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Bridging the Gap for Powering Data Centers

Center for Securing Digital Energy Technology

Technical Workshop Report

DECEMBER 2025

Luis Enriquez-Contreras
SM Shafiul Alam
Megan Culler
Kara Cafferty
Jonathan Tacke
Heather Ackenhusen

Idaho National Laboratory

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Idaho National Laboratory

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Idaho National Laboratory
Center for Securing Digital Energy Technology
Idaho Falls, Idaho 83415

http://www.inl.gov

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ABSTRACT

The rapid expansion of data centers, primarily driven by artificial intelligence, is outpacing the adaptability of the United States electric grid. This report summarizes insights from the Idaho National Laboratory's 2025 Data Center Workshop, "Enabling Data Center Demand Growth through Nuclear Energy," which convened over 100 stakeholders to examine technical, economic, and regulatory barriers to powering data centers at scale. Key themes include resource adequacy, interconnection delays, and the dynamic load behavior of modern artificial intelligence workloads, which strain traditional grid planning and stability frameworks. Participants emphasized the need for hybrid architectures, with behind-the-meter generation, microgrids, and energy storage, to mitigate transmission constraints and accelerate deployment. Additional concerns include supply chain bottlenecks, environmental impacts such as water use and noise, and uncertainty surrounding nuclear integration timelines. The report identifies critical research gaps in dynamic modeling, control systems, and forecasting, and proposes actionable strategies, ranging from standardized interconnection guidelines and data-sharing protocols to demonstration projects and risk-sharing models. These recommendations aim to enable resilient, scalable, and efficient integration of data centers into the United States energy landscape while fostering collaboration among industry, utilities, regulators, and national laboratories.

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EXECUTIVE SUMMARY

Data center expansion driven by artificial intelligence and high-performance computing is increasing electric demand at a rate that challenges planning, permitting, and construction timelines for generation, transmission, and distribution infrastructure. Stakeholders are focused on speed to power, firm capacity delivery, and maintaining reliability and power quality as load behavior evolves.

The 2025 Idaho National Laboratory Data Center Workshop (October 27 through 30, 2025, Idaho Falls, Idaho) convened over 100 invited industry professionals, including data center developers and operators, utilities and grid operators, nuclear technology providers, engineering and technology vendors, and public sector participants. The workshop assessed the feasibility of nuclear supported data centers and identified barriers to powering data centers at scale, including interconnection processes, deliverability constraints, dynamic load behavior, environmental considerations, and stakeholder engagement.

Cross cutting observations include:

- **Grid-only supply is losing favor** due to interconnection delays, transmission constraints, and upgrade uncertainty.
- **Hybrid architectures** that include behind the meter generation, microgrids, and onsite storage are viewed as near term pathways to reduce schedule risk and improve resilience.
- **Power quality and stability concerns are increasing** as data centers exhibit faster load ramps and increase in size and penetration.
- **Interest in nuclear as a power generation resource is substantial**, but participants expressed concerns about near term commercial availability and competitive timelines.

Input from the Workshop's plenary discussions, Gallery Walk, and the anonymous survey converged on a small set of system-level constraints. Although the full report organizes discussion by topical category, participants repeatedly returned to the same friction points: the inability to deliver capacity on data center timelines, uncertainty in interconnection obligations and cost responsibility, and a growing need to treat modern data centers as dynamic grid participants rather than static load.

Survey responses reinforced this prioritization. Respondents most frequently selected resource adequacy, cost and economic factors, and power quality and stability as the highest priorities for data center deployment. Those priorities, together with the discussion record, inform the ordering of themes below:

- **Schedule Mismatch:** Data center construction is outpacing the multi-year cycles required for grid upgrades, permitting, and the procurement of critical equipment like large transformers.
- **Interconnection Barriers:** Uncertainty around cost allocation, iterative study cycles, and a lack of standardized requirements are creating significant financing and schedule risks.
- **Technical Integration:** Modern artificial intelligence (AI) loads can fluctuate demand rapidly as the data center works through large complex problems in unison. Such demand behavior leads to new requirements for grid integration, including validated dynamic models, and updated stability assessments.
- **Hybrid & Onsite Solutions:** To bypass transmission delays, developers are increasingly looking at "behind-the-meter" and hybrid power architectures. These could include nuclear facilities among other power supply options.
- **Data Transparency:** Better information sharing—such as hourly load forecasts—is a low-cost way to improve timelines and reduce uncertainty.
- **Knowledge Gaps:** Significant uncertainty remains regarding environmental siting (water/noise), public perception, and the specific licensing pathways for advanced nuclear options.

In addition to discussing the issues for data centers and nuclear power deployment, the Workshop discussed paths forward, including areas where federal entities, could spur action and break through the logjam slowing the industry. The table below summarizes action areas, the value proposition of the activity, and potential deliverables associated with the activity. The audience for each activity would include utilities, independent system operators and regional transmission operators, technical consultants, and developers of both data centers and grid assets.

Action Area	Value Proposition	Primary Deliverables
Establish technical databases and model library for modern data center loads	Reduce bespoke modeling; improve study credibility; lower conservatism due to unfamiliar load behavior.	Validated load model library for artificial intelligence (AI) and high performance computing (HPC) modes; measurement protocols for ramps, harmonics, and voltage sensitivity; reference study assumptions; introductory and advanced training modules to expand workforce capacity in dynamic modeling and stability analysis
Clearly define interconnection requirements	Clarifies expectations and standardizes requirements; improve comparability across jurisdictions and projects.	Interconnection templates and test methods for ride-through, recovery, ramp behavior, harmonics compliance, and protection coordination; benchmark study cases
Stand up validation environments and pilots	Identify risks before field deployment; support targeted mitigations; reduce late-stage retrofit risks; build evidence that de-risks adoption at scale	Hardware-in-the-loop and real-time simulation test plans; controller interaction and protection validations reports; published failure modes and mitigations; pilot demonstrations
Accelerate transmission capacity and streamline supply chain dependencies	Expand qualified supplier base for utilities; reduce procurement uncertainty; bridge the schedule gap by maximizing existing corridors and de-risking long-lead equipment procurement	Perform and provide "time-to-power" bottleneck analysis; standardized technical specifications for equipment; qualification and acceptance test protocols for long-lead equipment; GETs deployment guidance; reconductoring decision frameworks
Support hybrid and behind-the-meter operations and acceptance	Align infrastructure needs (system planning) with credible conditions; support fair cost allocation; enhance speed-to-power by enabling standardized hybrid and BTM configurations	Develop credible operating envelopes for multiple configurations; quantify grid reliability requirements with co-location; evaluate maintenance driven import scenarios; establish compensation and market participation guidelines for grid support where applicable
Evaluate and Mitigate Risks from Water Access and Noise Concerns	Help data center developers anticipate and manage water usage and noise impacts, reducing compliance risks and optimizing cost efficiency.	Develop water and noise evaluation tools for conceptualizing and estimating cost impacts, create technical assistance guidance using best practices from other industries, demonstrate noise mitigation strategies
Enable data transparency,	Lower reserves and planning uncertainty; enable coordinated operations and trust across parties,	Reference data center load forecast data schemas; secure sharing architectures; staged nuclear integration demonstrations;

forecasting, and governance	improve operational coordination; build trust	standardized load-forecast data schemas and sharing platforms; develop communication and operational status protocols for the point of interconnection
Align policy, market, and partnership frameworks	Align incentives, cost recovery, and community acceptance; enable bankable, scalable pathways for large loads.	Model agreements for power purchase agreements; instruments for risk sharing; regulatory harmonization recommendations; tailored stakeholder engagement toolkits

Throughout the workshop, stakeholders expressed interest in a shift toward hybrid architectures that include behind-the-meter supply and storage, paired with strong demand for validated models, and predictable interconnection pathways. The strong interest in these topics showed how the industry is struggling across a range of subject matters to connect data centers at the scale and speed requested. The national laboratories can reduce deployment friction by delivering shared technical baselines and demonstration evidence that utilities, developers, and regulators can adopt at scale.

CONTENTS

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ACRONYMS

AI	Artificial intelligence
ANOPR	Advanced Notice On Proposed Rulemaking
ATT	advanced transmission technology
BESS	battery energy storage system
BTM	behind-the-meter
DOE	U.S. Department of Energy
EMS	energy management system
ERB-I	Experimental Breeder Reactor I
FERC	Federal Energy Regulatory Commission
FOAK	first-of-a-king
GET	grid enhancing technology
GW	gigawatt
HIL	hardware-in-the-loop
HPC	high-performance computing
INL	Idaho National Laboratory
ISO	independent system operator
ISP	internet service provider
kW	kilowatt
LNG	liquified natural gas
LCOE	levelized cost of energy
MW	megawatts
NOAK	next-of-a-kind
PMU	phasor measurement unit
POI	point of interconnection
PPA	power purchase agreement
RTO	regional transmission organization
SCADA	supervisory control and data acquisition
SMR	small modular reactor
TREAT	Transient Reactor Test Facility
UPS	uninterruptible power supply
U.S.	United States

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Bridging the Gap for Powering Data Centers

Technical Workshop Report

1. INTRODUCTION

Renewed enthusiasm for generative artificial intelligence (AI) is driving growth in data center construction faster than the electric grid can keep pace. The electric sector and data center customers are both contemplating questions of how to effectively address the need for power like: “should data centers bring their own power sources?” and “can flexibility of data center energy consumption be incentivized to relieve the pressure on utilities?”. The answers to these questions are not straightforward, and must account for technological readiness levels, physical and cyber risk assessments, operational implications, financial aspects, policy, and regulatory considerations, as well as other factors. The United States (U.S.) national laboratories are well-positioned to investigate, analyze, test, de-risk, and demonstrate these factors across complex and diverse disciplines [1].

To this end, Idaho National Laboratory (INL) has carried out a set of preliminary investigations to gather reported challenges from grid operators [2], considerations of nuclear power plants to serve data center loads [3], and considerations of large load characteristics to develop a taxonomy to classify and study large load behaviors and interactions with the grid [4]. It has been found that certain operational modes such as AI model training and inference drive high ramp rates of power demand. Coupled with data centers’ voltage sensitivity, the growth of data centers is increasing stress on power system stability. Additionally, rapid projected demand growth on a short timescale is raising grid operators’ reliability concerns as data center buildouts continue [2]. On the other side of the meter, data centers have high uptime requirements, creating a strong need for reliable power. Onsite generation options are popular options to supplement grid power. Nuclear power plants have the potential of addressing many of these grid reliability concerns, including through co-location, however such proposals have their own considerations. From the large load perspective, the degree of variability and flexibility between generation options will drive the decision between grid isolated or connected designs.

These topics formed the base of discussion during the 2025 INL Data Center Workshop, held October 27–30, 2025, in Idaho Falls, Idaho. The workshop was convened specifically to discuss how nuclear energy can be leveraged to power data centers, however other key considerations were discussed as well. Key themes included grid integration, electric and thermal energy coupling, licensing and permitting, workforce development, and collaborative demonstration opportunities. It brought together a variety of stakeholders, including data center developers, utility representatives, campus planners, nuclear technology providers, and federal agencies, to examine the intersection of data center growth and energy infrastructure. This report summarizes the key topics and discussion points from the workshop, providing analysis on the state of the industry according to insights from the workshop and identifying key gaps and next steps to address the present need to grow power grid capacity in support of both traditional and emerging AI-centric data center loads.

1.1. Workshop Summary

Overall, the primary objectives of the workshop were to assess the feasibility of nuclear-powered data centers, evaluate siting and interconnection strategies, and identify gaps in current modeling, regulatory frameworks, and community engagement. Sessions included topics such as microreactor deployment, flexible interconnection planning, and power system modeling tailored to data center needs. The INL Data Center Workshop drew strong interest from across the energy and digital infrastructure sectors with a total of 108 registrants external to INL and 90 actual industry attendees over the four-day event. Participants represented a broad cross-section of stakeholders, underscoring the workshop's role as a convening space for interdisciplinary collaboration. As illustrated in Figure 1, the private sector was well represented with attendees from data center, nuclear, and electric power sectors, along with broadly scoped technology providers, and construction & energy consultants.

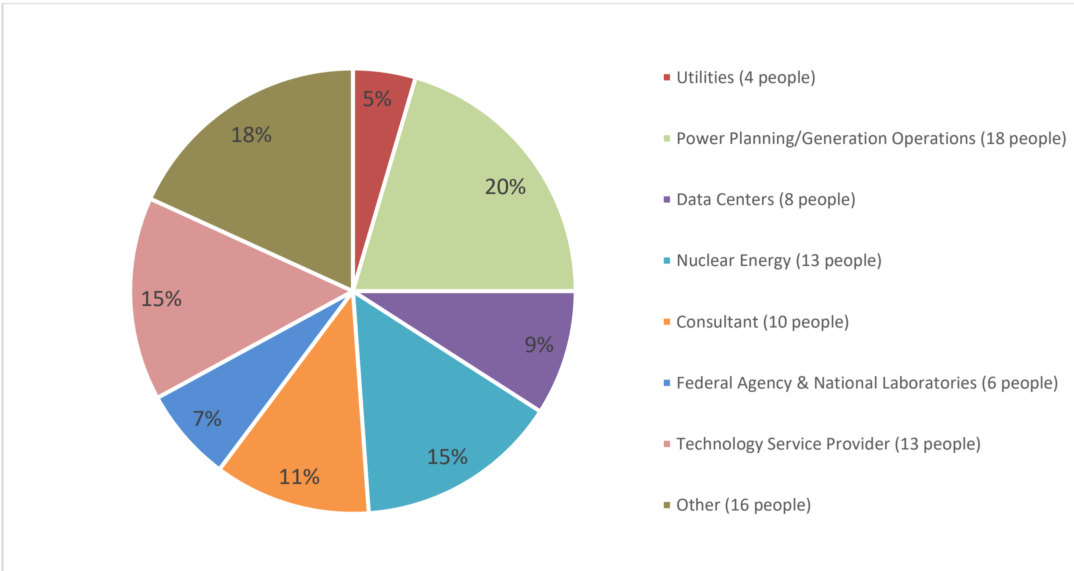

Figure 1: Industries represented at the workshop.

The four-day event included:

- Day 1: Technical site tours of INL facilities such as Experimental Breeding Reactor (EBR)-I, the Energy Technology Proving Ground, and Transient Reactor Test Facility (TREAT).
- Days 2–3: Plenary sessions and panels at the Downtown Events Center in Idaho Falls, featuring presentations from the Department of Energy (DOE), INL, industry leaders, and national labs.
- Day 4: A special session hosted at the INL Meeting Center, focused on integration, security, and resilience, followed by one-on-one sessions between industry participants and INL subject matter experts

The workshop employed a combination of structured and interactive methods: topical presentations provided technical context with questions from the audience; a poster session enabled researchers to talk with industry about details of active research projects, a "Gallery Walk" enabled participants to share written feedback on key issues, and an online anonymous survey was shared to request feedback on prioritization of key challenges and issues. Notes and data collected from all of these activities are included in this report, but we note that the organization and prioritization of key challenge areas described in Section 2 are largely informed by the online survey and the gallery walk, which allowed participants to provide their feedback and key takeaways from the workshop in a structured format.

1.2. Online Survey Response at the Workshop

The online survey was available during and after the workshop so that the participants could leverage the workshop resources as well as in-person discussions to support their responses. 21 participants responded to the 10-question survey. This is only a fifth of total industry attendees at the workshop, but these responses provide directed and specific feedback from a sample of attendees that provides insights into the nuances of top challenges for powering data centers.

The first question asked about the individual participants' role in "Powering the large loads", and 39% responded as "Data Center Campus Developer", and 28% as "Generation". Other participants included consultants, nonprofit technical advisors, and representatives from the nuclear sector.

Detailed survey results are provided in Appendix A, but this section briefly highlights key takeaways from the survey which were used to help inform organization and prioritize technical summaries and key discussion points. The survey questions and an analysis of the responses are presented below:

Question 2: Which of the following scenarios seems feasible to you? (See Appendix A for multiple choice selections available)

The survey responses indicate two principal observations. First, the concept of data centers relying primarily on the grid as their main source of power generation is losing favor among respondents. Secondly, data centers owning and controlling their own power generation is a highly favorable scenario, with a tendency to be in closer proximity to the generation source. The most favored approach is for data centers to generate power exclusively for their own use.

Question 3: Which three topics would you consider the top priority for data center deployment? (See Appendix A for multiple choice selections available)

The top three topics identified by the respondents include load size and need for generation resource adequacy, cost and economic factors, and power quality and stability. These topics were subjects of extensive discussion during the workshop and are discussed in more detail in the body of the report.

Question 4: Should data centers be required to provide ancillary services in general, such as voltage ride through or underfrequency load shedding?

The responses to this question were notably split, reflecting a lack of strong consensus on the role of data centers in providing ancillary services. The participants were divided on this issue, with half asserting that the grid should provide ancillary services and the other half responded that data centers should not be required to support the grid. This highlights the necessity for further investigation to understand where this divide comes from, e.g. if the issue is about loads being required to behave a certain way or if the phrasing of requirements in the question implied a lack of proper incentivization and compensation for the services provided.

Question 5: Data center load profiles and forecast are kept confidential. Should data centers be required to share this information with the utility?

There is a substantial consensus regarding the topic addressed in Question 5. While from a grid operator's perspective the data center load seems unpredictable it is very predictable from the data center perspective. The notion of data centers sharing their expected load profile, such as a 24 hour prediction, with the utility, ISO, and/or RTO has garnered significant support, although it is not yet a widespread practice. This indicates a growing recognition of the potential benefits of such arrangements. Most data centers already have this data, and the utility could optimize power allocation instead of addressing peaks that are unknown to the grid operation. Proactively sharing detailed load data between the data center and the utility could help reduce the friction grid operators have with peak loads from data centers.

Question 6: As a percentage of total operating costs for a data center, what do you feel is a reasonable amount to be spent towards power each month?

This percentage varied between 5% and 75% along with some subjective response, indicating a lack of strong consensus.

Question 7: As a percentage of total development costs for a data center that is co-located with a behind-the-meter nuclear reactor, what do you feel is the maximum amount to be spent developing the nuclear reactor?

The response included percentage between 40% and 60%. Some responded the maximum cost between $1 million and $1 billion, while some others had subjective responses.

Overall, the lack of consensus is clear from the responses to questions 6 and 7 and demands further investigation on cost allocation for on-site generation and electric power usage.

Question 8: Which requirements for grid interconnection are the most time consuming?

One-third of the respondents equally selected “Coordination with Grid Operators”, and “Cost responsibility and upgrades”.

Question 9: Which requirements for grid interconnection are the fastest?

More than half of the respondents said that they “don’t know”.

Question 10: Which interconnection requirements should be considered most critical for ensuring safety and power quality?

Most of the responses have equally selected “Disturbance ride-through and recovery performance testing”, and that they “don’t know”.

Question 11: Which interconnection requirements are the most redundant or outdated?

Nearly half of the respondents said that they “don’t know”.

The response statistics for the Questions 8 – 11 echo the divisive response on the question of ancillary services (Question 4). Overall, these questions reflect clear gaps on a) what needs to be amended to interconnection studies, b) what the cost-benefit tradeoffs are, and c) how to coordinate with grid (generation, transmission, distribution) operators to execute (a), (b) and operate generally.

1.3. Gallery Walk

The gallery walk activity served as a dynamic and participatory method for surfacing the most pressing concerns, opportunities, and strategic directions related to powering data centers, particularly through nuclear energy. This activity took place at the end of the second full day of presentations and discussions, so the inputs here were collected after participants had heard and digested most of the content discussed over the course of the event. Participants engaged with a series of whiteboard prompts, contributing their thoughts and voting on key issues. The resulting discussion revealed a rich tapestry of industry perspectives that now inform the structure of this report.

Industry Concerns and Operational Challenges

Participants expressed a range of anxieties about the future of data center operations, many of which centered on infrastructure readiness and energy reliability. Equipment lead-times emerged as the most frequently cited concern, a reflection of the urgency surrounding capacity expansion. Power availability, reliability, and quality were also top concerns, especially in the context of growing AI workloads and the strain they place on local grids. Political instability, regulatory uncertainty, and the potential for local opposition were seen as external risks that could derail progress. Communication and education were noted as keys to long-term success.

Opportunities for DOE and National Laboratory Engagement

There was strong consensus that national laboratories should continue to play a central role in convening stakeholders and facilitating innovation. Participants called for more workshops like this one, with expanded representation from internet service providers (ISPs), utilities, independent system operators (ISOs) and regional transmission operators (RTOs), hyperscalers, and large-scale data users. INL’s ability to support prototype testing, provide infrastructure (such as power and fiber), and accelerate research was seen as critical. Several comments emphasized the importance of national laboratories acting as a translator, bridging the gap between technical communities and the public to foster broader acceptance of nuclear energy. The idea of influencing public perception was not just about messaging, but about connecting passion and technical rigor to community engagement.

Technical Considerations: Cooling and Storage

Alternative cooling strategies, such as heat-driven chilling, received mixed feedback. While some participants viewed it as a valuable bonus, especially if it could reliably offset other power use, others saw it as a distraction from the primary challenge of securing sufficient power. Direct heat utilization and waste heat recovery were mentioned as potentially more efficient approaches.

Onsite energy storage was a more active area of interest. Battery Energy Storage Systems (BESS) received the most support, followed by thermal storage, liquid natural gas (LNG), and hybrid solutions. Emerging technologies like graphene supercapacitors and hydrogen production were discussed, though concerns about safety, cost, and scalability remain. Participants acknowledged that while nuclear energy is currently expensive, overcoming the price barrier is essential for broader adoption.

Nuclear Integration: Promise and Pitfalls

The expected timeline for nuclear integration varied among participants. Many anticipated meaningful contributions from nuclear post-2035. Some were hopeful for adoption by 2030, particularly as a complement to natural gas. The potential for power purchase agreements (PPAs) with remote providers was also raised. Despite optimism, concerns about cost overruns, schedule predictability, and definitive uptime for first-of-a-kind (FOAK) and next-of-a-kind (NOAK) reactors were prevalent. Speed to market was the most frequently cited barrier, followed by levelized cost of energy (LCOE), supply chain limitations, and the challenge of ensuring redundancy and reliability.

The discussion also touched on the risk of overpromising by nuclear developers, especially startups seeking investment. Participants emphasized the need for realistic cost estimates and cautioned against aggressive timelines that could undermine credibility. The lack of cost overrun insurance and the difficulty of securing qualified personnel were additional barriers to adoption.

Strategic Partnerships and Collaboration Models

Participants identified several key partnerships that could accelerate progress. Data center operators, energy storage providers, and public-private financing entities were seen as essential collaborators. There was interest in joint ventures between nuclear companies and data centers, with some suggesting that hyperscalers could play a pivotal role in de-risking investments. The idea of pairing with naval expertise or leveraging stranded power assets also surfaced. A recurring theme was the need for entities willing to build and operate infrastructure while absorbing risk, something most data centers are currently reluctant to do.

Grid Stability and Behind-the-Meter Assets

The gallery walk also explored the potential for data centers to contribute to grid stability through behind-the-meter assets. Participants discussed the need for additional infrastructure in land-saturated areas, the possibility of full autonomy when utilities fall short, and the role of co-located generation with interconnect agreements. The willingness of data center tenants to share power with the grid through ancillary services was questioned, and transmission line availability was flagged as a limiting factor.

2. KEY DISCUSSIONS FROM THE WORKSHOP

Industry stakeholders with various backgrounds, ranging from data center developers and consultants, to the generation developers and utilities have raised their concerns and shared opinions during topical presentations, participated in poster presentations and gallery walk discussions. The back-to-back queries and responses are leveraged to report the technical context of different categories in the following subsections.

2.1. Demand Growth, Load Size, and Generation Adequacy

2.1.1. Discussion Summary

The workshop highlighted the unprecedented and accelerating demand that data centers are placing on the electric grid, with Loudoun County, Virginia ("Data Center Alley") serving as a case study for national trends. According to data presented in the workshop, power demand increased by 176% over seven years, from 1.5 gigawatts (GW) in 2019 to 4.14 GW in 2024 [6]. Current linear projections estimate that demand could reach 11.43 GW by 2029. However, the rise of AI is further exacerbating the problem by increasing the power consumed per rack from 10-14 kW to over 100 kW per rack, which could increase the demand in Loudoun County to over 30 GW by 2029. Whether this potential demand could actually be served remains a question of supporting infrastructure growth and availability. Until recently, many data centers would purchase office locations to utilize "by right" regulations, allowing them to request hundreds of megawatts (MW) of power. However, this approach is becoming less viable as the regulatory environment has begun to adapt. As an example, with the larger-than-forecasted data center demand growth, PJM has informed Dominion that it will constrain interconnection requests for Data Center Alley until 2027 [6]. In response to this order, Loudon County ended "by right" data center regulations on March 18, 2025 [6].

This case exemplifies the current conflicts between data centers, regional governments, utilities, and regional transmission organizations. The workshop's online survey and gallery walk discussions reflected similar concerns from across the country, with participants noting that these challenges are not unique to Virginia but are emerging in other regions with rapid data center expansion.

Panelists and attendees discussed the limitations of traditional grid planning and capacity markets, which have struggled to keep pace with the scale and speed of data center-driven load growth. As one presenter explained, utilities have historically relied on deterministic capacity expansion models to inform their long-term integrated resource plans, but these approaches are being tested by the volatility and magnitude of new data center loads, which therefore leads to an increase in scenarios evaluated.

2.1.2. Analysis: Implications and Key Gaps

- **Generation Shortfalls and Strained Infrastructure**: Utilities and asset developers are struggling to build new generation and transmission fast enough to meet both current and forecasted needs, especially as AI and high performance computing (HPC) workloads drive even higher power densities and more variable load profiles. Meanwhile, data centers struggle to find providers who will be able to meet their rapid development timelines, leaving them potentially stranded and unable to reach their full potential.
- **Resource Adequacy Under Uncertainty:** Traditional resource adequacy planning, which relies on long-term, deterministic models, is being challenged by the unpredictable and non-linear nature of data center growth. Some utilities are finding that even aggressive buildouts of new generation may not be sufficient if demand continues to accelerate or if new loads materialize faster than anticipated. This creates a risk of localized or regional shortfalls, especially in areas with limited transmission import capacity or slow permitting processes.
- **Need for Flexible, High-Capacity Generation**: The workshop highlighted that the grid's ability to absorb new data center loads depends not only on total generation capacity, but also on the flexibility and reliability of that capacity. Nuclear, natural gas, and emerging technologies (such as small modular reactors (SMRs)) were discussed as potential solutions, but participants noted that siting, permitting, and construction timelines for these resources

often lag behind the pace of demand growth. There is also a growing need for fast-ramping and dispatchable resources to accommodate the variable and peaky nature of AI-driven data center loads.

- **Risk of Inadequate Planning for Extreme Scenarios:** Several participants raised concerns that current planning processes may underestimate the risk of extreme events, such as simultaneous heat waves, generator outages, or rapid surges in AI adoption, that could push the grid beyond its limits. The lack of robust scenario analysis and stress testing for these "tail risk" events was identified as a key gap in ensuring generation adequacy.

2.1.3. Next Steps

- **Enhance Collaborative Planning:** Establish formal mechanisms for ongoing collaboration among data center developers, utilities, grid operators, and local governments. This could include joint forecasting exercises, shared infrastructure planning, and regular stakeholder forums to align expectations and timelines.
- **Accelerate Infrastructure Investment**: Advocate for streamlined permitting and regulatory processes to enable faster deployment of new generation and transmission assets. Explore innovative financing models and public-private partnerships to share the costs and risks of large-scale infrastructure upgrades.
- **Promote Flexible and Distributed Solutions:** Encourage the development of on-site generation and energy storage to reduce reliance on constrained transmission corridors and improve local resource adequacy.
- **Leverage Grid-Enhancing and Advanced Transmission Technologies:** Pursue the deployment of grid-enhancing technologies (GETs) and advanced transmission technologies (ATTs), such as dynamic line rating, advanced conductors, and power flow control devices to maximize the capacity and flexibility of existing transmission infrastructure. These technologies can provide rapid, cost-effective increases in transmission capability, helping to bridge the gap between generation and load while longer-term infrastructure projects are developed.

2.2. Cost and Economic Factors

Cost and economic factors were central to nearly every discussion at the workshop, reflecting the complex interplay between data centers, utilities, grid operators, equipment suppliers, and regulators. Participants repeatedly cited concerns about obtaining timely approvals for interconnections and the rapid deployment of additional infrastructure needed to remain competitive in the AI race. The cost considerations related to meeting rapidly growing power demand from data center industry include, among others, the return on investments for upgrading/developing grid infrastructure, interconnection review, and approval, and potential burden on the existing ratepayers. These concerns are repeatedly brought up by several power industry stakeholders in response to Federal Energy Regulatory Commission (FERC) Advanced Notice On Proposed Rulemaking (ANOPR) Docket # RM26-4 [7]. Future coordination is needed where any provision of load flexibility, backup power availability, and uncertainty in long-term power demand, are all accounted for in grid infrastructure development/upgradation cost sharing.

Another factor that increases time and cost is the limited availability of grid components. There are significant backlogs for essential components such as gas turbines [8], and (generation step up) transformers [9]. When asked "What issues keep you up at night" at the Gallery Walk discussion, the top response was equipment lead times, with specific mention of backlogs for gas turbines and large transformers. A consolidated effort from both the power industry and data centers, in partnership with public and government organizations, was identified as a need to promote funding mechanisms for increasing domestic manufacturing capacity. This, in turn, would lower lead time, make essential grid components cheaper, and collectively lower the cost burdens over the power industry, data centers and other ratepayers.

Additionally, stakeholders during the workshop's Gallery Walk discussion expressed their openness to the idea of data centers utilizing nuclear reactors to power their operations. However, they noted several concerns: new nuclear reactors are not yet available for purchase, stakeholders are skeptical about the timeline for availability, and they do not believe that nuclear reactors will be accessible before 2035. This poses a significant concern, as the prolonged timeline may cause nuclear reactor companies to lose immediate business opportunities with the data centers. Consequently, data centers are likely to seek alternative energy sources, potentially hindering the adoption of nuclear power within the data center industry. It is imperative for nuclear reactor companies to address these concerns and provide clear, realistic timelines to maintain the interest and confidence of potential data center clients.

Aside from the grid component and nuclear power availability discussions and their cost implications, the workshop attendees were asked their opinions on the best payment mechanisms for "behind-the-meter" (BTM) sources at the Gallery Walk discussion. Options discussed ranged from requiring large loads to bring their own generation, to giving such loads preference in the interconnection queue, to requiring financial commitments as a condition for interconnection. The most popular options among attendees were those that incentivized self-generation and rewarded proactive investment in new capacity. Most attendees agreed that establishing their own generation was not a problem. However, there is further discrepancy regarding the conditions for going fully BTM. Navigating regulatory requirements for large generation sites, even those not grid-connected, poses challenges, as do models where a data center would be "islanded" the majority of the time, but still require grid connections to power their full capacity while on-site generation undergoes routine maintenance or upgrades. The consensus on pursuing all generation growth options shows some agreement between the power and data center industries. The power industry does not have the capabilities to maintain loads of this scale with existing resources; conversely the data center industry is seeking energy security and a faster interconnection process.

2.2.1. Analysis: Implications and Key Gaps

- **Interconnection Delays and Cost Uncertainty:** Delays in interconnection approvals and uncertainty around cost allocation for grid upgrades are major barriers to timely data center deployment. These delays can increase project costs, reduce competitiveness, and create friction between data centers and utilities.
- **Supply Chain Constraints:** The limited availability of critical grid components, such as gas turbines and transformers, drives up costs and extends project timelines. This is exacerbated by global supply chain disruptions and limited domestic manufacturing capacity, making it difficult for both utilities and data centers to plan and budget effectively.
- **Uncertain Economics of New Nuclear:** While nuclear energy is seen as a promising long-term solution for data center power needs, uncertainty around cost, schedule, and regulatory approval for new reactors remains a significant barrier. The probable lack of commercially available nuclear options before 2035 may force data centers to pursue alternative solutions, potentially delaying the adoption of nuclear power in the sector.
- **Ambiguity in BTM Cost Allocation:** There is no clear consensus on how to allocate costs and benefits for behind-the-meter generation. While many stakeholders support self-generation, there are unresolved questions about compensation for grid contributions, interconnection standards, and the role of utilities in regulating or supporting BTM operations.

- **Risk of Cost Shifting to Ratepayers:** Without clear policies and cost-sharing mechanisms, there is a risk that the costs of grid upgrades and new generation could be shifted onto existing ratepayers, raising concerns about fairness and public acceptance.

2.2.2. Next Steps

- **Clarify BTM Guidelines and Compensation Mechanisms:** To ensure reliability, it is essential to address the complexities associated with BTM generation for data centers. The consensus from workshop participants indicates a preference for self-generation capabilities, but the conditions for fully BTM operations remain contentious. On one hand, grid operators believe that data centers should contribute to the grid by supplying excess power and even demand response or ancillary services, thereby enhancing grid stability and reliability. This approach aligns with existing principles for distributed generators [10], and may support ancillary services such as voltage and frequency regulation. Conversely, some data center stakeholders believe that utilities should not influence the operational decisions of data centers, including how BTM resources are managed. This view emphasizes the autonomy of data centers in managing their energy resources and prioritizes operational efficiency and reliability without external constraints.

- **Enhance Domestic Manufacturing and Supply Chain Resilience:** Industry and government should work together to invest in domestic manufacturing capacity for critical grid components such as transformers and gas turbines. Funding mechanisms and incentives can help reduce lead times and lower costs for all stakeholders.

- **Increase Transparency on Nuclear Timelines and Costs:** Nuclear developers should provide clear, realistic timelines and cost estimates for new reactor deployment, and engage proactively with data center clients to maintain confidence and interest in nuclear solutions.

- **Streamline Interconnection and Cost Allocation Processes:** To address ambiguity associated with grid and data center interconnection, a structured guideline is recommended. This should offer clear guidelines for BTM operations, including interconnection standards, compensation mechanisms for grid contributions, and protocols for grid support services. Additionally, implementing advanced grid management technologies, such as virtual power plants, can facilitate seamless integration of BTM generation with the wider grid infrastructure [11]. While guidelines and templates will be useful tools, actual interconnection processes will vary among ISOs, and general recommendations will need to be customized to be actionable.

- **Leverage Federal and State Policy Coordination:** Engage with ongoing regulatory processes, such as FERC ANOPR Docket # RM26-4, to identify common ground and develop policies that minimize cost impacts while supporting innovation and reliability.

- **Promote Collaborative Cost-Sharing Models:** Explore new models for sharing the costs and benefits of grid upgrades, distributed generation, and reliability investments among data centers, utilities, and ratepayers, ensuring that no single group bears a disproportionate burden.

- **Align Contracting and Cost Recovery Mechanisms:** Work toward consensus on long-term contracting requirements and cost recovery mechanisms that balance the need for utility risk mitigation with the flexibility required by data center operators. Consider innovative approaches such as performance-based contracts or shared infrastructure investments.

2.3. Power Quality and Stability

2.3.1. Discussion Summary

Maintaining power quality and grid stability in the face of rapidly growing and increasingly dynamic data center loads was a central theme throughout the workshop. Presenters emphasized that traditional electrical distribution designs, optimized for steady-state industrial or commercial loads, are no longer adequate for the dynamic characteristics of modern data centers, especially those supporting AI workloads. These facilities now experience rapid load swings, high harmonic distortion, sub-synchronous oscillations, and stringent voltage ride-through requirements.

Several panelists highlighted the need for intelligent, hierarchical control systems that balance generation, storage, and load in real time. Data centers must provide grid operators with visibility into their operational status (voltage, frequency, and power), using technologies such as phasor measurement units (PMUs) and advanced monitoring at the point of interconnection. The control philosophy must ensure that every generation source, storage element, and load responds cohesively to maintain system integrity and operational reliability across all conditions.

A recurring point was the mismatch between traditional supervisory control and data acquisition (SCADA) and control systems, which typically operate on 2–4 second scan rates, compared to the sub-100 millisecond changes in load driven AI-driven load fluctuations. These behaviors are happening at a scale inappropriate for command-and-control architectures, driving need for autonomous functionality of distributed assets. New architectures and methodologies can help address this gap, including dynamic modeling, steady-state and transient stability analysis, and hardware-in-the-loop (HIL) testing for validation and verification.

Workshop discussions also noted that accurate dynamic models for data centers are lacking, and that transient stability and dynamic modeling are niche fields with limited expertise yet are becoming increasingly relevant as data centers represent a growing share of large electronic loads on the grid.

A hierarchy of controls was recommended, starting with dispatch oversight for strategic planning and economic optimization, followed by energy management systems (EMS) for forecasting and scheduling, power plant controllers for real-time balancing and voltage/frequency regulation, and local controllers for millisecond-level device control and protection. This is standard in power system design, but using this strategy to build up controls on the data center or onsite generation sites will help ensure compatibility with utility schemes and prioritize controls in a logical manner.

2.3.2. Analysis: Implications and Key Gaps

- **Legacy System Limitations:** Legacy electrical distribution designs optimized for steady-state industrial or commercial loads are inadequate for the dynamic characteristics of AI workloads. These facilities face challenges such as rapid load swings, high harmonic levels, sub-synchronous oscillations, and stringent voltage ride-through requirements. Newer SCADA and control systems are required for data centers at the point of interconnection that require response times not seen in conventional hardware.
- **Modeling and Expertise Shortage:** Dynamic modeling and power system analysis, including steady-state and transient stability analysis, are essential. However, there is a shortage of accurate, validated models for data center dynamics, and a lack of engineers with expertise in transient stability and dynamic modeling. Only a small fraction of electrical engineers are trained in these areas, and even fewer have experience with the unique challenges posed by large electric loads.
- **Validation and Testing:** HIL testing and early-stage dynamic modeling are essential for validating new control strategies and ensuring that systems will perform as expected under

real-world conditions. However, these practices are not yet standard in data center project development, leading to costly retrofits and operational surprise.

2.3.3. Next Steps

To address these challenges and advance the state of power quality and stability for data centers, the following actions are recommended:

- **Develop and Disseminate Accurate Dynamic Models:** INL and industry partners should prioritize the development and validation of dynamic models for data center loads, including AI and HPC scenarios. These models should be made available to utilities, grid operators, and engineering firms to support better planning and analysis.
- **Expand Training and Workforce Development:** Public and private organizations should invest in training to increase the pool of engineers skilled in transient stability, dynamic modeling, and advanced control systems. This could include workshops, certification programs, and partnerships with universities.
- **Standardize HIL Testing and Validation:** Make HIL testing and early-stage dynamic modeling standard practice in data center project development. Develop guidelines and best practices for integrating these steps into project timelines and budgets.
- **Enhance Data Center–Grid Communication:** Establish protocols for real-time data sharing between data centers and grid operators, including operational status, load forecasts, and contingency plans. This will enable more responsive and coordinated control strategies.
- **Promote Collaborative Research and Demonstration Projects**: Launch joint research and demonstration projects to test new control architectures, validate models, and explore innovative approaches to power quality and stability. These projects should include both technical and regulatory stakeholders.

2.4. Resource and Location Considerations

2.4.1. Discussion Summary

Both water needs and noise pollution concerns were discussed during the workshop. It was noted that nearby inhabitants can oppose data center development projects due to their perceived understanding of these environmental topics. Data centers have historically targeted areas where the cost of water has been low when compared to the cost for energy and/or real estate. However, as water stressed areas like Arizona, Texas, and Virginia are being considered, water needs to become part of the complex planning in order to derisk projects delays, engineering overruns, and impact to local water supplies.

For noise concerns, people in general do not like living near data centers as they can be significant contributors to noise pollution. Siting determinations should consider noise pollution influences and/or consider noise mitigation measures or even avoiding residential areas. Considering these impacts will help to alleviate this issue.

2.4.2. Analysis: Implications and Key Gaps

Most of the conversation about water involved consumption (known in this context as use and not necessarily the legal definition). A presentation during the workshop highlighted that water is much more than the physical resource and all aspects need to be considered including governance- the who, what, when, and how water can be used within a society. This is especially important in water-scarce areas where adding a data center may impact water access of other stakeholders or delay the data center from being successfully implemented.

- **Broader engagement of stakeholders:** It is critical for data centers to engage with the local stakeholders of water infrastructure and resources, but depending on the location there may be need for regional authority engagement. This could become a more pressing issue as data centers transition from air-cooled to water-cooling technology [12]. During the gallery walk, stakeholders were particularly interested in alternative cooling solutions to reduce energy usage of which water cooling is one the most popular options. However, there are known tradeoffs between less energy consumption and more water use.
- **Consider all formats of water to explore out of the box opportunities:** Types of water including groundwater, surface water, and recycled (reuse) water were presented, highlighting how water becomes very complex and nuanced quickly. Adding in the governance piece including the management and administration of water could mean these are unexplored opportunities to leverage policy and landscape variability. [13]
- **Addressing noise complaints:** Noise is a growing concern of data centers, especially as they move closer to residential and commercial areas, either through new development or population growth impeding existing locations. Data centers operate continually, without regard to human rhythm and routines which can create a nuisance to nearby inhabitants. Noise can be attributed to:

  1) Cooling systems- chillers and evaporative coolers, fans, and/ or cooling towers (70- 80 dBA),
  2) Backup power- diesel generators require short monthly testing and produce increased sustained levels when used during backup operations, (85-110 dBA),
  3) Electrical infrastructure- transformers and switchgear transmit low frequency noise that travels large distance which can permeate through walls and windows (40-75 dBA).

  Currently, communities employ multiple means of regulating noise with varying success. Examples include zoning, defining noise control standards-audibility levels, time of day and enforcement-fines/penalties. Most of the regulation occurs at pre-construction with limited penalties and enforcement post construction, as demonstrated by a 2022 review of U.S noise pollution ordinances [14].

2.4.3. Next Steps

Significant response was received after the workshop with developers inquiring more about water especially regarding specific locations. More work is needed in the area of water and noise to understand how barriers can be streamlined and considered earlier in the development process specific to data centers. Knowledge from other industrial applications of both water needs and noise should be leveraged.

- **Develop Water and Noise Evaluation Tools:** There is need to help industry navigate dynamic and developing environmental topics, especially to conceptualize and estimate the cost impacts of addressing water needs and noise mitigation efforts.
- **Technical Assistance Guidance:** Other sectors and industries have been navigating water and noise concerns for decades; this knowledge should be curated in formats that data center developers can digest specific to their developing needs.
- **Further Research:** Environmental topics were a small part of the workshop. More research is needed to understand if this is an artifact of the audience or if water and noise need to be given higher consideration. Given the feedback after the workshop, indications point to the latter.
- **Mitigate noise concerns:** As new types of infrastructure, some data centers have blurred the line between traditional commercial and industrial user classifications, potentially falling

through local noise ordinance requirements. A few cities have addressed this confusion by enacting data center specific ordinances, often requiring pre-construction sound studies like traditional industrial users, mitigation measures and more strict zoning requirements, and real-time monitoring or publicly facing noise dashboards. Mitigation measures that can be employed include:

1) Acoustic barriers-common in transportation noise pollution, these are walls and berms that block line of sight,
2) Silencers on fans and air intakes,
3) Lower noise cooling equipment- larger slower fans with variable speed motors,
4) Sound attenuating housing for generators,
5) Vibrational controls for chillers and transformers, and
6) Liquid cooling requiring fewer fans.

The emerging trend of AI data center clusters and noise concerns are also shifting data centers to industrial zoned sites, rural areas with less requirements or enforcements, and other areas with lower sound requirements.

2.5. Grid Interconnection Requirements and Coordination

2.5.1. Discussion Summary

Interconnection agreements were a major concern during the workshop. While each interconnection depends on the individual scenario, it is heavily influenced by the jurisdiction it falls under. Federal, state, and local regulations may apply, and the lack of coordination and alignment across jurisdictions was noted as a key challenge for data center developers. Different jurisdictions have different priorities, such as requirements for certain generation sources or reliability cost policies. Additional thresholds for large loads vary as well. However, most of these jurisdictions are reaching a consensus that large loads should sign long-term contracts, with a major motivation being to protect utilities from stranded costs. This is motivated by the need to ensure that investments in new generation and transmission infrastructure are financially secure, especially as data center demand can be volatile and subject to rapid change. The workshop also highlighted that interconnection timelines and requirements are often a bottleneck for data center deployment, with delays in approvals and infrastructure upgrades cited as a top concern by both data center and utility stakeholders. Details about state-specific requirements are given in Appendix B.

2.5.2. Analysis: Implications and Key Gaps

- **Jurisdictional Complexity:** The interconnection process is highly dependent on the jurisdiction in which a project is located. This creates uncertainty for data center developers, who must navigate a complex landscape of rules and requirements that can change from one state or utility territory to another.
- **Long-Term Contracting and Cost Recovery:** The move toward requiring long-term contracts for large loads before the sites are fully operational reflects a shift in risk management, with utilities seeking to avoid stranded costs if a data center reduces or ceases operations. However, this can also increase the financial burden and risk for data center operators, especially in fast-evolving markets.
- **Bottlenecks and Delays:** Interconnection studies, cost allocation for required upgrades, and coordination among multiple stakeholders (utilities, ISOs/RTOs, regulators, and developers) are frequently cited as sources of delay. These bottlenecks can slow the deployment of new

data centers and the associated infrastructure needed to support them. The combined burden of higher costs and unanticipated delays creates real risk for data center projects.

- **State-Specific Requirements:** While some states prioritize certain energy sources or grid reliability, others focus on economic development or cost containment. This patchwork of priorities can lead to inconsistent requirements and timelines, further complicating project planning and execution.

2.5.3. Next Steps

- **Develop Standardized Interconnection Guidelines**: Industry, utilities, and regulators should collaborate to develop more standardized, transparent, and predictable interconnection requirements for large loads. This could include model agreements, clear timelines, and standardized study processes to reduce uncertainty and delays.
- **Promote Early and Ongoing Coordination:** Encourage early engagement and ongoing communication among data center developers, utilities, ISOs/RTOs, and regulators to identify potential issues and align expectations before formal interconnection requests are submitted.
- **Leverage Advanced Planning Tools:** Utilize advanced grid modeling and scenario analysis to anticipate the impacts of large new loads and to streamline the interconnection study process. This can help identify optimal locations for new data centers and prioritize infrastructure upgrades.
- **Monitor and Adapt to Evolving State Policies:** Stay informed about state-specific requirements and policy changes, and advocate for regulatory harmonization where possible to reduce barriers to deployment and support efficient grid integration.

2.6. Proximity to Power: Considerations for Transmission and Onsite Generation and Storage

2.6.1. Discussion Summary

Workshop participants repeatedly raised concerns about the availability of sufficient transmission lines to deliver electricity to data center locations, as well as the timeframe required for deploying new infrastructure. For example, Loudon County is doubling its transmission capacity to accommodate the growth of data centers in the area [6] [6]. However, even with the new transmission lines, this increased capacity is projected to be insufficient to meet the expected growth [6].

Given these constraints, stakeholders discussed the importance of siting generation resources in close proximity to data centers. However, as noted in the workshop, generation cannot be built anywhere since the transmission capabilities to send power to the data center may not exist. Building new transmission lines is a notoriously lengthy process, with timelines measured in years or even decades. Alternate options include GETs, such as dynamic line rating (DLR), which can increase or decrease the rating of a conductor depending on weather conditions [15]. Reconductoring an existing line can increase capacity by 50 to 100% by reconductoring the lines [6].

With transmission limited, data center developers are exploring alternatives, particularly microgrids defined as "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode" [3]. The microgrid's primary use is to co-locate the generation assets with the data center forging the need for additional transmission. Loudon County has shown particular interest in this approach, and polling during the workshop indicated strong data center interest in owning generation outright, in many cases with a preference for not sharing it with the grid [6].

BESS emerged as the most popular storage option during the Gallery Walk, with additional interest in thermal storage, natural gas, and hybrid solutions to manage peak usage and enhance reliability

2.6.2. Analysis: Implications and Key Gaps

- **Transmission as a Bottleneck:** Even aggressive transmission upgrades may not keep pace with data center demand growth, especially in high-density regions like Loudoun County. The slow pace of new transmission development is a critical limiting factor for both grid-connected and new generation projects.
- **Siting Constraints:** The ability to build new generation is often limited by the availability of transmission capacity. This creates a "chicken-and-egg" problem, where generation and transmission must be planned and developed in tandem to ensure adequacy and reliability.
- **GETs as a Bridge Solution:** GETs offer a promising way to quickly and cost-effectively increase transmission capacity, but their deployment is not yet standard practice. Wider adoption of GETs could help bridge the gap while longer-term infrastructure is developed.
- **Microgrids and BTM Solutions**: The growing interest in microgrids and BTM generation reflects both a desire for energy security and frustration with slow interconnection and transmission upgrades. However, the implications for grid stability, cost allocation, and regulatory oversight remain areas of active debate.
- **Storage Integration:** As data centers pursue onsite generation, the integration of storage, particularly BESS, will be essential for managing variability, supporting peak loads, and enabling islanded operation when needed.

2.6.3. Next Steps

- **Accelerate Deployment of Grid-Enhancing Technologies**: Utilities and grid operators should prioritize the adoption of GETs, such as Dynamic Line Rating and advanced conductors, to maximize the capacity of existing transmission infrastructure and provide near-term relief for congested corridors.
- **Promote Integrated Planning for Generation and Transmission**: Encourage joint planning processes that align the development of new generation assets with transmission upgrades, ensuring that both are available when and where needed to support data center growth.
- **Support Microgrid and BTM Demonstration Projects:** Launch pilot projects to test the technical, economic, and regulatory implications of microgrids and BTM generation for data centers. Use these projects to develop best practices for integration, reliability, and cost allocation.
- **Facilitate Storage Integration:** Develop guidelines and incentives for the deployment of battery and thermal storage alongside onsite generation, enabling data centers to manage peak loads and enhance resilience.
- **Clarify Regulatory and Market Frameworks**: Work with regulators to establish clear rules for microgrid operation, BTM generation, and grid contributions, ensuring that new solutions support both data center needs and broader grid reliability.

2.7. Data Sharing and Load Forecasting

2.7.1. Discussion Summary

Throughout the workshop, data sharing and load forecasting emerged as critical themes for enabling reliable, efficient, and scalable power solutions for data centers, especially as nuclear energy and other advanced generation sources are considered. Participants repeatedly highlighted the disconnect between how grid operators perceive data center loads (as unpredictable and potentially disruptive) and the reality that data center operators typically have highly accurate, granular forecasts of their own power needs, starting with discussion in the plenary panel, and expanding on this theme in national lab and industry presentations.

Panelists and presenters described the current state of practice: most data centers already possess detailed 24-hour load profiles, but these are rarely shared with utilities or ISOs/RTOs. The lack of routine data exchange leads to friction, with grid operators forced to plan for worst-case scenarios and peak loads that may not materialize. Several industry experts advocated for more transparent and proactive sharing of load data, noting that such collaboration could enable utilities to allocate resources more efficiently, reduce the need for emergency reserves, and improve overall grid reliability.

This disconnect applies both for short-term and long-term forecasting. The need for short-term forecasting is clear. Daily and hourly forecasts are needed for ISOs and RTOs to perform efficient generation dispatch and ensure the reliability of the grid. Even higher fidelity forecasting, driven by the voltage sensitivity of data center operations and dependent on accurate system dynamic models, is needed to improve reliability. Additionally, some participants from the nuclear industry highlighted that they felt utility's evaluations of generation adequacy needs were unfair. If onsite nuclear generation was used, the data center would have minimal impact to the grid except during routine maintenance on the nuclear facilities, such as fuel cell replacement. However, utility participants countered that if the grid needed to support the full data center load at any point in time, all of the support infrastructure (transmission capacity, transformers, etc.) must be in place, along with the generation capacity. Enhanced mutual understanding of generation adequacy requirements and long-term forecasting could help all parties find solutions that meet short-term needs while enabling long-term optimization.

Research presented at the workshop reinforced that generation adequacy is needed across multiple aspects. For example, one presentation described how intelligent coordination between generation, storage, and load, enabled by accurate forecasting and real-time data exchange, can maintain grid stability even as data center workloads become more dynamic and variable (e.g., due to AI and HPC applications). The importance of sub-second response times and advanced control architectures was emphasized, with legacy approaches deemed inappropriate for the rapid load swings now observed in modern facilities.

The need for long-term forecasting has not yet been fully resolved either. There are lots of predictions about load growth in various regions, but ISOs and RTOs frequently revise their estimates. Many predictions are largely speculative based on previous trends, market signals, and policy decisions, and are sometimes skewed by things like multiple interconnection requests being submitted for a single planned data center to see where it can be built fastest. More transparency on actual demand and planned year-over-year growth will help grid planners make decisions about supporting grid infrastructure to enable the true growth.

Discussions also touched on the regulatory and market implications of data sharing, particularly in conversations with power engineers and economists. In competitive electricity markets, the ability to forecast and communicate load profiles can open new opportunities for data centers to participate in ancillary services, demand response, and capacity markets. However, the mechanisms for integrating these capabilities into market structures and regulatory frameworks remain underdeveloped.

2.7.2. Analysis: Implications and Key Gaps

- **Grid Reliability and Planning**: Without access to accurate load forecasts, utilities must procure reserves and infrastructure conservatively, driving up costs and potentially delaying new connections for large loads. Improved data sharing could streamline planning and reduce unnecessary expenditures.
- **Operational Efficiency:** Real-time and predictive data exchange enables more sophisticated control strategies, such as dynamic load management and coordinated dispatch of generation and storage assets. This is especially important as data centers integrate on-site generation (including nuclear) and storage, which can further complicate grid interactions.
- **Market Participation:** Transparent load data allows data centers to participate more actively in energy markets, providing flexibility and ancillary services that benefit both the grid and the data center operator. However, market rules and regulatory structures often lag behind technical capabilities, limiting the value that can be captured.
- **Trust and Confidentiality:** Despite technical feasibility, cultural and business barriers persist. Data centers may be reluctant to share proprietary load data due to concerns about confidentiality, competitive advantage, or regulatory exposure. Building trust and developing standardized protocols for data exchange are ongoing challenges.
- **Technical Gaps:** Legacy grid control systems are not designed for the speed and variability of modern data center loads. There is a need for advanced modeling, hardware-in-the-loop testing, and dynamic stability analysis to ensure that new control architectures can handle rapid fluctuations without compromising reliability.

2.7.3. Next Steps

- **Develop Standardized Data Sharing Protocols**: INL and industry partners should collaborate to define protocols and best practices for sharing load profiles and forecasts with utilities and grid operators. This includes addressing confidentiality concerns and establishing clear guidelines for data use.
- **Pilot Collaborative Forecasting Initiatives**: Launch demonstration projects where data centers and utilities exchange real-time and predictive load data, with the goal of improving grid planning, reducing reserve requirements, and enabling more flexible operations.
- **Advance Control System Research:** Invest in research and development of next-generation control architectures capable of integrating real-time load data, on-site generation, and storage. Hardware-in-the-loop testing and dynamic modeling should be prioritized to validate new approaches.
- **Engage Regulators and Market Operators:** Work with regulatory bodies and market operators to update rules and incentives that support data sharing, flexible load participation, and ancillary service provision by data centers.
- **Build Trust and Industry Consensus:** Facilitate ongoing dialogue between data center operators, utilities, and regulators to build trust, clarify expectations, and address concerns about data confidentiality and competitive impacts.
- **Document and Disseminate Best Practices**: INL should lead efforts to capture lessons learned from pilot projects and collaborative initiatives, publishing guidance and case studies to accelerate adoption across the industry.

2.8. Public Perception and Stakeholder Engagement

2.8.1. Discussion Summary

Public perception and stakeholder engagement emerged as recurring themes throughout the workshop, particularly in the context of siting new data centers, expanding grid infrastructure, and introducing advanced energy solutions such as nuclear power. Several speakers, including local government officials and industry representatives, emphasized that community acceptance is a critical factor in the success of large-scale energy and data infrastructure projects.

For example, a Loudoun County speaker described how rapid data center growth has led to increased community scrutiny and resistance, particularly regarding land use, noise, and visual impacts. He noted that while data centers bring significant economic benefits, such as business tax revenue and lower property taxes—they also raise concerns about quality of life and local infrastructure. Turner highlighted the importance of transparent communication and proactive engagement, stating that "one email and one phone call at a time" is often how community concerns are addressed.

The workshop also explored the evolving public perception of nuclear energy. Panelists noted that, while nuclear power has historically faced skepticism, recent trends show increasing public support, especially when nuclear is positioned as a solution for reliable, low-carbon energy to power digital infrastructure. However, participants cautioned that messaging must be tailored to local contexts, reflecting the sensitivity of the topic in some communities.

Stakeholder engagement was further discussed in the context of regulatory processes, with several participants emphasizing the need for early and ongoing dialogue among data center developers, utilities, local governments, and community members. The workshop highlighted that successful projects often result from collaborative environments where all parties are invited to share their perspectives and concern.

2.8.2. Analysis: Implication and Key Gaps

- **Community Acceptance as a Prerequisite**: The success of data center and energy projects increasingly depends on community buy-in. Concerns about noise, aesthetics, land use, and environmental impacts can delay or derail projects if not addressed proactively.
- **Evolving Perceptions of Nuclear Energy:** While there is growing openness to nuclear as a widespread energy solution, acceptance varies widely by region and is influenced by local history, leadership, and recent experiences. Effective engagement requires understanding and respecting these differences.
- **Importance of Transparent Communication:** Participants agreed that clear, honest, and frequent communication is essential for building trust. This includes sharing both the benefits and potential impacts of projects, as well as listening to and addressing stakeholder concerns.
- **Navigating Regulatory and Political Realities:** Engagement strategies must account for the complex regulatory and political environments in which projects are developed. This includes understanding local priorities, regulatory requirements, and the roles of various decision-makers.

2.8.3. Next Steps

- **Develop Tailored Engagement Plans:** Data center developers and energy providers should create engagement strategies that are customized to local contexts, addressing specific community concerns and values.
- **Foster Ongoing Dialogue:** Establish regular forums for communication among all stakeholders, including community members, local officials, utilities, and industry

representatives. These forums should encourage open discussion, feedback, and collaborative problem-solving.

- **Enhance Transparency and Education:** Provide accessible information about project benefits, impacts, and timelines. Educational initiatives can help demystify technologies like nuclear energy and clarify their role in supporting digital infrastructure.
- **Build Local Partnerships**: Collaborate with local organizations, educational institutions, and community leaders to build trust and demonstrate commitment to shared goals.
- **Monitor and Adapt Engagement Approaches:** Continuously assess the effectiveness of engagement strategies and be prepared to adapt based on feedback and changing community dynamics.

2.9. Strategic Partnerships and Risk-Sharing Models

2.9.1. Discussion Summary

The workshop underscored the importance of strategic partnerships and innovative risk-sharing models as essential tools for addressing the scale, complexity, and uncertainty of powering data centers with advanced energy solutions. Participants from both the data center and energy sectors emphasized that no single entity can solve these challenges alone. Several sessions highlighted the evolving landscape of partnerships, with hyperscalers, utilities, nuclear developers, and public agencies all seeking new ways to collaborate. For example, during the Gallery Walk and technical panels, attendees discussed the growing trend of joint ventures, public-private partnerships, and forward-funded power purchase agreements (PPAs) as mechanisms to share financial risk and accelerate project timelines.

There was also recognition that risk-sharing must extend beyond financing to include operational, regulatory, and technological risks. This includes sharing responsibility for interconnection upgrades, supply chain investments, and the integration of new technologies such as microgrids, storage, and nuclear reactors. The need for credit backstops, insurance mechanisms, and flexible contracting was raised as a way to de-risk investments for all parties.

2.9.2. Analysis: Implications and Key Gaps

- **Alignment of Incentives:** Effective partnerships require alignment of incentives and objectives among diverse stakeholders. This can be challenging when data centers prioritize speed and flexibility, while utilities and regulators focus on reliability and cost recovery.
- **Complexity of Multi-Party Agreements:** As projects become larger and more complex, the number of parties involved increases, making negotiations and risk allocation more challenging. There is a need for standardized frameworks and best practices to streamline these processes.
- **Need for New Financial Instruments:** Traditional project finance models may not be sufficient for the scale and risk profile of next-generation data center projects. Workshop participants discussed the need for new instruments, such as credit backstops, insurance for cost overruns, and performance-based contracts, to enable investment and innovation.
- **Regulatory and Policy Uncertainty:** Uncertainty around regulatory approval, cost allocation, and long-term policy direction can deter investment and slow partnership formation. Participants noted that clear, stable policies are essential for building trust and enabling risk-sharing.
- **Knowledge and Data Sharing:** Successful partnerships depend on open communication and data sharing among all parties. This includes sharing load forecasts, project plans, and operational data to support joint decision-making and risk management.

2.9.3. Next Steps

- **Develop Standardized Partnership Frameworks:** Industry groups, utilities, and regulators should collaborate to develop model agreements, best practices, and templates for joint ventures, PPAs, and public-private partnerships. These frameworks should address financial, operational, and regulatory risk allocation.
- **Pilot Innovative Risk-Sharing Mechanisms:** Launch demonstration projects that test new risk-sharing instruments, such as credit backstops, cost overrun insurance, and performance-based contracts. Use these pilots to generate lessons learned and refine approaches.
- **Facilitate Cross-Sector Collaboration:** Establish regular forums and working groups that bring together data center operators, utilities, technology providers, financiers, and regulators to identify shared challenges and opportunities for partnership.
- **Promote Policy and Regulatory Certainty:** Engage with policymakers to advocate for clear, stable, and supportive regulatory environments that enable long-term investment and partnership formation.
- **Encourage Transparent Data and Knowledge Sharing:** Create platforms and protocols for sharing data, forecasts, and best practices among partners, while respecting confidentiality and competitive concerns.
- **Support Workforce and Supply Chain Development:** Collaborate on initiatives to build the skilled workforce and resilient supply chains needed for large-scale, innovative projects, sharing both the risks and benefits of these investments.

2.10. Topics Not Discussed

While the workshop provided a comprehensive exploration of the technical, economic, and policy challenges facing data centers and advanced energy integration, several important topics were only briefly mentioned or not discussed in depth. Highlighting these areas is not intended as a critique, but rather as a recognition that the landscape is broad and evolving. Addressing these topics in future workshops or research will help ensure a more holistic approach to the challenges and opportunities ahead.

2.10.1. Other Large Loads

Although the workshop focused primarily on data centers, other large and rapidly growing loads, such as oil and gas extraction, hydrogen production facilities, and advanced manufacturing, are poised to have significant impacts on grid planning and resource adequacy. These loads may have different operational profiles, regulatory requirements, and siting considerations, but they compete for many of the same grid resources and infrastructure. Understanding how these sectors interact, overlap, or compete with data centers will be crucial for comprehensive grid planning and for developing fair, efficient policies.

2.10.2. Nuclear Design Differences

While nuclear energy was discussed as a promising solution for data center power needs, the workshop did not delve into the technical and operational differences among various nuclear reactor designs (e.g., large light-water reactors, small modular reactors, microreactors, and advanced non-light-water designs). These differences can have major implications for siting, safety, licensing, cost, and integration with data center operations. A more detailed exploration of design-specific considerations would help both data center operators and nuclear developers make informed decisions and foster more effective partnerships.

2.10.3. Cybersecurity

Cybersecurity was acknowledged as a critical concern, especially given the increasing digitalization and interconnection of energy and data infrastructure. However, the workshop did not provide an in-depth discussion of the unique cybersecurity risks facing data centers, grid operators, and nuclear facilities—nor of the strategies and best practices for mitigating these risks. As cyber threats continue to evolve, robust cybersecurity frameworks and cross-sector collaboration will be essential to ensure the resilience and reliability of both energy and digital infrastructure.

3. TAKING ACTION

The 2025 INL Data Center Workshop brought together a wide variety of industries and stakeholders to explore the challenges and opportunities of powering large-scale data centers with advanced energy solutions. Across technical sessions, surveys, and collaborative activities, participants identified a wide range of barriers—from infrastructure constraints and regulatory complexity to data transparency and risk allocation. Just as importantly, they proposed actionable strategies to address these challenges.

This section distills the most frequently cited and cross-cutting recommendations into a set of key themes and approaches for next steps. These themes reflect a shared understanding that no single organization can solve these challenges alone. Instead, progress will require coordinated action across industry, government, and research institutions. The section also outlines the roles and responsibilities of key stakeholder groups, clarifying who is best positioned to lead, support, or collaborate on each front.

Together, these insights form key takeaways for accelerating deployment, improving grid reliability, and enabling the secure, scalable integration of data centers into the U.S. energy landscape.

3.1. Key Action Items

The workshop surfaced a wide range of recommendations, but several consistent themes emerged across sessions, survey responses, and stakeholder discussions. These themes reflect the multifaceted nature of powering data centers at scale and the need for coordinated, forward-looking strategies. The following seven approaches represent the most critical and cross-cutting actions recommended by participants.

1. **Strengthen Cross-Sector Collaboration**
   A foundational takeaway from the workshop was the need for structured, ongoing collaboration among data center developers, utilities, grid operators, regulators, national labs, and local governments. Participants emphasized the value of joint forecasting, shared infrastructure planning, and regular stakeholder forums to align expectations and timelines. Building trust and industry consensus, particularly around data sharing, interconnection, and cost recovery, was seen as essential to accelerating deployment and reducing friction.
2. **Modernize Infrastructure and Accelerate Deployment**
   The scale and urgency of data center growth demand faster and more flexible infrastructure development. Recommendations included streamlining permitting and interconnection processes, investing in domestic manufacturing to reduce equipment lead times, and deploying GETs and advanced transmission solutions. These efforts can help bridge the gap between current grid capabilities and the demands of AI-driven workloads.
3. **Advance Data Transparency and Forecasting**
   Participants identified a significant disconnect between how data centers forecast their loads and how utilities perceive those loads. Standardized protocols for sharing load profiles, real-time operational data, and predictive forecasts were recommended to improve grid planning, reduce reserve requirements, and enable more responsive control strategies. Pilot projects and collaborative forecasting initiatives were proposed to test and refine these practices.
4. **Enable Flexible, Distributed, and Behind-the-Meter Solutions**
   As transmission constraints persist, many stakeholders advocated for increased use of on-site

generation, energy storage, and microgrids. BTM solutions were viewed as a way to enhance energy security and reduce reliance on centralized infrastructure. However, participants stressed the need for clear guidelines, compensation mechanisms, and regulatory frameworks to support BTM integration while maintaining grid reliability.

5. **Invest in Modeling, Control Systems, and Technical Validation**
   The dynamic nature of modern data center loads presents new challenges for grid stability and power quality. To address these, stakeholders recommended investing in dynamic modeling, HIL testing, and advanced control architectures. These tools are critical for validating new approaches and ensuring safe, efficient integration of data centers into the grid. Expanding workforce training in these areas was also identified as a priority.
6. **Proactively Address Siting and Resource Considerations to Limit Community Impact**
   Data center developers should integrate water availability and noise mitigation into early planning to reduce project delays and community opposition. Recommended actions include engaging local and regional water authorities, exploring alternative water sources and governance opportunities, and implementing proven noise control measures such as acoustic barriers, quieter cooling systems, and zoning compliance strategies.
7. **Clarify and Align Regulatory and Market Structures**
   Ambiguity in interconnection requirements, cost allocation, and market participation rules was cited as a source of delay and uncertainty. Participants urged regulators to develop standardized guidelines, update market rules to support flexible load participation, and promote policy certainty to enable long-term investment. Coordination between federal and state agencies was seen as vital to harmonizing requirements and reducing barriers to deployment.
8. **Demonstrate and Scale Innovative Approaches**
   Across multiple topics, stakeholders emphasized the importance of demonstration projects to test new technologies, business models, and regulatory frameworks. These pilots can generate lessons learned, inform policy development, and build confidence among stakeholders. Areas identified for demonstration include microgrid integration, risk-sharing mechanisms, collaborative forecasting, and advanced control systems.

3.2. Roles and Responsibilities

The successful implementation of the recommendations outlined in this report will require coordinated action across a diverse set of stakeholders. Each group brings unique capabilities, perspectives, and responsibilities to the table. This section outlines how these roles intersect and where leadership and collaboration are most needed.

National Laboratories are positioned to lead in research, development, and technical validation. Their capabilities in dynamic modeling, hardware-in-the-loop testing, cybersecurity, and systems integration make them essential partners in de-risking new technologies and approaches. Labs also serve as conveners—bringing together industry, government, and academic stakeholders to share knowledge, pilot solutions, and develop best practices. Their role includes publishing guidance, supporting demonstration projects, and offering technical assistance to utilities, developers, and regulators.

The **U.S. Government and Department of Energy (DOE)** play a critical role in setting national priorities, funding innovation, and coordinating across agencies. DOE can accelerate progress by supporting pilot projects, developing standardized frameworks for interconnection and cost allocation, and facilitating regulatory harmonization. Federal leadership is especially important for addressing systemic challenges such as supply chain resilience, cybersecurity, and the integration of large loads into the bulk power system.

Utilities and grid operators are central to planning and operating the infrastructure that supports data center growth. Their responsibilities include forecasting demand, coordinating interconnection studies, deploying grid-enhancing technologies, and ensuring system reliability. Utilities must also engage in joint planning with data center developers, balancing the need for cost recovery with the imperative to meet rapidly growing demand. As the interface between generation and load, utilities are uniquely positioned to lead efforts in flexible grid operations and infrastructure modernization.

Regulators, at the federal, state, and local levels, are responsible for shaping the policy environment that governs interconnection, permitting, cost recovery, and reliability standards. Their role is to ensure that rules and processes are transparent, equitable, and responsive to emerging technologies and market dynamics. Regulators must also work to harmonize requirements across jurisdictions to reduce uncertainty and streamline deployment.

Data center developers are the drivers of demand and innovation. Their responsibilities include sharing load forecasts and operational data with utilities, investing in on-site generation and storage, and participating in collaborative planning efforts. Developers must also engage with communities and regulators to build trust, address environmental and social concerns, and ensure that projects align with local priorities.

Nuclear developers have a unique opportunity to provide firm, low-carbon power to data centers, but must overcome challenges related to cost, licensing, and deployment timelines. Their role includes providing transparent information about reactor designs, engaging with data center clients to align expectations, and participating in risk-sharing partnerships and demonstration projects.

Finally, **local governments** are critical for enabling siting, permitting, and community engagement. They serve as the bridge between infrastructure developers and the public, helping to align projects with local needs and values. Local governments can facilitate stakeholder dialogue, support regional planning, and coordinate with utilities and developers to ensure that infrastructure investments deliver shared benefits.

Together, these stakeholders form a complex but complementary ecosystem. Progress will depend not only on individual leadership but on the strength of partnerships—where responsibilities are shared, risks are managed collaboratively, and solutions are developed with a common purpose.

3.3. Research Gap: Load Demand and Forecasting in Power Systems

The rapid growth of data centers as critical infrastructure has introduced unprecedented challenges to the reliable operation and planning of power systems. These facilities, with their immense energy consumption and unique load profiles, are reshaping the way utilities forecast and respond to demand. Despite the attention given to data center energy efficiency, significant gaps remain in understanding and managing their interactions with the grid. This subsection explores these gaps, weaving together a narrative of the challenges and opportunities for advancing research in load demand and forecasting.

3.3.1. The Complexity of Load Correlations Across Markets and Applications

A fundamental question persists: *To what degree are data center load demands temporally and spatially correlated with peak hour demands on the grid?* This is particularly relevant as energy markets grow increasingly complex, with varying dynamics between regulated and deregulated systems. How do these correlations shift depending on the type of data center load—whether driven by crypto mining, AI model training, inference tasks, or streaming services? The sensitivity of such correlations to load type has yet to be fully understood, leaving utilities and grid operators to operate with limited insight into these evolving patterns.

Addressing this gap is critical for grid operators tasked with maintaining reliability while accommodating high-intensity, often unpredictable, load centers. National laboratories, such as Idaho National Laboratory, could play a pivotal role in bridging this understanding by collaborating with industry stakeholders to develop innovative forecasting tools. Such tools would illuminate the interplay between data center operations and peak demand events, enabling utilities to better prepare for capacity needs and mitigate grid stress.

3.3.2. Engineering Challenges in Off-Grid and Dynamic Operations

Beyond grid-connected operation, the engineering complexities associated with off-grid, large-load data centers pose another research challenge. Off-grid operations, such as those supported by uninterruptible power supply (UPS) systems, are currently avoided by many data center developers due to high technical risk and cost. Developing reliable models for these systems, validated at scale, is an urgent need. Specifically, dynamic modeling of large-load UPS systems and the seamless restoration of grid-connected operations from UPS support remain underexplored. How can operators effectively leverage tiered hierarchies in such transitions to ensure system stability and resilience?

Furthermore, there is a lack of understanding regarding the control and stability implications at the point of interconnection (POI) when data centers engage in flexible operations, including rapid ramping of large loads. These dynamics are critical not only for reliable grid operation but also for preventing unintended interactions, such as forced resonance of power flows between the grid and data center. Intriguingly, forced resonance could compromise AI-related tasks within the data center, introducing operational inefficiencies and potential risks to mission-critical applications.

3.3.3. Scaling Research from Kilowatts to Megawatts

Another pressing gap lies in the scaling of research findings. While much research into data center energy consumption begins at the kilowatt (kW) range, real-world deployment occurs at the megawatt (MW) scale. This mismatch creates challenges in translating laboratory findings into practical applications. Developing application-specific scaling methods and models is essential to bridge this divide. Without this step, the industry risks deploying solutions that fail to address the real-world complexities of large-scale data center operations.

3.3.4. The Role of Behind-the-Meter (BTM) Systems

BTM systems, with their multi-tiered architectures, add another layer of complexity. What are the implications of various BTM tier levels on the control, stability, and ramping challenges outlined above? Understanding how these systems interact with the broader grid and their ability to support flexible operations is a critical research area. Properly leveraging BTM systems could enable data centers to become not just consumers of energy but active participants in grid stabilization and demand management.

3.3.5. Building Toward Solutions

The challenges outlined above paint a clear picture of the current research gaps in load demand and forecasting for data centers. However, they also highlight opportunities for progress. Collaboration between utilities, industry leaders, and national laboratories could lead to transformative solutions. By addressing these gaps, the industry can unlock new levels of reliability, efficiency, and flexibility in managing large, fixed loads while adapting to rapidly changing demand patterns.

In conclusion, the growth of data centers represents both a challenge and an opportunity for the power systems community. Addressing the gaps in load demand forecasting, dynamic modeling, and operational control will not only ensure grid reliability but also enable the long-term growth of this critical infrastructure. The time to act is now—before the next wave of data center development overwhelms the existing frameworks for grid planning and operation.

3.4. Framework and Policy Development

The current cooperation framework between data centers and grid operators needs further investigation. Various frameworks are needed, including those for data management, financial arrangements, and grid operations, to support large data centers and behind-the-meter generation services.

Utilities and data centers need to transition from a supplier-consumer model to a partnership model. This includes joint planning for grid capacity, shared investments in infrastructure, and co-development of energy resilience strategies. Many utilities and RTO/ISOs are generally not capable of meeting the demands of data centers. The increased generation, transmission, and distribution capacity is prohibitively expensive and cannot be provided solely by the grid.

Grid operators and data centers must:

1. Develop a transparent plan for generation, transmission, and distribution capacity needed to meet the demand of data centers in their service areas and for other customers.
2. Understand how much of the added infrastructure upgrades are attributed to data centers and establish a guaranteed compensation plan that adequately protects other constituents.
3. In reciprocity for compensating the utility, the utility should prioritize data centers that sign on to the compensation plan.

These frameworks require additional research not only from both parties but also from a neutral third party. The government, whether federal, state, or local, is best suited for this role. National labs can help establish these frameworks on a federal level. While there is no current standard for data center grid interconnects, one should be created for these agreements to follow, instead of drafting every interconnection agreement from scratch. This would also inform the public of the reasoning behind the terms of the new interconnection agreements and assure them that a new data center will not significantly impact their community or electric bill. The data center would benefit from priority processing in interconnection and a more comfortable public. Both factors would help data centers get deployed more quickly. Power purchase agreements can also be derived from these template frameworks, which can help small utilities that have never served such large loads before.

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Appendix A: Workshop Survey

A-1. Survey Questions

Question Number	Survey Question	Response Options
Q1	What is your role in "Powering the large loads?" Select multiple if needed.	☐ Generation ☐ Transmission ☐ Distribution ☐ Large load ☐ Data center campus developer ☐ Nuclear sector ☐ Other (Please specify) ☐ I do not know
Q2	Which of the following scenarios seems feasible to you? Select multiple if needed.	☐ Data Center is being deployed on the premises of a nuclear power plant ☐ Nuclear power plants are being deployed on the premises of a data center to exclusively meet data center load demand ☐ No onsite generation powering the grid. Backup power only ☐ Other (Please specify) ☐ I do not know
Q3	Which three topics would you consider the top priority for data center deployment?	☐ Load size and demand for resource adequacy ☐ Flexible operation of data center ☐ Location and substations proximity ☐ Redundancy and reliability ☐ Power quality and stability ☐ Environmental impact ☐ Cost and economic factors ☐ Scalability and future growth ☐ Power purchase agreements ☐ Interconnection agreements

Question Number	Survey Question	Response Options
		☐ Data center load modeling ☐ Other (Please specify)
Q4	Should data centers be required to provide ancillary services in general, such as voltage ride through or underfrequency load shedding?	☐ Yes (If yes, which services to be prioritized and should those be incentivized?) ☐ No ☐ I do not know
Q5	Data center load profiles and forecast are kept confidential. Should data centers be required to share this information with the utility?	☐ Yes (If yes, which parameters shall be shared and with what resolution? For example, should the rolling 24-hour load prediction be shared?) ☐ No ☐ I do not know
Q6	As a percentage of total operating costs for a data center, what do you feel is a reasonable amount to be spent towards power each month?	Open response
Q7	As a percentage of total development costs for a data center that is co-located with a behind-the-meter nuclear reactor, what do you feel is the maximum amount to be spent developing the nuclear reactor?	Open response
Q8	Which requirements for grid interconnection are the most time consuming?	☐ Disturbance ride-through and recovery performance testing ☐ Operational ramp rate limits ☐ Coordination with grid operators ☐ Power quality and harmonics control ☐ Protection system coordination ☐ Transparent and phased interconnection process ☐ Cost responsibility and upgrades ☐ Utility-imposed performance-based interconnection criteria

Question Number	Survey Question	Response Options
		☐ I do not know ☐ Other (please specify)
Q9	Which requirements for grid interconnection are the fastest?	☐ Comprehensive load modeling ☐ Disturbance ride-through and recovery performance testing ☐ Operational ramp rate limits ☐ High-speed monitoring and data capture ☐ Coordination with grid operators ☐ Protection system coordination ☐ Transparent and phased interconnection process ☐ Cost responsibility and upgrades ☐ I do not know ☐ Other (please specify)
Q10	Which interconnection requirements should be considered most critical for ensuring safety and power quality?	☐ Comprehensive load modeling ☐ Disturbance ride-through and recovery performance testing ☐ High-speed monitoring and data capture ☐ Coordination with grid operators ☐ Power quality and harmonics control ☐ Protection system coordination ☐ Transparent and phased interconnection process ☐ Cost responsibility and upgrades ☐ Utility-imposed performance-based interconnection criteria ☐ I do not know ☐ Other (please specify)
Q11	Which interconnection requirements are the most redundant or outdated?	☐ Comprehensive load modeling ☐ Disturbance ride-through and recovery performance testing

Question Number	Survey Question	Response Options
		☐ Operational ramp rate limits ☐ Coordination with grid operators ☐ Protection system coordination ☐ Transparent and phased interconnection process ☐ Cost responsibility and upgrades ☐ Utility-imposed performance-based interconnection criteria ☐ I do not know ☐ Other (please specify)

A-2. Survey Response

Q1: What is your role in "Powering the large loads?" Select multiple if needed.

Option	% Selected	Count
Generation	28%	5
Transmission	11%	2
Distribution	11%	2
Large load	17%	3
Data center campus developer	39%	7
Nuclear sector	11%	2
Other (Please specify)	39%	7
I do not know	6%	1

Other Responses:

- Workforce Housing and Logistics
- Builder of Power and Data Centers
- Hyperscale - EPC Owners Representation & Project Management
- I am low voltage dc lighting controls
- Nonprofit technical support/consulting and education

- Consumer (HPC/AI data center operator)

Q2: Which of the following scenarios seems feasible to you? Select multiple if needed.

Option	% Selected	Count
Data Center is being deployed on the premises of a nuclear power plant	53%	10
Nuclear power plants are being deployed on the premises of a data center	79%	15
No onsite generation powering the grid. Backup power only	11%	2
Other (Please specify)	21%	4
I do not know	5%	1

Other Responses:

- SMR/Microgrids as either Primary, Secondary and/or Supplemental power generation
- Nuclear supplying the grid
- Micro grid - commercial power
- Nuclear replacing or supplementing grid base load

Q3: Which three topics would you consider the top priority for data center deployment?

Option	% Selected	Count
Load size and demand for resource adequacy	53%	10
Flexible operation of data center	11%	2
Location and substations proximity	26%	5
Redundancy and reliability	11%	2
Power quality and stability	37%	7
Environmental impact	11%	2
Cost and economic factors	47%	9
Scalability and future growth	32%	6
Power purchase agreements	5%	1

Option	% Selected	Count
Interconnection agreements	26%	5
Data center load modeling	32%	6
Other (Please specify)	5%	1

Other Responses:

- Regulations, Permits, Zoning, AHJ's

Q4: Should data centers be required to provide ancillary services in general, such as voltage ride through or underfrequency load shedding?

Option	% Selected	Count
Yes	40%	8
No	40%	8
I do not know	20%	4

Other Responses:

- Only if primary power is from grid
- Ride through
- Should be required, not incentivized
- Load shedding
- Depends on the mission served by the data center. Federal requirements can be very different from commercial workloads

Q5: Data center load profiles and forecast are kept confidential. Should data centers be required to share this information with the utility?

Option	% Selected	Count
Yes	68%	13
No	26%	5
I do not know	5%	1

Other Responses:

- Yes, if only grid power is primary
- Yes, predictive profiling

- Very generalized if not only provide estimates vs. actual and if substantial difference is observed. Apply fees.
- 8760 of load profile, ramp rates, on site generation parameters
- Share the load prediction with the utility
- Yes, load prediction should be prepared. Especially implications with commercial energy prices and the effects.
- Firm and peak. HPC workloads are typically chaotic with rapid load swings measured in cycles. Utilities cannot respond to that, but must be aware of the profile

Q6: As a percentage of total operating costs for a data center, what do you feel is a reasonable amount to be spent on power each month?

Responses
As a percentage of cost, we believe 50% of all costs are appropriate.
20%
40-50%
75%
A majority
40%
75 Less than they make 70%
10%
5% or less
This depends on the density of the deployed solution(s) in the data center. Case by case basis makes this unanswerable

Note: Each response was selected by one respondent (total responses: 10). Percentages are not provided for this open-ended question.

Q7: As a percentage of total development costs for a data center that is co-located with a behind-the-meter nuclear reactor, what do you feel is the maximum amount to be spent developing the nuclear reactor?

Responses
The DC should cover the entire cost.

Responses
$1 Million per MWe
$500k-$1M
60%
I do not know but it would have to be low enough to incentivize the drop in cost that would be from a utility bill
Less than the data center will make
$1B
40%
N/A since my use case for power supports a nuclear for base load strategy

Q8: Which requirements for grid interconnection are the most time consuming?

Option	% Selected	Count
Disturbance ride-through and recovery performance testing	6%	1
Operational ramp rate limits	6%	1
Coordination with grid operators	33%	6
Power quality and harmonics control	6%	1
Protection system coordination	6%	1
Transparent and phased interconnection process	22%	4
Cost responsibility and upgrades	33%	6
Utility-imposed performance-based interconnection criteria	28%	5
I do not know	33%	6

Q9: Which requirements for grid interconnection are the fastest?

Option	% Selected	Count
Comprehensive load modeling	18%	3
Disturbance ride-through and recovery performance testing	6%	1
Operational ramp rate limits	6%	1
High-speed monitoring and data capture	18%	3
Coordination with grid operators	18%	3
Protection system coordination	12%	2
Transparent and phased interconnection process	12%	2
Cost responsibility and upgrades	6%	1
I do not know	53%	9

Q10: Which interconnection requirements should be considered most critical for ensuring safety and power quality?

Option	**% Selected**	**Count**
Comprehensive load modeling	18%	3
Disturbance ride-through and recovery performance testing	35%	6
High-speed monitoring and data capture	18%	3
Coordination with grid operators	18%	3
Power quality and harmonics control	24%	4
Protection system coordination	24%	4
Transparent and phased interconnection process	18%	3
Cost responsibility and upgrades	24%	4
Utility-imposed performance-based interconnection criteria	12%	2

Option	% Selected	Count
I do not know	35%	6

Q11: Which interconnection requirements are the most redundant or outdated?

Option	% Selected	Count
Comprehensive load modeling	7%	1
Disturbance ride-through and recovery performance testing	7%	1
Operational ramp rate limits	20%	3
Coordination with grid operators	7%	1
Protection system coordination	7%	1
Transparent and phased interconnection process	7%	1
Cost responsibility and upgrades	20%	3
Utility-imposed performance-based interconnection criteria	7%	1
I do not know	47%	7

Appendix B: State Interconnection Requirements

The following table provides a summary of state-level actions requirements related to powering large-scale data centers. These measures reflect the growing recognition among state governments of the unique challenges posed by high-density digital infrastructure, particularly in areas such as grid reliability, interconnection requirements, and permitting processes.

This appendix builds on insights from the INL reference sheet *Power System Implications of Operating Large Loads: A Summary of International and Domestic Initiatives*, which highlights global and national efforts to address the operational and policy implications of large electrical loads. By focusing on state-specific actions, this table aims to help stakeholders understand the regulatory landscape, identify emerging trends, and anticipate potential impacts on project planning and investment strategies.

Table 1: Interconnection requirements for large loads by state.

State	Regulator / Body	Rules & Requirements	Avg Wait Time	# Data Centers	References
Texas	PUCT / ERCOT	≥75 MW; $100k fee duplicate app disclosure site control backup gen disclosure Curtailment cost recovery	2–4 years (if transmission); faster if distribution only	~385	SB 6; ERCOT; Utility Dive; DataCenterMap
Georgia	GA PSC	>100 MW loads pay all upgrade costs contracts reviewed prevents cost shift	1–3 years (transmission exists); 3–5 years (new lines)	~160	GA PSC rule 2025; DCF; DataCenterMap
Virginia	VA SCC	≥25 MW (Dominion); ≥100-150 MW (APCo) 14-year contracts 60% gen 85% T&D min billing Collateral co-ops stricter	2–3 years typical; up to 7 years in NoVA	~636	VA SCC filings; JLARC; Dominion tariff; DataCenterMap
West Virginia	WV PSC / AEP	>200 MW 12-year contracts collateral; exit penalties HB 2014 microgrids allowed	12–18 months (ample capacity); longer if 500kV lines	~7	WV PSC orders; GovTech; DataCenterMap

Ohio	PUCO	≥25 MW 85% min billing collateral; 12-year term exit fees moratorium lifted 2025	12–18 months (dist); 2–3 years (transmission)	~191	PUCO settlement; Utility Dive; PowerMag; DataCenterMap
Oregon	OPUC (PGE, PacifiCorp)	PacifiCorp >25 MW full cost propose 1 MW threshold PGE min billing HB 3546 ≥20 MW 10-year contracts	12–24 months (dist); 2–4 years (transmission)	~137	OPUC dockets; OPB; CUB; DataCenterMap
Washington	Local PUDs / WA UTC	Chelan: >3 MW contract cap charges 60-day exit; Grant: 75 apps ~2900 MW Douglas: 75% peak billing IOUs standard	3–5 years (large PUD queues); 6–12 months (<5 MW)	~128	Chelan tariffs; Grant PUD; Wenatchee World; DataCenterMap
California	CPUC / IOUs	SB 57 requires DCs pay full costs PG&E Rule 30 streamlines cluster studies	6–12 months (small); 2–4 years (large); 5–10 years (new transmission)	~319	SB 57; PG&E; CAISO; DataCenterMap
New York	NY PSC / Legislature	Crypto moratorium (2022–24) CIAC for substations CLCPA clean mandates voluntary DR	1–2 years (upstate); 2–3 years (NYC)	~142	NY crypto law; PSC; NYT; DataCenterMap
Minnesota	MN PUC / GRE / Xcel	GRE deposits staff charges Xcel tariffs no statewide docket >100 MW monitored	1.5–2 years if serious; some proposals idle since 2020	~62	Utility Dive; APPA; Star Tribune; DataCenterMap