Distribution Transformer Rulemaking

Life Cycle Cost Analysis,
Design Line 1

(Draft for review only)

Report to
U.S. Department of Energy
Office of Building
Technology, State, and
Community Programs

June 6, 2002

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SETTING THE CONTEXT

On November 1st, 2000 the U.S. Department of Energy held a public meeting in Washington D.C. where it circulated and discussed its Framework Document for Distribution Transformer Energy Conservation Standards Rulemaking. An electronic copy of this report is available on the Department's web site at http://www.eren.doe.gov/buildings/codes_standards/applbrf/dist_transformer.html

The Framework Document describes the procedural and analytical approaches the Department is using as it considers energy conservation standards for distribution transformers. The formal rulemaking process for developing energy conservation standards includes three Federal Register notices: the Advanced Notice of Proposed Rulemaking (ANOPR), the Notice of Proposed Rulemaking (NOPR) and the Notice of Final Rulemaking. At the publication of this interim report, the Department is in what is commonly called the "pre-ANOPR" stage, meaning the Department is presently conducting the analysis that will be published for the ANOPR meeting later this year.

This structure of this report is as follows:

- The main body discusses the methodology and structure of the Life Cycle Cost (LCC) Analysis; along with the the input values and assumptions. In addition, example results from the life cycle cost analysis on a 50kVA unit are presented.
- Appendix A presents a comparison between an LCC Analysis and the Total Owning Cost (TOC) Analysis that electric utilities traditionally undertake;
- Appendix B presents an update to the Engineering Analysis that the Department circulated in December 2001.

In the spirit of early consultation with all stakeholders, the Department elected to circulate this draft report and spreadsheet model on the LCC Analysis. This is just one of several early opportunities that stakeholders have in providing the Department with data, recommendations and other comments. Comments from all concerned parties are welcome during the whole rulemaking process and will be entered into the docket.

The Department wishes to receive feedback not only on the draft report and its accompanying spreadsheet but also on the interest for having a discussion on utility A and B distributions, and a training session on the LCC spreadsheet. The Department recognizes the sensitivity of LCC results with respect to utility A and B distributions and wishes to receive comments to determine if having a public discussion with stakeholders would be worthwhile. A training session on the LCC spreadsheet can be arranged from LBNL if interest is there from stakeholders. The venue for these activities is open for discussion: conference call, internet broadcast, etc.

Please have all comments submitted to DOE by June 21, 2002 to:

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ABSTRACT

The Life-Cycle Cost (LCC) spreadsheet for the distribution transformer rulemaking compares the life-cycle costs for the baseline unit with more efficient units. The LCC spreadsheet will be used by the Department in determining the effects of standard levels on changes in operating expenses (usually decreased) and changes in purchase prices (usually increased). The draft LCC spreadsheet results presented in this report are derived primarily from a database of transformer designs and estimates of operating costs. The transformer design database (discussed in Appendix B) incorporates over 2000 units with varying costs, no-load losses and load losses. The estimates of operating costs are calculated after accounting for loading and marginal electricity prices.

The universe of electrical distribution transformers is relatively large and complex with numerous types and sizes. The Department recognized that it would be impractical to conduct detailed analyses of all 73 product classes identified in NEMA's TP-1 document, so it created 13 “design lines” which group transformers based on engineering similarities. The Department has selected one model from each design line for analysis and will extrapolate the findings to the other models in that design line. Each of the design lines will be analysed using a specific LCC spreadsheet constructed for the particular characteristics of that group of distribution transformers. This report focuses on the Design Line 1 spreadsheet. The representative unit for this Design Line (DL #1), as established in the Engineering Analysis, is a 50 kVA single-phase, liquid-immersed, pad-mounted transformer. This unit is assumed to be utility-owned and installed and connected to an existing 25 kV feeder line.

INTRODUCTION

Content Overview

This document provides a brief overview of the Life-Cycle Cost (LCC) analysis developed by the Department for use in the distribution transformer rulemaking. This overview includes descriptions of the computational methodology, LCC inputs and draft results. In addition, specific user instruction is provided for operating the LCC spreadsheet model and its Monte-Carlo simulation component. Appendices provide details on how the LCC analysis relates to traditional utility Total Owning Cost (TOC) methods and update the engineering analysis previously released by the Department in December 2001.

Overview of Methodological Intent

The Department by law must evaluate the economic impact of any potential energy efficiency standard. The effects of energy efficiency standards include changes in operating expenses (usually decreased) and changes in purchase price (usually increased). In conducting its rulemaking, the Department analyzes the net effect of transformer costs over transformer service life. The LCC includes the installed cost (purchase price plus installation cost), operating expenses (energy and maintenance costs), lifetime of the product, and a discount rate. The LCC is decreased (net savings) if the savings in reduced operating expenses from a more efficient transformer more than compensate for the increased installed cost. The utility industry has a similar method called TOC using A and B factors. The relationship between the Department's LCC process and the TOC evaluation process is discussed in Appendix A.

The Department developed an Excel® LCC spreadsheet model to calculate the economic impacts on distribution transformer purchasers and to make the analysis transparent and accessible to all interested stakeholders. The LCC spreadsheet is used to estimate the owner economic impacts of an efficiency standard by calculating the present value impacts on pairs of transformers. In these pairs, one transformer is a baseline unit representing what is currently available in the marketplace and the other transformer corresponds to designs that would meet a particular energy efficiency standard. It is expected that additional enhancements will be incorporated to the model as the Department receives comments from stakeholders. These enhancements will aid the Department in preparing the evaluation runs for its Advance Notice of Proposed Rulemaking (ANOPR).

Transformer design, efficiency, and economics are characterized by a large degree of diversity which is represented in the LCC by distributions. There are many possible transformer designs with different loss and efficiency characteristics. In the U.S., there are over 3000 retail utilities each of which may experience different costs and economic conditions. As part of a distribution system with varying load factors, system loads, and electricity costs, each individual transformer experiences different loads which vary over time. Each of these elements affects the economics of improving transformer efficiency. The LCC spreadsheet captures these effects by utilizing probability distributions instead of point values as inputs.

The LCC uses several data sets as its source for these distributions. Potential transformer designs are represented by a distribution of over 2000 potential designs from the engineering analysis. Utility economics are represented by a sample of over 50 utilities. Hourly loads are represented by over 2300 transformer load profiles based on simulations from actual system loads. Losses are valued (weighted) by hourly marginal generation costs, plus transmission and distribution cost adders. These hourly loads and costs manifest themselves in the spreadsheet as hourly load and price curves for each representative transformer for three day-types: weekdays, weekends, and peak days. As many of the inputs to the LCC are distributions rather than point values, the LCC results are also distributions, created by running the LCC model 10,000 times using a Monte-Carlo simulation tool.

METHOD

Life-Cycle Cost Equation

The foundation of the LCC methodology is the life-cycle cost equation, reflecting both the first costs of an item and the present value of the operating costs over the lifetime of the equipment:

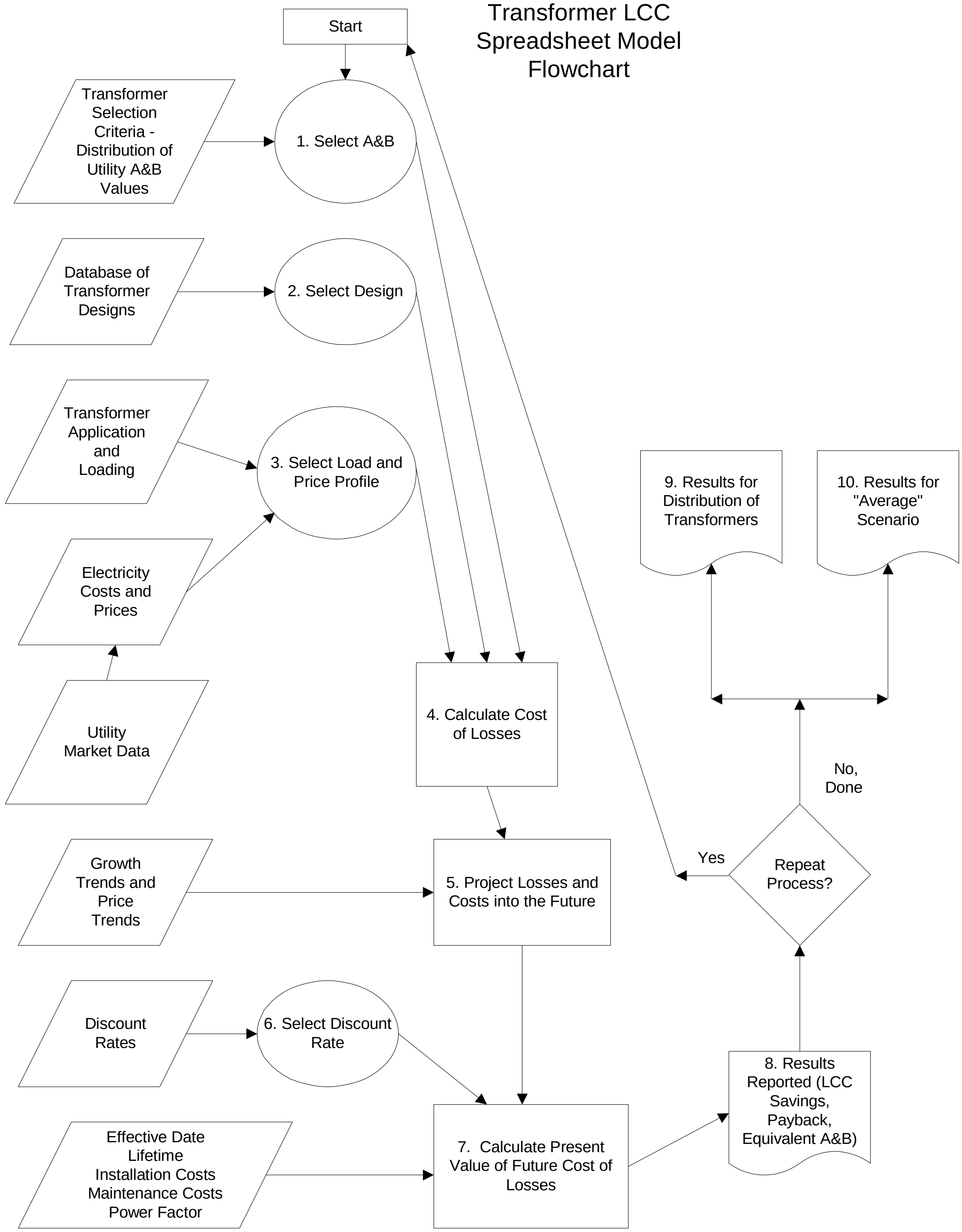
(1) $LCC = IC + SUM_{n=1,Lifetime}\ [OC_n/(1+Drate)^n]$

where, for transformers, IC is initial installed cost, SUM is the sum over transformer lifetime, n is the index for the year of operation, OC_n is the operating costs in year n, and Drate is the discount rate applied to the calculation.

The initial installed costs include the purchase price and installation cost of the transformer, while operating costs include the value of the losses and maintenance costs.

While the LCC equation is simple, the LCC analysis for distribution transformers needs to account for a number of complex factors. A simplified flowchart (Figure 1) illustrates the key steps implemented in the LCC spreadsheet: inputs, computational steps and outputs. Referencing these key steps and working through the flowchart, the subsequent sections of this document provide a detailed explanation of the LCC process leading to LCC results: LCC savings, payback and equivalent A & B.

Figure 1
Transformer LCC
Spreadsheet Model
Flowchart



LCC Inputs

The LCC inputs are provided below with the definition, source, approach, and key assumptions for each input.

A and B Transformer Selection Parameters

Definition	The A and B transformer selection parameters are the economic decision parameters that describe how a transformer purchaser evaluates transformer losses in the selection of a transformer design. The selection is described in terms of minimizing the Total Owning Cost (TOC) of the transformer, A is the no-load loss valuation parameter, B is the load loss valuation parameter.
Data Source	LBNL.
Approach	The distribution of A and B parameters is characterized by four parameters: an average A, a standard deviation of A values, a correlation between the A and B values, and a percent of transformers evaluated.
Assumptions	Three scenarios are offered for the percent of transformers evaluated. Two of these scenarios represent the high and low boundary cases where either all utility purchasers evaluate transformer losses or no utility purchasers evaluate transformer losses. The current default assumption is that 75% of utility transformer purchasers evaluate according to a distribution of A and B parameters.

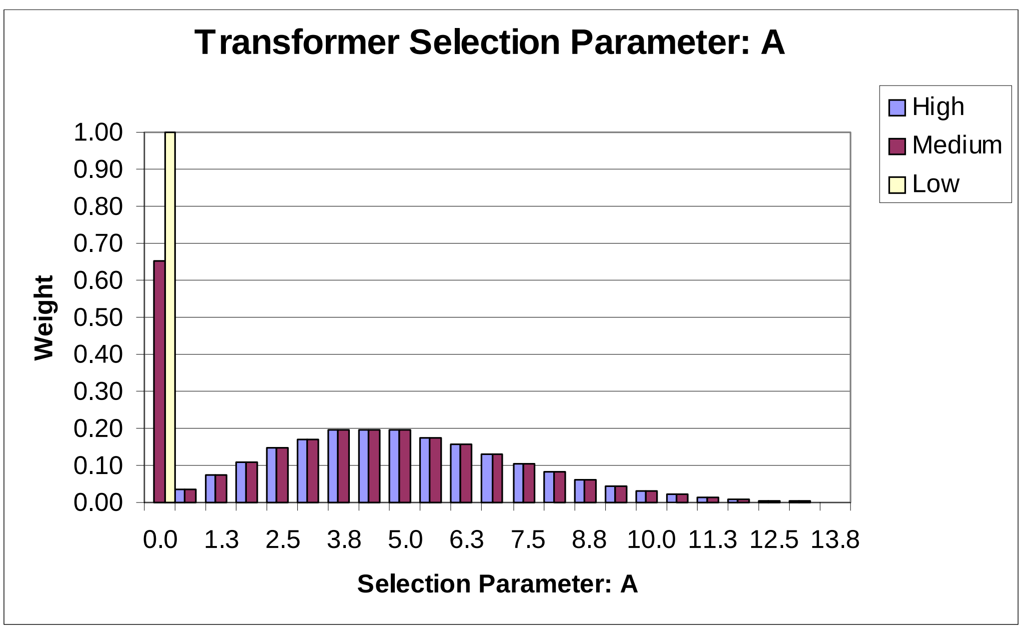


Figure 2. Transformer Selection Parameter: A

In summary, the following represents the three scenarios for the distribution of A and B parameters :

	High Distribution			Med Distribution			Low Distribution		
	A	B	Weight	A	B	Weight	A	B	Weight
	0	0	0	0	0	0.65	0	0	1
	0.6	0.2	0.04	0.6	0.2	0.04	1.5	0.3	0
	1.3	0.4	0.07	1.3	0.4	0.07	2.1	0.3	0
	1.9	0.7	0.11	1.9	0.7	0.11	2.4	0.7	0
	2.5	0.9	0.15	2.5	0.9	0.15	2.8	0.9	0
	3.1	1.1	0.17	3.1	1.1	0.17	3.0	0.7	0
	3.8	1.3	0.2	3.8	1.3	0.2	3.2	1.7	0
	4.4	1.5	0.2	4.4	1.5	0.2	3.4	1.6	0
	5.0	1.8	0.2	5.0	1.8	0.2	3.5	1.1	0
	5.6	2.0	0.18	5.6	2.0	0.18	3.6	1.7	0
	6.3	2.2	0.16	6.3	2.2	0.16	3.9	2.1	0
	6.9	2.4	0.13	6.9	2.4	0.13	4.2	1.7	0
	7.5	2.6	0.1	7.5	2.6	0.1	4.3	1.9	0
	8.1	2.8	0.08	8.1	2.8	0.08	4.5	1.4	0
	8.8	3.1	0.06	8.8	3.1	0.06	4.7	2.2	0
	9.4	3.3	0.04	9.4	3.3	0.04	4.9	2.5	0
	10.0	3.5	0.03	10.0	3.5	0.03	5.0	1.8	0
	10.6	3.7	0.02	10.6	3.7	0.02	5.9	1.6	0
	11.3	3.9	0.01	11.3	3.9	0.01	6.5	2.7	0
	11.9	4.2	0.01	11.9	4.2	0.01	7.4	2.3	0
	12.5	4.4	0.01	12.5	4.4	0.01	8.7	5.3	0
	13.1	4.6	0	13.1	4.6	0	9.8	2.1	0
	13.8	4.8	0	13.8	4.8	0	10.7	1.2	0
Average	*5.1*	*1.8*		*3.8*	*1.3*		*0*	*0*	

Database of Transformer Designs

Definition	The Department's Engineering Analysis yields a cost-efficiency relationship in the form of selling prices, no-load losses, and load losses for a wide range of realistic transformer designs.
Source	The Department's Engineering Analysis, the update of which is described in Appendix B of this document.
Approach	The database of transformer designs provides the LCC model with a distribution of transformer design choices.
Assumptions	See Engineering Analysis for details.

Transformer Loading

Definition	The economic value of transformer losses is a function of the load on the transformer and the timing of the load with respect to variable energy costs and system peak demand. The transformer load is an estimate.
Sources	Statistical properties of hourly loads are derived from analysis of End-Use Load and Consumer Assessment Program (ELCAP) hourly load data, proprietary hourly load data, and Federal Energy Regulatory Commission (FERC) Form 714 hourly load data.
Approach	Hourly loads on individual transformers are estimated using a statistical load simulation model. The statistical load simulation model takes several inputs and performs a statistical simulation for an hourly load sample. There are five main inputs to the statistical load simulation model: (1) An estimate of the annual peak load (2) A relationship between peak load and load factor (3) A relationship between the load factor and the load distribution function (4) The hourly system load (5) The correlation between hourly system load and an individual transformer load. The hourly load simulation is performed by a data processing program that generates inputs for the LCC spreadsheet. From the rated size of the transformer, the annual peak load is estimated from a distribution of peak loads that range from 50% to 130% of rated load with a mean of 85% of the rated peak load of the transformer. A scaling relationship between peak load and load factor is derived from available hourly load monitoring data. The simulated load is calculated to have a load distribution function with the estimated load factor. The hourly system load is obtained from FERC Form 714 data. The correlation between transformer load and system load is taken from distributions of correlation coefficients for commercial and residential customers that are derived from hourly load monitoring data available to the Department.
Assumptions	The economically important characteristics of transformer loads are determined by the load factor, the relationship between peak load and transformer capacity, and the correlation between transformer load and system load.

Installation Costs

Definition	The cost to install a transformer.
Source	LBNL consultant.
Approach	The installation cost elements are: • Single phase pre-fabricated stress cones at pole and transformer • Shielded cable run down pole from stress cone on pole and underground to stress cone at transformer • Pad • One fused cutout installed and connected to 25 kV line and stress cones • Ground rod with grounding conductor run to transformer • One distribution grade lightning arrester installed and connected to transformer and grounding conductor • Shop test to verify condition of oil and functionality of transformer before transportation to job site • Transportation to job site • Crane operation to lift transformer into place on pad • Bucket truck operation to install pole-mounted components • Connect, measure insulation resistance, energize, set taps, verify secondary voltage.
Assumptions	This unit is assumed to be utility-owned and installed and connected to an existing 25 kV feeder line. In general, installation costs are not expected to vary between baseline units and more efficient units.

Utility Market Data and Electricity Costs and Prices

Definition	Data and inputs used for the estimation of marginal electricity prices. See section on marginal costs for details.
Source	Includes data from the Energy Information Administration (EIA) and FERC: *Annual Energy Outlook 2002* (*AEO 2002*), hourly market prices for 1999, FERC Form 714 data, and EIA Form 861 data.
Approach	See section on marginal costs for details.
Assumptions	See section on marginal costs for details.

Hourly Transformer Load Shape

Definition	The hourly transformer load shape is the average hourly load on a transformer for a particular month and a particular day type.
Source	Hourly transformer load shapes are calculated from simulated hourly loads.
Approach	The approach is to take a load-square weighted average of the hourly loads for each day type and each month. The resulting periodic load profile is then represented by a truncated Fourier series.
Assumptions	It is assumed that high-frequency modes of the Fourier series representation of the load shape are not economically important.

Hourly Marginal Price/Cost

Definition	The hourly cost or price of electricity supply at the margin, i.e., for the last kWh of electricity.
Sources	Capacity cost data: *AEO 2002*, FERC Form 714, and electricity market data.
Approach	See description of Step 4 below for details.
Assumptions	Electricity market data has capacity cost implicit in the variation in hourly prices. The capacity cost for base load is that of a coal-fired power plant, while the capacity cost for load losses is that of a combustion turbine. Capacity costs can be annualized with the capital recovery factor.

Load Growth Rate

Definition	The LCC analysis looks at a cross-section of transformers. A load growth trend is applied to each new transformer.
Source	LBNL.
Approach	Spreadsheet users have the choice of three scenarios using the Transformer Load Growth/Year drop-box on the "Summary" worksheet. The three scenarios for load growth: no growth, 1% per year growth, and 2% per year growth.
Assumptions	The "default" scenario is the 1% per year load growth, medium load growth.

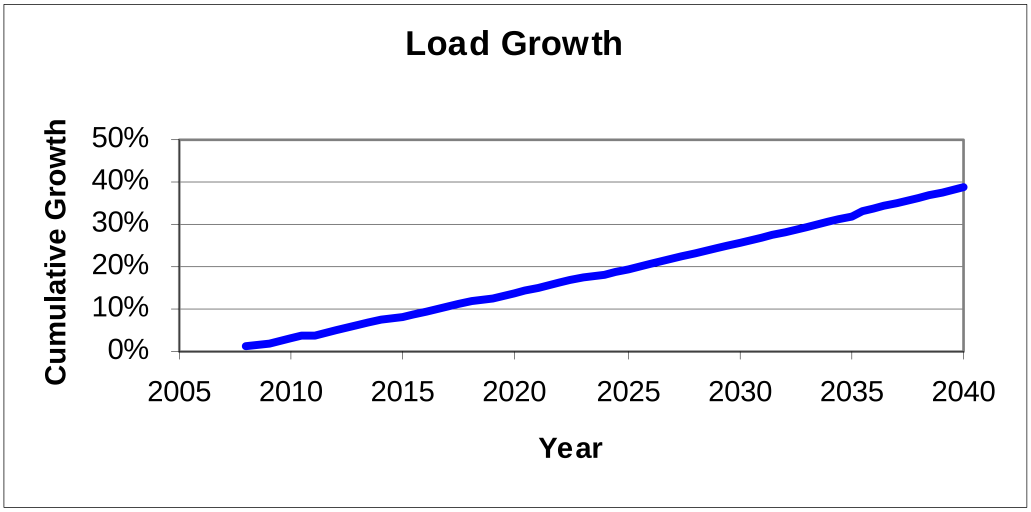


Figure 3. Load Growth

Electricity Price Trends

Definition	The relative change in electricity prices for future years.
Source	EIA's *AEO 2002*.
Approach	The Department has chosen to use the price trends from three AEO forecast scenarios developed by EIA. Spreadsheet users have the choice of these three scenarios: (1) *AEO 2002* Low Growth scenario (2) *AEO 2002* Reference scenario (3) *AEO 2002* High Growth scenario
Assumptions	The current LCC analysis uses the trend from the *AEO 2002* Reference scenario as its "medium" scenario. That is, the relative change in future marginal electricity prices is assumed to be the same as the relative change in average prices taken from the *AEO 2002* Reference scenario forecast. The EIA's projections in *AEO 2002* are through the year 2020. For this LCC analysis, electricity prices are assumed constant at 2020 levels after the year 2020.

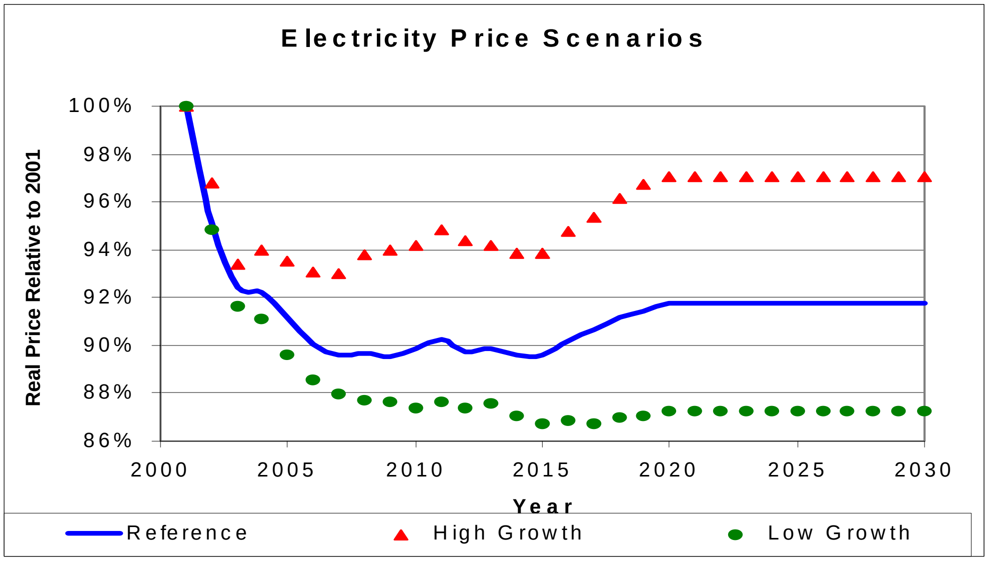


Figure 4. Electricity Price Scenarios

Discount Rates

Definition	The rate by which expenses in future years are "present-valued."
Source	Capital and debt structure for various firms and LBNL.
Approach	Discount rates for this analysis are taken to be equal to the cost of capital. The cost of capital is a combination of debt interest rates and the cost of equity capital. Distributions are calculated for the types of purchasers/owners appropriate for each Design Line. The types of purchasers/owners used by the Department are: • Property Owners • Manufacturers (Industrial) • Service (Commercial) • Investor-Owned Utilities • Publicly Owned Utilities
Assumptions	For each ownership type, the "Discount Rate" worksheet shows a distribution of discount rates. In addition, the "Discount Rate" worksheet also shows the assumed distribution of transformer ownership types for each Design Line.

Figure 5. Discount Rates

Effective Date of Standard

Definition	The year at which a new standard is expected to become effective.
Source	LBNL.
Approach	The LCC is calculated for all users as if they each purchase a new distribution transformer in the year the standard takes affect. The cost of the equipment is based on this year; however, all dollar values are expressed in 2001 dollars. Annual energy prices are included for the life of the distribution transformer.
Assumptions	The new energy efficiency standard for distribution transformers is assumed to take effect in the year 2007.

Transformer Lifetime

Definition	The age at which the distribution transformer is retired from service.
Source	ORNL 6804/R1 page D-1 with adjustments.
Approach	The Department utilizes a Weibull reliability function to describe the replacement of transformers. The lifetime adjustments include a constant failure rate of 0.5%/year for lighting and other random failures unrelated to transformer age with an additional corrosive failure rate of 0.5%/year at year 15 and beyond. The parameter of the Weibull distribution is adjusted to maintain an average life of 32 years.
Assumptions	The current assumption is that the average life of distribution transformers is 32 years.

Operating Costs

Definition	Includes energy, capacity, and maintenance costs. See the marginal cost calculation for details.
Source	Obtained from the marginal cost calculation. See the marginal cost calculation for details.
Approach	See the marginal cost calculation for details.
Assumptions	See the marginal cost calculation for details.

Maintenance Costs

Definition	The cost of maintaining the operation of the transformer "equipment."
Source	LBNL consultant.
Approach	The maintenance cost is associated with general maintenance. In practice, there is very little scheduled maintenance for a distribution transformer in Design Line 1. Annual inspections should be conducted to insure the integrity of the enclosure against vegetation encroachment and rodent or bird infestation, and to identify accident or lightning stroke damage.
Assumptions	This maintenance cost is assumed not to change with increased efficiency. The general maintenance of more efficient products should not be affected by the details of the core material or windings.

Power Factor

Definition	The power factor is the real power divided by the reactive power. Real power is the time average of the instantaneous produce of voltage and current. Apparent power is the product of the root mean square voltage times the root mean square current.
Source	LBNL.
Approach	For simplicity, a power factor of 1 is used in loss calculations.
Assumptions	The power factor is approximately 1.

Process Details

Selected individual steps of the process are expanded below to provide additional clarity to the overall process. Refer back to the process flow chart, Figure 1, to place the following discussion in context.

Step #1: Economic choice parameters (A & B values) are selected from the choices on the "A & B Dist" worksheet.

The key input for this step is the: *Transformer selection criteria.* Standard practice for some utilities is to provide manufacturers with economic "A and B factors," where A and B are the equivalent first cost of the no-load and load losses (in $/watt). Utilities calculate these A and B factors using confidential and public information related to their distribution systems and economic conditions. (Not all transformer purchases are based upon these A and B factors.) The LCC spreadsheet simulates this condition with three different A and B distributions. Spreadsheet users have the choice of three scenarios through the use of the "Utility Decision A's & B's" drop-down box on the "Summary" worksheet. These three scenarios represent using A and B factors

0%, 75%, and 100% of the time, respectively, in the selection process. These three scenarios are tabulated in the “A & B Dist” worksheet.

The first and third scenarios are the low and high bounds on the use of A and B factors, while the second scenario is intended to be more representative of the full mix of purchasers. The first scenario considers non-evaluating transformer purchases. Non-evaluating transformer customers are those purchasers of transformers who do not conduct an economic evaluation of transformer losses and purchase primarily on the basis of least first cost. Non-evaluating customers in the distribution of customer choice A's and B's are represented with both A and B equal to zero for all purchases; that is, these customers have 0% usage of A and B factors. The medium scenario for liquid-filled transformers is represented with a 75% usage rate of A and B factors in evaluating losses. The third scenario represents the case in which 100% of transformer purchases are evaluated using A and B factors.

For those transformer purchasers who evaluate transformer efficiency, the Department characterizes the distribution of A and B factors with four parameters: (1) the average value of A, (2) the ratio of the standard deviation of A to the average value of A, (3) the ratio of B to A, and (4) the correlation between B and A. Data on the use of A and B factors are used to estimate the parameters of the distribution.

Step #2: Base case designs are chosen for a particular customer from the full set of transformer designs. The standards case designs are chosen from that subset of base case designs that satisfy the standard criteria.

The key input for this step is the: *Transformer design (Transformer prices and ranges of NL and LL)*. The Department’s Engineering Analysis yields a cost-efficiency relationship in the form of selling prices, no-load losses, and load losses for a wide range of realistic transformer designs. This data set provides the LCC model with a distribution of transformer design choices. (See the “Design Table” worksheet, a condensed version of the engineering analysis output.) The selling prices are shown in column C. Similarly, for 50% loading the no-load losses and load losses are shown in columns D and E respectively.

Appendix B contains the revised engineering analysis data for the 50kVA pad-mount unit that was previously published by the Department in December 2001. This new data is based upon written and verbal comments the Department received from stakeholders on the input assumptions and resultant designs in the December 2001 report. The engineering analysis data was prepared for the Department by Navigant Consulting Incorporated (NCI) (formerly Arthur D. Little), and Optimized Program Services (OPS).

Step #3: A sample transformer load and price profile is selected from the choices of load and price profiles on the "Load & Price Parameters" worksheet.

The two key inputs for this steps are *Transformer loading* and *Installation costs*.

Transformer loading

Hourly loads (over the course of a year) are represented by over 2300 simulated transformers loads derived from actual system load data. (See the "Load & Price Parameters" worksheet, columns A through I.)

The LCC for each sampled transformer uses a composite hourly load profile for the following three loading conditions: weekdays, weekends, and peak days. Hourly load profiles are represented as Fourier series coefficients in the LCC spreadsheet. Using these Fourier coefficients, a composite average hourly load profile is derived by weighting these coefficients across a distribution of simulated loading conditions. The statistical model generates an annual hourly load (8760 hours) for each transformer sample. Appropriate averages of these loads are taken to generate the hourly load profiles that are represented as Fourier series coefficients in the LCC spreadsheet.

Installation costs

Installation costs vary by transformer type and size. In the LCC spreadsheet, installation costs are shown on the "Baseline LCC" and the "Design Option LCC" worksheets, cell C9. In general, installation costs are not expected to vary between baseline units and more efficient units.[1] For Design Line #1, the installation costs are detailed below.

The representative unit for this Design Line (DL #1), as established in the Engineering Analysis, is a 50 kVA single-phase, liquid-immersed, pad-mounted transformer. This unit is assumed to be utility-owned and installed and connected to an existing 25 kV feeder line. The Department estimates the total cost for these installation elements to be $675.[2]

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[1] If it appears that more efficient units would be larger or heavier than the baseline unit in a manner that would add significant costs to the installation process, the Department can consider using a higher estimate for installation costs for that particular unit.

[2] The total cost of $675 is comprised of $325 in materials, $50 in equipment, and $300 in labor.

Step #4: The cost of no-load and load losses are calculated from the loss coefficients of the design and the load and price profiles.

Two key inputs for this step, *Utility market data* and *Electricity costs and prices*, are discussed below.

To estimate the cost of transformer losses, the Department developed a method for estimating the hourly marginal cost equation for utility electricity supply. The hourly marginal cost equation is divided into the costs for capacity and for energy. The costs for capacity include cost components for generation capacity, transmission capacity, and distribution capacity. Capacity components also include a reserve margin needed to assure system reliability. The costs for energy include a marginal cost of supply that varies by the hour, factors that account for losses, and cost recovery of associated marginal expenses. The equation is as follows:

(2) $MEC = (1 + CM) * (GC * IGC + TC * ITC + DC * IDC) + (LAF * EC(hour) + RF) * IEU(hour)$

where MEC is the marginal electricity cost, CM is the system capacity margin required for reliability, GC is the unit cost of generation capacity, IGC is the incremental system capacity required by the load, TC is the unit cost of transmission capacity, ITC is the incremental transmission capacity required by the load, DC is the unit cost of (non-transformer) distribution capacity, IDC is the incremental distribution capacity required by the load, LAF is a system loss factor which is 1 plus the estimated system losses, EC(hour) is the hourly marginal cost of electrical energy either from a market or from marginal fuel and operating cost data, and IEU is the incremental energy use.

The various inputs to this equation are calculated as follows:

- ***Capacity Margin (CM):*** This element of the equation is the fraction of extra or reserve capacity needed to assure system reliability per unit of additional capacity requirement. It is assumed to be 15%.

- ***Unit Generation Capacity Cost (GC):*** This cost is the annualized cost of unit generating capacity for the particular load being served. It includes the cost of capital during the construction period, and the loss adjustment factor to account for losses between the generator and end-use load. *AEO 2002* provides forecasts of such costs for different generation technologies. This capacity cost depends on the type of load being served and the source of the electricity. For base-load the Department uses the capacity cost for a pulverized coal plant since this is currently the least cost base load technology. For peak loads, such as those associated with transformer peak load losses, the Department uses conventional combustion turbine capacity costs as the relevant marginal capacity cost.

For electricity obtained from wholesale electricity markets DOE assumes no capacity cost.

- ***Incremental Generation Capacity Requirement (IGC):*** This element of the equation is the amount of generation capacity required by a load. For the core loss component, it is equal to the core losses. For the load loss component, it is estimated by multiplying the Peak Responsibility Factor (PRF) by the transformer peak load and feeding the result to the load loss equation. The peak responsibility factor is the fraction of the transformer peak that is coincident with the system peak. Currently, the Department calculates a first-year peak responsibility factor. The Department may have to calculate a 5- or 10-year average for a more accurate calculation. Note that there is a multi-year delay between when new capacity is contracted and when it becomes available. AEO capacity cost forecasts are expressed in terms of when the capacity is contracted. The Department translates this cost into the cost at first year of service by adding capital costs as determined by the discount rate. Cost are annualized by applying the capital recovery factor to capacity costs assuming that such capacity has a 30-year lifetime.

- ***Unit Transmission Capacity Cost (TC):*** This cost is the annualized cost per unit for an increment of new transmission capacity. This cost is also provided by *AEO 2002* forecasts for the 12 NERC reliability regions. They range from $123/kW to $323/kW (dollars are real year 2000 dollars).

- ***Incremental Transmission Capacity Requirement (ITC):*** This element of the equation is the amount of transmission capacity required by an incremental load. As an initial approximation, DOE will assume that the transmission capacity requirement is the same as the generation capacity requirement.

- ***Unit Distribution Capacity Cost (DC)***: This cost is the cost per unit of distribution capacity. The Department currently does not have a refined estimate for this component. In the current version of the LCC spreadsheet, the Department is using a placeholder value of $300/kW for combined transmission and distribution capacity costs. Stakeholders are encouraged to provide the Department with additional data on transmission and distribution capacity costs to assist in the refinement of this estimate.

- ***Incremental Distribution Capacity Requirement (IDC):*** This element of the equation is the amount of distribution capacity required by an incremental load. It is assumed to be the same as the peak incremental energy use.

- ***Loss Adjustment Factor (LAF):*** The loss adjustment factor is the factor that one must multiply by an end-use load to estimate the amount of system electricity needed to supply that load. It is 1 plus the fractional losses in the system. It is assumed to have a constant value of 1.08.

- ***Hourly Energy Cost (EC):*** This cost is the hourly marginal energy cost obtained from utility system lambda data or market data. If it is obtained from market data, it is assumed to include generation capacity effects, and the generation capacity cost is assumed to be zero.

- ***Additional Cost Recovery Factor (RF):*** This element of the equation is a factor that is added to the hourly energy cost to account for costs besides energy losses that are associated with supplying that energy. It may include, for example, overhead associated with accounts receivable that scales with the volume of electricity sold, or other—possibly regulated—charges paid by the utility that are applied on a per-kWh-produced basis. Limited information of real-time pricing formulas indicates the cost recovery factor necessary for utilities to remain revenue neutral when they develop marginal pricing schemes. This may be a high estimate of actual additional marginal costs, but it provides an estimate of a markup on marginal energy costs. The additional cost recovery factor estimate that DOE will provisionally use is 15% of the marginal generation cost. It is a markup associated with the cost of supplying such energy from either wholesale markets or the utility's own generation.

- ***Incremental Energy Use (IEU):*** This element of the equation is the incremental hourly energy use calculated from the transformer loading that is obtained from the formula for the transformer losses.

The Department is relying on capacity cost estimates from data and estimates contained in the *AEO 2002* forecast. The cost recovery factors are being derived from real-time pricing formulas from a selection of utilities. Such factors are necessary for marking up the cost of generation to account for other costs that scale with generation, but which are not included in such costs. Such costs may include accounts payable and accounts receivable and operating capital costs which will have a component that scales with the volume of electricity sales. Based on the range of observed cost recovery factors, DOE will assume that the cost recovery factor is approximately 0.15 (i.e., 15%) of the cost of energy.

In summary, the following represent the inputs to the marginal cost calculation:

Marginal Cost Input	Value/Equation
Capacity Margin (CM)	0.15
Unit Generation Capacity Cost (GC)	
No Load Loss	$1110/kW * (1+Drate)^4
Load Loss	$336/kW * (1+Drate)^2
Transmission + Dist. Cost (TC+DC)	$300/kW
Incremental Generation Capacity (IGC)	PeakLoad * PRF, (PRF=0.37)
Load Adjustment Factor (LAF)	1.08
Hourly Energy Cost (EC)	
No-Load Loss	$0.015/kWh (average)
Load Loss	$0.029/kWh (average)
Additional Cost Recovery Factor (RF)	0.15

Step #5: Losses and costs are projected into the future based on load growth assumptions and forecast of future electricity price changes.
Step #6: A discount rate is selected from the discount rate distribution.
Step #7: The present value of future operating costs and losses is calculated and the present worth per watt of no-load and load-losses is calculated.
Step #8: LCC, LCC savings, payback period, and other results are recorded for inclusion in the distribution of results.
Step #9: The calculation is repeated until the specified maximum number of samples is reached.
Step #10: The results of the calculation for the "Average" scenario is reported on the 'Summary' worksheet.

RESULTS

LCC Run

One of the primary impacts of a standard is to change which set of transformer designs are purchased and their corresponding loss characteristics, load losses (LL) and no-load losses (NL). This impact is illustrated on the LL vs NL graph (far right on the spreadsheet menu). This graph plots an example Crystal Ball® LCC run. It shows different sets of designs by their load losses at rated load and their no-load losses. The full universe of potential designs is shown as small purple dots. The standard level is illustrated by a thick green line (those designs that satisfy the standard are to the left of this line). The unconstrained choices of designs are plotted as red triangles and the standard-constrained chosen designs are shown as green dots. As one increases the standard level, the thick green line moves to the left and down (to the area of the graph with lower losses) and so does the set of constrained designs. The standard level is selected with the corresponding pull-down menu on the “Summary” sheet. Figure 6 provides an illustration of the LL vs NL graph copied from the LCC spreadsheet. The indicated standard level in this case is TP 1.

The Department encourages stakeholders to conduct their own LCC simulation runs using their own specific sets of assumptions. Crystal Ball® output can be manipulated in many different ways to illustrate the impact of different variables on the LCC outcome.

Users experiencing difficulty with the spreadsheet should contact John L. Stoops at Lawrence Berkeley National Laboratory, Phone: 510.486.6114, or e-mail JLStoops@lbl.gov.

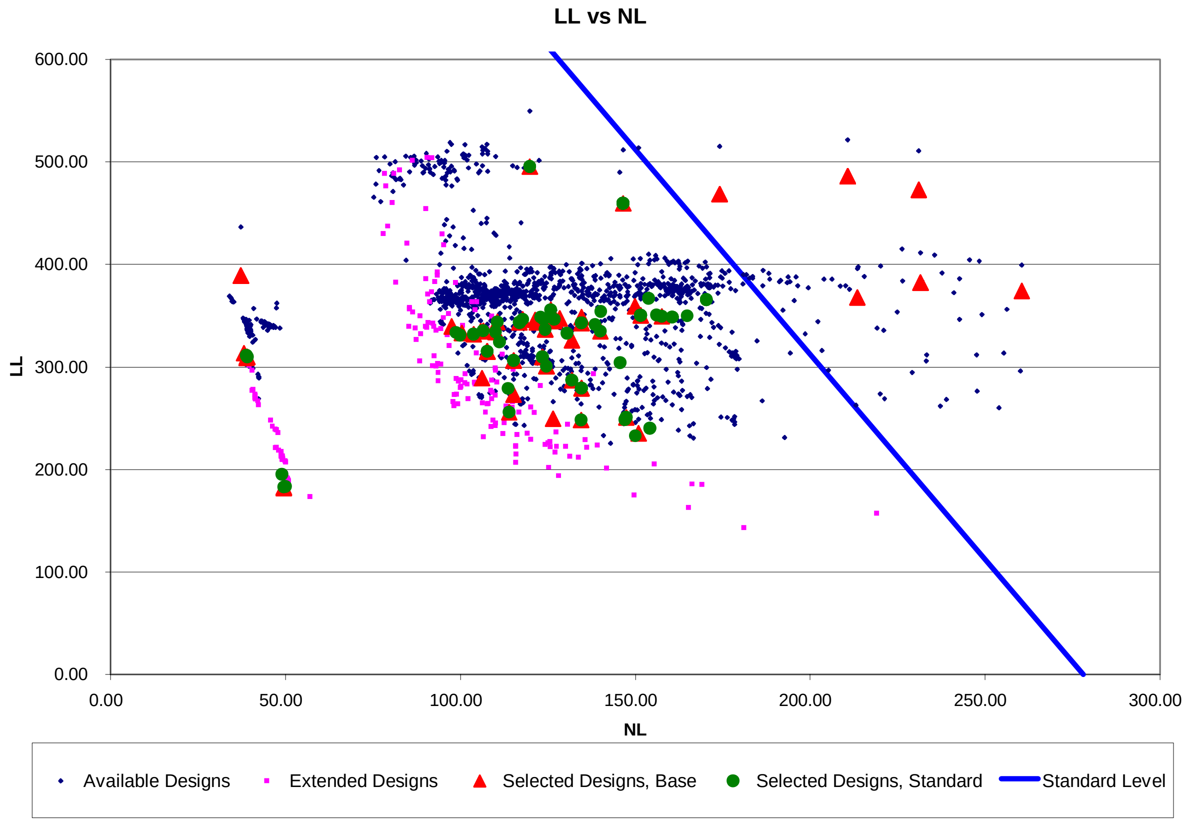

Figure 6. LL vs. NL for Standard Level 1 (TP 1)

LCC Results

Monte-Carlo simulations were run for standard levels 1 through 5. The following figures (Figures 7-16) provide stakeholders with an example set of the results of these Monte-Carlo simulations. The figures represent the LCC Savings for different possible standard levels compared to the baseline. The distributions of input variables result in distributions of the outputs for LCC savings as illustrated by the figures. All of the simulations are based on the Department's default assumptions, i.e., the medium scenario. Each simulation was based on 10,000 iterations, requiring several hours of computer time. For ease of visual comparison, the abscissa, x axis, for all the graphs are based on the same values.

The results for each standard level are expressed with two graphs—a Frequency Chart and a Cumulative Chart. On the graphs, the abscissa is equal to LCC Savings. Positive values represent reductions in LCC due to the standards and negative values represent increases in LCC due to the standards. Zero means no difference in LCC due to the standards. In the Frequency charts, the y-axis is equal to Frequency. In the Cumulative Charts, the y-axis is equal to the

Cumulative Frequency. As can be seen, the results for all of the standard levels display a significant spike in the Frequency Chart at an LCC Savings of zero dollars. This spike is mainly due to the assumption, in these medium scenario runs, that 75% of the transformer purchase decisions are evaluated using A and B values. This assumption results in significant fractions of transformer purchases meeting the standard for all the proposed standard levels, meaning zero LCC savings for the standard for those purchases. For example, the Frequency Chart for standard level 1 shows 75% of the transformers at LCC savings equal to zero with most of the remaining transformers having positive LCC Savings.

The following table provides an overview of all the LCC savings results presented in Figures 7-16.

Standard Level	Mean LCC Savings $	% LCC Savings ≥ $0	Min LCC Savings $	Max LCC Savings $
1	70	99	-84	938
2	95	96	-363	1074
3	109	87	-437	1338
4	36	46	-574	1178
5	-88	34	-668	1329

In evaluating possible standard levels and scenarios, the Department will conduct a large number of similar Monte-Carlo simulations. Interested stakeholders are encouraged to do likewise, to explore areas where they have particular interests and to report those results back to the Department.

Standard Level 1 (TP 1)

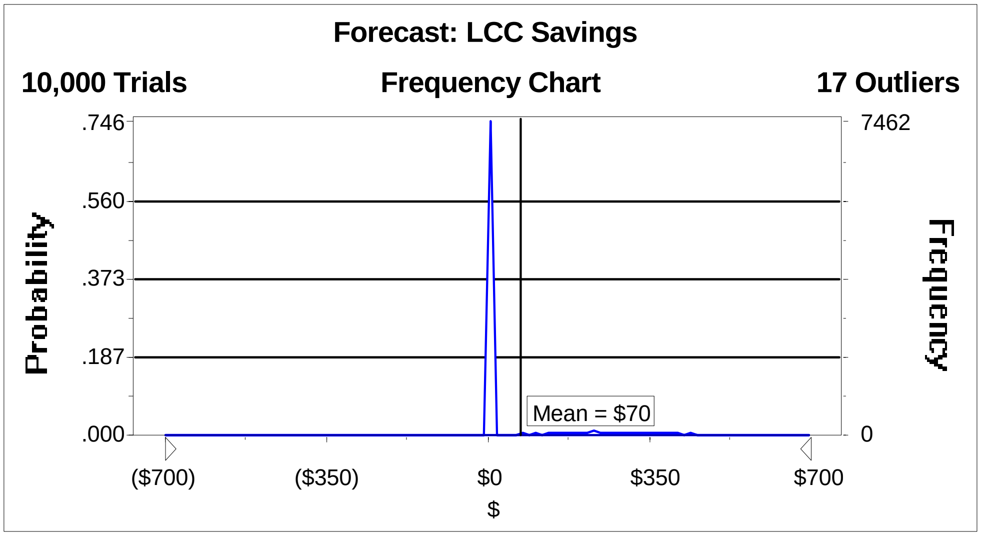

Figure 7. LCC Savings for Standard Level 1 (TP 1)—Frequency Chart

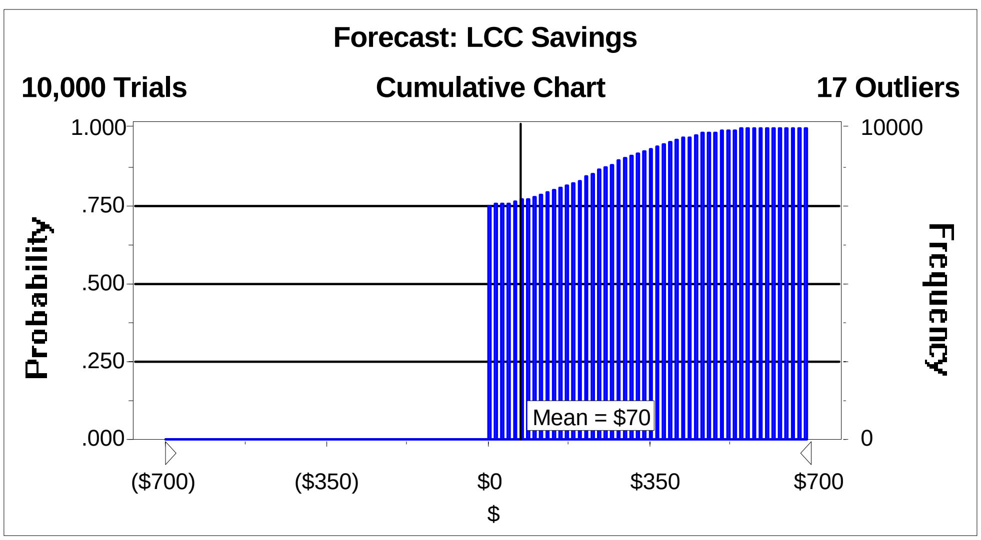

Figure 8. LCC Savings for Standard Level 1 (TP 1)—Cumulative Chart

Standard Level 2 (TP 1 + 0.2%)

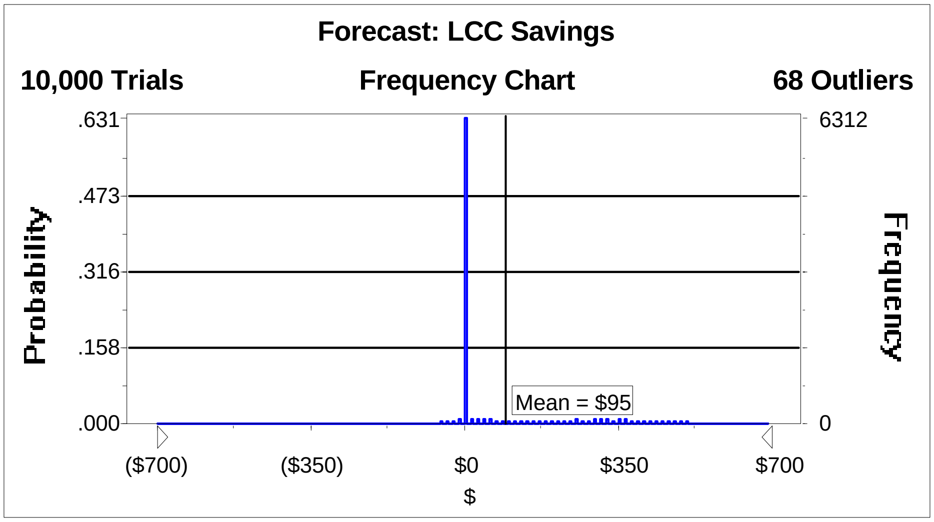

Figure 9. LCC Savings for Standard Level 2 (TP 1 + 0.2%)—Frequency Chart

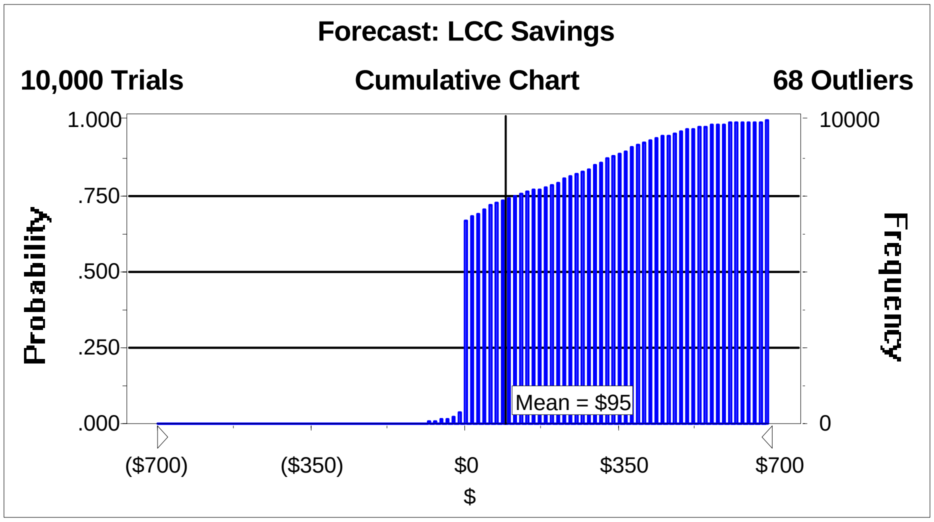

Figure 10. LCC Savings for Standard Level 2 (TP 1 + 0.2%)—Cumulative Chart

Standard Level 3 (TP 1 + 0.3%)

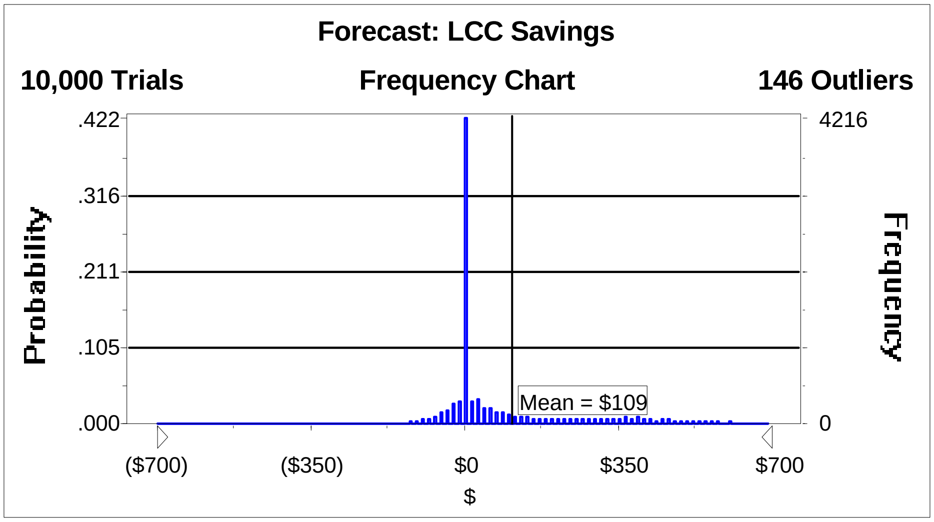

Figure 11. LCC Savings for Standard Level 3 (TP 1 + 0.3%)—Frequency Chart

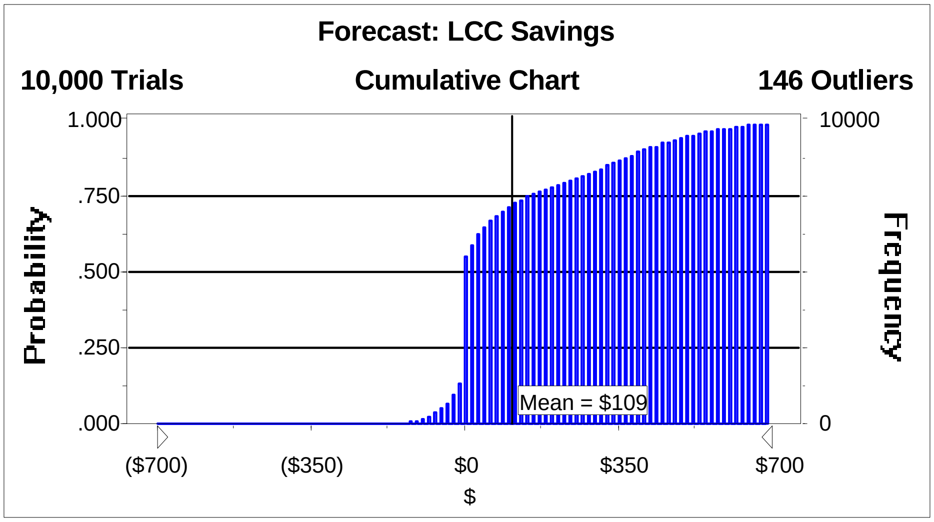

Figure 12. LCC Savings for Standard Level 3 (TP 1 + 0.3%)—Cumulative Chart

Standard Level 4 (TP 1 + 0.4%)

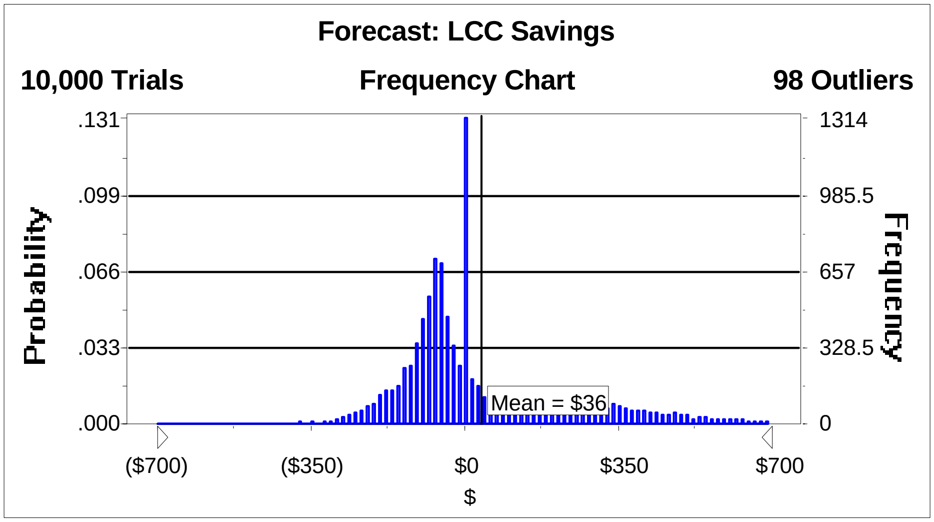

Figure 13. LCC Savings for Standard Level 4 (TP 1 + 0.4%)—Frequency Chart

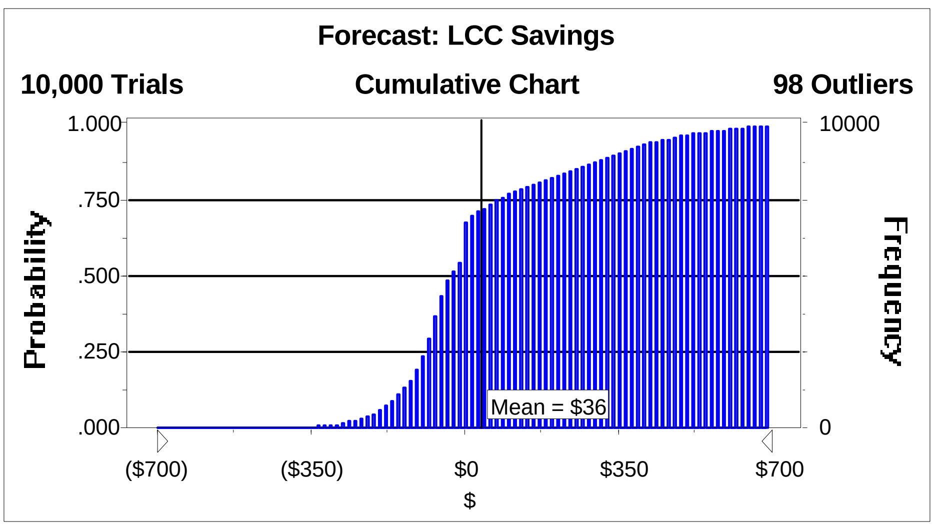

Figure 14. LCC Savings for Standard Level 4 (TP 1 + 0.4%)—Cumulative Chart

Standard Level 5 (TP 1 + 0.6%)

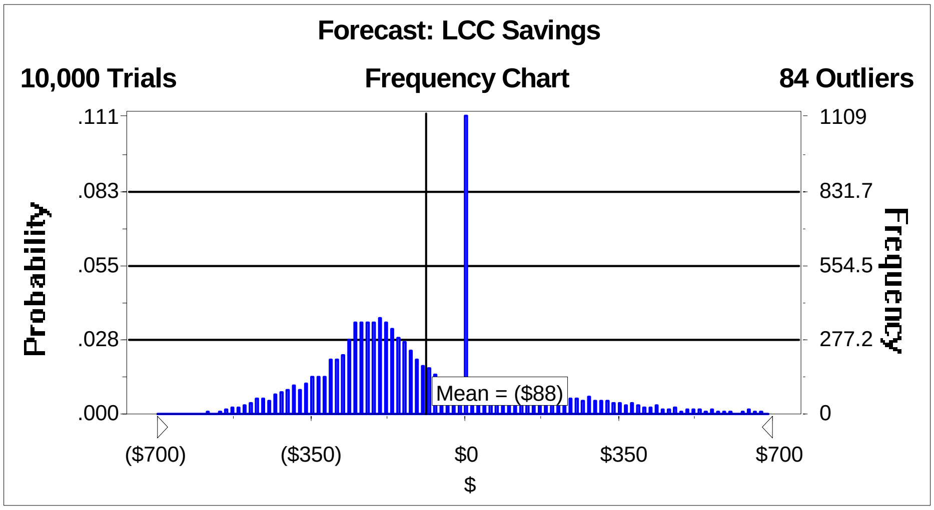

Figure 15. LCC Savings for Standard Level 5 (TP 1 + 0.6%)—Frequency Chart

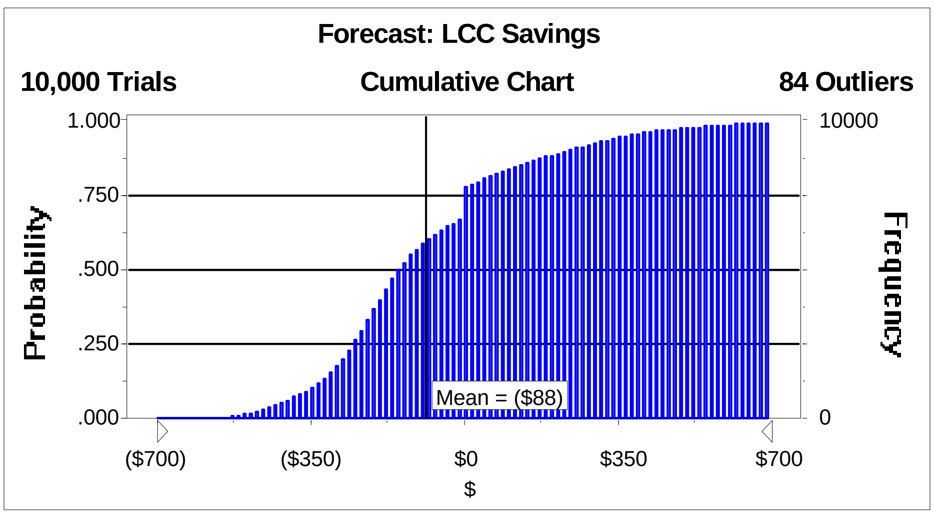

Figure 16. LCC Savings for Standard Level 5 (TP 1 + 0.6%)—Cumulative Chart

USER INSTRUCTIONS

Software and Hardware Requirements

To execute the LCC spreadsheet, the user must have the appropriate hardware and software tools operating under the Windows® operating system. Minimum system requirements have not been defined. Relatively new desktop computer systems were used during the spreadsheet development that should be similar to those used by most stakeholders. Help is available from LBNL in running the spreadsheet; contact John L. Stoops at Lawrence Berkeley National Laboratory, Phone: 510.486.6114, or e-mail JLStoops@lbl.gov. At a minimum, users need Microsoft Excel® to execute the spreadsheet. For full functionality, advanced users should have a copy of Crystal Ball®, a spreadsheet add-in to Excel®, to run Monte-Carlo simulations. Without Crystal Ball®, one can still run the LCC spreadsheet model but one will not be able to use or examine inputs and outputs as distributions. Approximate results are provided through a sample calculation that uses average values for the inputs and outputs, as displayed in the "Summary" worksheet.

Start Up

The LCC spreadsheet file is a stored Excel® file. Open the file. (Each computer system will have somewhat unique setup for loading a file. Users should refer to their software manuals if they have problem loading the spreadsheet file.)

Sheet Overview

The LCC spreadsheet is organized in the following 16 worksheets.

- Description
- Summary
- A & B Distribution
- Design Table
- Load and Price Parameters
- Utilities
- Discount Rate
- Hourly Loads
- Hourly Prices
- Annual Energy Price Forecast
- Baseline LCC
- Design Option LCC
- Lifetime
- Load-Price Charts
- Results—LLvNL
- LL vs NL

Most of the worksheets consist of the data inputs used in the spreadsheet calculations. For functionality in the spreadsheet model while maintaining reasonable size, some variables were pre-processed into a representative equation. "Hourly Loads" and "Hourly Prices" are the two best examples of using an equation (Fourier transform) to express a complex set of data in an equation. "Load—Price Charts" provides a graphical expression of the "Hourly Loads" and "Hourly Prices".

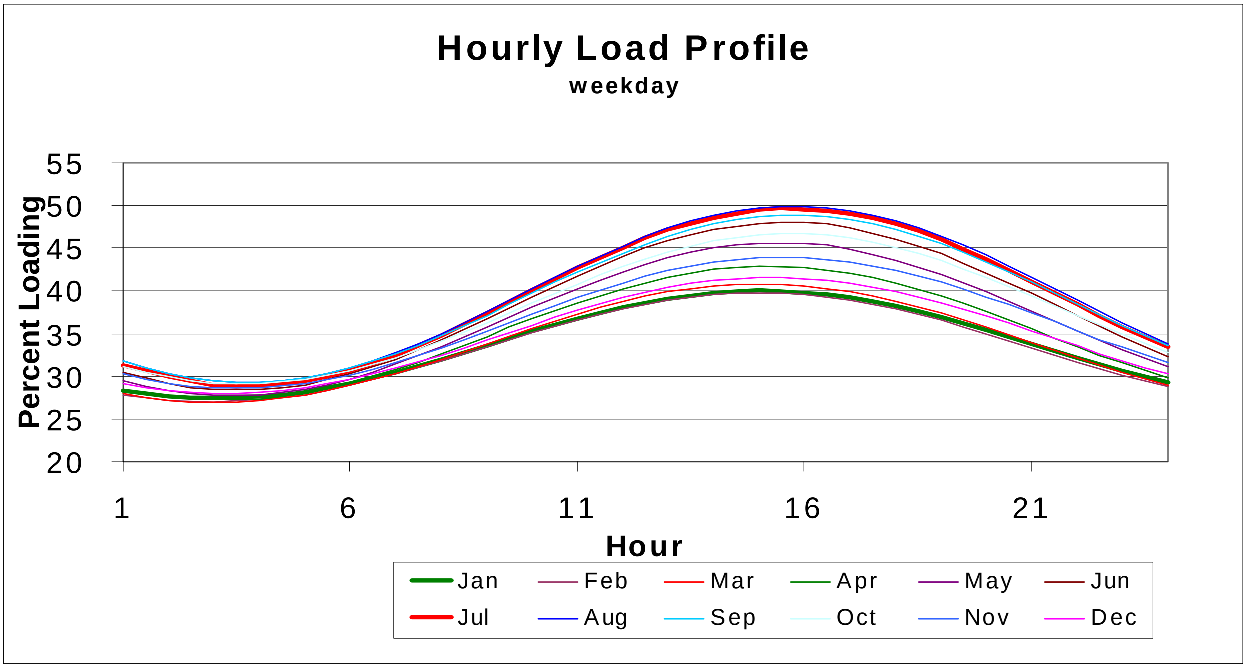

Figure 17. Hourly Load Profile

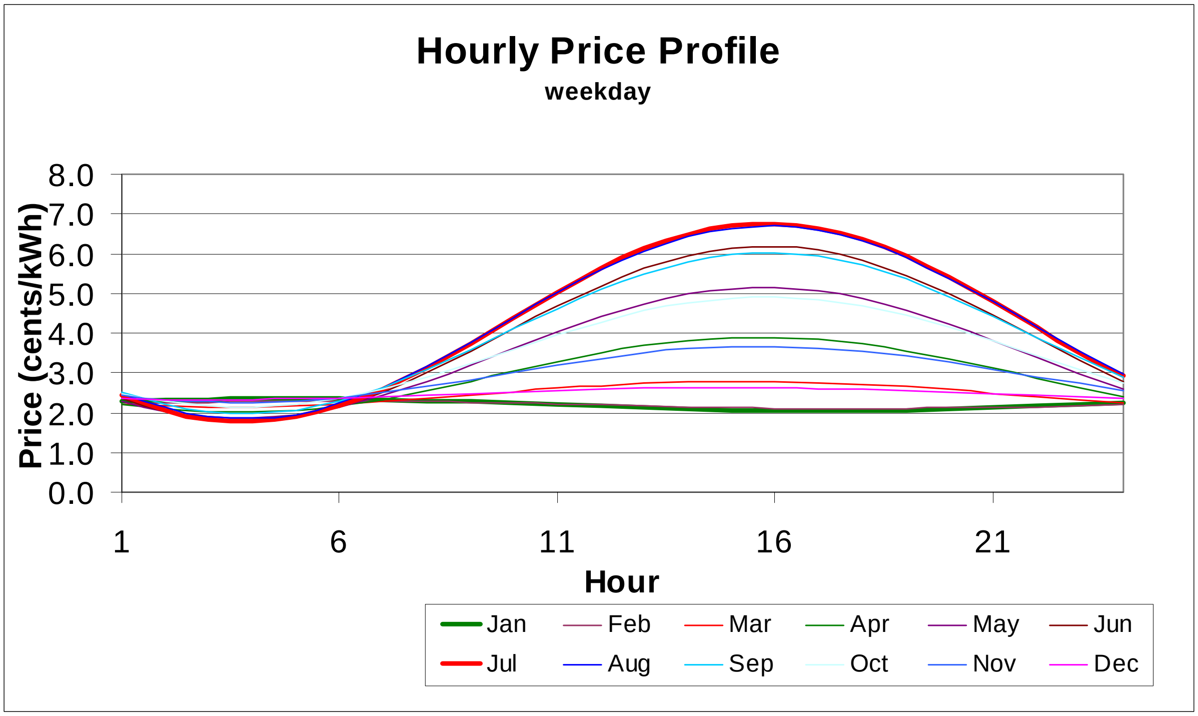

Figure 18. Hourly Price Profile (Weekday)

This document should be read in its entirety and the "Description" shown on the first (far left) worksheet should also be reviewed before using the spreadsheet. The spreadsheet/user interface is centered in the "Summary" worksheet. An example Monte-Carlo run was made to produce "Results —LLvNL" which is shown graphically as "LL vs NL". Selecting different standard levels in the "Summary" worksheet will produce a different graphical result on the "LL vs NL" sheet.

User-Selectable Variables

Several items on the "Summary" worksheet provide the user with selectable options in evaluating various standard alternatives. "User Options" can be selected from a menu for each of the following variables:

- Standard Level
- Transformer Load Growth/Year
- Transformer Loading (relative to current estimates)
- Electricity Prices (relative to current estimates)
- Utility Decision A's & B's
- Future Energy Price Trend

To account for the impact of steel duty differences for transformer manufacturers in Canada and Mexico, the "Cost Minimization Data" option allows the selection of "U.S. Only" or an alternative specified as "Include Mexico and Canada".

The effective date of the Standard can be modified from the default of 2007.

A "Reset" button brings all variables back to the starting default values.

The right side of the "Summary" sheet illustrates a sample LCC result using average values. Results utilizing the full distribution of inputs included with the spreadsheet requires a Monte-Carlo simulation.

Monte-Carlo Simulation using Crystal Ball®

Monte-Carlo Simulation is a calculation method for estimating probability distributions of results by repetitively sampling from probability distributions of input parameters. For each sampled set of input parameters/data, the simulation calculates a weight and a set of output results. The set of output results together with their weights define the probability distribution of outcomes.

Crystal Ball® is a spreadsheet add-on that allows one to perform Monte-Carlo simulations from within an Excel® spreadsheet. Spreadsheet users must have both Excel® and Crystal Ball® to run the Monte-Carlo simulations. As noted above, approximate results are provided through a sample calculation that uses average values for the inputs and is displayed on the "Summary" sheet. Making a Crystal Ball® simulation is relatively easy. First the user selects a representative set of assumptions to test by modifying the User Options on the "Summary" sheet. When configured with Crystal Ball®, the top line of the Excel® menu bar includes the entry <Run> which activates Crystal Ball®. The user should refer to the Crystal Ball® instruction manual for more complete information on conducting a simulation run.

APPENDIX A: COMPARISON BETWEEN LIFE-CYCLE COST (LCC) AND TOTAL OWNING COST (TOC) ANALYSES

The LCC analysis is used to calculate the total cost to purchasers of a transformer over its lifetime, including first cost and operating costs. The Department of Energy uses the LCC analysis as part of its consideration of economic justification for energy efficiency standards.

The TOC analysis considers first cost and operating costs and is used by some utilities to optimize their investments in new transformers. Not all transformer purchasers use the TOC method.

Life-Cycle Cost

The life-cycle cost equation reflects both the initial installed costs of a transformer and the present value of the operating costs over the life of the equipment:

(A1) $LCC = IC + SUM_{n=1,Lifetime} [OC_n/(1+Drate)^n]$

where IC is initial installed cost, SUM is the summation operation, n is the index for the year of operation, OC_n is the operating costs in year n, and Drate is the discount rate applied to the calculation.

The initial installed costs include the purchase price and installation cost of the transformer, while operating costs include the value of the losses and maintenance costs.

Total Owning Cost

Some utilities use an alternate evaluation process called the equivalent first cost Total Owning Cost (TOC) method (all terms in equation A2 expressed as equivalent first costs):

(A2) TOC = FC + cost of no-load loss + cost of load loss
(A3) cost of no-load loss = A($/Watt) * no-load loss watts * loss multiplier
(A4) cost of load loss = B ($/Watt) * load loss watts * loss multiplier

A and B are more fully explained below.

Differences in LCC and TOC Evaluation Methods

The LCC and TOC methods are quite similar, but are often used in different contexts. The LCC analysis used by the Department evaluates costs and benefits before taxes while the TOC analysis used by many utilities considers after-tax revenues and costs. The LCC analysis used by the Department analyzes economics in real inflation-adjusted dollars, while the TOC methods outlined by IEEE[1] use nominal prices and discount rates.

The LCC spreadsheet annualizes capacity costs by applying a capital recovery factor. The capital recovery factor is:

(A5) $CRF = Drate*(1+Drate)^n/(1+Drate)^n - 1)$

where in the LCC analysis Drate is the real discount rate and n is the lifetime of the capacity investment. The annualized unit cost of capacity is the capital recovery factor times the unit capacity cost. This annualized capacity cost is then applied to the annual capacity requirement and included in the cost stream that is evaluated for the LCC analysis.

The TOC analysis method uses a combination of levelized cost components to calculate A and B factors, whereas the LCC calculates forecasted annual costs, aggregates them into the annual operating costs, and calculates the present value of the annual cost stream. The TOC uses a methodology common in utility rate-making to calculate revenue requirements through the use of a fixed charge rate (FCR). The FCR includes markups for taxes and other expenses to assure that revenue streams set on the basis of the FCR will maintain the value of the company. The LCC uses a simple capital recovery factor and assumes that there is no net impact from taxes and other utility expenses that are not explicitly accounted for in the analysis.

In many cases, differences between the TOC and LCC methodologies do not produce significantly different answers. For a TOC calculation, one multiplies capacity costs times a fixed charge rate and then divides by the fixed charge rate when calculating an A or B factor. The result is an answer that depends on the capacity cost, but which is insensitive to the fixed charge rate.

With recent changes brought about by the restructuring of the electricity industry, in which utilities obtain electricity from wholesale markets at the margin, the generation capacity costs are implicit in the correlations between peak prices and peak loads. The TOC methodology currently does not have a mechanism for incorporating these economic effects. The LCC methodology used by the Department with its hourly load profiles does capture the impact of peak wholesale market prices on the operating costs of transformer losses by including the impact of peak wholesale prices on the economic value of load losses.

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[1]*Draft Guide for Distribution Transformer Loss Evaluation,* Report No. IEEE PC57.12.33/D8, 2001.

APPENDIX B. ENGINEERING ANALYSIS RESULTS: THE COST - EFFICIENCY RELATIONSHIP

In order to conduct a life-cycle cost analysis at several different trial standard efficiency levels, the relationship between a transformer’s efficiency and manufacturing cost must be understood. For instance, to move from an efficiency level of 98.5% to 98.6%, what are the design differences and the corresponding price impacts? The purpose of the Department’s Engineering Analysis is to address this question more broadly, estimating the manufacturer’s sales price over a broad range of efficiency levels.

The Department utilized a software product developed by Optimized Program Service in Cleveland, Ohio to generate a database of transformer designs for its Life Cycle Cost analysis. These designs were created using a range of TOC evaluation formulas (A and B combinations) for a set of designs incorporating commonly used core steels and winding materials.

Preliminary results of the engineering analysis were published on December 17, 2001, when the Department issued a draft report on the Engineering Analysis as part of its Distribution Transformer Rulemaking.[1] The purpose of that report was to outline the methodology selected for the Engineering Analysis, and to present the assumptions and initial findings on the first design line (50kVA). Comments were received from stakeholders following this draft report’s publication, as well as during manufacturer site visits conducted by the Department in early 2002.

Following a review of all the stakeholder input and comment, a revised database of designs was created for use by the Department in its LCC analysis. Thus, the LCC results that appear in this report are *not* based on the designs presented in the December 2001 report. These LCC results are based on a new set of designs created after the Department revised the OPS inputs based on stakeholder comments. This appendix provides information about the revised database of 50kVA designs.

Purpose of Engineering Analysis

The purpose of the engineering analysis is to estimate the relationship between the manufacturer’s sales price and a range of efficiency levels. This information is then used as input to the LCC spreadsheet, which considers a broad spectrum of possible efficiency levels in its analysis.

The Department recognized that it would be impractical to conduct detailed analysis on all 73 product classes identified in NEMA's TP-1 document, so it created thirteen 'design lines', which group together like transformers based on similar engineering principles. The Department modified the original design lines suggested in the December 2001 report, following the

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[1]A copy of the draft December 17, 2001 Engineering Analysis report can be found at the following web address: http://www.eren.doe.gov/buildings/codes_standards/applbrf/pdfs/ea_update.pdf

comments received from manufacturers and other stakeholders. The Department is still planning to use thirteen design lines, selecting one unit from each group for analysis, and then extrapolating the findings to the other units in that design line. This report concerns a 50kVA pad-mounted single-phase liquid-type unit, which is the representative model from Design Line 1.

Optimized Program Service Software

The Department selected transformer design software created by Optimized Program Service (OPS) to prepare a database of designs that span a range of efficiency levels. Given a range of inputs, the software will generate optimized, practical transformer designs spanning a range of efficiencies. The output from the software includes details on core construction, low and high voltage windings, insulation levels and so on. In addition to a design report, the software also provides a bill of materials and an electrical analysis of the unit at various loading points.

It should be noted that the manufacturing costs produced by the software do not include any redesigning costs, retooling or other necessary capital investments. Thus the manufacturer's price-efficiency relationship shown in this report is a best-case scenario, assuming no additional costs other than labor and materials in building more efficient units. The Department will be gathering information about these costs in 2003, when it conducts a Manufacturers Impact Assessment (MIA).

Creating a Database of Designs

Two key inputs that influence the resultant designs of the OPS software are the A and B values, reflecting the present value of all the future core (A) and coil (B) losses that the transformer will experience in its lifetime. The Department developed a matrix of A and B values that could be used to generate a database of designs spanning a range of efficiency levels. For its December 2001 report, the Department used 1031 combinations of A and B, where B is not greater than A:

A ranging from $0 to $8 by 0.2 increments
B ranging from $0 to $3 by 0.1 increments

Many stakeholders commented that the increments within the A and B values were too fine and should be reduced. The DOE responded to this comment, and also made a decision to conduct an 'extended analysis' on some of the designs to push the envelope of efficiency, and drive the materials to their physical maximum. The set of revised A and B combinations was reduced from 1031 to 179, using the values described below, with B not greater than A:

A ranging from $0 to $8 by 0.5 increments
B ranging from $0 to $3 by 0.25 increments

For those design option combinations that were evaluated under the extended analysis, an additional 62 runs were conducted, using the following combinations of A and B:

A ranging from $8 to $16 by 1.0 increments
B ranging from $3 to $6 by 0.5 increments

Figure B.1 shows all the A and B evaluation points used as input to the OPS software in generating the database of efficient designs.

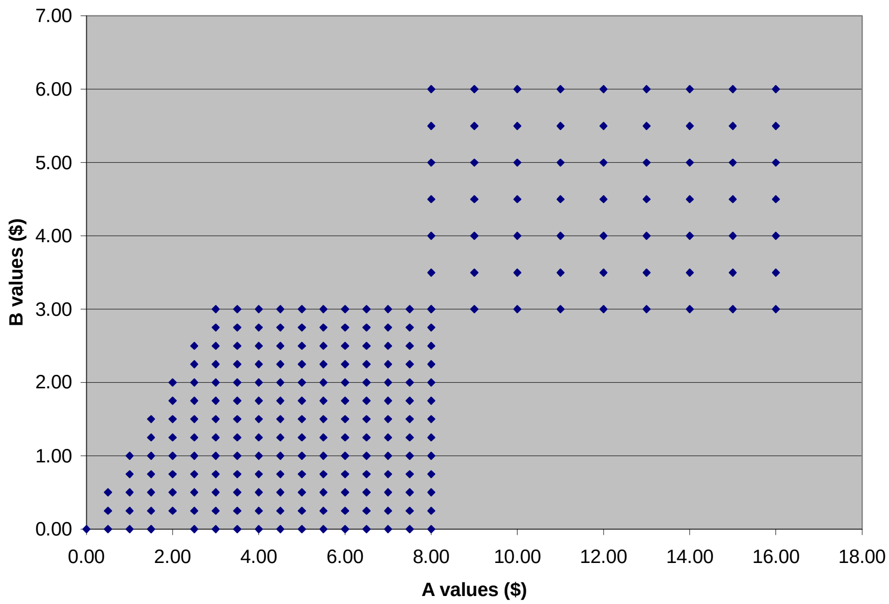

Figure B.1 Combinations of A and B used in Generating the 50kVA Database of Designs

Set-up for the 50kVA Liquid-Type Single-Phase Pad-Mount

The Department understands that there are several ways to build a 50kVA transformer. Depending on a number of factors, manufacturers may use different core steels (e.g., M2, M3, M6), winding materials (e.g., aluminum or copper) and core configurations (e.g., shell or core-type). In its draft December 2001 Engineering Analysis Update report, the Department presented twelve design option combinations (Table 5, page 15) that were intended to capture the most common ways of building a transformer with this rating in the United States. Following meetings with manufacturers in January and February 2002, the Department reduced the table of design options combinations to ten, and made some other modifications to input parameters to the OPS software.

The revised Design Line 1 incorporates single-phase, liquid-type transformers in a rectangular tank, either pad-mounted or submersible, from 10 through 100 kVA, with a BIL ≤95-150 kV, standard taps of ±2-2½ %, and secondary voltages of 240/120 through 600V. The representative unit for this design line is as follows:

kVA: 50 (pad mount)
Configuration: ANSI/IEEE C57.12.25 Fig 2(a)
Primary: 24940GrdY/14400 at 60Hz (125 kV BIL)
Secondary: 240/120V
T Rise: 65°C
Winding Configuration: Lo-Hi-Lo
Core: Shell form, Distributed Gap
Taps: Four full capacity, with two 2-½% above normal and two 2-½% below normal
Impedance Range: 1.5 - 3.5%

Table B.1 presents the combinations of core steel, winding materials and core configurations that were evaluated in the revised analysis. The"A & B Analysis" column refers to the range of A and B values used in generating the set of designs for that design option combination, as described in section B.3. Note that the extended analysis was only applied to design options which were considered likely core/coil combinations for the higher values of A and B.

Table B.1 Design Option Combinations for the 50 kVA Single Phase Liquid-Type Pad-Mount Transformer

Design Option	Core Metal	Conductor High Voltage Metal	Conductor Low Voltage Metal	Core/Coil Design Type	A & B Analysis
1	M2	Cu	Al	Shell	Normal
2	M2	Cu	Cu	Shell	Extended
3	M3	Al	Al	Shell	Normal
4	M3	Cu	Al	Shell	Normal
5	M3	Cu	Cu	Shell	Normal
6	M6	Al	Al	Shell	Normal
7	M6	Cu	Al	Shell	Normal
8	SA1 (Amorphous)	Cu	Cu	Core	Extended
9	ZDMH – price 1	Cu	Cu	Shell	Extended
10	ZDMH – price 2	Cu	Cu	Shell	Extended

ZDMH is mechanically scribed, deep domain refined core steel produced by Nippon Steel in Japan. This steel can 'survive' the annealing process, meaning its lower-loss properties are retained after the wound, shaped core has been annealed in a furnace. Two prices are used for this steel because Japanese and Italian core steels imported to the United States are subject to an anti-dumping tariff of ~31%. Thus, ZDMH is being analyzed at two price points in our analysis, one to reflect the cost of material with the tariff (for US manufacturers) and one to reflect the cost without the tariff (for non-US manufacturers). This is to ensure that the Department's analysis takes into consideration regional competition and differentiation of material prices when evaluating trial standard levels.

In its December 2001 report, the Department had used one fixed tank size for all the 50kVA designs. This simplification meant that many of the designs were in an oversized tank with an excessive quantity of oil. Manufacturer comments on the December report indicated that they include oil and tank steel in their optimization routines, and it was suggested the Department vary the tank size and oil in its engineering analysis. However, as written, the OPS software does not consider these variables as do the more sophisticated industry design programs. Thus, the Department elected to use five fixed tank sizes in its analysisto allow for some variation in the price differential of tank size and oil volume in the designs. Table B.2 provides the dimensions of the tanks used, and the prices assumed for each. The length and height of the tank were fixed at dimensions necessary for mounting the transformer bushings. The depth of the tank was varied to accommodate the core/coil assembly and to achieve the specified oil requirements of the OPS design.

Table B.2 Table of Fixed Tank Sizes Used for the 50 kVA Single Phase Liquid-Type Pad-Mount Transformer

Tank	Length (in)	Height (in)	Depth (in)	Volume (in^3)*	Volume (gal)*	Price ($)
A	32	24	13	8320	36.0	210
B	32	24	15	9600	41.6	220
C	32	24	17	10880	47.1	230
D	32	24	19	12160	52.6	240
E	32	24	21	13440	58.2	250

*Volume measurements are less a four inch air-gap between the top of the oil and the lid of the tank.

Data Provided to the Department and Results

After applying all the recommended modifications to the OPS software input parameters, a revised database of designs was generated for the LCC analysis presented in this report. The complete Engineering Analysis design database contains 2038 designs for building a 50kVA unit, spanning a broad range of efficiencies. From this database, the following six data fields were extracted for utilization in the LCC analysis:

No-load (core) losses (Watts)
Temperature corrected[1] load-loss (winding) at 50% load (Watts)
Load loss (winding) at 100% load (Watts)
Selling price ($)
A input ($/Watt)
B input ($/Watt)

These fields represent the information required to run a LCC analysis on the 50kVA unit. The other data contained in the design database, which includes core dimensions, number of turns, wire sizes, insulation levels and so on, were reviewed by experts working for the Department to verify that they were legitimate designs, validating the estimated cost - efficiency relationship.

The resultant cost - efficiency relationships for all of the core-winding material combinations presented in Table B.1 have been plotted to illustrate the approximate price and performance levels of the revised dataset being used in the LCC analysis. These efficiency plots are temperature corrected[2] according to the draft DOE test procedure at 50% of nameplate load, 55°C temperature rise. The prices on the Y-axis of these plots represent the manufacturer sales price, as it leaves the factory.

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[1]The Department utilized the equations in its draft Test Procedure to apply a temperature correction to the efficiency levels calculated at the evaluation point (50% of nameplate) by the OPS software.

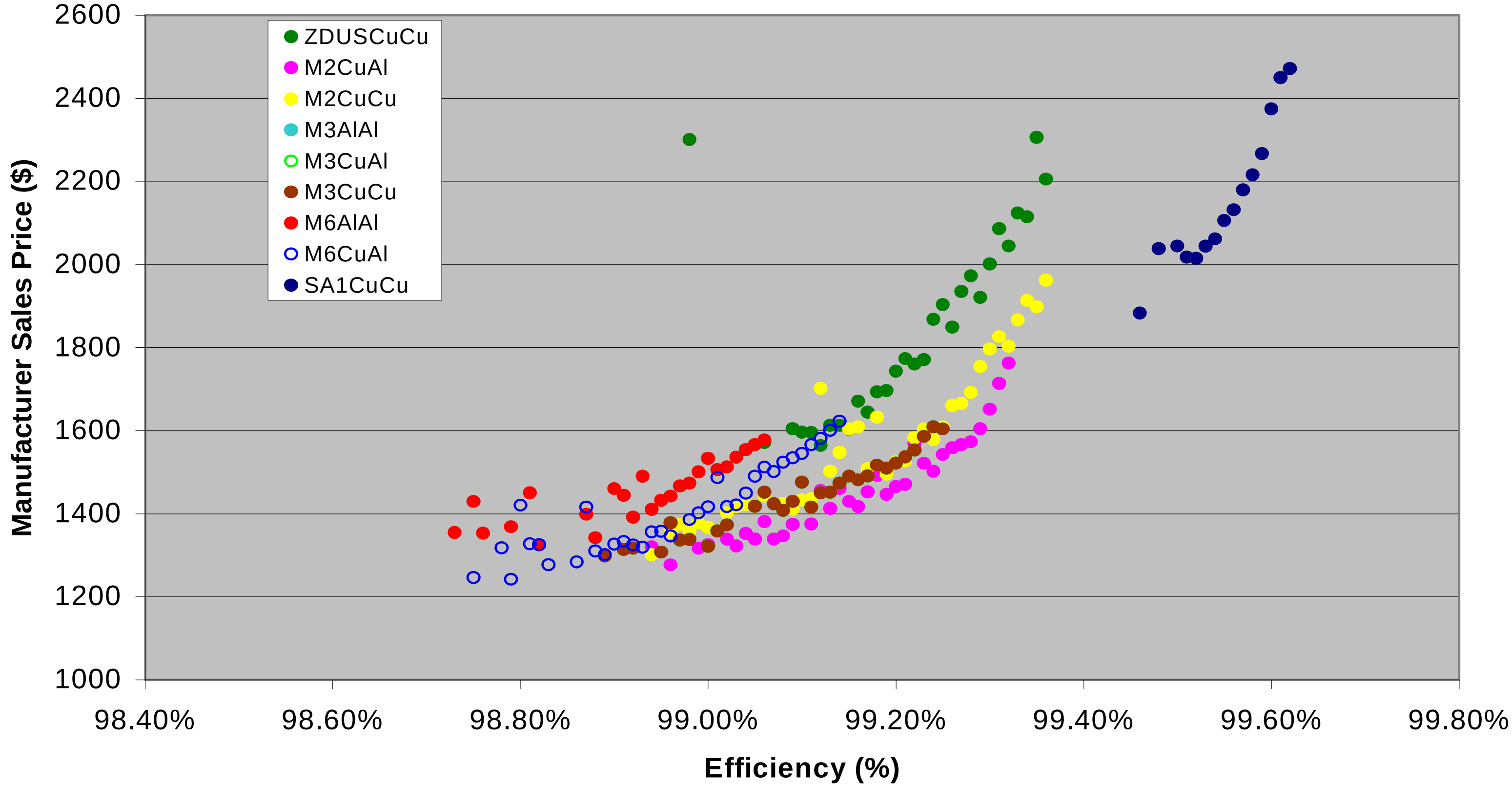

Figure B.2 Selling Price vs. Efficiency for 50kVA Single-Phase Liquid-Type Pad-Mount Transformers

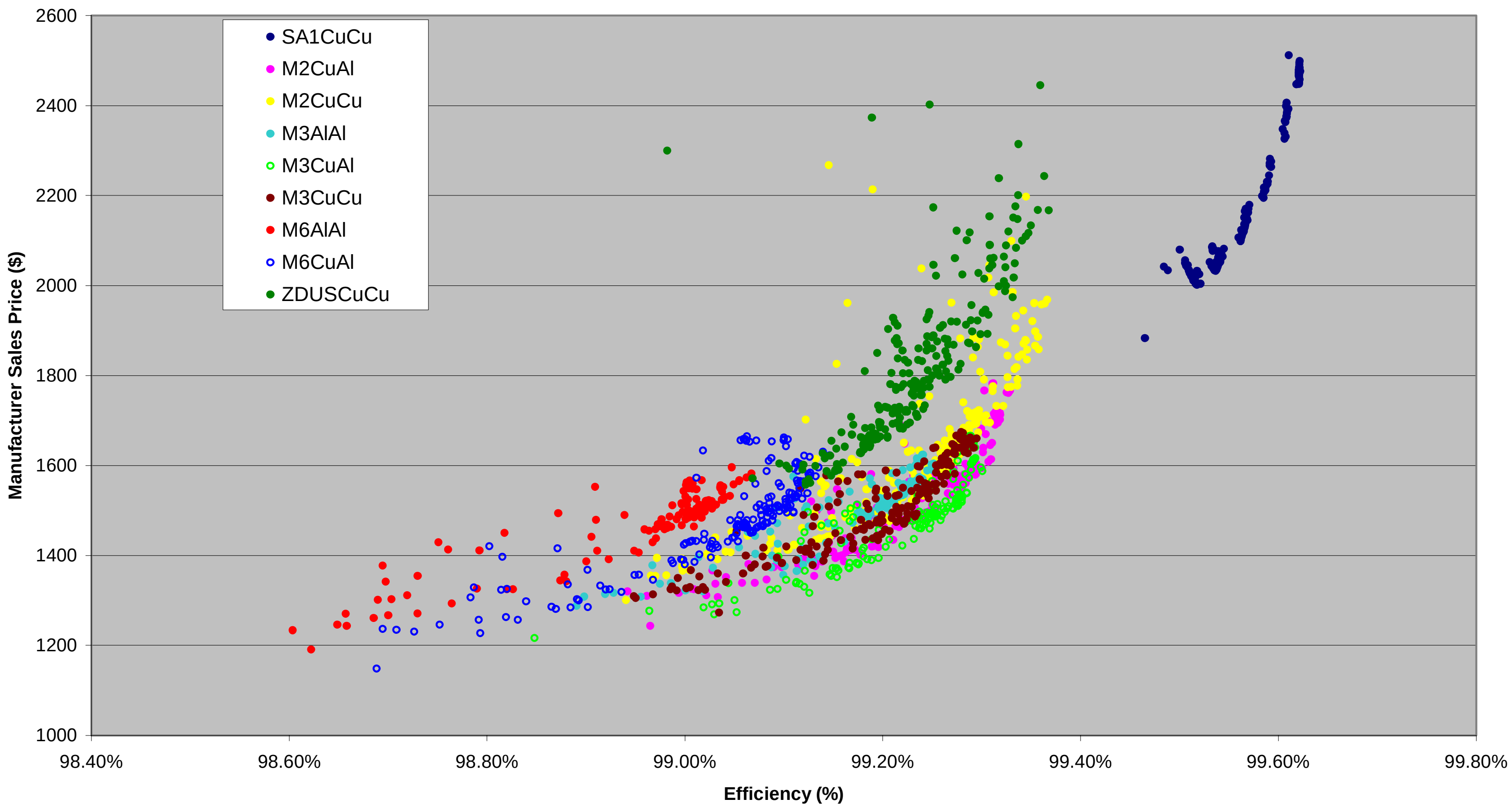

Figure B.3 Average Selling Prices vs. Efficiency for 50kVA Single-Phase Liquid-Type Pad-Mount Transformers

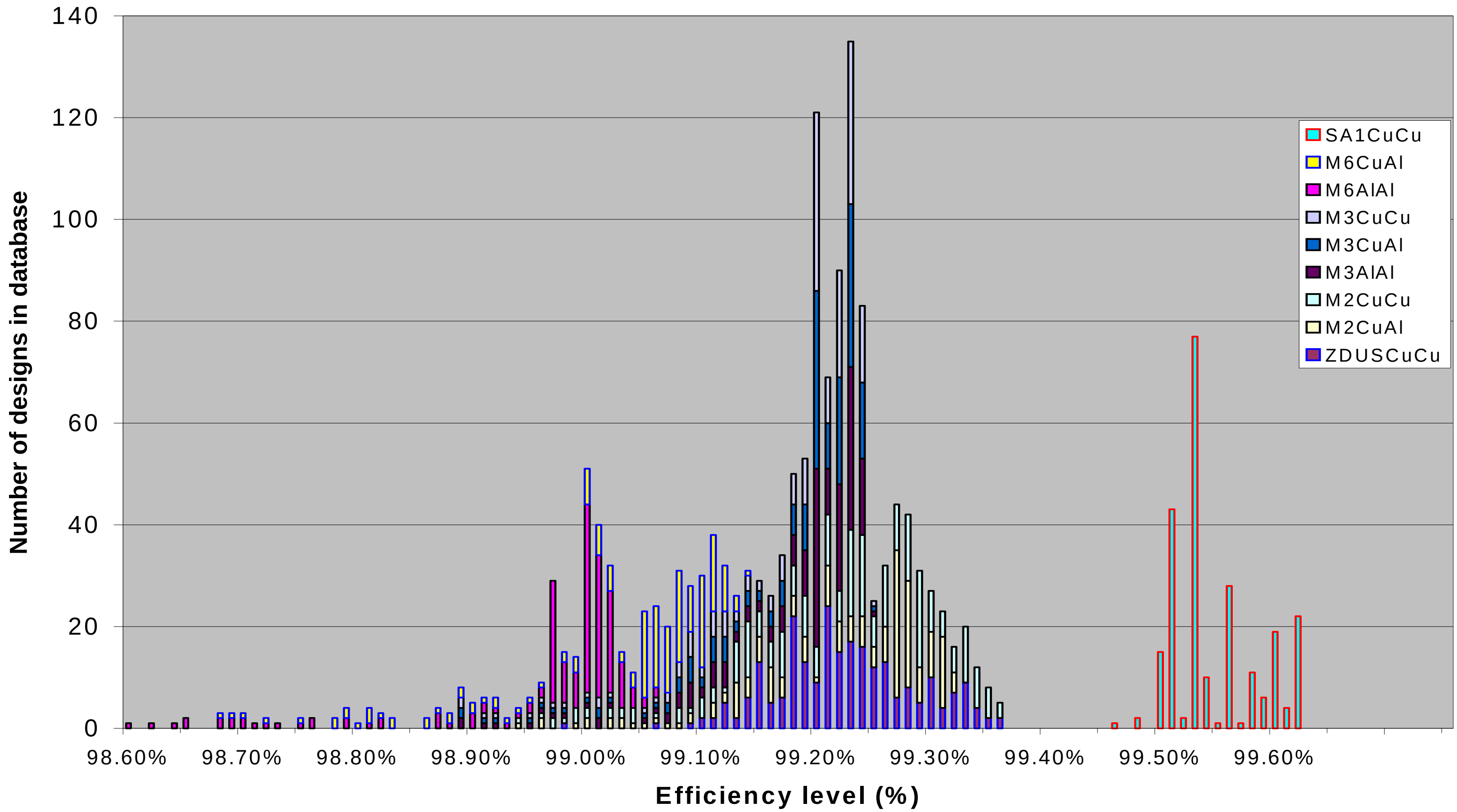

Figure B.4 Histogram Plot Showing Number of Designs in the Database of 50 kVA Single-Phase Liquid-Type Pad-Mount Transformers

Example Transformers from the New Database

Three designs of different core/coil combinations selected from the OPS database are presented in this section. These specification sheets provide detailed technical data that enable transformer engineers to review the revised designs being used in the analysis. The three core/coil combinations presented in this section are M6AlAl, M3CuAl and M2CuCu. The core/coil combinations are for the OPS design created for the $3A and $1B evaluation point.

M6AlAl 50kVA single-phase pad-mount liquid-type transformer

The following is a design specification sheet from the revised dataset for M6 core steel with an aluminum primary and secondary. The evaluation formula used to generate this optimized design was A=$3 and B=$1.

```
                    OPTIMIZED PROGRAM SERVICE
                    2002- 2-28    12:17:41


DG-CORE      SHELL   TYPE TRANSFORMER             L1PM6ALAL

FREQUENCY    60.0           KVA RATING     50.00 @ 100.00% DUTY CYCLE

CORE DG-M6         M 6                          THICKNESS .0140

  D: 8.004 E: 2.159 F: 4.302 G: 9.439  EFF. AREA  33.352 WEIGHT 312.941

WINDING FORM: INS. DIM.  8.254 X  4.504  THICKNESS  .072  LENGTH  8.939


                COIL SPECIFICATIONS
                -------------------

WNDG           WIRE           LENGTH   MEAN TURNS  MARGIN      WT
-----------------------------------------------------------------------
S1        .0466X 8.1893   AL      34.06      29.20     .375     15.210
P1     1X 1 #11 ROUND    H AL    6122.85      41.65     .375     44.125
S2        .0466X 8.1893   AL      63.05      54.05     .375     28.155


NUMBER OF COILS  1              TOTAL BARE CONDUCTOR WEIGHT    87.490


WNDG  TURNS  LO TAP  HI TAP  LAYRS   T/L   LAYR INS    SEC. INS    BUILD
-----------------------------------------------------------------------
S1      14.0                14      1.0  1(.00500)  1(.03000)     .717
P1    1680.0  1596.0  1764.0 24     74.0  3(.00500)  1(.10000)    2.037
S2      14.0                14      1.0  1(.00500)  1(.05000)     .717

                              TOTAL BUILD(%)  86.55

WNDG            TAPS: TURNS( VOLTS)
-----------------------------------------------------------
P1    1638.0( 14040.00)  1722.0( 14760.00)  1764.0( 15120.00)
```

WNDG	INTERNAL DUCTS(100.00) %EFF	EXTERNAL DUCTS(100.00) %EFF
S1	3 .125 X .125 IN. END	
P1	6 .125 X .125 IN. END	.125 X .125 IN. END
S2	1 .125 X .125 IN. END	.125 X .125 IN. END

ELECTRICAL ANALYSIS

WNDG	FULL-LOAD VOLTS	TAP VOLTS LOW	TAP VOLTS HIGH	TEST KV	LOAD CURRENT	RESIST. @20 C.	CURRNT DENS.	%REG
P1	14400.00	13680.00	15120.00	34.5	3.512	13.30197	571.	
S1	119.19			10.0	208.330	.00119	547.	.7
S2	118.93			10.0	208.330	.00221	547.	.9

	F.L.	N.L.		
FLUX DENS.	14.888	14.948	LEAKAGE INDUCTANCE MHYS	188.224
CORE LOSS	181.068	182.652	POWER FACTOR	1.0000
COIL LOSS	395.447	.004	IMPEDANCE %	1.88
EXCIT. VA	214.101	216.766	EFFICIENCY %	98.86
EXCIT. CURR.	.015	.015	TANK OIL GAL	24.05

AMBIENT TEMP.	30.00	NOMINAL LENGTH	17.24
TEMP.RISE	55.00	NOMINAL DEPTH	19.86
OPERATING TEMP.	85.00	NOMINAL HEIGHT	13.76

COND. I^2R LOSS = 382.6677
COND. EDDY CURRENT LOSS = 3.2122
OTHER STRAY LOSS = 9.5667
K VALUE = 1.0000

%LOAD	%REG	%EFF	%IR	%IX	%IZ	COIL LOSS	TEMP. RISE
25	.17	98.39	.163	.435	.464	22.047	19.5
35	.24	98.73	.229	.607	.648	43.338	21.3
50	.35	98.93	.330	.865	.926	89.472	25.2
65	.46	98.98	.437	1.124	1.206	153.878	30.4
75	.55	98.97	.512	1.296	1.394	207.843	34.6
100	.76	98.88	.714	1.730	1.872	386.277	47.7
125	1.01	98.71	.942	2.166	2.362	636.481	64.6
150	1.23	98.55	1.136	2.603	2.840	920.885	65.0

This is the breakdown of costs, or the 'bill of materials', associated with this design, M6 core steel, with a aluminum primary and aluminum secondary.

Bill of Materials and Labor for 50 kVA Pad-mount liquid-type
Design Option Combination: M6AlAl

Evaluation formula
A Input $3.00
B Input $1.00

Material item	Type	Quantity	$ each	$ total
Core Steel *	M6	312.94	$0.85	$272.65
P1 winding *	Al, wire	44.13	$2.25	$101.76
S1 winding *	Al, strip	15.21	$1.30	$20.27
S2 winding *	Al, strip	28.16	$1.30	$37.52
P1 insulation *	Kraft	3.40	$1.54	$5.37
S1 insulation *	Kraft	0.51	$1.54	$0.80
S2 insulation *	Kraft	1.12	$1.54	$1.76
Tank Oil Gal	Mineral Oil	37.8	$1.50	$56.68
Tank Size	C	1	$230.00	$230.00
H.V. Bushing	Universal, 7200V	2	$7.00	$14.00
L.V. Bushing	Copper studs	3	$8.00	$24.00
Fuse System	Bayonet	1	$35.00	$35.00
Core Clamp	shell-type	1	$9.25	$9.25
Tap Changer		1	$13.75	$13.75
Miscellaneous hardware		1	$5.65	$5.65
Scrap Factor				1.025
Factory Overhead				1.125
Total Material Cost (inc. scrap & factory overhead)				$ 932.03

Labor Item	Hours
P1 Labor	1.764
S1 Labor	0.028
S2 Labor	0.028
Lead Dressing Labor	0.800
Banding Labor	0.050
Assembly Labor	0.500
Inspection Labor	0.100
Preliminary Test Labor	0.100
Final Test Labor	0.150
Packing Labor	0.50
Marking Labor	0.100
Miscellaneous Labor	0.250
Total Labor	4.37
Hourly Rate	$42.77
Labor Cost $	$186.90
Manufacturing Cost	$ 1,118.93
Selling Factor	1.250
Selling Price	$ 1,398.66

** indicates those items which had a scrap factor calculated in the $ total = (quantity x $each x scrap factor)*

Figure B.5 provides a summary of the costs contributing to the total selling price of this particular transformer. From this illustration it becomes clear that approximately 60% of the final selling price of an M6 core steel, aluminum primary and secondary is direct material and scrap. Labor accounts for approximately 13% of the price, and the overhead and selling factor account for 27%. The definitions of each of these categories are contained in section 3.2 of the aforementioned Engineering Analysis Update Report.

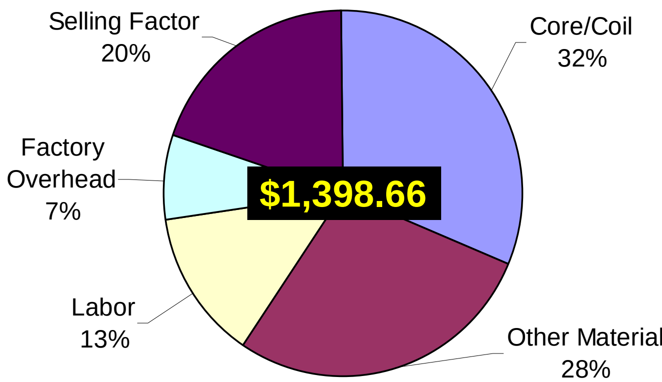

Figure B.5 Manufacturing Price Breakdown for M6AlAl

M3CuAl 50kVA single-phase pad-mount liquid-type transformer

The following is a design specification sheet from the revised dataset for M3 core steel with a copper primary and an aluminum secondary. The evaluation formula used to generate this optimized design was A=$3 and B=$1.

OPTIMIZED PROGRAM SERVICE
2002- 2-27 15:56:28

DG-CORE SHELL TYPE TRANSFORMER L1PM3CUAL

FREQUENCY 60.0 KVA RATING 50.00 @ 100.00% DUTY CYCLE

CORE DG-M3 M 3 THICKNESS .0090

D: 7.448 E: 2.028 F: 3.645 G: 9.595 EFF. AREA 28.995 WEIGHT 260.738

WINDING FORM: INS. DIM. 7.698 X 4.241 THICKNESS .072 LENGTH 9.095

COIL SPECIFICATIONS

WNDG	WIRE		LENGTH	MEAN TURNS	MARGIN	WT
S1	.0437X 8.3451	AL	34.49	27.59	.375	14.730
P1	1X 1 #13 ROUND	H CU	5970.75	37.91	.375	89.137
S2	.0437X 8.3451	AL	60.21	48.17	.375	25.718

NUMBER OF COILS 1 TOTAL BARE CONDUCTOR WEIGHT 129.585

WNDG	TURNS	LO TAP	HI TAP	LAYRS	T/L	LAYR INS	SEC. INS	BUILD
S1	15.0			15	1.0	1(.00500)	1(.03000)	.726
P1	1800.0	1710.0	1890.0	20	95.0	3(.00500)	1(.10000)	1.410
S2	15.0			15	1.0	1(.00500)	1(.05000)	.726

TOTAL BUILD(%) 85.44

WNDG	TAPS: TURNS(VOLTS)		
P1	1755.0(14040.00)	1845.0(14760.00)	1890.0(15120.00)

WNDG	INTERNAL DUCTS(100.00) %EFF	EXTERNAL DUCTS(100.00) %EFF
S1	3 .125 X .125 IN. END	
P1	6 .125 X .125 IN. END	.125 X .125 IN. END
S2	1 .125 X .125 IN. END	.125 X .125 IN. END

ELECTRICAL ANALYSIS

WNDG	FULL-LOAD VOLTS	TAP VOLTS LOW	HIGH	TEST KV	LOAD CURRENT	RESIST. @20 C.	CURRNT DENS.	%REG
P1	14400.00	13680.00	15120.00	34.5	3.507	12.55548	905.	
S1	119.21			10.0	208.330	.00126	572.	.7
S2	118.96			10.0	208.330	.00221	572.	.9

	F.L.	N.L.		
FLUX DENS.	15.987	16.048	LEAKAGE INDUCTANCE MHYS	176.703
CORE LOSS	125.351	126.801	POWER FACTOR	1.0000
COIL LOSS	385.725	.003	IMPEDANCE %	1.77
EXCIT. VA	202.372	207.498	EFFICIENCY %	98.99
EXCIT. CURR.	.014	.014	TANK OIL GAL	19.65

AMBIENT TEMP.	30.00	NOMINAL LENGTH	15.40
TEMP.RISE	55.00	NOMINAL DEPTH	17.99
OPERATING TEMP.	85.00	NOMINAL HEIGHT	13.65

COND. I^2R LOSS = 373.5609
COND. EDDY CURRENT LOSS = 2.8252
OTHER STRAY LOSS = 9.3390
K VALUE = 1.0000

%LOAD	%REG	%EFF	%IR	%IX	%IZ	COIL LOSS	TEMP. RISE
25	.16	98.83	.158	.406	.436	21.213	16.1
35	.23	99.05	.222	.568	.609	41.784	18.2
50	.34	99.16	.322	.810	.871	86.461	22.4
65	.45	99.16	.427	1.053	1.136	149.017	28.1
75	.53	99.13	.500	1.215	1.314	201.566	32.7
100	.74	99.01	.701	1.622	1.767	376.001	47.0
125	.99	98.82	.929	2.031	2.234	623.112	65.0

150 1.20 98.66 1.116 2.442 2.685 898.002 65.0

Bill of Materials and Labor for 50 kVA Pad-mount liquid-type
Design Option Combination: M3CuAl

Evaluation formula

A Input	$3.00
B Input	$1.00

Material item	**Type**	**Quantity**	**$ each**	**$ total**
Core Steel *	M3	260.74	$0.95	$253.90
P1 winding *	Cu, wire	89.14	$1.30	$118.78
S1 winding *	Al, strip	14.73	$1.30	$19.63
S2 winding *	Al, strip	25.72	$1.30	$34.27
P1 insulation *	Kraft	2.72	$1.54	$4.29
S1 insulation *	Kraft	0.52	$1.54	$0.81
S2 insulation *	Kraft	1.06	$1.54	$1.67
Tank Oil Gal	Mineral Oil	34.0	$1.50	$51.07
Tank Size	B	1	$220.00	$220.00
H.V. Bushing	Universal, 7200V	2	$7.00	$14.00
L.V. Bushing	Copper studs	3	$8.00	$24.00
Fuse System	Bayonet	1	$35.00	$35.00
Core Clamp	shell-type	1	$9.25	$9.25
Tap Changer		1	$13.75	$13.75
Miscellaneous hardware		1	$5.65	$5.65
Scrap Factor				1.025
Factory Overhead				1.125
Total Material Cost (inc. scrap & factory overhead)				$ 906.83

Labor Item	**Hours**
P1 Labor	1.89
S1 Labor	0.03
S2 Labor	0.03
Lead Dressing Labor	0.800
Banding Labor	0.050
Assembly Labor	0.500
Inspection Labor	0.100
Preliminary Test Labor	0.100
Final Test Labor	0.150
Packing Labor	0.50
Marking Labor	0.100
Miscellaneous Labor	0.250
Total Labor	4.5
Hourly Rate	$42.77
Labor Cost $	$192.47
Manufacturing Cost	$ 1,099.29
Selling Factor	1.250
Selling Price	$ 1,374.11

** indicates those items which had a scrap factor calculated in the $ total = (quantity x $each x scrap factor)*

This is the breakdown of costs, or the 'bill of materials', associated with this design, M3 core steel, with a copper primary and aluminum secondary.

Figure B.6 provides a summary of the costs contributing to the total selling price of this particular transformer. From this illustration it becomes clear that approximately 59% of the final selling price of an M3 core steel, copper primary and aluminum secondary is direct material and scrap. Labor accounts for approximately 14% of the price, and the overhead and selling factor account for 27%. The definitions of each of these categories are contained in section 3.2 of the aforementioned Engineering Analysis Update Report.

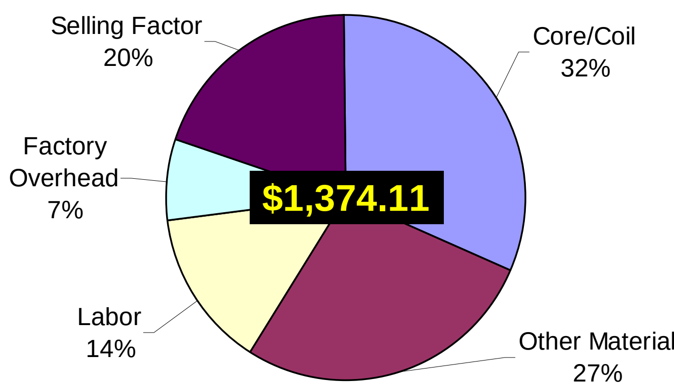

Figure B.6 Manufacturing Price Breakdown for M3CuA1

M2CuCu 50kVA Single-Phase Pad-Mount Liquid-Type Transformer

The following is a design specification sheet from the revised dataset for M2 core steel with a copper primary and secondary. The evaluation formula used to generate this optimized design was A=$3 and B=$1.

```
                OPTIMIZED PROGRAM SERVICE
                2002- 2-28    15:36:31

DG-CORE       SHELL   TYPE TRANSFORMER              L1PM2CUCU

FREQUENCY    60.0           KVA RATING     50.00 @ 100.00% DUTY CYCLE

CORE DG-M2         M 2                           THICKNESS .0070

  D: 8.651 E: 2.194 F: 2.934 G: 6.992  EFF. AREA  36.063 WEIGHT 266.189

WINDING FORM: INS. DIM.  8.901 X  4.574  THICKNESS  .072  LENGTH  6.492


                 COIL SPECIFICATIONS
                 -------------------

WNDG          WIRE          LENGTH   MEAN TURNS  MARGIN      WT
----------------------------------------------------------------------
S1       .0329X 5.7417   CU      29.71      29.71     .375     21.601
P1    1X 1 #14 ROUND    H CU    5038.46      39.99     .375     59.701
S2       .0329X 5.7417   CU      50.21      50.21     .375     36.508
```

NUMBER OF COILS 1 TOTAL BARE CONDUCTOR WEIGHT 117.811

WNDG	TURNS	LO TAP	HI TAP	LAYRS	T/L	LAYR INS	SEC. INS	BUILD
S1	12.0			12	1.0	1(.00500)	1(.03000)	.450
P1	1440.0	1368.0	1512.0	19	80.0	4(.00500)	1(.10000)	1.675
S2	12.0			12	1.0	1(.00500)	1(.05000)	.450

TOTAL BUILD(%) 96.33

WNDG	TAPS: TURNS(VOLTS)		
P1	1404.0(14040.00)	1476.0(14760.00)	1512.0(15120.00)

WNDG	INTERNAL DUCTS(100.00) %EFF	EXTERNAL DUCTS(100.00) %EFF
S1	3 .125 X .125 IN. END	
P1	6 .125 X .125 IN. END	.125 X .125 IN. END
S2	1 .125 X .125 IN. END	.125 X .125 IN. END

ELECTRICAL ANALYSIS

WNDG	FULL-LOAD VOLTS	TAP VOLTS LOW	TAP VOLTS HIGH	TEST KV	LOAD CURRENT	RESIST. @20 C.	CURRNT DENS.	%REG
P1	14400.00	13680.00	15120.00	34.5	3.508	13.34890	1141.	
S1	119.18			10.0	208.330	.00128	1104.	.7
S2	118.95			10.0	208.330	.00217	1104.	.9

	F.L.	N.L.		
FLUX DENS.	16.064	16.128	LEAKAGE INDUCTANCE MHYS	164.457
CORE LOSS	125.082	126.743	POWER FACTOR	1.0000
COIL LOSS	395.533	.005	IMPEDANCE %	1.68
EXCIT. VA	235.180	242.044	EFFICIENCY %	98.97
EXCIT. CURR.	.016	.017	TANK OIL GAL	16.62

AMBIENT TEMP.	30.00	NOMINAL LENGTH	14.64
TEMP.RISE	55.00	NOMINAL DEPTH	17.77
OPERATING TEMP.	85.00	NOMINAL HEIGHT	11.38

COND. I^2R LOSS = 382.7523
COND. EDDY CURRENT LOSS = 3.2115
OTHER STRAY LOSS = 9.5688
K VALUE = 1.0000

%LOAD %REG %EFF %IR %IX %IZ COIL LOSS TEMP. RISE

25	.17	98.83	.164	.378	.412	21.981	18.5
35	.24	99.04	.231	.528	.577	43.341	20.9
50	.35	99.14	.336	.754	.825	89.893	26.0
65	.47	99.14	.447	.980	1.077	155.414	32.8
75	.55	99.11	.526	1.131	1.247	210.733	38.3
100	.78	98.97	.741	1.510	1.682	395.971	55.4
125	1.01	98.79	.956	1.891	2.119	638.186	65.0
150	1.22	98.63	1.149	2.273	2.547	920.576	65.0

This is the breakdown of costs, or the 'bill of materials', associated with this design, M2 core steel, with a copper primary and copper secondary.

Bill of Materials and Labor for 50 kVA Pad-mount liquid-type
Design Option Combination: M2CuCu

Evaluation formula
A Input $3.00
B Input $1.00

Material item	Type	Quantity	$ each	$ total
Core Steel *	M2	266.19	$1.05	$286.49
P1 winding *	Cu, wire	59.70	$1.30	$79.55
S1 winding *	Cu, strip	21.60	$2.40	$53.14
S2 winding *	Cu, strip	36.51	$2.40	$89.81
P1 insulation *	Kraft	2.44	$1.54	$3.86
S1 insulation *	Kraft	0.33	$1.54	$0.53
S2 insulation *	Kraft	0.69	$1.54	$1.08
Tank Oil Gal	Mineral Oil	29.9	$1.50	$44.87
Tank Size	A	1	$210.00	$210.00
H.V. Bushing	Universal, 7200V	2	$7.00	$14.00
L.V. Bushing	Copper studs	3	$8.00	$24.00
Fuse System	Bayonet	1	$35.00	$35.00
Core Clamp	shell-type	1	$9.25	$9.25
Tap Changer		1	$13.75	$13.75
Miscellaneous hardware		1	$5.65	$5.65
Scrap Factor				1.025
Factory Overhead				1.125
Total Material Cost (inc. scrap & factory overhead)				$ 979.84

Labor Item	Hours
P1 Labor	1.512
S1 Labor	0.024
S2 Labor	0.024
Lead Dressing Labor	0.800
Banding Labor	0.050
Assembly Labor	0.500
Inspection Labor	0.100
Preliminary Test Labor	0.100
Final Test Labor	0.150
Packing Labor	0.50
Marking Labor	0.100
Miscellaneous Labor	0.250
Total Labor	4.11
Hourly Rate	$42.77
Labor Cost $	$175.78
Manufacturing Cost	$ 1,155.63
Selling Factor	1.250
Selling Price	$ 1,444.54

** indicates those items which had a scrap factor calculated in the $ total = (quantity x $each x scrap factor)*

Figure B.7 provides a summary of the costs contributing to the total selling price of this particular transformer. From this illustration it becomes clear that approximately 60% of the final selling price of an M2 core steel, copper primary and secondary is direct material and scrap. Labor accounts for approximately 12% of the price, and the overhead and selling factor account for 28%. The definitions of each of these categories are contained in section 3.2 of the aforementioned Engineering Analysis Update Report.

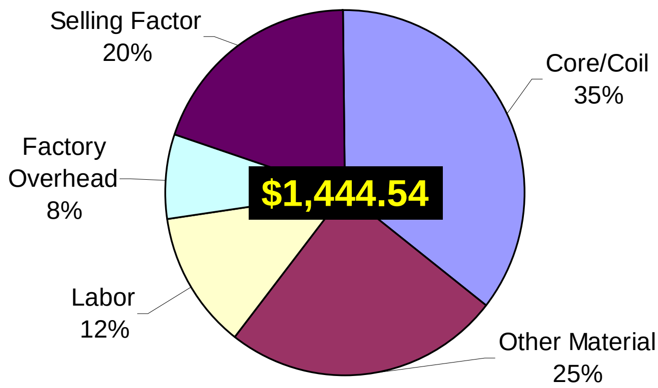

Figure B.7 Manufacturing Price Breakdown for M2CuCu