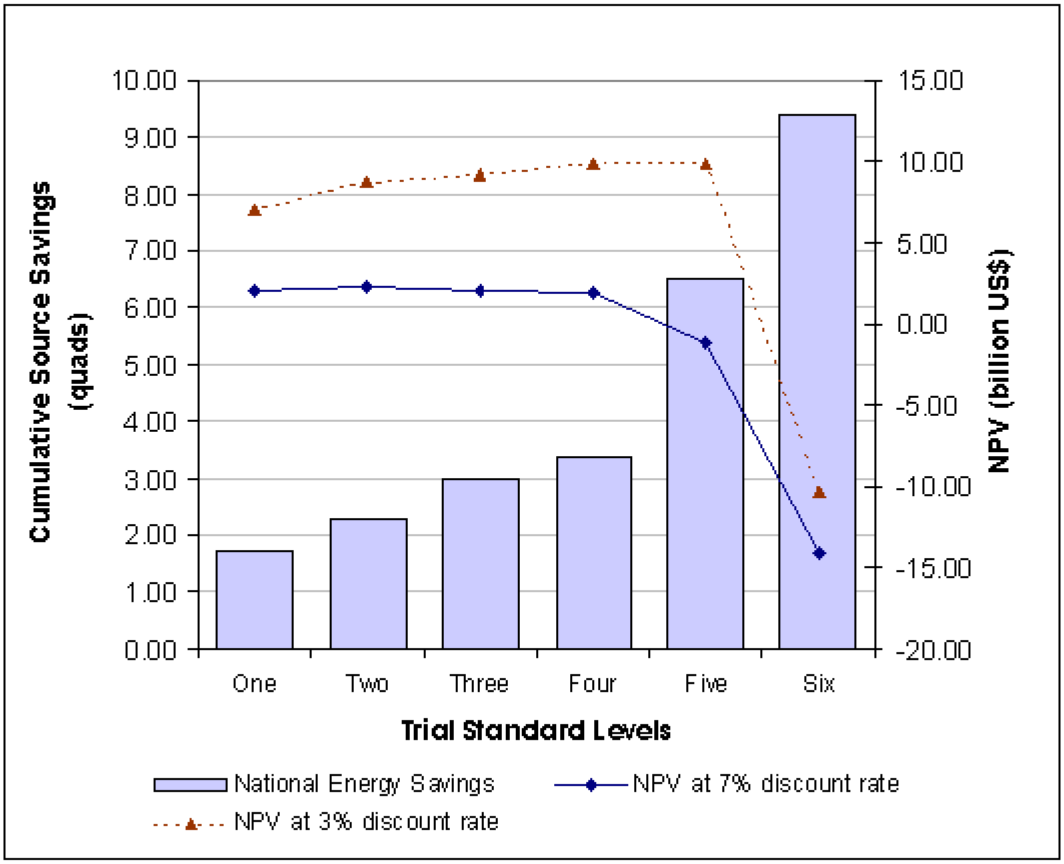

Figure 10.4.1 Liquid-Immersed Distribution Transformers: National Energy Savings and Net Present Value Impacts

10.4.1.2 Dry-Type Results

Tables 10.4.4 and 10.4.5 present NES and NPV results for dry-type transformers by product class. Figure 10.4.2 shows the typical pattern of national savings and costs resulting from standards for dry-type transformers over time. Again, the figure shows the nature of net savings for all six TSLs relative to the base case.

Table 10.4.4 Cumulative Primary Energy Savings During 2010–2038: Dry-Type Transformers by Product Class

Product Class	Cumulative Primary Energy Savings *quads*					
	TSL 1 (TP 1)	TSL 2	TSL 3	TSL 4	TSL 5	TSL 6
5. Dry-Type, MV, Single-Phase, 20-45 kV BIL	0.000	0.000	0.001	0.001	0.001	0.001
6. Dry-Type, MV, Three-Phase, 20-45 kV BIL	0.016	0.024	0.035	0.047	0.065	0.065
7. Dry-Type, MV, Single-Phase, 46-95 kV BIL	0.000	0.001	0.001	0.001	0.002	0.002
8. Dry-Type, MV, Three-Phase, 46-95 kV BIL	0.053	0.082	0.117	0.179	0.298	0.298
9. Dry-Type, MV, Single-Phase, ≥96 kV BIL	0.000	0.000	0.000	0.000	0.000	0.000
10. Dry-Type, MV, Three-Phase, ≥96 kV BIL	0.001	0.005	0.009	0.018	0.026	0.026
Total	0.07	0.11	0.16	0.25	0.39	0.39

Table 10.4.5 Net Present Value During 2010–2073: Dry-Type Transformers by Product Class

Product Class	Net Present Value *$billion*											
	Discount Rate: 3%						Discount Rate: 7%					
	TSL 1 (TP 1)	TSL 2	TSL 3	TSL 4	TSL 5	TSL 6	TSL 1 (TP 1)	TSL 2	TSL 3	TSL 4	TSL 5	TSL 6
5. Dry-Type, MV, Single-Phase, 20-45 kV BIL	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6. Dry-Type, MV, Three-Phase, 20-45 kV BIL	0.10	0.14	0.19	0.24	0.20	0.20	0.03	0.04	0.06	0.06	0.02	0.02
7. Dry-Type, MV, Single-Phase, 46-95 kV BIL	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
8. Dry-Type, MV, Three-Phase, 46-95 kV BIL	0.33	0.51	0.69	0.96	0.80	0.80	0.10	0.16	0.20	0.26	0.03	0.03
9. Dry-Type, MV, Single-Phase, ≥96 kV BIL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10. Dry-Type, MV, Three-Phase, ≥96 kV BIL	0.01	0.03	0.05	0.08	0.04	0.04	0.00	0.01	0.02	0.02	-0.01	-0.01
Total	0.44	0.68	0.95	1.29	1.05	1.05	0.13	0.21	0.28	0.34	0.03	0.03

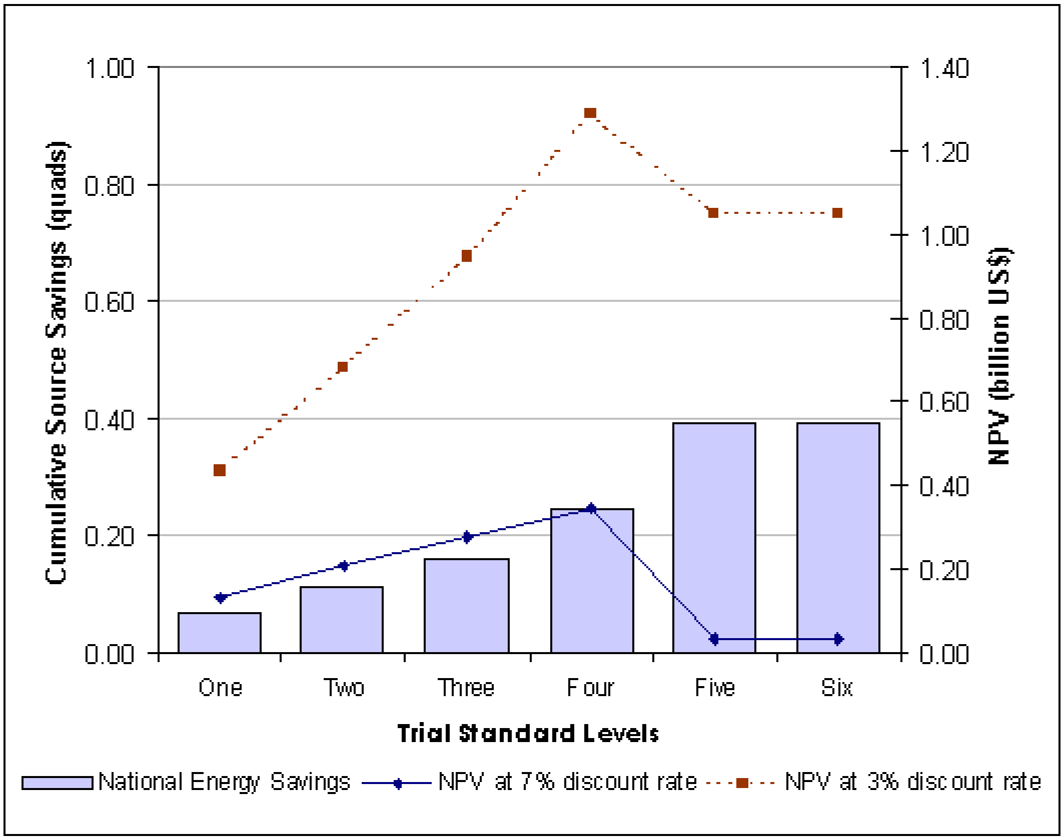

Figure 10.4.2 Dry-Type Distribution Transformers: Net Energy Savings and Net Present Value Impacts

The national impact spreadsheet is available as an Excel file on the DOE website: http://www.eere.energy.gov/buildings/appliance_standards/commercial/distribution_transformers.html. Instructions for using the spreadsheet are in Appendix 10A of this TSD.

10.4.1.3 Discounted Cumulative Energy Impacts

In the ANOPR, the Department stated that, for its NOPR analysis, it would calculate discounted values for future national energy savings. The Department used the same discount rates that it used in calculating the NPV (seven percent and three percent real) to calculate discounted cumulative NES. As described in section 10.3.2.7, it used the seven-percent and three-percent real discount rates in accordance with the OMB guidelines on regulatory analysis.[8] Table 10.4.6 shows the discounted national energy savings for both liquid-immersed and dry-type, medium-voltage transformers.

The seven-percent and three-percent real discount rate values are meant to capture the present value of costs and benefits associated with projects facing an average degree of risk. Other discount rates may be more applicable to discount costs and benefits associated with projects facing different risks and uncertainties. Risk adjustment theory suggests that lower discount rates may be called for to calculate the present value of future energy consumption or saving.

Table 10.4.6 Discounted Cumulative Energy Impacts, Liquid-Immersed and Dry-Type, Medium-Voltage Transformers

		Liquid-Immersed		**Dry-Type, Medium-Voltage**	
		Cumulative 2010-2038 3% discount	**Cumulative 2010-2038 7% discount**	**Cumulative 2010-2038 3% discount**	**Cumulative 2010-2038 7% discount**
TSL1	quads	0.86	0.38	0.04	0.02
TSL2	quads	1.15	0.51	0.06	0.03
TSL3	quads	1.50	0.67	0.08	0.04
TSL4	quads	1.70	0.76	0.12	0.06
TSL5	quads	3.27	1.45	0.20	0.09
TSL6	quads	4.71	2.10	0.20	0.09

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