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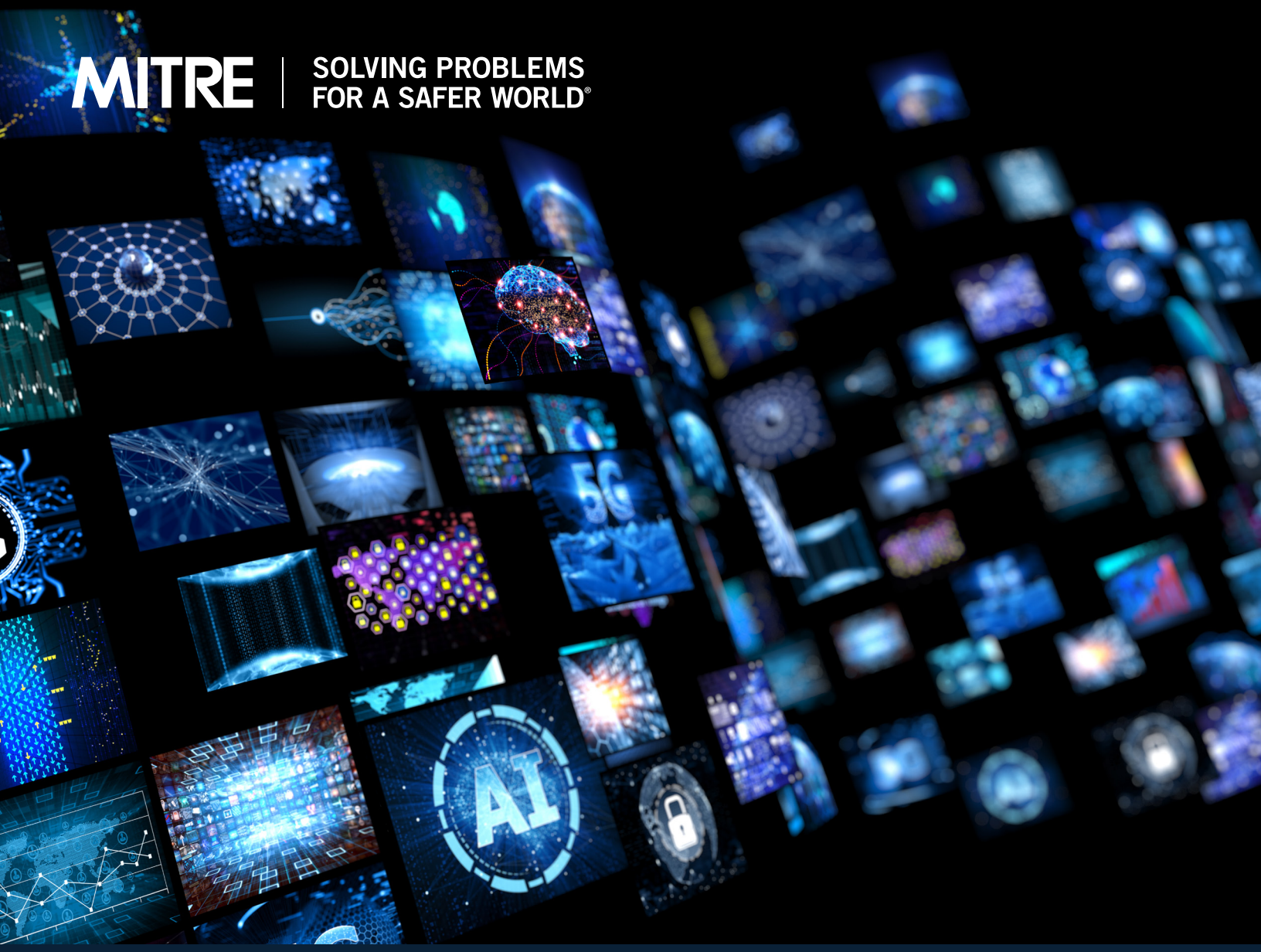

RESILIENT & EFFICIENT COMPUTING

Positioning Industry and Government for the Future

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– The MITRE Corporation

Introduction

Data centers are rapidly expanding to meet the nation's need for everything from streaming content on mobile devices to industry requirements for technology, healthcare, finance, and more. In turn, this growing demand challenges local communities and data centers to find new ways to balance quality of life while meeting the needs for real estate, energy, and other resources.

MITRE recently hosted a workshop aimed at addressing the challenges and impacts of Loudoun County's booming data center industry. The event was organized in response to the escalating energy and water demands of these data centers, which are straining local resources and raising concerns about the quality of life among residents. The goal was to bring together industry leaders, utility representatives, and government officials to brainstorm innovative solutions that balance the economic benefits of the data center industry with the preservation of the community's culture and quality of life.

Challenges

National Concern. New digital technologies are emerging daily. ChatGPT and other large language models are just one example of how critical resilient and efficient computing has become to U.S. and global security. Between 2010 and 2018, global data center (DC) computation increased by about 550%. This was impressively paired with an increase of only 6% in DC energy usage up to 205 terra-watt hours (TWh), or 1% of the global demand [1]. This success was driven by increases in DC efficiency. However, DC growth shows no sign of slowing down as our reliance on large data mature, while efficiency increases become increasingly hard-won. The U.S. hosts approximately one third of the total number of DCs around the world. Additionally, Google-owned DCs in the U.S. consumed approximately 3.37 billion gallons of water in 2021, 90% of which was potable water [2], while Microsoft increased its water consumption by 34% between FY21 and FY22 [3].

Northern Virginia Growth. Northern Virginia is home to the world's largest DC market, with nearly as much capacity as the second- to fifth-largest markets combined [4] [5]. Dominion Energy supplies most of Loudoun County's power. Currently, DCs account for roughly 20% of Dominion Energy's total electricity sales in Virginia [6]. Since 2019, Dominion Energy has connected nearly 70 DCs with over 2.6 gigawatts (GW) of capacity in Northern Virginia. In 2027, the demand from DCs is expected to grow by another 2.6 GW [7]. This growth further increases the energy demands on the power grid.

Load Projections. Accuracy is critical to planning infrastructure upgrades to meet customer demand. The power demands driven by DC growth and operations are increasingly difficult to track. PJM, the regional transmission organization that coordinates the local grid, has released successive 15-year load growth projections that jump from a 1.0% to a 4.4% annual growth rate alongside a 28 to 42 GW summer peak [8]. Frequent changes in forecasts make it difficult to justify the large-scale capital investments needed to meet even the most conservative of projections.

Quality of Life. Northern Virginia residents and government representatives have voiced concerns regarding the planned and potential continued construction of transmission lines to service increased energy demand [9] [10].

Water Stress. DCs often stress existing water supply and water/wastewater infrastructure. Loudoun County currently draws its water from the Potomac River in Maryland. Previous conflicts regarding increases in Virginia's use of that water have resulted in lengthy legal proceedings that ended up at the U.S. Supreme Court [11]. Additionally, reduced water levels in the region have led to the initiation of drought operations [12]. Further challenges may force a limit, even if temporary, on the water supply for Northern Virginia or may delay water infrastructure updates necessary to support DC growth.

Shrinking Space. Another constraint facing the DC industry in Loudoun is the available land with proximity to electric and water utilities. The Loudoun County DC Land Use Study, released in 2022, characterizes the potential for new DC developments based on land availability, proximity to utilities, and geographical conditions. Most land adjacent to Route 7 is unsuitable for growth, while portions of eastern and southeastern Loudoun County may show potential for DC expansion. Some areas may become suitable pending utility infrastructure updates [5].

CALL TO ACTION

The scale of DC growth in Loudoun County is an unavoidable concern. Novel and mutually beneficial solutions must be rapidly deployed to maintain the economic benefits brought to the region by the DC industry while maintaining the culture and quality of the community.

Solution Opportunities

Energy Optimization. Significant energy reductions or capacity increases can be made through upgrading and optimizing DC hardware. This includes low-capital opportunities that can be implemented on a short-term timescale to increase capacity without infrastructural changes. Utilizing modeling tools, such as computational fluid dynamics and thermal imaging, to optimize air management and cooling can provide a capacity increase of 10-30% without additional energy requirements [13] [14]. IT management strategies are also valuable tools in maximizing energy effectiveness [15]. With higher capital investments, DCs can better utilize floor space and consolidate IT workloads. For example, liquid cooling can be employed through rear-door heat exchangers, direct-to-chip cooling, or immersion cooling for increasing energy reductions and efficiencies [16].

Onsite Generation. Localized infrastructure provides a solution for meeting the energy requirements of a growing DC demand without requiring additional public infrastructure such as power lines. Microgrid technologies will allow DCs to adopt a behind-the-meter approach, combining renewables, stationary battery energy storage systems, thermal batteries, responsive end-use loads, and various other distributed energy resource technologies. Utilization of these technologies would allow DCs to operate autonomously and locally, thus mitigating grid disturbances, minimizing energy infrastructure in the community, and reducing carbon emissions [17] [18]. Several power production technologies could provide carbon-free local generation, including small modular nuclear reactors and green-hydrogen powered fuel cells. These technologies are not yet commercially viable; however, recent advancements have shown promise of deployable, nonvariable, and carbon-free power generation with minimal land use [19] [20].

Water Optimization. The Reclaimed Water Program implemented by Loudoun County will alleviate some of the strain on potable water supply caused by DC demand [21]. To reduce the burden on local utilities, many DCs have begun implementing water harvesting, treatment, and reuse measures to create more sustainable water management programs. Incentive programs for more water-efficient DC design could decrease Loudoun County's capital and operational expenditure while allowing DCs to enable the use of sustainable water management throughout their operations.

Federal and Industry Presentations

Presentations were provided by Loudoun County, Dominion, Converge Strategies, the Department of Energy (DOE) Advanced Research Projects Agency Energy (ARPA-E), the Office of Science Advanced Scientific Computing Research (ASCR) program, and the Loan Programs Office (LPO).

Rachael Mai, a Loudoun County representative, articulated the issues facing Loudoun County, focusing on topics including energy capacity constraints, electricity generation and delivery infrastructure, and land availability. Alan Bradshaw, VP of Dominion Energy, shared the utility's perspective, while former senior director of PJM, Jonathon Monken of Converge Strategies, provided insights from the regional transmission organization's standpoint. The economic benefits of the data center industry in Loudoun County were underscored by Buddy Rizer, the executive director of Loudoun Economic Development.

The conference also shed light on the role of the DOE in this critical issue. Tom Hucker, senior consultant for the DOE Loan Programs Office, and ARPA-E's tech-to-market advisor, Rakesh Radhakrishnan, laid out funding avenues for up-and-coming energy-efficient computing technologies. Ceren Susut, DOE ASCR Associate Director of Science, spoke about the department's research in high-performance computing.

The speakers also discussed the need to increase funding to expedite research, development, design, and engineering projects that would benefit DC energy resilience and efficiency. The important role of various organizations and stakeholders was highlighted, suggesting that partnerships and coordinated data sharing are required to provide innovative solutions to tackle DC growth. The presentations communicated the need to better understand local DC requirements and to improve projections of the energy growth impacting future community and utility infrastructure planning.

Top Left: Rachael Mai, Staff Aide for Loudoun County. Top Right: Ceren Susut, DOE ASCR Associate Director of Science. Bottom Left: Tom Hucker, Senior Consultant for the DOE Loan Programs Office. Bottom Right: Rakesh Radhakrishnan, ARPA-E tech-to-market advisor.

Chris Fall, Ph.D., MITRE vice president of applied sciences, with Alan Bradshaw, Dominion Energy's vice president of strategic partnerships.

Collaboration Group Discussions

During the workshop, stakeholders participated in targeted breakout sessions focused on three pivotal areas: enhancing power and water efficiency within data centers, fortifying infrastructure for power distribution, and exploring innovative power generation solutions to meet the ever-growing demand. The collaboration between attendees resulted in actionable outcomes to address DC growth in Loudoun County. The consensus among participants was that fostering an environment of open communication and integrated planning between customers and stakeholders is vital, as it promotes transparency and collaboration. Importantly, it was recognized that partnerships that span across the public and private sectors, as well as county lines, can lead to more comprehensive and effective advanced energy solutions.

Overall, participants agreed that increased energy resilience is critical. This goal can be achieved through the optimized operation of DCs, the decentralization of power generation, and the improvement of utility infrastructure and distribution. However, realizing opportunities would necessitate a comprehensive planning effort to accurately predict energy demand and load pockets, assess land availability for onsite power generation, and develop innovations to transmit power efficiently on the electric grid.

A central theme of the breakout sessions was the emphasis on guaranteeing the security and safety of Loudoun County's power grid and DCs. Cybersecurity, coupled with the efficient and dependable operation of energy and electrical components, is a critical factor in ensuring uninterrupted power is supplied to DCs and the residents of Loudoun County. The participants deliberated on the escalating need to establish consistent energy standards for DCs and the importance of rigorous testing of these standards.

A breakout session focused on fortifying infrastructure for power distribution with Brian Kimberly, Loudoun County Deputy Director of Information Technology, and Nick Squitieri, MITRE, Power Systems Engineer.

Stakeholders voting on valuable post-workshop actions with Kent Erwin, Loudoun County Chief of Staff to Supervisor Glass, Broad Run District.

Workshop Findings and Opportunities

The projected rate of DC growth presents a potentially insurmountable challenge of demand outpacing supply for the local electric utility. There is a need to explore the technical feasibility of modernized power solutions while addressing their financial and social challenges.

Transmission and Distribution

Utility-scale generation with overhead transmission and distribution lines currently represents one of the most cost-effective and simplest options. However, it places the burden of meeting growing demand on the public utility, and the lead time of deploying utility-scale power plants can take years and may not be a feasible option to meet DC growth. Additionally, the infrastructure for substations and overhead cables can impact the aesthetic quality and culture of the community.

Onsite Generation

Local generation offers the benefits of requiring minimal public infrastructure and no overhead power lines, but it also offers its own challenges. Diesel and natural gas generators offer viable backup capacity to support loads, but small-scale fossil fuel use is significantly less efficient and economic than utility-scale plants. Large amounts of behind-the-meter generation through rooftop solar and storage can also affect the stability of the grid. Maintaining stability in these scenarios could be supported by smart grid technologies, but it would require additional costs.

Zero-Carbon Alternatives. Small nuclear reactors are an emerging technology to generate onsite power without greenhouse gases but could be capital intensive, have a long development timeline, and potentially have a negative community perception. Rooftop solar presents a viable option, but generating sufficient power to cover loads would require significantly more land than is locally available. Utility wind and solar would reduce the environmental impact of DCs but still result in significant transmission and distribution infrastructure projects.

Alex Schlichting, Ph.D., MITRE, Group Leader, Principal Energy and Environmental Sciences Engineer

Resilience

DCs are critical infrastructure with significant resilience requirements, and the size of their energy load can place a strain on public power quality. Novel solutions included geospatially dispersing DCs over a wider region. A decentralized fiber optic network could connect Loudoun with neighboring counties without losing computational efficiency. This would allow load shifting between sites based on grid needs.

Policy Solutions

Potential solutions are not limited to technical approaches but include legislative and policy-based action. Green zoning is a sustainable approach to urban planning that can help reduce environmental impact by reducing the spread of industrial DC sites into the surrounding communities and natural environment. Financial incentives could be given to DCs that maintain high levels of efficiency and innovation.

Accelerate and Field Technologies

A significant amount of DC energy consumption goes to support functions (like HVAC), decreasing overall efficiency. Continued testing and implementation of new advanced energy technologies is necessary to increase efficiency. Advanced energy technologies discussed at the event included new methods of DC cooling to reduce water and energy use as well as computational efficiency advances like IT task optimization. A novel advanced energy technology test-bed facility based in Loudoun could act as an accelerator for improved prototyping and adoption of such technologies and does not currently exist. This facility would require financial collaboration and significant project development from both private and public entities. However, the results will benefit all DCs in the area and beyond.

Funding Pathways

External support for the development of solutions exists, including funding avenues for energy-efficient computing technologies from DHS, DOE, and other similar entities. Leveraging these opportunities can accelerate progress within the sector while increasing ties to publicly funded institutions that are invested in the continued health of the local region.

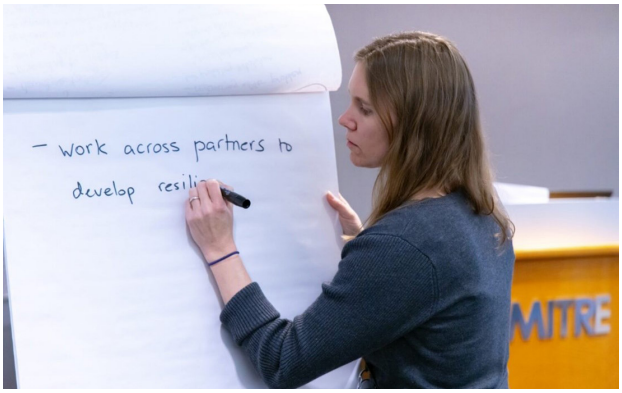
Energy Forecasting

Accurate modeling of both near-term demand and long-term growth is vital to maintaining stability in the grid and preventing blackouts. Sharing load data between DCs and the utility is necessary to deal with peaks, while the long-term projected goals of the parent tech companies are vital information to the utility when planning for expansions of grid infrastructure.

Stakeholder Collaboration

DC operation requires collaboration between many stakeholders. Building transparent public/private partnerships across county lines will improve information sharing and planning. This need is especially apparent when attempting to write regulations and standards for the DC community (cyber, reliability, power consumption, etc.). Power efficiency data collection and sharing between DCs, the utility, and the government will help improve the forecasting of DC growth and guide regulators in designing better policies. Early and frequent collaboration with all stakeholders can smooth the permitting and planning process and help limit negative impacts on timelines. Collaboration among DCs could increase technical literacy in best practices for cooling and efficiency upgrades and facilitate the propagation of solutions across the industry. Involvement of local stakeholders could improve the perception of infrastructure projects. Local and federal government stakeholders can help provide the funding necessary to achieve these objectives in the form of incentives and other resources.

Alan Bradshaw, Dominion Energy's vice president of strategic partnerships, with Ariel Castillo, Mitre Chief Engineer for Advanced Energy



Jenn Richkus, MITRE, Infrastructure and Environmental Resilience Group Leader

Potential Future Collaboration Events

Future Webinar

A follow-up webinar hosted by the DOE and MITRE focused on continuing the collaboration to help address Loudoun's data center growth and to provide solutions through ARPA-E's COOLERCHIPS technologies is on the horizon!

Industry Events

Participate in high-value conferences that address DC industry challenges and opportunities, such as DC World, taking place April 15–18, 2024 in Washington, D.C., where senior ARPA-E and MITRE subject matter experts will be in attendance.

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