Dry-type Transformers

Codes and Standards Enhancement (CASE) Study

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Table of Contents

ACKNOWLEDGMENTS II

INTRODUCTION 1

DRY-TYPE TRANSFORMERS 1

TECHNOLOGY DESCRIPTION 1

CURRENT PRACTICE 3

TRANSFORMER LOADING 3
STANDARD TECHNOLOGY 4
MARKET CHARACTERISTICS 4
HARMONICS 6
AMORPHOUS CORE TRANSFORMERS 6

ECONOMICS 6

COSTS 7
BENEFITS 8
AVAILABILITY AND COST 8
STATEWIDE ANALYSIS 9

KEY STAKEHOLDERS 10

IMPLEMENTATION STRATEGIES AND RECOMMENDATIONS 12

APPLIANCE STANDARDS 12
CEE DRY-TYPE TRANSFORMER INITIATIVE 12

BIBLIOGRAPHY 13

APPENDIX A 15

APPENDIX B 18

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Introduction

This Codes and Standards Enhancement (CASE) Study provides information to support including dry-type transformers in California's Title 20 Appliance Standards, and to assist stakeholders in reaching consensus. This CASE study for dry-type transformers includes a discussion of the:

- technology,
- current practice,
- economics,
- key stakeholders, and
- implementation options and recommendations for inclusion into codes.

Dry-type Transformers

Dry-type transformers are not a new technology. Commercial and industrial customers have used them for years to step down voltages from building distribution to plug load levels. These transformers are relatively efficient; most convert in excess of 95% of input power to output power. However, because most transformers are energized 24 hours per day, 365 days per year, even small improvements can yield significant energy and dollar savings for power users.

The efficiency of medium- and low-voltage equipment has improved little, if any, in the last 30 years. Average efficiencies for low-voltage equipment have actually deteriorated.

These trends occurred despite the availability of technological improvements that could yield substantial energy savings with simple paybacks of three years or less. These technological improvements, driven by utility purchases of transformers, have not been transferred to the commercial and industrial sectors.

Such market conditions have spurred the development of minimum efficiency standards. Over the past five years, a small body of research has investigated the market transformation and cost-benefit analysis of dry-type transformers.

In October of 1992, President George Bush signed the Energy Policy Act. This Act called for a study to determine if a transformer standard would be technologically feasible, economically justified, and result in significant energy savings. Preliminary analyses indicate that such a standard would improve efficiencies in both dry-type transformers and some oil-filled distribution transformers.

In response to the governmental activity, the National Electrical Manufacturers Association (NEMA) approved NEMA Standard TP 1-1996 "Guide for Developing Energy Efficiencies for Distribution Transformers." This voluntary standard, which cites a minimum efficiency for each transformer KVA rating, could become the basis for a governmental standard.

The NEMA standard provides a basis for determining the energy efficiency performance of certain single-phase and three-phase dry-type and liquid-filled distribution transformers. It can also assist in the proper selection of such equipment.

Technology Description

Transformers are needed throughout utility, commercial and industrial facilities to step down voltages from distribution to levels that are appropriate for lighting, plug loads, heavy machinery and all other end uses.

Transformers have no moving parts; they consist of a steel core wrapped with two high conductance wire coils (windings). The ratio of the number of times each wire is wrapped around the core (called the turns ratio) dictates the level that the input voltage is stepped up or down.

Transformers change the electrical voltage though the use of primary and secondary windings. The voltage on the secondary winding is the ratio of the number of turns on the secondary winding to the number of turns on the primary winding, multiplied by the voltage on the primary winding.

The transformers described in this study usually have two windings with multiple taps and a magnetic core. If the primary winding is wrapped with a greater number of turns than the secondary winding, the transfer decreases or "steps down" the voltage. If the primary winding is wrapped with a fewer number of turns than the secondary, the voltage increases or "steps up."

Transformers lose energy through no-load and load losses. No-load losses consist primarily of eddy-current and hysteresis losses in the core. Because the transformer must be energized at all times, these no-load losses are constant and present over all loads. Load losses, on the other hand, increase by the square of the load current. Resistive heating (I^2R) losses in the windings are the primary source of load losses.

The total losses are a combination of the load and no-load losses, but one will typically dominate depending on the load profile. The core losses dominate at low loads, but as the load increases and more current flows through the windings, then the load losses become more significant. Figure 1 illustrates the losses of a 150-kVA transformer over its load range.

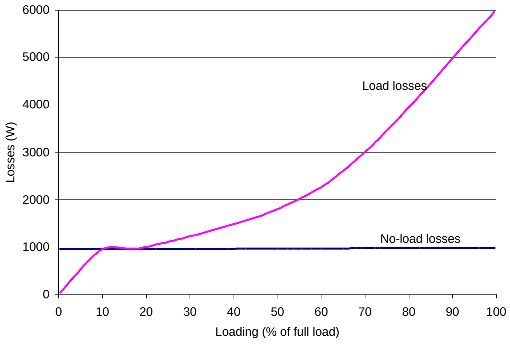

Figure 1. Losses in a 150ºC-rise Transformer. Source: E Source 1995.

Three factors differentiate transformers:

Input Voltage (medium or low). Transformers are classified by the unit's input (referred to as primary) voltage. Medium-voltage units will reduce distribution voltages (2.4 kV to 35 kV) to building power (typically 480 V); low-voltage units take building power (under 600 V) and reduce it typically to 208/110 V. Medium-voltage transformers can be dry-type or liquid immersed, while low-voltage units are almost exclusively dry-type transformers.

Cooling Media (air or liquid). Transformers need to be cooled to remove waste heat from the unit. Liquid-immersed transformers are filled with oil or other liquid, while dry-type transformers are air-cooled and rely on ventilation to remove all heat. Liquid dissipates heat and electrically insulates better than air, so liquid-immersed transformers are, in general, more efficient than dry-type units. Because of leakage and flammability concerns, liquid-immersed units must be installed in sealed enclosures and are typically located outdoors. New flame-resistant oils have made this less of a concern, but commercial and industrial users install dry-type transformers almost exclusively.

Temperature Rise (typically 80°C, 115°C and 150°C). Transformers are rated by the temperature rise in the coils above ambient temperature when the unit is fully loaded. Because internal winding losses are the primary drivers of heat gain, temperature rise is sometimes used as a proxy for energy efficiency. But this can be misleading for several reasons:

- First, transformers with the same temperature rating can have different full-load efficiencies because of factors not related to coil losses, such as ventilation and extra thermal mass.

- Second, temperature rise is rated at full load, but few transformers consistently operate at full-load conditions.
- Finally, increased core size in 80°C-rise models can increase no-load losses over comparable 150°C-rise units, thereby reducing part-load efficiency even further. Across the market, 150°C-rise units are the most common and, typically, the least expensive.

Transformers typically have long lifetimes of over 30 years. Because of their design and their lack of moving parts, maintenance requirements are negligible and failure rates are minimal. Dry-type transformers are typically installed or replaced only during new construction or major renovations, when the load increases dramatically, or when the unit reaches the end of its lifetime.

Cost savings can be superb: efficiency gains are locked for the entire life of the transformer, and maintenance costs are insignificant.

Besides basic commissioning to ensure proper installation, commissioning will typically not affect the transformer's life or performance.

There is no evidence that transformers in California are used differently than transformers described in national studies. Therefore, one can assume that transformers in California do not deviate from the national life and failure rate information. Additional studies are not needed.

Current Practice

Transformers in California are installed and used in the typical manner. All large commercial and industrial (C&I) facilities need one or more dry-type low-voltage distribution transformers to reduce the building voltage (typically 480 V) to levels appropriate for plug, lighting and equipment loads (208/120 V). C&I facilities use medium-voltage units to reduce utility distribution power to building voltages (480 V, one or three phase) to power large equipment or feed into smaller low-voltage transformers.

Transformer Loading

Because a transformer's efficiency can vary widely over its load range, it is valuable to understand the load profiles served by the units. Industry experts agree that transformers are typically lightly loaded (less than 40%). When NEMA developed its minimum transformer efficiency standards (TP 1) in 1996, they assumed an average load of 35%.

In response to legislation requiring all transformers sold or installed in Massachusetts to be TP 1-compliant, the Cadmus Group, on behalf of the Northeast Energy Efficiency Partnerships, Inc. (NEEP), surveyed load profiles of several hundred low-voltage distribution transformers across the state (Korn 1999). The monitored transformers had an average Root Mean Squared (RMS) load of only 16%, and fewer than 4% of the monitored transformers had average loads greater than 50% (see Figure 2).

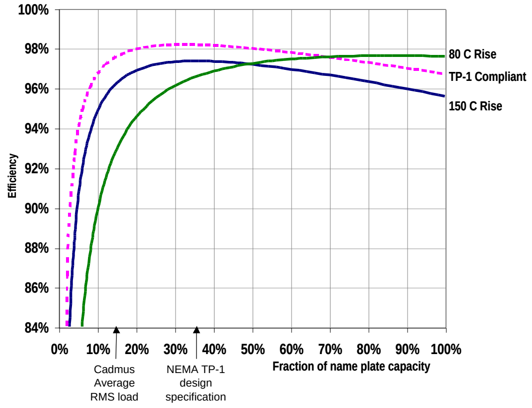

Figure 2. Transformer Performance Curves

Standard Technology

Standard dry-type transformers typically incorporate aluminum windings around the core rather than copper windings that are generally more efficient.

For a variety of reasons, dry-type transformers (Figure 3) have largely replaced liquid-filled units within industrial, commercial and institutional buildings in the United States.

Figure 3. Dry-type Transformer

Liquid-filled transformers typically use oil as a combination coolant and insulating medium. They are generally more efficient and are frequently installed outside because of fire codes and safety considerations (Figure 4).

Figure 4. Typical Liquid-filled Transformer Installation

Although utilities actively evaluate the efficiency of oil-filled units on the grid, building owners pay little attention to the energy efficiency of dry-type transformers, even though they can last 30 years or more.

Manufacturers have the know-how and technology to make more efficient equipment. But because of a variety of market barriers, end users don't demand even the most cost-effective energy-efficiency improvements. Market barriers include the following:

- Market channel participants (distributors, specifying engineers and electrical contractors) and facility owners lack knowledge of the efficiency opportunities available.
- The typical equipment purchaser or specifier is not ultimately responsible for the electric bill. Buyers search for the lowest priced equipment that meet the facility needs. Manufacturers compete by keeping prices as low as possible.
- There is widespread perception that the equipment is already energy efficient.
- Information about equipment efficiency is not readily available.
- While readily available, more efficient low-voltage products are not normally stocked in places where it is not required by code.

As a result of these barriers, the transformer market is largely first-cost driven.

Market Characteristics

The transformer market can be easily segmented by voltage class, technology and end user. While commercial and industrial users purchase less than 10% of liquid-immersed units, utilities purchase less than 10% of the dry-transformer market (1995 numbers). Table 1 summarizes these relationships. Note that low-voltage liquid-immersed units are rare, while low-voltage dry-type units are commodity stock items.

Table 1. Transformer Market by Type

	Dry-type	Liquid-immersed
Low voltage	Commercial and industrial market. Commodity stock items. (Primary focus of this study.)	Limited application.
Medium voltage	Commercial and industrial market. Special order if installed indoors.	Utility market. Generally built to customer specs and installed outdoors.

In California, the market for low-voltage dry-type transformers follows national trends. However, the medium-voltage market may differ from national trends in that more commercial and industrial customers are specifying liquid-immersed medium-voltage units instead of dry-type units.

For this study, we use TP 1 compliance to define the minimum efficiency that should be considered in the standards. Competing technologies, therefore, are noncompliant dry-type transformers. Because of the limited application of low-voltage liquid-immersed units and the small number of liquid units purchased by the commercial and industrial segment, liquid-immersed units are not considered to be a competing product class.

Market penetration varies strongly by voltage class. NEMA has tracked sales of TP 1-compliant transformers sold in 1997 and 1998 (Table 2).

Table 2. Percent of Shipments that Met or Exceeded NEMA Standard TP 1-1996

	1997	1998
Low-voltage, dry-type	0.1%	0.15%
Medium-voltage, dry-type	83.6%	80.3%

Over 80% of medium dry-type transformers currently meet or exceed Standard TP 1, while only trace numbers (<1%) of low-voltage dry-type units comply. Because of this, cost and availability concerns are typically focused on the low-voltage market.

National trends shown in Figure 5 illustrate the value of more stringent efficiency standards. According to national data, dry-type transformers accounted for 23% (14% + 9%) of total capacity sales, but they were responsible for 46% (15% +31%) of all estimated transformer losses. Low-voltage dry-type unit sales outnumbered medium-voltage units seven to one (about 233,000 units were sold, representing 14% of total capacity sales) and were responsible for 31% of total market losses (losses attributable to medium-voltage units were estimated at 15%).

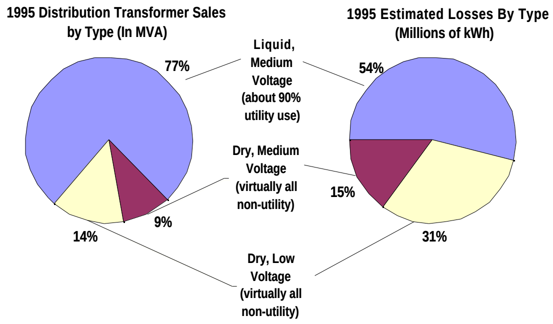

Figure 5. Distribution Transformer Sales and Losses by Type. Source: Barnes 1997.

In this study, we are concerned only with dry-type transformers and, therefore, large commercial and industrial users. Facilities will require varying numbers of transformers depending on the building's load. Title 24 does not apply to all commercial and industrial users; amending the Title 20 appliance standards to include minimum efficiency standards *would* affect all users and have a greater impact across the state.

Two other technologies are important from a market standpoint: harmonic mitigation and amorphous core transformers.

Harmonics

“Harmonics” refers to the higher order frequencies that can change the shape of voltage and current waves from sinusoidal to more nonlinear (or square) shapes. Concern about eliminating harmonics varies widely among engineers and building owners; some make it a priority while others see no need for concern.

Some manufacturers also doubt the need for harmonic transformers. They based this conclusion on monitored loads of **standard** transformers and the observation that lightly loaded transformers (low-voltage, three phase to single phase) effectively eliminated the harmonics from the input of the transformer.

The incremental price of a harmonic transformer (30–40%) is similar to that of TP 1-compliant models. However, harmonic-mitigating transformers are not an energy-efficient technology. Instead they are designed to cool faster from the assumed increased winding losses caused by the harmonics. Furthermore, since most transformers are lightly loaded, harmonics may cease to be an issue.

Amorphous Core Transformers

Amorphous core transformers are the most efficient dry-type transformers on the market at low loads. “Amorphous core” refers to the nonaligned molecules in the core material that reduce core losses dramatically.

Figure 6 shows the relative performance of an amorphous core transformer versus a traditional or TP 1-compliant transformer. Typically, amorphous core technology was available only in liquid-immersed transformers. Recently, one manufacturer has begun making low-voltage, dry-type transformers with amorphous cores. By reducing core losses by almost a factor of four, these units have dramatically higher efficiencies at low load levels.

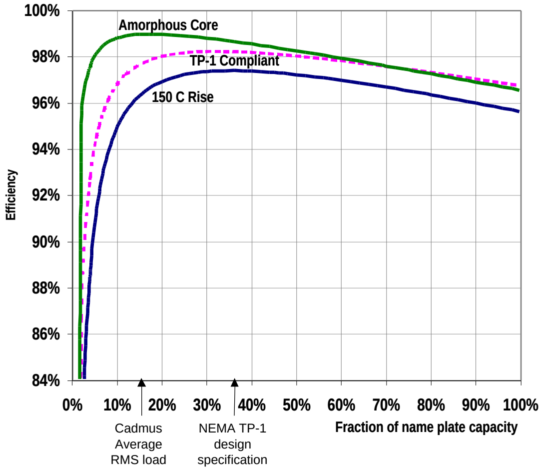

Figure 6. Comparative Efficiency of Amorphous Core Transformers

Economics

Buyers of dry-type transformers seldom specify efficiency. Values of 95% or higher are typical, and there is only a 1% to 2% difference between high- and low-efficiency units, with a significant first-cost premium for the more efficient units.

Table 3 shows the costs and benefits of a 1500 kVA, three-phase, medium-voltage transformer at TP 1’s recommended 99.0% efficiency level. This analysis shows that purchasing an energy-efficient transformer is cost-effective if the purchase price is less than $20,500 above the base model price.

Similarly, in the 25 kVA, single-phase, low-voltage example, TP 1’s recommended model, with 98.0% efficiency, is cost effective if its purchase price is $840 less than the base model.

Table 3. Transformer Cost-effectiveness Examples

Performance	Base Model	TP-1 Recommended Level
1500 kVA, Three-phase, Medium-voltage Dry-type		
Efficiency	98.6%	99.0%
Annual Energy Loss	91,380 kWh	66,360 kWh
Annual Energy Loss Cost	$5,480	$3,980
Lifetime Energy Loss Cost	$74,900	$54,400
Lifetime Energy Cost Savings	-	$20,500
25 kVA, Single-phase, Low-voltage Dry-type		
Efficiency	96.7%	98.0%
Annual Energy Loss	2,600 kWh	1,570 kWh
Annual Energy Loss Cost	$156	$94
Lifetime Energy Loss Cost	$2,130	$1,290
Lifetime Energy Cost Savings	-	$840

Costs

First cost is not the last cost of any transformer. Conductor losses, also known as coil losses or load losses, contribute to the cost of operating an inefficient transformer (such losses vary by the square of the load). That means a fully loaded transformer has four times the load losses compared with one running at 50% of its design load. In many applications, transformers are heavily loaded; but even at lower load factors, if the units are not efficient (and many are not), losses mount rapidly. This is because conductor losses are a key component of transformer energy efficiency. TP 1 promotes better core design to improve overall efficiency.

Complete life-cycle costs must be carefully examined along with the economics of high-efficiency dry-type transformers. Thus, the continuing costs of transformer losses should be balanced with the savings gained from efficient units—savings that go on year after year and quickly pay back the extra first cost of the efficient units.

Table 4 shows an example of a 150°C-rise, aluminum-wound, 1500-kVA dry-type transformer versus a premium-efficiency, 80°C-rise, copper-wound unit, and carrying a price premium of $5,900. In this example, motors connected to the transformer are used to illustrate transformer losses.

Table 4. Annual Energy Savings Example

Transformer Loss = (motor load + loss in wiring) x (transformer inefficiency)

Loss in *high-efficiency* transformer:

= (14.94 kW + 0.159 kW) x (1 - 0.9902)

= 0.148 kW, or 888 kWh/yr

Loss in *standard* transformer:

= (14.94 kW + 0.159 kW) x (1 - 0.9847)

= 0.231 kW, or 1386 kWh/yr

Additional annual savings due to more efficient transformer:

1386 - 888 = 498 kWh/yr

at $.09 per kWh	at $.07 per kWh
$44.82	**$34.86**

The high-efficiency transformer’s cost premium of $5,900 must be spread over the example motor *plus all other loads on the transformer*, since this is only a small part of its total load. For simplicity, we’ll estimate what fraction of the transformer’s output the example motor requires, and reduce the transformer’s cost premium proportionately.

The differential cost associated with the increment of the 25-hp high-efficiency motor is determined as shown in Table 5.

Table 5. Differential Cost with Motor

Motor kVA = 30 FLA x 0.460 kV x 23.9 kVA(1)

$5,900 cost premium x (23.9/1,500) = $94 cost premium for one motor

	at $.09 per kWh	at $.07 per kWh
Value of Annual Savings	$44.82	$34.86
Simple Payback	2.1 year	2.7 year

(1) 30 full load amps (FLA) are taken from the motor catalog.

Benefits

In addition to saving energy, efficient transformers run cooler, and thus more reliably, because of decreased stress on insulation materials. As a result, they will have a higher overload capacity, an important issue in dry-type transformers. The ultimate result can be units with a smaller kVA rating actually doing the same job with attendant first-cost savings.

Availability and Cost

Availability and cost have historically been the primary barriers to minimum efficiency standards for dry-type transformers, although these trends have changed considerably over the past three years. The market and cost structures differ for low- and medium-voltage transformers, and will be dealt with separately below.

Low-voltage transformers

Availability is becoming less of an issue. Even though they have scarcely penetrated the overall market, the availability of low-voltage, dry-type units has increased considerably in the past four years. Participation in the U.S. Environmental Protection Agency's (EPA) Energy Star transformer initiative (a program that registers and labels low-voltage units that meet the TP 1 standard) has increased by a factor of five, from 3 manufacturers in 1999 to 16 in June 2000.

Cost concerns are still challenging the widespread adoption of the TP 1 standard. Because the competitive technology is other dry-type transformers, installation and maintenance costs are negligibly affected, and only the incremental costs of the higher efficiency units must be considered. Some TP 1-compliant units have substantial price premiums.

The development of the TP 1 standard focused on cost effectiveness. NEMA manufacturers chose efficiency levels achievable with paybacks between three and five years. Our analysis of market pricing information confirms these figures. Based on data gathered in late 1999, TP 1-compliant units are cost effective over the entire range of capacities. This data was assembled by the Cadmus Group, and contains price and efficiency for a range of standard and TP 1-compliant low-voltage transformers.

Our analysis, shown in its entirety in Appendix A, compares the TP 1-compliant transformers to two standard 150°C-rise models in each capacity step. The two standard transformers were chosen as baselines to illustrate a range of cost effectiveness; one baseline is a high value performer and the other has higher losses.

Because they are a new technology and only one manufacturer is currently making them, amorphous core transformers were not included in this analysis. However, with their much greater efficiency at low loads, their paybacks are even more attractive than standard TP 1 units.

The main findings of our analysis include:

- All capacity ranges (except 500 kVA) contained models with simple paybacks less than three years. The 500-kVA category had paybacks between 3 and 16 years, but these represent only 7.5% of national annual sales by capacity (Barnes 1997).

- Net 15- and 30-year life-cycle benefits were positive across all categories, and ranged from $1,000 to $3,000 on the small units, and up to over $10,000 on units as small as 75 kVA.
- Savings and paybacks were calculated at 15.9% and 35% average RMS loading. The former is the average loading found in the Cadmus loading survey, and the latter is the assumed loading for TP 1 compliance. Paybacks and net life-cycle costing were similar for both assumed loads.

Medium-voltage transformers

As mentioned above, over 80% of medium-voltage units already meet TP-1 standards. Because of this, incremental cost should not be a major barrier to market acceptance.

Statewide Analysis

Consistent, stable, long-term energy savings are the single quantifiable benefit of establishing higher dry-type efficiency standards. These savings result from the intersection of several factors. First, transformer technology is ubiquitous. All power must pass through transformers during distribution, so even small gains in efficiency can provide significant savings. Second, transformers typically have long and trouble-free lives, so savings are assured for decades. Finally, the technological issues involved in producing energy-efficient dry-type transformers are well known. NEMA's adoption of the TP 1 voluntary standard implies that these efficiencies are readily achievable.

Increased energy efficiency has other benefits including lower peak loads and therefore increased power system reliability. Environmental benefits include reduction of greenhouse gas emissions and other externalities associated with energy production.

Low-voltage transformers

If all low-voltage transformers sold in California in 2000 were TP 1-compliant, the state would save between 26,900,000 kWh and 43,600,000 kWh. This works out to be a total load reduction between 3.0 MW and 4.9 MW.

Table 6 and Table 7 show potential statewide savings through 2010 if all low-voltage transformers sold in California were TP-1 compliant. These figures were calculated by extrapolating national savings estimates in the 1999 Cadmus survey, the only published research that has monitored actual load profiles and the most accurate estimate of potential energy savings.

Table 6. Statewide Savings (low estimate)

	GWh/yr	MW	$ Millions
2000	26.9	3.0	$ 2.7
2001	53.8	6.0	$ 5.4
2002	80.7	9.0	$ 8.1
2003	107.6	12.0	$ 10.8
2004	134.5	15.0	$ 13.5
2005	161.4	18.0	$ 16.1
2006	188.3	21.0	$ 18.8
2007	215.2	24.0	$ 21.5
2008	242.1	27.0	$ 24.2
2009	269.0	30.0	$ 26.9
2010	295.9	33.0	$ 29.6

Table 7. Statewide Savings (high estimate)

	GWh/yr	MW	$ Millions
2000	43.6	4.9	$ 4.4
2001	87.2	9.8	$ 8.7
2002	130.8	14.7	$ 13.1
2003	174.4	19.6	$ 17.4
2004	218.0	24.5	$ 21.8
2005	261.6	29.4	$ 26.2
2006	305.2	34.3	$ 30.5
2007	348.8	39.2	$ 34.9
2008	392.4	44.1	$ 39.2
2009	436.0	49.0	$ 43.6
2010	479.6	53.9	$ 48.0

Medium-voltage transformers

The energy impact of minimum efficiency requirements in this voltage class could not be calculated due to the lack of reliable loading studies and market information on the number of dry-type medium-voltage transformers currently sold in the state. National research reports have stated that commercial and industrial users split their medium-voltage equipment between liquid and dry units. Several utility representatives doubt this statement, however, and believe the statewide penetration of this technology to be negligible. But manufacturer representatives are confident that a significant number of large commercial and industrial customers use dry-type medium-voltage equipment.

Key Stakeholders

The transformer industry has a large number of stakeholders, including policy makers, manufacturers, the construction industry and end users. On a policy-making level the important stakeholders include:

- U.S. Environmental Protection Agency (EPA)
- U.S. Department of Energy (DOE)
- National Electric Manufacturers Association (NEMA)
- Consortium for Energy Efficiency (CEE)

End users include large utility customers and electric utilities. Figure 7 shows the relationship between the various stakeholders.

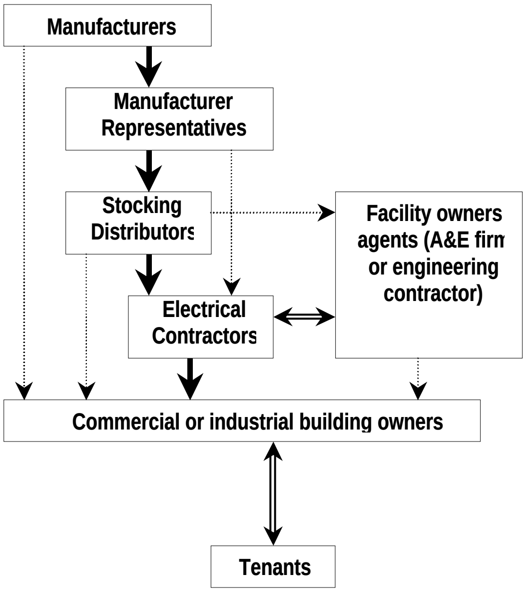

Figure 7. Transformer Industry Stakeholders

Manufacturers. About 20 manufacturers produce the majority of dry-type transformers (not including small, less than 10 kVA units). Three manufacturers account for 65–80% of the market: Square D, GE and Cutler-Hammer.

The manufacturers listed below (list provided by NEMA) represent dry-type transformer manufacturers as well as competing technologies and transformer controls companies.

Manufacturer

- ABB Control Inc.
- ABB Power T&D
- Acme Electric
- AEG Electric Power Systems
- Airborne Power
- Allen-Bradley

- ASC Industries
- Audiosone, Inc.
- AYA Instruments
- Baldor Electric
- Bryant Electric, Inc.
- Challenger Electrical Equipment Corp.
- Controlled Power Co.
- Cooper Power Systems
- Cutler-Hammer
- Edwards/EST, A Unit of General Signal
- Ericson Mfg.
- Ferranti-Packard
- G.E.C. Durham Industries
- GE Meter
- GEC Alsthom
- Hammond Mfg.
- HDR Power Systems
- Honeywell Home and Building Control
- Kentucky Association of Electrical Coop., Inc.
- Leviton Mfg.
- MagneTek
- Magnetran
- Meter Devices
- Niagara Transformer Corporation
- North American Transformer
- Olsun Electrics Corporation
- Pacific Western Extruded Plastics
- Pass & Seymour/Legrand
- Patton Building Products
- Pauwels Transformers, Inc.
- Power Distribution, Inc.
- Power Magnetics
- Power Paragon
- Power Systems Group
- Products Unlimited
- R.E. Uptegraff Mfg. Co.
- Schlumberger Industries, Inc.
- Shape Electronics, Inc.
- Siemens Energy & Automation
- Smit USA Inc.
- Sola/Hevi-Duty Electric
- Solidstate Controls Inc.
- Southern Transformer
- Square D
- Superior Electric
- Toshiba International
- VanTran Industries
- Virginia Transformer
- Waukesha Electric Systems

Manufacturer Representatives. These representatives serve as the manufacturers' marketing arm and may be salaried sales personnel or independent agents. They are a key source of technical information.

Stocking Distributors. These are independent electrical equipment sellers that maintain an inventory of low-voltage equipment and often sell used equipment as well.

Electrical Contractors. Contractors are responsible for electrical system installation, but have no direct concern regarding energy bills. Electrical contractors purchase transformers from stocking distributors, or, in the case of larger equipment or very large orders, directly from the manufacturer representative. The end-user's agent or the electrical contractor determines equipment specifications, and they do not always include efficiency. Their incentive is typically to purchase the least expensive transformer possible.

Facility Owners' Agents. This group consists of architect and engineering firms or engineering contractors selected by the building owner to evaluate design options and specify equipment. They generally write specifications for the electrical contractor who actually procures the transformers. Currently, some place little emphasis on efficiency, while others are unaware of the issues surrounding transformer efficiency and include specifications for less-efficient units.

Commercial and Industrial Facility Owners. This group owns the transformer, but is rarely involved in the actual purchase transaction. Some large industrial facilities maintain in-house experts who give them the capacity to order equipment directly from manufacturers. Owner-occupants pay the electric bill.

Tenants. Most commercial and some industrial space is tenant occupied. In these instances, someone other than the equipment owner pays for transformer losses.

Implementation Strategies and Recommendations

Although transformer efficiency requirements can be implemented through both building energy standards and equipment appliance standards, we recommend that implementation be pursued through the Title 20 Appliance Standards. Unlike Title 24, the Title 20 Appliance Standards apply to all commercial and industrial end users, and would therefore have greater statewide impact. Furthermore, we recommend that dry-type transformer efficiency requirements meet or exceed NEMA's voluntary TP 1 standard. NEMA's TP 1 standard has broad acceptance among transformer manufacturers, would result in significant energy savings in California if adopted into Title 20, and has already been adopted by the Consortium for Energy Efficiency and the U.S. EPA's Energy Star Transformers program (see below for a description of these two initiatives). Sample language for the appliance standard, as well as NEMA's table of minimum efficiency levels, are provided below.

Appliance Standards

The following text provides sample language for dry-type transformer efficiency requirements in the Title 20 appliance standards.

Minimum Transformer Efficiency: New distribution transformers shall meet or exceed the minimum efficiency levels listed in NEMA TP 1-1996, Table 8 (in this document) when tested and rated in accordance with NEMA TP 2. In addition, new distribution transformers shall be labeled in accordance with NEMA TP 3.

Table 8. NEMA Class 1 Efficiency Levels for Distribution Transformers

Reference Condition	Temperature	% of Nameplate Load
Low-voltage	75°C	35%
Medium-voltage	75°C	50%

Single-phase Efficiency			**Three-phase Efficiency**		
kVA	Low Voltage	Med Voltage	kVA	Low Voltage	Med Voltage
15	97.7	97.6	15	97.0	96.8
25	98.0	97.7	30	97.5	97.3
37.5	98.2	98.1	45	97.7	97.6
50	98.3	98.2	75	98.0	97.9
75	98.5	98.4	112.5	98.2	98.1
100	98.6	98.5	150	98.3	98.2
167	98.7	98.7	225	98.5	98.4
250	98.8	98.8	300	98.6	98.5
333	98.9	98.9	500	98.7	98.7
500	--	99.0	750	98.8	98.8
667	--	99.0	1000	98.9	98.9
833	--	99.1	1500	--	99.0
			2000	--	99.0
			2500	--	99.1

Source: NEMA TP 1-1996 ***Guide for Determining Energy Efficiency for Distribution Transformers***

CEE Dry-type Transformer Initiative

The Consortium for Energy Efficiency (CEE) has adopted NEMA's voluntary standard for energy-efficient, low-voltage transformers. Products meeting the NEMA standard reduce transformer losses by about 50%, yielding simple paybacks from one to three years. Most non-utility transformer purchasers are unaware of this range of efficiency or the new NEMA standard.

CEE's initiative is closely coordinated with the U.S. EPA Energy Star Transformers program, which has adopted the same specification for energy-efficient, low-voltage transformers. Under the Energy Star program, manufacturers provide EPA with lists of equipment meeting the program specification. This list is published on EPA's Web site. For the medium-voltage class, CEE encourages purchasers to evaluate options using a cost-of-ownership methodology that includes operating costs in the purchase decision.

Based on research by Oak Ridge National Laboratory, the potential annual incremental energy savings in the United States would exceed 1 billion kWh if all new dry-type transformers met the NEMA standard. In addition, significant energy savings are available in the medium-voltage market if transformer buyers evaluate their purchases based on their sales price plus the operating cost. Since most transformers operate for 30 years or more, the potential exists to lock in significant energy savings for decades.

About 233,000 low-voltage, dry-type distribution transformers over 10 kVA are sold annually in the United States, of which 90% are sold to facilities other than utilities. Most of these units serve lighting and plug loads in commercial buildings. Another 34,000 medium-voltage units, split about evenly between liquid-immersed and dry-type equipment, are purchased for industrial and large commercial applications.

CEE's role in this initiative is that of organizer, facilitator and information clearinghouse. CEE's partners, including members of CEE and other organizations, implement the initiative. These implementers include electric utilities and statewide or regional efficiency organizations, which may be utility-based. Implementers are said to participate in the initiative when they adopt the CEE efficiency performance specification for low-voltage equipment and undertake efforts to build awareness of energy-efficient transformers.

Bibliography

Barnes, P.R., J.W. Van Dyke, B.W. McConnell, and S. Das. 1996. Determination analysis of energy conservation standards for distribution transformers. Oak Ridge National Laboratory ORNL-6847 (July).

Widely quoted initial research into the technical and economic feasibility of minimum efficiency standards for dry-type transformers. Includes market information that is used by most of the other literature. Contains a detailed review of transformer technology and efficiency issues.

Barnes P.R., S. Das, B.W. McConnell, and J.W. Van Dyke. 1997. Supplement to the "Determination Analysis" (ORNL-6847) and Analysis of the NEMA efficiency standard for distribution transformers. Oak Ridge National Laboratory ORNL-6925 (September).

Supplements the previous report. Reanalyzes the market data in light of NEMA's TP 1 standard to develop a new impact analysis.

Consortium for Energy Efficiency. March 2000 Newsletter. http://www.ceeformt.org/resrc/updates/00-03trnsfm/00-03trnsfm.html.

Updates on transformer availability; the results of the Cadmus/NEEP transformer loading survey; regional, utility and national program updates; and CEE contacts.

Dagher, F. Personal communication. Letter in support of changes to ASHRAE Standard 90.1. 2000.

Letter addresses issues raised by J. Speilvogel on behalf of ASHRAE committee members. Includes payback data on six TP 1-compliant units, justifications of the exclusions listed in Dagher's proposed amendments, the applicability of the Cadmus study to the rest of the country, and other miscellaneous items.

E Source. 1995. Selecting dry-type transformers: Getting the most energy efficiency for the dollar. Tech Update TU 95-6 (August). Boulder, Colorado: E Source

Describes the relationship between temperature rise and efficiency and develops recommendation for selecting the most efficient transformer for a particular load profile. Contains excellent background information.

Hinge, Adam. Personal Communication. Letter in response to request for additional information substantiating Barnes's proposal to ASHRAE 90.1 Committee to include NEMA TP 1 as part of the standard. 2000.

Includes updates of availability and cost effectiveness. References the NEMA TP 1 compliance numbers referenced in this report. Includes details of the Cadmus cost effectiveness analysis of low-voltage dry-type transformers.

Hinge A., M. Suozzo, T. Jones, D. Korn, C. Peverell. 2000. Market transformation for dry-type distribution transformers: The opportunity and the challenges. Paper to be presented at ACEEE conference in August 2000.

Excellent overview of the history of the technology, the status of the market, and market barriers to wider acceptance of TP 1-compliant transformers.

Korn, David L., Gene E. Fax, and James J. Siegmund. 1999. Low-voltage transformer loads in commercial, industrial, and public buildings. Prepared for Northeast Energy Efficiency Partnerships, by The Cadmus Group, Inc., 135 Beaver Street, Waltham, MA 02452, December 7, 1999.

Analyzes the average loading of low-voltage dry-type transformers of a sample of units in the Northeast. Discovered that the average RMS loads of 15.9% were much lower than the 35% that NEMA used in its assumptions. This analysis was initiated in response to Massachusetts's development of minimum efficiency standards. These findings support the cost effectiveness of the TP 1 transformers because their more efficient cores generate significant energy savings at lower loads than noncompliant models.

Korn, David L. 1999. Memo: Method used to calculate energy savings in low voltage transformer report, by The Cadmus Group, Inc. 135 Beaver Street, Waltham, MA 02452, December 7, 1999.

Details of the methodology used to quantify the statewide energy impacts of TP 1-compliant equipment.

National Electrical Manufacturers Association (NEMA). 1996. *Guide for determining energy efficiency for distribution transformers.* NEMA Standards Publication TP 1-1996. Rosslyn, VA: National Electrical Manufacturers Association.

Standard developed by NEMA. Includes the table of recommended efficiencies, all applicable exclusions, and detailed efficiency equations.

Appendix A

The cost effectiveness calculations compare a subset of TP 1-compliant low-voltage dry-type transformers to two different baseline models at each capacity step. The price and loss data for the baseline models is summarized in Table 9.

Table 9. Price and Loss Data for Baseline Standard Efficiency Models

		Manufacturer	Cost	Core Loss (W)	Winding Loss (W)
15 kVA	Top Value	GGG	$500	212	605
	Standard Value	CCC	$550	290	665
30 kVA	Top Value	AAA	$610	250	1400
	Standard Value	CCC	$635	410	1454
45 kVA	Top Value	AAA	$725	250	1930
	Standard Value	GGG	$705	335	1923
75 kVA	Top Value	AAA	$1,042	375	3042
	Standard Value	DDD	$1,000	599	3057
112.5 kVA	Top Value	CCC	$1,500	700	3681
	Standard Value	GGG	$1,475	853	2678
150 kVA	Top Value	CCC	$1,600	850	6269
	Standard Value	DDD	$1,600	1338	4799
225 kVA	Top Value	GGG	$2,000	1091	5690
	Standard Value	DDD	$2,000	1597	5356
300 kVA	Top Value	GGG	$2,500	1053	7096
	Standard Value	DDD	$2,500	1812	8233
500 kVA	Top Value	GGG	$3,000	1480	9550
	Standard Value	DDD	$3,000	2202	8484

Life-cycle costing analysis were calculated at $0.10/kWh and 3% discount rate.

Two different RMS loading levels were assumed.

Table 10 shows the cost analysis at 15.9% assumed load. This was the average loading level found in the Cadmus study. The authors of this research are confident that these loading levels can be used in other geographic locations because climate-dependent equipment was a small percentage of the overall load. Table 11 shows the analysis at 35% assumed load. This is the value chosen by NEMA in determining the efficiency levels for TP 1.

Table 10. Cost Analysis of TP 1 Compliant Transformers at 15.9% Average Loading

					Performance at 15.9% average RMS load					
					Compared to a top value 150C unit			Compared to a standard value 150C unit		
	Brand	Price	Core losses	Winding losses	Simple Payback	15 year net LCC savings	30 year net LCC savings	Simple Payback	15 year net LCC savings	30 year net LCC savings
15 kVA	BBB	680	92	768	1.8	$1,405	$2,190	0.8	$2,182	$3,498
	CCC	870	100	656	3.8	$1,532	$2,277	1.9	$2,309	$3,585
	Default	1569	70	280	8.3	$2,615	$3,607	5.1	$3,392	$4,914
	FFF	1569	70	280	8.3	$2,615	$3,607	5.1	$3,392	$4,914
	GGG	1254	154	618	14.9	$1,358	$1,746	5.9	$2,135	$3,053
30 kVA	EEE	669	120	1230	0.5	$1,450	$2,343	0.1	$3,109	$5,082
	CCC	987	95	1439	2.8	$1,991	$3,026	1.3	$3,650	$5,765
	BBB	895	145	1128	3.0	$1,434	$2,171	1.1	$3,093	$4,910
	Default	1400	135	1220	7.6	$2,026	$2,820	3.1	$3,685	$5,558
	GGG	1831	141	1222	12.4	$2,394	$3,147	5.0	$4,053	$5,886
45 kVA	EEE	819	153	1360	1.0	$1,215	$1,934	0.7	$2,123	$3,411
	CCC	1160	164	1965	5.8	$1,328	$1,901	3.1	$2,236	$3,378
	BBB	1220	205	1746	11.7	$1,000	$1,324	4.4	$1,908	$2,801
	FFF	2490	140	600	15.1	$3,164	$4,061	9.3	$4,071	$5,538
	Default	1651	200	1480	18.2	$1,533	$1,922	7.6	$2,441	$3,399
75 kVA	EEE	1000	300	2000	cheaper	$937	$1,565	0.0	$3,324	$5,457
	EEE	1175	208	2150	0.8	$2,046	$3,273	0.5	$4,434	$7,166
	HHH	1900	70	2600	3.1	$4,131	$6,230	1.9	$6,518	$10,123
	BBB	1650	272	2338	6.0	$1,817	$2,592	2.2	$4,204	$6,485
	CCC	1903	255	2366	7.4	$2,242	$3,128	2.9	$4,630	$7,021
	Default	2109	230	2280	7.7	$2,726	$3,790	3.3	$5,113	$7,682
	FFF	3389	190	910	12.0	$4,680	$6,176	6.1	$7,067	$10,068
	GGG	3321	288	2453	26.7	$3,299	$3,953	8.2	$5,687	$7,846
112.5 kVA	EEE	1700	326	2280	0.6	$4,373	$7,050	0.5	$5,811	$9,395
	BBB	2100	413	3254	2.3	$3,681	$5,658	1.7	$5,120	$8,003
	Default	2651	350	1650	3.4	$5,190	$7,782	2.6	$6,629	$10,127
	CCC	2508	399	3566	3.8	$4,178	$6,211	2.7	$5,616	$8,556
	FFF	5124	270	1400	8.8	$8,547	$11,705	6.9	$9,985	$14,050
	GGG	4424	377	3266	10.1	$6,380	$8,597	7.2	$7,818	$10,942
150 kVA	EEE	2205	394	3200	1.4	$5,947	$9,374	0.7	$10,777	$17,303
	CCC	2607	443	4540	2.6	$5,586	$8,524	1.3	$10,416	$16,453
	BBB	2950	520	3696	4.1	$5,281	$7,803	1.8	$10,111	$15,732
	GGG	5000	435	4342	8.6	$8,100	$11,115	4.3	$12,930	$19,044
225 kVA	EEE	2820	557	4150	1.7	$6,692	$10,460	0.9	$11,923	$19,046
	BBB	4265	564	6845	5.1	$7,562	$10,960	2.6	$12,792	$19,545
	CCC	4903	513	5993	5.8	$8,892	$12,734	3.1	$14,122	$21,320
	Default	4400	650	5100	6.1	$7,123	$10,152	2.9	$12,353	$18,738
	GGG	5500	662	5205	9.1	$8,078	$11,014	4.3	$13,308	$19,600
300 kVA	EEE	3880	812	5400	5.8	$4,217	$6,037	1.5	$12,368	$19,417
	Default	5500	850	5600	14.9	$5,402	$6,943	3.4	$13,553	$20,323
	GGG	6000	861	5802	18.6	$5,749	$7,193	4.0	$13,900	$20,572
500 kVA	EEE	6765	1052	7900	9.4	$8,549	$11,619	3.7	$15,902	$23,689
	Default	7250	1055	9000	11.2	$8,798	$11,715	4.3	$16,151	$23,786
	GGG	8000	1065	10167	14.1	$9,226	$11,937	5.2	$16,579	$24,007

Table 11. Cost Analysis of TP 1 Compliant Transformers at 35% Average Loading

					Performance at 35% average RMS load					
					Compared to a top value 150C unit			Compared to a standard value 150C unit		
	Brand	Price	Core losses	Winding losses	Simple Payback	15 year net LCC savings	30 year net LCC savings	Simple Payback	15 year net LCC savings	30 year net LCC savings
15 kVA	BBB	680	92	768	2.0	$1,264	$1,960	0.8	$2,093	$3,352
	CCC	870	100	656	4.0	$1,488	$2,205	1.9	$2,317	$3,598
	Default	1569	70	280	7.0	$2,895	$4,067	4.5	$3,724	$5,460
	FFF	1569	70	280	7.0	$2,895	$4,067	4.5	$3,724	$5,460
	GGG	1254	154	618	15.2	$1,347	$1,727	5.7	$2,176	$3,120
30 kVA	EEE	669	120	1230	0.5	$1,597	$2,584	0.1	$3,302	$5,399
	CCC	987	95	1439	2.8	$1,957	$2,971	1.3	$3,662	$5,786
	BBB	895	145	1128	2.5	$1,669	$2,556	1.0	$3,374	$5,372
	Default	1400	135	1220	6.8	$2,182	$3,075	2.9	$3,887	$5,890
	GGG	1831	141	1222	11.0	$2,548	$3,399	4.7	$4,253	$6,214
45 kVA	EEE	819	153	1360	0.7	$1,707	$2,742	0.5	$2,609	$4,209
	CCC	1160	164	1965	6.0	$1,298	$1,851	3.1	$2,199	$3,319
	BBB	1220	205	1746	8.9	$1,159	$1,585	4.0	$2,061	$3,052
	FFF	2490	140	600	8.3	$4,311	$5,945	6.2	$5,213	$7,413
	Default	1651	200	1480	11.1	$1,921	$2,560	6.0	$2,823	$4,027
75 kVA	EEE	1000	300	2000	cheaper	$1,836	$3,041	0.0	$4,237	$6,955
	EEE	1175	208	2150	0.6	$2,816	$4,537	0.4	$5,217	$8,451
	HHH	1900	70	2600	2.8	$4,512	$6,856	1.8	$6,913	$10,770
	BBB	1650	272	2338	4.0	$2,424	$3,589	1.9	$4,825	$7,503
	CCC	1903	255	2366	5.2	$2,826	$4,086	2.5	$5,226	$8,000
	Default	2109	230	2280	5.5	$3,383	$4,869	2.8	$5,784	$8,783
	FFF	3389	190	910	6.7	$6,520	$9,197	4.4	$8,920	$13,111
	GGG	3321	288	2453	17.8	$3,807	$4,788	7.1	$6,208	$8,701
112.5 kVA	EEE	1700	326	2280	0.4	$5,582	$9,035	0.5	$6,155	$9,959
	BBB	2100	413	3254	2.1	$4,050	$6,263	1.9	$4,623	$7,187
	Default	2651	350	1650	2.4	$6,944	$10,660	2.2	$7,516	$11,583
	CCC	2508	399	3566	3.7	$4,277	$6,374	3.2	$4,850	$7,298
	FFF	5124	270	1400	6.3	$10,516	$14,937	5.9	$11,088	$15,861
	GGG	4424	377	3266	9.2	$6,738	$9,185	8.1	$7,311	$10,109
150 kVA	EEE	2205	394	3200	0.9	$8,596	$13,722	0.6	$12,157	$19,568
	CCC	2607	443	4540	2.0	$7,079	$10,974	1.2	$10,640	$16,820
	BBB	2950	520	3696	2.6	$7,502	$11,449	1.7	$11,064	$17,295
	GGG	5000	435	4342	6.4	$9,763	$13,845	4.1	$13,325	$19,692
225 kVA	EEE	2820	557	4150	1.4	$8,022	$12,642	0.8	$12,964	$20,754
	BBB	4265	564	6845	6.3	$6,565	$9,323	2.9	$11,507	$17,436
	CCC	4903	513	5993	6.1	$8,631	$12,305	3.2	$13,572	$20,417
	Default	4400	650	5100	5.5	$7,632	$10,988	2.8	$12,574	$19,101
	GGG	5500	662	5205	8.4	$8,496	$11,701	4.2	$13,438	$19,814
300 kVA	EEE	3880	812	5400	3.8	$5,681	$8,440	1.2	$14,813	$23,431
	Default	5500	850	5600	9.7	$6,693	$9,063	2.8	$15,826	$24,054
	GGG	6000	861	5802	12.4	$6,866	$9,026	3.3	$15,998	$24,017
500 kVA	EEE	6765	1052	7900	7.2	$9,973	$13,956	3.6	$16,406	$24,516
	Default	7250	1055	9000	10.1	$9,273	$12,495	4.4	$15,705	$23,054
	GGG	8000	1065	10167	16.2	$8,693	$11,062	5.9	$15,126	$21,622

Appendix B

The quantification of benefits was extrapolated from estimates in the Cadmus research. This research was chosen because it is the only survey of actual transformer loads. The estimates of annual savings between 26,900,000 and 43,600,000 kWh were calculated as follows.

- Cadmus surveyed 321 three-phase, low-voltage, dry-type transformers covering a capacity of 26,098 kVA. These transformers were used to determine the market distribution by capacity.
- Cadmus also assembled a database of transformer losses at each capacity step for standard efficiency and TP 1-compliant models. Using these losses and the population distribution in the survey, the researchers calculated the potential annual savings of 790,283 kWh/yr. This figure represents the potential savings of all of the surveyed transformers would have been TP 1 compliant.
- The potential survey savings (Barnes 1997) were extrapolated to national amounts using the estimated 11,845MVA of national low-voltage dry-type sales in 2000. The United States would have saved 358,655,254 kWh in 2000 if all low-voltage dry-type transformers sold in that year were TP 1 compliant.
- The national savings figure was adapted to California in two ways: population and electricity sales. California contains 12.1% of the national population (U.S. Census, www.census.gov/population/www/estimates/statepop.html). Applying this percentage to the national estimate above, estimated state savings are 43,593,958 kWh (rounded to 43,600,000 kWh in the report). California commercial and industrial users are responsible for 7.49% of all national commercial and industrial electricity sales (Energy Information Administration, State Energy Data Report, 1997). This translates to an estimated 26,873,878 kWh of savings (rounded to 26,900,000 kWh in the report).
- Assuming that the transformers remained at low load levels (an assumption that was overwhelmingly confirmed by the Cadmus study over all building types), the transformer losses would be relatively constant. Therefore, total MW reductions were calculated by simply dividing the kWh savings by 8760.

We believe this represents the most accurate approximation of savings due to the lack of California data needed to generate more detailed estimates. Several market realities challenge precise quantification of benefits. One significant and unknown variable is how much of total delivered power is stepped down by low-voltage transformers. Many industrial equipment, lighting, and HVAC systems use 480/277 V service, and therefore do not need to be stepped down. Only a dedicated survey of installed transformers would answer this question accurately. In addition, only one rigorous survey of transformer capacity by facility type and square footage has been published, and the wide variance of the data eliminated its use as an approximation method.