Large Load Literature Review

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ENERGY TECHNOLOGIES AREA
BERKELEY LAB

Large Load Literature Review - 2025

- Reviewed more than 90 publications and categorized into 12 themes.
  - Load forecasting
  - Artificial Intelligence (AI) and infrastructure
  - Reliability and resource adequacy
  - Large load interconnection
  - Demand flexibility
  - Generation
  - Co-location
  - Large load tariffs
  - Policy options
  - Maps and tools
  - Design and operations
  - Data sources

- Each report is linked and has a short description and key takeaways.
- The reports are organized in chronological order, with the newest reports listed first. Ongoing activities (e.g., task forces, working groups) are listed last.
- Beginning in September 2025, there is a 'Data Sources' section that identifies data and inputs used in report analysis. Reports that have information on supporting data sources are marked with an asterisk (*).
- The final 2025 report is located here.

Large Load Literature Review - 2026

- Reviewed 35 publications and categorized into 11 themes.
  - Rate impacts of data centers
  - Utility models & markets
  - Interconnection
  - Tariffs
  - Demand flexibility
  - Load forecasting
  - Data center siting and infrastructure
  - Reliability and resource adequacy
  - Policy options
  - Generation
  - Design and operations

- Each report is linked and has a short description and key takeaways.
- This is a living document and will continue to be updated.
- There is a companion document that identifies data sources used in reports with quantitative analysis, available here.

New this month

1. Understanding the Drivers of Rising Electricity Rates and the Role of Data Centers (Energy+Environmental Economics (E3), May 2026)
2. Have Data Centers Raised Your Electric Bill? Causal Evidence from the United States (Electric Power Research Institute (EPRI), June 2026)
3. Federal Transmission Pricing Volume 2: Options for Ensuring Affordability and Reliability in an Era of High Load Growth (Grid Strategies, June 2026)
4. Interconnection Processes for Large Loads (Energy Systems Integration Group (ESIG), June 2026)
5. Federal Transmission Pricing Volume 1: The Evolution of Current Policies and Practices (Grid Strategies, May 2026)
6. United States Data Center Energy Usage Report: 2025 Update (Lawrence Berkeley National Laboratory, June 2026)

New this month

7. The Role of the U.S. Electric Distribution System in Serving Data Center and Other Large Loads (National Laboratory of the Rockies, May 2026)
8. 2026 Summer Reliability Assessment (North American Electric Reliability Corporation (NERC), May 2026)
9. Large Loads: Behaviors, Capabilities, and Limitations (Energy Systems Integration Group (ESIG), July 2026)
10. Reliability Impacts of Large Loads (Energy Systems Integration Group (ESIG), July 2026)

Rate Impacts of Data Centers

Rate Impacts of Data Centers (1)

[Processing Power: The Effect of Data Centers on Wholesale Electricity Markets (Federal Reserve Bank of Dallas, March 2026)]

- This paper quantifies the impact of AI-driven data center expansion on wholesale electricity markets across the continental United States, using an hourly, unit-level least-cost dispatch model to estimate effects on generation costs, and competitive wholesale prices.
- The analysis finds that existing data centers have already increased wholesale generation costs by 5–15% and wholesale energy prices by 2–6% on average nationwide from 2021 to 2025.
- There are substantially larger effects in regions with more data centers such as northern Virginia, where price increases exceeded 10%. Texas (ERCOT), despite having the second-highest data center concentration, saw minimal price impact due to aggressive supply buildout.
- The authors conclude that broader transmission investment and market integration can reduce localized price impacts by allowing lower-cost idle generation to serve constrained regions.

Rate Impacts of Data Centers (2)

Retail Electricity Price Trends and Drivers: Data Update – 2026 Edition (LBNL, April 2026)

- This report update summarizes publicly available information on retail electricity price trends and drivers at the national, regional, and state levels. The data presented are through 2025. The update intends to serve as a reference document and provide a factual basis for assessing recent changes in retail electricity prices and key underlying drivers.
- The update covers: (1) trends in recent retail prices; (2) drivers of year-over-year price changes from 2024 to 2025; (3) drivers of price changes over a longer period, specifically 2019 to 2025; (4) focused attention to the varied impacts of load growth on prices; and (5) data on recent rate increase requests and regulatory approval of those requests.
- Findings include
  - National-average nominal retail prices have spiked in recent years, though the increases have largely tracked inflation. All-sector average retail prices increased in 2025 versus 2024 by 5.3% in nominal terms and 2.6% in inflation adjusted terms.
  - Residential customers may have benefited from load growth from 2019 to 2025 in some states, but the relationship is less clear and may change.
  - A case study on PJM shows their capacity prices increased due to multiple factors, including load growth from data centers. Capacity price increases are only one of the contributors to retail price increases.

Rate Impacts of Data Centers (3)

Impacts of Large Loads on Electricity Rates: A Primer (Energy Systems Integration Group, May 2026)

- This report provides an overview of the fundamental mechanics of electricity ratemaking to explicitly map how and why a new large load affects the rates of existing, everyday customers.
- It outlines five factors that determine rate impacts:
  - Available system headroom: under sufficient existing generation and transmission capacity, new large loads can be served with minimal incremental capital investment, hence helping recover existing fixed costs across a broader base.
  - Incremental vs. Embedded Costs: Rate direction is influenced y whether incremental costs of new infrastructure are lower or higher than the system's average embedded cost.
  - Existing customer market exposure: Elaborates influence of large loads on generation capacity prices in wholesale markets and its impact on unhedged customers.
  - Load forecast accuracy: Describes the risk of underutilized or stranded assets.
  - Tariff design for large loads: This covers tariff instruments like minimum bills, capacity reservation charges, and exit fees, which can protect existing ratepayers from cost-shifting.
- Key takeaway of the report is that rate impact of large loads is not always fixed in either direction; rather, it is a function of utility system conditions, market dynamics, regulatory frameworks, and rate design.

Rate Impacts of Data Centers (4)

[Understanding the Drivers of Rising Electricity Rates and the Role of Data Centers (Energy+Environmental Economics (E3), May 2026)]

- This report evaluates the relationship between data center load growth and electricity rate outcomes by reviewing recent electricity rate trends, empirical studies, and the broader drivers of utility costs.
- It finds that rising electricity rates are driven by inflation, natural gas price volatility, wildfire mitigation, and grid modernization, rather than just by load growth.
- Another finding is that quantitative studies show no historical evidence that data centers are subsidized by other utility customers; instead, high load factors can generate surplus utility revenues that spread fixed costs and put downward pressure on retail rates.
- The report highlights that in the PJM wholesale market, data center load growth accounted for approximately 50% of the recent capacity price increase, with the rest driven by power plant retirements and market design changes.

Rate Impacts of Data Centers (5)

[Have Data Centers Raised Your Electric Bill? Causal Evidence from the United States (Electric Power Research Institute (EPRI), June 2026)]

– This study estimates price changes that have been caused by data centers utilizing an econometric approach.

– The authors of the study estimate that data center growth modestly lowered average residential retail electricity rates by approximately 0.4% for every 10% increase in data center load from 2015 to 2024.

– This price-decreasing effect is attributed to the massive fixed costs of the power sector - adding durable demand allows for fixed transmission, distribution, and generation capital costs to be amortized over a larger amount of kilowatt-hours.

– The researchers caution that this historical benefit depends on unconstrained supply, and severe supply constraints (such as transformer or gas turbine shortages) could reverse the effect and temporarily increase average costs.

Rate Impacts of Data Centers (6)

[Federal Transmission Pricing Volume 2: Options for Ensuring Affordability and Reliability in an Era of High Load Growth (Grid Strategies, June 2026)]

- This report evaluates twelve transmission pricing policy options across four categories aimed at ensuring all transmission customers, including new data centers, pay their fair share of transmission costs.
- A key finding is that serving new large loads does not inherently raise electricity rates - if properly planned, large loads can spread fixed system costs over more units of demand, potentially lowering average costs for existing customers.
- The study also finds that grid connection remains the preferred choice for large loads to achieve long-term reliability and scale, even as they pursue temporary on-site generation workarounds.
- The authors recommend that transmission pricing should incorporate upfront funding, long-term service commitments, and exit charges to mitigate stranded cost risks if speculative loads delay or fail to materialize.

Utility Models & Markets

Utility Models & Markets (1)

Bridging the Load Gap (Alliance to Save Energy (ASE), The Ad Hoc Group, January 2026)

- This report explores the Bring Your Own Distributed Capacity (BYODC) model, a collaborative framework where large load customers fund incremental investments to create capacity headroom. In return the customer receives a capacity credit for the independently verified incremental capacity contributions.
- Demand-side management programs (demand response and energy efficiency programs) are the focus of the BYODC model.
- ASE conducted interviews with nine investor-owned and public power utilities as part of its report methodology. Utilities were selected to represent the breadth of geographic regions and market structures.
- Key interview findings highlight the need for collaborative design of the program portfolio between utilities and large load customers. Another consideration is to accurately and independently verify capacity accreditation of the demand-side investments to ensure that the capacity reductions sufficiently avoid or defer infrastructure investments.
- Based on interview findings, the authors state that this framework can support utility business goals by helping them secure high-value large loads within their territory, while ensuring energy affordability for customers by allowing utilities to defer costly capital investments.

Utility Models & Markets (2)

[2026 Data Center Power Report (Bloom Energy, January 2026)]

- This report explores market shifts driven by data center growth in the AI era.
- One key finding is that data center growth is being reallocated geographically toward power-advantaged regions. For example, Texas is poised to become the nation’s leading data center market within three years, projected to exceed 40 GW of IT load capacity by 2028, representing a 142% increase in its market share relative to today.
- Several other states are gaining momentum in their relative market share, due to the speed of securing large blocks of power, as cited in the report.
- Another finding is that hyperscalers and colocation providers are increasingly integrating permanent onsite power into their long-term strategies, with 33% developers expecting that data centers will be powered by 100% onsite generation by 2030.

Utility Models & Markets (3)

[Large Load Considerations Issue Paper (California ISO, January 2026)]

- This paper describes the role of California Independent System Operator (CAISO) in integrating large loads on the grid and how that interplays with state and federal regulators, transmission service providers, utility distribution companies, load-serving entities (LSEs), and customers.
- It outlines the current treatment of large load planning elements, including transmission and resource planning, service offerings, cost allocation, technical standards, and operational requirements.
- This comes at a time of growing energy demand from data centers. The California Energy Commission (CEC) forecasts data center load in the ISO grid to increase by 1.8 GW by 2030.

Utility Models & Markets (4)

[Balancing Speed and Affordability: The NIPSCO GenCo Model for Hyperscale Load Growth (Electric Power Research Institute (EPRI), February 2026)]

- This document summarizes the long-term contract between Northern Indiana Public Service Company LLC (NIPSCO) and Amazon. This agreement involves serving 2.4 GW of data center load in northern Indiana by 2032.
- The new load arising from data centers is comparable to NIPSCO's entire existing non-data-center load.
- NIPSCO's affiliate, NIPSCO Generation LLC (GenCo), will invest $7 billion in 3 GW in new infrastructure.
- The study states that this deal structure can enable utilities to serve large data center loads without shifting costs onto existing customers. Further, creating the GenCo affiliate model can increase speed-to-market for data center customers by reducing regulatory approval timelines.

Utility Models & Markets (5)

[Processing Power: The Effect of Data Centers on Wholesale Electricity Markets (Federal Reserve Bank of Dallas, March 2026)]

- This paper quantifies the impact of AI-driven data center expansion on wholesale electricity markets across the continental United States, using an hourly, unit-level least-cost dispatch model to estimate effects on generation costs, and competitive wholesale prices.
- The analysis finds that existing data centers have already increased wholesale generation costs by 5–15% and wholesale prices by 2–6% on average nationwide from 2021 to 2025.
- There are substantially larger effects in regions hosting major data center corridors such as northern Virginia, where price increases exceeded 10%. Texas (ERCOT), despite having the second-highest data center concentration, saw minimal price impact due to aggressive supply buildout.
- The authors conclude that broader transmission investment and market integration can reduce localized price impacts by allowing lower-cost idle generation to serve constrained regions.

Interconnection

Interconnection (1)

[Large Load Performance Requirements (Energy Systems Integration Group (ESIG), February 2026)]

- This report provides guidance for system operators and utilities as they develop interconnection performance requirements for large electronic loads tailored to their own jurisdictions.
- It recommends a minimum set of performance requirements for large load facilities to safeguard power system reliability.
- These recommendations cover various categories, including frequency ride-through standards, ramp rate requirements, and enhancing modeling practices.
- The report lists specific examples of requirements from various system operators(ISOs)/regions:
  - Fingrid (Finland): Requires large loads to ride through 10 bolted faults of 100 ms each within a 90-second period.
  - TenneT (Germany): Specifies that loads must ride through three low-voltage ride-through (LVRT) events and five high-voltage ride-through (HVRT) events within 30 minutes.
  - Alberta Electric System Operator (AESO): Draft requirements limit forced oscillation variability to less than 16 kW per 100 ms, with a total change limit of 160 kW.
  - American Transmission Company (ATC): Limits load active power oscillations for large load facilities over 200 MW to 25 MW over a period of less than 5 seconds.
  - Examples from several other ISOs are provided in Table 1 of the report.

Interconnection (2)

[Interconnection Processes for Large Loads (Energy Systems Integration Group (ESIG), June 2026)]

- This report provides a detailed examination of the interconnection process for large loads to identify current practices as well as gaps, bottlenecks and systemic risks.
- It finds that unlike generation resources, large loads lack uniform national performance requirements and clear regulatory jurisdictions, complicating the interconnection process across utility territories.
- The report highlights how independent system operators (ISOs) and regional transmission organizations (RTOs) are exploring using a clustering-based approach to handle the high volume of large load interconnection requests, similar to reforms in FERC Order 2023.
- Another observation is that large load interconnections span distribution, sub-transmission, and transmission systems, which requires significantly enhanced coordination and data-sharing between utilities and ISOs/RTOs.
- The authors offer a set of recommendations designed to create a more harmonized, transparent, and efficient interconnection framework for large loads that allows for regional and local variation.

Tariffs

Tariffs (1)

[Large Load Projects and Tariffs (March 2026) (Edison Electric Institute (EEI), March 2026)]

- This summary from EEI compiles a portion of the publicly announced large load projects that are underway within EEI member company service territories, and approved and pending large load tariffs before state commissions.
- This list includes publicly announced projects with loads of 20 MW or higher, and includes data centers and large manufacturers. The list of publicly announced projects represents approximately $840 billion in investment and greater than 39 GW of connected load.
- EEI finds that 19 states have approved at least one large load tariff, and another 9 states have pending large load tariffs (as of March 2026). These are listed by state in the document.

Tariffs (2)

[Large Load Tariffs and Load Forecasting (National Association of Regulatory Utility Commissioners (NARUC), April 2026)]

- This report bridges the gap between financial risk-mitigation tools (tariffs) and integrated resource planning (load forecasting). It treats large load tariffs as key inputs for predicting grid demand.
- It proposes a four-step framework for Public Utility Commissions (PUCs) to consider for integrating tariff provisions into load forecast inputs:
  - Baseline Planning Assumptions: Use commercial readiness indicators (e.g., site control, permits) and financial commitment indicators (e.g., collateral) to determine if a load should be included in the baseline forecast.
  - Load Shape and Duration: Apply tariff-defined load ramps and contract lengths in modeling to determine the duration the load will appear on the system.
  - Sensitivity and Scenario Analysis: Test risks by applying tariff limits, such as minimum demand obligations or contract adjustment rights, to see how deviations impact the system.
  - Iterative Refinement: Update forecasts regularly using empirical data from the interconnection queue, such as project withdrawal rates.
- Through the real-world case study of American Electric Power (AEP) Ohio, the study finds that strict tariff provisions can filter out speculative projects and improve forecast accuracy.

Tariffs (3)

[Large Load Tariff Whitepaper (Energy and Environmental Economics (E3), May 2026)]

- This study aims to compare large load tariffs across U.S. utilities that are in effect or recently approved, by calculating what would a data center customer would pay in annual electricity costs across different tariffs.
- The tariffs and their associated utilities considered in this study are:
  - Dominion Energy Virginia (VA): Large General Service Rate (GS-4) and Very Large General Service Rate (GS-5).
  - Georgia Power (GA): Large Power & Light Tariff (PLL-18).
  - Commonwealth Edison (ComEd) (IL): Extra Large Load Delivery Class (used as a proxy for transmission-connected data centers).
  - Oncor Texas (TX): Transmission Service Tariff.
- The approach involves calculating energy costs for a hypothetical 25 MW data center under two high–load-factor load shapes. For this, E3 utilized tariff provisions and rate components to perform a bottom-up assessment of energy bills.
- Based on this, E3 developed a standardized framework to enable direct comparison across utilities and regions.
- According to the study authors, this provides actionable insight for data center customers evaluating potential sites.

Tariffs (4)

[Federal Transmission Pricing Volume 1: The Evolution of Current Policies and Practices (Grid Strategies, May 2026)]

- This report explores the history and mechanics of federal transmission pricing and wholesale cost allocation, describing the evolution leading to current practices, why the current framework exists and emerging challenges.
- A key finding is that large load cost allocation operates under a cooperative federalism framework where the Federal Energy Regulatory Commission (FERC) regulates wholesale transmission cost allocation, while state regulators determine retail cost allocation to end-use customers.
- It highlights the historical evolution of federal transmission pricing, starting from cost-of-service ratemaking influencing early transmission pricing, to recent FERC orders requiring transmission planning at a regional level.
- The report highlights that state regulators are increasingly adopting large load-specific retail tariffs to protect existing ratepayers from rapid load growth, utilizing minimum commitment and payment requirements.

Demand Flexibility

Demand Flexibility (1)

[Flexible Grid Connections Implementation Guide (CHARGED, January 2026)]

- This guide provides a roadmap for utilities to implement flexible grid connection methods to reduce the need for grid upgrades and associated delays.
- This includes strategies to expedite large load connections by replacing conservative demand assumptions with flexible operational limits.
- It details three main flexible grid connection methods - Staggered, Scheduled, and Dynamically Managed connections.
  - Staggered Connections: This method involves pre-defined import/export limits that are established in the contracting process and ramp up according to a set timeline.
  - Schedule-Based Connections: This method involves pre-defined import/export limits that vary by time (such as hourly or seasonal) based on known grid constraints and the customer's operating profile.
  - Dynamically Managed Connections: This is the most operationally complex method, where import/export limits are set in real-time or via forecasts based on actual or projected system constraints.
- The guide primarily focuses on distribution-connected large loads, such as commercial and industrial customers and loads (on the order of 1-20 MW).

Demand Flexibility (2)

[Leveraging Large Load Flexibility to Facilitate Access to Power While Protecting Customers (Roselle LLP, Duke University, March 2026)]

- This policy brief proposes a formal class for flexible large loads based on voluntary, long-term curtailment commitments with specific technical requirements.
- It provides several recommendations to state regulators across four key policy areas:
  - Interconnection: Prioritizing interconnection requests for flexible loads in queue-based or cluster study processes and requiring utilities to incorporate curtailment commitments into study assumptions to reduce unnecessary infrastructure buildout.
  - Ratemaking: Adjusting large load tariffs for flexible large loads to account for the fact that they avoid the need for new infrastructure by virtue of their flexibility commitments.
  - Load forecasting and planning: Requiring utilities to embed flexibility commitments directly into planning models to quantify avoided infrastructure costs.
  - Bring-Your-Own-Capacity (BYOC): Ensuring that flexible large loads that meet stringent commitments are exempt from the BYOC framework, or that their curtailment capability is reflected in the framework.

Demand Flexibility (3)

[A Proposed Framework to Assess Headroom for Integrating Data Centers into Regional Power Systems (Electric Power Research Institute (EPRI), April 2026)]

- This report presents a comprehensive framework for estimating a power system's headroom, which is the amount of new load that can be integrated using existing infrastructure without breaching reliability limits.
- It specifically explores how flexible data centers which can shift workloads based on grid signals can help unlock additional headroom that static loads cannot.
- The proposed framework is targeted toward electric system planners, utilizing relevant concepts such as production cost models (PCM) and power flow simulations. It consists of 4 steps:
  - Resource Adequacy (RA) Assessment: Identifying baseline headroom considering inflexible data center load.
  - Hourly Nodal Operations Simulation: Refining estimates with real-world generator and transmission constraints.
  - Sub-Hourly Nodal Operations: Capturing high-resolution temporal dynamics.
  - Power Flow Simulation: Finalizing the estimates by performing power flow simulations and assessing transmission reliability.
- A key finding is that incorporating Grid-Enhancing Technologies (GETs), such as dynamic line ratings, can further expand headroom by optimizing existing transmission.

Load Forecasting

Load Forecasting (1)

Powering Intelligence 2026 (Electric Power Research Institute (EPRI), February 2026)

- This white paper provides updated projections and scenarios for U.S. data center electricity demand through 2030, driven by the rapid growth of artificial intelligence (AI).
- The study projects data centers to consume 9% to 17% of U.S. electricity demand by 2030, a significant increase from the 4% to 5% share estimated for 2024.
- Data center electricity use is estimated to grow to approximately 380 to 790 TWh by 2030. This range is around 60% higher than EPRI's 2024 report estimates, attributed by the study to record levels of data center development over the past 18 months.
- Projections are based on three underlying scenarios with varying levels of operation of data center projects.
- The study also provides state-level projections of data center nominal IT capacity and the share of data center’s electricity use within the state’s total electricity demand.

Load Forecasting (2)

[Separating Fact from Fiction in Data Center Electricity Forecasts (Koomey Analytics, GridLab, March 2026)]

- This report provides a rigorous analysis of historical electricity consumption data against current utility and industry forecasts driven by data center growth, to provide a balanced perspective on this expected surge in electric demand.
- It is designed as a guide for regulators to help them navigate various coverage of data center growth projections and avoid overbuilding utility infrastructure based on potentially inflated industry claims.
- Their analysis is based on data from the Federal Energy Regulatory Commission's (FERC) Form 714, in addition to data the authors compiled from 14 utilities and balancing authorities that represented ~75% of US generation in 2023.
- A key finding is that utility/ISO forecasts for ERCOT (TX), PJM (Mid-Atlantic), California, and MISO (Midwest) for the year 2024 show a massive divergence from historical trends and even from their 2023 projections.
- According to the authors, one reason for this potential overestimation is due to developers submitting duplicate requests to different regions.
- The study also indicates that improvements in computing efficiency and cooling systems may lower the energy demand of data centers.

Load Forecasting (3)

[United States Data Center Energy Usage Report: 2025 Update (LBNL, June 2026)]

– This report estimates data center electricity usage in the U.S. out to 2030 for a Reference Case and a range of Sensitivity Scenarios corresponding to alternative data sources and parameters.

– The report estimates that data center electricity consumption in the U.S. could reach 649 TWh by 2030 in the Reference Case, accounting for 11.8% of total U.S. electricity. The range across the Sensitivity Scenarios is between 9.5 and 15.3%.

– A key finding is that this consumption growth is primarily driven by AI servers, accounting for 84% of projected total server energy and 55% of all projected data center electricity use by 2030.

– The report also estimates the interconnection capacity required to meet the electricity demand of data centers in 2030 to be 148 GW, assuming a 50% average utilization rate.

– There are four Sensitivity Scenarios (Consolidated Deployment, High ASIC (Application-Specific Integrated Circuits), Low Accelerator Lifetime, and High Inference Energy) that explore targeted adjustments to the Reference Case.

Data Center Siting and Infrastructure

Data Center Siting and Infrastructure (1)

[Evaluating Potential Artificial Intelligence Energy Capacity at Different Data Center Sites (RAND, March 2026)]

- This report proposes a Multicriterion Decision-making (MCDM) framework to address favorability of siting AI data centers across five key dimensions:
  - Energy supply: Availability of on-site behind-the-meter (BTM) and generation resources.
  - Energy system infrastructure: Grid characteristics, including interconnection timelines and projected capacity additions.
  - Supporting inputs: Practical needs such as access to cleared land and water for cooling
  - Environmental factors: Temperature-driven cooling requirements
  - Governance/community considerations: Locational regulatory and community landscape
- The authors of the study apply this framework to assess the suitability of 22 specific sites for hosting large-scale AI data centers.
- A key finding from this analysis is that many sites in the United States have access to existing infrastructure that can be leveraged for meeting the power demand for AI data centers by 2030. This strategy includes repurposing power plants that are recently retired or slated for retirement.

Data Center Siting and Infrastructure (2)

[Historical and Modern Large Loads (Energy Systems Integration Group (ESIG), March 2026)]

- This report provides a structured analysis of how modern large loads like data centers differ from historical industrial and manufacturing loads, in terms of development speed, facility size, and grid interactions.
- It emphasizes the emergence of hyperscalers reaching ~1,000 MW, contrasting them with traditional large loads that rarely exceeded peak demand of 200 MW.
- Another key area of distinction is how the modern large loads interface with the grid and have the ability to leverage demand flexibility and back-up generation, which is limited with historical large loads.
- The study also discusses challenges and opportunities associated with various aspects of large load integration:
  - Large load forecasting and tariffs: Updating methods to filter speculative requests and using new fees (like exit or minimum billing fees) to protect existing ratepayers.
  - Large load interconnection processes: Streamlining massive backlogs through cluster analysis and requiring more granular technical data from developers.
  - Transmission service: Implementing "contract demand" and non-firm options to allow faster connection while required network upgrades are built.
  - Other topics covered include resource adequacy, large load flexibility, and operational reliability

Data Center Siting and Infrastructure (3)

[The Role of the U.S. Electric Distribution System in Serving Data Center and Other Large Loads (National Laboratory of the Rockies, May 2026)]

- This report examines the role of the U.S. electric distribution system in serving large loads by analyzing expected service configurations and infrastructure needs.
- A key finding is that while historical developments connected to mixed-use distribution systems, the future pipeline is dominated by massive 50–200 MW requests that necessitate dedicated substations and greenfield distribution infrastructure.
- Another finding is that there is a severe timeline mismatch complicating interconnections, as data centers are built in 12 to 24 months whereas utility substation reinforcements take 3 to 5 years, driving the need for bridging solutions like temporary feeders.
- The authors suggest adapting hosting capacity maps to help developers identify existing feeder and substation headroom, which could streamline the large load siting process.

Reliability and Resource Adequacy

Reliability and Resource Adequacy (1)

[Review of Industry Efforts and Standards of Grid Readiness for Data Center Deployment (Institute of Electrical and Electronics Engineers (IEEE), January 2026)]

- This report is a comprehensive, technical review of the current engineering standards, task forces, and grid code updates managed by multiple transmission system operators (TSOs) worldwide.
- Some of the grid operators covered in this review include:
  - Electric Reliability Council of Texas (ERCOT): Texas, United States
  - Dominion Energy Virginia (DEV): Virginia, United States
  - Alberta Electric System Operator (AESO): Alberta, Canada
  - European Network of Transmission System Operators for Electricity (ENTSO-E): Europe (representing 40 European transmission system operators)
- It catalogs and analyzes the distinct technical challenges and mitigation strategies of various system operators regarding data centers, focusing on issues like dynamic load profiles, fault ride-through capabilities, and power quality.
- The report finds that there is a lack of industry-wide engineering standards governing large loads. This requires the development of global technical standards and harmonized grid codes to ensure continued power system reliability and stability.

Reliability and Resource Adequacy (2)

[Large Load Disturbance Events (Energy Systems Integration Group (ESIG), March 2026)]

- The report highlights the grid reliability risks of modern large loads such as AI training clusters, data centers, and hydrogen production, that are often inverter-based and highly sensitive to voltage and frequency excursions, with examples of recent disturbances.
- It focuses on two types of disturbance events:
  - Ride-through events: It occurs when controls of a large load sense a sudden change in system voltage or frequency and drop the facility offline to protect it from the grid.
  - Power oscillations on the grid: This can be triggered by rapid changes in power consumption of large loads, or uncontrolled frequency swings and voltage fluctuations from the equipment inside the facility.
- The report provides detailed examples of ride-through and oscillation events experienced by Electric Reliability Council of Texas (ERCOT), Dominion Energy, and American Electric Power (AEP).
- The authors state that these events highlight the need for coordination between transmission operators and large load owners before and during events, and having a vast network of high-resolution monitoring and metering to identify and mitigate risks.

Reliability and Resource Adequacy (3)

[Resource Adequacy with Large Loads: Planning for Flexibility to Accelerate Integration (Energy Systems Integration Group (ESIG), April 2026)]

- The report addresses the resource adequacy challenges posed by the rapid proliferation of large electronic loads, particularly hyperscale data centers. It proposes a framework to integrate the inherent flexibility of data centers as a capacity resource into long-term grid planning.
- The authors propose a six-step approach for integrating large load flexibility into capacity planning. This involves:
  - Characterizing large loads by their end-use (such as AI training, AI inference models).
  - Basing forecasts on contractual agreements rather than only on interconnection queue requests.
  - Quantifying the baseline capacity requirements needed if these large loads were 100% firm and inflexible.
  - Quantifying the capacity contributions of of flexibility using probabilistic methods like Effective Load-Carrying Capability (ELCC).
  - Calculating the avoided infrastructure costs resulting from this flexibility.
  - Utilize the results to develop large load tariffs and interconnection agreements.
- The report provides recommendations for resource planners, market operators, large load customers, and regulators to better incorporate large load flexibility in their planning processes.

Reliability and Resource Adequacy (4)

Risk Mitigation for Emerging Large Loads (North American Electric Reliability Corporation (NERC), May 2026)

- The report provides recommendations for integrating large loads like data centers and cryptocurrency mines into the bulk power system (BPS).
- It outlines strategies across the project lifecycle and tailors its recommendations for various stakeholders such as Large Load Entities, utility providers and planners, balancing authorities, and reliability coordinators.
- A critical finding is that Customer-Initiated Load Reduction (CILR), beyond a certain threshold, can cause a nearly instantaneous generation-load imbalance, leading to frequency disturbances and system instability.
- The report identifies a new driver of CILR where an interruption at one data center triggers synchronized demand reductions across geographically disparate facilities sharing the same workload.
- One of the recommendations from the report is to integrate physical and cyber security controls in the design phase rather than introducing them as retrofitted additions.

Reliability and Resource Adequacy (5)

[2026 Summer Reliability Assessment (North American Electric Reliability Corporation (NERC), May 2026)]

- This assessment evaluates generation resource and transmission system adequacy to meet projected summer peak demands for the summer of 2026 (June–September) across the North American bulk power system (BPS).
- The study includes detailed resource adequacy and energy risk analysis assessments for the 6 regional entities spanning the North American BPS: the Midwest Reliability Organization (MRO), Northeast Power Coordinating Council (NPCC), ReliabilityFirst (RF), SERC Reliability Corporation (SERC), Texas Reliability Entity (Texas RE) and the Western Electricity Coordinating Council (WECC).
- A key finding is that load growth is accelerating, driven heavily by data centers and large loads. Aggregated peak demand across all assessment areas has increased by over 11 GW relative to summer 2025 projections.
- Another key finding is that while all assessment areas are projected to have adequate resources under normal conditions, several areas (NPCC-New England, MRO-SaskPower, WECC-Northwest, and Texas RE) have elevated risk during more extreme conditions.
- The assessment highlights rising demand, significant generation growth in many areas, the prospect of challenging hydrological conditions, and the unpredictability of large loads as important drivers of the Summer 2026 risk profile.

Reliability and Resource Adequacy (6)

Large Loads: Behaviors, Capabilities, and Limitations (Energy Systems Integration Group (ESIG), July 2026)

- This report discusses the capabilities and limitations of new large loads from the perspective of interconnection requirements and large loads' abilities to reduce grid reliability risks.
- It provides a deep-dive into the internal physical architectures, hardware components, and specific electrical topologies of emerging large loads.
- The report dissects AI power consumption into three distinct drivers: compute power, memory power, and transfer power, explaining that their combination causes rapid load transients. This causes an amplified power profile for AI data centers, which distinguishes them from conventional data centers.
- The authors conclude that to mitigate grid impacts, large loads can provide load flexibility through hardware and software solutions, such as utilizing capacitor-based systems, Solid State Transformers, dynamic frequency scaling, and job pausing to smooth power transients.

Reliability and Resource Adequacy (7)

[Reliability Impacts of Large Loads (Energy Systems Integration Group (ESIG), July 2026)]

- This report provides a comprehensive technical analysis of the reliability impacts of large loads, identifying critical vulnerabilities and proposing mitigation strategies.
- A key finding is that the sudden, synchronized tripping of large loads creates severe positive imbalances between generation and demand, sparking major frequency excursions and cascading instability comparable to losing a large power plant.
- Another finding notes that cyber-physical security vulnerabilities targeting large loads could trigger synchronized tripping or deliberate demand manipulation to destabilize the grid, mimicking physical grid disturbances.
- The authors conclude that addressing these novel reliability risks requires layered mitigation strategies, including strict interconnection performance requirements, high-fidelity modeling, facility-level energy buffering, and fast, telemetry-based backstop monitoring.

Policy Options

Policy Options (1)

Building Resilient Foundations for Large Loads (Regulatory Assistance Project (RAP), February 2026)

- This guide focuses on transparency and planning in managing the rapid growth of data center loads.
- It identifies four key steps for decision-makers: Get Collaborative, Gather Information About What Is Coming, Scrutinize Data Center Demand in Planning, and Evaluate Existing System and Resource Options.
- Strategies such as aligning incentives with state energy policy, modeling data center load flexibility, and expanding energy efficiency and transmission innovations are discussed, along with state examples.
- According to the authors, these solutions can help decision-makers address the data center growth while ensuring an affordable and reliable electric grid.

Generation

Generation (1)

[Bridging the Gap for Powering Data Centers: Technical Workshop Report (Idaho National Laboratory (INL), December 2025)]

- INL's 2025 Data Center Workshop gathered over 100 stakeholders to explore challenges and solutions at the intersection of data center growth and energy infrastructure, with an emphasis on how nuclear energy can be leveraged to power data centers.
- INL administered an anonymous survey as part of the workshop. Survey findings highlight key challenges: 1) matching capacity needs with data center timelines, 2) uncertainty in interconnection obligations and cost responsibility, and 3) need to treat data centers as dynamic grid participants rather than static loads.
- The report concludes with proposed actions, such as developing standardized interconnection guidelines, improving data-sharing protocols between data centers and utilities, and launching demonstration projects to validate new hybrid and behind-the-meter (BTM) solutions.

Design and Operations

Design and Operations

CENTER OF EXPERTISE FOR DATA CENTER ENERGY

DOE/LBNL data center program assists organizations with optimizing the design and operation of energy and water systems in data centers.

Assistance

- Project and technical assistance from the Center of Expertise including identifying and evaluating ECMs, M&V plan review, and project design review
- Support optimization of high-performance and enterprise data centers

Tools

- Data Center Profiler (DC Pro) Tools (x2)
- Air Management Tools (x3)
- IT Equipment Tool
- Electrical Power Chain Tool
- Energy Assessment Worksheets
- Data Center Master List of Energy Efficiency Actions

Key Resources

- Best Practices Guide for Energy-Efficient Data Center Design
- Center of Expertise Library – filterable list of reports, guides and presentations
- Small Data Centers, Big Energy Savings: An Introduction for Owners and Operators

Training

- Data Center Energy Practitioner (DCEP) Trainings
- Better Buildings webinar series
- On-demand FEMP data center trainings
- Center of Expertise Webinars

https://datacenters.lbl.gov/

Additional resources?

If you are aware of other reports that would be useful to include in this literature review, please send the resource to jacook@lbl.gov.

Thank you

Contact

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