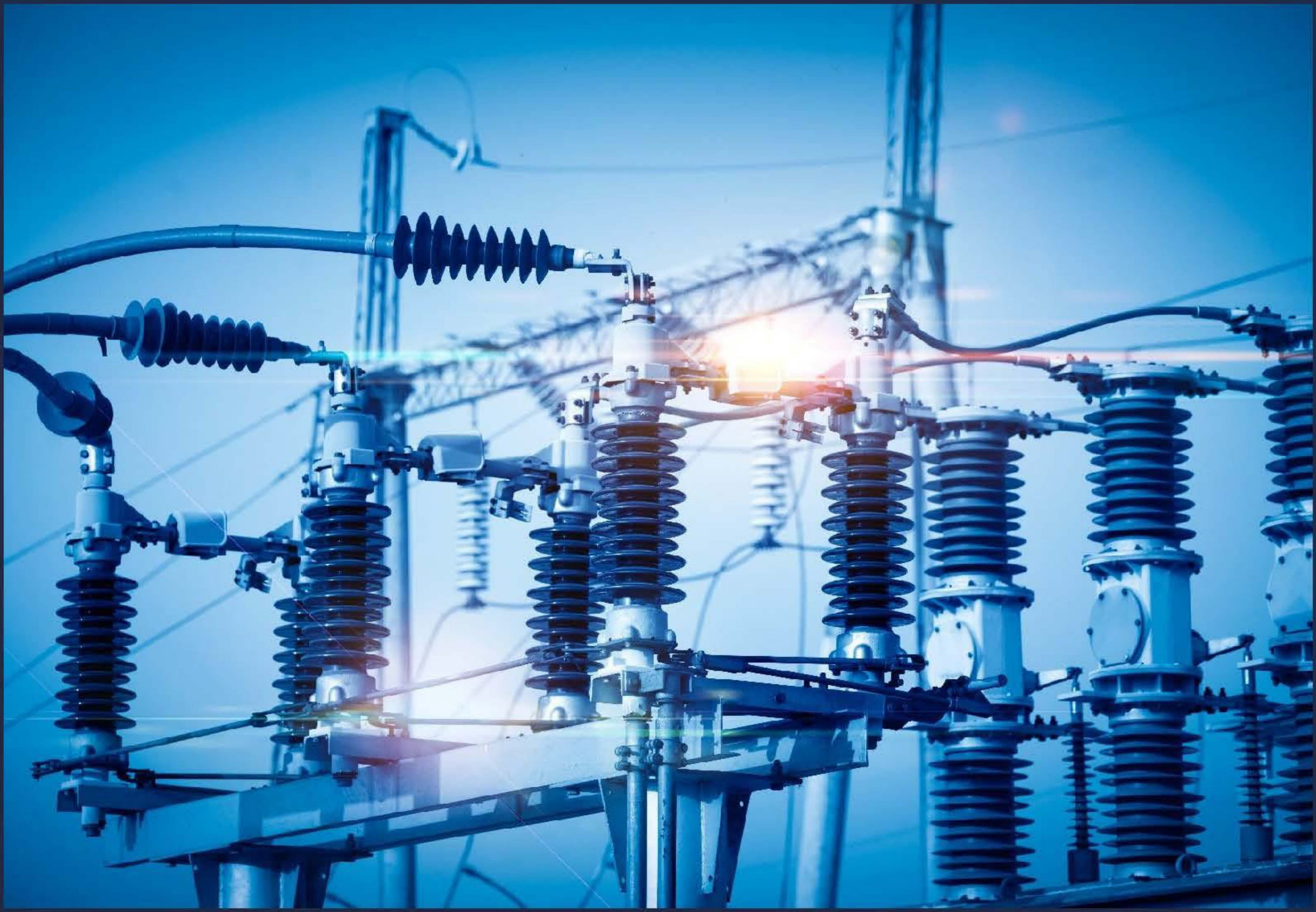
NIAC The National Infrastructure Advisory Council



Addressing the Critical Shortage of Power Transformers to Ensure Reliability of the U.S. Grid

JUNE 2024

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About the NIAC

The President's National Infrastructure Advisory Council (NIAC or the Council) is composed of senior executives from industry and state and local government who own and operate the critical infrastructure essential to modern life. The Council was established by executive order in October 2001 to advise the President on practical strategies for industry and government to reduce complex risks to the designated critical infrastructure sectors.

At the President's request, NIAC members conduct in-depth studies on physical and cyber risks to critical infrastructure and recommend solutions that reduce risks and improve security and resilience. Members draw upon their deep experience, engage national experts, and conduct extensive research to discern the key insights that lead to practical Federal solutions to complex problems.

For more information on the NIAC and its work, please visit: https://www.cisa.gov/niac.

1. Executive Summary

Electricity is vital to modern life, and transformers are critical components of a stable and resilient electric grid, which, in turn, is a linchpin of United States (U.S.) infrastructure and economic wellbeing. Transformers change the voltage of electricity to enable the efficient flow of power from the source of generation to the end user where the power is consumed. During the COVID-19 pandemic, the transformer manufacturing industry was among those that experienced severe supply chain disruptions – and the impact of those disruptions have only become more pronounced in subsequent years. Currently, an electric utility or generation developer that orders a transformer may have to wait 2 to 4[1] years for it to be delivered, compared to a wait of just months as recently as 2020.[2] One large power transformer manufacturing facility based in the U.S. disclosed a 5-year wait time for new transformer orders.

Wood Mackenzie, a consulting firm, recently reported[3] that "transformer lead times have been increasing for the last 2 years – from around 50 weeks in 2021, to 120 weeks on average in 2024. Large transformers, both substation power and generator step-up transformers, have lead times ranging from 80 to 210 weeks." This data is shown in **Figure 1**.

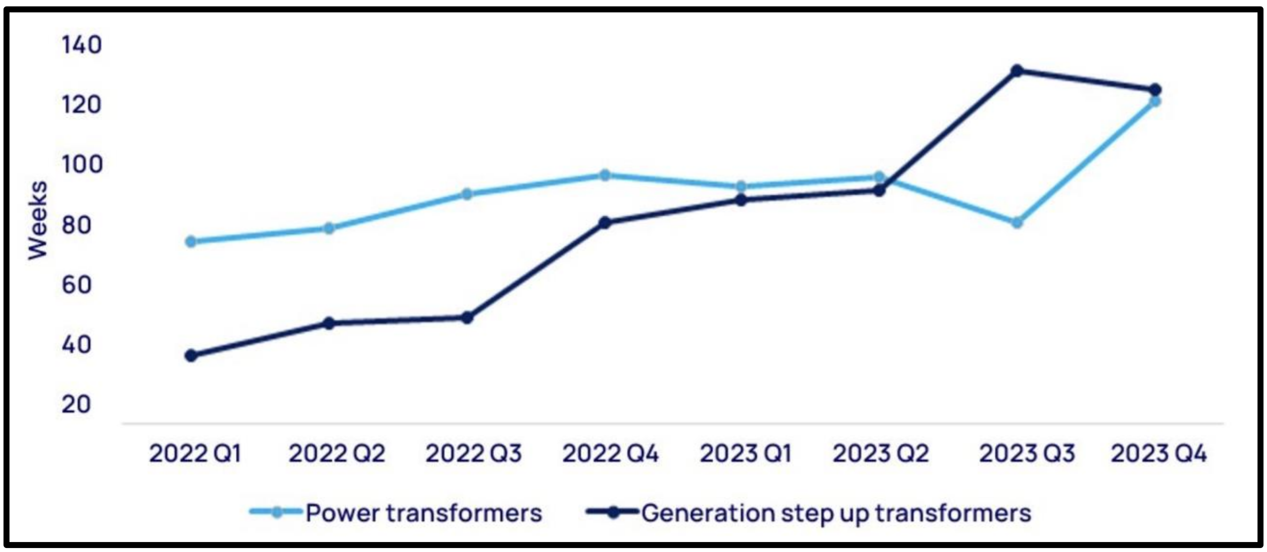

Figure 1: Growth in Large Power Transformer Lead Time

Rising demand for transformers has exacerbated supply chain challenges, driven by increasing electrification across the U.S. and global economies, the build-out of renewable electricity generation, and growth in large-load customers such as data centers. This has led to a sharp increase in prices that is likely to have a ripple effect on the costs of electricity for business and residential consumers.

Figure 2 shows the 10-year price history of large power and distribution transformers scaled to an index of 100 in February 2014. Transformer prices are 80 percent higher since the beginning of the pandemic.

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[1] Anthony Allard (Hitachi) and David Garza Herrera (Xignux), April 23, 2024, meeting.

[2] Kann, Shayle. 2024. "Understanding the Electric Transformer Shortage." Latitude Media.

[3] Wood Mackenzie. 2023. "Supply Shortages and an Inflexible Market Give Rise to High Power Transformer Lead Times." The discrepancy between the 210-week lead time cited in the article and the 120-week figure shown in the graph is presumed to be the outside extreme of the range of lead times.

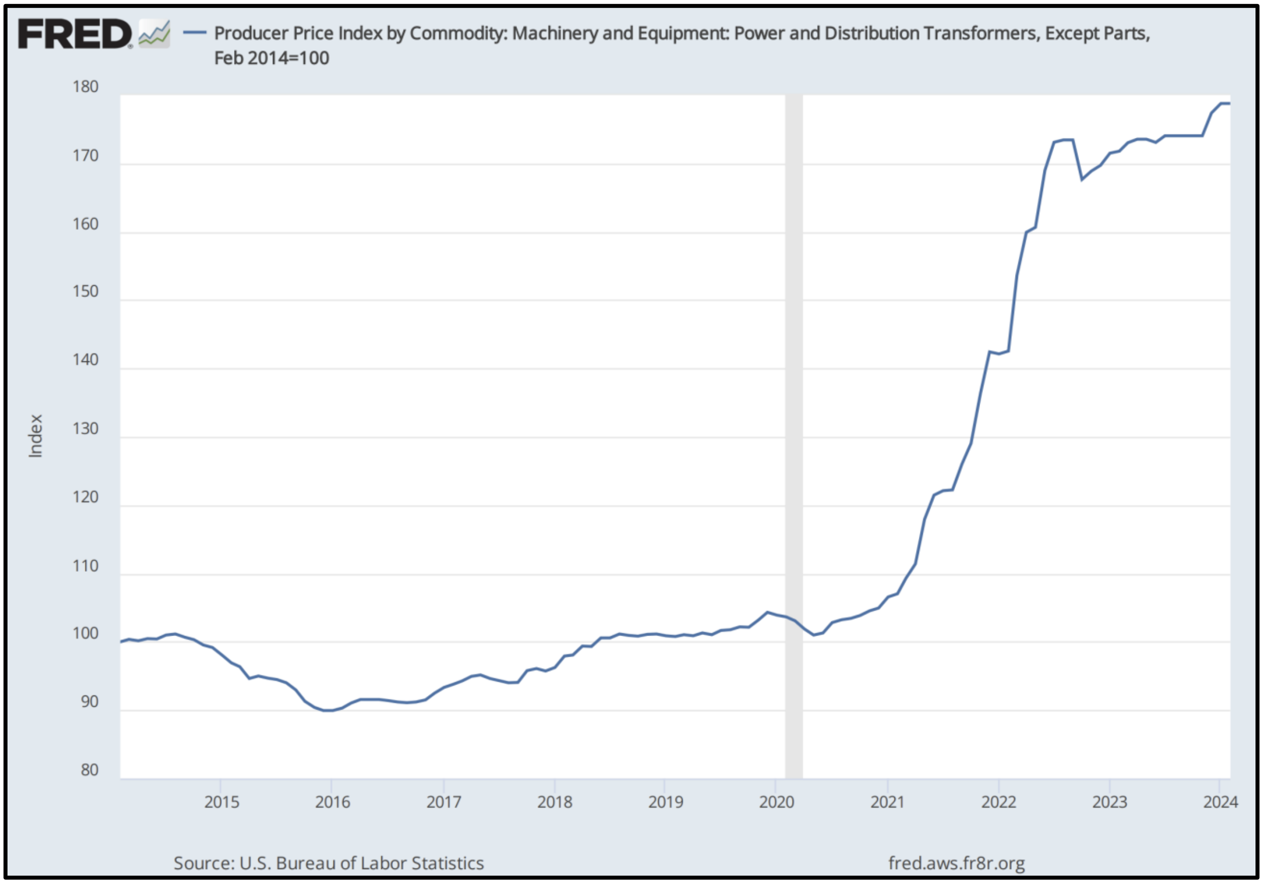

Figure 2: St. Louis Federal Reserve Bank Transformer Price Index

Electric transformers are critical to support grid transformation. Strong action is needed to increase the capacity of transformer production to ensure resiliency of national infrastructure, withstand storms, promote stability and growth of the U.S. electric grid, and to avoid the broad economic disruptions that would result from power outages and delays in connecting homes and businesses to the grid. In addition, transformers will be needed to meet state and national climate goals by successfully integrating clean energy on the grid, such as solar, wind, and battery energy storage system generation. Finally, the industry's current dependence on foreign-made large transformers and key transformer components, such as electrical steel, presents a significant national security risk that must be addressed.

From a national security perspective, increasing domestic production of transformers and critical components presents the best option, and this report reflects that as a top priority. Near-shoring certain production to Canada and Mexico is an option with slightly more risk, while friend-shoring production overseas, with transportation of transformers and components via merchant vessels, carries even more risk exposure, though measures could be taken to minimize it.

This report outlines the **causes** of supply chain-related delays in transformer production that have resulted in a transformer shortage and the steep increase in prices. It then offers **seven recommendations** to encourage more domestic production capacity.

Among other challenges, the domestic transformer manufacturing industry has had difficulties attracting and retaining qualified workers.[4] The previous cyclical nature of the industry has made manufacturers wary of increasing capacity despite rising demand, even as it became evident that the recent transformer shortage was not merely the product of a normal cycle.[5] The lack of standardization in transformer design has made automation, assembly optimization initiatives, and other technologies that aid efficient mass production more difficult. Finally, manufacturers have faced cost and regulatory uncertainty concerning electrical steel, which is used to make the core of the transformers and has a limited domestic supply.

These are significant challenges, but they are surmountable.

Based on the briefings and a review of reports pertaining to this issue, the NIAC makes the following recommendations:

1. Craft Federal policies and designate funding targeted at increasing domestic capacity, such as tax credits, grants, accelerated depreciation, funding for new apprentice or training programs, and other incentives, using the Crafting Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act as a model.
2. Achieve greater accuracy in transformer-demand forecasting that provides a more comprehensive outlook across the next 10 to 15 years by convening all parties who drive demand.
3. Encourage long-term contracts/customer commitments between transformer suppliers and the industry sectors driving demand and establish favorable regulatory frameworks to enable them.
4. Establish a strategic virtual reserve of transformers, with the U.S. government as the buyer of last resort.
5. Promote collaboration between design engineers from utilities, engineering firms, trade associations, and domestic and foreign manufacturers to standardize transformer design, reduce complexity associated with customization, and facilitate interoperability through standardized interfaces between transformers and other grid components.
6. Ensure a sufficient supply of electrical steel by coordinating incentives for new domestic supply, governmental efficiency standards, and trade policy.
7. Grow the pipeline of qualified workers by partnering with universities, community colleges, and trade schools on training programs, while working with Federal, state, and local governments to craft tax incentives for workers who enter the field.

While the emphasis of this report is on large power and distribution transformers, some of these seven recommendations also apply to other critical grid components such as conduit, smart meters, switchgear, and high voltage circuit breakers, among others. More domestic or diversified production of this equipment is also needed.

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[4] Anthony Allard (Hitachi) and David Garza Herrera (Xignux), April 23, 2024, meeting.
[5] Kann, Shayle. 2024. "Understanding the Electric Transformer Shortage." Latitude Media.

2. Introduction

2.1. The NIAC's Charge

On December 13, 2023, the NIAC's Electrification Subcommittee presented a report to President Joseph Biden on *Managing the Infrastructure Challenges of Increasing Electrification*, highlighting, among other infrastructure-related risks, the national shortage of transformers due to supply chain difficulties. At that time, President Biden asked the NIAC to research the transformer shortage and draft a report to provide recommendations that, if implemented, would increase capacity of domestic transformer production.

The Transformer Production Subcommittee was formed to answer the following questions:

- What steps must the government take to bring transformer manufacturing back to the U.S.?
- How can the private sector be more engaged as a partner to the government?[6]

2.2. Subcommittee Activities

The Subcommittee held meetings on the following dates:

April 3, 2024 – Virtual kickoff meeting.

April 10, 2024 – Subcommittee meeting featured Gene Rodrigues, Assistant Secretary of Energy, U.S. Department of Energy (DOE); and Tom Galloway, President and CEO, North American Transmission Forum.

April 23, 2024 – Subcommittee meeting featured David Garza Herrera, board member, Xignux[7]; and Anthony Allard, Executive Vice President, Head of North America, Hitachi Energy.

May 6, 2024 – Subcommittee meeting featured Tim Mills, CEO of ERMCO[8] and Richard Voorberg of Siemens Energy.

May 10, 2024 – Subcommittee meeting featured Dr. Monica Gorman, Deputy Assistant Secretary for Manufacturing, U.S. Department of Commerce.

May 17, 2024 – Subcommittee discussed comments and feedback from members on the initial draft of the report.

2.3. Organization of this Report

The remainder of this report is organized into the following sections:

Current Challenges Related to Transformer Availability: This section provides more detail on the current obstacles to an adequate supply of large power and distribution transformers.

[6] National Security Council Guidance to the NIAC, January 25, 2024.
[7] Xignux is the parent company of Prolec. Prolec manufactures and distributes a comprehensive range of transformers and other grid products under the Prolec, General Electric, Waukesha, and Celeco brands. It has manufacturing facilities in Louisiana, North Carolina, Texas, Wisconsin, Mexico, and Brazil.
[8] ERMCO is the largest manufacturer of distribution transformers in the U.S. It has manufacturing facilities in Tennessee, Georgia, North Carolina, Canada, and Mexico, among others.

Economic and Environmental Impact of Transformer Shortage: This section offers a perspective on the potential consequences of not encouraging greater domestic transformer manufacturing capacity.

Recommendations: This section presents more detail regarding the NIAC's recommendations.

Call to Action: Based on analysis of the challenges related to transformers, as well as the recommendations aimed at addressing those challenges, this section provides a suggestion of next steps for the Federal government to take.

3. Current Challenges Related to Transformer Availability

At present, there is an extremely tight market for large power and distribution transformers. The following sections discuss the major factors at the heart of these challenges.[9]

Figure 3: Large Power and Distribution Transformers[10]

3.1. Post-Pandemic Economic Growth

The COVID-19 pandemic disrupted supply chains throughout the world. The grid component sector, including transformers, was no exception as shortages of material, equipment, and labor created slowdowns in both manufacturing and construction. As pandemic restrictions were lifted, projects that had been delayed deliberately, or because of component unavailability, suddenly were resumed. This created supply chain ripple effects that are still subsiding. As measures across the globe were taken to stimulate economies, more disruptions and supply pressures ensued and are still plaguing various industries.

3.2. Grid Modernization

A significant driver of demand is the need to replace aging transformers with new ones. A 2020 study by the U.S. Department of Commerce[11] indicated that the average age of in-service large power transformers was 38 years, which is already near or even past design life. Since the stock of existing transformers in the U.S. has been estimated at over 60 million,[12] replacement alone is sufficient to support considerable annual demand.

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[9] Large power transformers operate at electric transmission voltages above 34.5 kilovolts (kV) whereas distribution transformers operate at 34.5 kV and below.

[10] The large power transformer photo on the left side was excerpted from a Siemens Energy power transformers brochure; the overhead distribution transformers photo on the right side was excerpted from a Duquesne Light Co. overhead line safety announcement.

[11] U.S. Department of Commerce Bureau of Industry and Security Office of Technology Evaluation. 2020. "The Effect of Imports of Transformers and Transformer Components on the National Security."

[12] DOE final distribution transformer rule adds two years for compliance, Utility Dive, April 4, 2024.

According to the Electric Power Research Institute (EPRI), changing duty cycles associated with grid transformation and renewable energy integration may reduce the lifespan of certain transformers or induce capacity deratings, placing further strain on available capacity.[13]

3.3. National Electrification Trend

The national trend toward greater electrification is a large driver of future transformer demand. As transportation, space and water heating, and other economic sectors switch gradually from fossil fuel to electricity, load growth has increased.

In addition, new loads like data centers, electric vehicle charging facilities, heat pumps, and forecasted hydrogen production facilities are all expected to boost U.S. electricity consumption. Rising electrification of homes will increase the load factor on transformers serving those homes. When these transformers are near capacity, they may need to be replaced with larger transformers, further driving demand in that market segment.

A prime example of increasing electrification is the rapid proliferation of large data centers. **Figure 4** shows McKinsey & Company's forecast of data center power consumption in gigawatts by 2030.[14]

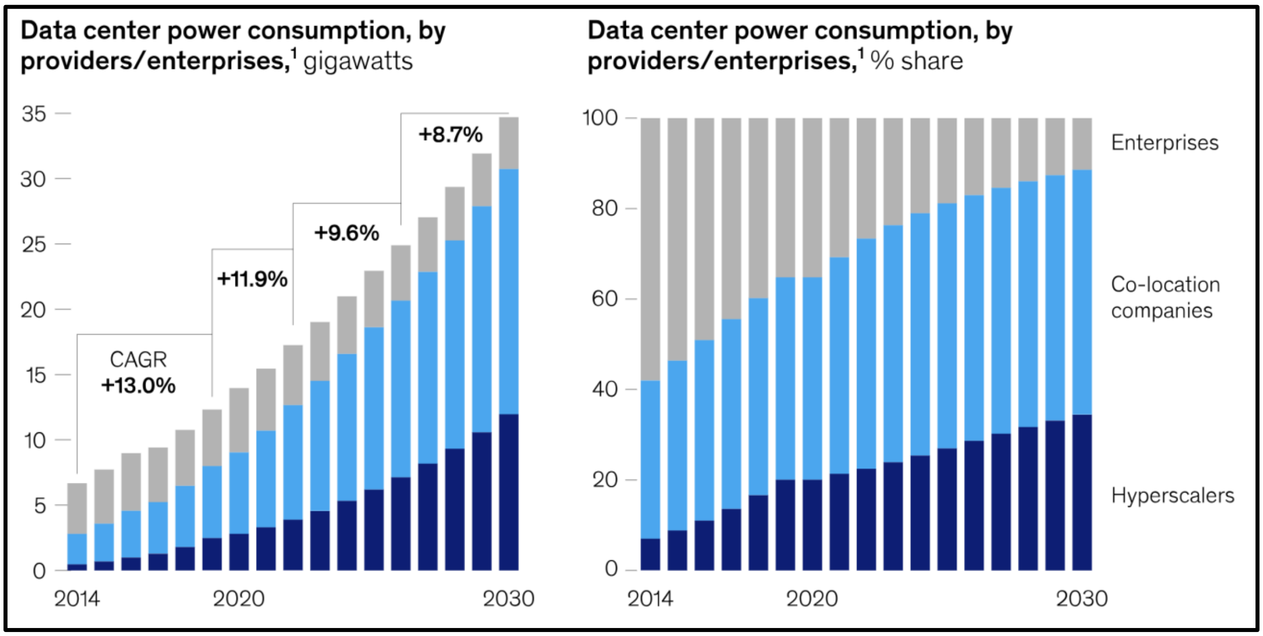

Figure 4: Historical and Forecast U.S. Data Center Power Consumption

The rise in electrification factoring into the growth in demand for transformers is distinct from past trends that have driven demand growth, such as the housing bubble of 2004 through 2007.[15] Rather, increasing electrification is driven both by policy and consumer behavior. There is a buildout of transmission infrastructure already underway that is effectively irreversible, and these actions are driven by the societal

[13] Arshad Mansoor, President of the Electric Power Research Institute.
[14] McKinsey & Company. 2023. "Investing in the Rising Data Center Economy." Hyperscalers are massive data centers for the use of a single owner.
[15] Baker, Dean. 2018. "The Housing Bubble and the Great Recession: Ten Years Later."

urgency of addressing climate change. As such, the demand growth is likely to continue, if not accelerate, making this period distinct from the boom-bust dynamics that the industry has experienced historically.

3.4. Renewable Generation and Transmission Build-Out

Another major driver of future transformer demand is that the annual capacity factors achieved by renewable- and storage-generating resources are much lower than those achieved by conventional thermal plants. Accordingly, the amount of installed transformer capacity required for the same amount of energy production is much higher. For example, a 1,000-megawatt conventional thermal generating plant, operating at 90-percent annual capacity factor, would produce about 7.9 million megawatt-hours annually. It would take 5,000 megawatts of solar photovoltaic capacity, operating at 18 percent annual capacity factor, to produce the same amount of annual energy.

A recent National Renewable Energy Laboratory (NREL) study[16] forecasts that the number of distribution transformers required in the U.S. by 2050 will be 160 to 280 percent higher than 2021 levels. This is a compound annual growth rate of installed transformer capacity from 3.7 to 5.3 percent. Many existing transformers will also have to be replaced over the same period, which contributes to the demand for new transformers being much higher than overall U.S. electricity consumption growth rates over the same period. In addition, recent market research suggests that the transformer market will grow at the rate of 5 to 7 percent annually in dollar terms over the next decade.[17]

Figure 5 is excerpted from the Energy Information Administration's (EIA) Annual Energy Outlook 2023. The EIA performs detailed modeling on the expected build-out of new electric generating capacity under various scenarios of economic growth, oil and natural gas supply, and low or high zero-carbon technology cost. Regardless of the economic, oil and gas production, and/or renewable technology scenario, the EIA forecasts that installed generating capacity in gigawatts will double 2022 levels. This means that large power and renewable step-up transformer demand will remain very robust.

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[16] McKenna, Killian. 2024. "Major Drivers of Long-Term Distribution Transformer Demand." NREL Grid Planning and Analysis Center.

[17] Market research firms sell discrete reports on certain markets or offer a periodic subscription service. However, many market research firms will disclose a few "headline" conclusions from these studies to help attract customers. In developing this report, firms like Grand View Research, Global Market Insights, Allied Market Research, and others estimated that the value of the U.S. transformer market would be growing 5 to 7 percent annually in dollar terms over the next decade.

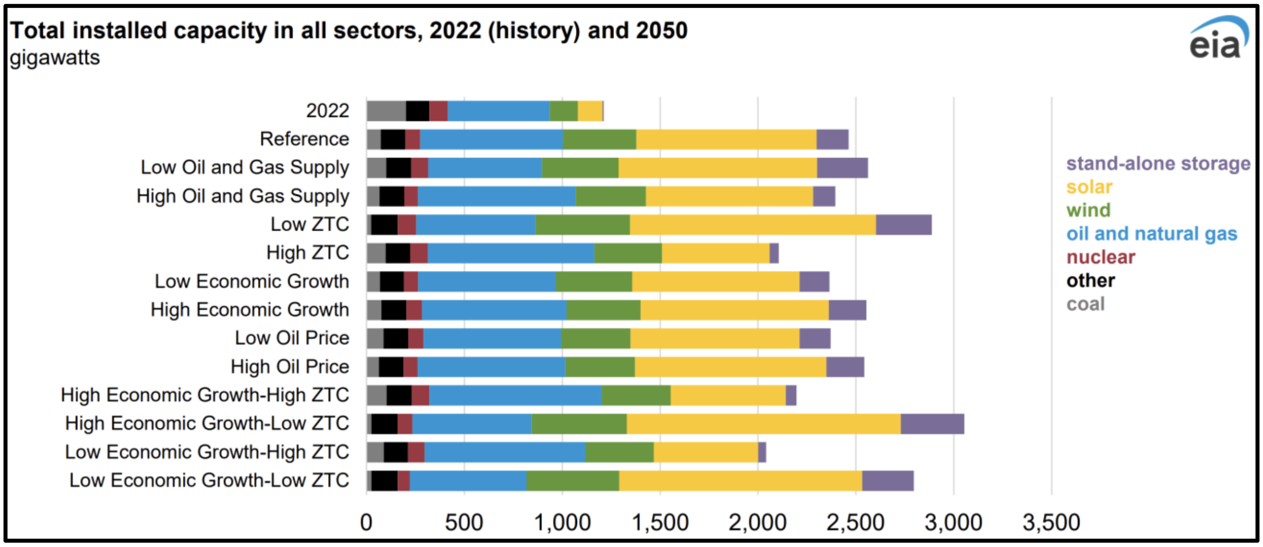

Figure 5: Forecast of Installed U.S. Generating Capacity in 2050

Figure 6 shows the DOE's forecast of expected bulk power transmission additions by 2035, according to different scenarios such as moderate load growth, high clean energy growth, and both high load and clean energy growth. Depending on the U.S. region, potential growth may be extraordinary. Most regions, excluding California, New York, and the Northwest U.S. under certain scenarios, indicate significant expansion is expected.[18]

[18] U.S. Department of Energy. 2023. "National Transmission Needs Study." Certain designated regions include only portions of states. For example, the Delta region includes the entire State of Louisiana, but only portions of Arkansas, Mississippi, and Texas. The DOE report provides a map indicating the footprint of the regions. Note that under certain scenarios, New York and the Northwest also forecast significant transmission expansion.

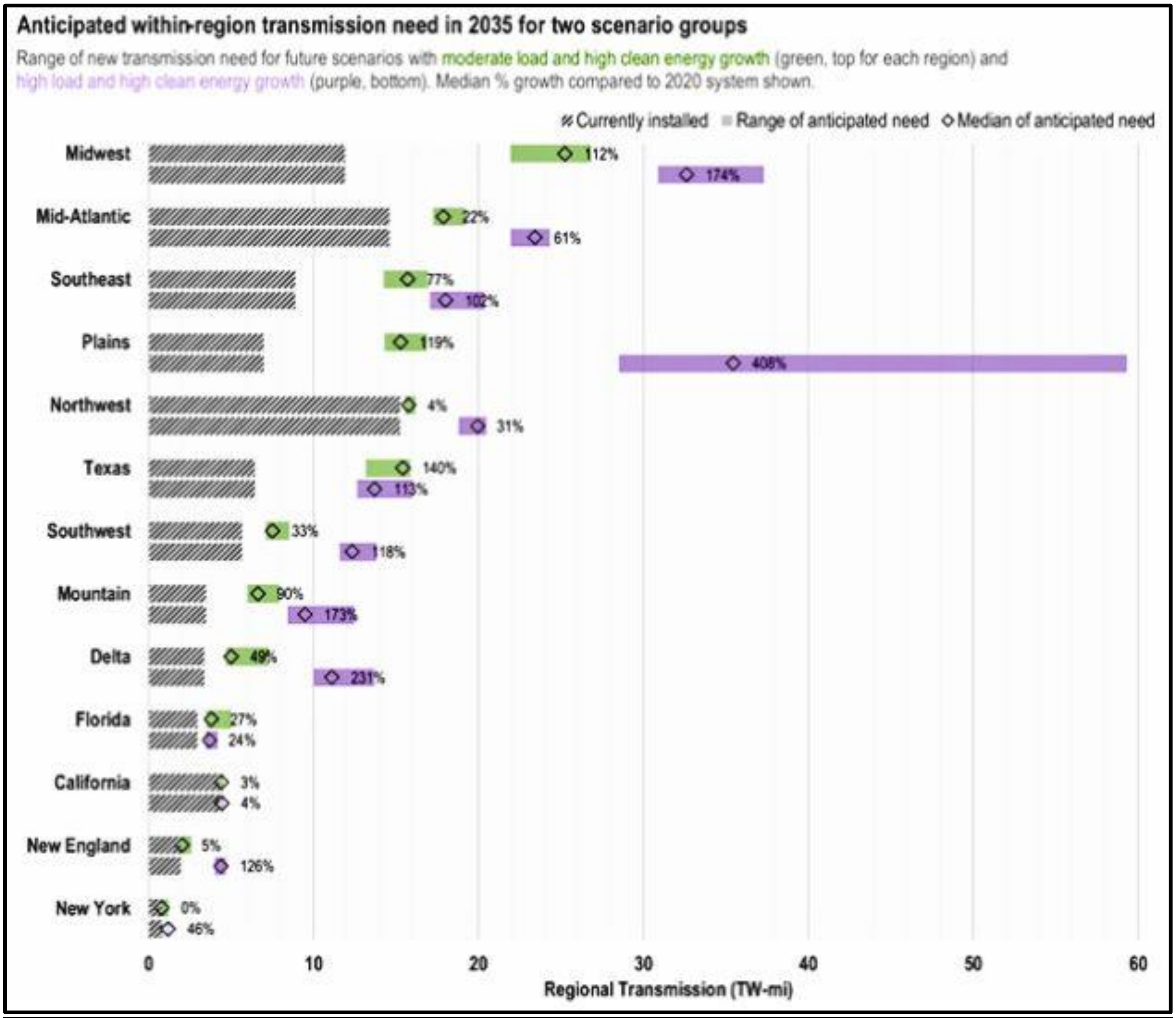

Figure 6: DOE Bulk Power Transmission Expansion Forecast by 2035

3.5. Labor Shortages

The domestic transformer manufacturing industry faces labor shortages due in part to the demands of training, working conditions, and some of the manufacturing facilities being in rural areas that offer a limited regional labor pool. Domestic manufacturers indicated that a lack of workers is one of the largest impediments to expanding capacity. With distribution transformers in particular, manufacturers have found it necessary to add shifts to meet higher demand.

3.6. Historic Industry Cyclicality

The historic cyclical nature of the transformer industry presents yet another challenge. Transformer manufacturers that increased capacity during the housing boom of 2004-2007 experienced severe impact from the 2008 global financial crisis, which has made them wary of increasing capacity despite rising demand. Since there may be opportunities to boost output at certain plants by adding another shift or weekend work, labor shortages may also be blocking an avenue to more production.

Past cyclicality may be tempered by the forecast of strong demand for both distribution and large power transformers over the next several decades.

3.7. Lack of Equipment Standardization

Another challenge is the lack of standardized transformer designs. Many utilities have custom transformer designs and requirements, and they place orders with these unique specifications. This makes mass production impractical, and it has challenged the industry to deploy further automation that could boost production. One large manufacturer suggested that more standardization could boost output at the company's existing plants by a significant factor. The DOE has studied the potential effect of standardization and found that standardization could increase production significantly. The DOE is also exploring the feasibility of designing a standard transformer that can be mass produced.

The current variety of transformers is primarily a consequence of the following (with other special considerations driving variability as well):[19]

1. The need to specify the correct size transformer to serve customer load
2. The standard high voltage distribution levels[20] of each electric utility
3. The low voltage requirements of the customer load served
4. Whether the load is single phase or three phase
5. Whether the customer is served overhead or underground

3.8. Electrical Steel

Finally, manufacturers have faced regulatory uncertainty related to electrical steel, which is used to make a transformer's core. Historically, transformers have been made with grain-oriented electrical steel (GOES), but it is difficult to source that material domestically. At the same time, certain limits on foreign-made steel have made it more expensive to purchase internationally. In addition, the DOE initially proposed a set of efficiency standards that would favor amorphous steel and would require significant changes in the manufacturing process and transformer design. In April 2024, the DOE modified the new efficiency standard to allow more time for manufacturers to adjust production processes and source key components from other suppliers.

[19] As an example, one large domestic manufacturer of single-phase pole-mounted transformers offers 18 different sizes between 0.5 kVa and 500 kVa, 12 different high side voltages (e.g., 2.4 kV, 4.16 kV, etc.), different end use voltages such as 277 or 480 volts, etc. Each of the permutations results in manufacturing complexity.

[20] Distribution voltage levels have tended to increase over the years. While a 4.16 kV or 4.8 kV system might have been standard in the 1940s and 1950s, the current standard might be 13.2 kV or 13.8 kV. However, many utilities still have portions of their service areas where older and lower voltage feeders are still in service. Accordingly, this expands the variety of transformers that must be produced and deployed.

4. Economic and Environmental Impact of Transformer Shortage

In some instances, electric utilities have cautioned local developers that certain new construction projects may be delayed due to the unavailability of transformers and other required grid equipment. Among these utilities are CPS Energy in San Antonio, Texas,[21] and Portland General Electric in Oregon.[22] Other public and investor-owned utilities have experienced similar challenges. Trade groups such as the National Association of Home Builders have also reported construction delays caused by the unavailability of transformers.[23] These delays are disruptive and costly both to builders and to property owners.

Figure 7 is excerpted from a presentation by the DOE's Lawrence Berkeley National Laboratory. The national lab monitors grid interconnection queues of the seven independent system operators (ISO)/regional transmission operators and 44 non-ISO balancing areas, which collectively represent greater than 95 percent of currently installed U.S. electric generating capacity.[24] While many of the proposed generating projects will not be completed, the interconnection queues are a good proxy for the massive grid transformation that is already underway. For a sense of the massive size of the interconnection queue, the total amount of installed utility-scale capacity in the U.S. was about 1,277 gigawatts in 2023, according to an American Public Power Association (APPA) analysis. Therefore, the pending interconnection queue is close to double the installed capacity base.[25]

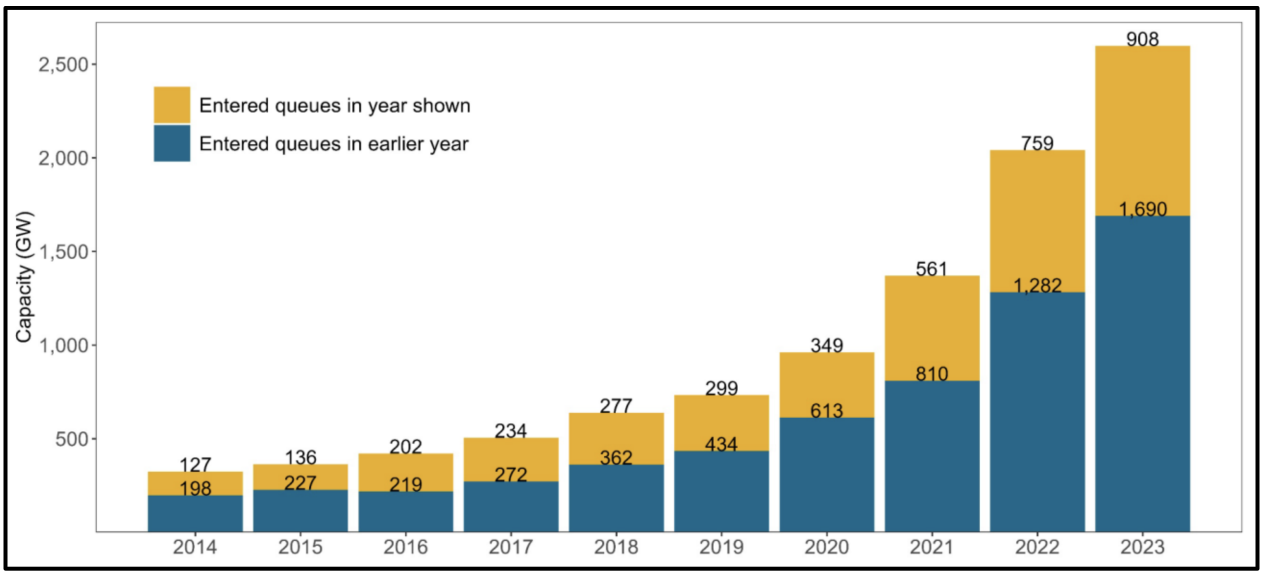

Figure 7: U.S. Generating Capacity Interconnection Queue

According to the Clean Energy States Alliance, 23 states as well as the District of Columbia and Puerto Rico have all enacted legislation or other policies mandating a zero-carbon electricity sector between 2032 and

[21] CPS Energy. n.d. "Single-Phase Project Queues."
[22] Portland General Electric. 2022. "Nationwide Shortage of Certain Transformers: FAQ for Builders and New Construction."
[23] National Association of Home Builders. 2023. "Electrical Component Shortage is Wreaking Havoc and Demands Action."
[24] Rand, Joseph, et al. 2024. "Queued Up: 2024 Edition, Characteristics of Power Plants Seeking Transmission Interconnection as of the End of 2023."
[25] Buttel, Lindsey. 2023. "America's Electricity Generation Capacity 2023 Update." American Public Power Association.

2050. The map in **Figure 8** shows the 23 states that have such public policy mandates shaded in green.[26] If too many projects are delayed by the lack of transformer or other key electrical grid components, it will inhibit the pace of the energy transition, leading to more greenhouse gases entering the atmosphere and increasing impacts from climate change. Collectively, these 23 states represent an estimated 53 percent of the total U.S. population.

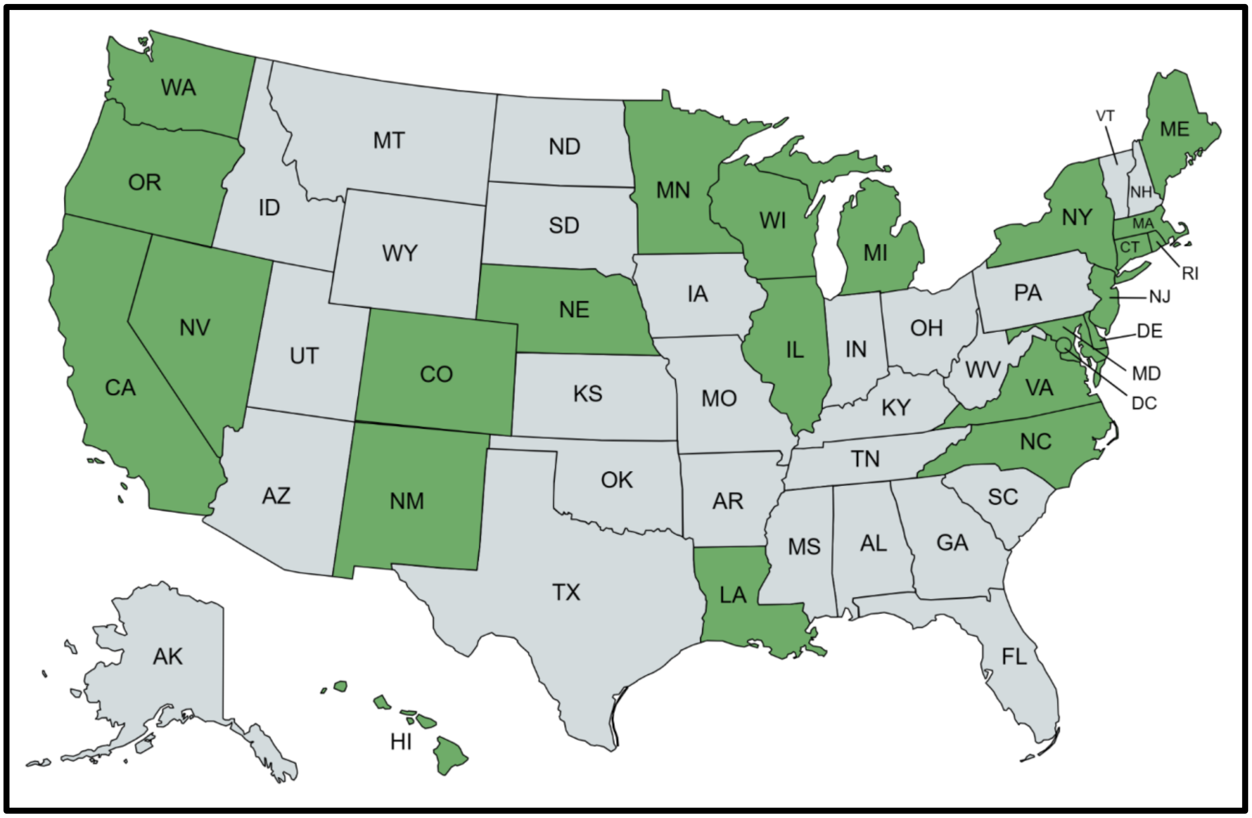

Figure 8: States Enacting Legislation or Policy to Decarbonize the Electric Sector

Extreme weather events are among the most visible, tangible effects of climate change, and a continuing shortage of transformers is likely to impair the resilience of electric grids in affected regions, leading to more frequent, longer lasting outages, thus exacerbating the effect on economies and increasing risks to the health of residents.

Investing in solutions to address the shortage of transformers, however, is not solely about avoiding a set of negative consequences. These investments also have the potential to create value in terms of new jobs, economic growth, and strengthening the nation's energy security.

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[26] Detail regarding the legislative or other decarbonization policy of these 23 states is available from the Clean States Energy Alliance website. The map was created using a template from MapChart.

5. Recommendations

The NIAC offers **seven recommendations** to boost domestic production of transformers and promote a closer partnership between the private sector and the government to ensure adequate supply of this critical grid component.

5.1. Expand Domestic Capacity through Federal Policies and Funding Incentives

The NIAC recommends the Federal government craft policies and designate funding targeted at increasing domestic capacity, such as tax credits, grants, accelerated depreciation, funding for new working apprentice and/or training programs, and other incentives, using the CHIPS Act as a model.

Domestic distribution transformer production is still strong in the U.S. This has been attributed, in part, to the degree of customization that utilities have historically required for their distribution transformers. In the case of large power transformers, however, the U.S. is heavily dependent on foreign manufacturers. This dependence creates national security concerns.

The NIAC recommends that the Federal government develop a set of incentives to increase domestic production of electrical steel and expand annual production capacity of both distribution and large power transformers. Incentives could come in the form of grants, investment tax credits, or production-cost tax credits linked to a verifiable and permanent increase in annual production capacity. The capacity increase would be associated with new capital investment to debottleneck current production processes, boost automation, and/or expand manufacturing capacity (floor space, assembly bays, production lines, etc.).

Mechanisms like the investment tax and production tax credits available in the Inflation Reduction Act (IRA) to encourage domestic renewable generation projects should be devised to expand permanent domestic transformer production. These incentives would reduce the risk for manufacturers considering capacity expansion.

In a subcommittee briefing with Siemens, a company executive shared that IRA incentives for buying American-made products influenced the company's recent decision to onshore large transformer production at an expanded facility in North Carolina.

The goal is to expand domestic production of large power transformers to 50 percent by 2029 to reduce supply risk and improve national security. Given the current estimated figure of only 20 percent, and with market growth expected, additional capacity will be required. The NIAC recognizes that some manufacturers may elect to produce certain transformer sub-assemblies in other countries with longstanding transformer supply relationships with the U.S., such as Canada, Mexico, and certain European or Asian producers.

The NIAC also recommends that the DOE coordinate a task force to recommend the magnitude of financial support required to induce more domestic production, augmenting work it has already done in this regard.

In addition, an Electric Subsector Coordinating Council Tiger Team should review the supply chain and foreign dependency of other critical grid elements, such as high voltage circuit breakers and switchgear. Increased domestic or diversified production of this equipment is needed. Finally, the Federal government should consider using Defense Production Act funding to support the increased development of large transformer domestic capacity and the gradual conversion of U.S.-based distribution transformers to more efficient methods of transformer production.

5.2. Increase Collaboration to Achieve Greater Accuracy in Transformer Demand Forecasting

The NIAC recommends convening all parties who drive demand to achieve greater accuracy in transformer demand forecasting that will provide a more precise outlook across the next 10 to 15 years.

While most of the large power and distribution transformers in the U.S. are ordered by electric utilities, there are other important market segments, including generation-resource developers, large manufacturers, data center developers, and commercial enterprises. The NIAC recommends that the DOE commence a biannual process to work closely with each transformer market segment to develop a long-term forecast of transformer demand, by type.

This effort would account for how energy policy is shaping market trends. For example, under new transformer efficiency standards,[27] 25 percent of distribution transformers will be made using amorphous steel, which lacks domestic sources of production. The forecasting of transformer demand, then, must reflect the need for sufficient supply of both GOES and amorphous steel.

In addition, the forecasting should account for global supply and demand trends related to utility infrastructure, since those trends have the potential to impact the cost and availability of essential electric equipment like transformers.

By aggregating expected demand from key market participants and factoring in broader global trends related to utility infrastructure, domestic transformer manufacturers will be positioned to make decisions based on more accurate and timely information pertaining to future demand.

The demand forecast should be separated by key market segments, and be as granular as possible on transformer variants, such as overhead versus pad-mounted, standard size in kilovolt-amperes (kVA) or megavolt-amperes (MVA), voltage level, distribution versus large power transformers, etc. There are already market research firms that provide forecasts of electric grid equipment demand. The intent is not to displace these activities but rather to encourage all market participants to develop a comprehensive source where all available data can be gathered in a systematic manner.

Much like electric peak load and annual energy forecasts, the DOE should develop scenarios to help industry participants assess the effect of low, base, and high transformer demand forecasts and make its aggregate data sets available publicly. The DOE's Annual Energy Outlook is a widely used source of energy forecasts and could serve as a model for this recommendation, recognizing that the transformer outlook will be less complex and not as far-reaching.

[27] U.S. Department of Energy. 2024. "DOE Finalizes Energy Efficiency Standards for Distribution Transformers that Protect Domestic Supply Chains and Jobs, Strengthen Grid Reliability, and Deliver Billions in Energy Savings." DOE final distribution transformer rule adds 2 years for compliance.

5.3. Encourage Commitments Between Transformer Suppliers and the Sectors Driving Demand

The NIAC recommends encouraging long-term contracts/customer commitments between transformer suppliers and the sectors driving demand.

Most electric utilities do not source transformers under long-term contracts. Historically, grid-equipment lead times have been reasonable, and the disparate nature of transformers in terms of size, type, and application makes identifying the needs difficult until the utility's replacement, with the new construction pipeline well-defined. While most electric utilities develop a 5-year capital budget (and sometimes an associated 10-year outlook), only the first several years of the program are known. The out-years of a 5-year budget are typically reasonable in terms of volume, based on typical growth and replacement programs, but are seldom specific regarding discrete projects.

Several large power transformer manufacturers have indicated that longer firm commitments by electric utilities (and major renewable and conventional generation developers) would provide more certainty and therefore make capacity expansion decisions easier to justify. Several manufacturers also indicated that European utilities have been making 5- to 10-year equipment purchase commitments, and therefore have already reserved significant manufacturing capacity. However, firm commitments for certain types and sizes of transformers may be difficult for U.S. utilities to identify, creating risks of tying up too much working capital in inventory or raising concerns from various state public utility commissions. On the other hand, some regulators may be receptive to utilities making longer term commitments if it enables the utility to support growth and/or more rapid renewable and storage capacity deployment.

Given the complex state and Federal regulatory overlay over electric utilities, it would be useful to create a model policy whereby the Federal government offers recommended guidance regarding commitments for critical infrastructure equipment and building larger power and distribution transformer inventories to cope with unforeseen contingencies.[28] Having the Federal Energy Regulatory Commission support a larger set of critical spares in jurisdictional transmission rate bases, for example, would set a strong precedent for national resiliency.

5.4. Establish a Reserve of Transformers

The NIAC recommends establishing a strategic reserve of transformers, with the U.S. government as the buyer of last resort.

Various industry participants have advocated that the U.S. government establish a strategic virtual reserve of transformers. The reserve's function would be like that of the U.S. Strategic National Stockpile (SNS) for medical equipment needed to respond to large public health emergencies. The SNS was created in 1999 to help counter potential biological, disease, and chemical threats to civilian populations.[29] The stockpile contains supplies, medicines, and devices for lifesaving care that can be used as a short-term, stopgap buffer when the immediate supply of these materials may not be available or sufficient.

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[28] Note that many public power and cooperative utilities are not regulated by state-level public utility commissions. However, a broad national policy regarding increased inventories of critical spares could be considered by their respective governance boards.

[29] Kuiken, Todd and Gottron, Frank. "The Strategic National Stockpile: Overview and Issues for Congress," Updated September 26, 2023. Congressional Research Service, R47400.

Unlike the SNS, however, the transformer reserve would not be created in advance. Rather, a virtual reserve could be created over time where the Federal government would step in as buyer of last resort if domestic manufacturers experienced a slowdown in orders that would result in production below predetermined levels.

As envisioned, the mechanism would function like U.S. Department of Agriculture commodity Price Supports, except that price would not be the trigger; rather, the supports would be activated when plant capacity utilization dips below a particular threshold. The resulting physical reserve could then be stored until production capacity utilization was high and lead times expanded again to unacceptable levels. At that point, the Federal government, working with its private sector partners, would determine a suitable reserve drawdown to alleviate shortages. The virtual reserve, like all stockpiles, would therefore dampen the historical boom/bust cycle of transformer manufacturers and could help improve manufacturing capacity utilization over the cycles. It is likely that any government sales of transformers would occur in periods when market prices are high.

Ideally, the transformer reserve would be set up as a public-private partnership where cooperative-, public-, and investor-owned utilities work closely with other transformer users and the Federal government to ensure that the reserve is eventually stocked with the equipment most likely needed, and withdrawal mechanisms are pre-determined, transparent, and rapid to meet emergency needs.

The concept of a virtual distribution transformer reserve is complicated by the sheer variety of transformers that are available (broad array of different sizes, overhead versus pad-mounted, cooling method, application, specialty units, and so on). The NIAC envisions that a Federally funded virtual reserve program would focus on a smaller subset of transformers in use based on the most common sizes and types. By limiting the type and size of units that would be purchased, the program could also help drive more standardization in transformer specifications.

To ensure readiness, all stored equipment in the reserve would be inspected on a periodic basis to ensure its operability. In addition, given the logistical challenges of transporting large transformers, steps must be taken to ensure that they are stored in multiple locations with suitable inland port, waterway, and/or rail access that enable the transformers to be cost-effectively dispatched to sites where needed.

5.5. Promote Collaboration to Standardize Transformer Design and Reduce Complexity

The NIAC recommends the Federal government promote collaboration between design engineers from utilities, trade associations, and domestic manufacturers with the goal of standardizing transformer design and reducing complexity associated with customization.

Because customer loads and generator sizes are disparate, a broad array of transformer sizes is required to match each application. The use of different distribution and transmission voltages across the U.S. further expands the variety of transformers that must be produced. One estimate indicates there are over 80,000 different distribution transformers available. In addition, the industry could improve interoperability by standardizing the interfaces between transformers and other grid components.

This complexity and customization can complicate the production processes of transformer manufacturers and reduces potential throughput. A potential goal of the standardization effort may be to develop modular transformer components that would allow for faster assembly.

By increasing standardization, manufacturers may be able to boost production and reduce costs at the same time, thereby improving industry profitability.

Historically, standardization has lagged because neither the utility industry nor the manufacturers of transformers had sufficient incentives to pursue it. A study may be needed to test that it is possible to create a standard transformer model that can be widely adopted by utilities, and as a result drive savings in the costs of production. Again, the DOE and EPRI would be natural candidates for sponsoring and assisting this research. Public utility commissions could play an important role in engaging utilities and promoting adoption of standardized equipment.

Gaining broad agreement on standards may be arduous, but an industry-wide effort supported by the utility trade associations, the National Electrical Manufacturers Association, and the Federal government is likely to succeed in reducing the degree of current transformer customization, driving reductions in costs, and boosting productivity. Over time, additional benefits will accrue from standardization, including reduced spare parts complexity and utility training requirements, and better performance analytics to improve reliability of the equipment.

The DOE, the industry trade associations, and a few of the large utilities in the U.S. should be the initial nucleus to launch a standardization effort. According to our briefer from the DOE, the Office of Electricity is actively working to promote standardization of transformers and will continue to need robust support.

It may also be worthwhile to explore the formation of a global inventory of transformers. This strategy has been effective in other industries.[30]

5.6. Coordinate Incentives for Supply, Efficiency Standards, and Trade Policy

The NIAC recommends the Federal government ensure a sufficient supply of electrical steel by coordinating incentives for supply, governmental efficiency standards, and trade policy.

The DOE, electric utilities, and transformer manufacturers worked collaboratively over several years to adopt new energy conservation standards for distribution transformers. This effort culminated in a carefully synchronized path to transition gradually to more efficient amorphous steel transformer cores while enabling transformer manufacturers to cultivate new sources of supply and add new production capacity in an orderly way. This approach avoided further supply disruption, undue price escalation, and over-reliance on subcomponent suppliers. At the same time, the new standard will enable the industry to reduce transformer technical losses for the benefit of customers and the environment.

With a 5-year planning horizon, and more certainty regarding standards, transformer manufacturers have additional time to expand capacity and migrate to more secure supplies of amorphous steel as the industry shifts from GOES to amorphous steel. It also enables current suppliers of GOES to adjust production gradually and avoid costly and disruptive production facility shutdowns and job losses.

The thrust of the NIAC's recommendation is to continue to allow enough time for amorphous steel production capacity to expand in the U.S. or other near-shore areas of reliable supply. Since it will take years and considerable investment to develop and diversify sources of the more efficient electrical steel, a

[30] International Atomic Energy Agency. 2006. "Potential for Sharing Nuclear Power Infrastructure between Countries."

carefully coordinated and gradual tightening of the efficiency standards will ensure that an orderly transition occurs.

Given the urgency of the supply issue, it may be best to pursue a near-term solution for the shortfall in electrical steel supply, while at the same time advancing a longer-term strategy aimed at increasing its domestic production.

The NIAC believes that the development of alternative supply sources for more domestic amorphous steel or GOES may be a prime candidate for Federal support as discussed in Recommendation 5.1: Expand Domestic Capacity through Federal Policy and Funding Initiatives.

5.7. Grow the Workforce Pipeline through Public and Academic Partnerships

The NIAC recommends the Federal government grow the pipeline of qualified workers by partnering with universities, community colleges, and trade schools on training programs, while working with federal, state, and local governments to craft tax incentives for workers who enter the field.

Industry groups have called for the Federal, state, and local governments to encourage universities, community colleges, and trade schools to establish and fund programs to develop a steady pipeline of qualified workers in areas near existing domestic transformer or transformer component manufacturing facilities. As such, the NIAC recommends that the Federal government, coordinated by the DOE, fund the development of training and/or certification programs, working closely with transformer manufacturers to ensure that graduates have the requisite skills to be effective employees. Instead of a lengthy classroom-based program, it may be useful to obtain Federal support for initial on-the-job training (e.g., for the 6 to 8 months that it takes to become fully trained and productive).

An ideal approach might be to help fund apprenticeship-type or certification programs that combine shop floor experience with periodic classroom training on tool usage, safety, rigging, welding, and other pertinent skill sets.

Federal consideration of this recommendation should consider careful coordination with another NIAC study, Expanding the Workforce for Critical Infrastructure.

In addition, Federal, state, and local governments should consider offering tax breaks or subsidies to expand the pool of workers who choose to work in this field.

6. Call to Action

The NIAC urges the President to consider these recommendations and move expeditiously to implement them to ensure rapid growth in domestic production of transformers, strengthening the reliability of the U.S. power grid, and securing it against associated risks to national security.

Appendix A: Acknowledgements

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Appendix B: Definitions

Term	Common Definition
Distribution transformer	Distribution transformers are used to reduce the voltage level of a power supply to that needed by an end-use customer. The electric utility industry defines a distribution transformer as having a high side voltage at or below 34.5 kV.
Grain-oriented electric steel (GOES)	GOES is a specialty steel used for transformer cores because it reduces power losses and makes the device more efficient. It is an iron alloy with silicon instead of carbon as the main component besides iron.
Large power transformer	The Department of Energy uses the term large power transformer to characterize a power transformer with a capacity rating of 100 MVA or higher. As used in this report, a large power transformer is one that is part of the transmission grid and has a low side voltage above 34.5 kV.

Appendix C: Acronyms and Abbreviations

Acronym/ Abbreviation	Definition
CHIPS	Crafting Helpful Incentives to Produce Semiconductors
DOE	Department of Energy
GOES	Grain-Oriented Electric Steel
EPRI	Electric Power Research Institute
EIA	Energy Information Administration
IRA	Inflation Reduction Act
ISO	Independent System Operator
kVA	Kilovolt-amperes
MVA	Megavolt-amperes
NIAC	National Infrastructure Advisory Council
NREL	National Renewable Energy Laboratory
SNS	Strategic National Stockpile

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