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Response to Request for Information on Securing the United States Bulk-Power System

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October 2026

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PE-A5394-1

About This Paper

On September 9, 2026, the Department of Energy issued a notice requesting information on securing the United States bulk-power system.[1] In this paper, we provide written comments in response to that request for information. This paper is composed of a summary and detailed responses to specific questions posed in the request for information. Our responses are based on our expert knowledge and our recent publications on supply chain risk management for ensuring secure and agile maintenance, operations, and modernization of the bulk-power system.[2]

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Funding

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[1] Office of Cybersecurity, Energy Security, and Emergency Response, Department of Energy, "Securing the United States Bulk-Power System," *Federal Register*, Vol. 91, No. 173, September 9, 2026.

[2] Recent publications include Ismael E. Arciniegas Rueda, Rahim Ali, Frank Andujar Lugo, Karishma V. Patel, and Robin Wang, *Supply Chain, Energy, and AI Nexus: Evaluating AI Energy Supply Chain Vulnerabilities*, RAND Corporation, RR-A4707-1, 2026; Ismael E. Arciniegas Rueda, Austin Smidt, Robin Wang, Hye Min Park, David Gill, and Henri van Soest, *Evaluating Potential Artificial Intelligence Energy Capacity at Different Data Center Sites*, RAND Corporation, RR-A3845-3, 2026; and Ismael E. Arciniegas Rueda, Aisha Najera, Austin Smidt, Robin Wang, Hye Min Park, Henri van Soest, and David Gill, *Expanding U.S. Net Available Power Capacity by 2030: Barriers and Solutions*, RAND Corporation, RR-A3845-2, 2025.

Summary

This response to the Department of Energy's (DOE's) request for information called "Securing the United States Bulk Power System" addresses questions C-2, C-3, F-1, and F-5,[3] subjects on which the authors have published research.[4] We recommend that DOE use publicly available trade data to screen bulk-power system equipment for signs of supply chain vulnerability and foreign source concentration and then focus deeper investigation and any response on the components that the screening flags.

- **Measuring supply chain risk (questions C-2 and C-3):** Using U.S. import data from 2016 through 2025, we constructed indicators of foreign supplier concentration, supply volume contraction, price spikes, and import decline and combined them into a composite vulnerability score for each component. These screening indicators identify components whose import patterns have **shifted with respect to their recent past** and so their supply chains **warrant closer attention**. These screening indicators do not by themselves establish that a shortage exists or measure domestic production, inventories, or demand. When applied to 2025 data, the indicators flagged turbines, steam generation systems, geothermal production well equipment, battery systems, and wind components among generation equipment, and they flagged conductors, reactive power compensation equipment, support structures, and large power transformers among transmission equipment. Generation equipment accounts for a larger share of the highly flagged components than transmission equipment does.
- **Foreign source dependence (question F-1):** Several categories of equipment have imports that are overwhelmingly concentrated in one supplying country. Nuclear reactors, production well equipment, and hydraulic turbines each have a top supplier that accounts for more than 95 percent of U.S. imports. Steam generation systems; boilers; battery systems; heating, ventilation, and air conditioning systems; and voltage regulators also show concentrated sourcing, led by Canada, Mexico, China, and Italy. Concentration in an allied country carries different risk than concentration in a strategic competitor, and import data alone cannot show how much of U.S. demand is met domestically. These results are therefore best read alongside domestic production data before drawing conclusions about material dependence.

[3] Office of Cybersecurity, Energy Security, and Emergency Response, Department of Energy, "Securing the United States Bulk-Power System," *Federal Register*, Vol. 91, No. 173, September 9, 2026.

[4] This research includes Ismael E. Arciniegas Rueda, Rahim Ali, Frank Andujar Lugo, Karishma V. Patel, and Robin Wang, *Supply Chain, Energy, and AI Nexus: Evaluating AI Energy Supply Chain Vulnerabilities*, RAND Corporation, RR-A4707-1, 2026; Ismael E. Arciniegas Rueda, Austin Smidt, Robin Wang, Hye Min Park, David Gill, and Henri van Soest, *Evaluating Potential Artificial Intelligence Energy Capacity at Different Data Center Sites*, RAND Corporation, RR-A3845-3, 2026; and Ismael E. Arciniegas Rueda, Aisha Najera, Austin Smidt, Robin Wang, Hye Min Park, Henri van Soest, and David Gill, *Expanding U.S. Net Available Power Capacity by 2030: Barriers and Solutions*, RAND Corporation, RR-A3845-2, 2025.

- **Policy options to strengthen supply (question F-5, with related data policy options under C-2 and C-3):** Matching a specific mitigation to the risk profile of a particular component is beyond the scope of this paper. The following policy options should be read as a toolkit that DOE and its partners could draw on rather than as a prioritized action plan for any component. The policy options are working through the existing interagency 484(f) process to improve the granularity of trade codes for critical electrical components; considering reasonable disclosure requirements that would support more-complete supply chain mapping; supporting standardization and modular designs through such bodies as the Institute of Electrical and Electronics Engineers (IEEE); strengthening coordination between utilities and large new loads on demand forecasting and procurement; and examining strategic reserves of the critical electrical components that exhibit the most supply chain vulnerabilities, where a transparent selection process and a well-designed cost-recovery mechanism could help support both effectiveness and economic sustainability.[5]

[5] For an inventory of critical electrical grid components, see Chapter 3 and Tables B.1 through B.9 in Arciniegas Rueda, Ali, et al., 2026.

Contents

About This Paper iii
Summary iv
Figures, Tables, and Equation vii

Response to Request for Information on Securing the United States Bulk-Power System 1
Response to Questions C-2 and C-3 1
Questions 1
Scope 1
Data and Methods 2
Evidence and Findings 5
Assumptions and Limitations 7
Alternatives and Policy Options 8
Response to Questions F-1 and F-5 9
Questions 9
Scope 9
Evidence and Findings 9
Assumptions and Limitations 11
Alternatives and Policy Options 12

Abbreviations 14
References 15
About the Authors 17

Figures, Tables, and Equation

Figures

Figure 1. Supply Chain Vulnerability Measurement 2
Figure 2. Process of Matching HTS Codes to Critical Components 4
Figure 3. Composite Supply Chain Vulnerability for FTM Components in 2025 6
Figure 4. Composite Supply Chain Vulnerability for BTM Components in 2025 7
Figure 5. Foreign Source Concentration and Market Structure of FTM Components in 2025 10

Tables

Table 1. Description and Interpretation of Vulnerability Metrics 3
Table 2. Foreign Source Concentration Metrics for Components of Concern in 2025 11

Equation

Equation 1. Supply Chain Composite Vulnerability Metric 4

Response to Request for Information on Securing the United States Bulk-Power System

Response to Questions C-2 and C-3

Questions

- C-2. What evidence should DOE [the Department of Energy] consider when evaluating technical and supply chain risk?
- C-3. What factors best measure the risk of supply disruption?[6]

Scope

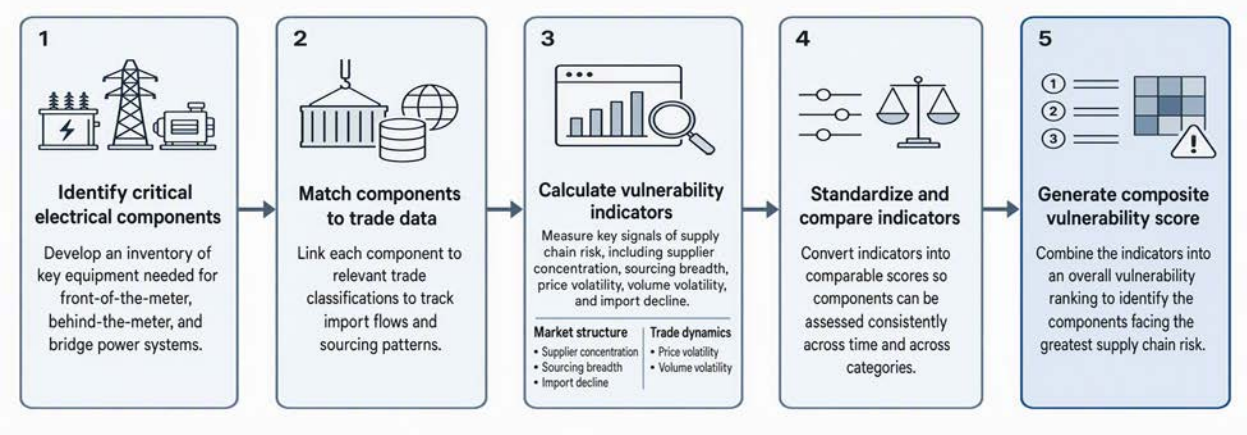
Maintenance, development, and modernization of bulk power systems depend on the *reliable* supply of critical components. From a procurement perspective, a reliable supply chain is characterized by a steady flow of goods, predictable pricing, and dependable sourcing to meet demand and support project needs.[7] Supply chains are particularly vulnerable to unexpected shocks or disruptions when components are harder to substitute, suppliers are concentrated, and pricing or volume flows become unpredictable.

In this section, we focus on changes in foreign supply chains by developing metrics that signal a sudden change in reliability by detecting anomalies in trends in U.S. imports over time and flagging concerns for DOE to further investigate or implement response options. These anomalies include a perceived tightening or contraction in supply volumes, unexpected spikes in prices, and structural changes in market concentration or the number of countries supplying equipment. The focus on anomalies is designed to detect unexpected changes in the character of what makes a supply chain appear reliable. Although the anomalies can thus reflect vulnerabilities that can affect procurement, they can also be responses to changes in domestic production—for example, when imports decline because of onshoring. The assumption is that some metrics will detect fewer anomalies in the future as volume and price eventually stabilize in response, but the signal can still be used to flag a component of concern for further investigation. Our overall approach is presented in Figure 1.

[6] Office of Cybersecurity, Energy Security, and Emergency Response, Department of Energy, "Securing the United States Bulk-Power System," *Federal Register*, Vol. 91, No. 173, September 9, 2026.

[7] Ismael E. Arciniegas Rueda, Rahim Ali, Frank Andujar Lugo, Karishma V. Patel, and Robin Wang, *Supply Chain, Energy, and AI Nexus: Evaluating AI Energy Supply Chain Vulnerabilities*, RAND Corporation, RR-A4707-1, 2026.

Figure 1. Supply Chain Vulnerability Measurement



SOURCE: GPT-Image-2, output from a prompt by the authors, Azure OpenAI, October 2026.

Data and Methods

We used publicly available granular trade data to develop structural and dynamic indicators of vulnerability that were used to identify anomalies in the foreign supply chain over a ten-year period between January 2016 and December 2025 (see Table 1). Because geographic attributes of supply chains take longer to change, we classified the following indicators as structural:

- **Supplier concentration and market structure:** We used the Herfindahl-Hirschman Index (HHI) and counts of numbers of distinct supplying countries to measure market power and exposure to potential single points of failure or country monopolies.[8]

Because changes in prices and volumes more quickly respond to exogenous shocks or influences on supply chains, we classified the following indicators as dynamic:

- **Supply volume contraction:** Coefficients of downside variation track negative deviations from historical average import volumes, indicating risks of supply contracting or disruptions to inventories.
- **Price spikes:** Coefficients of upside variation capture sudden price spikes that introduce budgeting risks, contract renegotiations, and project delays.
- **Import decline:** Year-over-year reductions in physical import quantities indicate tightening supply, order cancellations, upstream production constraints, or substitution of more domestic supplies and technological change.

[8] The HHI is an economic measure of market concentration, calculated by summing the squares of each firm's market share in an industry, indicating competition levels from 0 (perfect competition) to 10,000 (absolute monopoly). It was originally conceptualized by Albert O. Hirschman (*National Power and the Structure of Foreign Trade*, University of California Press, 1945) and independently reformulated by Orris C. Herfindahl (*Concentration in the U.S. Steel Industry*, dissertation, Columbia University, 1950). In our adoption, 0–1,500 mathematically reflects a relatively unconcentrated supply, 1,500–2,500 reflects dependency on four to six major supplier countries, and 2,500–10,000 reflects dependency on three or fewer major supplier countries.

Table 1. Description and Interpretation of Vulnerability Metrics

Indicator	Description	Scale/Units	Interpretation[a]
HHI	Index of supplier concentration across all supplying countries to the United States	0–10,000	Higher → more concentrated import market → more vulnerable
Supplier country count	Number of distinct countries exporting components to the United States (any positive shipment in the same period)	Count (integer)[b]	Higher → more supplier alternatives → less vulnerable
Volume contraction	Measures the variability of import volumes below their mean over time (risk of supply contraction)	Coefficient of downside variation (ratio of downside standard deviation [SD] over the mean)	Higher → potential instability or risk in supply availability → more vulnerable
Price spikes	Measures the variability of import prices above their mean over time (risk of price spikes)	Coefficient of upside variation (ratio of upside SD over the mean)	Higher → greater risk of supply constraints → more vulnerable
Import decline	Sum of negative year-over-year changes in import quantities over three years	Absolute value of reduction in imports	Higher → imports decreasing over time → more vulnerable

[a] Higher indicator values flag potential supply chain vulnerability concerns for investigation rather than established shortages.
[b] The contribution of this metric is inverted in the final calculation because a higher number is associated with less vulnerability.

To make these indicators into measures of anomalies in trends, we converted them to z-scores that compare indicators calculated in one time period for one component against other time periods. Because supplier count is the only metric for which a higher value represents less vulnerability, we inverted the z-score for supplier count before combining it with the other indicators. A high z-score implies that a component's supply could be more at risk to shocks or facing unexpected constraints, **signaling a problem that may warrant monitoring and early intervention**.

Equation 1 shows how a weighted composite score is constructed to combine the market, volume, price, and import decline metrics into one overall supply chain composite vulnerability metric. The time-based z-scores for the dynamic metrics are calculated within each component, comparing a value in one year against the component's own history. The structural market metrics of the HHI and the number of countries exporting to the United States are calculated using peer-based z-scores relative to which side of the meter the components are on. This allows a comparison in relative vulnerability by energy system. HHI and supplier count are weighted by one-eighth, or one-half of one-quarter contribution by an overall market metric to the composite score.[9]

[9] Because we were looking for anomalies across time, we gave more weight in our metric to the dynamic indicators. However, the metric analysis is robust to alternative selections of weights. For an analysis using an equal weight strategy, see Table C.4 in Arciniegas Rueda, Ali, et al., 2026.

Equation 1. Supply Chain Composite Vulnerability Metric

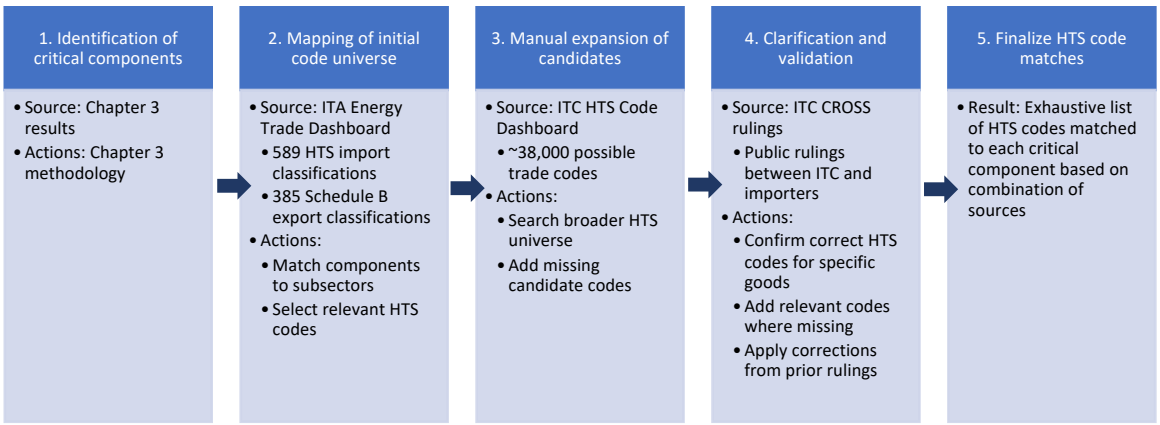
Structural Metrics | Dynamic Metrics

$$Composite\ Vulnerability = \frac{1}{8}z_{HHI} + \frac{1}{8} \cdot \frac{1}{z_{\substack{supplier \\ count}}} + \frac{1}{4}z_{\substack{volume \\ contraction}} + \frac{1}{4}z_{\substack{price \\ spikes}} + \frac{1}{4}z_{\substack{import \\ decline}}$$

NOTE: Z-scores for structural metrics (HHI and supplier count) are calculated on a peer basis, comparing values across components on a given year. Z-scores for dynamic metrics (volume contraction, price spikes, and import decline) are calculated on a time basis, comparing values in a given year with other years.

The data were prepared by cross-referencing Harmonized Tariff Schedule (HTS) codes from the U.S. International Trade Commission (ITC) with data from customs rulings in the Customs Rulings Online Search System (CROSS) database to match critical components to appropriate HTS codes.[10] The International Trade Administration (ITA) also maintains 589 HTS import classifications to track what it deems are critical components for primary energy, energy equipment, and materials for battery supply chains. These classifications are used to ensure external validity and consistency in assigning HTS codes. Figure 2 shows the process through which HTS codes are matched to critical components.[11] Monetary and volume flows are then captured and aggregated into the supply chain vulnerability metrics, using volume and price data from the ITC DataWeb database,[12] which maps U.S. monthly import data to HTS codes.

Figure 2. Process of Matching HTS Codes to Critical Components



SOURCES: Contains data from the following: Box 1: Chapter 3 in Arciniegas Rueda, Ali, et al., 2026; Box 2: International Trade Administration, "U.S. Energy Trade Dashboard," database, undated; Box 3: ITC, undated-c; Box 4: CBP, undated.

[10] ITC, "Harmonized Tariff Schedule," webpage, undated-c; U.S. Customs and Border Protection (CBP), "Customs Rulings Online Search System (CROSS), webpage, undated.

[11] For more detail on the matching process, see Arciniegas Rueda, Ali, et al., 2026.

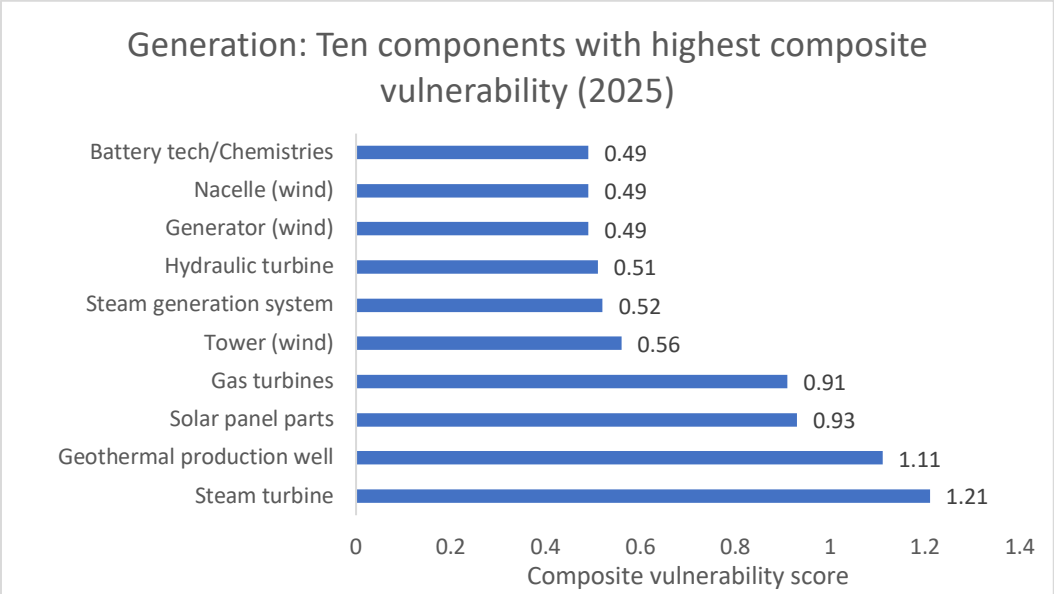
[12] ITC, "DataWeb," webpage, undated-b.

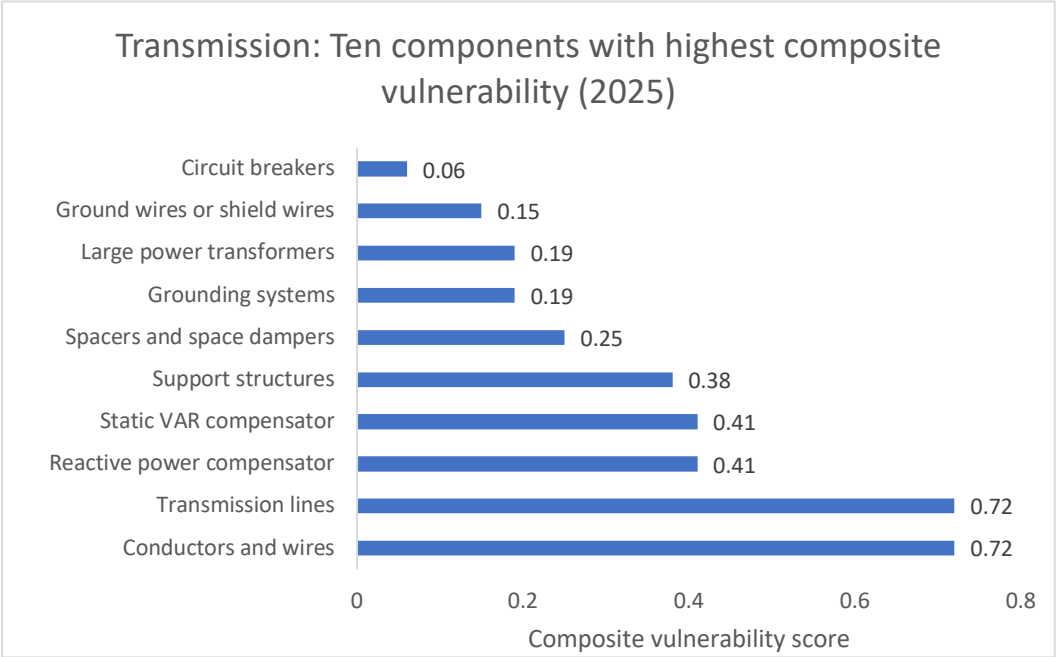
Evidence and Findings

Different sets of critical electrical equipment face different levels and types of supply chain risk. Some components appear vulnerable because U.S. imports are concentrated among a small number of suppliers or countries. Other components experience price spikes or signs of declining availability. Alternatively, a change in these metrics could mean a change in dependence on domestic suppliers. Altogether, the detection of a supply chain vulnerability is meant to flag components of concern for further investigation before designing and selecting response options. Response options include targeted market monitoring, diversifying or substituting suppliers, stockpiling, standardizing requirements, or supporting domestic production. The findings in this section should therefore be read as screening results that flag components that may have vulnerabilities, not as a complete measure of reliability of those components' supply chains.

Figure 3 shows the ten components with the highest composite vulnerabilities among front-of-the-meter (FTM) components that DOE may be concerned with. For instance, among generation components, steam turbines have the highest composite vulnerability scores in 2025. Overall, the components for power generation have a higher proportion of highly vulnerable components compared to components for transmission. This could be due to their more specialized manufacturing requirements.

Figure 3. Composite Supply Chain Vulnerability for FTM Components in 2025



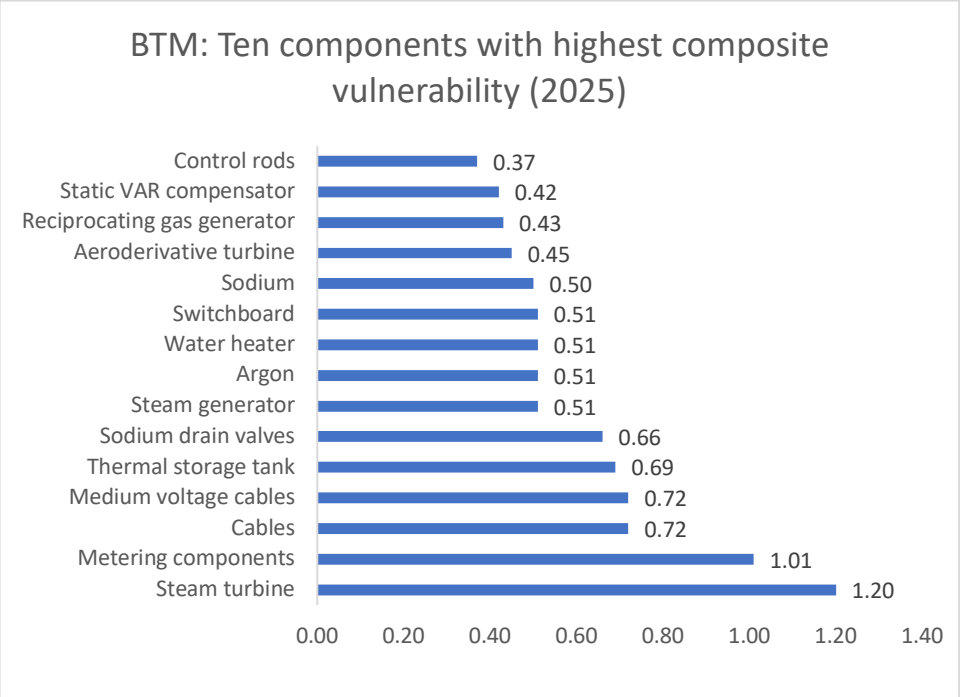


NOTE: HTS codes used for equipment for production wells correspond to drilling and production platforms. In practice, geothermal production drills are likely imported on a component-by-component basis, rather than fully assembled. Accordingly, this is the code that more closely captures a complete platform; HTS codes used to define wind-energy related parts include shared classifications across nacelles, tower, and wind generators; HTS codes across transmission lines, conductors, and wires are the same. VAR = volt-ampere reactive.

Figure 4 shows the top ten components facing the highest composite vulnerabilities in 2025 among behind-the-meter (BTM) components. The findings for the most vulnerable BTM components are included because overlaps of their criticality and demand with FTM components

may put additional pressure on key components. Turbines, cables,[13] steam generators, and static VAR compensators rank among the most vulnerable components across both sides of the meter. Metering components, thermal storage tanks, sodium drain valves, such chemicals as argon and sodium, water heaters, switchboards, reciprocating gas generators, and control rods also rank among the components with the highest composite vulnerability scores.

Figure 4. Composite Supply Chain Vulnerability for BTM Components in 2025



NOTE: HTS codes used to define cables and medium voltage cables include shared classifications.

Assumptions and Limitations

The three main limitations of this analysis are data availability, quality, and structure. These limitations have prompted our policy options for DOE to consider setting data requirements to better monitor, manage, and respond to supply chain risks.

First, we assume that individual imports of critical components aggregated into annual customs data can be used to detect changes in trends, signifying a vulnerability or change in supply chain reliability. The customs processes to obtain these data involve corrections, retractions, and reassignments of HTS codes, quantities, and values, affecting data quality.

Second, by relying on ITC trade data, our analysis uses the most suitable publicly available source for tracking U.S. trade flows, but it effectively infers vulnerabilities for goods that cross borders, omitting intrafirm trade, domestic production, stockpiles, and non-U.S. sourcing that

[13] Cables and transmission lines are imported under similar HTS codes.

manufacturers might rely on as buffers. This is why we emphasize this method as a means of flagging components of concern for further investigation. In addition, the focus on U.S. imports means that market concentration and number of countries are being measured with respect to the United States as a subset of global trade flows. These import-based indicators are useful for screening how diversified U.S. sourcing is and for identifying components that warrant further investigation, but these indicators are not by themselves a sufficient measure of the overall reliability of a U.S. supply chain. A measure of substitutability or resilience could be the total number of countries that export the component to all countries.

Third, when trade codes are applied to shipments, they can range from highly specific to a broad "catchall" for families of goods, often mixing items used in power systems with other applications. Because these codes underpin how movements in imports of components are observed, the accuracy of trade-code-to-component mappings directly affects the ability to trace supply chains specific to the power grid.

Alternatives and Policy Options

- **DOE could work with the interagency Committee for the Statistical Annotation of Tariff Schedules (484[f] Committee)[14]—comprising ITC, CBP, and the U.S. Census Bureau—to assess the feasibility and value of increasing the specificity of selected HTS and Schedule B statistical reporting categories at the ten-digit level.** Building on the methodology in Figure 2,[15] DOE could identify electrical components for which existing trade classifications limit visibility into supply chain vulnerabilities and provide technical input on characteristics that could distinguish those components, such as voltage class, size, material composition, or function. Through the existing 484(f) process, ITC, CBP, and the Census Bureau could evaluate proposed statistical breakouts for consistency with the tariff schedule, administrability, and trade-data requirements. Where feasible, more-granular statistical categories could improve the government's ability to monitor imports and exports of critical electrical components and support more-precise supply chain vulnerability assessments and potential interventions.
- **Supply chain mapping capabilities could be enhanced by designing reasonable disclosure requirements for firms transacting or handling key critical components.** Trade codes only capture a subset of the supply chain in which goods move across borders, but they also represent the best publicly available data suited for this analysis. Mandated disclosures could provide the basis for more-comprehensive supply chain mappings and vulnerability assessments. Such disclosures have precedent in this sector. In its 2020 Section 232 investigation of transformer imports, the Department of Commerce issued mandatory surveys under Section 705 of the Defense Production Act to 87 companies producing or distributing electrical steel, transformer cores, and power and

[14] ITC, "484(f) Committee," webpage, undated-a.

[15] More details are in Arciniegas Rueda, Ali, et al., 2026.

distribution transformers, collecting data on imports, exports, production, capacity utilization, and operating status that were not otherwise publicly available.[16]

Response to Questions F-1 and F-5

Questions

- F-1. Which categories of bulk-power system electric equipment, critical components, software, firmware, production tooling, testing capability, critical minerals, or other supply chain inputs are materially dependent on foreign sources or concentrated in a limited number of countries or suppliers?
- F-5. What additional actions could improve the availability and resilience of secure supply?[17]

Scope

We focused on the market structure component of the composite supply chain vulnerability measured in response to questions C-2 and C-3 to identify categories of critical components for which supply to the United States is concentrated in a limited number of countries. The analysis depends on publicly available granular trade data collected from ITC over a ten-year period between January 2016 and December 2025. To identify foreign market concentration, we used the HHI and counts of numbers of distinct supplying countries to the United States to measure market power and exposure to potential single points of failure or country monopolies.[18]

Evidence and Findings

Figure 5 provides a closer look at foreign supplier concentration and market structure across all FTM critical component exports to the United States. The number of countries (y-axis) is plotted against the HHI (x-axis). The higher the share of imports arriving from the dominant supplying country, the larger the plot point, and a vertical line is drawn at 2,500 where HHI is considered high market concentration, suggesting a potential need to consider diversification. Among the components of concern in Table 2 are nuclear reactors, production well drilling

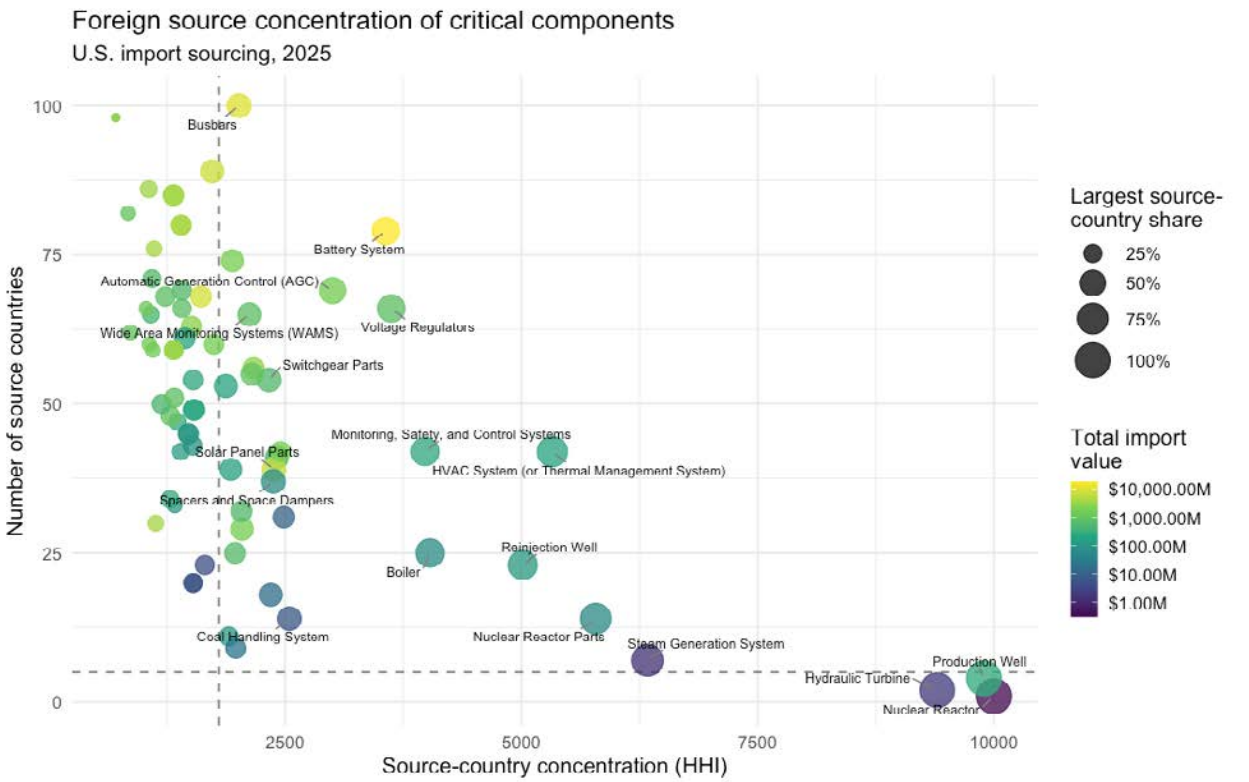
[16] The surveys were conducted under the Defense Production Act of 1950, as amended, Section 705 (50 U.S.C. § 4555). See U.S. Department of Commerce, Bureau of Industry and Security, Office of Technology Evaluation, *The Effect of Imports of Transformers and Transformer Components on the National Security*, October 15, 2020, pp. 30–31.

[17] Office of Cybersecurity, Energy Security, and Emergency Response, Department of Energy, 2026.

[18] The HHI is an economic measure of market concentration, calculated by summing the squares of each firm's market share in an industry, indicating competition levels from 0 (perfect competition) to 10,000 (absolute monopoly). It was originally conceptualized by Albert O. Hirschman (*National Power and the Structure of Foreign Trade*, University of California Press, 1945) and independently reformulated by Orris C. Herfindahl (*Concentration in the U.S. Steel Industry*, dissertation, Columbia University, 1950). In our adoption, 0–1,500 mathematically reflects a relatively unconcentrated supply, 1,500–2,500 reflects dependency on four to six major supplier countries, and 2,500–10,000 reflects dependency on three or fewer major supplier countries.

equipment, and hydraulic turbines because of their highly concentrated supplier bases. The difference between the share of imports coming from the top three countries and the top country is between 0 and 3 percentage points, indicating a high supplier concentration in one country. Steam generation systems and boilers are also considered of concern because of high HHI scores despite coming from more source countries.

Figure 5. Foreign Source Concentration and Market Structure of FTM Components in 2025



NOTE: HVAC = heating, ventilation, and air conditioning; M = million.

Table 2 further evaluates a subset of components, with the most concerning levels of supplier concentration and market structure identified. The difference between the share of imports coming from the top three supplier countries and the share of imports coming from the top supplier country is used to measure how diversified sourcing is across the top supplier countries. The top suppliers among components of concern appear to be Canada, South Korea, the Czech Republic, Mexico, Italy, and China, with each country accounting for more than 50 percent of the share of a respective component. At the same time, the foreign supplier market concentration analysis should be complemented with domestic production data to further understand what components are materially dependent on foreign versus domestic sources beyond understanding what foreign supply is concentrated in a one or a few countries. Additionally, when assessing foreign supplier concentration risks, it is important to consider that different countries are more or less at risk of exposure to different types of hazards. Recent DOE discussions highlight unique

hazards, including cross-border logistic stress, jurisdiction-specific restrictions, disaster risks, strategic competition, competing demand, limited surge capacity, volatile commodity pricing, long shipping distances, and geopolitical tensions.[19] For example, Mexico has limited ability to rapidly scale production in some sectors and remains dependent on imported inputs, meaning that it often serves as an assembly and export platform for goods destined for the United States.[20] Meanwhile, China continues to play both direct and indirect roles in many critical supply chains, even as U.S.-China tensions have potential to reshape sourcing strategies.

Table 2. Foreign Source Concentration Metrics for Components of Concern in 2025

Component	Top Supplier Country	Top 1 Supplier Country Share	Top 3 Supplier Countries Share	Difference Between Top 3 and Top 1 Country Share	Number of Supplier Countries	HHI
Nuclear reactors	Canada	100.0%	100.0%	0.0%	1	10,000
Production well equipment	South Korea	99.5%	99.9%	0.5%	4	9,894
Hydraulic turbines	Czech Republic	96.9%	100.0%	3.1%	2	9,400
Steam generation systems	Canada	78.8%	92.3%	13.5%	7	6,336
Boilers	Canada	61.6%	77.9%	16.2%	25	4,033
Monitoring, safety, and control systems	Canada	61.3%	78.1%	16.8%	42	3,981
HVAC systems	Mexico	71.5%	89.1%	17.6%	42	5,328
Automatic generation control	Mexico	52.3%	70.5%	18.2%	69	3,004
Nuclear reactor parts	Italy	74.6%	92.9%	18.4%	14	5,788
Battery system	China	57.4%	78.0%	20.6%	79	3,566
Voltage regulators	Mexico	57.6%	78.7%	21.1%	66	3,624
Reinjection well	China	65.3%	95.4%	30.1%	23	5,015

Assumptions and Limitations

The analysis in this section is based on the same data used in the analysis in response to questions C-2 and C-3—including data availability, quality, and structure. Briefly, by relying on ITC trade data, the analysis uses the most suitable publicly available source for tracking trade flows, but it effectively infers vulnerabilities for goods that cross borders, omitting intrafirm

[19] Department of Energy, Office of Electricity, *Advanced Transformers Workshop Report*, October 2023.

[20] Luisa Rivera-Basques and Maria Fernanda Higuera-Cota, "Integration into Global Value Chains: Evidence from Mexico, 1995–2020," *Economies*, Vol. 14, No. 1, 2026.

trade, domestic production, stockpiles, and non-U.S. sourcing that manufacturers might rely on as buffers. In addition, when trade codes are applied to shipments, they can range from highly specific to a broad "catchall" for families of goods, often mixing items used in power systems with other applications. Because these codes underpin how movements in imports of components are observed, the accuracy of trade-code-to-component mappings directly affects the ability to trace supply chains specific to the power grid.

Specific to this foreign supplier market concentration analysis, the ITC data only track U.S. imports and exports. This means that our analysis is tracking market concentration of suppliers to the United States. Global trade data on imports and exports could be used to compare U.S. sourcing with global sourcing,[21] helping to identify substitute supplier countries and offer some visibility into how primary supplier countries depend on other foreign countries for sourcing.

Alternatives and Policy Options

Matching a specific mitigation to the risk profile of a particular component is beyond the scope of this paper. The options below should be read as a toolkit that DOE and its partners could draw on rather than as a prioritized action plan for any component. These options draw on the foreign source concentration findings above, on related research, and on the authors' judgment, and each would require further evaluation of feasibility, cost, and fit with the responsibilities of the organizations involved.

- **DOE could work with consensus-driven organizations, such as the Institute of Electrical and Electronics Engineers (IEEE), the National Electrical Manufacturers Association, and the American National Standards Institute, and with utilities to develop and promote adoption of codes and standards that encourage standardization, such as the IEEE C57 series of transformer standards.** Standardization of designs (e.g., the maximum diameter for wind turbines) facilitates production by reducing complexity and leading to new entrants, reducing market concentration on components with high HHI scores.[22] Development of modular approaches to equipment (e.g., transformers) can also reduce assembly times. A National Infrastructure Advisory Council report identifies the lack of standardization as a barrier to increasing production to address the scarcity of transformers.[23]
- **Mechanisms for collaboration and transparency between utilities and the introduction of large new loads could be developed to improve load forecasting and to better manage procurement of scarce equipment (e.g., turbines).** Although some supply chain threats may be out of the control of utilities and data centers, the consequences of these threats could be mitigated by more collaboration. Utilities have a

[21] E.g., United Nations Comtrade Database, homepage, undated.

[22] National Infrastructure Advisory Council, *Addressing the Critical Shortage of Power Transformers to Ensure Reliability of the U.S. Grid*, June 2024.

[23] National Infrastructure Advisory Council, 2024.

long history of collaborating with each other to address resiliency challenges.[24] For example, *supply chain taskforces* can forecast demand and prioritize the procurement of critical components; *joint procurement pools* increase purchasing power for critical electrical infrastructure components that multiple actors require, reducing procurement times; [25] and pilots for collaboration agreements between utilities and developers have been recently announced.[26]

- **DOE and the Federal Energy Regulatory Commission could coordinate with utilities and new large loads, such as data centers, to identify and maintain reserves of the most-critical grid components to buffer against supply chain shocks.** A transparent selection process and an appropriately designed cost-recovery mechanism could help support the effectiveness and economic sustainability of such reserves. Proven models for strategic reserves across critical sectors provide guidance on building technical operations. These models include Grid Assurance for transmission equipment,[27] the Strategic Petroleum Reserve for energy security, the National Defense Stockpile for critical minerals, and the Strategic National Stockpile for medical supplies.

[24] An example of these collaborative solutions across utilities is Grid Assurance, "Grid Resilience Solution," webpage, undated-b.

[25] John D. Wilson, Sophie Meyer, Zach Zimmerman, and Rob Gramlic, *Power Demand Forecasts Revised Up for Three Years Running, Led by Data Centers*, Grid Strategies, Connected Grid Initiative, November 2025.

[26] Ethan Howland, "With Blackstone Venture, PPL Is 'Biggest Winner' from Data Center Summit," Utility Dive, July 17, 2025.

[27] Grid Assurance, homepage, undated-a.

Abbreviations

AI	artificial intelligence
BTM	behind-the-meter
CBP	U.S. Customs and Border Protection
CROSS	Customs Rulings Online Search System
DOE	Department of Energy
FTM	front-of-the-meter
HHI	Herfindahl-Hirschman Index
HTS	Harmonized Tariff Schedule
HVAC	heating, ventilation, and air conditioning
IEEE	Institute of Electrical and Electronics Engineers
ITA	International Trade Administration
ITC	U.S. International Trade Commission
SD	standard deviation
VAR	volt-ampere reactive

References

Arciniegas Rueda, Ismael E., Rahim Ali, Frank Andujar Lugo, Karishma V. Patel, and Robin Wang, *Supply Chain, Energy, and AI Nexus: Evaluating AI Energy Supply Chain Vulnerabilities*, RAND Corporation, RR-A4707-1, 2026. As of October 6, 2026: https://www.rand.org/pubs/research_reports/RRA4707-1.html

Arciniegas Rueda, Ismael E., Aisha Najera, Austin Smidt, Robin Wang, Hye Min Park, Henri van Soest, and David Gill, *Expanding U.S. Net Available Power Capacity by 2030: Barriers and Solutions*, RAND Corporation, RR-A3845-2, 2025. As of October 8, 2026: https://www.rand.org/pubs/research_reports/RRA3845-2.html

Arciniegas Rueda, Ismael E., Austin Smidt, Robin Wang, Hye Min Park, David Gill, and Henri van Soest, *Evaluating Potential Artificial Intelligence Energy Capacity at Different Data Center Sites*, RAND Corporation, RR-A3845-3, 2026. As of October 8, 2026: https://www.rand.org/pubs/research_reports/RRA3845-3.html

CBP—*See* U.S. Customs and Border Protection.

Defense Production Act of 1950, as amended; Section 705, Investigations; Records; Reports; Subpoenas; Right to Counsel (at U.S. Code, Title 50, Section 4555).

Department of Energy, Office of Electricity, *Advanced Transformers Workshop Report*, October 2023. As of October 6, 2026: https://netl.doe.gov/sites/default/files/2023-10/Advanced%20Transformers%20Workshop%20Report.pdf

Grid Assurance, homepage, undated-a. As of September 30, 2026: https://gridassurance.com/

Grid Assurance, "Grid Resilience Solution," webpage, undated-b. As of October 6, 2026: https://gridassurance.com/grid-resilience-solution/

Herfindahl, Orris C., *Concentration in the U.S. Steel Industry*, dissertation, Columbia University, 1950.

Hirschman, Albert O., *National Power and the Structure of Foreign Trade*, University of California Press, 1945.

Howland, Ethan, "With Blackstone Venture, PPL Is 'Biggest Winner' from Data Center Summit," Utility Dive, July 17, 2025.

International Trade Administration, "U.S. Energy Trade Dashboard," database, undated. As of May 27, 2025:
https://www.trade.gov/data-visualization/us-energy-trade-dashboard

ITC—*See* U.S. International Trade Commission.

National Infrastructure Advisory Council, *Addressing the Critical Shortage of Power Transformers to Ensure Reliability of the U.S. Grid*, June 2024.

Office of Cybersecurity, Energy Security, and Emergency Response, Department of Energy, "Securing the United States Bulk-Power System," *Federal Register*, Vol. 91, No. 173, September 9, 2026. As of October 6, 2026:
https://www.federalregister.gov/documents/2026/09/09/2026-18370/securing-the-united-states-bulk-power-system

Rivera-Basques, Luisa, and Maria Fernanda Higuera-Cota, "Integration into Global Value Chains: Evidence from Mexico, 1995–2020," *Economies*, Vol. 14, No. 1, 2026.

U.S. Customs and Border Protection, "Customs Rulings Online Search System (CROSS)," webpage, undated. As of September 28, 2026:
https://rulings.cbp.gov/home

U.S. Department of Commerce, Bureau of Industry and Security, Office of Technology Evaluation, *The Effect of Imports of Transformers and Transformer Components on the National Security*, October 15, 2020. As of October 6, 2026:
https://www.bis.gov/media/documents/redacted-goes-report-updated-10-26-21.pdf

U.S. International Trade Commission, "484(f) Committee," webpage, undated-a. As of September 30, 2026:
https://www.usitc.gov/harmonized_tariff_information/484_f_committee

U.S. International Trade Commission, "DataWeb," webpage, undated-b. As of September 28, 2026:
https://dataweb.usitc.gov/trade/search/Export/HTS

U.S. International Trade Commission, "Harmonized Tariff Schedule," webpage, undated-c. As of September 28, 2026:
https://hts.usitc.gov/

United Nations Comtrade Database, homepage, undated. As of October 6, 2026:
https://comtrade.un.org/

Wilson, John D., Sophie Meyer, Zach Zimmerman, and Rob Gramlic, *Power Demand Forecasts Revised Up for Three Years Running, Led by Data Centers*, Grid Strategies, Connected Grid Initiative, November 2025.

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