Market Transformation for Dry-Type Distribution Transformers: The Opportunity and the Challenges

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ABSTRACT

Beginning with the Energy Policy Act of 1992, when the substantial energy savings opportunity from distribution transformers was identified and further investigating it became a public priority, a number of public and private organizations have worked in concert to develop efficiency criteria, and a viable market for higher-efficiency products. As a result of these coordinated efforts, substantial market progress has been achieved in a relatively short time.

Dry-type distribution transformers, purchased by commercial and industrial customers to convert utility electric line voltages to voltages suitable for building equipment, offer a largely untapped opportunity for energy savings in buildings. Purchasers, specifiers, and others are largely unaware of these losses, and as such, they have gone largely unchecked. To address these losses and encourage the purchase of more efficient transformers, NEMA published an efficiency standard (TP 1-1996). Transformers that meet TP 1 can cut a facility's total electric bill and pay back in about three years, but, in the past, been difficult to find or were highly priced as "special order" items.

Several national and state activities, each relying on TP 1 as its platform, have emerged to address the lack of information in the marketplace. These initiatives include the Consortium for Energy Efficiency's (CEE's) Commercial and Industrial (C&I) Transformer Initiative and an ENERGYSTAR™ labeling program, as well as state promotional and mandatory activities, such as minimum efficiency standards in Massachusetts and building code requirements in Minnesota. Contributions to these efforts by manufacturers, electrical contractors, facilities managers, and others have led to a greater understanding of the transformer market. Supplementing this is new data on transformer loading practices and potential energy savings.

This paper provides an overview of the energy savings opportunity, reports on progress to date as well as the remaining market and technical challenges, and describes strategies for "transforming" the dry-type transformer market.

Introduction

Thanks to the efforts of a number of organizations, energy-efficient, dry-type distribution transformers are beginning to gain momentum in the market. Five years ago, there were no recognized energy performance standards for dry-type, distribution transformers and competition was causing overall energy-efficiency levels to decline (Barnes

1996). Even after the transformer industry defined and published efficiency standards, high-efficiency, dry-type transformers were mostly custom-ordered, high-priced products; and few people were aware of them. Following a description of the technology and the market for distribution transformers, this paper describes how transformer manufacturers, utilities, and federal and state governments, have helped move this market forward. The paper also highlights the challenges, opportunities and progress to date to promote the market for high-efficiency dry-type building transformers.

Distribution Transformers: A Technology and Market Overview

Distribution transformers reduce electric utility power distribution line voltages (4-35 kilovolts) to lower secondary voltages (120-480 volts) suitable for customer equipment. This equipment is generally further characterized by the medium employed for cooling (liquid or air) and the voltages that they typically serve (low or medium).

Liquid-immersed transformers rely on an oil or other liquid circulating around the coils for cooling. In contrast, dry-type transformers use only the natural convection of air for insulation and cooling. Liquid, removes heat more effectively than air, and as such, liquid-immersed transformers are generally more efficient than dry-type. However, many liquids used in transformers are also toxic or flammable. Concerns over fire safety have led to use of liquid-immersed transformers principally in outdoor applications (such as on utility lines) and dry-type transformers, more commonly in indoor applications.

Medium-voltage transformers step line voltage down from utility line voltages to lower voltages, depending on the application. Medium-voltage dry-type transformers will convert higher voltages to 480-volt 3-phase power to service equipment such as large motors. Smaller low-voltage dry transformers, will in turn take this power and further reduce it to 208/120-volt service. Table 1 below shows the characteristics and typical applications for different distribution transformer technologies.

Table 1 - Typical Applications for Distribution Transformer Technologies

	Low-voltage	**Medium-voltage**
Liquid-immersed	Very limited application	Utility Market Generally outdoors Often built to purchasers' specifications
Dry-Type	C&I Market Typically indoors Commodity products	C&I Market Often indoors, although may be located just outside of facility Often special order

Relatively speaking distribution transformers are reliable and efficient devices, with no moving parts and average life spans of more than 30 years. They do, however, experience continuous "no-load" or core losses that arise from being constantly energized ready to serve a needed load. As a result, even small changes in efficiency can add up to large energy savings. Additionally, when serving a given load, they also lose energy at a level which increases rapidly as the load increases (proportional to the square of the current running through the transformer). Collectively distribution transformers account for an estimated 140 billion kWh in electricity losses annually, of which a significant portion, 46 percent, is attributable to dry-type transformers (see Figure 1 below). Compared to overall electricity sales of about 3,300 billion kWh per year, transformer losses represent about 4 percent of annual sales – a small but important share.

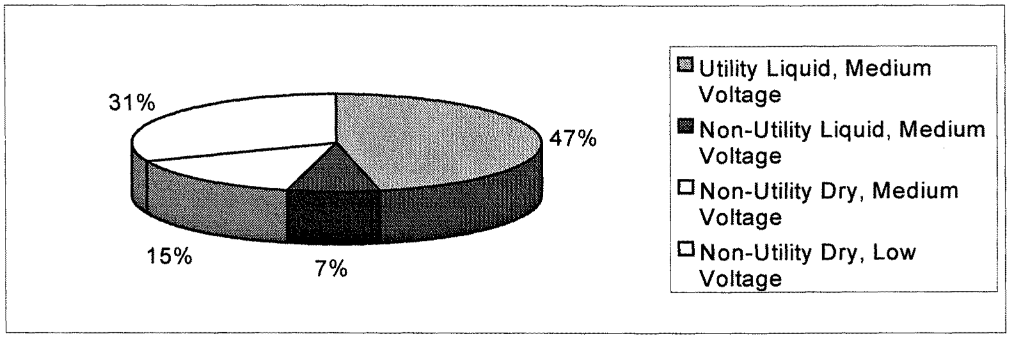

Figure 1 - 1995 Estimated Losses by Type of Transformers (Millions of kWh)
Source: Barnes et. al. 1997.

The markets for both utility and C&I distribution transformers are driven by continuous replacement of retiring transformers as well as new construction and major renovation activity. Total annual medium- and low-voltage transformer sales were collected as part of an Oak Ridge National Laboratory. In 1995, according to this study, total dry-type transformer sales were estimated by capacity to be 20,660 MVA (megaVolt-Ampere) (Barnes et. al. 1997). Discussions with major manufacturers suggest that this sales level has increased in recent years due to the strong economy and high level of new construction. Approximately 77 percent of distribution transformer sales by capacity is devoted to the utility market, while 23 percent of sales is devoted to the non-utility, or commercial and industrial market. Of these non-utility sales, about 60% of the dry-type market is low-voltage equipment, with the other 40% medium voltage (see Figure 2). Given that dry-type transformers represent less than a quarter of total transformer sales by capacity, the fact that their losses contribute nearly half of the total losses is significant .

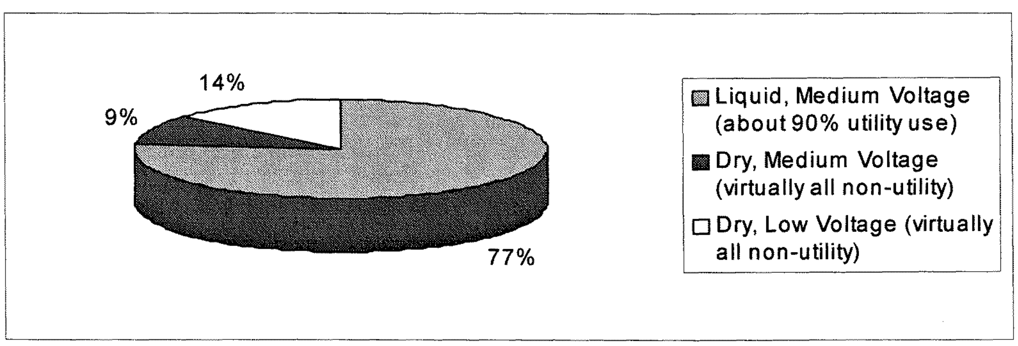

Figure 2 - 1995 Distribution Transformer Sales by Type (in MVA)
Source: Barnes et. al. 1997

Additional insights on the distribution transformer market include the following:

- Utilities and commercial and industrial users purchase more than one million new distribution transformers annually.
- Most liquid-immersed transformers are owned by utilities and purchased using total owning cost criteria, accounting for the cost of energy losses. (See Barnes et al. 1996 and Thorne and Kubo 1999 for additional information).
- Commercial and industrial customers purchase virtually all dry-type transformers.
- Medium-voltage dry-type transformers are generally special-order items, because of their high first cost and the need to specify the exact model and characteristics desired. Some purchasers, possibly as many as 60% of C&I users, consider the cost of operation in their purchasing decisions. (Barnes et. al. 1996)
- Low-voltage, dry-type transformers are commodity items purchased primarily on the basis of first cost and local availability, and demand for more efficient products has been limited.
- There are a relatively large number of dry-type transformer manufacturers, though three to four manufacturers (including GE, Square D, and Cutler-Hammer) control 65 to 80% of the market. Many of the smaller manufacturers have specialty lines of equipment (addressing harmonic loads or other specific needs), or have larger market shares in a particular geographic region of the country.

Opportunities/Savings Potential

Few sources are available on dry-type distribution transformer losses and savings potential. They include a paper by E Source; the above-mentioned study by ORNL conducted for the U.S Department of Energy (DOE); and a recent Cadmus estimate in a study prepared for Northeast Energy Efficiency Partnerships (NEEP) and two Massachusetts utilities. Table 2 below summarizes the findings from these studies.

	E Source -1995	ORNL - 1997	CADMUS – 1999
Annual Losses	60-80 billion kWh (based on discussions with researchers from ORNL)	80 billion kWh	17 billion kWh(energy savings for low voltage only)
Annual Savings Potential	$1 billion per year (1-3 cents per square foot of building space.)	330 – 400 million kWh	350 million kWh
Load Factor	35%	35%	16%

Table 2 - Opportunities/Savings Potential of Dry-type Transformers
Sources: Barnes et. al. 1997; E-Source 1995; Korn et. al. 1999.

Of these three studies, it is interesting to note that the Cadmus study found that metered transformers in New England were loaded at an average of 16% rather than the industry convention of 35%.

ORNL's study was the first major investigation into transformer losses and efficiency opportunities. It was conducted to determine the feasibility of minimum federal efficiency standards for transformers. This initial "determination analysis", published in 1996, found that distribution transformer standards were both economically justified and technically feasible. However, the determination was not made with respect to adopting standards at the TP 1 level. So in 1997, ORNL produced a supplemental study to determine the savings potential from adopting the NEMA standard nationally. This study showed the potential savings from the application of TP 1 to those dry-type transformers (low and medium voltage) sold in 1995 would be about 330 million kWh, and with growth in annual sales, would accrue to more than 400 million kWh in 2004. By comparison, the savings from application of TP 1 to liquid filled transformers would be only 60 million kWh in 1995, and 67 million kWh in 2003, due to the higher existing efficiency levels of liquid filled transformers, and the minimal efficiency improvement required by TP 1 (Barnes et. al. 1997). ORNL further estimated that manufacturer participation and universal acceptance of equipment meeting the NEMA TP 1 standard would yield cumulative energy savings approaching 2.5 quads, or 250 billion kWh, over a 30-year period.

The Cadmus study, funded by several utilities in the Northeast, was undertaken in response to questions about the uncertainty of the range of typical loads served by dry-type transformers (assumptions about which could affect transformer selection and energy loss estimates). Three-hundred transformers in 43 buildings throughout Boston Edison and NEES Companies service territories were surveyed. Their key finding – that average transformer loading across a range of building types is less than half that assumed by the industry for the purpose of TP 1 and other analyses -- suggests that the greatest opportunity for energy-savings is through reducing no-load losses – or in other words through improving the efficiency of the transformer core (Korn et. al. 1999).

Challenges/Barriers to Improved Efficiency

Although the savings potential is sizable, neither the commercial nor the industrial markets have emphasized efficiency. A 1996 ORNL survey of manufacturers found that virtually no commercial or industrial purchasers specify efficiency in their transformer purchases. There are several reasons for this:

- Lack of awareness and knowledge: Key market actors including vendors, specifiers, electrical contractors and end-users are unaware of efficient transformers (see description of NEMA TP 1 below) and the cost savings available from specifying more efficient transformers.
- Split incentives: Engineers responsible for specifying transformers and electrical contractors who purchase and install the equipment have virtually no incentive to reduce operating costs for the building owner. Therefore, they specify and purchase low first cost, low efficiency units to keep up-front project costs low. Furthermore, building owners who lease building space, lack a direct incentive to require the purchase of more efficient transformers because they bear the burden of a higher up-front cost, but their tenants gain the benefit of lower energy bills.
- Lack of availability: Availability of energy-efficient transformers has been very limited, as a result of limited manufacture and stocking. Furthermore, it has been

difficult to identify energy-efficient equipment. Efficiency performance data historically have not been widely published in catalogs or on transformer nameplates. As a result, specifiers or end-users that want to purchase an efficient transformer, have difficulty finding one. This barrier is decreasing as more manufacturers enter the market and EPA publishes ENERGY STAR qualifying equipment on its web site.

- High cost: Energy-efficient transformers are rarely a stock item and in many cases, must be special ordered. As a special order item, efficient transformers have a high mark-up and are often more expensive than the incremental material and labor costs to produce them.

The cumulative effect of these barriers is that the transformer market has been largely first-cost driven, with the exception of some purchases of larger medium-voltage equipment. Specifiers and purchasers search for the lowest priced equipment that meets the facility's needs, and manufacturers compete by attempting to keep prices as low as possible.

Current Market Interventions

To address the challenges and barriers listed above, a group of loosely coordinated industry, voluntary, and regulatory activities are underway. In recent years, these forces have combined to effect a substantial shift in the market for energy-efficient distribution transformers (see deLaski et. al. 1998 for background).

Industry Efforts

In an effort to reduce the need for minimum efficiency standards, in 1996 the National Electrical Manufacturers Association (NEMA) developed the voluntary industry standard TP 1-1996, *Guide to Determining Energy Efficiency for Distribution Transformers* (NEMA 1996, deLaski et. al. 1998). (Several manufacturers have had "energy saving" lines of transformers available that had more efficient windings, but only save energy at quite high loads). The standard addresses both dry type and liquid-filled distribution transformers, and recommends a life-cycle costing methodology and includes a table of default transformer efficiencies, by transformer type and size. These recommended efficiencies were developed based on a goal of a three-year simple payback period. Recent manufacturer price quotes for low-voltage TP 1 transformers reveal that purchasers would realize a payback of about 4 years, assuming an average electric rate of 6.6 cents per kWh (kiloWatt-hour). However, manufacturers project that prices will decline as the market matures, such that, the payback period will fall to between 1.5 and 2 years.

In addition to TP 1, NEMA has developed and issued TP 2, a test method for transformer efficiency, and is in the process of developing TP 3, a labeling standard to identify transformers that meet TP 1. Additionally, TP 1 is in the process of being updated, but any changes to the standard are expected to be minor. The industry is currently considering TP 1 as a North American standard that would apply to manufacturers from Canada and Mexico, in addition to those from the US.

Voluntary Programs

To further promote the market energy efficient equipment, a number of organizations have rallied to support the NEMA's voluntary standard. Soon after NEMA developed TP 1, CEE and ENERGY STAR® and the Federal Energy Management Program (FEMP) began working on a strategy to promote high-efficiency distribution transformers in the market. In addition, the State of New York recently launched a statewide voluntary program.

Consortium for Energy Efficiency. In 1997, CEE developed a model transformer initiative for low- and medium-voltage products, based on the TP 1 standard. This initiative provides a platform for promotional efforts that utilities and others can support nationwide. The initiative includes voluntary low-voltage transformer efficiency performance specification (TP 1), guidelines for using cost-of-ownership methods in transformer purchases, suggested strategies for implementers to educate key market players regarding the benefits of choosing energy-efficient transformers, and guidance regarding incentives (where appropriate). By aggregating utility demand-building efforts to promote high-efficiency transformers, CEE also encourages manufacturers to produce qualifying products.

In order to overcome the higher first costs for more efficient equipment and to stimulate a market for energy efficiency services, some CEE members target new construction or major renovation projects, where a new transformer may be involved. Current programs typically have some type of "custom measure" component, where any technology that saves energy can be considered for an incentive, but the burden of proof of energy savings and cost effectiveness is on the contractor, customer and/or its design team, and can be prohibitively burdensome. Other utilities or jurisdictions have "standard offer" programs that provide financial incentives to contractors and customers for every kiloWatt-hour (kWh) or kiloWatt (kW) saved from the installation of more energy-efficient equipment. Standard offer programs through state programs or utilities are available in New York, New Jersey, Wisconsin, Texas, and California.

Additionally, several utilities in New England, such as National Grid, USA (formerly NEES Companies), are examining the possibility of prescriptive rebates for low-voltage dry-type transformers, to increase awareness, availability, and cost effectiveness, of these models. While only a limited number of transformer projects have received incentives through standard offer programs, it is anticipated that the volume will increase significantly with programs that provide targeted incentives for transformers.

ENERGYSTAR. In 1998, working with NEMA, CEE, and others EPA launched the ENERGYSTAR Commercial and Industrial (C&I) Transformers labeling program for low-voltage dry-type transformers, making it simple for specifiers, contractors and building professionals to identify efficient transformers. Like the CEE initiative, the ENERGYSTAR Program relies on the TP 1 standard. Through this program, EPA encourages manufacturers to produce ENERGYSTAR-compliant models, and has developed a variety of education and marketing materials and tools to help build understanding of, and demand for, efficient transformers.

Over the past two years, the number of Manufacturer Partners in the ENERGYSTAR C&I Transformers Program has increased 5-fold (had been 3, up to 16 in May 2000), with some of the largest transformer manufacturers signing-on to produce and market high efficiency transformers. In addition to providing Partners with the use of the internationally-recognized logo, the ENERGYSTAR Program provides tools to help manufacturers market their products including a calculator to estimate potential savings and a cost evaluation model to enable building managers to accurately consider the costs associated with transformer purchases. The ENERGY STAR Program also promotes the Partners by listing their names and product information on the ENERGY STAR Web site (see www.energystar.gov). In addition, the Program participates in seminars with manufacturers and engineers to inform interested parties about the cost and environmental benefits of ENERGY STAR-labeled C&I transformers.

The New York State Energy $mart Program. At the state level, the New York State Energy Research and Development Authority (NYSERDA) has initiated a two-year program to develop the market for energy-efficient, low-voltage TP 1 transformers through a majority of the state. The project will begin by characterizing the baseline market conditions in New York. Program implementers will then focus on developing and disseminating needed technical tools, such as model specifications and computer-based and hand-held life-cycle cost calculators to help consulting engineers, electrical contractors, and building owners evaluate alternative products and make more informed decisions regarding their (or their customers') transformer purchases. This activity will draw heavily on resources already developed by NEMA, ENERGYSTAR, CEE, FEMP, and others. Short-term incentives will be provided through the New York State Energy $mart New Commercial Construction program to capture the attention of the market and create momentum for manufacturers to increase the local supply of transformers. This will be supplemented by educational outreach to a broader community, such as professional associations of building developers and facilities and energy managers, and by coordinated promotion activities in conjunction with other national efforts to promote efficient transformers. The two-year effort is anticipated to begin in early summer 2000.

Federal Energy Management Program. Pursuant to a presidential executive order directing federal agencies to purchase ENERGYSTAR and other energy-efficient products, FEMP issues a series of product efficiency recommendations (available through www.eren.doe.gov/femp/procurement) for federal buyers and specifiers. FEMP's recommended distribution transformer efficiencies match the TP 1, CEE, and ENERGYSTAR levels. FEMP is presently concentrating its efforts on getting federal agency guide specification writers to "hard-wire" the prescriptive levels into their respective master specifications.

Regulatory Activity

Under the Energy Policy Act of 1992, DOE was directed to consider minimum efficiency standards for distribution transformers. In 1996, the Department issued a determination that transformer efficiency standards are both technically feasible and economically justified. The agency is about halfway through a process of establishing transformer test procedures, and once the test procedure rule is complete (which DOE plans to finalize in 2000), DOE will initiate the process to develop a transformer standard. The first step will be a kick-off meeting, tentatively scheduled for the summer of 2000.

Additionally, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), which writes the national model building energy code for new commercial buildings, considered including TP 1 in the recent revision to ASHRAE Standard 90.1, but concerns about product availability and cost led to its elimination. ASHRAE plans to revisit the issue this year, and will make a decision then, based on demonstration of energy savings, product availability and incremental cost. An important consideration is the impact that inclusion in the ASHRAE Standard has on DOE's activity. DOE is required by law to revisit the basis for all state and federal agency energy codes whenever the ASHRAE Standard is updated. A requirement for more efficient transformers, if incorporated into ASHRAE Standard 90.1, could trigger several federal actions that could lead to requirements for efficient transformers in states that reference 90.1 in their building codes.

Absent rapid progress on minimum efficiency standards at the federal level, a number of states have either passed regulations or are incorporating efficient transformers into purchasing specifications:

- Massachusetts: The passage of the Massachusetts Electric Industry Restructuring Act in 1997 contained a provision requiring minimum efficiency levels for all distribution transformers. Section 313 mandates that all distribution transformers at primary voltages of 34.5 kV and below and secondary voltages of 600 volts or below sold or first installed in the commonwealth after December 31, 1999, shall meet the minimum efficiency levels of NEMA TP 1. The NEMA standard has been integrated into the revised Massachusetts Energy Code, which has more stringent enforcement provisions. The revised energy code takes effect January 2001.
- Minnesota: Minnesota proposed a revised energy code requiring the use of NEMA TP 1 transformers in the December 1997 State Register. These transformers are now required as part of the Minnesota Building Code administrative rules, which are enforced by building officials. The TP 1 requirement of the Minnesota code went into effect in July 1999.
- Wisconsin: The Division of Facilities Development of the Wisconsin Department of Administration, working with the Wisconsin Energy Bureau has prepared a state master specification that requires all contractors to use distribution transformers that meet NEMA TP 1 efficiency standard for all new state facility construction and remodeling projects.
- Other states, such as California and New York are also considering similar codes and standards. Additionally, Canada has proposed a minimum efficiency requirement based on TP 1 (details can be found at http://regulations.nrcan.gc.ca/).

Evidence of Market Changes

These market interventions by industry, utilities, and governments have helped motivate recent changes in product availability. A number of manufacturers recently announced the availability of, or plans to begin production of, efficient transformers. Square D, one of the largest manufacturers, announced in 1998 the availability of a full line of TP 1 product. In 1999, Cutler Hammer -- another major manufacturer -- introduced a line of TP 1 products. Other manufacturers, such as Federal Pacific, Acme, Marcus Transformers of Canada and Olsun Electric, that supply smaller portions of the market, also produce TP 1 transformers, some of which greatly exceed the minimum efficiencies specified in TP 1. Honeywell has also just begun producing its Transtar model, which incorporates an amorphous metal core. These models have core losses that are on the order of one fourth of those of a TP 1 model. Efficiencies achieved approach 99 percent or nearly a full percent above the TP 1 efficiency for most sizes at typical loads.

Additionally, the number of ENERGYSTAR partners has risen from about 3 in early 1999 to 16 at present. Availability seems also to be on the rise. Based on a recent review of several electrical distributors across the country, TP 1/ENERGYSTAR models are readily available from several makers. Furthermore, costs are coming down. Marcus, for example, offers TP 1 transformers in the northern U.S, at a minor cost premium over conventional models available from major manufacturers (i.e., less than 20 percent). TP 1 models from several major manufacturers are available for cost premiums of 50 to 100%, depending on size. While this is somewhat higher than the 33 percent premium projected by many manufacturers in the past year, prices are expected to drop as more makers ship TP 1 models.

The simple payback period associated with the savings provided by TP 1 models vary from several months for a minor brand of transformer to 3 to 6 years for major brands for most size categories based on an electricity cost of $0.066/kWh. The amorphous core transformer by Honeywell delivers greater savings than most TP 1 models with a projected payback period of roughly 3 to 4years. Savings in higher cost regions would be higher, with paybacks of approximately 2 years in many utility service territories.

Finally, media exposure of the concept of energy-efficient transformers has come a long way. There has been substantial progress on this front in the past year: while there had been virtually no articles in the trade press in recent years about transformer efficiency options, a spate of recent articles has reversed this trend.

Conclusions/Next Steps

Much progress has been made in a relatively short time with regard to energy-efficient, dry-type, distribution transformers. The barriers to market adoption are beginning to be bridged through a combination of efforts: industry-defined voluntary efficiency levels, CEE, ENERGYSTAR, and FEMP as national initiatives to build demand, state-based promotions and mandates, and utility financial incentives. As a result products meeting NEMA standard TP 1 are beginning to gain momentum in the market.

However, continued efforts to build market share for TP 1 transformers so that products are routinely produced, specified, stocked and purchased are required to fully "transform" this market. Three types of actions are recommended for organizations seeking to capitalize on the substantial efficiency opportunity and momentum in the market. These include:

Awareness/Education

- Providing education to various market players to raise awareness of transformer efficiency levels and how to identify and specify more efficient transformers will lead to increased transformer purchases.
- Providing targeted education on the benefits of energy-efficient transformers to upstream market players, including electrical system designers/specifiers, electrical

contractors, distributors, and corporate facilities planners will enable them to make more informed decisions for their purchasers.

Tools Development

- Developing case studies of selected buildings where energy-efficient transformers have been installed as well as marketing materials that include basic information about transformers, available alternatives, and their economics can enable upstream market actors to provide real-world examples of efficiency gains as well as credibility to customers.
- Promoting and refining existing technical tools for use by consulting engineers, electrical contractors, and building owners, such as CD-ROM and web-based life-cycle cost calculators (currently available from EPA), a hand-held slide-rule type of tool for quick evaluation of alternative products, and model specifications to enable upstream market actors to make fast and well-grounded decisions regarding purchases of efficient transformers.

Short-term Incentives

- Providing short-term incentives captures the attention of the market, assists with education, and affords and opportunity for customers and specifiers to gain technical and commercial acceptance of products. Additionally, it creates momentum for manufacturers to increase the supply of local stocks and more-fully support local efforts.

Future activities to promote energy-efficient transformers will undoubtedly take advantage of these recent developments and leverage industry, national, and regional promotion efforts. Together these efforts can effect greater purchases of efficient transformers, greater availability, lower incremental costs, and eventual market transformation. Furthermore, activities to develop the market for efficient transformers could help to influence a potential federal efficiency standard (or conceivably a state standard or code change) and thus help to effect broad and permanent market transformation.

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