Transformers: Industry Overview

Q1 2023

Glossary

	Term	Definition
	Transformer	▪ Transformers facilitate energy transfer over networks that operate at varying voltage levels and are designed and manufactured in a variety of shapes and voltages to serve a diverse set of customers across end markets.
Transformer Classifications – Voltages	**Voltage Rating**	▪ Although product classifications and power ratings vary across the industry, the figures used throughout this document will refer to the primary (incoming) voltage.
Transformer Classifications – Voltages	**Low-Voltage**	▪ Low-voltage electrical equipment is typically found in smaller end markets, such as residential and small-scale commercial and industrial (C&I) markets; typical voltage range is less than 600 volts (V).
Transformer Classifications – Voltages	**Medium-Voltage**	▪ Medium-voltage electrical equipment is common among C&I, renewables, data centers, and smaller utility markets; typical voltage range is 600V – 69kV.
Transformer Classifications – Voltages	**High-Voltage**	▪ High-voltage electrical equipment is most common among heavy utilities, manufacturing, and oil & gas markets; typical voltage range is 69kV – 765kV.
Transformer Classifications – Voltages	**Ultra-High Voltage**	▪ Ultra-high voltage electrical equipment is seen much less frequently, generally in very large facilities; typical voltage range is greater than 765kV.
Transformer Classifications	**Dry-Type**	▪ Dry-type transformers do not use any insulating liquid; rather, the windings and core are enclosed in sheet-metal housing; common applications include distribution and substation transformers.
Transformer Classifications – Dry-Type	**Cast Coil**	▪ Cast coil transformers contain windings that have been solidly cast in epoxy resin under a vacuum in a mold.
Transformer Classifications – Dry-Type	**Vacuum Pressure**	▪ These transformers are vacuum-pressure impregnated in a polyester resin varnish, which enhances durability and makes these units virtually impermeable to moisture, debris, and other industrial contaminants.
Transformer Classifications	**Liquid-Immersed**	▪ Liquid-immersed transformers use a variety of cooling fluids, including oil that is typically mineral-based to act as an insulator and cooling agent; large, high-voltage transformers are most typically liquid-immersed.
Transformer Classifications – Liquid-Immersed	**Polemount**	▪ Polemount transformers are found on overhead transmission and distribution poles and are used to step down voltages prior to consumption.
Transformer Classifications – Liquid-Immersed	**Padmount**	▪ Padmount transformers are often tamperproof and are essential for stepping down primary voltage from transmission lines to secondary voltages for end customers and are typically installed on a concrete “pad” in open, outdoor areas
Transformer Classifications – Liquid-Immersed	**Power**	▪ Power transformers are available in medium- and high-voltage configurations and are critical to electrical substations, where they are used to regulate voltage levels between generation and distribution.

Glossary (Cont'd)

Industry Acronyms

Term	Definition
CHIPS Act	▪ Creating Helpful Incentives to Produce Semiconductors Act of 2022 authorizes semiconductor and domestic manufacturing spending
DOE	▪ U.S. Department of Energy
EPCA	▪ U.S. Energy Policy and Conservation Act of 1975
IEC	▪ International Electrotechnical Commission sets standards for electrical equipment and is the leading organization in the European market
IEEE	▪ Institute of Electrical and Electronics Engineers is a professional association for electronic and electrical engineering and has ownership of the public U.S. transformer standards
IIJA	▪ Infrastructure Investment and Jobs Act of 2021 allocates significant spending to critical infrastructure and electric grid modernization
IRA	▪ Inflation Reduction Act, passed in 2022, provides landmark legislation into domestic and clean energy production
kVA	▪ Kilo-volt-ampere is 1K volt-amperes, a common measurement of transformer power ratings
MVA	▪ Mega-volt-ampere is 1M volt-amperes, a common power measurement of large power transformers
NAHB	▪ National Association of Homebuilders
NEMA	▪ National Electrical Manufacturers Association is the largest trade association of electrical equipment manufacturers in the U.S.
NEVI	▪ National Electric Vehicle Infrastructure Program provides federal funding to deploy a nationwide EV charging network
UL	▪ Underwriters Laboratories is a third-party certifications and standards organization

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Opportunities in the Transformer Industry

The Transformer Market Opportunity

- The North American transformer market is poised for significant growth, particularly as federal investments in the development and implementation of renewable sources of energy increase, underpinning the ongoing support to create better and more efficient electricity infrastructure.
- Several key market trends are expected to continue driving growth, including aging electrical infrastructure, grid hardening and modernization initiatives, expanding renewable distributed energy, and increasing demand from high-growth sectors, among many others.

Key Industry Themes

Transformers are a fundamental part of the grid, guaranteeing the safe and efficient transmission of electricity from generators to end users, and will remain a critical link within the electrical power system to ensure continuous operation of the electrical power grid; as a result, the market remains highly stable.

Market forces accelerated by the energy transition are fundamentally altering the electrical equipment industry, creating secular trends that are driving significant demand growth.

Demand and supply imbalances have emerged and will intensify as energy-intensive sectors, such as data centers, electric vehicles, and renewable energy, place further demand on increased infrastructure capability and resilience driving heightened demand for distribution transformers.

New clean energy policies set at both the federal and state level require new investments in infrastructure to accommodate the shift in source mix, and ongoing political changes, including public and private sector reshoring initiatives, are expected to continue driving regulatory and investment support for electrical grid development.

The outlook for current market participants remains highly favorable and offers attractive growth opportunities, which is further supported by growing investor interest.

Transmission & Distribution Infrastructure

T&D Infrastructure and Electric Grid Overview

The North American electric infrastructure grid has an estimated asset value of over $1 trillion[1] and is widely thought to be one of the most advanced and increasingly clean systems in the world. The grid consists of millions of miles of transmission and distribution lines connected to a growing, interconnected network of power generation facilities and substations. It is also currently undergoing a material transformation as it evolves from fossil fuels to renewable and clean energy sources, a goal most aim to have complete by 2050. However, despite the sophistication of the U.S. grid, the progress made to date could be jeopardized without significant investment in grid infrastructure, which is aging and obsolete due to decades of underinvestment. Revitalization and modernization of critical grid infrastructure is needed in order to provide clean, efficient, and reliable energy for future generations.

The grid consists of a vast network of critical infrastructure supported by millions of transformers, which regulate voltage levels between each segment of transmission, from generation to consumption. Given the complexity of the grid, many different types of transformers are required for operability; however, for the purpose of this document, the focus will center around transmission and distribution transformers, the two main types, and exclude all other transformer types, including instrumentation units.

Electric Grid by the Numbers

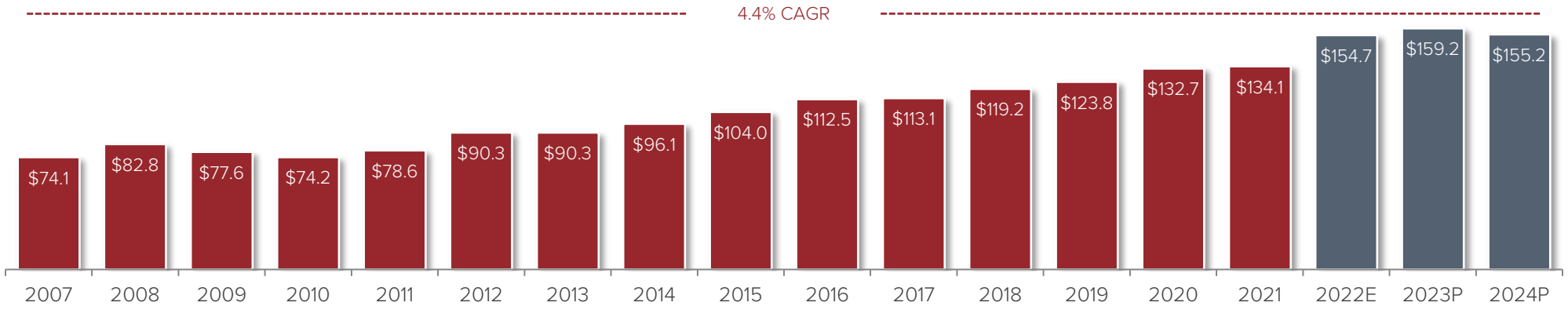
- **4.6B+** Total Kilowatt-Hours 2021 Energy Output[3]
- **70+ Thousand** Total Wind Turbines[6]
- **6.3M+** Miles of Distribution Lines[2]
- **50+ Thousand** EV Charging Stations[1]
- **642+ Thousand** Miles of High-Voltage Transmission Lines[4]
- **2+ Thousand** Photovoltaic Generating Facilities[5]
- **7+ Thousand** Total Power Plants[5]
- **1+ Thousand** Wind Power Projects[6]
- **~50M+** Distribution Transformers Currently in Use[7]

Transformers are critical infrastructure and connect every power source throughout the grid.

Continued Spend in the Sector Is Driving Growth

Total investment by IOUs at the parent or holding company level [8]
($ in billions)

Grid infrastructure spending has remained resilient through economic cycles.



1. U.S. Department of Energy; 2. Platts; 3. NERC; 4. U.S. Geological Survey; 5. U.S. Energy Information Administration; 6. U.S. Geological Survey; 7. GRID20/20; 8. Edison Electric Institute

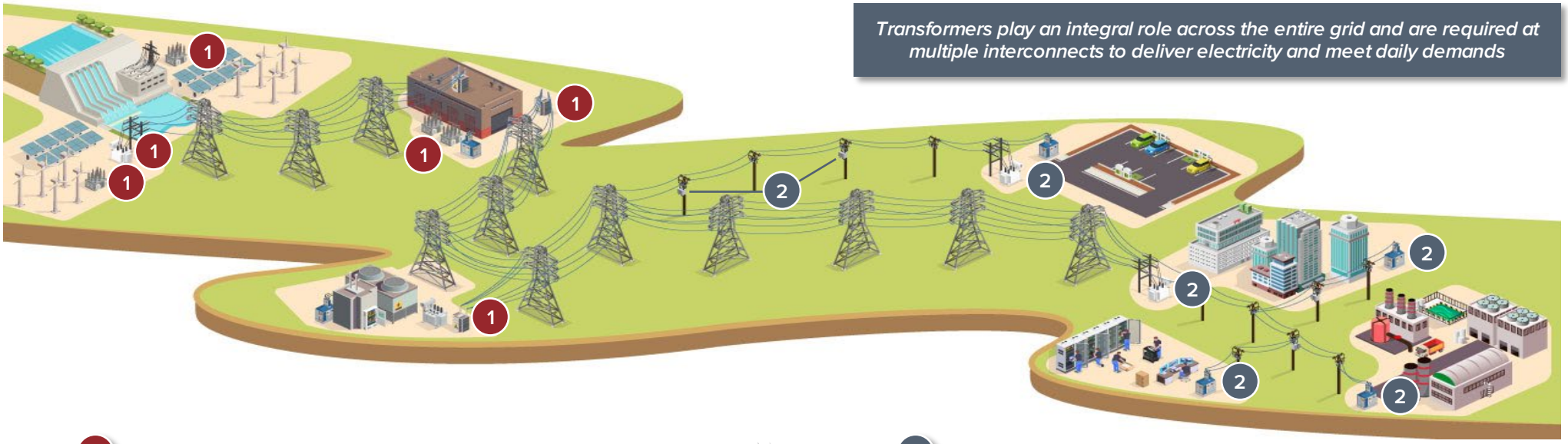
Transformers Serve as a Critical Link Across the Electric Grid

The Vital Role Transformers Play

- Transformers perform a critical role and are needed at every stage of the grid, from generation to delivery to the end user, including multiple phases in between.
  - Because power generation typically occurs at a distance from demand centers, transformers are necessary to transmit electricity over long distances while minimizing resistance and power loss.
  - Minimizing power loss requires transmitting electricity at as high a voltage as possible for long-distance transmission, creating a need for transformers at both ends of the transmission network (i.e., transformers to step up to high-voltage at the start of the network and transformers to step down to low-voltage at the end of the network).
- Many different transformer types exist to serve the specific power and environmental requirements of commercial, industrial, and residential users and are characterized by the voltage they help transmit throughout the grid.
- The transformer industry is a multibillion-dollar market and is expected to grow rapidly due to the transformation to sustainable energy, replacement of aging infrastructure, and strong demand for electricity.

Electrical Power Supply Overview[2]

Power Generation and Transmission | **Distribution**



Transformers play an integral role across the entire grid and are required at multiple interconnects to deliver electricity and meet daily demands

1 Power Generation and Transmission

Generation facilities produce hydroelectric, nuclear, thermal, solar, and wind power, while transmission delivers high-voltage electricity over long distances to the distribution grid.

2 Distribution

The distribution phase steps down voltage prior to electricity consumption to service commercial and residential power markets across a variety of end markets.

1. Refer to glossary for different types within these two main categories; 2. Note, throughout the document, power generation and transmission is used interchangeably with power transformers as well as high-voltage transformers; distribution is used interchangeably with low- and medium-voltage transformers

The Role of Transformers

Transformers Are Essential to the Grid

- Electrical transformers transfer electric power from one circuit to another through changing voltage levels with no change in frequency and serve to improve the safety and efficiency of power systems by raising and lowering voltage levels to facilitate the movement of electricity across the grid.

Electrical Power Supply Overview

1 Power Transformers

Overview: Power transformers are used to step up and step down power output from generation through transmission.

Voltage Range: ~69kV – 1,000kV

Primary Suppliers: Multinationals

Hitachi Energy, Hyundai Electric, Mitsubishi Electric (Changes for the Better), Prolec GE, Weg

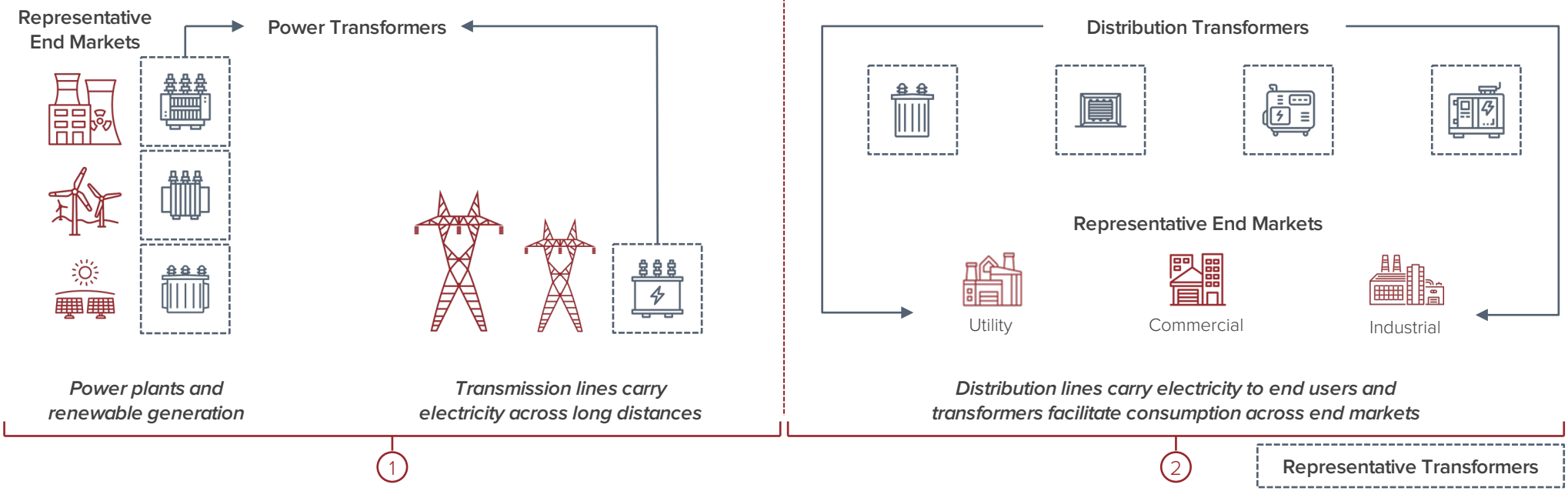
2 Distribution Transformers

Overview: Distribution consists of further stepping down power outputs to the final electrical power usage by customers across a variety of end markets.

Voltage Range: ~120V – ~69kV

Primary Suppliers: Domestic players

Eaton (Powering Business Worldwide), ERMCO Distribution Transformers, HPS Hammond Power Solutions, Howard Power Solutions, MGM Transformer Company, Square D



Power transformers continue to be dominated by multinationals, whereas distribution relies heavily on domestic providers.[2]

1. Refer to glossary for different types within these two main categories; 2. Refer to page 11 for additional detail related to competitive dynamics between power transformers and distribution transformers

Highly Engineered Products…

Transformer Overview

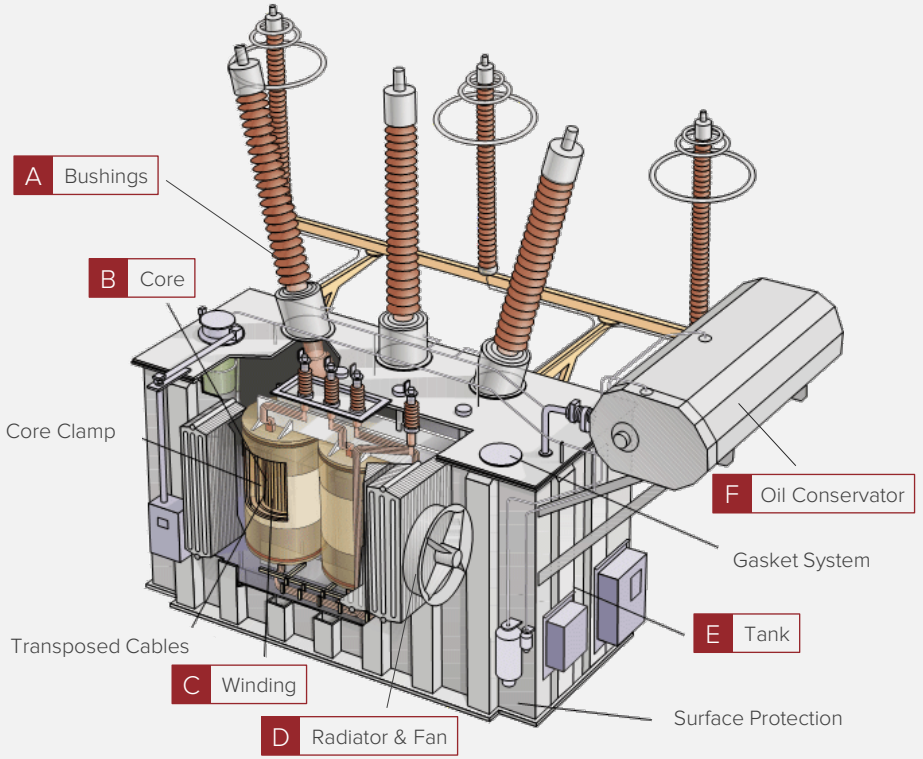
- Transformers are highly engineered products, requiring sophisticated technical and industry knowledge as well as tailored procurement, design, and testing capabilities.
- The main components of transformers include a laminated magnetic core, as well as primary and secondary windings.
  - The primary winding is connected to the power source and is where the magnetic flux (a magnetic field-inducing electrical current) is produced in the core by the current and the windings and is constant in all windings.
- If the number of secondary turns is greater than the number of primary turns, then the secondary voltage is greater than the primary voltage (step up).
- Conversely, if the number of secondary turns is less than the number of primary turns, then the secondary voltage is less than the primary voltage (step down).

Transformer Applications

- Transformers form the foundation of the electric grid and are critical components from power generation to distribution and end use.
- Primary uses of an electrical transformer include:
  - Raising or lowering the voltage level in the circuit of an alternating current (AC) system;
  - Preventing the passage of direct current (DC) from one circuit to another;
  - Isolating two electric circuits;
  - Stepping up the voltage level at power generation and stepping down the voltage level at the distribution phase; and
  - In rare instances, mainly for power factor correction, increasing or decreasing the value of an inductor or capacitor in an AC circuit.
- A range of specialty transformers serves unique end markets such as technology and data centers, electric vehicle charging, light rail networks, and solar and wind turbine generating facilities.

Key Components of Transformers[1]

*Denotes components that are not typically included in dry-type transformers



A Bushings serve as an insulation device and allow safe connection of transmission wires into the tank enclosure.

B The core houses the windings and provides the path for magnetic flux.

C Windings receive electricity from the AC source and deliver it to the load.

D The radiator and fan provide air flow and cooling to regulate internal equipment temperature levels.

E The tank protects internal components from dirt, moisture, and mechanical damage.

F The oil conservator provides storage for insulation liquids, which can increase in volume at high temperatures.

1. The transformer pictured is a large, liquid-immersed power transformer and does not represent every type of transformer

…Across a Variety of Categories

Multiple Categories of Transformers Serve a Range of Applications and End Markets

- Because transformers and related equipment facilitate energy transfer over networks that operate at varying power output levels, they are designed and manufactured in variety of shapes, sizes, and voltages and serve a diverse set of customers across a range of end markets.
- The diversity of transformers across the grid landscape ensures that electrical power is delivered safely, reliably, and in the most efficient manner possible.

Transformer Classifications

The various sizes of transformers are determined by the primary (input) voltage, the secondary (output) voltage, and the load capacity, measured by MVA or kVA, which quantifies the amount of power that can be transferred. These voltage and power ratings are used to distinguish different classes of transformers.

In addition to their voltage power ratings, transformers are further classified into dry-type and liquid-immersed categories. Dry-type transformers do not use insulating liquids; rather, the windings and core are cooled by air. Dry-type units are commonly used in the distribution phase. Liquid-immersed transformers use various fluids as an insulator and cooling agent. Large, high-voltage transformers are typically liquid-immersed and used in the transmission phase.

High-Voltage Transformers

High-voltage transformers provide the generation step up to enable bulk power to be transmitted over long distances and are used at power generation stations and in substations to facilitate power flow between systems of varying high-voltage levels.

10 – 100+MVA
Power Rating

Greater than 69kV
Voltage Range

Medium-Voltage Transformers

Medium-voltage transformers are utilized across a variety of applications and end markets and perform a critical function in electrical transmission by stepping down high-voltage transmission to levels used to distribute electricity to customers across a variety of end markets.

500kVA – 30MVA
Power Rating

600V –69kV
Voltage Range

Low-Voltage Transformers

Low-voltage transformers further step down electrical voltage for end-use consumption by customers. These transformers are available in many different types and are used to regulate electrical voltage for use in many common household and commercial applications.

10VA – 2.5MVA
Power Rating

Less than 600V
Voltage Range

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The Transformer Market Remains Highly Competitive

A Highly Competitive Market…

- The transformer market consists of large multinational electrical equipment manufacturers, small and medium suppliers specializing in custom units, and aftermarket providers focused on reconditioning and repair services.
- Although many multinational manufacturers experience fierce import competition leading to the outsourcing of manufacturing, most distribution transformers (i.e., low- and medium-voltage units) continue to be specifically designed and domestically manufactured for the North American market.
  - Distribution units will continue to be manufactured in local markets as a result of shipping costs (i.e., higher percentage of overall costs given total unit cost), lead times, and differing global standards (i.e., there has never been a world standard; the U.S. sets standards through IEEE).
- Over the last several years, manufacturers have been adversely impacted by supply chain disruptions, which have contributed to a lack of raw materials, rising input costs, and longer lead times for most products.
- A lack of skilled labor has also contributed to declining capacity: as a generation of highly skilled and experienced engineers retire, fewer skilled workers are available to train the workforce of the next generation.
- Although the industry has experienced secular challenges, a few domestic manufacturers have continued to gain market share from multinationals that have chosen to reduce their portfolio and focus on a limited product offering.

…Where Suppliers Are Heavily Influenced by Production & Import Dynamics

The Power Transformer Market Remains Highly Competitive Globally…

The U.S. is heavily reliant on overseas power transformer production, and the loss of this critical infrastructure could severely disrupt electricity services.[1]

Key reasons why multinationals are competitive:

- **High capital spend**: the significant size and complexity of power transformers requires significant capital expenditure and labor investment.
- **Commodity exposure**: rising material prices and fluctuating exchange rates significantly reduce the ability to pass through the high costs of manufacturing power transformers.
- **Specification risk**: differing input quality and testing expectations demand robust regulatory knowledge and a deep employee base to meet U.S. or other international market quality or specifications.

Long lead times in every phase of power transformer production, various specification standards, and scarce domestic production significantly increase import risk.

…Whereas the Distribution Market Is Reliant on Local, High-Quality Producers

Unlike power transformer manufacturers, low- and medium-voltage distribution transformer manufacturers are much better insulated from import competition.

Key reasons why domestic providers win in the U.S. market:

- **Shipping costs**: higher shipping costs as a percentage of sales for distribution transformers makes it difficult for multinational players to enter the distribution market.
- **Labor access**: access to both high-skilled and low-cost North American labor (i.e., U.S. and Mexico) allow domestic providers to differentiate on price.
- **Strict specifications**: the U.S. and European markets have significantly different transformer specifications, coupled with certification challenges from varying local building and electrical codes, has resulted in fewer overseas imports of distribution transformers.

The distribution market is well insulated from new market entrants and will continue to comprise players able to differentiate on product customization and delivery.

1. U.S. Office of Electricity

Sophisticated Manufacturing Process

Supply Chain Overview

- Certain raw materials, such as grain-oriented or amorphous steel, critical components in transformer cores, have a limited number of domestic suppliers, leaving U.S.-based manufacturers dependent on foreign imports.
  - Many of the countries producing these grades of electrical steel are currently in the process of large power grid buildouts, resulting in internal consumption and an increasingly limited supply of exports.
- Due to ongoing raw material shortages, transit times, and an intensive manufacturing process, power and distribution transformers have average lead times of 12 – 38 months, nearly double those since the onset of the pandemic.
- Historically strong demand, supply chain disruptions, and rising material costs have contributed to elevated manufacturing costs, and manufacturers have responded with significant price increases on most products.

Aftermarket Solutions Overview

- Units that reach the end of their useful life can be disposed of or reconditioned to extend the operating life of an asset by select aftermarket providers.
- Units acquired from utility and industrial customers are refurbished for resale by either:
  - Recondition & Repair: returns equipment to fit-for-service status by changing the fluids, regasketing the units, replacing any broken components, and performing electrical tests
  - Rewind: overhauling a unit by disassembling its components, designing and winding new coils, and performing reconditioning services

Transformer Manufacturing Overview

The typical manufacturing process for transformers consists of the following steps:

Engineering and Design
Complex transformer designs must balance cost and performance parameters

Core Building
High-skill process utilizing cold-rolled, grain-oriented electrical steel core components

Winding Production
Transformer winding is a very intensive and high-skill process; windings are assembled from copper and other specialty materials

Liquid-Immersed

Drying Stage
Moisture is removed from the core to protect the insulation

Tank Production
Tank completed prior to assembly to eliminate moisture

Dry-Type

Dip & Bake Stage
Conductor coils are dipped in varnish and baked (may include casting for cast-resin units)

Enclosure Production
Transformer enclosures are manufactured and assembled

Final Assembly
Transformers are assembled in a clean environment to ensure optimal performance and reliability

Product Testing
Testing is performed to ensure accuracy of voltage ratios, verify power ratings, and determine electrical impedances

Order Placement

Product Shipment

1. U.S. Department of Commerce; 2. U.S. Congressional Research Service

Key Barriers to Entry Prevents New Entrants

Key Barriers to Entry for New Market Entrants

 Capital Intensity	Entrants in the transformer market require a large initial capital investment to establish a manufacturing facility, specialty equipment, and the technology to design, manufacture, and test transformers.
 Labor Requirements	New entrants must also recruit, hire, and train a highly skilled and technical workforce capable of operating the latest technology while meeting demanding product specifications.
 Material Sourcing	Manufacturers must have the ability to develop and maintain a global supply chain to source copper, electrical steel, cooling fluids, and other specialty materials that are essential in transformer production.
 Sales Channels	Manufacturers need to develop and grow multiple sales channels, including direct sales and national distributor networks, as well as private label sales to other electrical manufacturers.
 Regulatory Environment	Manufacturers are required to comply with a variety of evolving federal, state, and environmental regulations and ensure their products complete a range of testing procedures and evolving energy efficiency standards.
 Product Suite	New entrants need to develop a product suite that meets the specific needs of a diverse customer base in order to win new business and drive long-term customer retention, areas where established market participants usually excel.
 Speed and Efficiency	Established manufacturers compete on transformer lead times, with specialized providers typically offering significantly shorter lead times than OEMs, making it very difficult for a new market entrant to compete.
 Reputation in Market	It is also important to build and maintain a reputation as an employer of choice with highly skilled technicians in order to deliver the highest quality and most reliable products to customers.

Evolving Regulatory Environment

Evolving DOE Efficiency Standards

- The Department of Energy (DOE) has regulated the energy efficiency characteristics of distribution transformers since 2007 (the DOE last increased these standards in 2016), and through the Energy Policy and Conservation Act (EPCA), the DOE is required to evaluate test procedures to determine a product's efficiency over its useful life.
  - The implementation of new standards requires the reengineering of transformers from the ground up, redrawing of supply chains to source new core and conductor materials, and upgrading of aging factories and processes.
- In December 2022, the DOE proposed new energy efficiency standards for distribution transformers sold in the U.S. The new standards aim to improve grid resiliency, lower energy costs for consumers, and reduce carbon-dioxide emissions.
  - Under the proposed rule change, which would go into effect in 2027 if adopted, nearly all new transformers would be required to be manufactured using new materials to make transformer cores more efficient than the grain-oriented electrical steel cores that are used in most distribution transformers today.
  - The evolving standards are unique to the U.S. transformer market and serve as an additional barrier to protect domestic manufacturers from import competition; however, the limited availability and higher cost of new materials along with reengineering of existing products will pose considerable challenges for most small manufacturers and will likely lead to higher prices for consumers.

IEEE — Institute of Electrical and Electronics Engineers

- IEEE is a global association of professionals that develop and maintain consensus standards for electrical and electronic equipment including transformers, Wi-Fi, Ethernet, and other products.
- The Transformers Committee is one of the largest and most active of the 17 technical committees within the IEEE Power and Energy Society (PES).
- The most significant IEEE standards include the C57.12.00 standard for liquid-immersed transformers and the C57.12.01 standard for dry-type transformers; additional IEEE standards govern transformer components and specialty uses such as power rectifier and solar transformers.

NEMA — National Electrical Manufacturers Association

- NEMA oversees a variety of responsibilities in the electrical manufacturing industry and is most closely associated with "NEMA ratings" and the type of enclosure and construction of electrical components.
- NEMA ratings are published every fifth year to rate enclosures and protect electrical equipment from damage due to liquids, dust, and corrosive chemicals.
- The ratings provide a range of standards that are useful in defining the types of environments in which an electrical component enclosure can be used.

UL — Underwriters Laboratories

- UL, a third-party certification company, sets industry-wide standards on new products; UL Certifications can be found on machinery, industrial equipment, and appliances.
- Testing and inspection procedures are routinely run on these products to ensure they meet industry standards and are constructed for utmost safety.
- UL Recognition focuses on component product parts; certifications ensure machine safety and efficiency, generating sustainable practices within companies and OEM preference for UL Recognized products.

Adapting to regulatory developments, maintaining industry ratings, conforming to standards, and holding certifications are all requirements for being "spec'd in" and achieving preferred status among manufacturers. These strict and costly requisites create high barriers to entry and provide a competitive edge relative to peers.

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Transformer Demand Drivers…

Transformer Demand Overview

- Clean energy and renewables have experienced rapid growth due to a surge in electric vehicles and sweeping initiatives to combat rising CO_2 levels and climate change.
- In order to facilitate the transformation to a clean energy economy, new grid infrastructure will be needed to transmit the growing and interconnected network of wind, solar, and distributed energy resources.
- The transition will require significant investment in transformers, T&D infrastructure, and storage solutions to transport renewable electric power, which is often generated in rural, sparsely populated areas, to distant population centers.

Drivers of Transformer Spending

1 Aging Infrastructure	Aging transformers and related transmission and distribution infrastructure are anticipated to receive meaningful equipment upgrades while undergoing significant revitalization and modernization to minimize outages and prevent high-cost grid failures.
2 Grid Resiliency	Extreme weather, natural disasters, and growing national security concerns after recent attacks on substation transformers have resulted in an increasing emphasis on grid resiliency and durability, all while customers express decreasing tolerance for outages.
3 Landmark Legislation	Increasing focus on the nation's aging infrastructure, grid resiliency, and climate impact have inspired sweeping legislation and significant investment that are expected to drive both near- and long-term spending.
4 Renewables Growth	Continued expansion and integration of renewable energy sources into the electric grid will require investment in new transformers with each project that is brought online; the IIJA and IRA have allocated billions in targeted spending to facilitate the Energy Transition.
5 High-Growth End Markets	Strong demand from high-growth end markets, such as technology and data centers, EV charging networks, and renewable energy will place additional stress on grid capacity and resiliency, and require new, modern transformers.
6 Reshoring Initiatives	Both the public and private sectors are focused on reshoring domestic manufacturing as a result of the pandemic, supply chain disruptions, and geopolitical tensions; the reshoring of manufacturing is expected to generate greater electricity demand and increase transformer spending.

…Are Testing Current Inventory Levels and Availability…

Industry Impacts

Supply Chains

Global supply chains have experienced significant disruptions in recent years driven by the compounding effects of increasing demand and decreasing materials supply, which was exacerbated following Russia's invasion of Ukraine.

Limited Inventories

Although electric utilities maintain reserve inventories of transformers to replace damaged or destroyed transformers following natural disasters, much of that supply has been drawn down without replenishment or any indication when replacement inventory will be available.

Labor Constraints

Labor and workforce availability are often cited as the most critical threat to transformer production capacity due to difficulty in attracting and retaining skilled labor, while highly trained and experienced engineers continue to age out of the workforce; manufacturers have also noted that high-skill requirements and low relative wages have created a labor shortage, along with high turnover, which is around 10% in many cases.[1]

Production Capacity

Despite increasingly limited supplies, the demand for distribution transformers continues to outpace current production capacity, which is extremely difficult to scale, prompting the DOE to contemplate a range of actions, including engagements with manufacturers, elevating best practices to address the underlying problems, and potentially using the Defense Production Act (DPA), pending congressional approval.

Government Action

Due to strong demand and persistent supply shortages across the electrical power market, the DOE is taking action to address the limited supply of critical grid components, including distribution transformers, which the department has described as the most urgent near-term supply issue.

1. DOE

…Resulting in an Emerging Transformer Shortage

Strong Demand Driving Shortages

- Many electric utilities have recently expressed concern over the growing shortage of electrical transformers, particularly distribution transformers.
- Due to the scarcity of these critical components, utilities and electrical equipment suppliers have begun sharing their already limited inventories while curbing the supply of transformers to the construction industry to ensure adequate inventories during the storm season.
- Public utility companies have also begun to reuse, repair, and delay the deployment of new transformers in response to growing shortages and increasing lead times, and several states have asked the Federal Emergency Management Agency for assistance in securing additional transformers.

Factors Contributing to Reduced Availability

Raw Materials

With only one domestic manufacturer, grain-oriented electrical steel has been cited as a critical barrier to increased transformer production capacity.

Electricity Demand

The electrification of new and rapidly expanding industries, such as electric vehicles and data centers, continues to generate strong demand for transformers.

Aging Infrastructure

Resilient demand due to the repair and replacement of aging infrastructure as well as modernization initiatives continue to consume available supplies.

Seasonal Demand

Seasonal storms result in damaged and impaired transformers that require replacement, while utilities increase inventories in advance of peak storm season.

Bringing National Attention to Transformer Shortages

429%

Lead Time Increase for Distribution Transformers From ’20 – ‘22[1]

1 of 5

Public Utility Projects Canceled or Deferred Due to Shortages[1]

- In November 2022, six construction and utility trade groups, including the National Association of Homebuilders (NAHB) and Edison Electric Institute, sent a joint letter to the House and Senate appropriations committees urging leaders in Congress to allocate $1B to address transformer supply chain challenges.
- Due to the unprecedented supply chain disruptions and declining inventories of critical transformers, the electrical, residential, and commercial construction industries have experienced significant challenges in procuring the necessary equipment to maintain the power grid and build new housing stock.
- Electric utilities have also experienced difficulties sourcing equipment, especially distribution transformers, which are required for grid maintenance and restoring power following storms, wildfires, and other natural disasters.
- Rising shortages prompted the Electricity Subsector Coordinating Council (ESCC) to further examine the causes through a specialized working group, which reported that current demand is far outpacing supply.
  - The ESSC team reported that average lead times for all classes of distribution transformers have risen from a few months to well over a year.
  - It also noted that construction and electrification projects are being delayed or canceled due to limited supplies of transformers.
  - The ESSC group recommended that the government utilize DPA authorities to address labor shortages and material availability, which it found to be the most immediate obstacles to increasing transformer production capacity.

1. American Public Power Association

1, 2 Aging Grid Infrastructure…

Grid Infrastructure Requires a Transformative Renovation

- The existing network of transformers is aging and obsolete due to decades of underinvestment, changing patterns in the use of electrical power, and a greater reliance on renewable energy sources.
- Aging infrastructure and severe weather pose risks to grid reliability, requiring T&D infrastructure investment to reduce the frequency and duration of outages and improve grid resiliency.
- The nation's power infrastructure system has become one of the greatest barriers to the Energy Transition and carbon-reduction goals.
- These challenges arise at a time of historic underinvestment in the nation's critical T&D infrastructure.
  - The average age of large power transformers, which handle 90% of U.S. electricity, is now more than 40 years.

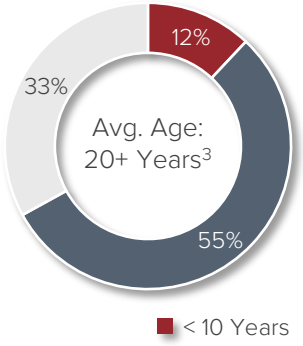
"To maintain the strongest economy in the world, we also need the best infrastructure in the world. We used to be #1 in the world in infrastructure, then we fell to #13th" – President Biden, State of the Union Address, February 2023.

Energy Infrastructure Report Card[1]

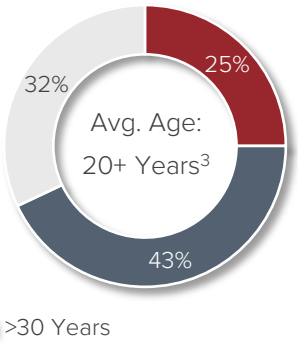
- In its most recent 2021 review, the ASCE (American Society of Civil Engineers), awarded the nation's energy infrastructure a C– rating.[1]
- The ASCE noted that although spending had accelerated for both transmission and distribution infrastructure, severe weather remains an increasing threat.
  - Distribution infrastructure, the "last mile" of the electric grid, struggles with reliability, with nearly 92% of all outages occurring along this segment.[2]
- The ASCE also reported that all electric grid components (generation, transmission, and distribution) have a significant investment gap, which is projected to grow to $197B by 2029.[1]
- Further, according to the DOE, power outages are now costing the U.S. economy $28B - $169B annually.[2]
- In the near term, supplementary T&D infrastructure, smart planning systems, and improved reliability are needed to enable the grid transformation, as distributed resources and renewable energy continue to grow.

Age of Existing Transformers

Industrial Transformer Equipment



Commercial Transformer Equipment



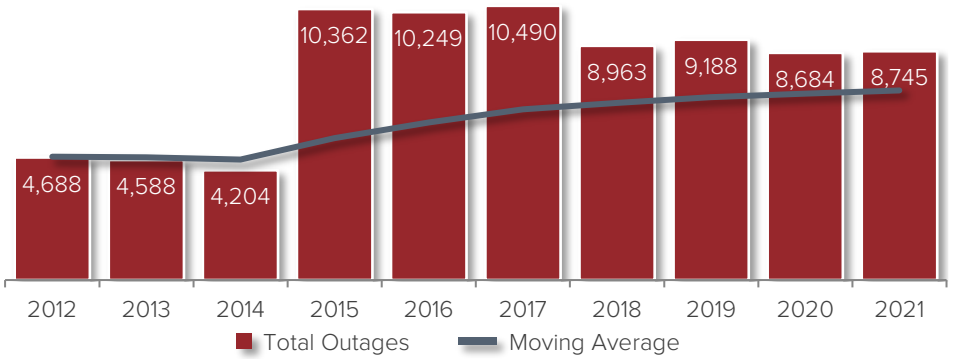
< 10 Years | 11-29 Years | >30 Years

Transformers, especially units used in data centers, are burdened with higher loads relative to their rating, resulting in a shorter useful life of ~10 years

U.S. Power Outages Are Becoming More Frequent

Temporary and Sustained Transmission Outages[4]

Increasing outages have prompted billions in federal spending to modernize the grid, leading to strong demand for transformers.



1. ASCE, 2021 Report Card; 2. U.S. DOE; 3. Independent Third-Party Market Study; 4. NERC

3 …Supported by Landmark Legislation…

Evolution of Legislation Supporting Energy Infrastructure and the Shift to Clean and Renewable Energy Sources

The transformer market is set to experience explosive growth driven by billions in federal spending targeting key initiatives in which transformers are critical components, including clean energy, EV charging, and grid resiliency; moreover, American transformer manufacturers are poised to benefit from expanded Buy America rules and material tax credits for domestic production.

IIJA

- The IIJA, passed in 2021, represents a historic investment in the nation's core infrastructure systems.
  - The IIJA authorizes $1.2T in spending with approximately $550B allocated to new programs and investments and $73B earmarked for Power and Grid spending, including the bipartisan Energy Infrastructure Act.
  - Power and Grid spending will be allocated to grid reliability and resiliency; critical minerals and supply chains for clean energy technology; critical energy technologies including carbon capture, direct air capture, hydrogen, and energy efficiency; and various energy projects from the bipartisan Energy Act of 2020.
  - The U.S. Department of Transportation's Federal Highway Administration (FHWA) announced it will release ~$60B to support critical infrastructure.

IRA

- The IRA, passed in 2022, was designed to serve as a major catalyst to the electrification of the U.S. economy while achieving meaningful carbon reductions; the IRA represents the largest investment to address climate change in U.S. history.
  - In total, the IRA will raise $738B, allocating roughly $391B in spending to address a variety of clean energy and climate change initiatives.
  - The IRA legislation targets renewable and clean energy sources – both existing and developing – and provides additional incentives for electric vehicles, as well as the electrification of heating and cooling systems.

CHIPS Act

- The CHIPS Act of 2022 was designed to boost U.S. competitiveness, innovation, and national security, and aims to catalyze investments in domestic semiconductor manufacturing capacity.
  - The CHIPS Act directs $280B in the next ten years to position supply chains and scientific progress in the U.S. more competitively.
  - The legislation aims to incentivize the production capacity of high-tech manufacturing companies, increase production capacity of US semiconductors, spark domestic R&D, create regional high-tech hubs, and develop a more robust STEM workforce.

NEVI Program

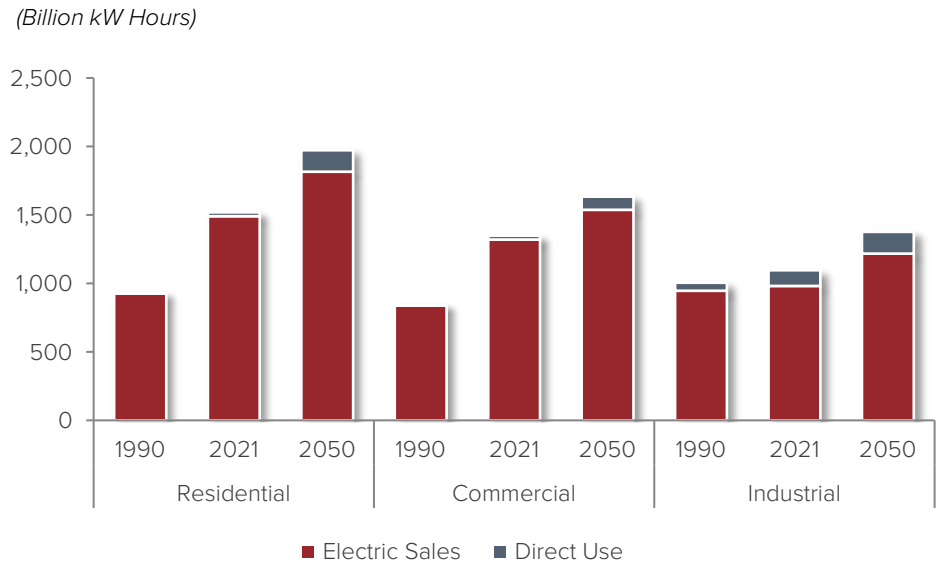
- The NEVI Formula Program, established as part of the IIJA, provides funding to states to strategically deploy electric vehicle charging infrastructure and to establish an interconnected network to facilitate data collection, access, and reliability, amounting to a down payment that is the largest-ever U.S. investment in EV charging.
  - Under the NEVI Formula Program, ~$5B will be made available to states over the next five years to build out a national EV charging network.
  - The law also provides $2.5 billion for communities and corridors through a competitive grant program that will support innovative approaches and ensure that charger deployment meets administration priorities such as supporting rural charging, improving local air quality, and increasing EV charging access in disadvantaged communities.
  - Altogether, the NEVI establishes the blueprint to construct an equitable network of 500,000 chargers covering 75,000 miles of highways by 2030.

4 ...Is Driving Electricity and Renewables Growth...

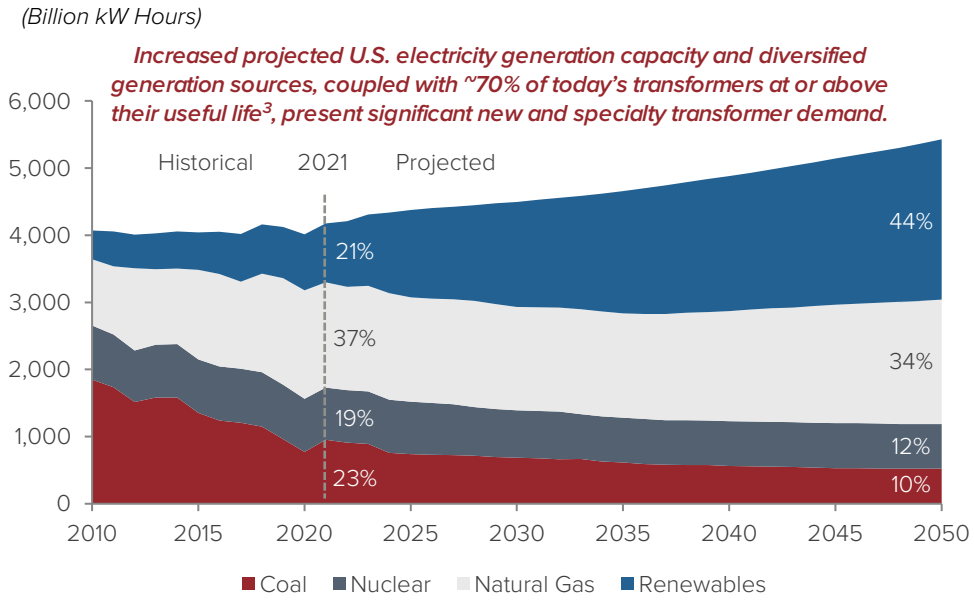
Existing T&D Infrastructure Requires Modernization

- The transition to clean and renewable energy is well underway but remains in the early innings of a decades-long transformation of the entire electric grid.
- Landmark legislation, including the IRA and IIJA, will serve as catalysts, bringing billions of dollars of investment to a range of renewable and clean energy projects.
- As a result of the ongoing grid transformation, the transformer market is poised for significant growth, driven by increasing demand for electricity and the growing contribution of electrical power derived from renewable sources.
  - Further, the existing transmission and distribution infrastructure is aging and requires replacement of older transformer units to ensure the grid remains reliable and efficient.
- The transition to a clean energy economy is accelerating, requiring new, high-efficiency transformers and modernized grid infrastructure to deliver electricity throughout a more regionally focused grid powered by intermittent and variable energy sources, such as wind and sunlight.

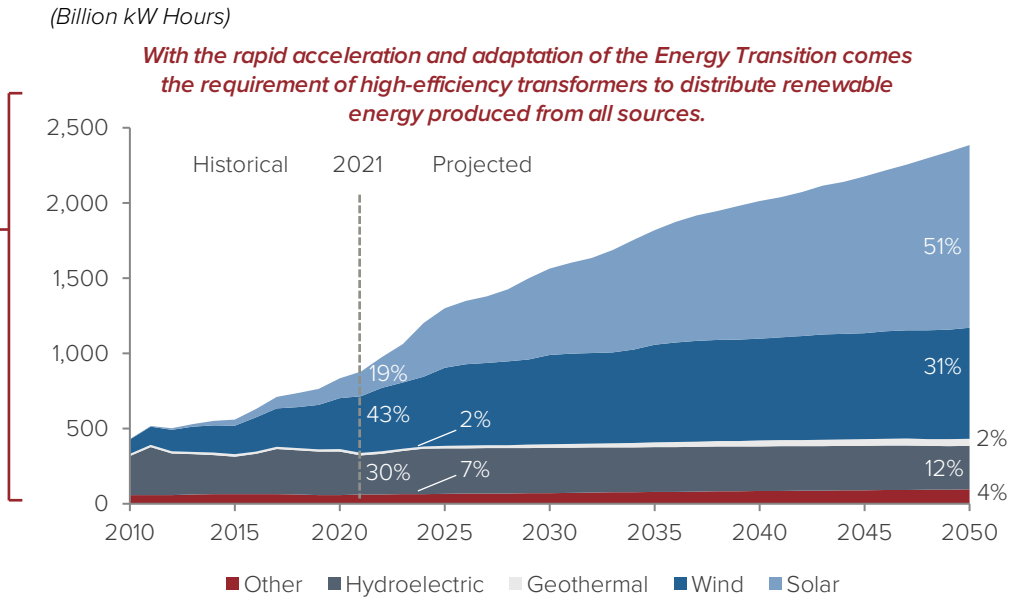
U.S. Electricity Use by End-Use Sector[1,2]



U.S. Electricity Generation by Source[1]



U.S. Renewable Electricity Generation by Source[1]



1. U.S. EIA; 2. In the transportation sector, electric sales in 1990, 2021, and 2050 were and are projected to be 4.8, 12.9, and 145.7 billion kW Hours, respectively, with direct use being 0 kW Hours in each period
3. T&D World

5 …Along With High Growth Across a Variety of End Markets

Several High-Growth End Markets Will Accelerate Transformer Demand

Data Center

- Explosive demand for data and streaming content is driving an expansion of data centers worldwide.
- Several new technologies, including 5G connectivity, autonomous driving, and a range of IoT edge devices, such as smart home, security, and access control systems will generate even greater demand for data.
- As demand for data continues to grow, the demand for data centers will increase, along with the industry's enormous levels of energy consumption.
- Transformers are critical to the data center industry, particularly as it transitions to small edge data centers located closer to end users and connected devices.

Data center transformers operate in demanding environments with a high density of electronic equipment and must be engineered to avoid overheating and costly outages.

Key Recent and Ongoing Data Center Investments

aws	$35B investment in data centers in Virginia from 2023-2040
Google	$9B investment in data centers across the U.S. in 2022
Microsoft	Billions in spending and plans to build 50 to 100 data centers annually for the foreseeable future

EV Charging

- Under the NEVI Program, nearly $7.5B has been allocated to states over the next five years to build out a national electric vehicle charging network under the Bipartisan Infrastructure Law.
- NEVI will support efforts to target a 50% EV share of new vehicle sales and build a network of 500k EV chargers covering approximately 75k miles of highway across the country.[1]
- "Buy America" initiatives give preference to domestic manufacturers of EV charging stations and will generate significant demand for new transformers, which distribute power to EV charging networks.
- U.S. EV growth requires a $28B cumulative investment in charging infrastructure over 2021 to 2030.[2]

"As EVs proliferate, charging infrastructure must follow – if not lead" … EV charging transformers support multiple charging configurations for small and rapid charge commercial systems.

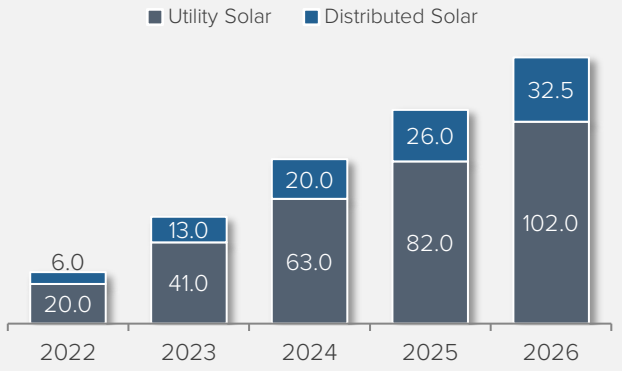
Link: Harris Williams EV Charging and Fueling Infrastructure Report

Solar Power

- The U.S. currently operates more than 2,500 utility-scale solar generating facilities and contains thousands of major commercial solar projects that are active or under development.[3]
- In August 2022, the IRA was enacted, significantly increasing the amount of federal incentives and lengthening the duration of tax credits to manufacture and deploy domestic solar equipment.
- Solar power is now the fastest-growing energy source, and massive growth in solar transformers will be required to support the expansion of both commercial and industrial generation facilities as the grid transitions to a greater contribution of solar energy.

Solar and wind power systems require voltage adjustments between the system, end user, and utility provider, requiring specialized bidirectional transformers.

(U.S. cumulative solar additions in gigawatts) [4]



Growth in specialty transformers will be critical to several rapidly expanding end markets, including data centers, EV charging networks, and solar and wind power projects, and transformers serving these markets possess unique characteristics and often require highly engineered, customized solutions to meet end-market and project specifications.

1. U.S. Department of Transportation; 2. International Council on Clean Transportation; 3. Solar Energy Industries Association; 4. International Energy Agency

6 Reshoring Initiatives

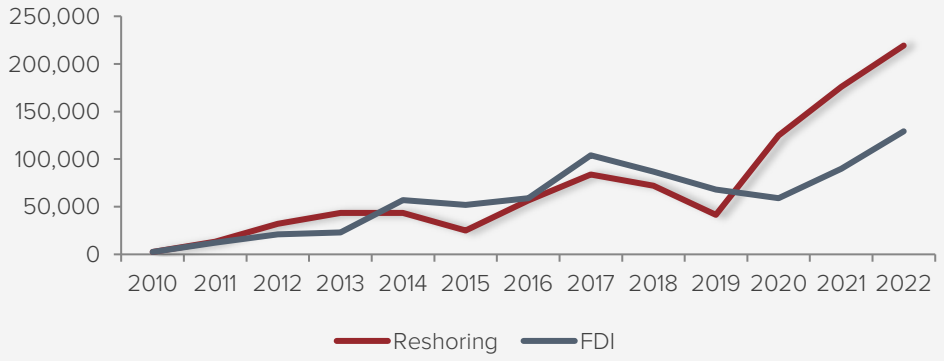
Significant Reshoring Tailwinds…

- Global catalysts, including climate forces and geopolitical destabilization, have highlighted U.S. supply chain vulnerabilities and an overreliance on international manufacturing.
- Private and public sectors are highly focused on creating greater self-sufficiency as declining levels of emergency electrical equipment reserves, domestic manufacturing capacity, and availability of critical raw materials drive continued manufacturing reshoring.
  - The Facilitating the Reshoring of Energy Grid Component Manufacturing Act was recently introduced and aims to establish an electric grid product loan program within the Department of Energy.
- Reshoring momentum is expected to continue following ~350,000 jobs returning to the U.S. in 2022, driving continued U.S. manufacturing and jobs growth, as well as deficit reduction.
  - These initiatives, coupled with the fact that no new entrants have entered the U.S. market in years, will create sustained growth for established domestic manufacturers, helping make the U.S. more self-reliant and resilient.

…Validate Continued Reshoring Momentum[1]

(Job Announcements per Year, Reshoring)

~350,000 jobs returned to the U.S. in 2022, with ~220,000 from reshoring and ~130,000 from foreign direct investment



Strong Reshoring Support from American Executives[2]

Positive Sentiment
92% of executives expressed positive sentiments towards reshoring in Kearney's Operations and Performance research report.

Operation Relocation
79% of executives with manufacturing operations in China have moved part of their operations to the U.S. or plan to so in the next three years.

Declining Imports
China's share of U.S. manufacturing imports decreased from 66% to 55% in 2021 based on Kearney's China Diversification index, which tracks shifting U.S. imports.

Self-Reliance
American companies began to diversify away from China before COVID-19 and continued this trend even as other low-cost Asian countries started to recover from the pandemic.

Reshoring Initiatives in the News

'The Reshoring Craze Is Real' – These Companies Should Benefit, Experts Say

CNBC

"The reshoring craze is real, especially as you continue to hear more and more about this general theme of deglobalization. It is a trend that is going to accelerate, especially in the first part of the year. The U.S. has learned its lesson during COVID and the lockdown and supply chains breaking. Companies will continue to focus on improving operating efficiencies, reducing costs, preserving cash, and sustaining earnings growth – and North America will provide a safe haven. Supply chains will not only move closer to home but evolve, as there is no longer a 'one size fits all' solution in the face of sever disruptions, but rather, a 'best way forward' as opposed to the accustomed 'cheapest way forward'."

- December 2022

1. Reshoring Initiative IH 2022 Data Report; 2. Kearney's Reshoring Index

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Transformer Landscape Today

Actionable Targets

Manufacturer	HQ	Ownership	Primary Product Offering	Business Description
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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For the full market taxonomy, please reach out to EPIInsights@harriswilliams.com

Transformer Landscape Today (Cont'd)

	Manufacturer	HQ	Ownership	Primary Product Offering	Business Description
Multinationals	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Other	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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For the full market taxonomy, please reach out to EPIInsights@harriswilliams.com

Transformer Landscape Today

Aftermarket

Manufacturer	HQ	Ownership	Primary Product Offering	Business Description
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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For the full market taxonomy, please reach out to EPIInsights@harriswilliams.com

Key Macro Considerations for Investors

Investment Considerations	Key Characteristics
Resilient Demand	▪ Transformer demand is expected to remain strong, driven by increasing demand for electricity, grid durability and resiliency initiatives, and the need for secure, reliable electrical power.
Energy Transition	▪ The Energy Transition is well underway, requiring a substantial shift to clean and renewable energy sources and heightened electric vehicle charging demand to meet ambitious climate and decarbonization goals. ▪ A transformer is required with every new connection to the grid and at every new EV charging station, increasing grid complexity and driving long-term demand for transformer solutions.
Regulatory	▪ Recent legislation, such as the IIJA and IRA, is driving massive investment into transformers and the T&D landscape, supported by tax credit program expansions and extensions and the buildout of nationwide EV charging infrastructure through the NEVI Formula Program. ▪ Evolving DOE standards scrutinize transformer inputs to ensure maximum energy efficiency and environmental responsibility, benefiting scaled providers with established supplier relationships and vertically integrated platforms.
Limited Platforms of Scale	▪ Limited access to materials, personnel, and key relationships for distribution transformer manufacturers has resulted in a limited number of domestic transformer manufacturers of scale. ▪ Given the limited number of transformer manufacturers, continued consolidation, and significant capital requirements, only a limited number of both power transformer and distribution transformer manufacturers have emerged.
High Barriers to Entry	▪ Manufacturers are required to comply with numerous state and federal regulations, rigorous testing and inspection standards, and a variety of environmental regulations. ▪ Greenfield operations in transformer manufacturing are especially challenging due to high capital requirements, material sourcing, and engineering expertise.
High Capital Intensity for New Entrants	▪ High initial capital investment is required to open a manufacturing facility, acquire the necessary equipment, access the latest design and engineering technology, and recruit a highly skilled and technical workforce. ▪ As manufacturers of scale, companies must also have the necessary capital to establish and grow their distribution networks and material sourcing capabilities in order to remain competitive with other manufacturers and larger multinationals.
Commodity Exposure	▪ Approximately 75% of the cost to manufacture a transformer is directly tied to commodities, which are subject to constraints and significant cost fluctuations.[1] ▪ Steel, copper, and oil are all assets that regularly experience price fluctuations, and each have experienced an increase in price, though have recently begun to normalize; products with longer lead times and producers with higher levels of inventory have increased exposure.

1. T&D World

Key Business Considerations for Investors

Investment Considerations	Key Characteristics
Highly Skilled and Technical Workforce	▪ Workforces in the increasingly technical T&D environment must be highly skilled, capable of utilizing the latest technology, and able to adapt to the rapidly evolving product and regulatory environment. ▪ There are a limited number of qualified transformer technicians; access to skilled labor, long and costly training programs, and high employee turnover have all contributed to an industry-wide labor shortage.
Lead Times	▪ Supply chain dynamics, delivery coordination, material scarcity, tariffs, and transit costs are all key aspects factoring into each transformer manufacturer's lead times. ▪ Shorter lead times is a crucial consideration in maintaining a competitive advantage relative to market peers, especially given the non-discretionary nature of transformers.
Established Sales Channels	▪ Transformer sales have multiple potential routes to market, including sales to electrical equipment conglomerates and their respective business units, direct sales to companies across a wide range of end markets, sales to distributors, and sales to the public sector. ▪ Market leaders operate across multiple sales channels with distinct strategies and fortified partnerships for each route to market.
Access to Raw Materials	▪ Transformer manufacturers are highly reliant on metals, including electrical steel, copper, aluminum, and standard steel. ▪ Grain-oriented electrical steel and non-oriented electrical steel, inputs that provide the most economically and energy-efficient transformers through reducing core loss and boosting permeability, are essential yet scarce, providing an advantage to those with supplier relationships.
Standard vs. Customized Product Mix	▪ Transformers can either be produced in standardized categories, or they can be highly customized to fit specific requests of the customer. ▪ While custom transformer offerings can boost margins, these products increase lead times for those that are not vertically integrated and require a highly specialized engineering team to deliver upon all customer specifications while conforming to industry regulations.
Ability to Scale	▪ To effectively scale their operations, transformer manufacturers must develop strong vendor and customer relationships in order to deliver products across geographies and through various sales channels. ▪ Key aspects factoring into scalability include the establishment of operational best practices and manufacturing capacity, which requires adequate facility space, specialized equipment, and a highly trained workforce.
Ratings, Standards, & Specification Compliance	▪ Although not legally enforced, several standards and certification organizations, including NEMA, IEEE, and UL, have a strong influence on the success of transformer providers. ▪ While costly and time-consuming, maintaining industry ratings, conforming with standards, and holding certifications are all requirements for achieving a preferred status among manufacturers.

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Luke Semple
Managing Director
lsemple@harriswilliams.com
(804) 915-0158

Drew Spitzer
Managing Director
aspitzer@harriswilliams.com
(804) 915-0174

Matt White
Managing Director
mwhite@harriswilliams.com
(804) 915-0131

Thomas Saunders
Director
tsaunders@harriswilliams.com
(804) 915-0143

Neha Shah
Director
nshah@harriswilliams.com
(804) 887-6036

Greg Waller
Director
gwaller@harriswilliams.com
(804) 887-6138

ENERCON — a portfolio company of ae Industrial Partners — has been acquired by OAKTREE

TURNSPIRE CAPITAL PARTNERS — has acquired USG Water Solutions — a division of VEOLIA

LITTLEJOHN & CO. — has acquired ARDURRA — a portfolio company of RTC PARTNERS

Morgan Stanley CAPITAL PARTNERS — has acquired APEX — a portfolio company of Sentinel CAPITAL PARTNERS

USIC US INFRASTRUCTURE COMPANY — a portfolio company of Partners Group — has received an investment from KOHLBERG & COMPANY / NEUBERGER BERMAN

United FUELING SOLUTIONS — a portfolio company of KLH CAPITAL — has been acquired by WIND POINT PARTNERS

TERRAMILLENNIUM CORPORATION — a portfolio company of COURT SQUARE — has been acquired by H.I.G. CAPITAL

TSS Technical Safety Services — a portfolio company of the edgewater funds / JZ PARTNERS — has been acquired by LEVINE LEICHTMAN CAPITAL PARTNERS

BHI energy — a portfolio company of ae Industrial Partners — has been acquired by Westinghouse — a portfolio company of Brookfield

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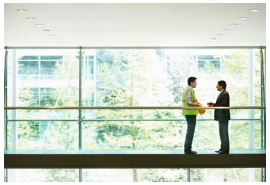

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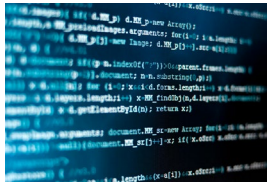
Consumer

Energy, Power & Infrastructure

Healthcare & Life Sciences

Industrials



Technology

Transportation & Logistics

70% Revenue from repeat clients

83% Managing directors promoted from within the firm

30+ Year history

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