ENERGY STAR Market and Industry Scoping Report
Medium Voltage Distribution Transformers
February 2014

The U.S. Environmental Protection Agency (EPA) consistently looks for new opportunities to expand ENERGY STAR to new product categories that will deliver significant benefits to consumers and the environment in the form of energy and dollar savings plus greenhouse gas reductions. A key step in this evaluation is the development of a scoping report that provides a snapshot of the product market, energy use, and savings potential associated with an ENERGY STAR program for the scoped product type. EPA uses scoping findings to prioritize product specification development work. While scoping reports are drafted primarily for internal evaluation purposes, and are not intended to be exhaustive but rather a guidepost for the ENERGY STAR program, EPA makes the reports available with the interest of benefiting other efficiency programs evaluating similar opportunities. For more information about the ENERGY STAR specification development process, go to: www.energystar.gov/productdevelopment.

1. Executive Summary

Approximately one-third of all distribution network losses are due to transformers and 70% of the transformer loss is due to distribution transformers.[1] Installing slightly more efficient transformers in the United States has the potential to yield large energy and monetary savings. Additional research and stakeholder engagement is necessary to understand the potential barriers to adopting the more efficient technology, from its different operational characteristics to the incentives that utilities face during purchasing decisions.

2. Product & Technology Overview

Distribution Transformer: A static device constructed with a core and two or more coils (also known as windings) used to transfer alternating-current by electromagnetic induction from one circuit to another and to change the value of the original voltage and current. Distribution transformers are used to reduce the voltage of the electric grid system to the voltage serving the consumer and have an input voltage of 34 kV or less and an output voltage of 600 V or less.[2]

The capacity of a distribution transformer is measured in kilovolt-amperes (kVA) and is defined as the amount of current the transformer can allow at the rated voltage without exceeding the design temperature, multiplied by the rated voltage.[3]

There are two types of transformer insulation, which refers to the medium used to insulate and cool a transformer's coils: liquid-immersed or dry-type. Liquid insulation is more efficient and can have a longer lifetime but is not as safe, with additional risk of leaking, catching fire, or catastrophic failure. For these reasons, liquid-immersed transformers are limited mostly to outdoor use.[4]

---

[1] M. Scholand, T. Blackburn, E. Carey, P. Hopkinson and M. Sampat, "SEAD Standards & Labelling Working Group Distribution Transformers Collaboration," CLASP, 2013.
[2] U.S. Department of Energy, "2013-04 Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment Distribution Transformers," 2013.
[3] J. E. Mack and T. Shoemaker, "Chapter 15 - Distribution Transformers," in *The Lineman's and Cableman's Handbook,* 11th ed. (New York: McGraw-Hill, 2006) pp. 1–22.
[4] U.S. Department of Energy.

Another distinction between different transformers is the number of phases they can process – either one or three. Power is transmitted in three phases over long distances. Dry-type distribution transformers can also be grouped into low or medium voltage for different applications. The voltage class is defined by the input voltage: low voltage transformers have an input voltage less than 600 V, while medium voltage transformers have an input voltage above more than 600 V.[5]

One last classification that can be used when describing a medium voltage dry-type transformer is basic impulse insulation level (BIL). BIL is the measure of resistance to very large changes in voltage, like those from a lightning strike. Generally a higher BIL rating will have a reduced operating efficiency because additional insulation is added to the coil wire, which increases the distance between the core and the coils.[6]

Table 1 shows the Super-efficient Equipment and Appliance Deployment (SEAD) categorization of transformers based on power. SEAD does not take the same approach as the DOE categorization system (described above), but the advantage of SEAD's categorization is that it groups transformers by application.

Table 1: SEAD Overview of Transformer Categories by Capacity, Insulation, and Common Use[7]

Transformer Group	Voltage	Phases	Typical Insulation	Common Use
Large Power	>245 kV (High voltage)	Single and Three	Liquid-filled	Stepping up to or down from higher voltages for transmission of electricity over distances; substation transformers
Medium Power	>36 kV & ≤230 kV (Medium voltage)	Single and Three	Dry-type or liquid-filled	Stepping voltages down from a subtransmission system to a primary distribution system
Medium Voltage Distribution	≤36 kV (Medium voltage)	Single and Three	Dry-type or liquid-filled	Stepping voltages down within a distribution circuit from a primary to a secondary distribution voltage
Low Voltage Distribution	≤1 kV (Low voltage)	Single and Three	Dry-type	Stepping voltages down within a distribution circuit of a building or to supply power to equipment

The scope of this report will be limited to medium voltage distribution transformers which represents 10 to 2500 kVA for liquid-immersed and 15 to 2500 kVA for dry-type according to the DOE assessment.[8]

Distribution transformers can have various types of cores with laminated steel being the most common. Using amorphous metal as the core material over laminated steel can reduce the core losses by approximately 60%.[9] Amorphous alloys are produced by a process of rapidly cooling a liquid metal in order for it to keep its liquid, non-crystalline structure. The advantage of an amorphous alloy is its strength and electrical characteristics. A disadvantage is that it requires advanced, more-costly techniques to produce.[10]

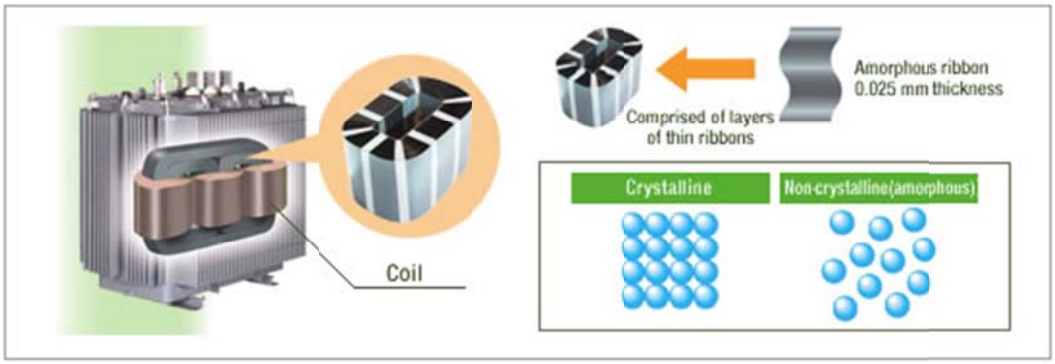
Transformers made with amorphous cores have advantages such as low core losses, less noise, higher efficiency and a longer life. Their disadvantages include higher inrush current,

---

[5] Ibid.
[6] Ibid.
[7] Scholand et al.
[8] U.S. Department of Energy.
[9] Mack and Shoemaker.
[10] Hitachi Industrial Equipment Systems Co., Ltd., "Amorphous Core Transformers," http://www.hitachi.com/environment/showcase/solution/industrial/trans.html [Accessed 17 December 2013].

more harmonic problems, bigger size and higher initial cost.[11] Figure 1 below demonstrates a typical amorphous core transformer.

Figure 1: Hitachi Industrial Equipment Systems Co., Ltd. Amorphous Core Distribution Transformer[12]



3. Market Assessment

Due to high manufacturer sensitivity to unit shipment data by transformer type, exact numbers could not be located. However, DOE estimated the unit shipment data for transformers by equipment class (as described in Section 2) as seen in Table 2.

Table 2: DOE National Medium-Voltage Distribution Transformer Unit Shipment Data for 2009[13]

Distribution Transformer Equipment Type	Units Shipped	MVA Capacity Shipped	Shipment Value (2009 US$million)
Liquid-immersed, medium-voltage, single-phase	683,726	21,994	714.8
Liquid-immersed, medium-voltage, three-phase	49,739	32,266	786
Dry-type, medium-voltage, single-phase, 20-45 kV BIL	709	23	0.7
Dry-type, medium-voltage, three-phase, 20-45 kV BIL	522	257	6.2
Dry-type, medium-voltage, single-phase, 46-95 kV BIL	546	23	0.8
Dry-type, medium-voltage, three-phase, 46-95 kV BIL	2,074	3,655	98.7
Dry-type, medium-voltage, single-phase, ≥ 96 kV BIL	202	9	0.3
Dry-type, medium-voltage, three-phase, ≥ 96 kV BIL	1,286	2,206	66.2
Total	**738,804**	**60,433**	**$ 1,673.70**

The lifetime of a typical distribution transformer is estimated at 25–30 years;[14] DOE calculated the average lifetime to be 32 years.[15]

In the U.S. there are 12 major companies manufacturing transformers, representing about 80% of the medium voltage dry-type and liquid-immersed markets. These are listed below.

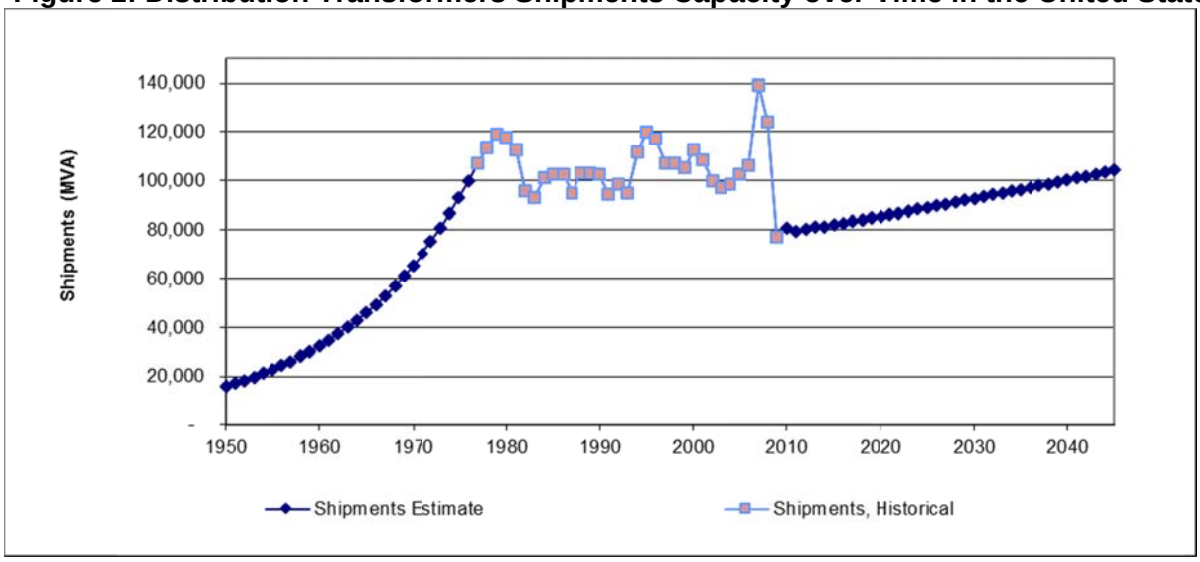
- ABB Power T&D Company – liquid-immersed manufacturer and dry-type manufacturer
- CG Power Systems USA Inc.
- Cooper Power Systems– liquid-immersed and dry-type manufacturer
- EGS Electrical Group
- Electrical Repair and Maintenance Company (ERMCO) – liquid-immersed manufacturer

[11] M. Mohan, "An Overview on Amorphous Core Transformers," *Journal of Emerging Trends in Engineering and Applied Sciences*, 2 (2012): pp. 217–220.
[12] Hitachi Industrial Equipment Systems Co., Ltd.
[13] U.S. Department of Energy.
[14] Hitachi Industrial Equipment Systems Co., Ltd.
[15] U.S. Department of Energy.

- Federal Pacific – dry-type manufacturer
- GE Industrial Solutions
- Hammond Power Solutions, Inc. – dry-type manufacturer
- Howard Industries – liquid-immersed manufacturer
- Jinpan International Ltd. – dry-type manufacturer
- Kentucky Association of Electric Cooperatives, Inc.
- Magnetic Technologies Corp. – dry-type manufacturer
- MGM Transformer Company – dry-type manufacturer
- Mirus International Inc.
- Niagara Transformer Corporation
- Olson Electrics Corporation – dry-type manufacturer
- Power Partners – liquid-immersed manufacturer
- Power Quality International, Inc.
- Powersmiths International Corp.
- Prolec-General Electric – liquid-immersed manufacturer
- Schneider Electric
- VanTran Industries, Inc.

The DOE Final Rule Technical Support Document (TSD) for Distribution Transformers states that there are several amorphous core manufacturers in the United States; however, there is currently only one supplier of the amorphous ribbon used in the manufacturing of amorphous cores.[16] The supplier is Hitachi America, Ltd. via its subsidiary Metglas. Metglas manufactures amorphous ribbon in the United States and can supply about ten times more than the current demand, equal to 3–5% of the transformer market per year.[17] The shipments of distribution transformers in terms of total output capacity from 1950 to 2040 are presented in Figure 2. The 2009 shipment estimates were based on several insights including a general reduction in commercial and industrial market activity. After the decrease in shipments in 2009, the market began to steadily climb and is forecasted to grow.[18]

Figure 2: Distribution Transformers Shipments Capacity over Time in the United States[19]



[16] Ibid.
[17] R. Dugan, email correspondence with Douglas Frazee, ICF International, 31 January 2013.
[18] U.S. Department of Energy.
[19] Ibid.

The shipments illustrated above are driven by two deployment scenarios: new distribution facilities and failure replacement, with the majority being failure replacements. Utilities do not replace non-failed transformers with higher efficiency models because the cost to remove and install is too great.[20]

4. Energy Efficiency Assessment

Transformer losses can be divided into two types: load losses, occurring during use, and no-load losses, also called standby losses. The two parts of a transformer responsible for losses are the coils (responsible for load losses) and the core (responsible for no-load losses). The maximum efficiency of a transformer occurs at the percentage loading where core losses are equivalent to coil losses.

The efficiency of a distribution transformer can be improved in two main ways:

- Improving the materials – core and winding materials
- Altering the geometric configuration of the transformer

These methods generally result in a trade-off between energy efficiency and expense. Amorphous metal can be used to achieve extremely low no-load losses but these materials have properties that make manufacturing challenging. Table 3, below, outlines approaches to increasing efficiency. There are trade-offs between decreasing core losses and coil losses, and these can have an inverse relationship.

Table 3: Loss-Reduction Approaches[21]

Objective	Approach	No-Load Losses	Load Losses	Effect on Price
Decrease Core Losses	Use lower-loss core materials	Lower	No change	Higher
	Decrease flux density by increasing core cross-sectional area	Lower	Higher	Higher
	Decrease flux density by decreasing volts/turn	Lower	Higher	Same to Higher
	Decrease flux path length by decreasing conductor cross-sectional area	Lower	Higher	Lower
Decrease Coil Losses	Use lower-loss conductor materials	No change	Lower	Higher
	Decrease current density by increasing conductor cross-sectional area	Higher	Lower	Higher
	Decrease current path length by decreasing core cross-sectional area	Higher	Lower	Lower
	Decrease current path length by increasing volts/turn	Higher	Lower	Lower

Efficiency gains can be realized by using these methods, with amorphous core transformers having 60% less core losses at low- to no-load conditions but similar efficiency as steel-core transformers under 50% loading. The DOE TSD analyzed the costs of designing transformers in

[20] M. Sampat, telephone interview with Douglas Frazee and Emmy Phelan, ICF International, 24 December 2013.
[21] Scholand et al.

each equipment class to meet a range of efficiency levels at an assumed 50% loading. Incremental cost associated with efficiency gains can be seen in Table 4, below. The current 2010 DOE standard is represented in the table as the baseline and the amended standard that will be effective in January 2016 is highlighted in yellow.

For efficiency levels 1 through 3, red highlighting identifies that the efficiency level is lower than the 2016 DOE amended standard, while green highlighting identifies efficiency levels that exceed the 2016 DOE amended standard. The DOE 2016 amended standards generally align with or are below efficiency level 1. For three equipment categories, the 2016 standard aligns with efficiency level 2.

Later in the analysis, DOE took the transformer designs meeting the various efficiency levels, and modeled their expected loading based on peak and average energy consumption for a variety of industrial and commercial buildings to calculate their energy consumption and the impacts of various standard levels on users and the nation as a whole. Tables 5 and 6, below, compare the analysis results for the DOE 2016 amended standard levels with Efficiency Levels 2 and 3 for liquid-immersed distribution transformers, which constitute the overwhelming majority of unit shipments and capacity. The payback is highly dependent on the equipment class but is on the order of 10 years, which compares favorably with the 32-year average lifetime, and typical 20 year capitalization periods.[22] If all medium voltage distribution transformers met Efficiency Level 2, the energy savings over the DOE Federal standard would be 9.68 TWh per year. If all medium voltage distribution transformers met Efficiency Level 3, the energy savings would be 10.61 TWh per year.

[22] V. Tendulkar, telephone interview with Matt Malinowski, ICF International, 31 January 2014.

Table 4: DOE Baseline Efficiency, 2016 Standard, and Various Analyzed DOE Efficiency Levels with Associated Incremental Costs Based on Different Transformers Designs

Design Line	Type of Transformer	Representative Unit	Baseline - 2010 DOE Standard	2016 DOE Standard	Efficiency Level 1		Efficiency Level 2		Efficiency Level 3		Efficiency Level 4		Efficiency Level 5		Efficiency Level 6		Efficiency Level 7	
		Baseline	Eff. %	Eff. %	Eff. %	2011 $	Eff. %	2011 $	Eff. %	2011 $	Eff. %	2011 $	Eff. %	2011 $	Eff. %	2011 $	Eff. %	2011 $
1	Liquid-immersed, single-phase, rectangular tank	50 kVA, 65°C, single-phase, 60Hz, 14400V primary, 240/120V secondary, rectangular tank	99.08	**99.11**	99.16	170	99.22	651	99.25	794	99.31	472	99.42	923	99.5	1253	99.5	N/A
2	Liquid-immersed, single-phase, round tank	25 kVA, 65°C, single-phase, 60Hz, 14400V primary, 120/240V secondary, round tank	98.91	**98.95**	99	209	99.07	378	99.11	272	99.18	302	99.31	531	99.41	749	99.47	1232
3	Liquid-immersed, single-phase	500 kVA, 65°C, single-phase, 60Hz, 14400V primary, 277V secondary	99.42	**99.49**	99.48	841	99.51	1581	99.54	3104	99.57	2280	99.61	2764	99.69	4675	99.73	7394
4	Liquid-immersed, three-phase	150 kVA, 65°C, three-phase, 60Hz, 12470Y/7200V primary, 208Y/120V secondary	99.08	**99.16**	99.16	460	99.22	1282	99.25	2218	99.31	1375	99.42	1090	99.5	1793	99.6	4573
5	Liquid-immersed, three-phase	1500 kVA, 65°C, three-phase, 60Hz, 24940GrdY/14400V primary, 480Y/277V secondary	99.42	**99.48**	99.48	4037	99.51	4394	99.54	6341	99.57	7045	99.61	9703	99.69	26145	99.69	N/A
9	Dry-type, medium-voltage, three-phase, 20-45kV BIL	300 kVA, 150°C, three-phase, 60Hz, 4160V Delta primary, 480Y/277V secondary, 45kV BIL	98.82	**98.93**	98.93	-170	99.04	-234	99.15	750	99.22	1586	99.39	2393	99.55	4837	99.55	N/A
10	Dry-type, medium-voltage, three-phase, 20-45kV BIL	1500 kVA, 150°C, three-phase, 60Hz, 4160V primary, 480Y/277V secondary, 45kV BIL	99.22	**99.37**	99.29	-327	99.37	1538	99.45	6326	99.51	13392	99.58	16858	99.63	22374	99.67	N/A
11	Dry-type, medium-voltage, three-phase, 46-95kV BIL	300 kVA, 150°C, three-phase, 60Hz, 12470V primary, 480Y/277V secondary, 95kV BIL	98.67	**98.81**	98.81	-88	98.94	1176	99.06	2592	99.13	2723	99.32	4517	99.5	8378	99.5	N/A
12	Dry-type, medium-voltage, three-phase, 46-95kV BIL	1500 kVA, 150°C, three-phase, 60Hz, 12470V primary, 480Y/277V secondary, 95kV BIL	99.12	**99.3**	99.21	468	99.3	2915	99.39	7820	99.46	10430	99.53	13254	99.59	19295	99.63	26749
13A	Dry-type, medium-voltage, three-phase, 96-150kV BIL	300kVA, 150˚C, three-phase, 60Hz, 24940V primary, 480Y/277V secondary, 125kV BIL	98.63	**98.69**	98.69	-344	98.84	392	98.97	-731	99.04	488	99.25	7113	99.45	13187	99.45	N/A
13B	Dry-type, medium-voltage, three-phase, 96-150kV BIL	2000kVA, 150˚C, three-phase, 60Hz, 24940V primary, 480Y/277V secondary, 125kV BIL	99.15	**99.28**	99.19	1073	99.28	4420	99.38	11564	99.45	22162	99.52	29706	99.58	N/A	99.62	N/A

Table 5: Energy and Carbon Dioxide Savings for Efficiency Level 2 over the DOE 2016 Amended Standard Level

				Baseline	DOE Std. Level		Eff. Level 2						
Equipment Class	Design Line	2009 Shipments (units)	2016 Shipments (MVA Capacity)	Annual Energy Consumption for Shipped Units at Baseline (TWh)	Annual Energy Consumption for Shipped Units at DOE Std. Level (TWh)	Median Payback (yr)	Annual Energy Consumption for Shipped Units at Eff. Level 2 (TWh)	Annual Energy Savings for Eff. Level 2 over DOE Std. Level (TWh)	Cumulative Energy Savings for Eff. Level 2 over DOE Std. Level with 50% Stock Replacement (>16 yr) (TWh)	Cumulative CO2 Savings for Eff. Level 2 over DOE Std. Level with 50% Stock Replacement (>16 yr) (MMTCO2E)	Cumulative Energy Savings for Eff. Level 2 over DOE Std. Level with 100% Stock Replacement (>32 yr) (TWh)	Cumulative CO2 Savings for Eff. Level 2 over DOE Std. Level with 100% Stock Replacement (>32 yr) (MMTCO2E)	Median Payback (yr)
1a	1 & 2: Liquid-immersed 50 kVA and 25 kVA, single-phase	683,726	7,788	0.22	0.21	Design Line 1: 17.7 Design Line 2: 5.92	0.14	0.07	1.19	0.83	2.39	1.67	Design Line 1: 10.8 Design Line 2: 11.1
1b	3: Liquid-immersed, 500 kVA, single-phase		15,766	0.53	0.50	8.5	0.38	0.11	1.83	1.28	3.65	2.55	5.8
2a	4: Liquid-immersed, 150 kVA, three-phase	49,739	31,796	0.70	0.58	7.0	0.47	0.11	1.77	1.24	3.55	2.48	5.6
2b	5: Liquid-immersed, 1500 kVA, three-phase		2,224	0.05	0.04	6.5	0.04	0.00	0.05	0.03	0.09	0.07	6.5
Liquid Immersed Subtotal		**733,465**	**57,575**	**1.50**	**1.34**		**1.04**	**0.30**	**4.84**	**3.38**	**9.68**	**6.76**	

Table 6: Energy and Emission Savings for Efficiency Level 3 over the DOE 2016 Amended Standard Level

				Baseline	DOE Std. Level		Eff. Level 3						
Equipment Class	Design Line	2009 Shipments (units)	2016 Shipments (MVA Capacity)	Annual Energy Consumption for Shipped Units at Baseline (TWh)	Annual Energy Consumption for Shipped Units at DOE Std. Level (TWh)	Median Payback (yr)	Annual Energy Consumption for Shipped Units at Eff. Level 3 (TWh)	Annual Energy Savings for Eff. Level 3 over DOE Std. Level (TWh)	Cumulative Energy Savings for Eff. Level 3 over DOE Std. Level with 50% Stock Replacement (>16 yr) (TWh)	Cumulative CO2 Savings for Eff. Level 3 over DOE Std. Level with 50% Stock Replacement (>16 yr) (MMTCO2E)	Cumulative Energy Savings for Eff. Level 3 over DOE Std. Level with 100% Stock Replacement (>32 yr) (TWh)	Cumulative CO2 Savings for Eff. Level 3 over DOE Std. Level with 100% Stock Replacement (>32 yr) (MMTCO2E)	Median Payback (yr)
1a	1 & 2: Liquid-immersed 50 kVA and 25 kVA, single-phase	683,726	7,788	0.22	0.21	Design Line 1: 17.7 Design Line 2: 5.92	0.14	0.07	1.19	0.83	2.39	1.67	Design Line 1: 10.8 Design Line 2: 13.0
1b	3: Liquid-immersed, 500 kVA, single-phase		15,766	0.53	0.50	8.5	0.35	0.15	2.40	1.67	4.79	3.35	6.4
2a	4: Liquid-immersed, 150 kVA, three-phase	49,739	31,796	0.70	0.58	7.0	0.48	0.10	1.61	1.12	3.21	2.24	5.6
2b	5: Liquid-immersed, 1500 kVA, three-phase		2,224	0.05	0.04	6.5	0.04	0.01	0.11	0.08	0.22	0.15	8.5
Liquid Immersed Subtotal		**733,465**	**57,575**	**1.50**	**1.34**		**1.01**	**0.33**	**5.31**	**3.71**	**10.61**	**7.41**	

5. Test Standards & Metrics

The Department of Energy (DOE) published a Final Rule for Energy Conservation Standards for medium voltage liquid-immersed and dry-type distribution transformers in October 2007, which became effective in January 2010. DOE then amended these standards and published new, more stringent minimum efficiency levels in April 2013. The amended standards (seen in Table 4) will take effect in January 2016.

These conservation standards set minimum efficiency levels for low voltage dry-type transformers as well as medium voltage dry-type and medium voltage liquid-immersed transformers. DOE specified efficiency values for medium voltage transformers at a 50% rated load condition. This is the standard for most countries with transformer efficiency requirements. DOE follows the NEMA and IEEE approach to defining the kVA ratings and testing.[23]

In contrast, Europe's voluntary transformer requirements are based on the IEC 60076 Power Transformers standard and specify two requirements that a transformer must meet:

1. Maximum no-load loss (core loss)
2. Maximum load loss at 100% of rated load (coil loss)

However, a metric based on maximum losses at two efficiency points may limit the design of a transformer. A requirement at 50% load allows a trade-off between core losses and coil losses to optimize a system for lower overall cost or for a particular application.[24]

There are no apparent barriers with testing and shipping these products. Models are currently tested by manufacturers in order to meet the Federal standards but there are also capable third party testing laboratories. The size and weight of transformers is not an issue for testing and verifying their compliance.[25]

[23] Scholand et al.
[24] Ibid.
[25] Sampat.