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Adequate Transformer Reserves

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GAO Highlights

Highlights of [GAO-23-106180](#), a report to congressional committees

Why GAO Did This Study

Robust electricity grid infrastructure is critical to the nation's economic, energy, and national security. Transformers serve a critical function on the electricity grid, managing voltage for efficient power transmission and distribution. Transformers are a source of grid vulnerability, susceptible to natural disasters and cyber and physical threats. Federal agencies such as DOE play an advisory, coordinating, and research role in the effort to ensure adequate transformer reserves.

Congress included a provision in statute for GAO to review issues related to certain disasters. This report examines (1) challenges to ensuring adequate transformer reserves and (2) the extent to which federal and industry stakeholders have taken steps to ensure adequate transformer reserves. For this report, GAO examined agency and industry actions; reviewed relevant reports, policies, and documents; and interviewed federal and industry officials.

What GAO Recommends

GAO is making two recommendations to DOE to establish plans, including time frames, for (1) developing solutions and support for addressing transformer supply chain challenges and (2) guiding its support for utilities and facilitating greater participation in industry sharing efforts. DOE partially concurred with these recommendations.

View [GAO-23-106180](#). For more information, contact Frank Rusco at (202) 512-3841 or RuscoF@gao.gov.

ELECTRICITY GRID

DOE Could Better Support Industry Efforts to Ensure Adequate Transformer Reserves

What GAO Found

Electric utilities and the Department of Energy (DOE) face several challenges to ensuring that large power transformers (LPT)—both in use and in reserve—are available in adequate numbers to maintain a resilient electricity grid. Utilities identified supply chain constraints as the most pressing challenge, including long (and increasing) manufacturing lead times, limited manufacturing capacity, and labor and material shortages. Moreover, the costs of purchasing and transporting LPTs prevents some utilities from keeping spares. For example, utilities reported that LPTs can cost as high as \$10 million to purchase and hundreds of thousands of dollars to move. Furthermore, federal and industry stakeholders stated that establishing a federally owned inventory of transformers would face additional challenges (such as lack of standardization) and could aggravate existing supply chain constraints.

Example of a Large Power Transformer at a Substation



Source: GAO. | GAO-23-106180

DOE has identified options for addressing the supply chain challenges that affect utilities' ability to ensure adequate reserves but has not developed plans that specify how to implement these options. For example, in 2022, DOE issued a report and gathered information from industry on how the Defense Production Act could be used to expand domestic transformer manufacturing capacity. However, DOE officials have not identified actionable objectives, or time frames, for these efforts. Furthermore, a 2017 DOE report recommended supporting industry sharing efforts to ensure adequate reserves by encouraging the participation of smaller, resource-constrained utilities in such efforts. However, DOE does not have a plan for operationalizing such support. Without plans to guide DOE's efforts to address supply chain challenges and to facilitate solutions to ensure adequate reserves, these efforts could stall or remain incomplete, leaving critical grid infrastructure vulnerable.

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Abbreviations

CIP	Critical Infrastructure Protection
CISA	Cybersecurity and Infrastructure Security Agency
DOE	Department of Energy
DPA	Defense Production Act
EI	Edison Electric Institute
FERC	Federal Energy Regulatory Commission
GOES	grain-oriented electrical steel
ISO	Independent System Operator
kV	kilovolt
LPT	Large Power Transformer
NATF	North American Transmission Forum
NERC	North American Electric Reliability Corporation
RESTORE	Regional Equipment Sharing for Transmission Outage Restoration
STEP	Spare Transformer Equipment Program

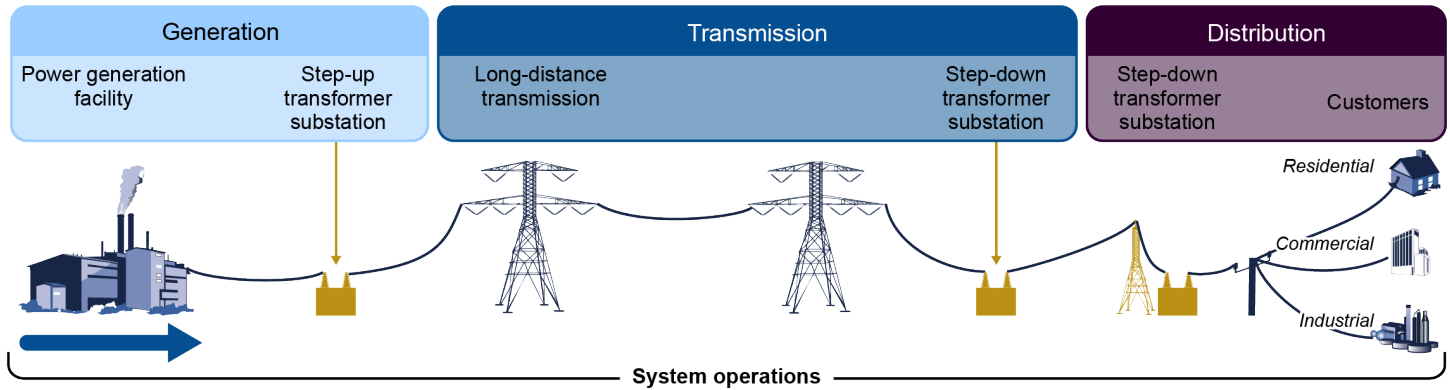
Background

The Electricity Grid and Transformers

The electricity grid involves three distinct functions: generation, transmission, and distribution (see fig. 1). Once electricity is produced at power generation facilities, it is sent through high-voltage, high-capacity transmission systems (i.e., high-voltage power lines and towers) to areas where it is transformed to a lower voltage. It is then sent through the local distribution system for use by residential and other customers. Substations are a critical component of the grid that include transformers. Electricity is generally produced at between 5 and 34.5 kilovolts (kV), stepped up to between 230 and 765 kV for electrical power transfer through the high-voltage transmission system, and then stepped down to between 15 and 34.5 kV for distribution to customers.

⁹We also determined that the Define Objectives and Risk Tolerances component of internal control was significant to this objective, along with the underlying principle that management should define objectives clearly to enable the identification of risks and define risk tolerances. GAO, *Standards for Internal Control in the Federal Government*, [GAO-14-704G](#) (Washington, D.C.: Sept. 10, 2014).

Figure 1: Basic Structure of the Electricity Grid



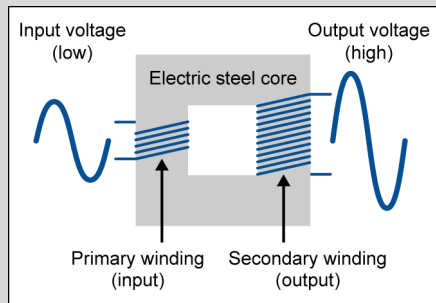
Sources: GAO; Art Explosion (clip art). | GAO-23-106180

Substations contain a variety of equipment designed to ensure the reliable flow of electricity through the grid, including transformers, circuit breakers, and sensors that allow a utility to monitor equipment. Most substations are fixed in place at locations across the grid. Some utilities employ mobile substations mounted onto flatbed trailers that can be deployed to temporarily replace substation transformers in the event of a failure. However, the transformers used in mobile substations may differ significantly from LPTs at substations, according to DOE officials.

Transformers

Transformers enable electricity to be transmitted over very long distances by increasing or decreasing voltage—the force that makes electricity flow through a wire—as necessary. They come in a wide variety of sizes and configurations and serve highly specific functions within the electricity delivery system. For example, generator step-up transformers are used to convert low-voltage power produced by power plants into high voltages needed to transmit power over long-distance transmission systems. Electrical power is transmitted in three phases; together, the three phases deliver constant power. Utilities use either a three-phase transformer, or three single-phase transformers banked together, depending on their need. To illustrate the concept, a single-phase transformer is depicted below, containing two windings. These are coils of wire wound around the core—usually made of highly permeable grain-oriented electrical steel (GOES)—to change voltage levels.

Single-Phase Step-Up Transformer



Sources: Department of Energy; GAO (illustration). | GAO-23-106180

Transformers are a critical electrical component that facilitate the efficient transfer of electricity by converting electrical power to different voltages throughout the grid. The majority of transformers in service are distribution-level transformers, which step down distributed electricity for use by customers like residents and businesses. LPTs are transformers that are generally used for higher voltages in the transmission system. Far fewer LPTs exist than distribution transformers, and each LPT tends to have a unique design and specifications, according to DOE officials.

There are a relatively low number of transformers manufactured domestically in the U.S., and this is especially the case with LPTs. According to a 2020 Commerce report, over 80 percent of LPTs used in the U.S. were imported in 2019.¹⁰ According to the report, there are five U.S.-based manufacturers of LPTs. Moreover, as of 2023, there was one domestic manufacturer of grain-oriented electrical steel (GOES), a key transformer component. Both Commerce and DOE have stated that the relatively low volume of domestic manufacturing is a potential risk to national security, given transformers' importance in the electricity grid.

Transformers are vulnerable to a range of threats. Wear and tear from normal operation causes all transformers to age and eventually need replacement, although with proper maintenance transformer life can be expected to last many decades. In addition, extreme weather can damage transformers. Threats to transformers also include natural disasters—such as earthquakes, wildfires, and electromagnetic events. In addition to natural events, cyberattacks can damage transformers and create vulnerabilities for other types of attacks, such as by disabling physical security systems.¹¹ Physical attacks, ranging from break-ins for theft to vandalism and terrorism, have received increased media coverage in recent years. In 2013, a substation attack in California caused more than \$15 million in damage. At the end of 2022, multiple attacks on substations occurred in North Carolina, Oregon, and

¹⁰Department of Commerce, Bureau of Industry and Security, Office of Technology Evaluation, *The Effects of Imports of Transformers and Transformer Components on the National Security* (Oct. 15, 2020).

¹¹We have previously highlighted physical and cyber threats to the electricity grid. See the Related GAO Products section at the end of this report. In addition, GAO has designated the protection of cyber-critical infrastructure—including the electricity grid—as a government-wide high-risk area. See GAO, *High-Risk Series: Urgent Actions Are Needed to Address Cybersecurity Challenges Facing the Nation*, GAO-18-622 (Washington, D.C.: Sept. 6, 2018).

Washington. As of early 2023, the motives behind the attacks from the 2022 attacks were still under investigation.

Utilities own most of the electricity grid infrastructure and share management of the grid with transmission operators. There are three main types of electric utilities:

- investor-owned utilities, which are large—in terms of customer base—electric utilities that issue stock owned by shareholders. Almost three-quarters of utility customers get their electricity from investor-owned utilities that are most prevalent in heavily populated areas on the East and West Coasts of the U.S.;
- publicly owned utilities, which include federal-, state-, and municipal-run utilities; and
- electric cooperatives, which are not-for-profit, member-owned utilities that tend to serve customers in rural areas.

Federal Agencies and the Electricity Grid

Responsibility for regulating the electricity grid is divided between states and the federal government. Most electricity consumers are served by electric utilities that are regulated by the states, generally through state public utility commissions or equivalent organizations. These state commissions regulate many aspects of utility operations, such as approving rate increases by utilities for recovering costs of infrastructure investments (e.g., purchasing spare transformers or implementing other resilience measures).

FERC regulates the interstate transmission of electricity and provides for the reliability of the transmission system through the establishment and enforcement of mandatory standards. FERC reviews and approves mandatory standards developed by the North American Electric Reliability Corporation (NERC), which is the federally approved electric reliability organization. NERC, which is subject to FERC oversight, is responsible for developing reliability standards to provide for the reliable operation of

the power transmission system.¹² This includes the facilities and control systems necessary for operating the interconnected electricity grid and electric energy from generation facilities needed to maintain transmission system reliability.¹³ FERC, NERC, and NERC's regional entities all play a role in monitoring and enforcing compliance with reliability standards.¹⁴

DOE's objectives include providing support for a more secure and resilient U.S. energy infrastructure. In particular, DOE undertakes various efforts to ensure a resilient and reliable electric power system and to support emergency preparedness and a coordinated response to disruptions.¹⁵ In addition, DOE and its national laboratories conduct research and assess risks to the electric power system and recommend measures to mitigate risks. In some regions of the country, DOE's four power marketing administrations sell and transmit electricity primarily

¹²Section 215 of the Federal Power Act requires the Electric Reliability Organization to develop mandatory and enforceable reliability standards, which are subject to FERC review and approval. See 16 U.S.C. § 824o. FERC-approved reliability standards become mandatory and enforceable in the U.S. on a date established in the orders approving the standards. Among the reliability standards developed and enforced by NERC are Critical Infrastructure Protection (CIP) standards. In response to a 2013 attack on a substation, FERC directed NERC to develop new physical security standards, which were published in 2014 as CIP-014-1. These standards, updated in 2015 to CIP-014-2 and in 2022 to CIP-014-3, include a requirement that utilities develop plans to prevent and address any threats to physical security at their facilities, including the option of maintaining spare equipment.

¹³At the highest level, the U.S. power system is composed of three main interconnections, which operate largely independently from each other with limited transfers of electricity between them. These three main interconnections are the Eastern Interconnection, which encompasses the area east of the Rocky Mountains and a portion of the Texas panhandle; the Western Interconnection, which encompasses the area from the Rockies to the West; and the Electric Reliability Council of Texas, which covers most of Texas. These interconnections extend into parts of Canada and Mexico. The network structure of the interconnections helps maintain the reliability of the grid by providing multiple routes for power to flow and allowing generators to supply electricity to many load centers. This redundancy helps prevent transmission line or power plant failures from causing interruptions in service to customers.

¹⁴In 2007, FERC approved agreements by which NERC delegates its authority to monitor and enforce compliance with reliability standards to six Regional Entities.

¹⁵The Department of Homeland Security's Cybersecurity and Infrastructure Security Agency (CISA) is the national coordinator for critical infrastructure, and DOE is the sector risk management agency for energy and, thus, responsible for grid infrastructure. CISA officials told us that they assist entities such as the Electricity Subsector Coordinating Council and the Energy Sector Government Coordinating Council by performing analyses to identify gaps in critical infrastructure needs. However, DOE would take the lead on any actions, according to CISA officials.

from federally owned and operated hydroelectric power plants in over 30 states.¹⁶ These federal electrical power suppliers often own and operate transmission systems in their regions and are responsible for the systems' reliable operation and compliance with NERC reliability standards.

The Fixing America's Surface Transportation Act required DOE to prepare and submit to Congress a plan to establish a reserve of spare LPTs that could replace damaged LPTs that are critical electrical infrastructure.¹⁷ DOE's March 2017 report evaluated options and recommended an approach driven by voluntary industry actions and requirements in NERC's Critical Infrastructure Protection standards.¹⁸ Furthermore, in 2021, the Infrastructure Investment and Jobs Act required DOE to develop common analytical frameworks, tools, metrics, and data to assess the resilience, reliability, safety, and security of domestic energy infrastructure, including by developing and storing an inventory of easily transported spare LPTs and other required related equipment.¹⁹

Utilities and the Federal Government Face Several Challenges to Ensuring Adequate Transformer Reserves

Selected industry stakeholders reported several challenges to ensuring adequate reserves of transformers, with the most pressing challenges relating to the transformer supply chain. Most stakeholders also told us that establishing a strategic federal inventory of transformer reserves would pose additional challenges.

¹⁶The federal hydroelectric power plants are owned and operated by the U.S. Army Corps of Engineers, the Bureau of Reclamation in the Department of the Interior, or the International Boundary and Water Commission. In addition, the Tennessee Valley Authority—a federal government corporation—generates, sells, and transmits electric power in seven states.

¹⁷Pub. L. No. 114-94, § 61004(c), 129 Stat. 1312, 1780 (2015).

¹⁸Department of Energy, *Strategic Transformer Reserve*.

¹⁹Pub. L. No. 117-58, § 40103(d), 135 Stat. 429, 929 (2021). The act provides that DOE, in conducting the required assessment, is to do so in collaboration with the Secretary of Homeland Security, FERC, NERC, and interested energy infrastructure stakeholders. Additionally, the act uses the term "high-voltage recovery transformers"; for the purposes of our report, we refer to such transformers as LPTs.

Key Challenges Faced by Utilities in Ensuring Adequate Transformer Reserves Include Supply Chain Constraints

Nearly all stakeholders we spoke with identified supply chain constraints as the most pressing challenge for utilities attempting to ensure adequate reserves of transformers. Stakeholders reported that these constraints apply to and affect not only the manufacturing of transformers but the entire electric utility industry and that the COVID-19 pandemic exacerbated some of the issues (see fig. 2).

Figure 2. Challenges for Electric Utilities Attempting to Ensure Adequate Reserves of Transformers



Sources: GAO analysis of information from the Departments of Commerce and Energy and selected industry stakeholders. | GAO-23-106180

Supply chain constraints have affected manufacturing for transformers of all types, and some have had significant impacts on the manufacturing of LPTs specifically, including the following:

- Manufacturing lead times.** According to officials from nearly all utilities we spoke with, the time between ordering a transformer and receiving it (lead time) has lengthened significantly, in some cases doubling or more. Officials from several utilities told us that these delays began during the last 3 years, and officials from one utility specifically cited the COVID-19 pandemic as the starting point for their increased lead times. According to DOE and industry reports and officials, these longer lead times affected transformers of all types, and officials from some utilities highlighted LPTs specifically as experiencing worsening delays. The effect of these lead times varied, depending on the size of the utilities. For example, officials from larger utilities generally reported relatively smaller impacts to their lead times, with one large utility reporting that its previous LPT lead times of 12 to 18 months had increased to 18 to 36 months. However, smaller utilities told us that delays had substantially worsened for transformers of all sizes. Officials from one municipal utility told us that, in the last 3 years, quoted lead times for several sizes of distribution transformer had increased from an average of 10 months to a range of 1 to 7 years. Officials from another utility seeking to purchase transformers told us that manufacturers gave them

estimates of 2 to 4 years for an order to be delivered. Industry officials told us that some manufacturers have stopped taking new orders entirely due to the existing backlog and corresponding delays.

- **Manufacturing capacity.** According to industry officials, transformer manufacturers face challenges keeping up with demand due to constraints such as the size of existing factories and workforce availability. According to DOE and Commerce reports and manufacturers' representatives we spoke to, building new factories, expanding existing factories, and hiring and training additional workers are all challenges that will require significant time and resource investments to address. Some utilities have sought out newer manufacturers because of capacity issues with usual sellers but have concerns about product reliability and quality control. For example, officials from one utility told us that they placed orders with newer, foreign manufacturers for this reason but noted that they had observed less consistency in the quality of transformers ordered from these manufacturers.
- **Materials and components shortages.** According to officials from both domestic manufacturers and utilities, shortages of components and raw materials have meant that even in situations where manufacturers otherwise have the capacity to produce additional transformers, they are unable to do so. For example, there is an increasingly limited availability of GOES, an especially critical material. According to Commerce and DOE reports, there is only one company in the U.S. that produces GOES, and domestic transformer manufacturers told both us and Commerce that its product is of insufficient quality to meet their standards.²⁰ Meanwhile, according to officials from domestic transformer manufacturers, foreign steel manufacturers are reducing their production of GOES. Instead, they are moving toward production of the non-grain-oriented electrical steel needed to meet the growing demand for electric vehicles.²¹
- **Labor shortages.** According to officials from several industry stakeholders we spoke to, as well as DOE and Commerce reports,

²⁰Department of Commerce, *The Effects of Imports of Transformers and Transformer Components on the National Security*.

²¹Concerns about the cybersecurity of grid infrastructure components manufactured abroad (e.g., in China) further complicate supply chain constraints and lead times. In December 2022, FERC and DOE held a joint technical conference to gather industry information on this issue, and prior GAO work has highlighted cyber supply chain risks. GAO, *Information Technology: Federal Agencies Need to Take Urgent Action to Manage Supply Chain Risks*, [GAO-21-171](#) (Washington, D.C.: Dec. 15, 2020).

finding and retaining labor is difficult for a range of reasons.²² For example, transformer manufacturing and refurbishment, especially for LPTs, is labor intensive and requires specialized training. In addition, prospective employees must be willing to work at factories in relatively remote locations. Domestic manufacturers surveyed by Commerce also reported that few postsecondary institutions offer degrees or specializations relevant to transformer manufacturing. Stakeholders interviewed by DOE added that, as of 2022, they have not offered internships or cooperative education programs to assist with hiring for the LPT manufacturing workforce. DOE also reported in February 2022 that, more broadly, the COVID-19 pandemic has reduced the size of the nation’s manufacturing workforce as a whole.²³

- **Competition with foreign manufacturers.** According to the domestic manufacturers we spoke to, several challenges make competition with foreign manufacturers difficult, which, in turn, suppresses industry growth. As mentioned above, most transformer manufacturing capacity is located abroad, and Commerce reported in 2020 that over 80 percent of LPTs in 2019 were imported.²⁴ In addition, domestic LPT manufacturers reported to DOE that foreign manufacturers regularly sold their transformers in the U.S. market at a price that is below the cost of domestic production. This practice, known as dumping, prevents domestic manufacturers from selling their products at competitive prices. While domestic manufacturers stated that they have successfully litigated many antidumping cases, they added that such litigation is costly and distracts from their primary activity of manufacturing transformers. Officials also commented to DOE that there are few to no incentives for utilities to purchase transformers manufactured domestically.

Agency and industry officials and reports highlighted additional challenges, and the associated high costs, experienced by utilities and industry that affect the ability to ensure adequate transformer reserves, including the following:

²²Department of Energy, *Electric Grid Supply Chain Review*; and Department of Commerce, *The Effects of Imports of Transformers and Transformer Components on the National Security*.

²³Department of Energy, *Electric Grid Supply Chain Review: Large Power Transformers and High Voltage Direct Current Systems: Supply Chain Deep Dive Assessment*.

²⁴Department of Commerce, *The Effects of Imports of Transformers and Transformer Components on the National Security*.

- **Logistical challenges.** Utility officials told us that the massive size and weight of most LPTs make them expensive and time-consuming to move, with several associated challenges that ultimately pose problems for both the delivery of new transformers and the deployment of spares. For example, officials from one utility told us that moving an LPT via flatbed truck over a distance of about 275 miles cost over \$400,000. Moreover, officials from some utilities told us that moving LPTs on and off of vehicles and into position requires specialized equipment and trained personnel. Vehicles for LPT transport are expensive and customized for that task and not readily available. For example, officials from one large utility showed us a modular flatbed truck trailer for moving LPTs that they told us cost over \$1 million.²⁵ Furthermore, according to some utility officials, maintaining the underlying infrastructure—such as railroad spurs and road bridges—required to carry the weight of LPTs during transport adds to logistical costs, even if the interval between moves may be decades.
- **Purchase costs.** LPTs are expensive, with a purchase price of several million dollars each. Utility officials we spoke with gave us a range of estimates for LPT costs, with some as high as \$10 million. Officials from some utilities told us that purchasing a spare LPT was an expense they could not afford, even if they were otherwise operating LPTs that are critical to the whole electricity grid. Others expressed concerns that they would not be able to obtain approval to recover the cost of spare transformers from customers, whether from state and federal regulators, their members, or other entities responsible for setting their rates.²⁶ Officials from smaller utilities also highlighted how purchasing transformers of all sizes has grown more difficult as a result of cost increases associated with supply chain challenges, as described above. For example, one utility told us that a relatively small distribution transformer was quoted in 2020 at about \$5,700. In February 2023, these were now being quoted from approximately \$22,000 to \$27,000. They told us that quotes for a

²⁵In addition to a custom trailer, the same utility had two custom rail cars for LPT transport that were both out of service for repairs at the time of our visit. Custom rail cars for the transport of the largest LPTs, called Schnabel cars, are uncommon and costly. As of April 2023, there were 10 Schnabel cars that are dedicated to service for the electrical industry in the U.S., according to the Association of American Railroads.

²⁶Officials from some larger utilities stated that they had been able to get regulatory approval to recover the costs of some, but not all, spare LPTs they had purchased to meet the goals of their transformer reserve strategy.

larger distribution transformer model had increased from about \$24,000 in 2020 to a range of \$81,000 to \$109,000 in February 2023.

- **Lack of standardization.** According to industry stakeholders, grid infrastructure, including substations and LPTs, is not standardized, making it difficult to have spares that can replace more than one specific LPT. This also affects the cost of new LPTs, as they are often custom designed. Utility officials told us that standardizing transformers would be very expensive and could require rebuilding parts of the grid to align to such a standard.
- **Threats to spares.** Spare LPTs are vulnerable to the same threats of natural disaster and attack facing operational LPTs, requiring measures to mitigate those threats, which may be costly. For example, measures like fencing, cameras, or bulletproof walls used to protect an LPT in operation would need to include the spare LPT if stored on-site. Officials from one utility that had built bulletproof walls to shield a transformer told us that the walls were prohibitively expensive to build and deploy across their entire system.

Establishment of a Strategic Federal Inventory of Transformers Would Face Additional Challenges and Could Aggravate Supply Chain Constraints

In response to our questions about the challenges to establishing a federally owned inventory of transformers, stakeholders told us that establishing such an inventory of transformers could aggravate the supply chain constraints we described earlier. Specifically, federal efforts to purchase transformers would put additional pressure on the market and could drive up manufacturing lead times and costs. Stakeholders also identified challenges to managing such an inventory, including the following:

- **Wide array of specifications.** Because of a lack of standardization, a transformer reserve would require numerous different transformer types to accommodate potential needs from systems across the nation.
- **Logistics.** Purchasing and deploying any federally owned spares would face the same logistical challenges as transformers purchased by utilities. Moreover, officials told us that identifying a location to store federal reserves that minimizes these challenges may be difficult to accomplish in a way that reduces the distance and critical infrastructure needed to reach as many utilities as possible. This may mean storing spare transformers at multiple locations, maintaining security of the storage facility, matching spare transformer characteristics to the transformers in the area of use, and ensuring adequate transportation to the utility facility when needed.

- **Duplication of efforts.** Officials from some utilities told us that a federal reserve would be duplicative of existing industry efforts to ensure adequate transformer reserves, as discussed below.

Given the challenges above, managing a limited inventory that may not meet demand for every utility would require decisions about who receives a transformer in an incident where multiple utilities suffer losses. However, smaller utilities we spoke with suggested that a strategic federal reserve of mobile substations—which include transformers—could provide a temporary stopgap while utilities acquired permanent replacements (see fig. 3 below for an example). Some of these officials told us that establishing a federal inventory of mobile substations would still face some of the challenges described above, depending on its configuration. Furthermore, utility officials described other ways the federal government could ensure adequate transformer reserves. For example, some officials suggested that federal entities, such as the power marketing administrations, could securely store privately owned spares on their property. Others suggested that the federal government could survey utilities to develop and share a comprehensive list of available spares nationwide.

Figure 3. Example of a Mobile Substation



Source: GAO. | GAO-23-106180

Utilities and DOE Have Taken Steps to Address Challenges, but DOE Has Not Made Plans to Support Industry Efforts

Utilities and DOE have taken steps to address challenges to ensuring adequate transformer reserves, but DOE has not made plans to implement support for addressing supply chain challenges experienced by the industry. Opportunities exist for DOE to better support utilities—especially smaller, resource-constrained utilities—in addressing challenges. However, DOE has not developed a plan for how it will target its support for utilities’ participation in industry sharing efforts.

Utilities Have Adopted Strategies to Address Challenges to Ensuring Adequate Transformer Reserves

Utilities and industry groups have adopted strategies to address challenges associated with supply chain constraints and threats to infrastructure. The industry has also engaged in efforts to share grid equipment, including transformers, as another way to ensure adequate transformer reserves.

Individual Utilities’ Strategies

Utilities have adopted various strategies to address challenges to ensuring adequate transformer reserves, according to officials we spoke to. These included the following:

- **Maintaining spare equipment.** Most utilities we spoke to maintain an inventory of spare equipment, including transformers and key transformer components, in order to rapidly restore power in the event of transformer failure. For example, utilities maintained “cold” spares—spares stored on location or centrally located—and “hot” spares—spares operating on the system, but redundant. In some cases, utilities also configured their system so that power can be rerouted around a substation while repairs or maintenance are underway. Similarly, some utilities had the option of replacing a critical transformer with one from a less crucial substation. Some utilities we spoke to maintained spare components, such as the bushings that allow the transformer to safely connect with power lines (see fig. 4).²⁷

²⁷According to DOE, some Independent System Operators (ISO) and Regional Transmission Organizations at the regional level require entities to maintain spare transformers or equipment on hand. For example, one ISO requires its utilities to provide descriptions of their spare inventories as well as any mutual sharing agreements. However, this only pertains to utilities with transmission assets that participate in these markets. Department of Energy, *Strategic Transformer Reserve*.

Figure 4: Spare Transformer Bushings Stored at a Utility Facility



Source: GAO. | GAO-23-106180

- **Strategically managing inventory.** To address long lead times for manufacturing, utilities take actions to strategically manage inventory through various practices. These include consolidating design specifications across the utility. For example, officials from one utility told us that they recently finalized a contract for the long-term purchase of transformers. The process took about 15 years to complete because, even internally, it was difficult to agree on specifications for the equipment, according to those officials. However, the result was a consolidation of the types of transformers, and spare components needed, on their system. Other actions

included paying to reserve manufacturing slots by year; relying more heavily on refurbishing transformers; and ordering ahead of schedule to get ahead of long lead times, which may entail retiring older transformers early.

- **Hardening infrastructure.** Every utility we spoke to took steps to prevent damage by hardening their equipment against threats to their system. This included physical hardening to address natural threats (e.g., bolting down transformers to prevent earthquake damage) and security measures to prevent damage from terrorism or vandalism (e.g., cut-proof fencing, security cameras, and ballistic barriers).²⁸

Industry Sharing Efforts

To ensure adequate transformer reserves and possibly reduce individual costs, the utility industry has established a variety of collaborative efforts for sharing spare equipment, including transformers (see table 1). According to the entities managing the efforts described below, participation varies, the majority of participants being larger, investor-owned utilities. Among the utilities we spoke to, there was limited participation among smaller, resource-constrained utilities. Instead, these utilities had mutual aid agreements or other informal sharing efforts with utilities in their region. Officials from some utilities told us that the agreements mostly pertained to sending crews to assist in restoring power in the wake of an outage but could also include equipment sharing.

²⁸In December 2022, FERC directed NERC to evaluate whether the physical security protection requirements in NERC's Reliability Standards (CIP-014-3) should be expanded to include a broader set of facilities than those currently covered. In April 2023, NERC issued a report that stated that it did not recommend such an expansion of the CIP-014-3 applicability criteria. However, the report included a finding that the language of one CIP requirement should be refined to ensure that entities conduct effective risk assessments of their applicable substations. NERC also recommended further evaluation of measures that would be effective in helping to mitigate the impact of physical security attacks, and a joint FERC-NERC technical conference has been scheduled for August 10, 2023 to gather additional data and discuss whether and how those measures should be incorporated into mandatory reliability standards. See North American Electric Reliability Corporation, *Evaluation of the Physical Security Reliability Standard and Physical Security Attacks to the Bulk-Power System* (Washington, D.C.: Apr. 14, 2023).

Table 1: Examples of Voluntary Industry-Based Efforts for Sharing Spare Electricity Grid Equipment

There are a variety of industry efforts for sharing spare equipment, including transformers. Participation in these industry sharing efforts is voluntary and varies, with limited participation among smaller, resource-constrained utilities.

Program	Description	Triggering event	Membership
Spare Transformer Equipment Program (STEP)	Edison Electric Institute’s (EEI) STEP requires participating utilities to maintain (and sometimes acquire) a specific number of transformers to share with other utilities in case of a critical substation failure.	Although participation in STEP is voluntary, sharing transformers is mandatory for participants and is triggered by an act of terrorism and presidential declaration of emergency or grid security emergency.	Transmission-owning entities. As of March 2023, there were 57 asset owners participating, according to EEI.
SpareConnect	EEI’s SpareConnect is a voluntary online networking tool that connects transmission asset owners and operators at participating utilities. Participants who are interested in providing additional information or sharing equipment work directly with each other on the specific terms and conditions of any potential equipment sale or other transaction.	Voluntary sharing during an emergency or other nonroutine failure	Transmission and generation-owning entities. As of March 2023, there were 120 asset owners participating, according to EEI.
Regional Equipment Sharing for Transmission Outage Restoration (RESTORE)	According to the North American Transmission Forum (NATF), the RESTORE program is designed to enhance the resiliency and reliability of the grid by identifying sources and facilitating replacement of equipment (including transformers) following disastrous events. This voluntary program is available to NATF members for an additional cost. RESTORE is intended to be supplemental to other industry programs.	Catastrophic event or physical attack within service territory resulting in loss of load or affecting grid stability	Transmission-owning entities. As of October 2022, RESTORE included 18 total companies (40 individual utilities), according to NATF.
Grid Assurance	Subscription-based initiative that owns and maintains equipment at secure, strategically located warehouses and provides preplanned logistics to expedite equipment transportation to affected sites. Grid Assurance charges a cost-based subscription fee to facilitate subscribers’ ability to recover expenses.	Self-declared qualifying events like physical attacks, electromagnetic pulses, solar storms, cyberattacks, earthquakes, and severe weather events	Transmission-owning entities. According to Grid Assurance, 31 companies covering parts of 28 states subscribed as of March 2023.

Source: GAO analysis of industry information. | GAO-23-106180.

Note: EEI is a trade organization that represents U.S. investor-owned electric companies. NATF represents public and private utilities with assets on transmission systems.

DOE Has Identified Options to Address Supply Chain Constraints but Has Not Developed a Plan to Implement Those Options

Through a variety of efforts, DOE has identified options for addressing the supply chain constraints that affect utilities' ability to ensure adequate transformer reserves. These efforts include various reports, information gathering, and participation in a cross-sector grid coordination team, through which DOE has identified options for federal support. However, the agency has not developed a plan that specifies how to implement these options.

For example, in February 2022, DOE published an assessment that identified and assessed grid supply chain issues, especially those related to LPTs,²⁹ and highlighted options to reduce these vulnerabilities, such as

- short-term efforts aimed at improving domestic GOES manufacturing capabilities, such as capital subsidies in the form of tax credits, tax breaks, or low-interest loans;
- medium-term efforts focused on decreasing the import quantity of LPTs, increasing the capacity utilization of the domestic LPT manufacturers,³⁰ and improving workforce training by funding partnerships with industry and local trade schools to create a broader labor pool; and
- long-term efforts focused on research and development to improve efficiency and modularity, and lower domestic manufacturing costs, of LPTs and related materials.³¹

This assessment fed into another, broader DOE report—also issued in February 2022—that identifies cross-cutting strategies to address supply chain challenges.³² These strategies highlight the need for workforce development and to raise awareness, coordinate, and expand manufacturing programs. According to DOE, such strategies could include expanding federal mechanisms, such as competitive grants, direct loans, and guarantees, possibly in support of GOES and LPT

²⁹Department of Energy, *Electric Grid Supply Chain Review*.

³⁰According to a 2020 Commerce report, there were six companies in the U.S. in 2010 that produced LPTs with a capacity utilization of approximately 40 percent. Capacity utilization is the ratio of output that is produced by a manufacturer to the potential output that could be produced by the manufacturer.

³¹DOE's Transformer Resilience and Advanced Components program aims to develop new designs for transformer components that enhance modularity and standardization.

³²Department of Energy, *America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition* (Washington, D.C.: Feb. 24, 2022).

manufacturing. In April 2023, DOE officials told us that they are working toward implementing these strategies in various ways, including by sharing demand forecast analyses for transformers with stakeholders. They hope that demonstrating a growing demand for transformers will encourage manufacturers to expand production capacity through increased capital investment. While this effort may address aspects of supply chain challenges, DOE has not yet developed a plan to operationalize or provide actionable objectives for the range of options it identified and the strategies it proposed.

Moreover, as of July 2023, agency officials told us that they had initiated plans to complete a congressionally directed assessment related to an inventory of transformers and other equipment and expected the report to be completed by the end of August 2023.³³ According to agency documents, DOE has tasked two national laboratories with providing a technical report on the resilience impacts of extreme events and supply chains on LPTs. The scope of work includes an assessment of the current posture of LPTs from different geographical areas—including current inventory levels, existing programs for resilience, supply chain root cause analysis, and evaluation of gaps in current programs—and the development of potential solutions to impacts related to extreme events and supply chain challenges.

In addition, DOE is working to gather relevant information and recommendations from industry on options for addressing supply chain challenges. For example, in October 2022, DOE issued a request for information to inform how authority under Title III of the Defense Production Act (DPA) could best be used by DOE as a tool to accelerate manufacturing and deployment of energy technologies to bolster national

³³Specifically, the Infrastructure Investment and Jobs Act, enacted in 2021, calls for DOE to carry out an assessment of, among other things, technical specifications, storage locations, quantity, transport, and security of transformers. Pub. L. No. 117-58, § 40103(d), 135 Stat. 429, 929 (2021). The agency is also to assess industry efforts to share transformers and equipment, develop plans for next generation transformers, and plan for surge and long-term manufacturing of, and long-term standardization of, transformer designs. *Id.* Agency officials noted that they are utilizing another provision of the act, regarding modeling and assessing energy infrastructure risk, to aid in the assessment and study delineated in section 40103(d). *See id.* § 40125(d), 135 Stat. at 956.

defense, including transformers.³⁴ DOE also convened a roundtable in August 2022 to gather input and ideas from key industry stakeholders on this topic.

In April 2023, DOE officials told us that the agency had not received funding to execute its DPA authority for grid components but that they were continuing to coordinate with other federal agencies and industry to gather relevant information and to stay current on industry needs. Officials told us that one mechanism for this coordination is the supply chain Tiger Team, a cross-sector coordination effort that is part of the industry-lead Electricity Subsector Coordinating Council. According to council documents, this team is focused on spotting issues and developing tools and resources that stakeholders can use to address supply chain challenges. However, DOE has not yet developed a plan for how to use the information it has gathered from industry to rapidly deploy DPA-funded programs and efforts, should funding become available.

While DOE has collected information and identified strategies for supporting industry efforts to address supply chain constraints, DOE has not developed plans and time frames to implement the strategies nor has it defined clear objectives to guide these actions. Agency officials told us that, while they have various efforts under way, they have yet to establish plans and time frames. *Standards for Internal Control in the Federal Government* state that agency management should define objectives clearly, including plans and time frames for achieving these objectives.³⁵ Without a plan to guide DOE's efforts to further target funding, resources, and technical assistance that could address supply chain challenges, these efforts could stall or remain incomplete, further delaying the implementation of strategies and resources that utilities and other stakeholders need to address these challenges.

³⁴For DOE's notice of availability of its request for information, see 87 Fed. Reg. 61,306 (Oct. 11, 2022). In June 2022, President Biden issued presidential determinations providing DOE with the authority to utilize the Defense Production Act to accelerate domestic production of five key energy technologies, including transformers and grid components.

³⁵[GAO-14-704G](#).

Opportunities Exist for DOE to Better Support Utilities' Participation in Industry Sharing Efforts or Facilitate Other Approaches

Opportunities exist for DOE to better support the participation of smaller utilities in industry sharing efforts to ensure adequate transformer reserves, according to agency reports and utility officials. For example, DOE's 2017 assessment found that the agency should be encouraging and supporting industry approaches, including voluntary transformer-sharing mechanisms aimed at ensuring adequate transformer reserves.³⁶ Specifically, the assessment included a number of DOE action items, including those related to industry sharing efforts:

- (1) supporting the creation of regional organizations to support increased cooperation and resilience, which would then enable all utilities to partake in various spare equipment programs; and
- (2) understanding and providing the nature of technical support and other incentives needed by small utilities, municipals, and cooperatives (co-ops) to enable their participation in industry-led efforts.

However, DOE officials could not identify the agency's actions taken to support smaller utilities, and none of the co-ops or municipals we spoke to participated in existing industry sharing efforts. In some cases, utilities were concerned about the cost and administrative burden of participating in such programs, and others were not aware of these efforts. DOE officials told us that the agency is supposed to play a supporting role in industry efforts, but it was not clear what actions DOE had taken to provide the technical support and incentives needed to increase participation of smaller utilities in industry sharing efforts, as recommended by the 2017 assessment. Furthermore, they said that the agency did not have a plan to identify where additional support is needed or to gather and share information to encourage and support participation in industry efforts to ensure adequate transformer reserves.

According to GAO's *Disaster Resilience Framework*, federal efforts should help decision makers identify and select among disaster risk-reduction alternatives, provide technical assistance to help build the capacity of nonfederal partners, and contribute to an understanding of approaches for estimating returns on investment.³⁷ In addition, the

³⁶Department of Energy, *Strategic Transformer Reserve*.

³⁷GAO, *Disaster Resilience Framework: Principles for Analyzing Federal Efforts to Facilitate and Promote Resilience to Natural Disasters*, [GAO-20-100SP](#) (Washington, D.C.: Oct. 23, 2019).

framework states that federal agencies have the opportunity to create incentives that encourage disaster resilience decision-making for infrastructure while reducing unnecessary administrative burdens associated with federal support. Although smaller and resource constrained compared with investor-owned utilities, co-ops and municipals may be responsible for critical nodes and interconnections whose failure could result in large-scale outages or other cascading effects. Unless DOE develops a plan to target federal support and facilitate equipment sharing or other solutions to ensure adequate reserves among smaller utilities, critical nodes on the grid could remain vulnerable to disasters, attacks, and other hazards.

Conclusions

Congress and federal agencies have sought ways to ensure that utilities have an adequate reserve of transformers in the event of failure. DOE has taken the important steps of gathering relevant information from industry and identifying options and strategies for addressing transformer supply chain constraints, such as long lead times and labor shortages. However, the agency has yet to develop a plan that sets actionable objectives to operationalize these options and strategies. Without such a plan to guide DOE's efforts, those efforts could stall or remain incomplete, further delaying potential solutions and support that utilities and other stakeholders need to address supply chain challenges.

Moreover, the utility industry has undertaken efforts to ensure adequate transformer reserves through various sharing mechanisms, and DOE officials have determined that its optimal role is in supporting such efforts. In particular, DOE has proposed collaborating with the industry to provide increased support and technical assistance to smaller and resource-constrained utilities that may not be participating in industry efforts as much as their larger counterparts. However, DOE has not identified its specific actions taken to support these utilities nor has the agency developed a plan to identify where additional support and information is needed to encourage and support participation. These smaller and resource-constrained utilities may be responsible for critical grid infrastructure that is vulnerable to the same threats as other utilities. Unless DOE develops a plan to target federal support and facilitate equipment sharing or other solutions among smaller utilities, this critical infrastructure could remain vulnerable.

Recommendations for Executive Action

We are making the following two recommendations to DOE:

The Secretary of Energy should establish a plan, including time frames as appropriate, to guide the agency's efforts to develop solutions and

support for addressing transformer supply chain challenges.
(Recommendation 1)

The Secretary of Energy should establish a plan, including time frames as appropriate, to guide the agency’s support for utilities and facilitate greater participation in industry sharing efforts. (Recommendation 2)

Agency Comments and Our Evaluation

We provided a draft of this report to Commerce, DOE, FERC, and the Department of Homeland Security for review and comment. DOE provided written comments, reprinted in appendix I, and partially concurred with our recommendations. DOE, FERC, and the Department of Homeland Security provided technical comments, which we incorporated as appropriate.

In its comments, DOE stated that it partially concurred with our two recommendations. The comment letter describes steps that DOE has taken, or is in the process of taking, to address the recommendations. With regard to the first recommendation that DOE establish a plan to guide the agency’s efforts to address transformer supply chain challenges, DOE stated that it has engaged with relevant stakeholders and highlighted efforts it has undertaken to develop an energy sector industrial base. However, as stated in the report, these efforts are in their preliminary stages and we continue to believe that establishing a plan to guide and operationalize such efforts is needed.

With regard to the second recommendation that DOE establish a plan to guide the agency’s support for utilities and facilitate greater participation in industry sharing efforts, DOE stated that it will develop such a plan and highlighted actions it is considering to collect information and convene stakeholders. We continue to believe that DOE should develop a plan to target federal support and other solutions among smaller utilities, where critical infrastructure could remain vulnerable.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Commerce, the Secretary of Energy, the FERC Chairman, and the Secretary of Homeland Security.

If you or your staff have any questions about this report, please contact me at (202) 512-3841 or ruscof@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix II.

A handwritten signature in black ink that reads "Frank Rusco". The signature is written in a cursive style with a long, sweeping horizontal line extending to the right from the end of the name.

Frank Rusco
Director, Natural Resources and Environment

Appendix I: Comments from the Department of Energy



Department of Energy
Washington, DC 20585

Mr. Frank Rusco
Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G Street, N.W.
Washington, DC 20548

Dear Mr. Rusco:

The U.S. Department of Energy (DOE or Department) appreciates the opportunity to provide a management response to the Government Accountability Office (GAO) draft report titled, *“Electricity Grid DOE Could Better Support Industry Efforts to Ensure Adequate Transformer Reserves and GAO-23-106180.”*

The draft report contained a total of two recommendations. DOE partially concurs with GAO’s recommendations. DOE’s full response to the recommendation is included in the enclosure and provides detailed responses to each recommendation.

GAO should direct any questions to Mara Winn, Deputy Director for Preparedness, Policy, and Risk Analysis, Office of Cybersecurity, Energy Security, and Emergency Response, at Mara.Winn@hq.doe.gov.

Sincerely,

**Puesh M.
Kumar**

Digitally signed by Puesh
M. Kumar
Date: 2023.07.21
15:06:46 -04'00'

Puesh Kumar
Director
Office of Cybersecurity, Energy Security and
Emergency Response

Enclosure

Appendix I: Comments from the Department of Energy

ENCLOSURE

GAO Draft Report: Electricity Grid: DOE Could Better Support Industry Efforts to Ensure Adequate Transformer Reserves GAO-23-106180

Response to Report Recommendations

Recommendation 1: The Secretary of Energy should establish a plan, including times frames as appropriate, to guide the agency's efforts to develop solutions and support for addressing transformer supply chain challenges.

DOE Response: Partial Concur

The Department of Energy (Department or DOE) has taken several efforts to address transformer supply chain challenges, from a public Request for Information (RFI) issued in October 2022 to statutorily require assessment and analysis within section 40125(d) of the Bipartisan Infrastructure Law.

In April 2023, the Department issued a summary of roundtables and RFI responses regarding the use of the Defense Production Act as a tool to accelerate the domestic production of five clean energy technology areas: transformers and grid components; heat pumps; electrolyzers, platinum group metals, and fuel cells for clean hydrogen; solar photovoltaic components; and building insulation.

The Department has initiated engagement with power sector and manufacturers and is taking a leadership role to convene participants from across US Government, the Electricity Subsector, and Transformer Manufacturers to identify issues and work collaboratively address concerns. This effort is an action-oriented, broadly inclusive, and Electricity Subsector and Transformer Manufacturer supported collaboration that is responsive to the issues identified within the report. DOE has identified the primary challenge being workforce challenges and the Department has engaged with other Federal Departments and Agencies to leverage resources to explore apprenticeship programs and other opportunities to address this issue. Workforce challenges are impacting many critical infrastructure sectors.

The Department recognizes the critical importance of transformers to the reliable operation of the Nation's electric grid and is working in coordination with industry owners and operators as well as transformer manufacturers to address issues across the transformer supply chain. The Department will continue to evaluate a requirement for the development of a plan specific to transformer supply chain to address identified issues but would like to highlight the comprehensive efforts that the Department has undertaken to develop an energy sector industrial base through targeted investments as more appropriate solution to address the supply chain issues of transformers.

Estimated Completion Date: June 30, 2024

Appendix I: Comments from the Department of Energy

2

Recommendation 2: The Secretary of Energy should establish a plan, including times as appropriate, to guide the agency's support for utilities and facilitate greater participation in industry sharing efforts.

DOE Response: Partial Concur

The Department will develop a plan that will include timeframes as appropriate to further engage utilities to facilitate greater participation in industry sharing efforts, noting that the Department does not have a regulatory role and cannot require participation in these programs. The Department can utilize voluntary industry forums such as the Electricity Subsector Coordinating Council, to highlight the benefits of these programs, while ensuring the Department does not favor a new or existing transformer sparing programs offered by the private sector over another program.

The Department is considering the use of voluntary information collection surveys to improve Federal decision-making on reported supply chain issues. These information collection efforts will comply with Paperwork Reduction Act data collection requirements and are intended to be completed in coordination with the Department of Homeland Security to protect and secure the information provided by industry stakeholders.

The Department also would like to highlight, that as part of the actions to convene participants identified in the response to Recommendation 1, that the Department has created a Distribution Transformer standardization sub-group, with an objective of this to broaden transformer sharing opportunities under mutual assistance activities.

Estimated Completion Date: June 30, 2024

Appendix II: GAO Contact and Staff Acknowledgments

GAO Contact

Frank Rusco, (202) 512-3841 or ruscof@gao.gov

Staff Acknowledgments

In addition to the contact named above, Janice Ceperich (Assistant Director), Jarrod West (Analyst in Charge), Cindy Gilbert, Gwen Kirby, Patricia Moye, Sara Sullivan, Eamon Vahidi, and Brennan Williams made key contributions to this report.

Related GAO Products

Electricity Grid: DOE Should Address Lessons Learned from Previous Disasters to Enhance Resilience. [GAO-22-105093](#). Washington, D.C.: June 9, 2022.

Electricity Grid Resilience. [GAO-21-105403](#). Washington, D.C.: September 20, 2021.

Electricity Grid Cybersecurity: DOE Needs to Ensure Its Plans Fully Address Risks to Distribution Systems. [GAO-21-81](#). Washington, D.C.: March 18, 2021.

Electricity Grid Resilience: Climate Change Is Expected to Have Far-reaching Effects and DOE and FERC Should Take Actions. [GAO-21-346](#). Washington, D.C.: March 5, 2021.

Electricity Grid: Opportunities Exist for DOE to Better Support Utilities in Improving Resilience to Hurricanes. [GAO-21-274](#). Washington, D.C.: March 5, 2021.

High-Risk Series: Dedicated Leadership Needed to Address Limited Progress in Most High-Risk Areas. [GAO-21-119SP](#). Washington, D.C.: March 2, 2021.

Information Technology: Federal Agencies Need to Take Urgent Action to Manage Supply Chain Risks. [GAO-21-171](#). Washington, D.C.: December 15, 2020.

Critical Infrastructure Protection: Actions Needed to Address Significant Cybersecurity Risks Facing the Electric Grid. [GAO-19-332](#). Washington, D.C.: August 26, 2019.

Critical Infrastructure Protection: Protecting the Electric Grid from Geomagnetic Disturbances. [GAO-19-98](#). Washington, D.C.: December 19, 2018.

High-Risk Series: Urgent Actions Are Needed to Address Cybersecurity Challenges Facing the Nation. [GAO-18-622](#). Washington, D.C.: September 6, 2018.

Critical Infrastructure Protection: Electricity Suppliers Have Taken Actions to Address Electromagnetic Risks, and Additional Research Is Ongoing. [GAO-18-67](#). Washington, D.C.: February 7, 2018.

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