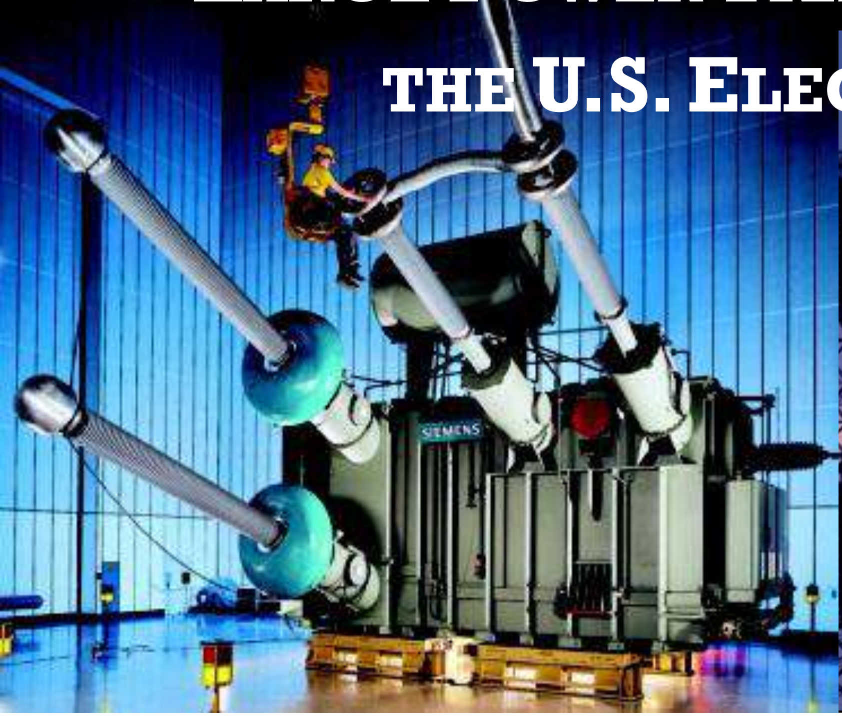
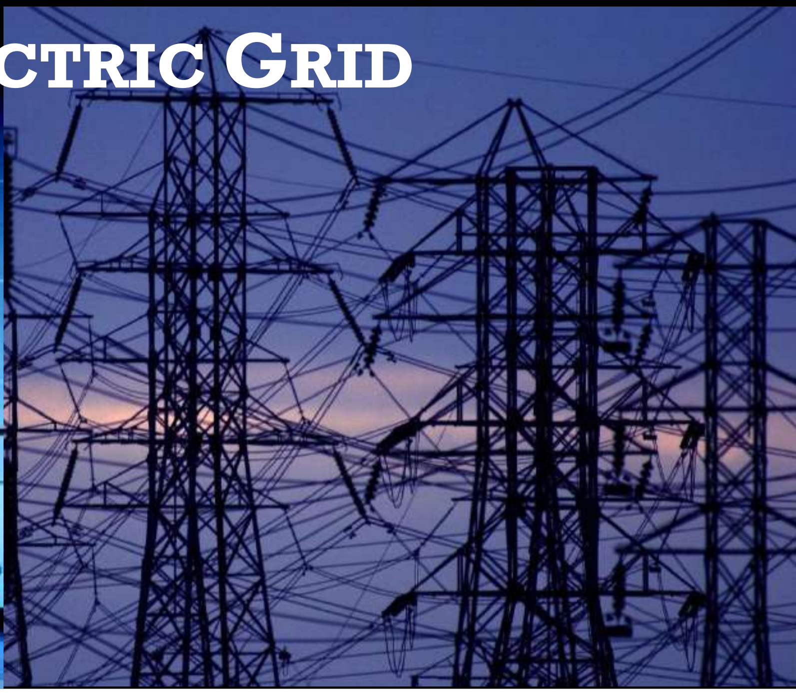
LARGE POWER TRANSFORMERS AND THE U.S. ELECTRIC GRID





Infrastructure Security and Energy Restoration
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FOR FURTHER INFORMATION

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EXECUTIVE SUMMARY

The Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy (DOE) assessed the procurement and supply environment of large power transformers (LPT)[1] in this report. LPTs have long been a major concern for the U.S. electric power sector, because failure of a single unit can cause temporary service interruption and lead to collateral damages, and it could be difficult to quickly replace it. Key industry sources—including the *Energy Sector Specific Plan*, the National Infrastructure Advisory Council's *A Framework for Establishing Critical Infrastructure Resilience Goals* and the North American Electric Reliability Corporation's *Critical Infrastructure Strategic Roadmap*—have identified the limited availability of spare LPTs as a potential issue for critical infrastructure resilience in the United States, and both the public and private sectors have been undertaking a variety of efforts to address this concern. Therefore, DOE examined the following topics in this report: characteristics and procurement of LPTs, including key raw materials and transportation; historical trends and future demands; global and domestic LPT suppliers; and potential issues in the global sourcing of LPTs.

LPTs are custom-designed equipment that entail significant capital expenditures and long lead times due to an intricate procurement and manufacturing process. Although the costs and pricing vary by manufacturer and by size, an LPT can cost millions of dollars and weigh between approximately 100 and 400 tons (or between 200,000 and 800,000 pounds). Procurement and manufacturing of LPTs is a complex process that requires prequalification of manufacturers, a competitive bidding process, the purchase of raw materials, and special modes of transportation due to its size and weight. The result is the possibility of extended lead times that could stretch beyond 20 months if the manufacturer has difficulty obtaining certain key parts or materials. Two raw materials—copper and electrical steel—account for over 50 percent of the total cost of an LPT. Electrical steel is used for the core of a power transformer and is critical to the efficiency and performance of the equipment; copper is used for the windings. In recent years, the price volatility of these two commodities in the global market has affected the manufacturing conditions and procurement strategy for LPTs.

The rising global demand for copper and electrical steel can be partially attributed to the increased power and transmission infrastructure investment in growing economies as well as the replacement market for aging infrastructure in developed countries. The United States is one of the world's largest markets for power transformers and holds the largest installed base of LPTs—and this installed base is aging. The average age of installed LPTs in the United States is approximately 40 years, with 70 percent of LPTs being 25 years or older. While the life expectancy of a power transformer varies depending on how it is used, aging power transformers are subject to an increased risk of failure.

Since the late 1990's, the United States has experienced an increased demand for LPTs; however, despite the growing need, the United States has had a limited domestic capacity to produce LPTs. In 2010, six power transformer manufacturing facilities existed in the United States, and together, they met approximately 15 percent of the Nation's demand for power

[1] Throughout this report, the term large power transformer (LPT) is broadly used to describe a power transformer with a maximum capacity rating greater and or equal to 100 MVA unless otherwise noted.

transformers of a capacity rating greater than or equal to 60 MVA. Although the exact statistics are unavailable, global power transformer supply conditions indicate that the Nation's reliance on foreign manufacturers is even greater for extra high-voltage (EHV) power transformers with a maximum voltage rating greater than or equal to 345 kV.

However, the domestic production capacity for LPTs in the United States is improving. In addition to EFACEC's first U.S. transformer plant that began operation in Rincon, Georgia in April 2010, at least three new or expanded facilities will produce EHV LPTs starting in 2012 and beyond. These include: SPX Transformer Solution's facility in Waukesha, Wisconsin, which completed expansion in April 2012; Hyundai Heavy Industries' new manufacturing facility, which was inaugurated in Montgomery, Alabama in November 2011; and Mitsubishi's proposed development of a power transformer plant in Memphis, Tennessee, which is expected to be completed in 2013.

The upward trend of transmission infrastructure investment in the United States since the late 1990s is one of the key drivers for the recent addition of domestic manufacturing capacity for power transformers. Between 2005 and 2011, the total value of LPTs imported to the United States grew by 188 percent (or at an annual growth rate of 34 percent) from $284 to $817 million U.S. dollar. Power transformers are globally traded equipment, and the demand for this machinery is forecasted to continue to grow at a compound annual growth rate of three to seven percent in the United States according to industry sources. In addition to replacing aging infrastructure, the United States has needs for transmission expansion and upgrades to accommodate new generation connections and maintain electric reliability.

While global procurement has become a common practice for many utilities to meet their growing need for LPTs, there are several challenges associated with it. Such challenges include: the potential for extended lead times due to unexpected global events (e.g., hurricanes) or difficulty in transportation; the fluctuation of currency exchange rates and material prices; and cultural differences and communication barriers. The utility industry is also facing the challenge of maintaining experienced in-house workforce that is able to address procurement and maintenance issues.

The U.S. electric power grid is one of the Nation's critical life-line infrastructure on which many other critical infrastructure depend, and the destruction of this infrastructure can cause a significant impact to national security and the U.S. economy. The U.S. electric grid faces a wide variety of possible threats, including natural, physical, cyber, and space weather. While the potential effect of these threats on the electric power grid is uncertain, public and private stakeholders of the energy industry are considering various risk management strategies to mitigate potential impacts. This DOE report, through the assessment of LPT procurement and supply issues, provides information to help the industry's continuous efforts to build critical energy infrastructure resilience in today's complex, interdependent global economy.

I. INTRODUCTION

1.1 FOCUS OF THE STUDY

In today's dynamic, intersected global economies, understanding market characteristics and securing the supply basis of critical equipment, such as large power transformers (LPTs),[2] becomes increasing imperative for maintaining the resilience of the Electricity Subsector.[3] The purpose of this report is to provide information to decision-makers in both public and private sectors about the country's reliance on foreign-manufactured LPTs and potential supply issues.

The Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy (DOE), as part of its on-going efforts to enhance the resilience of the Nation's critical infrastructure, assessed the manufacturing and supply conditions of LPTs in this report.[4] Power transformers have long been a major concern for the U.S. electric power sector.[5] Failure of a single unit could result in temporary service interruption and considerable revenue loss, as well as incur replacement and other collateral costs. Should several of these units fail catastrophically, it will be challenging to replace them.

> **Paths Forward**
>
> "Refine our understanding of the threats and risks associated with the global supply chain through updated assessments."
>
> - *The National Strategy for Global Supply Chain Security,* White House, 2012

LPTs are special-ordered machineries that require highly-skilled workforces and state-of-the-art facilities. Installation of LPTs entails not only significant capital expenditures but also a long lead time due to intricate manufacturing processes, including securing raw materials. As a result, asset owners and operators invest considerable resources to monitor and maintain LPTs, as failure to replace aging LPTS could present potential concerns including mounting maintenance costs and unexpected power failure.

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[2] Throughout this report, the term large power transformer (LPT) is broadly used to describe a power transformer with a maximum capacity rating of 100 MVA or higher, unless otherwise noted. See Section 1.3, Scope and Definition of Large Power Transformers, for discussions relating to the inconsistencies in the industry's definition for LPTs, and see Section 2.2, Physical Characteristics of Large Power Transformers, for key physical attributes of LPTs.

[3] The Electricity Subsector refers to the electricity industry as described in the Energy Sector Specific Plan (SSP). The Energy Sector, as delineated by Homeland Security Presidential Directive 7 (HSPD-7), includes the production, refining, storage, and distribution of oil, gas, and electric power, except for hydroelectric and commercial nuclear power facilities. The "Energy Sector" is not monolithic and contains many interrelated industries that support the exploration, production, transportation, and delivery of fuels and electricity to the U.S. economy. This SSP distinguishes between the Electricity Subsector and the Oil and Natural Gas Subsector. See the 2010 Energy SSP, http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/Energy_SSP_2010.pdf (accessed January 5, 2012).

[4] The Homeland Security Presidential Directive-7 (HSPD-7) established the United States' national policy for identifying and prioritizing critical infrastructure for protection from terrorist attacks. It also identified the Nation's 18 critical infrastructure sectors and the agencies that would be responsible for carrying out the policy for each sector. The DOE is the Sector-Specific Agency responsible for the coordination of critical infrastructure protection activities for the Energy Sector, which consists of two Subsectors: Oil and Natural Gas and Electricity. See HSPD-7 full text at http://www.dhs.gov/xabout/laws/gc_1214597989952.shtm (accessed January 4, 2012).

[5] Such concern was raised in a June 1990 Congressional Report. See U.S. Congress, Office of Technology Assessment, Physical Vulnerability of Electric System to Natural Disasters and Sabotage, OTA-E-453 (Washington, DC: U.S. Government Printing Office, June 1990).

Therefore, this report examines the following:

- Classification and physical characteristics of LPTs;
- Power transformer procurement and manufacturing processes;
- Supply sources and price variability of two raw commodities—copper and electrical steel;
- Global and domestic power transformer market and manufacturing conditions;
- Key global suppliers of LPTs to the United States; and
- Potential challenges in the global sourcing of power transformers.

1.2 Background

As applied to infrastructure, the concept of resilience embodies "the ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption."[6] The resilience strategy is a cornerstone of the United States' national policy as adopted in the 2009 *National Infrastructure Protection Plan (NIPP)*, the 2010 *National Security Strategy*, and the 2012 *National Strategy for Global Supply Chain Security*.[7] Broadly defined as the ability to withstand and recover from adversity, resilience is also increasingly applied to broad technical systems and social context.

The Electricity Subsector has long embraced resilience as part of the continuity of operations planning, risk management, and systems reliability. These practices have been so well established in the operation of the electric grid that utility owners and operators often do not think of their practices as "resilience."[8] Although reliability and redundancy are built into the system, the electricity industry identified that the limited domestic manufacturing capacity of high-voltage power transformers could present a potential supply concern in the event that many LPTs failed simultaneously.[9]

Challenges and Opportunities in Increasing Resilience

"The limited availability of [spare] extra-high-voltage transformers in crisis situations presents potential supply chain vulnerability."

- *A Framework for Establishing Critical Infrastructure Resilience Goals,* National Infrastructure Advisory Council, 2010

The same issue was brought to light in the Electricity Subsector's High-Impact Low-Frequency (HILF) Risk Workshop in November 2009.[10] Cosponsored by DOE and the North American

[6] The National Security Strategy, the White House, May 2010, http://www.whitehouse.gov/sites/default/files/rss_viewer/national_security_strategy.pdf (accessed December 15, 2011).

[7] See the National Infrastructure Protection Plan: Partnering To Enhance Protection and Resiliency, the U.S. Department of Homeland Security, 2009, http://www.dhs.gov/xlibrary/assets/NIPP_Plan.pdf (accessed December 15, 2011); the National Security Strategy, the White House, May 2010, http://www.whitehouse.gov/sites/default/files/rss_viewer/national_security_strategy.pdf (accessed December 15, 2011) ; and the National Strategy for Global Supply Chain Security, the White House, January 25, 2012, http://www.whitehouse.gov/sites/default/files/national_strategy_for_global_supply_chain_security.pdf (accessed February 1, 2011).

[8] "A Framework for Establishing Critical Infrastructure Resilience Goals," the National Infrastructure Advisory Council, October 16, 2010, http://www.dhs.gov/xlibrary/assets/niac/niac-a-framework-for-establishing-critical-infrastructure-resilience-goals-2010-10-19.pdf (accessed December 8, 2011).

[9] Ibid.

[10] High-Impact, Low-Frequency Event Risk to the North American Bulk Power System, NERC, June 2010, http://www.nerc.com/files/HILF.pdf (accessed November 30, 2011).

Electrical Reliability Corporation (NERC), the HILF Risk Workshop examined select severe impact risks to the Nation's electrical grid. The workshop participants produced a report entitled *High Impact, Low Frequency Event Risk to the North American Bulk Power System,* outlining the results of the joint NERC/DOE workshop and recommendations for industry partners.

The workshop considered four main risk scenarios concerning the Electricity Subsector:

1. A physical attack on electricity system equipment that disabled difficult-to-replace equipment in multiple generating stations or substations and caused a prolonged outage;
2. A coordinated cyber attack that impaired the integrity of multiple control systems;
3. A severe geomagnetic disturbance (GMD) that damaged difficult-to-replace generating station and substation equipment and caused a cascading effect on the system; and
4. A potential widespread pandemic influenza that resulted in the loss of critical personnel.

In November 2010, NERC released the Critical Infrastructure Strategic Roadmap to provide a framework on how to address some of the severe impact risks identified in the HILF report. [11] The Roadmap supported *the Energy Sector-Specific Plan'*s vision and goals as well as strengthening of the public-private partnership.[12] Further, the Roadmap provided recommendations on how to enhance electricity reliability and resilience from an all-hazards perspective and suggested direction for the Electricity Subsector.

> **Multi-Element Approach to Address Severe Risk Impacts**
>
> "Prevention: Work with infrastructure vendors and suppliers to enhance identification of vulnerabilities, protections, and recoverability."
>
> "Recovery: Verify and enhance plans to provide human and material resources, with particular attention on equipment that may not be readily available."
>
> - *Critical Infrastructure Strategic Roadmap,* NERC, 2010

In the Roadmap, the Electricity Subsector Coordinating Council advised electricity sector entities to consider a full spectrum of risk management elements to address severe impact risks—planning, prevention, mitigation, and recovery.[13] In accordance with the Roadmap, both public and private sectors of the Electricity Subsector have undertaken a variety of activities that consider these risk management elements.

This assessment supplements the sector's ongoing resilience efforts, specifically of prevention and recovery elements, through an examination of the supply chain of LPTs.

1.3 Scope and Definition of Large Power Transformers

Throughout this report, the term LPT is broadly used to describe a power transformer with a maximum nameplate rating of 100 megavolt-amperes (MVA) or higher unless otherwise noted. However, it should be noted that there is no single, absolute industry definition or criterion for

[11] Critical Infrastructure Strategic Roadmap, Electricity Sub-sector Coordinating Council, August 2010, http://www.nerc.com/docs/escc/ESCC_Strat_Roadmap_V3_31_Aug2010_clean.pdf (accessed November 30, 2011). Note: The roadmap does not include discussion on the pandemic risk.

[12] For the Energy Sector goals and visions, see Energy Sector Specific Plan, 2010, http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/Energy_SSP_2010.pdf (accessed December 7, 2011).

[13] The Electricity Subsector Coordinating Council represents the electricity sector as described in the Energy Sector Specific Plan, which includes bulk power system entities defined by Section 215 of the Federal Power Act.

what constitutes an LPT and that additional specifications are often used to describe different classes of LPTs.

The size of a power transformer is determined by the primary (input) voltage, the secondary (output) voltage, and the load capacity measured by MVA. Of the three, the capacity rating, or the amount of power that can be transferred, is often the key parameter rather than the voltage.[14] In addition to the capacity rating, voltage ratings are often used to describe different classes of power transformers, such as extra high voltage (EHV), 345 to 765 kilovolts (kV); high voltage, 115 to 230 kV; medium voltage, 34.5 to 115 kV; and distribution voltage, 2.5 to 35 kV.[15] A power transformer with a capacity rating greater than or equal to 100 MVA typically has a voltage rating of greater than or equal to 115 kV on the high side; therefore, an LPT with a capacity rating of 100 MVA or greater can have a transmission voltage class of medium, high, or extra high (greater than or equal to115 kV).

Table 1. Transmission Voltage Classes

Class	Voltage Ratings (kV)
Medium Voltage	34.5, 46, 69, 115/138
High Voltage	115/138, 161, 230
Extra High Voltage	345, 500, 765

Source: DOE, 2006; see Footnote 14. Modified based on industry review.

There are considerable differences in the definitions used to describe an LPT, including the transmission voltage classifications shown in Table 1. This report derived the criterion of an LPT from the following sources:

- In a 2006 DOE study entitled, *Benefits of Using Mobile Transformers and Mobile Substations for Rapidly Restoring Electrical Service*, LPTs were described as "high-power transformers . . . with a rating over 100 MVA."[16]
- A 2011 preliminary report from an ongoing antidumping investigation by the United States International Trade Commission (USITC) established LPTs as "large liquid dielectric power transformers having a top power handling capacity greater than or equal to 60,000 kilovolt amperes (60 megavolt amperes), whether assembled or unassembled, complete or incomplete."[17]
- The 2011 NERC Spare Equipment Database Task Force Report defined LPTs as follows:[18]

[14] "Benefits of Using Mobile Transformers and Mobile Substations for Rapidly Restoring Electrical Service," a report to the United States Congress pursuant to Section 1816 of the Energy Policy Act of 2005, U.S. Department of Energy, August 2006. http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/MTS_Report_to_Congress_FINAL_73106.pdf (accessed November 1, 2010).
[15] Ibid. This study does not consider distribution transformers in the assessment, as the United States maintains domestic manufacturing capacity and backup supplies of distribution transformers. Moreover, a localized power outage at distribution level does not present significant reliability threats, and utilities often maintain spare transformer equipment of this size range.
[16] Ibid.
[17] "Large Power Transformers from Korea," U.S. International Trade Commission (USITC), Preliminary Investigation No. 731-TA-1189, September 2011, http://www.usitc.gov/publications/701_731/Pub4256.pdf (accessed December 11, 2012).
[18] Special Report: Spare Equipment Database System, the North American Electric Reliability Corporation, October 2011, http://www.nerc.com/docs/pc/sedtf/SEDTF_Special_Report_October_2011.pdf (accessed November 22, 2011).

- Transmission Transformers: Low voltage side is rated 100 kV or higher and the maximum nameplate rating is 100 MVA or higher.
- Generation Step-up Transformers: High voltage side is 100 kV or higher and the maximum nameplate rating is 75 MVA or higher.

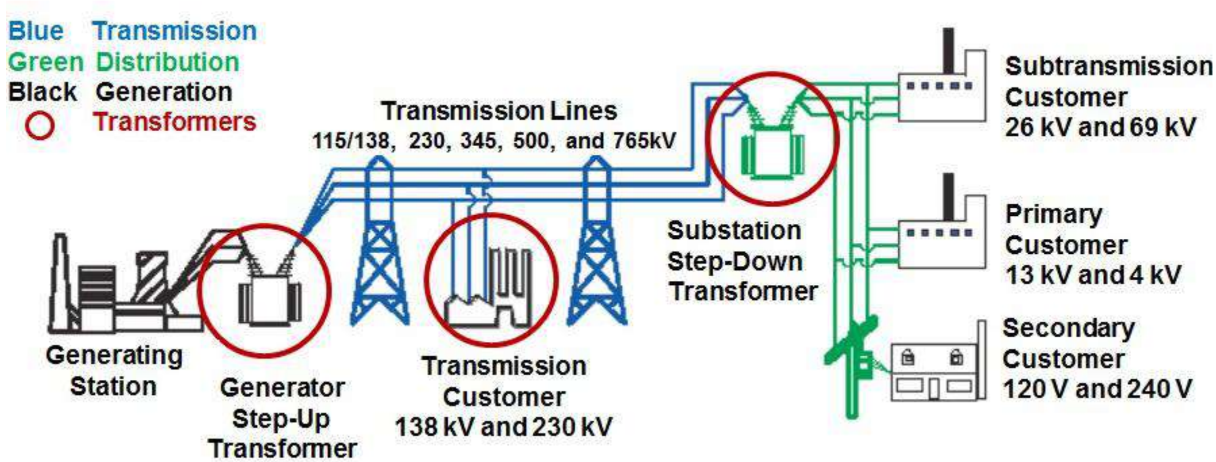
In addition, preliminary findings from the aforementioned USITC antidumping investigation are cited throughout the report; however, the investigation was still ongoing at the time of the analysis and therefore, these preliminary findings are not conclusive until the USITC reaches the final decisions on the case.[19]

II. POWER TRANSFORMER CLASSIFICATION

2.1 POWER TRANSFORMERS IN THE ELECTRIC GRID

North America's electricity infrastructure represents more than $1 trillion U.S. dollars (USD) in asset value and is one of the most advanced and reliable systems in the world. The United States' bulk grid consists of over 360,000 miles of transmission lines, including approximately 180,000 miles of high-voltage lines, connecting to over 6,000 power plants.[20] Power transformers are a critical component of the transmission system, because they adjust the electric voltage to a suitable level on each segment of the power transmission from generation to the end user. In other words, a power transformer steps up the voltage at generation for efficient, long-haul

Figure 1. Electric Power Grid Representation



Source: DOE, 2006; see Footnote 14. Modified based on industry review.

[19] On July 14, 2011, an antidumping duty petition was filed with the U.S. Department of Commerce's International Trade Administration and the USITC concerning imports of LPTs from two Korean producers, Hyundai Heavy Industries and Hyosung Corporation. The petition alleged that between 2008 and 2010, the Korean manufacturers aggressively expanded in the United States' market by selling LPTs at prices that significantly undercut domestic market prices and in some instances below the domestic producers' cost of materials. Final decision on this case is expected in April 2012.

[20] Source: NERC Electricity Supply & Demand Database, http://www.nerc.com/page.php?cid=4|38 (accessed December 15, 2011).

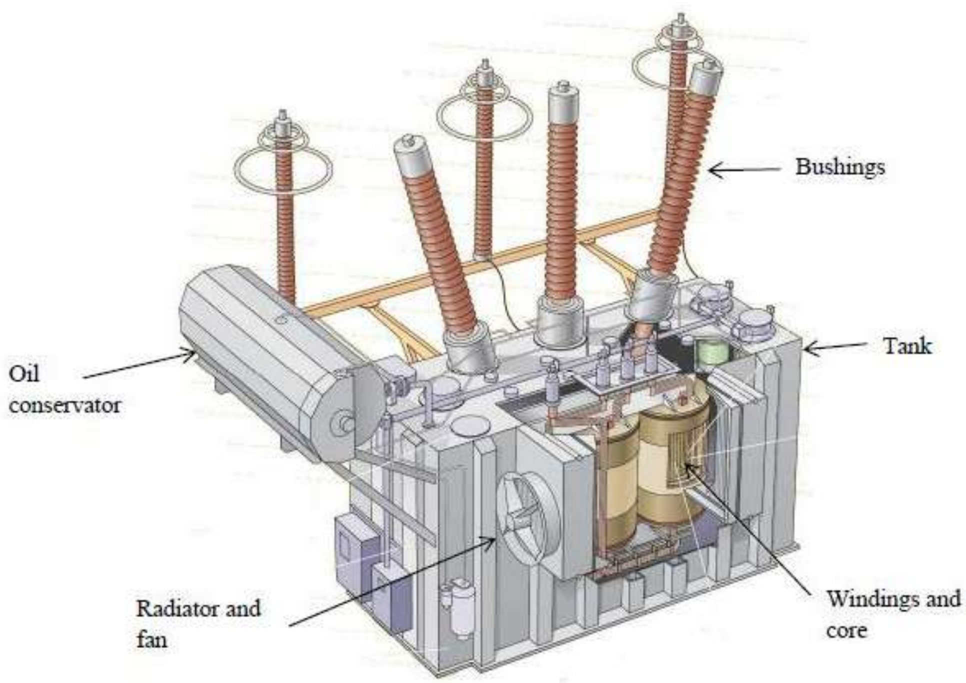
transmission of electricity and steps it down for distribution to the level used by customers.[21] Power transformers are also needed at every point where there is a change in voltage in power transmission to step the voltage either up or down. Figure 1 illustrates a simplified arrangement of the U.S. electric grid system.

2.2 Physical Characteristics of Large Power Transformers

An LPT is a large, custom-built piece of equipment that is a critical component of the bulk transmission grid. Because LPTs are very expensive and tailored to customers' specifications, they are usually neither interchangeable with each other nor produced for extensive spare inventories.[22] According to an industry source, approximately 1.3 transformers are produced for each transformer design. Figure 2 illustrates a standard core-type LPT and its major internal components.

Although LPTs come in a wide variety of sizes and configurations, they consist of two main active parts: the core, which is made of high-permeability, grain-oriented, silicon electrical steel, layered in pieces; and windings, which are made of copper conductors wound around the core, providing electrical input and output. Two basic configurations of core and windings exist, the core form and the shell form. In the usual shell-type power transformer, both primary and secondary are on one leg and are surrounded by the core, whereas in a core-type power

Figure 2. Core-Type Large Power Transformer Showing Major Internal Components



Source: ABB, "Liquid-Filled Power Transformers," http://www05.abb.com/global/scot/scot252.nsf/veritydisplay/299a52373c3fd0e6c12578be003a476f/$file/pptr_mpt_brochure_2406pl170-w1-en.pdf (accessed August 16, 2011).

[21] ABB, http://www.abb.com/cawp/db0003db002698/1d5674d769397bc8c12572f40045bd75.aspx (accessed December 7, 2011). Electricity is generally produced at 5 to 34.5 kV and distributed at 15 to 34.5 kV, but transmitted at 115 to 765 kV for economical, low-loss, long-distance transmission on the grid.

[22] "Large Power Transformers from Korea," USITC, Preliminary Investigation, September 2011.

transformer, cylindrical windings cover the core legs. Shell form LPTs typically use more electrical steel for the core and are more resilient to short-circuit in the transmission systems and are frequently used in industrial applications.[23] The core and windings are contained in a rectangular, mechanical frame called the "tank." Other parts include bushings, which connect LPTs to transmission lines, as well as tap changers, power cable connectors, gas-operated relays, thermometers, relief devices, dehydrating breathers, oil level indicators, and other controls.[24]

Power transformer costs and pricing vary by manufacturer, by market condition, and by location of the manufacturing facility. In 2010, the approximate cost of an LPT with an MVA rating between 75 MVA and 500 MVA was estimated to range from $2 to $7.5 million in the United States; however, these estimates were Free on Board (FOB) factory costs, exclusive of transportation, installation, and other associated expenses, which generally add 25 to 30 percent to the total cost (see Table 2).[25] Raw materials, particularly copper and electrical steel, are a significant factor in power transformer prices. Transportation is also an important element of the total LPT cost, because an LPT can weigh as much as 410 tons (820,000 lb) and often requires long-distance transport.

Table 2. Estimated Magnitude of Large Power Transformers in 2011

Voltage Rating (Primary-Secondary)	Capability MVA Rating	Approximate Price ($)	Approximate Weight & Dimensions
Transmission Transformer			
Three Phase			
230–115kV	300	$2,000,000	170 tons (340,000 lb) 21ft W–27ft L–25ft H
345–138kV	500	$4,000,000	335 tons (670,000 lb) 45ft W–25ft L–30ft H
765–138kV	750	$7,500,000	410 tons (820,000 lb) 56ft W–40ft L–45ft H
Single Phase			
765–345kV	500	$4,500,000	235 tons (470,000 lb) 40ft W–30ft L–40ft H
Generator Step-Up Transformer			
Three Phase			
115–13.8kV	75	$1,000,000	110 tons (220,000 lb) 16ft W–25ft L–20ft H
345-–13.8kV	300	$2,500,000	185 tons (370,000 lb) 21ft W–40ft L–27ft H
Single Phase			
345–22kV	300	$3,000,000	225 tons (450,000 lb) 35ft W–20ft L–30ft H
765–26kV	500	$5,000,000	325 tons (650,000 lb) 33ft W–25ft L–40ft H

Note: Prices are FOB factory and do not include taxes, transportation, special features and accessories, special testing (short-circuit, etc.), insulating oil, field installation, and/or optional services. The total installed cost is estimated to be about 25–30 percent higher.

Source: NERC Special Report: Spare Equipment Database System, 2011; see Footnote 25.

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[23] "Large Power Transformers from Korea," USITC, Preliminary Investigation, September 2011, p. I-5.

[24] "Benefits of Using Mobile Transformers and Mobile Substations for Rapidly Restoring Electrical Service," U.S. Department of Energy, 2006.

[25] NERC Special Report: Spare Equipment Database System, October 2011, http://www.nerc.com/docs/pc/sedtf/SEDTF_Special_Report_October_2011.pdf (accessed November 11, 2011).

LPTs require substantial capital and a long-lead time (in excess of six months) to manufacture, and its production requires large crane capacities, ample floor space, and adequate testing and drying equipment. The following section provides further discussions on the production processes and requirements of LPTs, including transportation and key raw commodities.

III. Large Power Transformer Procurement and Manufacturing

3.1 Overview

This section provides an overview of key steps in the procurement and manufacturing process of an LPT, including bidding, production, and transportation. This overview is then followed by a discussion of key raw materials—electrical steel and copper—which are integral to LPTs. The several distinct steps and procedures as well as the estimated lead time for each step required in power transformer manufacturing and procurement are illustrated in Figure 3.

3.1.1 Prequalification of Manufacturers

As discussed in Section II, LPTs are custom-made equipment that incurs significant capital costs. Utilities generally procure LPTs through a competitive bidding process, which all interested producers must prequalify to be eligible to bid. Prequalification is a lengthy process that can take years.[26] A typical qualification process includes an audit of production and quality processes, verification of certain International Organization for Standardization (ISO) certifications, and

Figure 3. Large Power Transformer Procurement Process and Estimated Lead Time

Note: This figure illustrates an optimal flow of the manufacturing process and the estimated lead time, which can extend beyond the estimated time frame shown.

* Variable depending on distance and logistical issues.

Source: USITC and industry estimate.

[26] Conference Hearing for Investigation No.731-TA-1189, In the Matter of Large Power Transformers from Korea, USITC, August 4, 2011, http://www.usitc.gov/trade_remedy/731_ad_701_cvd/investigations/2011/large_power_transformers/preliminary/PDF/Conference%2008-04-2011.pdf (accessed November 23, 2011).

inspection of the manufacturing environment. This process can often be rigorous and costly to purchasers; however, it is an important step, as the manufacturing environment and capability can significantly affect reliability of the product, especially of high-voltage power transformers.[27]

3.1.2 Bidding Process

A standard bidding process is initiated by a purchaser, who sends commercial specifications to qualified LPT producers. The producers then design LPTs to meet the specifications, estimate the cost, and submit a bid to the purchaser. The bids not only include the power transformer but also services such as transportation, installation, and warranties.[28] Except for a few municipalities, most U.S. utilities do not announce the amount of the winning bid or the identity of the winning bidder. The winning bidder is notified, and bid terms normally require that the results be kept confidential by all parties involved.[29]

3.1.3 Production

The typical manufacturing process of an LPT consists of the following steps:[30]

1. **Engineering and design:** LPT design is complex, balancing the costs of raw materials (copper, steel, and cooling oil), electrical losses, manufacturing labor hours, plant capability constraints, and shipping constraints.
2. **Core building:** Core is the most critical component of an LPT which requires highly-skilled work force and cold-rolled grain-oriented (CRGO) laminated electrical steel.
3. **Windings production and assembly of core and windings:** Windings are predominantly copper and have an insulating material.
4. **Drying operations:** Excess moisture must be removed from the core and windings, because moisture can degrade the dielectric strength of the insulation.
5. **Tank production:** A tank must be completed before the winding and core assembly finish the drying phase so that the core and windings do not start to reabsorb moisture.
6. **Final assembly of the LPT:** The final assembly must be done in a clean environment; even a tiny amount of dust or moisture can deteriorate the performance of an LPT.
7. **Testing:** Testing is performed to ensure the accuracy of voltage ratios, verify power ratings, and determine electrical impedances.

In the manufacturing process, certain parts can be produced either at the transformer plant or at another vendor or subsidiary location, depending on how vertically integrated the particular plant is, whether the plant has the necessary tools and capabilities, as well as economic reasons.[31]

3.1.4 Lead Time

In 2010, the average lead time between a customer's LPT order and the date of delivery ranged from five to 12 months for domestic producers and six to 16 months for producers outside the United States.[32] However, this lead time could extend beyond 20 months and up to five years in extreme cases if the manufacturer has difficulties obtaining any key inputs, such as bushings and

[27] "Large Power Transformers from Korea," USITC, Preliminary Investigation, September 2011.
[28] Ibid., p. V-I.
[29] Conference Hearing for Investigation No.731-TA-1189, USITC, August 4, 2011, pp. 135–136.
[30] "Large Power Transformers from Korea," USITC, Preliminary Investigation, September 2011, pp. I-9–I-10.
[31] Conference Hearing for Investigation No.731-TA-1189, USITC, August 4, 2011, p. 95.
[32] Ibid., p. II-7.

other key raw materials, or if considerable new engineering is needed.[33] An industry source noted that HV bushings often have a long lead time extending up to five months. Another industry source added that HV bushings are usually customized for each power transformer and there are limited bushing manufacturers in the United States. Manufacturers must also secure supplies of specific raw materials or otherwise could endure an extended lead time.[34]

Once completed, a power transformer is disassembled for transport, including the removal of oil, radiators, bushings, convertors, arrestors, etc. The proper transportation of power transformer and its key parts is critical to ensuring high reliability of the product and minimizing the period for onsite installation.

3.1.5 Transportation

Transporting an LPT is challenging—its large dimensions and heavy weight pose unique requirements to ensure safe and efficient transportation. Current road, rail, and port conditions are such that transportation is taking more time and becoming more expensive.[35] Although rail transport is most common, LPTs cannot be transferred over normal rail cars, because they cannot be rolled down a hill or bumped into other rail cars, which can damage the power transformer. This is because the heaviest load a railroad normally carries is about 100 tons, or 200,000 lb, whereas an LPT can weight two to three times that.[36]

Figure 4. Transport of Large Power Transformers

Note: Workers move wires, lights, and poles to transport a 340-ton power transformer, causing hours of traffic delay.

Source: Pittsburgh Live News, December 2011.

Note: Schnabel Car transporting an LPT.

Source: ABB

A specialized railroad freight car known as the Schnabel railcar is used to transport extremely heavy loads and to accommodate height via railways (see Figure 4); however, there are a limited number of Schnabel cars available worldwide, with only about 30 of them in North

[33] Industry source estimate.
[34] Ibid., p. II-7.
[35] Siemens, Transformer Lifecycle Management, http://www.energy.siemens.com/mx/pool/hq/services/power-transmission-distribution/transformer-lifecycle-management/TLM_EN_.pdf (accessed November 30, 2011).
[36] Conference Hearing for Investigation No.731-TA-1189, USITC, August 4, 2011, p. 100.

America.[37] Certain manufacturers operate a Schnabel car rental program and charge up to $2,500 per day for the rental in addition to other applicable fees.[38] Access to railroad is also becoming an issue in certain areas due to the closure, damage, or removal of rail lines.

When an LPT is transported on the road, it requires obtaining special permits and routes from the department of transportation of each state on the route of the LPT being transported. According to an industry source, obtaining these special permits can require an inspection of various infrastructure (e.g., bridges), which can add delay. In addition, transporting LPTs on the road can require temporary road closures due to traffic issues, as well as a number of crew and police officers to coordinate logistics and redirect traffic. Figure 4 depicts LPTs being transported via road and Schnabel car. The transport modular shown is 70 feet long with 12 axles and 192 wheels, and occupies two lanes of traffic.[39] The Schnabel car shown in Figure 4 has 20 axles.

Logistics and transportation accounted for approximately three to 20 percent of the total cost of an LPT for both domestic and international producers.[40] While important, this is less significant than the cost of raw materials and the potential sourcing concerns surrounding them. The next section describes some of the issues concerning raw materials vital to LPT manufacturing.

3.2 Raw Materials Used in Large Power Transformers

The main raw materials needed to build power transformers are copper conductors, silicon iron/steel, oil, and insulation materials. The cost of these raw materials is significant, accounting for well over 50 percent of the total cost of a typical LPT.[41] Specifically, manufacturers have estimated that the cost of raw materials accounted for 57 to 67 percent of the total cost of LPTs sold in the United States between 2008 and 2010.[42] Of the total material cost, about 18 to 27 percent was for copper and 22 to 24 percent was for electrical steel.[43]

Aluminum windings were used in 1970s and 1980s when copper prices were high; however, today, only copper is used in LPTs due to certain issues surrounding conductivity, connection failures, and short circuit strength.[44] For this reason, this section examines the issues surrounding the supply chain and price variability of the two key raw materials used in LPTs—copper and electrical steel.

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[37] "Large Power Transformer and Schnabel Rail Car," Business and Technical Report, National Security Industrial Readiness, Pre-decisional Draft for Official Use Only.

[38] "Railcar rental program for power transformer relocation," ABB, http://www05.abb.com/global/scot/scot252.nsf/veritydisplay/36bcc4e173d5c1558525760b00711641/$file/1zul004605-300_railcar_r4.pdf (accessed January 12, 2012).

[39] Adam Brandolph, "340-ton transformer makes 9-mile trek," December 30, 2011, http://www.pittsburghlive.com/x/pittsburghtrib/news/s_774162.html (accessed January 12, 2012).

[40] "Large Power Transformers from Korea," USITC, Preliminary Investigation, September 2011, p. V-1, and an industry source estimate.

[41] "Transformer Manufacturer Uses Only Copper," Copper Development Association Inc., http://www.copper.org/applications/electrical/energy/pdf/transformer_manufacturer_a6100.pdf (accessed November 24, 2011).

[42] "Large Power Transformers from Korea," USITC, Preliminary Investigation, September 2011, p. V-1.

[43] Ibid., p. VI-1.

[44] According to Copper Development Association Inc., aluminum's conductivity is about 62 percent that of copper when measured on a volume basis and an industry source review.

3.2.1 Electrical Steel and Large Power Transformers

The electrical steel used in power transformer manufacture is a specialty steel tailored to produce certain magnetic properties and high permeability.[45] A special type of steel called CRGO laminated steel (hereinafter refer to as "electrical steel") makes up the core of a power transformer. Electrical steel is the most critical component that has the greatest impact on the performance of the power transformer, because it provides low core loss and high permeability, which are essential to efficient and economical power transformers.

Conventional electrical steel is available in various grades generally called M3, M4, M5, and M6, which are classified based on the thickness of the steel (see Table 3). The quality of electrical steel is measured in terms of loss of electrical current flowing in the core. In general, core losses are measured in watts per kilogram (W/kg), and the thinner the material, the better the quality.[46] An industry source noted that electrical steel grade of M3 or better is typically used in an LPT to minimize core loss. The price of electrical steel fluctuates over time and has been recorded as high as $2.80 per pound, according to an industry source (see Figure 6 for historical price variability of copper and steel). As a reference, approximately 80,000 – 120,000 Kg (170,000 to 220,000 lbs.) of core steel is needed in a power transformer with a capacity rating between 300 and 500 MVA.[47]

Table 3. Electrical Steel Grades

Thickness (mm)	Grade	Core Losses (w/Kg)	Price per Pound* (USD)
N/A	M2	N/A	$1.42
0.23	M3	0.90	$1.37
0.27	M4	1.12	N/A
0.30	M5	1.30	N/A
0.35	M6	1.45	$.95

*Notes: Price per pound information is estimated 2012 data provided by an industry source.

Source: World of Steel; see Footnote 45.

The quality or degree of loss that is desired can vary depending on the primary use of the LPT—whether the LPT located on a site carries a moderate or heavy load. In other words, the grade of electrical steel used for the LPT's core varies depending on how highly the utility values losses.[48] Recently, due to environmental protection requirements, energy savings and minimizing core loss in power transformers are becoming important. Hi-B grade is a special grade of electrical steel that not only offers the lowest core loss but also is designed to operate at a much higher flux density, thus reducing the overall size of the power transformer.[49] There are a limited number of electrical steel suppliers, including Hi-B materials, in the world as is further explored in the following section.

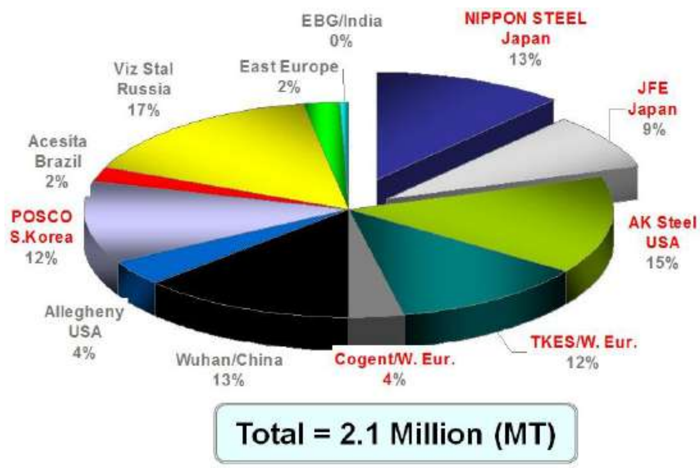
3.2.2 Global Electrical Steel Suppliers

The availability of electrical steel supply sources worldwide is limited. According to a 2007 DOE technical document, in 2007, there were only 11 manufacturers in the world that produced

[45] "About Electrical Steel," World of Steel, http://www.worldofsteel.com/resources/electrical_steel.htm (accessed January 12, 2012).
[46] Ibid.
[47] Estimates provided by an industry source.
[48] Conference Hearing for Investigation No.731-TA-1189, USITC, August 4, 2011, p. 97.
[49] "Future bright for transformer lamination industry," November 2007, http://www.kryfs.com/05_EM_Interview.pdf (accessed November 15, 2011).

electrical steel, the major manufacturing countries being Japan, Germany, United States, France, Korea, and China (see Figure 5).[50] The technology for manufacturing Hi-B electrical steel is closely held, and only six mills in the world produced it in 2007: AK Steel (United States), POSCO (Korea), Nippon and Kawasaki (Japan), TKES (Germany), and Cogent (United Kingdom).[51] See Appendix B, Global Electrical Steel Manufacturer Profiles, for additional information on the electrical steel producers.

Figure 5. World Installed Production of Electrical Steel in 2007



Note: Data courtesy of Sumitomo Corp.

Source: Prolec GE, 2008; see Footnote 51.

3.3 Variability of Commodity Prices

Since 2004, the global commodity market has experienced price fluctuations for both steel and copper, driven up largely by the demand from emerging economies. Global consumption of these metals is expected to continue to rise in the next decade as supply conditions tighten, leading to increased worries about the future price movement of these key commodities. The average price of copper more than quadrupled between 2004 and 2011, costing more than $4.27 a pound by 2011 (see Figure 6). While the price of steel shown in this figure does not represent the electrical steel used to manufacture LPTs, it does shed some light on the volatility of steel commodity prices worldwide.

In 2011, China was the single biggest buyer of steel in the world, consuming over 610 million metric tons of steel, almost half of the world's total steel consumption of 1,360 million metric tons that year.[52] The World Steel Association forecasted that world steel demand would reach a

[50] Distribution Transformers Final Rule Technical Support Document, Appendix 3A. Core Steel Market Analysis, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, September 2007, http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/transformer_fr_tsd/appendix_3a.pdf (accessed November 4, 2011).

[51] Prolec GE, November 2008, http://www.ieeerepc.org/documents/ProlecGEDOETransformerEfficiencyStandardsREPC.ppt (accessed November 15, 2011).

[52] "China Steel Products Demand To Reach 646mil Tonnes in 2012," Reuters, December 28, 2011, http://www.reuters.com/article/2011/12/28/china-steel-consumption-idUSL3E7NS03Q20111228 (accessed January 3, 2012); "World Steel Demand to Hit New Record in 2012," Metal Center News, May 4, 2011,

new record of 1,440 million tons in 2012, and that 72 percent of this would come from developing economies, including China and India.[53] Although China's primary need for steel is in the construction sector, China also has a significant demand for power transmission infrastructure. Particularly, China's and India's demand for steel, including high-efficiency, grain-oriented steel, is expected to continue to affect the availability and price of steel and copper to the rest of the world.[54]

Figure 6. Historical Copper and Steel Price Variability From 2000 to 2011

Source: Bloomberg, 2011.

Faced with the price volatility of raw materials and increased global demand for LPTs in recent years, the industry's procurement teams have revamped their sourcing strategies. According to a sourcing analyst from a major U.S. electric utility, a procurement strategy companies are increasingly using is multi-year "blanket agreements" in which they lock in volumes and price points for power transformers.[55] Blanket agreements are long-term alliances between an investor-owned utility and a specific LPT supplier; the utility selects and locks in with one manufacturer to provide it with LPTs for a period of two to five years. These agreements benefit the utility because once it provides specifications and buys one power transformer from the supplier, additional LPTs can be produced and shipped more rapidly. Although industry executives suggest that sales based on these alliances account for a significant share of LPT sales in the United States, the actual percentage of sales based on these agreements is unavailable.[56]

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http://www.metalcenternews.com/Editorial/SearchBackIssues/2011Issues/MCNMay2011/542011NewsWorldSteelDemandHitNewRecord/tabid/5078/Default.aspx (accessed January 3, 2012).

[53] Ibid.

[54] Distribution Transformers Final Rule Technical Support Document, Appendix 3A. Core Steel Market Analysis, DOE, September 2007.

[55] Judson Schumacher, "Buying Transformers," Transmission & Distribution World, May 1, 2006, http://tdworld.com/business/power_buying_transformers/ (accessed November 15, 2011).

[56] "Large Power Transformers from Korea," USITC, September 29, 2011.

Two examples of blanket agreements between a utility and manufacturer are:

- ABB's five-year agreement with Tennessee Valley Authority in 2002, for power transformers of 230 kV and below, with an estimated value of $200 million USD;[57] and
- Hyundai Heavy Industries (HHI)'s 10-year agreement with Southern California Edison in 2010, for power transformers of 200 kV to 500 kV, with an estimated value of $600 million USD.[58]

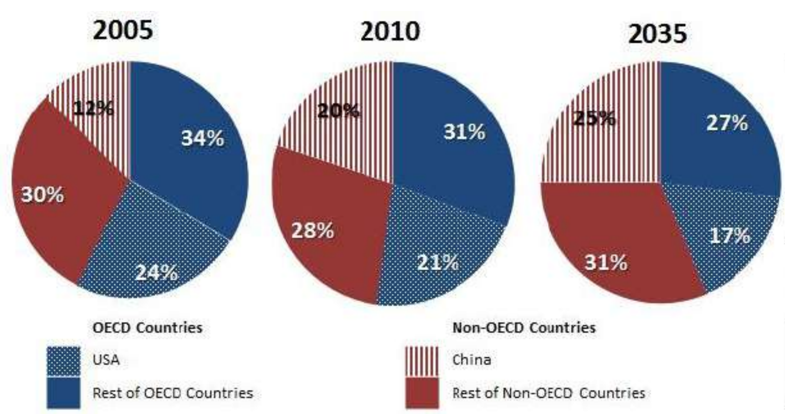
IV. POWER AND TRANSMISSION INFRASTRUCTURE INVESTMENT TRENDS

4.1 GLOBAL POWER GENERATION CAPACITY

In 2011, the world had approximately five trillion watts of power generation capacity, which was growing at an annual rate of two percent. The United States and China had the largest generation capacity, with each holding about 20 percent of the world's total installed capacity.

According to the U.S. Energy Information Administration's (EIA) 2011 International Energy Outlook, the world will add 2,365 GW of new capacity by 2035, a majority of which will be installed in non-OECD (Organization for Economic Co-operation and Development) countries.[59] China's generating capacity is forecasted to increase by approximately three percent annually through 2035, while the United States' capacity is expected to rise at less than one percent

Figure 7. Global Installed Power Generation Capacity From 2005 to 2035



Region	Percent as Share of World Total			Annual Growth Rate (2008-2035)
	2005	2010	2035	
Total OECD	58%	52%	44%	1 %
Total Non-OECD	42%	48%	56%	3 %
Total World Capacity (GW)	4,110	4,907	7,272	2 %

Source: 2011 International Energy Outlook, Table F1, U.S. Energy Information Administration, September 2011.

[57] "ABB Signs US$ 200 Million Agreement for Power Transformers in United States," ABB, November 26, 2002, http://www.abb.com/cawp/seitp202/c1256c290031524bc1256c7d003d7992.aspx (accessed December 15, 2011).

[58] "Hyundai Heavy Received US$600 Million Transformer Order," May 23, 2010, http://english.hhi.co.kr/press/news_view.asp?idx=554&page=1 (accessed December 15, 2011).

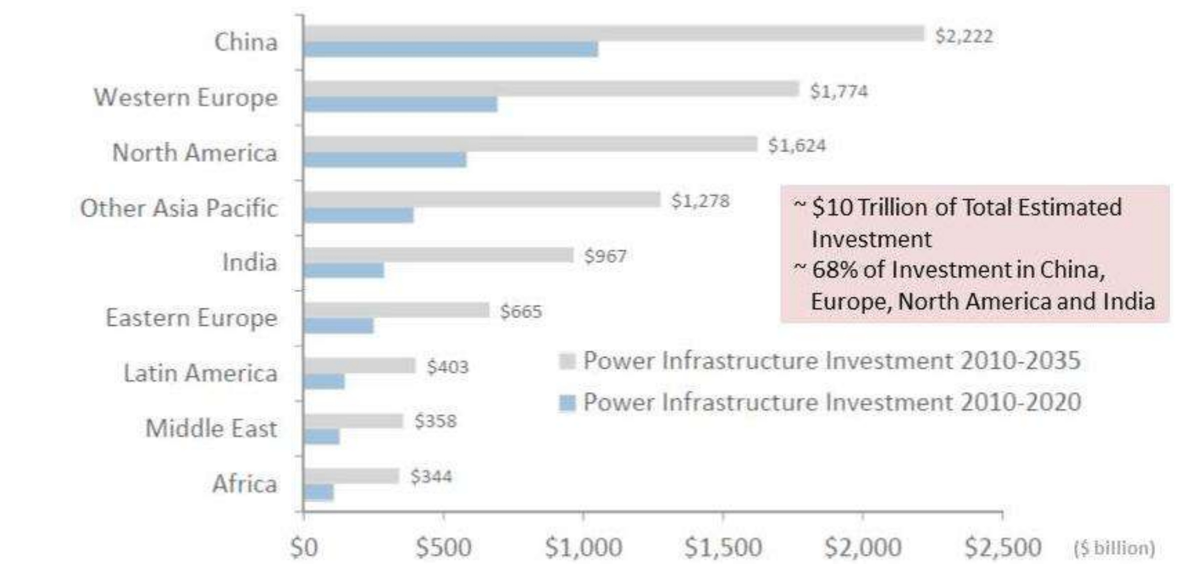
[59] The EIA's 2011 IEO data are divided according to Organization for Economic Cooperation and Development members (OECD) and nonmembers (non-OECD). OECD member countries (as of September 1, 2010) are the United States, Canada, Mexico, Austria, Belgium, Chile, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, Japan, South Korea, Australia, and New Zealand. See http://www.oecd.org/pages/0,3417,en_36734052_36761800_1_1_1_1_1,00.html (accessed January 3, 2012).

annual rate during the same period (see Figure 7).[60] By 2035, China's installed power generation capacity will surpass that of the United States and will hold a quarter of the world's total capacity of 7,272 GW, becoming the world's largest power generating capacity holder.

As a general rule, electricity generation capacity addition spurs investment in not only power generation infrastructure but also in transmission infrastructure, including transmission line equipment and power transformers, which are necessary to transmit power from generators to end users.

Similar to EIA, the International Energy Agency's (IEA) 2010 World Energy Outlook forecasted that the increase in new power generation capacity in the next two decades would be attributed to non-OECD countries, with China in the lead. Additionally, IEA projected an estimated infrastructure investment of $10 trillion USD by 2030 worldwide, with 68 percent placed in China, Europe, North America, and India (see Figure 8).[61] While the infrastructure investment needs in developing countries (e.g., China) were mainly attributed to new generation capacity additions, the key catalyst for power infrastructure investment in developed countries (e.g., United States) was the replacement market for aging infrastructure.[62] In addition to aging infrastructure, the United States has needs for transmission expansion and upgrade to accommodate new generation connections and maintain electric reliability.

Figure 8. Estimated Power Generation Infrastructure Investment Needs in the World From 2010 to 2035



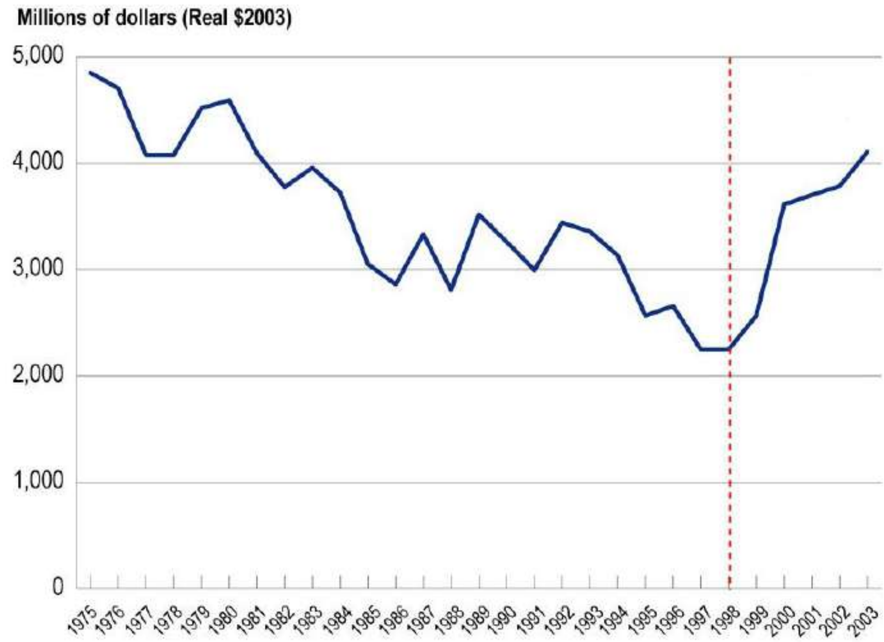
Source: World Energy Outlook 2010, OECD/IEA, 2010, as modified by SPX Electrical Products Group. See Footnote 61.

[60] 2011 International Energy Outlook, EIA.
[61] SPX Electrical Products Group, Presented May 16, 2011, http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9NDI3NDYzfENoaWxkSUQ9NDQ0NTg1fFR5cGU9MQ==&t=1 (accessed November 23, 2011).
[62] Ibid.

4.2 Transmission Infrastructure Investment in the United States

According to recent analyses by the Edison Electric Institute (EEI),[63] the United States' power industry overturned a long-standing downward trend in transmission investment in the late 1990s. The uncertainty about the nature and extent of power industry restructuring had triggered a decline in transmission investment in the 1980s and the 1990s. During this period of stagnant investment in transmission infrastructure, the electric load on the Nation's grid more than doubled.[64] This resulted in transmission congestion in certain regions and limited renewable implementation.[65] Figure 9 illustrates a long-term decline in transmission investment (in 2003 dollars) between the 1970s and the 1990s, as well as the reversing of that trend beginning in the late 1990s. Specifically, transmission investments grew at a 12 percent annual rate between 1999 and 2003.[66] Reliability and generation interconnection needs were viewed as the main reasons for transmission investments in the United States during this period.

Figure 9. Historical Transmission Investment in the United States From 1975 to 2003



Source: EEI, Survey of Transmission Investment, May 2005; see Footnote 66.

Note: Data sources for annual transmission investments vary. Data prior to 1998 are from EEI's Uniform Statistical Report. For 1998, data are from EEI's Annual Construction Expenditures Survey, FERC Form 1s, and company 10-Ks. For years 1999–2003, data are from EEI's Annual Property & Plant Capital Investment Survey and FERC Form 1s.

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[63] The EEI is an association of U.S. shareholder-owned electric power companies. Its members serve 95 percent of the ultimate customers in the shareholder-owned segment of the industry and represent approximately 70 percent of the U.S. electric power industry. See http://www.eei.org/Pages/default.aspx (accessed December 1, 2011).

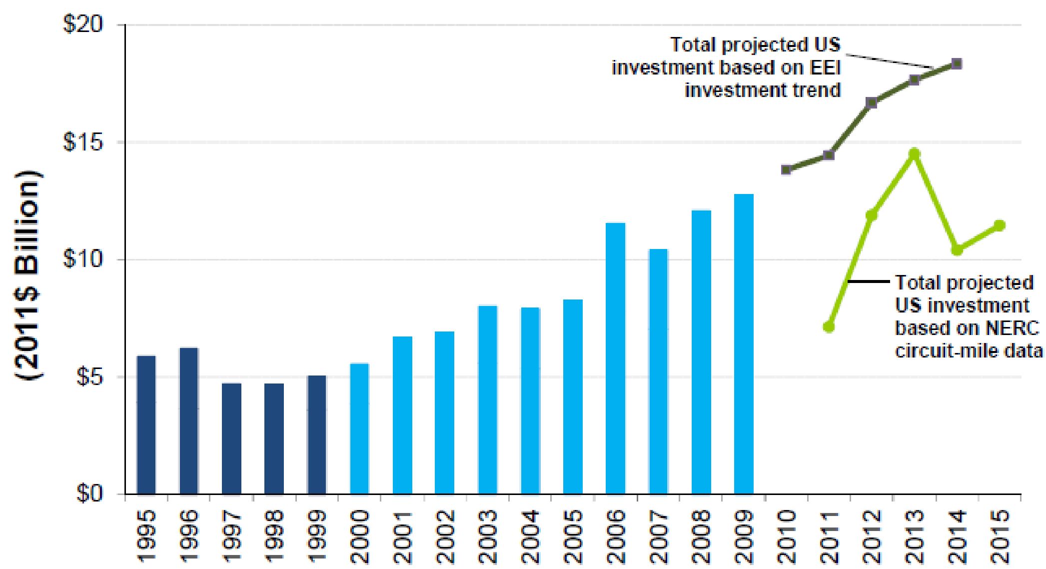
[64] Campbell, Richard J., "Regulatory Incentives for Electricity Transmissions – Issues and Cost Concerns," Congressional Research Service, October 28, 2011, http://www.ieeeusa.org/policy/eyeonwashington/2011/documents/electrans.pdf (accessed November 23, 2011).

[65] GE, May 2009, http://www.usea.org/USEA_Events/Smart-Grid-Briefings/Session_1-The_Smart_Grid_and_its_Benefits.pdf (accessed November 23, 2011).

[66] EEI Survey of Transmission Investment, EEI, May 2005, http://www.eei.org/ourissues/ElectricityTransmission/Documents/Trans_Survey_Web.pdf (accessed November 29, 2011).

Figure 10 represents the United States' transmission investment forecast through 2015, based on (1) EEI's projected capital expenditure growth rates applied to the 2009 U.S. total investment level, and (2) estimated investment requirements associated with transmission circuit-mile additions data from NERC.[67] Note, however, that NERC data are derived from EIA Form 411, which provides projected "circuit-miles" of transmission additions rather than investment dollars. The data reflect projects that are "under construction" or "planned" but tend to miss newly proposed projects of the last few years. NERC data indicate that 22,669 circuit-miles of transmission lines will be added between 2011 and 2015, and that 67 percent of those will be in EHV lines (see Appendix C, Planned Transmission Lines in the United States).[68] Figure 10 shows that the reported additions peak in 2013 and drop off quickly. This reflects the likelihood that many newly proposed conceptual transmission projects were not yet reported in these circuit-mile data.

Figure 10. Estimated Historical and Projected Transmission Investment in the United States From 1995 to 2015



Note: 1995–2009 Historical additions to plant-in-service as reported in FERC Form 1, which is an annual reporting requirement for major U.S. electric utilities. 2004–2009 estimated plant additions based on share of projected circuit-miles in EIA Form 411. 2010–2015 estimates of forecasted total plant additions (dark green line) based on EEI projections of investment trends; 2011–2015 estimate of forecasted plant additions (light green line) based on NERC/EIA Form 411 and EEI project survey cost estimates (for facilities ≥100kV only). NERC's forecast uses only projected "circuit-miles" of transmission additions rather than investment dollars.

Source: The Brattle Group, 2011; see Footnote 67.

In Figure 10, the range between the dark and light green lines illustrates some of the uncertainties in transmission investment levels, ranging from a low of approximately $8 billion per year to a possible high that may exceed $18 billion per year. On average, the annual

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[67] "Employment and Economic Benefits of Transmission Infrastructure Investment in the U.S. and Canada," WIRES (Working Group for Investment in Reliable and Economic Electric Systems) In Conjunction with The Brattle Group, May 2011, http://www.wiresgroup.com/images/Brattle-WIRES_Jobs_Study_May2011.pdf (accessed December 1, 2011).

[68] Ibid.

transmission investment is forecasted to range from $12 to $16 billion through 2030, totalling about $240 to $320 billion. The cost of power transformers accounts for anywhere between 15 percent to half of the total transmission capital expenditures; the rest is attributed to the transmission line equipment (conductors, towers, poles, etc.).[69] Given the developing investment in overall transmission infrastructure, the following section provides a market overview and investment forecast specific to power transformers in the world and in the United States.

V. GLOBAL POWER TRANSFORMER MARKET

The global power transformer market is well matured, without many technological or product innovations taking place.[70] Analysts have reported that for most of the 1990s, power transformer prices were depressed and that the relationship between sales value and sales volume remained fairly constant.[71] However, starting in 2002, this situation was completely reversed due to volatile raw commodity prices, unprecedented market demand, and rationalization of manufacturing bases.[72] Particularly, a sudden rise in the cost of raw materials had a significant impact on the price of power transformers. According to recent industry analyses, the total revenues for the global electricity transformer market (combining power and distribution transformers) in 2009 were $23 billion USD.[73] Of the total, revenues from power transformer sales were $11 billion in 2009, and this market rose at a compound annual growth rate (CAGR) of about 13 percent from 2000 to 2009.[74] The global transformer market is forecasted to continue to develop in the next decade. One source estimated the global transformer market to grow at a CAGR of eight percent through 2020;[75] another estimated that the global transformer market would reach $54 billion USD (almost 10 million units) by the year 2017.[76]

Key drivers for future transformer market development include an increase in electricity demand in developing countries, replacement of old electric power equipment in matured economies, and a boost for high-voltage power transformers and capital expenditure in the power sector worldwide. In addition, the adoption of energy-efficiency standards in developed markets, such as Europe and the United States, as well as in emerging markets, such as China and India, are expected to create demand for new, more efficient electricity equipment, including power transformers.[77]

The remainder of this section discusses the current condition of the LPT market in the United States, as well as its domestic manufacturing capacity and historical imports of LPTs. China's

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[69] EEI Survey of Transmission Investment, EEI, May 2005.
[70] An industry source indicated that there are research and development efforts in high temperature superconductor transformers and solid state transformers.
[71] "World Transformer Markets 2002 to 2012," Gouldon Reports 2009, Presented to Leonardo Energy, May 15, 2009, http://www.leonardo-energy.org/webfm_send/2731 (accessed November 22, 2011).
[72] Ibid.
[73] "Power Transformers Market Analysis to 2020," Global Data, 2009, http://www.articlesnatch.com/Article/Power-Transformers-Market-Analysis-To-2020-/1861724 (accessed November 11, 2011).
[74] Ibid., Gouldon Report 2009.
[75] "Power Transformers Market Analysis to 2020," Global Data, 2009.
[76] "Global Electricity Transformers Market To Reach US$53.6 Billion, 9.7 Million Units by 2017," Global Industry Analysts, October 12, 2011, http://tdworld.com/business/global-transformer-market-1011/ (accessed November 21, 2011).
[77] Global Industry Analysts, October 12, 2011.

LPT demand and production capacity are also discussed briefly because of its sizeable market and the potential effects its power transformer industry has on the global marketplace. An overview of China's power transformer industry, including demand, manufacturing capacity, and key manufacturers, is provided in Appendix G, Power Transformer Industry in China.

5.1 U.S. Power Transformer Market Overview

The United States is one of the world's largest markets for power transformers, with an estimated market value of over $1 billion USD in 2010, or almost 20 percent of the global market. The United States also holds the largest installed base of LPTs in the world. Using certain analysis and modeling tools, various sources estimate that the number EHV LPTs in the United States to be approximately 2,000.[78] While the estimated total number of LPTs (capacity rating of 100 MVA and above) installed in the United States is unavailable, it could be in the range of tens of thousands, including LPTs that are located in medium voltage transmission lines with a primary voltage rating of 115 kV. Figure 11 represents the historical annual installment of LPTs in the United States, not including replacement demand.

This world's largest installed base of LPTs is aging. Power equipment manufacturers estimated that the average age of LPTs installed in the United States is approximately 40 years, with 70 percent of LPTs being 25 years or older.[79] According to an industry source, there are some units well over 40 years old and some as old as over 70 years old that are still operating in the grid. The same source also noted that these transformers are typically warranted by the manufacturers for approximately 30 to 35 years. An LPT is subjected to faults that result in high radial and compressive forces, as the load and operating stress increase with system growth.[80] In an aging power transformer failure, typically the conductor insulation is weakened to the degree at which it can no longer sustain mechanical stresses of a fault.[81] Given the technical valuation that a power transformer's risk of failure increases with age, many of the LPTs in the United States have outlived their useful lives and will need to be replaced or refurbished. Although age can be a factor, the life expectancy of a power transformer varies depending on how it is used. In addition, according to an industry source, there were also some bad batches of LPTs from certain vendors. The same source also estimated that the failure rate of LPTs to be around .5 percent.

As illustrated in Figure 11, a large volume of LPTs were installed in the United States between the 1950s and 1970s. Although the investment remained low in the 1990s, the need for LPTs has been growing steadily since 1999. Despite its mounting demand for power transformers, the United States has a limited domestic capacity to produce LPTs.

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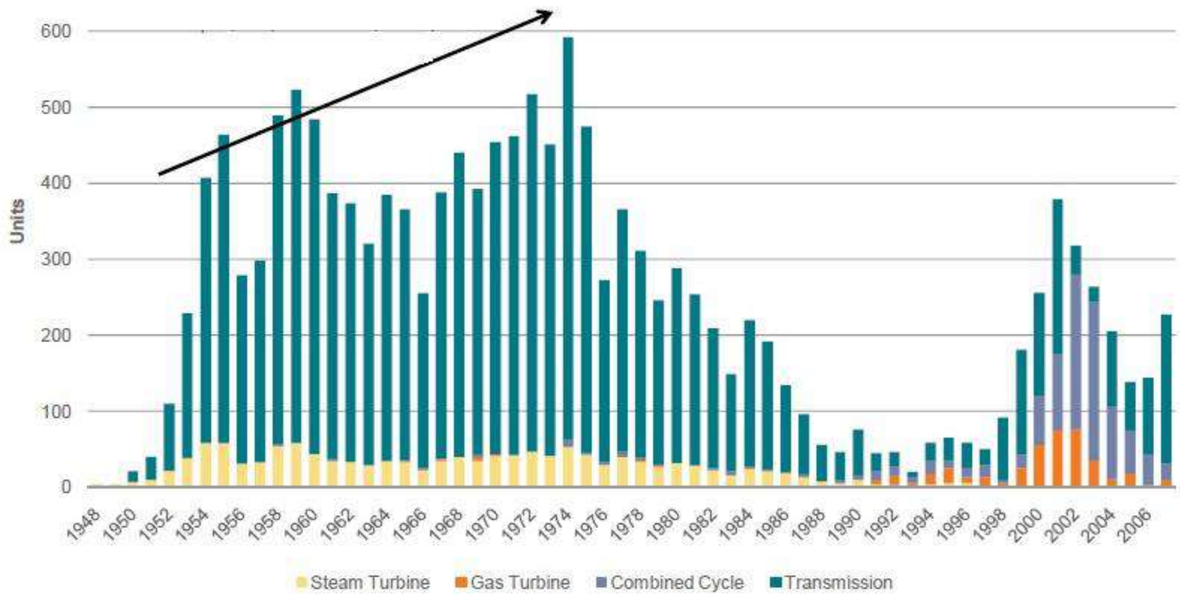
[78] Benefits of Using Mobile Transformers and Mobile Substations for Rapidly Restoring Electrical Service, DOE, August 2006. This DOE source provides an estimated voltage range of an LPT as 115–765 kV and the estimated power range as 200–1,200 MVA. "Report of the Commission To Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack," EMP Commission, April 2008, http://www.empcommission.org/docs/A2473-EMP_Commission-7MB.pdf (accessed January 3, 2012). Kappenman, John, "Geomagnetic Storms and Their Impacts on the U.S. Power Grid." Prepared for Oak Ridge National Laboratory, January 2010, http://www.fas.org/irp/eprint/geomag.pdf (accessed January 3, 2012).

[79] Conference Hearing for Investigation No.731-TA-1189, USITC, August 4, 2011, pp. 147–148.

[80] "Analysis of Transformer Failures," William H. Bartley P.E., Hartford Steam Boiler Inspection & Insurance Co. 2003, http://www.bplglobal.net/eng/knowledge-center/download.aspx?id=191 (accessed November 18, 2011).

[81] Ibid.

Figure 11. Yearly Installment of Large Power Transformers in the United States From 1948 to 2006
(Power transformers with a capacity rating greater than or equal to 100 MVA)



Note: Figure includes LPTs with a capacity rating greater than or equal to 100 MVA and excludes replacement demand.
Source: EIA; SPX Electrical Products Group, May 2010.

In 2010, the United States' demand for LPTs was 127,309 MVA, valued at over $1 billion USD (see Table 4).[82] Only 15 percent of the Nation's demand, or 19 percent in terms of sales value, was met through domestic production. Note, however, that the data shown in Table 4 includes production capacity and actual production of power transformers with a capacity rating of 60 MVA and above, which is different from "capacity rating of greater than or equal to 100 MVA," which was used to describe LPTs in the rest of the report.

Table 4. Summary of Power Transformer Market (60 MVA +) in the United States in 2010

	Market Share by Quantity		Market Share by Value	
	Quantity (MVA)	Percent (%)	Value (1,000 dollars)	Percent (%)
U.S.	19,279	15%	213,070	19%
All Import Sources	108,030	85%	911,863	81%
Total	127,309	100%	1,124,933	100%

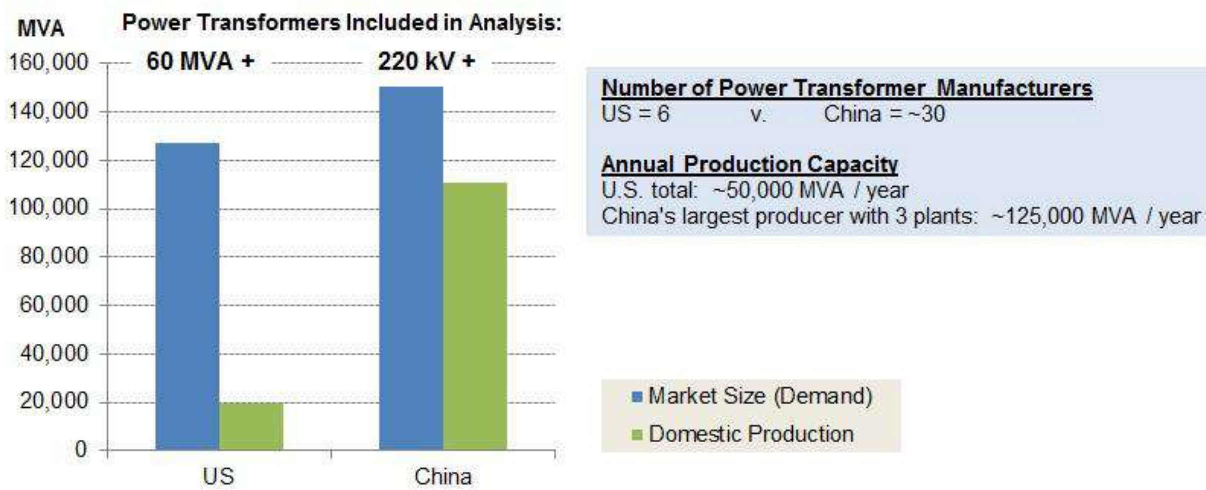
Note: This analysis includes power transformers with capacity greater than or equal to 60 MVA.
Source: "Large Power Transformers from Korea," USITC, Preliminary Investigation, September 29, 2011.

Figure 12 provides a comparison of the estimated market size and production of power transformers in the United States and China in 2010. Different parameters are used to define power transformers – a capacity rating of 60 MVA and above for the United States and a voltage rating of 220 kV and above for China.[83] While attributes may vary, the comparison shows

[82] "Large Power Transformers from Korea," USITC, Preliminary Investigation, September 2011.
[83] Figure 12 was derived from the USITC's preliminary investigation report on "Large Power Transformers from Korea," which defined an LPT as a power transformer with capacity greater than or equal to 60 MVA. China's LPT data were derived from an industry analysis as reported in Reuters, which described used transformers with capacity 220 kV and above to describe the market.

distinct characteristics of the two markets – the United States' heavy reliance on foreign-manufactured power transformers and China's abundant domestic production capacity. In 2010, although the estimated market size for the two countries were comparable in the range of 120,000 MVA and 150,000 MVA , the actual production of power transformers in the United States was less than one fifth that of China's.

Figure 12. Estimated Power Transformer Markets: United States v. China in 2010



Note: Different criteria used for the United States and China. For the United States, power transformers with capacity greater than or equal to 60 MVA are included in the data; for China, power transformers with capacity greater than or equal to 220 kV are included in the data.

Sources: USITC, 2011; China Transformer Net, 2010; China's Power Transformer Industry Report, Reuters, 2011.

In terms of manufacturing base in 2010, six domestic manufacturers accounted for all power transformers produced in the United States, whereas over 30 power transformer manufacturers existed in China. The total annual production capacity[84] of the six domestic factories was approximately 50,000 MVA in 2010, far below the U.S. market demand of 127,309 MVA for that year. On the contrary, China displayed a self-contained LPT market, in which the vast majority of its demand was met through domestic production. For example, three of China's largest power transformer manufacturers each held an annual production capacity of more than 100,000 MVA.

The following section will explore today's power transformer manufacturing industry, including major players in the global scene and in the United States. As a comparison to the global and domestic suppliers, Chinese manufacturers of LPTs are profiled in Appendix G, Power Transformer Industry in China.

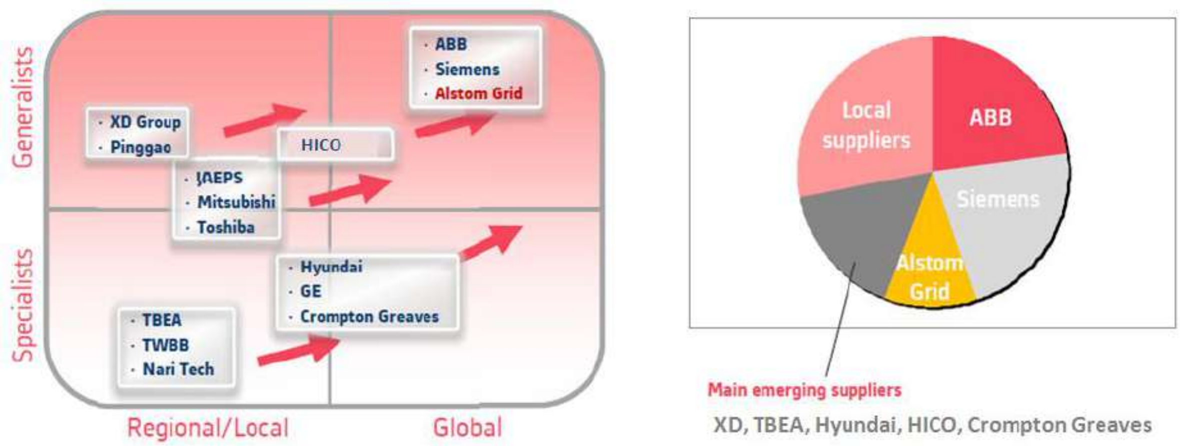
5.2 Key Global Suppliers of Power Transformers

The global power transformer market has been one of fluidity and constant adaptation, characterized by a myriad of consolidations, new players, and power shifts throughout the last few decades. Due to the market's shifting nature, the latest statistics of the market share by

[84] In this paper, the term annual production capacity represents the capability of a manufacturer to produce transformers of all types and sizes, ranging from small to large, in an annual basis.

manufacturer are unavailable. In 2011, key manufacturers and analysts reported that ABB, Siemens, and Alstom Grid were the dominant suppliers of power transformers worldwide but indicated that emerging players also had a formidable presence in the global market place.[85] Figure 13 illustrates the dynamics of key power transformer manufacturers in the global market in 2011, including several emerging suppliers.

Figure 13. Global Suppliers of Power Transformers in 2011



Note: HHI stands for Hyundai Heavy Industries; HICO stands for Hyosung Power and Industrial Systems; JAPES stands for Japan AE Power Systems Corporation; TBEA stands for Tebian Electric Apparatus Stock Co.; TWBB stands for Baoding Tianwei Baodian Electric Co.; and XD stands for Xian XD Transformer.

Source: Alstom, 2011.

According to company reports, ABB had 20 transformer manufacturing plants worldwide in 2011, while Siemens and Alstom Grid had 21 and 13, respectively.[86] In terms of annual production capacity, ABB and Alstom Grid each had approximately 200,000 MVA and 130,000 MVA of annual production capacity, respectively.[87] Alstom Grid's production capacity reflects the additional manufacturing base it obtained through a recent acquisition of AREVA's transmission business in 2010.

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[85] Global Industry Analysts, Inc., October 5, 2011; "Shareholders Meeting," Alstom, June 28, 2011, http://www.alstom.com/assetmanagement/DownloadAsset.aspx?ID=326a901d-467d-4bc3-8504-2ab917598501&version=d568ca975d59485db0ae81a9c8fa76be1.pdf&lang=2057 (accessed December 1, 2011); ABB Strategy 2011, Sept. 5, 2007, http://www02.abb.com/global/abbzh/abbzh259.nsf/bf177942f19f4a98c1257148003b7a0a/b78db666da1a0697c125734f003ba49a/$FILE/ABB+Strategy+2011.pdf (accessed December 1, 2011).

[86] ABB: http://www.eyeproject.cl/files/94151d_ABB-BR-31-TrafoStar-FlipChart12Reasons.pdf; Siemens: http://www.energy.siemens.com.cn/CN/powerTransmission/Transformers/Documents/TR%20China%20catalog_EN_2010.pdf; Alstom Grid: http://www.alstom.com/grid/news-and-events/press-releases/upgrade-project-at-Alstom-Grid-s-Rocklea-factory/ (all accessed December 3, 2011).

[87] ABB: http://www.eyeproject.cl/files/94151d_ABB-BR-31-TrafoStar-FlipChart12Reasons.pdf and http://www.abb.mu/cawp/seitp202/51719ef8b8b364ee48257690001f063a.aspx; Alstom Grid: http://www.alstom.com/grid/solutions/high-voltage-power-products/electrical-power-transformers/; Siemens does not disclose its total annual production capacity; however, it has an annual manufacturing capacity of 70,000 MVA in China. See http://www.stcl.com.cn/stcl/en/aboutus.asp (all accessed December 3, 2011).

In addition, several local players have emerged in recent years and have been extending their offer coverage and geographical reach. These include HHI and Hyosung Power and Industrial Systems (HICO) of South Korea; Crompton Greaves of India; Tebian Electric Apparatus Stock Co., Ltd. (TBEA), Baoding Tianwei Baobian Electric Co., Ltd. (TWBB), and Xian XD Transformer of China (XD) (see Figure 13). Each of these companies boasts an annual production capacity in the range of 70,000 to 125,000 MVA. While Chinese firms currently do not have considerable presence in the North American market, HHI and Hyosung of South Korea already contribute a significant share of the North American market and are expanding their footprint in other geographical regions. As these local players have emerged in the global marketplace, traditional global firms have experienced a wave of consolidations. The following section provides brief insight to these phenomena that have been occurring since the 1980s.

5.2.1 Consolidation of Power Equipment Manufacturers

Over the past few decades, the power equipment industry has witnessed a series of mergers and acquisitions (M&As) and consolidation of operations to remove excess capacity and move their operations offshore, fueled by dramatic run-ups in commodity metals prices. In doing so, the firms also took advantage of lower labor costs in certain countries and their rapidly growing domestic electricity demand. Table 5 is a summary of global M&A activities among power equipment manufacturers that have taken place since the 1980s.

Table 5. Key International Mergers and Acquisitions of Power Equipment Industry From 1980 to 2010

1980s
• GEC (UK) + Alcatel (France) = **GEC Alstom** • ASEA (Sweden) + BBC (Switzerland) = **ABB** • **ABB** (Switzerland): Acquired 39 companies, plus power transmission and distribution (T&D) business of Westinghouse Electric Corporation to become a technology leader in T&D business
1990s

• In 1998, **Siemens** (Germany) acquired:
  ○ Westinghouse's fossil power plant activities
  ○ Voith's (Germany) Hydro division
  ○ Parson's Power Engineering (UK)
• **Babcock Borsig Power** took over B&W (Spain)
• **GE Hydro** (Canada) bought Kvaerner (Norway)
• GEC Alstom + ABB = **ABB-Alstom Power (AAP)**

Early 2000s
• **Alstom** (France) bought ABB's stake in AAP • **GE** (USA) acquired EGT (France) • **Siemens AG** took over Alstom's industrial turbine business • **AREVA** (France) acquired Alstom T&D business • **Hitachi** (Japan) took over the assets of insolvent Babcock Borsig • **JAEPS** (Japan) created a joint venture among Hitachi, Fuji and Meidensha
2005–2010
• 2005: **Crompton Greaves** (India) acquired Pauwels (Belgium) • 2005: **Siemens** took over VA Tech's (Austria) T&D business • 2008: **ABB** acquired Kulman Electric (US) • 2010: **Alstom** took over AREVA's transmission business   **Schneider** took over AREVA's distribution business

Sources: 1980–early 2000s, http://dhi.nic.in/indian_capital_goods_industry.pdf ;

http://www.hitachipowersystems.us/products/power_transformers_breakers/index.html
For 2005–2010:
Crompton Greaves: http://www.cgglobal.com/pdfs/annual-report/AR_05-06.pdf
Siemens: http://tdworld.com/news/Siemens-VA-Tech-takeover/
ABB: http://tdworld.com/business/abb_acquire_kuhlman_electric/
Alstom/Schneider: http://www.areva-td.com/

These mergers have reduced the number of firms competing in the global market, and through them, stronger companies have emerged with "increased size, economies of scale, wider product ranges and enhanced financial strength . . . [who benefit] from having greater access to markets and higher bargaining power as a result of combined technological strengths."[88]

5.3 Large Power Transformer Manufacturing Capacity in North America

The United States was not an exception to the global, strategic consolidation of manufacturing bases. By the beginning of 2010, there were only six manufacturing facilities in the United States that produced LPTs. Although certain manufacturers reported having the capability to produce power transformers with a capacity rating of 300 MVA or higher, industry experts cautioned that the capacity to produce does not necessarily warrant actual production of power transformers of that magnitude.[89] Often, domestic producers did not have the required machinery and equipment to produce power transformers of 300 MVA, or 345 kV, and above. A number of firms identified constraints in equipment (cranes, ovens, testing, winding, and vapor phase systems) and the availability of trained personnel set limits to their production capacity.[90]

Figure 14 is a map of power transformer manufacturing facilities in North America in 2012 and the maximum rating of LPTs they are capable of producing.[91] In this figure, the blue triangles indicate facilities that produce LPTs with a voltage rating up to 345 kV, the red circles indicate facilities with the capacity to produce LPTs with a voltage rating greater than 345 kV, and the green stars indicate proposed new plants or expansion at existing facilities. In 2010, although a few domestic facilities including EFACEC of South Rincon, Georgia and ABB of St. Louis, MO were capable of producing EHV power transformers, it is unclear whether they actually produced any. While the exact statistics of EHV power transformers produced by domestic facilities are unavailable, this suggests that the United States procured almost all of its EHV power transformers overseas. (See Figure 14, which includes two manufacturing plants in Canada and three companies in Mexico.)

The limited domestic production capacity for LPTs is improving, however. In addition to the opening of EFACEC's first U.S. transformer manufacturing facility in Rincon, Georgia in April 2010, the United States has gained and will gain additional capabilities to produce LPTs in 2012 and beyond. Key global power transformer producers have discerned a market potential for LPTs

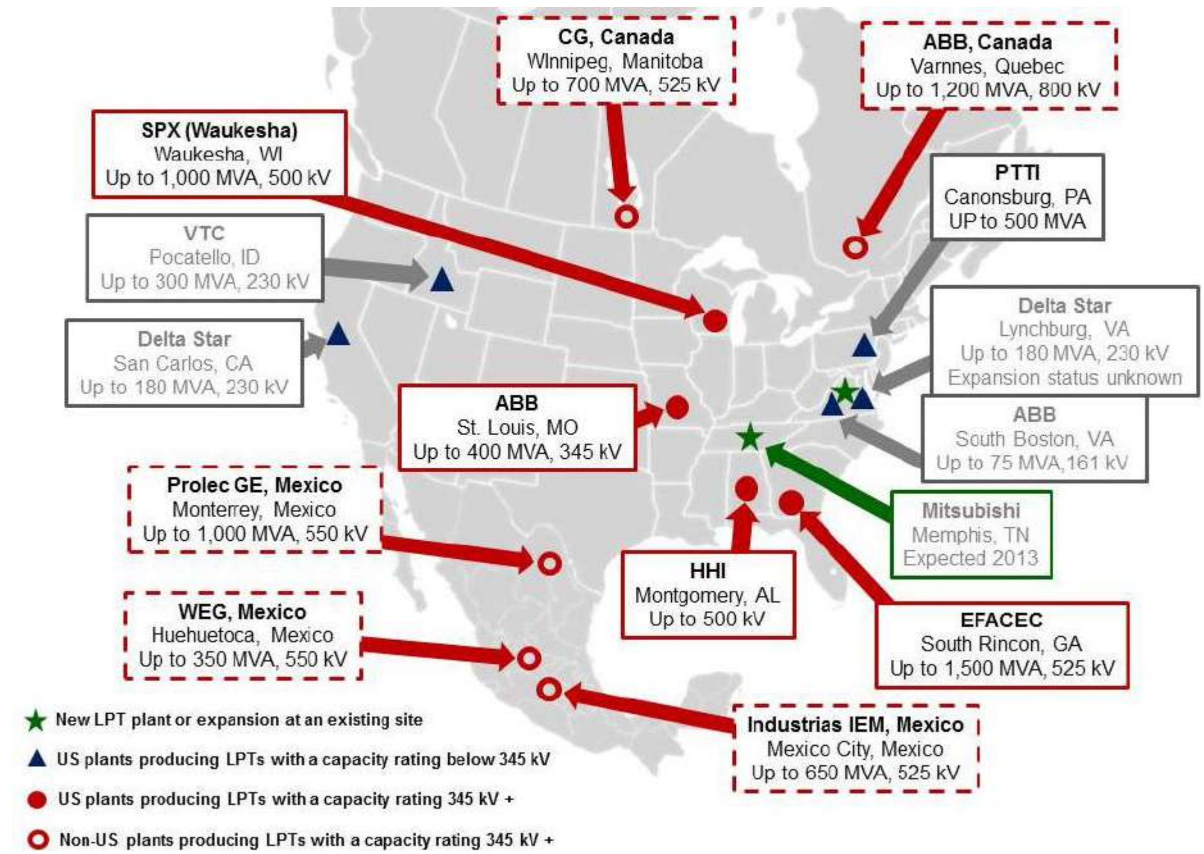
[88] Final Report on the Indian Capital Goods Industry, http://dhi.nic.in/indian_capital_goods_industry.pdf (accessed December 14, 2011).
[89] Conference Hearing for Investigation No.731-TA-1189, USITC, August 4, 2011, p. 113.
[90] "Large Power Transformers from Korea," USITC, Preliminary Investigation, September 2011.
[91] Figure 14 represents all LPT manufacturing plants in North America as of May 2012. SPX completed an expansion of existing facility in April 2012 and increased its capacity to produce EHV power transformers. Also Hyundai's new facility in Montgomery, Alabama was inaugurated in November 2011; therefore, it was not considered in the 2010 LPT market analysis.

and announced plans to develop manufacturing capacity in the United States. An industry source advised that the strong dollar and shipping costs are the biggest factors influencing foreign companies building factories in the United States.

Here are the three manufacturers who have announced expansion or development plans in the past few years, two of which have recently completed their efforts:

- HHI's new 404,000 square feet power transformer manufacturing plant was inaugurated in November 2011 and is expected to produce power transformers of a capacity rating up to 550 MVA/500 kV and up to 200 power transformers annually.[92]
- SPX Transformer Solutions, Inc. (SPX, also formally known as Waukesha Electric Systems, Inc.) completed an expansion at its existing facility in Waukesha, Wisconsin in April 2012.[93] With a total of 432,000 square feet and additional crane capacity now up to 500 tons, the plant is expected to produce power transformers with a capacity rating up to

Figure 14. Large Power Transformer Manufacturing Facilities in North America in 2012



Note: Hyundai is the latest entrant whose plant in Montgomery, Alabama was inaugurated in November 2011. Also, SPX completed an expansion in April 2012 and increased its production capacity. Further note, CG stands for Crompton Greaves; HHI stands for Hyundai Heavy Industries; PTTI stands for Pennsylvania Transformer Technology Inc.; VTC stands for Virginia Transformer Corp.

Source: ICF International.

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[92] Hyundai Heavy Completes Transformer Factory in Alabama, November 21, 2011, http://english.hhi.co.kr/press/news_view.asp?idx=727&page=1 (accessed December 2, 2011).

[93] "SPX Unveils Newly Expanded SPX Transformer Solutions Manufacturing Facility in Waukesha, Wisconsin," April 12, 2012, http://www.spxtransformersolutions.com/large_power.html (accessed June 5, 2012).

1,000 MVA/500 kV.[94]

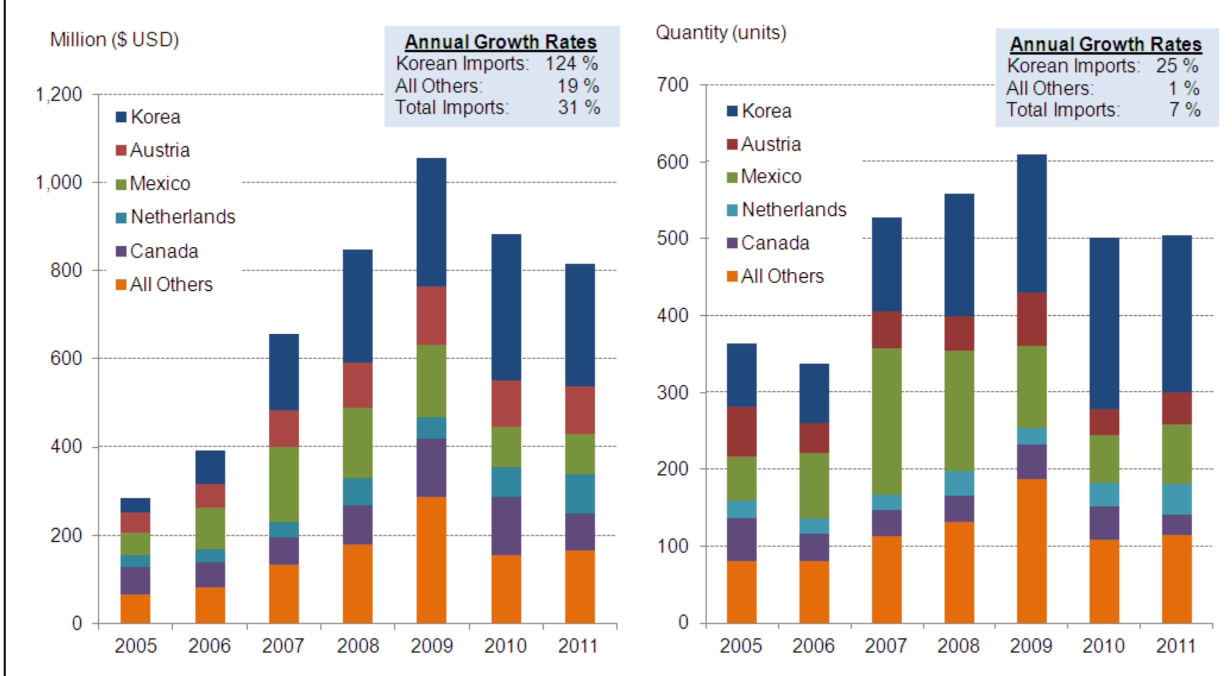
- Mitsubishi is building a new, 350,000 square feet facility in Memphis, Tennessee and plans to manufacture EHV power transformers from this plant starting in 2013.[95]

Appendix E, Large Power Transformers Manufacturing Facilities in North America, provides a list of all LPT manufacturing plants in North America, including the aforementioned new or proposed plants. The remainder of the section examines the recent historical trend of LPT imports in the United States, as well as the forecast for future market demand.

5.4 Historical Imports of Large Power Transformers to the United States

The upward trend of transmission infrastructure investment in the United States starting around 1999 has continued in the 21st century. Figure 15 presents the historical LPT (capacity rating greater than or equal to 100 MVA) imports in terms of value (USD) and quantity (units) between 2005 and 2011.[96] In 2005, the United States imported 363 LPT units, with a total value of $284 million USD; in 2011, the United States imported 505 units, totaling $817 million USD.[97] In other words, the LPT market's monetary value grew at a much faster pace than the number of

Figure 15. U.S. Imports of Large Power Transformers by Country From 2005 to 2011
(Power transformers with a capacity rating greater than or equal to 100 MVA)



Source: USITC Interactive Tariff and Trade DataWeb. 2012.

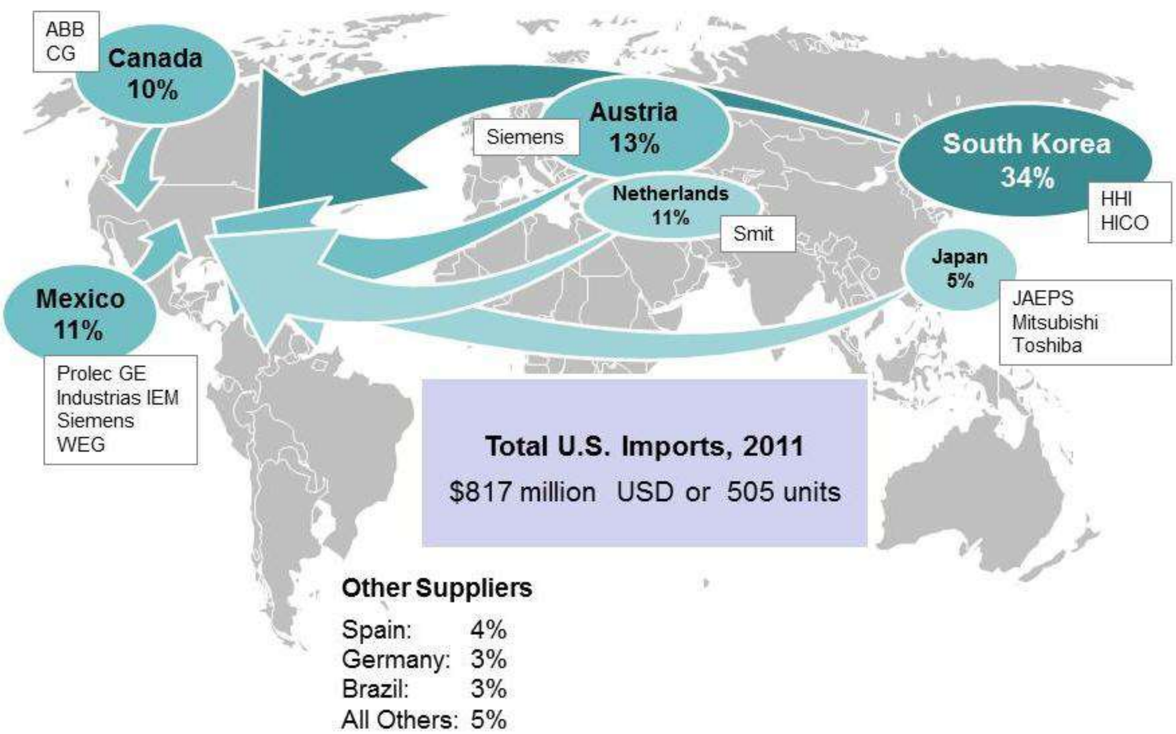
[94] Ibid.; "Large Power Transformers," SPX, http://www.spxtransformersolutions.com/assets/documents/LP%20Brochure_web.pdf (accessed December 22, 2011).
[95] "Mitsubishi Electric To Build Transformer Factory in Memphis," Mitsubishi Press Release, February 14, 2011, http://www.mitsubishielectric.com/news/2011/0214-a.html (accessed December 2, 2011).
[96] See Appendix D. Historical Imports of Large Power Transformers in the United States for the data used in Figure 15.
[97] USITC Interactive Tariff and Trade DataWeb, http://dataweb.usitc.gov/scripts/user_set.asp (accessed June 5, 2012).

units, at an average annual growth rate of 31 percent, as compared with seven percent, respectively.[98] Nonetheless, LPT imports showed a strong growth both in terms of value and quantity. Between 2007 and 2011, the United States imported more than 500 LPT units each year.

Figure 15 also shows a prominent, rapid market penetration by South Korean imports during this period. Between 2005 and 2011, the total value of LPT imports in the United States grew by 31 percent. During the same period, LPT imports from South Korea increased by 124 percent, from $33 million in 2005 to $279 million in 2011.[99] In 2011, South Korea was the largest LPT supplier in the United States and obtained more than 34 percent of the total U.S. import market in terms of USD value and 40 percent in terms of number of units.

Below is a global representation of LPT import activities in the United States in 2011 (see Figure 16). Two South Korean firms, HHI and Hyosung, were the largest exporters of LPTs to the United States. HHI, particularly, is recognized as a key global supplier of LPTs in North America. HHI holds an annual production capacity of 120,000 MVA at its Ulsan, South Korea plant, which is considered the largest transformer manufacturing facility in the world.[100] Other

Figure 16. Global Suppliers of Large Power Transformers to the United States in 2011
(Power transformers with a capacity rating greater than or equal to 100 MVA)



Note: CG stands for Crompton Greaves; HHI stands for Hyundai Heavy Industries; HICO stands for Hyosung Power and Industrial Systems; JAPES stands for Japan AE Power Systems Corporation.
Source: USITC, ICF International Analysis.

[98] Ibid.
[99] USITC Interactive Tariff and Trade DataWeb, 2012.
[100] Ibid.; HHI Electro Electric Systems, http://www.hyundai-elec.com/new/eng/product/product.jsp?p_code=A0100 (accessed December 3, 2011).

notable global exporters of LPTs to the United States include ABB and Crompton Greaves of Canada, Siemens of Austria, and Prolec GE of Mexico. Smit Transformer of the Netherlands and various power equipment firms from Japan supplied 11 percent and five percent of the total LPT imports in the United States in 2011, respectively. A brief profile of these and some of the world's largest power transformer manufacturers is provided in Appendix F. Selected Global Power Transformer Manufacturers.

Power transformers are a globally traded product, and the demand for this equipment is forecasted to continue to grow in the United States (see Figure 17). According to two major power transformer manufacturers, the North American power transformer market is expected to grow at a CAGR of three to seven percent between 2011 and 2015.[101] In terms of units, one source estimated that the demand for LPTs in the United States would be around 500 to 600 units per year.[102] According to Goulden Reports, a research firm specializing in the electricity and electrical equipment markets, the U.S. transformer market will grow to $4.3 billion USD by 2015.[103] However, the demand for LPTs has varied greatly over time as the electricity growth rates have changed.

In addition to the aging of power transformers, key demand drivers for LPTs include: transmission expansion to integrate solar and wind renewable sources; electric reliability improvement; and new capacity addition in thermal and nuclear power generation.

Figure 17. Projected Demand Growth for Large Power Transformers in the United States through 2030
(Power transformers with a capacity rating greater than or equal to 100 MVA)

Note: As noted in earlier discussions, utilities were not investing in the 1990s due to uncertainty surrounding regulation.
Source: SPX Electrical Products Group, May 2010. SPX analysis based on EIA data and research.

101 SPX Electrical Products Group, May 2011 and an industry source estimate.
102 SPX Electrical Products Group, May 2011.
103 Hyundai Heavy Completes Transformer Factory in Alabama, November 21, 2011, http://english.hhi.co.kr/press/news_view.asp?idx=727&page=1 (accessed December 2, 2011).

5.5 Challenges in Global Sourcing of Large Power Transformers

The global demand for LPTs has increased significantly since the late 1990s to meet the power demand growth and the need to replace aging power transformers. Purchasing decisions in the global marketplace is more complex than simply comparing prices. Some of the challenges associated with global procurement of LPTs are as follows:[104]

- Ocean and inland transportation, compliance with specifications, quality, testing, raw materials, and major global events (e.g., hurricanes) can significantly influence a supplier's lead time and delivery reliability. In addition, some railroad companies are removing rail lines due to infrequent use and other lines are not being maintained. This can pose a challenge to moving the LPTs to certain locations where they are needed.
- Fluctuations in currency exchange rates and prices of materials during the time in which a power transformer is being manufactured can quickly change the competitive bid price for the order.
- Cultural differences and other communication barriers can be challenging. In many cultures, what the buyer-manufacturer relationship entails may vary from what is written in the contract.
- Foreign factories may not understand the U.S. standards such as the Institute of Electrical and Electronics Engineers and American National Standards Institute standards or have appropriate testing facilities.
- Foreign vendors may not have the ability to repair damaged power transformers in the United States.
- It is expensive to travel overseas for quality inspections and to witness factory acceptance testing.
- The utility industry is also facing the challenge of maintaining experienced, well-trained in-house workforce that is able to address power transformer procurement and maintenance issues.

Utilities can minimize potential risks related to global sourcing by focusing on proactive business strategies, planning effectively, and managing a portfolio of qualified and experienced suppliers.

VI. Concluding Remarks

This report examined the global power-transformer manufacturing industry, one that is characterized by continuous adaptations because of shifting and difficult-to-predict market dynamics. In particular, this report addressed the considerable dependence the United States has on foreign suppliers to meet its growing need for LPTs. The intent of this study is to inform decision-makers about the potential supply concerns of LPTs in the United States, and this report provides the following

> "We build upon the solid foundation of previous efforts but also look ahead to the future we are working to create. Our Strategy is therefore one of continuity and change."
>
> - *The National Strategy for Global Supply Chain Security,* the White House, 2012

[104] Judson Schumacher, T&D World, May 1, 2006, http://tdworld.com/business/power_buying_transformers/index.html (accessed January 11, 2012).

observations:

- **Demand for LPTs is on the rise globally and domestically.** Key drivers of demand include the development of power and transmission infrastructure in emerging economies (e.g., China and India) and the replacement market for aging infrastructure in mature economies (e.g., United States), as well as the integration of alternative energy sources into the grid and an increased focus on nuclear energy in light of climate change concerns.
- **Two key raw materials—copper and electrical steel—are vital to LPT manufacturing.** However, there are limited supply sources for special grades of electrical steel needed for the LPT core, and both steel and copper have experienced wide price fluctuations since 2004. Their price volatility is expected to continue as the demand for these commodities, especially from developing economies (i.e., China and India), is forecasted to grow in the next several years.
- **LPTs require a long lead time and transporting them can be challenging.** The average lead time for an LPT is between five and 16 months; however, the lead time can extend beyond 20 months if there are any supply disruptions or delays with the supplies, raw materials, or key parts. Its large size and weight can further complicate the procurement process, as an LPT requires special arrangements and special rail cars for transport.
- **The United States has limited production capability to manufacture LPTs.** In 2010, only 15 percent of the Nation's demand for power transformers (with a capacity rating of 60 MVA and above) was met through domestic production. Although the exact statistics are unavailable, power transformer market supply conditions indicate that the Nation's reliance on foreign manufacturers is even greater for EHV power transformers, which have a capacity rating of 300 MVA and above (or a voltage rating of 345 kV and above).
- **However, domestic production of LPTs is expected to improve in the near future.** In addition to the opening of EFACEC's Rincon, Georgia plant in 2010, at least three new or expanded facilities will produce EHV LPTs in the United States starting 2012 and beyond, including: SPX's recently expanded Waukesha, Wisconsin plant; HHI's newly inaugurated Montgomery, Alabama plant; and Mitsubishi's proposed Memphis, Tennessee plant.
- **A NERC effort may enhance understanding of LPT spares.** During 2012, NERC is implementing its Spare Equipment Database Program that will help determine the extent to which spare transformers are available across North America. As this information becomes available, this will help decision makers understand what additional programs or incentives may be needed to increase the number of available spares.
- **New recovery transformer (RecX) concept may provide some relief.** The U.S. Department of Homeland Security's (DHS) Science and Technology Directorate, along with their partners, the Electric Power Research Institute, ABB, and CenterPoint Energy (CNP), and the support of DOE and DHS Office Infrastructure Protection, have developed a prototype EHV transformer that will drastically reduce the recovery time associated with EHV transformer issues. The Recovery Transformer (RecX) is lighter (approximately 125 tons), smaller and easier to transport and quicker to install than a traditional EHV transformer. The prototype transformer delivery and set up was successfully demonstrated in March of 2012 in an exercise that included the

> transportation, installation, assembly, commissioning and energization of the transformer in less than 1 week. The RecX is currently operating in CNP's grid for a one-year monitoring period. The RecX is a 345:138kV, 200 MVA per phase transformer (equivalent to 600MVA) and was designed to be an applicable replacement for over 90 percent of transformers in this voltage class, which is the largest voltage class of EHV transformers.[105]

The U.S. electric power grid is one of the Nation's critical life-line infrastructure on which many other critical infrastructure depend, and the destruction of this infrastructure can cause a significant impact to national security and the U.S. economy. The U.S. electric grid faces a wide variety of threats, including natural, physical, cyber, and space weather. LPTs are large, custom-built electric infrastructure. If several LPTs were to fail at the same time, it could be challenging to quickly replace them. While the potential effects of these threats on the electric grid are uncertain, the Electricity Subsector continues to work on a variety of risk management strategies to address these potential severe risk impacts. Understanding the characteristics of today's power transformer procurement and supply environment is indispensable to both public and private sectors. The assessment of LPTs in this DOE report provides background to the industry and government stakeholders who continue their efforts to enhance critical energy infrastructure resilience in today's complex, interdependent global economy. More information on this and additional relevant references are provided in the appendixes.

[105] For more information about RecX, see: http://www.dhs.gov/files/programs/st-snapshots-prototyping-replacement-ehv-transformers.shtm (accessed June 11, 2012) and http://www.nytimes.com/2012/03/15/business/energy-environment/electric-industry-runs-transformer-replacement-test.html?_r=1 (accessed June 11, 2012).

APPENDIX A. ACRONYMS

CAGR	Compound annual growth rate
CG	Crompton Greaves
CNP	CenterPoint Energy
CRGO	Cold-rolled grain-oriented
DHS	U.S. Department of Homeland Security
DOE	U.S. Department of Energy
EEI	Edison Electric Institute
EHV	Extra high voltage
EIA	U.S. Energy Information Administration
FOB	Free on Board
GMD	Geomagnetic disturbance
JAEPS	Japan AE Power Systems Corporation
HHI	Hyundai Heavy Industries
HICO	Hyosung Power and Industrial Systems
HILF	High-Impact Low-Frequency
HSPD-7	Homeland Security Presidential Directive-7
IEA	International Energy Agency
ISO	International Organization for Standardization
kV	Kilovolts
LPT	Large power transformers
M&A	Mergers and acquisitions
MVA	Megavolt amperes
NERC	North American Electric Reliability Corporation
NIPP	National Infrastructure Protection Plan
OECD	Organization for Economic Co-operation and Development
PTTI	Pennsylvania Transformer Technology Inc.
ReX	Recovery Transformer
SGCC	State Grid Corporation of China
TBEA	Tebian Electric Apparatus Stock Co., Ltd.
TWBB	Baoding Tianwei Baobian Electric Co., Ltd.
T&D	Transmission and Distribution
USD	U.S. dollar
USITC	United States International Trade Commission
VTC	Virginia Transformer Corp.
W/kg	Watts per kilogram

Appendix B. Global Electrical Steel Manufacturer Profiles

Name	Description
Acesita SA	Acesita SA, a Brazilian company with an annual steel production capacity of 850,000 metric tons, was founded in 1944. Acesita offers two types of grain-oriented electrical steel and three types of nonoriented electrical steel.
AK Steel	AK Steel, founded in 1899 and headquartered in Middletown, Ohio, employs more than 8,400 people in Ohio, Kentucky, Indiana, and Pennsylvania. This company, with over $5 billion in sales, produces flat-rolled carbon, stainless, and electrical steel products. AK Steel produces a range of electrical steels, including oriented steel grades of M2, M3, M4, M5, and M6 nonoriented standard steel grades of M15 to M47, and domain-refined, laser-scribed steels, H-O DR, H-1 DR, and H-2 DR.
Allegheny Ludlum	Allegheny Ludlum Corporation, headquartered in Pittsburgh, Pennsylvania, operates specialty metals, manufacturing facilities in Pennsylvania, Connecticut, Massachusetts, Indiana, and Ohio. Allegheny Ludlum employs approximately 3,800 people, and in addition to its other stainless and specialty steel products, produces grain-oriented steel with grades from M2 to M6.
BlueScope Steel	BlueScope Steel, a manufacturer specializing in flat-steel products, is the leading producer of steel in Australia and New Zealand. Ly-Core, BlueScope's nonoriented electrical steel line, is produced in three grades.
China Steel Corporation	China Steel Corporation, the only integrated steel producer in Taiwan, was founded in 1971 and exports nearly 30 percent of its steel production volume. It currently produces four grades of nonoriented electrical steel with a thickness of 0.50 mm.
Cogent Power Ltd.	Corus, an international metal company providing steel and aluminum products worldwide, entered into a joint venture with Svenskt Stal AB (SSAB) to form Cogent Power, Ltd. Corus owns 75 percent of the joint venture, while SSAB owns the remaining 25 percent. Cogent Power Ltd. is divided into an electrical steel division and a laminations division. The electrical steel division is comprised of Orb Works, located in South Wales, and Surahammars Bruk, headquartered in Sweden. Orb Works produces both grain-oriented and nonoriented steels. Surahammars Bruk produces grain-oriented steels in grades M3 through M7 and nonoriented steels in grades M15 through M47.
Duferco Viz Stal Metallurgical Plant	The Viz Stal plant was founded in 1726, as a pig iron processing facility. In 1914, the plant became the first producer of hot-rolled, nonoriented steel in Russia. Then, in 1934 it began producing hot-rolled, grain-oriented steel. In 1973, the plant began producing cold-rolled, grain-oriented electrical steel, and in 1978 Viz Stal became the first manufacturer of cold-rolled, nonoriented electrical steel in the Soviet Union. Duferco, a Swiss international manufacturing and trading company, acquired the plant. Finally, in 2004, Viz Stal gained the capability to supply their customers with slit coils.
JFE Steel Corporation	Another Japanese company, JFE Steel Corporation, the result of a December 2001 merger between Kawasaki Steel and NKK Corp., produces nine types (each with several grades) of grain-oriented electrical steel and six types of nonoriented electrical steel.
Nippon Steel Corporation	In 1970, Yawata Iron and Steel and Fuji Steel merged to form Nippon Steel. Located in Tokyo, Japan, Nippon Steel has 21,500 employees and produces over 27 million metric tons of crude steel annually. Nippon produces eight types of grain-oriented electrical steel and five types of nonoriented electrical steel.
Novolipetsk (NLMK) Metallurgical Plant	NLMK started in 1931, when iron ore and limestone deposits were discovered in Lipetsk, Russia. NLMK is now the largest steel-sheet producer in Russia. The integrated facility can produce 9.5 million metric tons of pig iron and up to 9.9 million metric tons of steel annually. NLMK also has the capacity of producing 500,000 metric tons of electrical steel annually.
Pohang Iron and Steel (POSCO)	POSCO, located in the port city of Pohang, South Korea, and founded in 1958, produces 30 million tons of steel annually and has more than19,000 employees. In 2004, POSCO produced 701,000 metric tons of electrical steel, 34 percent of which was exported. In

Name	Description
	2005, POSCO invested over $250 million to expand the capacity of their electrical steel production facility. POSCO recently announced a $12 billion deal in the State of Orissa, located in India. Between 2007 and 2010, $3 billion were invested in a three million ton plant. From 2010 to 2016, three million additional tons will be added every two years, bringing the plant to its full capacity of 12 million tons. This deal is the largest foreign investment in India.
Shanghai Baosteel	Shanghai Baosteel, formerly Baoshan Iron & Steel, is state-owned and China's largest iron and steel maker. Baosteel and its 22 wholly owned subsidiaries produce over 20 million metric tons of crude steel annually. Baosteel produces nearly 500,000 metric tons of nonoriented electrical steel annually, accounting for more than 50 percent of the nonoriented electrical steel produced in China.
ThyssenKrupp Steel	ThyssenKrupp Steel, a subsidiary of ThyssenKrupp AG, entered the electrical steel market in 1989. In 2002, ThyssenKrupp Electrical Steel (TKES) was formed to consolidate all of the company's electrical steel activities. Further restructuring in 2004 created ThyssenKrupp Stahl AG to handle the company's nonoriented electrical steel products. TKES now deals solely with grain-oriented steels. ThyssenKrupp produces over one million tons of electrical steel each year, making it the largest electrical steel producer in Europe and the second largest producer worldwide. ThyssenKrupp Steel is headquartered in Essen, Germany, and has plants in Germany, India, and France. EBG India, a joint venture between Thyssen Krupp and Raymond Ltd., is a producer of both grain-oriented and nonoriented steels. EBG India is located in Nashik, India. A plant in Isbergues, France, was acquired by TKES in 2002.
WCI Steel	WCI, a U.S. manufacturer based in Warren, Ohio, produced nonoriented electrical steel until exiting the business in January 2004. In September 2003, WCI filed for protection under Chapter 11 of the U.S. Bankruptcy Code. WCI management cited continuing volume deterioration and negative profit margins for the halt of steel production.
Wuhan Iron and Steel	Wuhan, a Chinese company with an annual steel production capacity of 10 million metric tons, was expected to add significant electrical steel production capacity beginning in September 2006.

Source: Distribution Transformers Final Rule Technical Support Document, Appendix 3A. Core Steel Market Analysis, DOE, Office of Energy Efficiency and Renewable Energy, September 2007, http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/transformer_fr_tsd/appendix_3a.pdf (accessed November 4, 2011).

APPENDIX C. PLANNED TRANSMISSION LINES IN THE UNITED STATES

Projected Circuit Miles of Transmission Additions by Voltage Level, 2011–2015

Voltage (kV)	2011	2012	2013	2014	2015	**Total**
100-199	1,012	1,229	691	345	242	**3,519**
200-299	1,126	855	711	529	671	**3,892**
300-399	767	1,576	3,478	1,300	589	**7,710**
400-599	336	1,400	1,314	1,512	2,710	**7,273**
600+	0	0	0	275	0	**275**
Total	3,242	5,060	6,194	3,962	4,212	**22,669**

Voltage (kV)	2011	2012	2013	2014	2015	**Total**
100-199	31%	24%	11%	9%	6%	**16%**
200-299	35%	17%	11%	13%	16%	**17%**
300-399	24%	31%	56%	33%	14%	**34%**
400-599	10%	28%	21%	38%	64%	**32%**
600+	0%	0%	0%	7%	0%	**1%**
Total	100%	100%	100%	100%	100%	**100%**

Notes: Derived from EIA Form 411, "Table 6. Proposed High-voltage Transmission Line Additions Filed Covering Calendar Year 2009," December 2010. EIA Form 411 is a voluntary report to NERC and EIA by IOUs, coop/munis, State/Federal power agencies, ISOs/RTOs, and merchant developers.

Source: "Employment and Economic Benefits of Transmission Infrastructure Investment in the U.S. and Canada," WIRES (Working Group for Investment in Reliable and Economic Electric Systems) In Conjunction with The Brattle Group, May 2011, http://www.wiresgroup.com/images/Brattle-WIRES_Jobs_Study_May2011.pdf (accessed December 1, 2011).

APPENDIX D. HISTORICAL IMPORTS OF LARGE POWER TRANSFORMERS IN THE UNITED STATES

Table D1. Large Power Transformers Imports by Country, 2005–2011 (in USD value)

(Liquid dielectric transformers having a power handling capacity exceeding 100,000 kVA)

Country	2005	2006	2007	2008	2009	2010	2011	Market Share 2011 (%)	Annual Growth (%) 2005–2011
	In 1,000,000 Dollars								
Korea	33	73	173	255	292	331	279	34%	124%
Austria	46	55	84	102	132	106	109	13%	23%
Mexico	51	94	171	159	165	91	91	11%	13%
Netherlands	27	31	35	63	48	67	88	11%	38%
Canada	60	56	63	88	132	133	85	10%	7%
Japan	12	0	4	0	14	17	41	5%	40%
Spain	6	3	5	0	0	12	32	4%	72%
Germany	16	30	23	47	54	11	26	3%	10%
Brazil	7	23	47	51	87	30	23	3%	38%
Colombia	2	6	25	36	28	2	16	2%	117%
Subtotal	259	370	630	802	952	801	790	97%	34%
All Other	25	21	29	45	105	81	27	3%	1%
Total	284	391	658	847	1,057	883	817	**100%**	**31%**

Table D2. Large Power Transformers Imports by Country, 2005–2011 (in quantity)

(Liquid dielectric transformers having a power-handling capacity exceeding 100,000 kVA)

Country	2005	2006	2007	2008	2009	2010	2011	Market Share 2011 (%)	Annual Growth (%) 2005–2011
	In Actual Units of Quantity								
Korea	82	77	123	160	180	223	204	40%	25%
Mexico	57	85	190	156	107	63	77	15%	6%
Austria	64	38	47	45	69	33	43	9%	-5%
Netherlands	24	21	21	33	22	30	40	8%	11%
Spain	3	2	5	0	0	14	29	6%	144%
Canada	56	36	34	34	44	43	26	5%	-9%
Germany	11	21	23	42	36	11	26	5%	23%
China	0	0	0	4	11	9	15	3%	N/A
Colombia	5	10	30	37	29	2	14	3%	30%
Brazil	9	17	27	25	37	12	13	3%	7%
Subtotal	311	307	500	536	535	440	487	96%	9%
All Others	52	30	28	23	75	61	18	4%	-11%
Total	**363**	**337**	**528**	**559**	**610**	**501**	**505**	**100%**	**7%**

Source: USITC Interactive Tariff and Trade DataWeb, http://dataweb.usitc.gov/scripts/user_set.asp, accessed June 5, 2012.

APPENDIX E. LARGE POWER TRANSFORMERS MANUFACTURING FACILITIES IN NORTH AMERICA

Firm	Plant Location	Produced LPTs in 2011?	Types of Transformers Produced at Location	Notes
ABB	South Boston, VA St. Louis, MO	Y	Small to large size (up to 400 MVA and 345 kV) and midsize	
Delta Star	Lynchburg, VA San Carlos, CA	Y	Small to medium size of 5-230 kV and 5-180 MVA	Expansion plan status unknown as of Oct. 2011
EFACEC	South Rincon, GA	Y	Both core- and shell-type transformers of up to 1,500 MVA and 525 kV	New entrant to the U.S. market as of April 2010
PTTI	Canonsburg, PA	Y	From 60 MVA up to 500 MVA	
SPX (Waukesha)	Goldsboro, NC Waukesha, WI	Y	Mid to large size power transformers of up to 1000 MVA, 500 kV Had limited capacity to produce EHV prior to 2012 expansion	Expansion completed in April 2012
VTC	Roanoke, VA Pocatello, ID	Y	Up to 300 MVA /230 kV	
HHI	Montgomery, AL	N	Up to 500 kV (200 units/year once fully operational)	Inaugurated November 2011
Mitsubishi	Memphis, TN	N	N/A	Completion expected in 2013
ABB	Varnnes, Quebec	Y	Up to 1,200 MVA/800 kV	Outside the U.S.
Crompton Greaves	Winnipeg, Manitoba	Y	Up to 700 MVA/525 kV	Outside the U.S.
Industrias IEM	Mexico City, Mexico	Y	Up to 650 MVA/525 kV	Outside the U.S.
Prolec GE	Monterrey, Mexico	Y	Up to 1,000 MVA/550 kV	Outside the U.S.
WEG	Huehuetoca, Mexico	Y	Up to 350 MVA/550 kV	Outside the U.S.

Source: Open source research.

APPENDIX F. SELECTED GLOBAL POWER TRANSFORMER MANUFACTURERS

Company Name	Number & Location of Plants	Annual Production Capacity (MVA)*	LPT Production	Presence & Primary Markets Served	Notes
ABB	20 worldwide (Brazil, Canada, China, Germany, India, Poland, Spain, Sweden, Thailand, Turkey, USA)	200,000 MVA (50,000 MVA in Chongqing, China; 15,500 MVA in Quebec, Canada)	Full range LPTs up to 800kV/1200 MVA	Worldwide	Remains the largest transformer manufacturer and the global leader in transformer technology
Alstom (AREVA)	13 worldwide	130,000 MVA	Full range LPTs up to 1200 kV	Worldwide	Primary markets are Asia/Pacific, Americas, and Europe/Africa
Bharat Heavy Electricals	India	45,000 MVA		Asia, Middle East, Africa, Europe	
Crompton Greaves Ltd.	(Belgium, Canada, Hungary, India, Indonesia, Ireland, France, UK, USA)	70,000 MVA	100 MVA–1100 MVA		Acquired Belgium-based Pauwels Group and gained facilities in 5 countries: Belgium, Ireland, Canada, USA, and Indonesia
HHI	3 (South Korea, Bulgaria, USA)	120,000 MVA (Excluding a new U.S. plant)	Full range LPTs up to 800 kV/1500 MVA	Worldwide Market presence in 2009: North America (46%) Middle East (28%)	Construction of a new U.S. plant completed in Nov. 2011
HICO	4 (South Korea, China)	75,000 MVA	765 kV/2200 MVA	Korea; North America	
Mitsubishi	Japan	N/A	1050 kV/3000 MVA	Worldwide	USA plant to open in 2013
Prolec GE	Mexico	100,000 MVA	Full range LPTs up to 550kV/1000MVA	Americas, Africa, the Middle East	
Siemens (VA Tech)	21 worldwide (China, India, Austria, Brazil)	Total production capacity unavailable. 70,000 MVA in China	Full range LPTs up to 800kV/1000 MVA	Worldwide	Primary markets are Europe, China, and North America
Smit Transformers	Netherlands, Germany, Malaysia	N/A	800 kV/1200 MVA	Germany, Netherlands, USA, Malaysia	Exports to the USA
SPX	USA	N/A	500 kV/1200 MVA	North America	Expansion completed in April 2012 in Waukesha, Wisconsin

*Note: The term Annual Production Capacity (MVA) represents a combined capability of each manufacturer to produce a range of transformers (from small to large) from all of its facilities in an annual basis.

APPENDIX G. POWER TRANSFORMER INDUSTRY IN CHINA

China is the largest rising market for power transformers in both manufacturing capacity and demand, and whose market conditions undoubtedly affect those of the world and the United States. The vast majority of China's power transmission system is run by the State Grid Corporation of China (SGCC), a state-owned enterprise that constructs, owns, and operates the transmission and distribution systems in China's 26 provinces.[106] Established in 2002, SGCC implemented a centralized bidding system for the procurement of transmission and distribution equipment.

China's transformer market is dominated by 220 kV transformers and below, despite the strengthening of super-high and ultra-high voltage power grid construction in recent years. In 2011, approximately 81 percent of the SGCC's bidding capacity was for 220 kV and below, while power transformers of 500 kV and above occupied less than 17 percent.[107] In 2010, the total bidding capacity for power transformers of 220 kV and above was 150,337 MVA, after a 25 percent decline from the prior year.[108] At present, China's transformer market shows signs of oversupply, boasting approximately 30 manufacturers of transformers of 220 kV and above and more than 1,000 manufacturers of power transformers of 110 kV and below.[109]

In addition to local companies, large multinational firms—Siemens and ABB in particular—also play main roles in the manufacturing of 220 kV and above transformers in China. With manufacturing facilities in the mainland, they share 20 to 30 percent of China's transformer market and continue to expand their footprint by leveraging advanced technology.[110] As of December 2011, Siemens had three transformer manufacturing plants in China, boasting a total annual production capacity of over 70,000 MVA.[111] ABB had five transformer manufacturing facilities in China, and its largest facility in Chongqing had an annual production capacity of 50,000 MVA.

Table G1 provides the top eight Chinese transformer manufacturers in terms of sales value in 2009. As of 2011, the primary market for these Chinese manufacturers was inland; however, some of the firms have begun extending their footprints overseas. With what appears to be large excess capacity, some Chinese manufacturers already export transformers abroad. Some of them have established sales offices in the United States, including TBEA, TWBB, and JiangSu HuaPeng Co., Ltd.

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[106] Corporate Profile, State Grid of Corporation of China, http://www.sgcc.com.cn/ywlm/aboutus/profile.shtml (accessed January 5, 2012). Another state-owned enterprise, China Southern Power Grid manages the power transmission and distribution systems in the remaining five provinces in the mainland.
[107] "Research and Markets: China's Power Transformer Industry Report, 2010–2011," Reuters, September 18, 2011, http://www.reuters.com/article/2011/09/19/idUS19990+19-Sep-2011+BW20110919 (accessed December 14, 2011).
[108] Ibid.
[109] "Research and Markets: China's Power Transformer Industry Report, 2010–2011," Reuters, September 18, 2011.
[110] "Frbiz Analyzes China's Power Transformer Market," PR News, July 26, 2011, http://www.prnewswire.com/news-releases/frbiz-analyzes-chinas-power-transformer-market-99231019.html (accessed December 14, 2011).
[111] "Siemens Transformers China," 2010,http://www.energy.siemens.com.cn/CN/powerTransmission/Transformers/Documents/TR%20China%20catalog_EN_2010.pdf (accessed December 21, 2011).

Table G1. Top Chinese Power Transformers Manufacturers

Company Name	Annual Production Capacity*	Notes	Contact in the United States	Web site
Tebian Electric Apparatus Stock Co., Ltd (TBEA)	100,000 MVA (Two plants combined)	China's largest transformer manufacturer produces transformers up to 1,000 kV, with technical advantage on transformers 220 kV and above.	3452 E. Foothill Blvd., Ste. 1020 Pasadena, CA Phone: 001–626–7921037 Fax: 001–626–6283459 Email: shilin@tbea-usa.com	http://www.tbea-usa.com/ http://en.tbea.com.cn/
JiangSu HuaPeng Transformer Co., Ltd. (JSHP Transformer)	100,000 MVA	In 2008, JSHP delivered 832 transformer units with a capacity of 110kV–345kV, or a total of 59,253 MVA.	4030 MoorparkAve.,Ste. 222 San Jose, CA 95117 Phone: +1–408–850–1416 Fax: +1–408–519–7091 Email: sales@jshp.com	http://www.jshp.com/
Xi'an XD Transformer Co., Ltd (XD Transformer)	50,000 MVA	Produces a wide range of transformers (10kV–1000 kV) and has technical advantage with transformers 110 kV and above.	N/A	http://www.xdxb.com.cn/English/index.asp
Baoding Tianwei Baobian Electric Co., Ltd. (TWBB)	125,000 MVA (Three plants combined)	Exports 230kV/400MVA transformers to over 30 countries, including the U.S.	Rotterdam, New York 12303 Phone: 518–357–9290 Cell: 518–421–4081 Email:wpesales@worldpowerequipment.com	http://www.twbb.com/web/einfo.asp?bid=8
Shandong DaChi Electric	N/A	Main products include 550 kV/400 MVA power transformers, 35kV/200 MVA, and distribution transformers.	N/A	http://www.chinadachi.com/index.asp
Sunten Areva Electric	N/A	Mainly produces 35 kV distribution transformers.	N/A	http://www.sunten.com.cn/ENGLISH_B/index.asp
Changzhou Xiandian Transformer	28,000 MVA	Produces transformers of capacity 500kV and below.	N/A	http://www.czxd.com.cn/en/about.asp
Hangzhou Qianjiang Electric Group	N/A	Produces transformers with capacity up to 400 kV and distributes transformers.	N/A	http://www.qre.com.cn/en/index.aspx

*Note: The term Annual Production Capacity (MVA) represents a combined capability of a manufacturer to produce a range of transformers (from small to large) from all of its facilities in an annual basis.

Source: "2009 - Top 10 China Transformer Manufacturers," China National Transformer Association, June 22, 2010, http://www.dsius.com/Top10_TR_inChina.pdf (accessed November 3, 2011).

APPENDIX H. POWER TRANSFORMER MANUFACTURERS WEB SITES

Company Name	URL
ABB China	http://www.abb.us/cawp/cnabb051/81b11d62d13b6c0548256f9c00090f88.aspx
ABB Transformers	http://www.abb.com/transformers
Alstom	http://www.alstom.com/grid/solutions/high-voltage-power-products/electrical-power-transformers/
Bharat Heavy Electricals	http://www.bhel.com/home.php
Crompton Greaves, Ltd.	http://www.cgglobal.com/index.aspx
Delta Star, Inc.	http://www.deltastar.com/default.aspx
EFACEC	http://www.efacec.pt/PresentationLayer/efacec_competencias_00.aspx?idioma=2&area=2&local=68
Fortune Electric	http://www.fortune.com.tw/2004/english/index.asp
Hitachi (JAEPS)	http://www.hitachipowersystems.us/products/power_transformers_breakers/index.html
Hyosung Power and Industrial Systems	http://www.hyosungpni.com/eng/main/main1.do
Hyundai Heavy Industry Electro Electric Systems	http://www.hyundai-elec.com/new/eng/product/product.jsp?p_code=A0100
Iljin Electric	http://www.iljinelectric.com/main.asp
Mitsubishi	http://www.mitsubishielectric.com/bu/powersystems/products/transmission/transformers/index.html
Mitsubishi Power	http://www.mpshq.com/
Pennsylvania Transformer Technology, Inc.	http://www.patransformer.com/
Prolec GE	http://www.prolecge.com/interneten/
Shihlin Electric & Engineering Corporation	http://www.seec.com.tw/en/public/public.asp?selno=363&no1=270&no2=356&no3=363
Siemens China	http://www.stcl.com.cn/stcl/en/aboutus.asp
Siemens Transformer	http://www.energy.siemens.com/hq/en/power-transmission/transformers/
Smit Transformers	http://www.powersystempartners.com/smit_power_transformers.html
SPX Transformer Solutions, Inc.	http://www.spxtransformersolutions.com/
Toshiba	http://www.toshiba.co.jp/sis/en/tands/trans/index.htm
Virginia Transformer Corp.	http://www.vatransformer.com/Default.aspx
WEG	http://www.weg.net/us/Products-Services/Generation-Transmission-and-Distribution-of-Energy/Transformers/Power-Transformers

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