Loudoun County, Virginia: Data Center Capital of the World

"A Strategy for a Changing Paradigm"

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Preface

Since my last update, we've seen the onset of a significantly intensified debate about data centers. I've been conducting this research since November 2023, but it's only in the past few months that data centers and Artificial Intelligence (AI) have become the subjects of a continuing national conversation featured on mainstream television media, social media, print media and in countless town halls and county commission or board meetings throughout America.

I began—now almost three years ago—to compile the lessons we've learned here in Loudoun County, VA, a community with the highest concentration of data centers in the world, to disseminate those lessons to communities considering data center land applications. I did not actively market this research, and yet I'm now receiving no less than 5-10 requests each week from around the country for presentations, panel discussions, webinars and personal phone calls to discuss my findings based on our experiences here in Loudoun County. I believe this organic demand has developed because the lessons we've learned, and the recommendations I've made, have been validated repeatedly over the past three years and remain as relevant now as they were three years ago.

With that in mind, let me state for the record that, despite the national fervor and frequent demonization surrounding them, data centers are neither inherently bad nor good. Unless we all want to give up our cell phones, our streaming TV, our social media or our car mapping systems, data centers are here to stay; they are our new reality. At the same time, it must be acknowledged that the national dialogue is replete with examples of the egregious harm poorly planned data center construction can inflict on local communities. Why is this happening?

As I say repeatedly in this paper, it is incumbent upon local governing bodies to preemptively impose stringent land-use and performance standards on data center construction in their communities. We are in a national state of "market failure" in which demand vastly exceeds supply, and the market, in responding to that demand, is causing significant social harm to many communities. According to Investopedia, the key until the market stabilizes is

government intervention.[1] That is precisely why I wrote this paper: to give local governments the tools they need to make informed decisions about data centers before they are allowed to develop in local communities.

That this has not happened in many cases around the country is not surprising. The combination of historically rapid sector growth, the extraordinary wealth present in the data center community, the speed with which technology has advanced and the very understandable inability of many local, state and federal government officials to keep up with and understand the implications of these tectonic changes has enabled many data centers seeking the path of least resistance to take advantage of local governments. This must stop if we are to begin to manage this historic growth.

The 15 best practices I offer in this paper to communities considering data centers remain as valid as the day I first compiled them almost three years ago. Rigorous application of these best practices **before** data centers come to town will avoid the harm to one's community of a badly planned data center. For those of us who already have a large population of data centers in place, these best practices can serve as a guide to both incentivize changes or disincentivize a reluctance to change within our existing data center population going forward.

If we are to successfully navigate through these historic times, we must talk to each other regularly, and we must remain grounded in fact-based dialogue. It is in that spirit I'm pleased to offer this updated version of my white paper.

Summary of Updates Since April 6th Edition

- Addition of a preface reflecting current national trends.
- Moves Joint Legislative Audit Review Commission (JLARC) report to attachment 1.
- Updated sq. ft. and power data (pg. 9).
- Adds a description of AI modes and the Loudoun County AI role (pg. 24).
- Updates limitations of natural gas turbines (pg. 34).
- Updates information about blue hydrogen fuel cells and establishes them as a potential baseload power source.
- Adds possible new paradigms for Loudoun County (pg. 40).
- Adds "15 Best Practices for Communities Considering Data Centers" as attachment 2.

Executive Summary (citations included in applicable main body text)

- Loudoun County, VA, and particularly "Data Center Alley" in eastern Loudoun, has the highest concentration of data centers in the world with approximately 250 data centers built and more than 100 in the development pipeline. There has not been a single day in 16 years when a data center was not under construction in Loudoun County.

[1] The Investopedia Team. "Market Failure in Economics: Types and Causes Explained." Investopedia. January 23, 2026. https://www.investopedia.com/terms/m/marketfailure.asp

- Two source documents guide and regulate Loudoun County's approval and placement of data centers: the Comprehensive Plan and the Zoning Ordinance. The Comprehensive Plan is a guide and details the Board of Supervisors' vision for land development over the next 20 years in the county. It is not legally binding. The Zoning Ordinance provides the legal basis for the Comprehensive Plan and is legally binding. Prior to March 18, 2025, each parcel of land under the zoning ordinance allowed certain types of development "by right," meaning such development did not need legislative approval from the county Board of Supervisors. Much of Loudoun County's data center development has been "by right."
- Key developmental milestones:
    - **Late 1990's:** U.S. government's Advanced Research Project (ARPA) establishes the Metropolitan Area Exchange-East (MAE-East) as a national internet hub. Extensive underground fiber optic network is laid giving Loudoun County the lowest (fastest) latency rates for moving data from point A to point B in the world. This latency advantage exists to the present day and represents a significant market advantage for data centers located in Loudoun's "Data Center Alley."
    - **CY 2000:** Loudoun County Zoning Administrator determines data centers should be treated as office parks, thereby making any data center development "by right" on land parcels that permit office parks.
    - **CY 2003:** First mention of data centers in the Zoning Ordinance.
    - **CY 2008:** Loudoun County Economic Development launches an aggressive marketing campaign touting our low latency rates to attract data centers to the county. "Data Center Alley" is born.
    - **CY 2019:** County Comprehensive Plan updated fully for the first time in 18 years. Incorporates a wide range of data center performance criteria.
    - **CY 2022:** A landmark year marking the start of a new era for the worldwide data center market.
        - After ten years of slightly declining power demand within the Dominion Energy service area, PJM, the northeast Regional Transmission Organization, of which Dominion Energy is a member, recognizes an impending exponential increase in power demand from Loudoun County's "Data Center Alley." Dominion Energy immediately imposes power constraints on "Data Center Alley" (which ended in December 2025). In September 2023, Dominion Energy announces plans to construct a "reliability" loop of three 500Kv/230Kv transmission lines (Aspen/Golden/Mars/Wishing Star) to connect "Data Center Alley" to the main north/south power line bringing power into Loudoun County
        - ChatGPT is launched. Artificial Intelligence, with its exponentially higher demand for power, enters the commercial market.
        - Coming out of COVID, the world demand for digital products increases exponentially.

- **CY 2023:** Loudoun County Zoning Ordinance updated for the first time in 20 years to align with the 2019 Comprehensive Plan. This increases local legislative oversight of data center applications, thereby limiting "by right" development for the first time.
- **CY 2024:** JLARC (see atch. 1) releases long-awaited data center report to the Governor and General Assembly.
- **CY 2025:** On March 18, 2025, this author's motion to end all "by right" data center development in Loudoun County passes. Any new data center application in Loudoun County now requires legislative approval by the Board of Supervisors.[21]

- From 2021-2025, largely before the dawn of Artificial Intelligence (AI), Loudoun County's energy use increased 233%, from 2.0 Gw to 5.33 Gw of power consumption. Using a simple linear extrapolation over the next five years, without accounting for a likely tenfold increase in power required by AI, Loudoun will need 14.2 Gw of power. An independently commissioned Kimley-Horn report has confirmed a similar prediction, estimating 11.59 Gw of power will be needed by 2028. Loudoun County is currently receiving about 9.3 Gw of power, though only a portion of that reaches "data center alley." PJM and Dominion Energy plan to bring an additional 8.6 Gw into Loudoun County by 2028 to meet Loudoun's growing power demands, but it is unclear how much of this additional power will reach "Data Center Alley." None of this development addresses the vast increase in power demand anticipated for AI.
- Demand for data processing is growing exponentially worldwide. With that increase in demand for data processing comes a concomitant exponential increase in demand for electricity by the world's data centers. In the author's opinion, the electric utilities serving Northern Virginia (PJM; Dominion Energy) will be unable to build sufficient grid infrastructure to meet the growing demand for power by the region's data centers. This conclusion, originally stated in the preface below in July 2024, was similarly arrived at in the December 2024 JLARC data center report to the Virginia Governor and General Assembly.
- The exponential increase in the use of Artificial Intelligence (AI) is not only increasing the demand for more power, it is increasing the demand for more water to cool the power-intensive AI data racks. This in turn is introducing the problem of how to treat data center wastewater.
- The rapid increase in data center sector demand for power has resulted in a significant increase in constituent resistance to more data centers in their communities. It has also caused both PJM and Dominion Energy to slow or cancel the decommissioning of fossil fuel generation plants throughout the region. Given that the most recent U.N. climate change report indicates 2024 was likely the warmest year on record, this delay or cancellation of fossil-fuel plant decommissioning will likely add to community resistance to more data center development.
- The three key stakeholder groups critical to developing a new strategic paradigm for energy consumption amidst a worldwide data revolution are the data center sector, the electric utility sector and the constituent sector, represented by local, state and federal

elected bodies. Heretofore, these groups have rarely collaborated. Systematic collaboration and communication between and among these groups will be essential going forward.

- Certain realities must be acknowledged if we are to successfully meet Loudoun County's energy challenges:
    - The 135-year-old paradigm of power generated by large, remote power plants and transmitted over hundreds of miles of transmission lines to end-user distribution locations will not solve Loudoun County's unique energy challenges.
    - The utilities will likely continue to slow or halt fossil fuel generation plant decommissioning. This will lead to increased community pressure on elected officials to oppose data center development and increased market pressure on data centers to develop onsite, regional or distributed energy networks with a greater reliance on low-carbon or carbon net-zero power.
    - Because of their low capacity factors, solar and wind power will not be sufficient to solve Loudoun County's data center energy needs.
    - Halting data center construction in Loudoun County will not solve the problem. AI will drive up energy demands for our existing data centers far in excess of Dominion Energy's and NOVEC's (Northern Virginia Electric Cooperative) capacity to meet that demand.
- Immediate steps available to PJM and Dominion Energy to begin to address rising power demand are 1) reconductoring new and existing transmission lines, and 2) considering the development of a regional High Voltage Direct Current (HVDC) network for the exclusive use of the Loudoun County data center sector. Within five years, nuclear Small Modular Reactors (SMRs) will likely become an onsite power reality.
- If, as this paper and the JLARC study predict, the power grid infrastructure in Loudoun County—even with its planned expansion—will be insufficient to meet the future energy demand of the county's data center market, there are only three possible future scenarios by which that demand can be reduced to manageable levels:

    Scenario #1: Government-Imposed Energy Consumption Constraints. In this scenario, the Commonwealth of Virginia, the power utilities or both artificially constrain the energy use of high-energy consumers to ensure grid stabilization for all Virginia energy consumers. This scenario would likely cap continued data center development in Loudoun County and cause new data center development to take place in locations with much lower power constraints.

    Scenario #2: Technological Breakthrough. A technological breakthrough occurs significantly reducing the power needed by AI and cloud-based computing. Such a development would stabilize the power grid and could enable the power utilities to meet the stabilized infrastructure needs of the industry. This scenario could lead to significant stranded costs and will likely prove only temporary as data centers fill up empty rack space with newer chips.

Scenario #3: Industry Conversion to Onsite Power. Faced with exponential market demand and possessed with almost unlimited resources to meet that demand, the data center industry rapidly develops the capacity to generate onsite, local or distributed energy power (microgrids) for its operations and, in so doing, significantly reduces its reliance on the regional power grid. Such a development would stabilize the grid and could enable the power utilities to meet the stabilized infrastructure needs of the industry. (Widespread microgrid development in Loudoun County is unlikely due to geographic constraints.) Additionally, this scenario could also lead to significant stranded costs.

- In the future, the three scenarios will likely occur simultaneously but in varying and fluctuating degrees based upon market and grid infrastructure conditions. The utilities have already begun delaying additions of large loads to the grid, and the JLARC study recommends codifying this in state code to allow delays for generation in addition to transmission (scenario #1). Meanwhile, new GPU chips are emerging that use significantly less power (scenario #2), and we already have examples of data centers in Loudoun County building advanced microgrids to reduce their dependence on grid power (scenario #3). All three scenarios will continue to develop for the foreseeable future.

- Stranded costs occur when a regulated utility, required by law to meet the energy demand of its customers, is forced to build new infrastructure to meet predicted, future demand for energy. If at any time during the infrastructure buildout process the predicted demand is not realized, stranded costs occur. The regulated utility has incurred the costs of the buildout, but the reduced consumer demand can no longer defray those costs. The utility must then absorb the costs or pass them on to residential and small commercial customers. A tool to insulate the utilities from stranded costs is the imposition of preemptive tariffs on high-energy consumers. Dominion Energy has proposed such tariffs to the State Corporation Commission.

- While the 2024 JLARC study concludes it will be very difficult to meet the data center sector's unconstrained energy demand, it offers only two broad approaches to reduce that demand: 1) utilities should be allowed to delay large energy load additions to the grid while local jurisdictions impose performance standards to increase energy efficiency, and 2) the state should use the sales tax exemption to incentivize greater data center energy efficiencies. These approaches represent an acceptance of scenario #1 above as the only way to decrease energy demand. Approach #1 is occurring already due to physical grid infrastructure limits that will exist for the foreseeable future. Approach #2 would fail to achieve data center energy efficiencies sufficient to adequately reduce stress on the power grid and would cause data centers to leave the Commonwealth.

- Microgrids generally comprise up to five key components:
    - A major power consumer (e.g. data center)
    - A baseload power source (onsite power capable of meeting the major consumer's maximum power needs 24/7/365)
    - A backup power source (e.g. generators, gas turbines, energy storage units, etc.)

    - A connection to the regional power grid (optional)
    - A demand-response management system to manage microgrid power sources and determine when and how the microgrid will interface, if at all, with the regional power grid
- There are currently six types of onsite power sources capable of practical application within the next five years:
    - Diesel generators
    - Long-Duration Energy Storage units or Battery Energy Storage Systems (BESS)
    - Natural gas turbines
    - Green hydrogen fuel cells
    - Blue hydrogen fuel cells
    - Small Modular Reactors/Advanced Nuclear Reactors (more than 50 variations)
- Only natural gas turbines or generators are immediately capable of delivering baseload, onsite power, however both have significant noise and pollution issues.
- Small modular reactors have the highest capacity factor (ability to deliver maximum power for the longest duration) and solar power has the lowest.
- Small Modular Reactors (SMRs) and Advanced Nuclear Reactors (ANRs) have the highest potential for delivering maximum, carbon net-zero power. They create new types of nuclear waste different than traditional light-water reactors and require onsite waste storage. These two factors would likely prohibit their use in Loudoun County with its very dense data center community located near residential areas. However, the federal government could install SMRs on federal property without local approval. Dulles Airport is federal land and is in close proximity to "Data Center Alley."
- The data center industry is facing historic market demand and possesses virtually unlimited resources to meet that demand. History suggests that any market experiencing these two forces simultaneously will derive its own market-based solution. Loudoun County, through constant collaboration with the data center sector and local utilities, should strive to anticipate in what direction its data center community will choose to move. Towards that end, the county should develop precise performance standards to 1) shape and manage future data center development, and 2) create significant incentives/disincentives to effect environmentally friendly and energy efficient design changes to existing data centers.

Introduction

I was elected to the Loudoun County Board of Supervisors in November 2019 and took office in January 2020. For my entire tenure, our bipartisan Board has had to deal with two enduring and overarching issues: data center growth and housing. While the need for attainable housing in

Loudoun County, the wealthiest county in America,[2] remains a critical issue, the explosion of data center growth in the past four years, both unprecedented and accelerating, has created urgent policy issues I believe our Board must now address.

This paper is intended to form the factual basis for a new policy regarding data center growth in Loudoun County. Stated simply—based on the data, logic and conclusions offered herein—the existing paradigm of power generation, transmission and consumption this nation has relied on for more than a century is simply not capable of providing sufficient power to Loudoun County data centers (and very likely Prince William County data centers) going forward. The demand from that sector of our market environment is too high, and that demand is accelerating rapidly to historic levels. This same conclusion was reached by the December, 2024 JLARC data center report submitted to the Virginia Governor and General Assembly:

> "Data center demand would drive immense increase in energy needs in Virginia, based on JLARC's independent forecast and other forecasts. Building enough infrastructure for unconstrained data center demand will be very difficult and meeting half that demand is still difficult."[3]

I suspect the data center sector and the power utilities will not agree with several of my conclusions expressed in this paper, and I both respect and value their feedback. However, having done the research on this issue, I believe we have all been considering these changes within the context of our historic organizational paradigms. The data centers' imperative is to meet market demand, and that's their focus. Dominion Energy and PJM, the Regional Transmission Organization (RTO) for the northeast power grid, are required by law to provide power to all customers, and that's their focus. And the Board of Supervisors is an elected body responsible for making land-use decisions and encouraging economic growth, and that has been our focus. But the post-COVID world since 2022 has seen a seismic increase in demand for data representing not an evolution, but a revolution of technological change now very likely to overwhelm our existing power infrastructure. Essentially, we've invented the airplane but just realized we haven't yet invented runways. This level of systemic change demands new paradigms at almost every level if we are to avoid an involuntary and likely painful landing.

This paper offers a summary of how we got here, presents data to capture the magnitude of the change we are all facing, acknowledges what I believe are the new realities of our current and future data center environment, and proposes the key elements of a new policy going forward. I do not consider the ideas presented or the policy elements I'm proposing the only viable answers to the historic challenges we now face. But my overarching responsibility, and I believe the responsibility of the Loudoun County Board of Supervisors, is to protect the quality of life of our citizens, even if the decisions we make are controversial, politically fraught and decidedly unpopular. My purpose here is to start a conversation based not on our ungrounded hopes but on our fact-based needs. That is the only basis upon which we can, collectively and collaboratively, formulate a transformational strategy for Loudoun County. We are the nexus for the world data center community. We have both a profound responsibility and an historic

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[2] Ibeh, Kemi. "The Wealthiest County in the U.S. Is Not Where You Think." Fodor's Travel. January 23, 2024. https://www.fodors.com/world/north-america/usa/virginia/experiences/news/heres-where-the-wealthiest-u-s-county-actually-is

[3] Joint Legislative and Audit Review Commission. "Data Centers in Virginia, Commission Draft." Report to the Governor and the General Assembly of Virginia. December 9, 2024, pg. ii-iii. https://jlarc.virginia.gov/pdfs/reports/Rpt598-2.pdf

opportunity to redefine and permanently reshape the digital world and the power infrastructure it relies on. And we must act now.

Loudoun County Current Landscape

As of this writing, Loudoun County, Virginia—and more precisely, eastern Loudoun County comprising approximately 30 square miles—is home to about 250 data centers. A recent independent analysis by consultant Kimley-Horn indicates there are another 117 data centers in Loudoun County's development pipeline, with presumably many of them "by right," not requiring approval by the Loudoun County Board of Supervisors.[4] (Note: on March 18, 2025, "by right" data centers ended in Loudoun County. All new data centers now require Board of Supervisors approval.) Combined with the rest of Northern Virginia, our data centers use more power than the next three U.S. markets combined.[5] In 2024, the JLARC report stated that northern Virginia (Loudoun, Fairfax and Prince William Counties) energy capacity was 4.14 Gw^2 up from just 1.5 Gw in 2019[6]. More recent data shows a 233% increase between 2020 and 2025. If we apply just a linear extrapolation of that growth rate in power demand over the next five years—and that is probably an unrealistically conservative growth rate based on the preponderance of growth trends in power demand—that means by 2030, Loudoun County will require about 14.2 Gw of power. An independent analysis by Kimley-Horn arrived at an estimate of 11.59 Gw of power needed by 2028.[7] Those are remarkably similar, independent analyses, both of which do not bode well for the Loudoun County power grid.

Regarding actual data center construction growth, in 2021 we had about 26.4 million sq. ft. of permitted data centers in the county. In 2025, we have about 53 million sq. ft. of data centers permitted.[8] That's a 100% increase in five years. Moreover, we have at least an additional 40 million sq. ft. in the pipeline (application being reviewed or site plan submitted).

By every metric, the rate of data center growth in Loudoun County over the past 20 years has been among the highest of any community in the world, and that rate has accelerated exponentially since 2022. All indications suggest that growth will be accompanied by a commensurate increase in demand for power, unless outside factors—governmental action, technological breakthroughs or increased use of onsite power—reduce the demands on the regional power grid to manageable levels.

Our county is at the edge of the frontier in data center development. The lessons we have learned as a community can serve as invaluable roadmaps for communities across the nation, ranging from those contemplating their first data center, to those with modest growth, to those with an established and thriving data center community.

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[4] Kimley-Horn staff report to the Loudoun County Transportation and Land Use Committee. "Power Transmission Evaluation of Loudoun County, Virginia." October 17, 2024, item #9, Atch. 2, pg. 4. https://www.loudoun.gov/3432/Transportation-and-Land-Use-Committee

[5] United States Data Centers: Top 10 Locations in the USA - Dgtl Infra

[6] Abdulsalam, Sami. "Dominion Northern Virginia Area Immediate Need." Slide #2, "Data Center Alley Area Load Growth and Transmission System." Slide #3, "Dominion 2022 Load Forecast." Data interpolated from data center load forecast line (orange). June 7, 2022. https://www.pjm.com/-/media/committees-groups/committees/teac/2022/20220712/item-08---dominion-northern-virginia---immediate-need.ashx

[7] Op. Cit.

[8] Yearly data provided by the Loudoun County Commissioner of Revenue.

At the same time, because of our uniqueness, many of the challenges we now face have no corollary outside of Loudoun County. Yes, our journey can be instructive to other communities still in the early to moderate growth cycles, but many of the issues our data center community, our utility companies and our local elected leaders are now facing have never before been encountered.

Three Key Stakeholder Groups

There are three core stakeholder groups in Loudoun County with an urgent interest in developing a comprehensive strategy for future data center sector growth: the data center community, the core utilities (electricity, gas, water), and local government representing our citizens who benefit from the data produced by our data centers.

Data Centers. This group involves not just data center owners and land developers, but the land-use attorneys representing them, construction companies, unions who provide labor, non-union laborers, and a wide range of corollary businesses that benefit from the construction, growth and increased impact of data centers on our society. All the members of this stakeholder group are primarily focused on enabling data centers to meet the rapidly increasing demand for data processing in our society. **Their market imperative is to continue to grow.** There are two broad types of data centers:

Hyperscale (Enterprise) Data Centers. Hyperscale (100 Mw or more) or enterprise data centers are generally owned and operated by a single owner and are extremely large with very high power demands. According to an August article in *Enterprise Storage Forum,*[9]a hyperscale data center is any data center with more than 10,000 sq. ft. of space and more than 5,000 servers. However, by this standard, just about every data center in Loudoun County, including most of our legacy data centers, would be considered hyperscale. For the purposes of this paper, I will distinguish between the two based on function. An enterprise data center is usually owned by a single entity and is designed to process enormous data loads at scale for just that entity or perhaps a handful of partners. According to a major colocation data center owner I talked to recently, hyperscale or enterprise data centers require significantly more power than colocation data centers as defined below. This trend is likely to accelerate significantly as hyperscale/enterprise data centers pick up more and more of the generative AI load worldwide.[10]

Colocation Data Centers. Colocation data centers are owned by a company that leases data rack space to tenant companies. It's a shared-space data center often hosting hundreds of clients who own and operate their own servers and infrastructure in an ideal data processing environment. The power requirements of a colocation data center have historically been much less than hyperscale/enterprise

[9] Vyas, Kashyap. "Hyperscale Data Centers vs. Colocation Data Centers." Enterprise Storage Forum. August 24, 2023. https://www.enterprisestorageforum.com/cloud/hyperscale-vs-colocation/#:~:text=Hyperscale%20data%20centers%20meet%20enterprise%20data%20needs%20by,essential%20resources%2C%20allowing%20for%20cost-effective%20expansion%20and%20management.

[10] McKinsey & Company. "AI power: Expanding data center capacity to meet growing demand." October 29, 2024. https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/ai-power-expanding-data-center-capacity-to-meet-growing-demand

data centers. While this is likely to remain true, AI is also going to significantly increase the power demands of colocation data centers.[11]

Core Utilities. Though services like internet, phone, cable T.V. etc. can be considered utilities, for the purposes of this discussion, we will limit our focus to just the core utilities of electricity, water and gas. The principal core utility and the one facing the most urgent current demand in Loudoun County due to accelerating data center growth is power (electricity). However, our other two utilities could play increasingly important roles in the future. Submerged data racks using water cooling could significantly lower data center power needs but increase demand for closed-loop, reclaimed water systems. Use of onsite gas-generated electricity is a viable future option and one already being used in Loudoun County, although this onsite power option has serious noise and pollution issues. Rapid growth in these sectors would also require more resources. But this paper's principal focus will be on power. There are two major players and one currently minor player in the Loudoun County power space:

Dominion Energy. Dominion Energy is the largest supplier of electricity in the Commonwealth of Virginia and the predominant electricity provider in Loudoun County. It is an investor-owned utility and, **because we are a regulated state, is required by Virginia law to provide power to every customer it serves.** This is a critical point underlying the entire issue of data center growth in Loudoun County and will be addressed later.

PJM. According to the PJM website, "PJM is a Regional Transmission Organization (RTO) that coordinates the movement of wholesale electricity in all or parts of 13 states and the District of Columbia."[12] PJM monitors and regulates all the power companies in the northeast region, including Dominion Energy, to ensure the stability and resiliency of the entire northeast power grid. Northern Virginia, and specifically Loudoun County, are among PJM's largest customers due to our data centers. Approximately 60% of the PJM grid is carbon dioxide-producing, and about 40% is carbon-net-zero energy with about 82% of the carbon-net-zero portion being nuclear.[13] As we will note later in this paper, that ratio could change significantly in the years ahead.

Northern Virginia Electric Cooperative (NOVEC). According to their website, "NOVEC is a distribution electric cooperative. NOVEC purchases wholesale power through the PJM marketplace."[14] As stated, NOVEC's principal function is to distribute electricity purchased by wholesale providers such as Dominion Energy. Generally, they provide power to residential customers and commercial businesses not powered directly by Dominion. At present, they are not a major player in the data center space in Loudoun County, but that could change in the near future as well.

Local Elected Officials Representing the Community. In Loudoun County, the senior elected body charged with land-use planning is the nine-member Board of Supervisors (BOS). The BOS works for the citizens of Loudoun County and must be responsive to their

[11] Ibid.
[12] https://www.pjm.com/about-pjm
[13] https://en.wikipedia.org/wiki/PJM_Interconnection
[14] https://www.novec.com/About_NOVEC/index.cfm

needs and concerns. No individual Supervisor may act alone; all proposed actions by the BOS require at least five votes to be implemented.

Regarding the BOS's role in land-use issues, the extent of BOS involvement in the decision-making process for land development depends on what type of land development is proposed. There are generally two types: "by right" and legislative.

"By Right." Every parcel of land in the county has permitted uses, and if a landowner decides to develop one of those permitted uses, s/he is not required to obtain BOS approval to develop that land unless they wish to change a "by right" use or add a new use.

Note: Loudoun County ended "by right" data center development by a 7-2 vote at a March 18, 2025 Board of Supervisors meeting. All new data centers in Loudoun County (except for 22 data centers "grandfathered" at the March 18th meeting) now require Board of Supervisors approval.

Legislative. If the landowner decides to modify the use of the land beyond what's permitted "by right," s/he must submit a legislative application to county staff and obtain final approval from the BOS.

The Roles of the Comprehensive Plan and the Zoning Ordinance. Key to understanding the planning environment within which these three stakeholders have been operating throughout the period of rapid data center growth is the relationship between the Loudoun County Comprehensive Plan and the Zoning Ordinance. Stated simply, the Comprehensive Plan is the Board of Supervisors' vision of how land should be developed in the county (plus the transportation infrastructure needed to support that vision). The Zoning Ordinance is the legally binding code landowners must abide by when developing their land, and it is used to implement the vision outlined in the Comprehensive Plan. The Comprehensive Plan is not legally enforceable; the Zoning Ordinance is.

These two documents should always be aligned and updated every five years. Yet Loudoun County went from 2001 to 2019 without a complete update of its Comprehensive Plan and from 2003 to 2023 without a corresponding update of its Zoning Ordinance. These two decades precisely aligned with the growth, from inception to maturity, of the data center sector in Loudoun County, the largest such sector in the world today. The BOS finally updated the Comprehensive Plan in 2019, but due to COVID, it took four more years to update the Zoning Ordinance in December 2023. These four years of misalignment between the Comprehensive Plan and the Zoning Ordinance occurred just as data centers began exercising their "by right" development options. Additionally, PJM, Dominion, and Aurora Energy, a leading global advisor to energy investors, mark 2022 as the year data center power demand began increasing rapidly.[15] This plan/ordinance misalignment could not have occurred at a worse time and seriously limited the Board's ability to manage data center growth as envisioned in the Comprehensive Plan.

How We Got Here: A Timeline of the Growth of the Loudoun County Data Center Sector

The following is a timeline of key events shaping the proliferation of data centers in Loudoun County:

- **1993:** Update of 1972 Zoning Ordinance: No mention of data centers.

[15] https://auroraer.com/company/about/

- **1990s (latter half):** Metropolitan Area Exchange-East established in Loudoun County; AOL HQ comes to Ashburn in 1997 and expands on existing fiber optic network.
- **2000:** Loudoun County Zoning Administrator determination; data centers are viewed as similar to office buildings in the 1993 Zoning Ordinance. Office parks are a hot trend.
- **2001:** General Plan (land use) updated.
- **2003:** Revised 1993 Zoning Ordinance passed to match the 2001 General Plan: First Mention of Data Centers in the Zoning Ordinance.
- **2008:** Loudoun County Economic Development initiates marketing strategy to actively recruit data centers to build on land specifically permitting data centers.
- **2014:** Zoning Ordinance Amendment (ZOAM) addressing data center sight, setback, sound.
- **2019:** General Plan updated (land use).
- **2022:** May-July: The Loudoun County Transportation and Land Use Committee (TLUC) holds a series of three meetings to inventory current and potential locations of data centers, obtain staff recommendations about how best to manage data center growth, and to determine the best process to implement a future data center Comprehensive Plan Amendment (CPAM)/Zoning Ordinance Amendment (ZOAM) to codify those managerial changes. Dominion announces new 500/230 Kv Wishing Star-Mars transmission line.
- **2022:** July: After ten years of slightly declining power demand within the Dominion Energy service area, PJM, the northeast Regional Transmission Organization, of which Dominion Energy is a member, recognizes an impending exponential increase in power demand from Loudoun County's "Data Center Alley."
    - Dominion Energy immediately imposes power constraints on "Data Center Alley" (which ended in December 2025). In September 2022, Dominion Energy announces plans to construct a "reliability" loop of three 500Kv/230Kv transmission lines (Aspen/Golden/Mars/Wishing Star) to connect "Data Center Alley" to the main north/south power line bringing power into Loudoun County. Dominion Energy informs "Data Center Alley" it will have less power available for at least five years. The power "constrained area" is created until new power lines can be built by 2027.[16] [17] PJM announces a new 500 Kv line from Doubs-Aspen.[18]
    - ChatGPT is launched. Artificial Intelligence, with its exponentially higher demand for power, enters the commercial market.
    - Coming out of COVID, the world demand for digital products increases exponentially.

[16] RTO Insider LLC. "PJM Orders Dominion 'Immediate Need' Projects to Serve Load Jump in 'Data Center Alley'." June 16, 2024. https://www.rtoinsider.com/30472-pjm-orders-dominion-immediate-need-projects-load-jump-data-center-alley/

[17] Abdulsalam, Sami. "Data Center Planning and Need Assessment Update." PJM. January 10, 2023. https://www.pjm.com/-/media/committees-groups/committees/teac/2023/20230110/item-04---data-center-load-planning.ashx

[18] PJM. "Transmission Expansion Advisory Committee (TEAC) Recommendations to the PJM Board." PJM. Dec. 11, 2023. Slide 44, last entry in table. https://pjm.com/-/media/committees-groups/committees/teac/2023/20231205/20231205-pjm-teac-board-whitepaper-december-2023.ashx

- **2023:** Dominion Energy announces a new 500/230Kv transmission line along Route 7 in Loudoun County.[19] This line, the southern Wishing Star-Mars line and a third Golden-Mars line will be connected to form a loop to "Data Center Alley."
- **2023:** Dec: Zoning Ordinance Rewrite (ZOR) to align with the 2019 Comprehensive Plan is approved by the BOS. This zoning ordinance rewrite established new, more restrictive construction and performance standards for data centers and attached Special Exceptions (SPEX) to data centers being built on Research and Development Park or Office Park land.
- **2023:** Dec: PJM announces acceptance of a NextEra proposal to build a new 500Kv transmission line through western Loudoun County.[20] Public resistance is significant, and PJM later decides to build this line in existing right-of-way.
- **2024:** Mar: The Loudoun County Board of Supervisors denies the construction of a 4.9 million sq. ft./600 Mw data center next to a residential neighborhood but approves the application when the applicant reduces its size to 1.3 million sq. ft., the "by right" permitted size, and retains the environmental proffers from the larger application.
- **2025:** Mar: The Loudoun County Board of Supervisors ends "by right" data center development in Loudoun County by a 7-2 vote at a March 18, 2025 Board meeting.[21]

It's important to note here the strategy initiated in 2008 by the Loudoun County Economic Development Department had the full support of the Loudoun County Board of Supervisors and proved to be enormously successful.

- There has not been a single day in the past 16 years when a data center was not under some type of initial construction or expansion in Loudoun County.
- Loudoun County now has about 250 data centers, more than any other community on Earth.[22] An additional 117 data centers are in the development pipeline.[3]

And the reasons why the Loudoun County BOS fully supported this program are easy to discern:

- Enormous tax revenue: In FY2027, Loudoun County estimates about $1.3 billion in data center real and personal property tax revenue. The county's total Local Tax Revenue is projected to be $2.9 billion.[23]
- As a result of data center tax revenue, Loudoun County has the lowest real property tax rate in NOVA; about 25% lower than our neighbors.[24]

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[19] Kirby, Jess. "Lansdowne residents oppose Route 7 transmission line proposal." Loudoun Times Mirror. Oct. 5, 2023. https://www.loudountimes.com/news/lansdowne-residents-oppose-route-7-transmission-line-proposal/article_46190288-639f-11ee-9908-7722c63f7ffd.html

[20] Kirby, Jess. "PJM advances proposal for transmission line in western Loudoun." Loudoun Times Mirror. Dec. 13, 2023. https://www.loudountimes.com/0local-or-not/1local/pjm-advances-proposal-for-transmission-line-in-western-loudoun/article_c0202122-99e3-11ee-9896-b71271fc88fc.html

[21] Loudoun County Board of Supervisors business meeting minutes, March 18, 2025. file:///C:/Users/mike.turner/Downloads/Item%2007%20Data%20Center%20Standards%20&%20Locations%20CPAM-ZOAM%20Phase%201.pdf

[22] Zhang, Mary. "United States Data Centers: Top 10 Locations in the USA." Dgtl Infra. April 11, 2024. https://dgtlinfra.com/united-states-data-centers/

[23] Loudoun County FY2027 Approved Loudoun County budget. Available on request.

[24] "City of Alexandria Revenues." City of Alexandria. 2024. Pg. 7-19 table. https://www.alexandriava.gov/sites/default/files/2023-02/Section%2007%20Revenues%20FY24.pdf

- A data center costs the county $0.04 per $1 of tax revenue received, whereas normal businesses cost about $0.25 per $1 of revenue.[25]
- Data centers put very few cars on the road.
- Data centers put very few kids in schools.

Thus, with the full and enthusiastic support of the Board of Supervisors and the visionary foresight of the Loudoun County Department of Economic Development, Loudoun County capitalized on its unique geography (Washington, D.C. and Dulles Airport), its role as a high-tech digital incubator and home of the internet, and its extensive fiber-optic infrastructure touting the lowest latency rates in the industry to become ground zero for historic digital development. Until 2022, though Dominion and the Department of Economic Development had cautioned for years infrastructure would have to be built to accommodate the rapid increase in demand for power, the future looked relatively unconstrained.

Then, in 2022, PJM informed Dominion Energy that Dominion's infrastructure predictions were significantly underestimating the growing power needs of Loudoun County's data center sector. In response, Dominion Energy established what is now known as the "constrained area" in Loudoun County and informed the data center sector they would have significant power constraints until 2027 when new transmission lines could be built. This deadline has now been pushed back to June 1, 2028.[26] This marked the start of a sobering new reality in Loudoun County: the rapid growth of four competing forces affecting the data center community and the larger Loudoun County community.

Five Accelerating, Co-Dependent, Conflicting Trends

There is no question five co-dependent, conflicting trends are going to dominate the Loudoun County data center landscape for the foreseeable future: 1) Rapidly increasing demand for data, 2) Rapidly increasing demand for power to process that data, 3) Rapidly increasing demand for water to cool AI data racks, 4) Rapidly increasing negative impacts on Virginia climate change initiatives, 5) Rapidly increasing local community resistance to changes in quality of life, changes to neighborhoods, and the proliferation of overhead transmission lines.

1. **Increasing Demand for Data.** As shown below, the years between 2016-2025 have seen staggering data center growth in Loudoun County:[27]
   - In 2016, 8.8 million sq. ft. of permitted data center floor space
   - In 2017, 10.1 million sq. ft. (14.7% increase)
   - In 2018, 13.1 million sq. ft. (29.7% increase)
   - In 2019, 18.3 million sq. ft. (39.7% increase)
   - In 2020, 21.5 million sq. ft. (17.5% increase)
   - In 2021, 26.4 million sq. ft. (22.8% increase)
   - In 2022, 28.1 million sq. ft. (6.4% increase)

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[25] Northern Virginia Technology Council. "The Impact of Data Centers on Virginia's State and Local Economies 5th Biennial Report." April, 2024. Pg. 7. https://info.nvtc.org/acton/attachment/45522/f-1c3915e6-b8b1-4914-818e-9fae14877a3d/1/-/-/-/-/2024%20NVTC%20Data%20Center%20Report.pdf

[26] Kirby, Jess. "Dominion files SCC application for Route 7 transmission lines." Loudoun Times Mirror. April 8, 2024. https://www.loudountimes.com/0local-or-not/1local/dominion-files-scc-application-for-route-7-transmission-lines/article_85f0c24c-f607-11ee-b165-e343f9408d14.html

[27] Data provided by the Loudoun County Commissioner of the Revenue, May 31, 2024.

- In 2023, 31.9 million sq. ft. (13.5% increase)
- In 2024, 41.2 million sq. ft. (29.2% increase)
- In 2025, 53.0 million sq. ft. (28.6% increase)

This steady increase in data center square footage is the result of the growth of our society's dependence on social media, "smart" device technology, personal computing and communication, and a host of other data-dependent advancements our society has come to depend on. And now, Artificial Intelligence (AI) is increasing the demand for data exponentially as well. A January 2024 article by a major data center realty company suggests consumers and businesses will generate twice as much data in the next five years as was generated in the previous ten.[28] That's a statement with staggering implications. The article provides a stark prediction of the speed and magnitude of growth in the data center sector and also illustrates convergence of the three conflicting growth trends:

"With the growing demands of AI, data center storage capacity is expected to grow from 10.1 zettabytes (ZB) in 2023 to 21.0 ZB in 2027, for a five-year compound annual growth rate of 18.5%[1]. Not only will this increased storage generate a need for more data centers, but generative AI's greater energy requirements – ranging from 300 to 500+ megawatts – will also require more energy efficient designs and locations. The need for more power will require data center operators to increase efficiency and work with local governments to find sustainable energy sources to support data center needs."[29]

2. Increasing Demand for Power

In the author's opinion, growth in data center power demand in Virginia is increasing at a rate far exceeding Dominion Energy's capacity to provide it. A January 2024 Data Center Dynamics article projected data center power consumption will double by 2030.[30] This trend is magnified in Loudoun County because of our unique data center load. In a May 2, 2024 article, Bloomberg reports that Northern Virginia data center developers are now asking Dominion Energy for the energy equivalent of several nuclear reactors' output. In a recent quarterly earnings call, Dominion Energy's CEO Bob Blue stated that Dominion Energy is now receiving requests from data center campus developers for "several gigawatts" of power.[31] This is a staggering increase in data center power demand in just a few years. Below is a summarized timeline of actual power usage in Loudoun County since 2018, the year we first reached approximately 1 Gw (1,000 Mw; a megawatt is one million watts) of power consumption in "Data Center Alley."[32]

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[28] Steele, Kimberly. "Growth of AI creates unprecedented demand for global data centers." Jones Lang LaSalle IP, Inc. January 31, 2024. https://www.us.jll.com/en/newsroom/growth-of-ai-creates-unprecedented-demand-for-global-data-centers

[29] Ibid.

[30] Gooding, Mathew. "Newmark: US Power Consumption to Double by 2030." Data Center Dynamics. January 15, 2024. https://www.datacenterdynamics.com/en/news/us-data-center-power-consumption/#:~:text=While%20the%20hyperscalers%20typically%20need,up%20from%2017GW%20in%202022.

[31] Saul, Josh. "Data Centers Now Need a Reactor's Worth of Power, Dominion Says." Bloomberg. May 2, 2024. https://www.bloomberg.com/news/articles/2024-05-02/data-centers-now-need-a-reactor-s-worth-of-power-dominion-says?utm_source=website&utm_medium=share&utm_campaign=email

[32] Abdulsalam, Sami. "Dominion Northern Virginia Area Immediate Need." Slide #2, "Data Center Alley Area Load Growth and Transmission System." Slide #3, "Dominion 2022 Load Forecast." Data

- 2018: 1 Gw (chart interpolation)
- 2019: 1.5 Gw (chart interpolation)
- 2020: 1.6 Gw (chart interpolation)
- 2021: 2.0 Gw (chart interpolation)
- 2022: 2.8 Gw (actual)
- 2023: 3.4 Gw (chart interpolation)[33]
- 2024: 4.14 Gw (actual)[2]
- 2025: 5.33 Gw (actual)[34]

If we assume a linear growth rate over the next five years similar to the previous five years, Loudoun County will demand 14.20 Gw of power by 2030. As mentioned earlier, an independently commissioned Kimley-Horn report has confirmed a similar estimate almost exactly, estimating 11.59 Gw of power will be needed by 2028.[3] But Artificial Intelligence (AI) is raising power demand much faster than a simple linear rate. As the use of AI grows, the need for more computing power within existing data centers means the demand for power within those walls is going to increase commensurately. According to an article in Data Center Knowledge, the average data rack power usage in a typical hyperscale data center in 2023 was 6-12 Kw. Because of their much higher reliance on Graphics Processing Units (GPUs) within the data rack, AI applications are going to increase that data rack power consumption to 40-60 Kw.[35] An October, 2024 McKinsey & Company report states the new Nvidia GB200 GPU AI chip could increase data rack density to 120 Kw per rack, a tenfold increase in the power required per rack.[10] This increase will affect both new data centers and existing data centers as well as both hyperscale/enterprise data centers and colocation data centers. This means that, using a base year of 2025 and 5.33 Gw of power consumption, by 2030, Loudoun County could easily require as much as 20-30 Gw of power due to AI demands. Put more bluntly, it is unlikely PJM and Dominion are going to be able to build enough grid infrastructure to meet Loudoun County's future energy needs. Moreover, we could stop building data centers today, and that would not stop a significant increase in existing data center demand for more power in the near to mid-term. As noted previously, the JLARC data center study arrived at the same conclusion.[2]

Recognizing this rapid growth in demand for power, and mindful of the legal requirement to provide power to all consumers in a regulated state, PJM, in the summer of 2022, advised Dominion Energy it would need to significantly increase its transmission infrastructure to handle the projected load in Loudoun County and to specifically address the urgent power

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interpolated from data center load forecast line (orange). PJM. July 12, 2022. https://www.pjm.com/-/media/committees-groups/committees/teac/2022/20220712/item-08---dominion-northern-virginia---immediate-need.ashx

[33] Ibid.

[34] U.S. Dept. of Energy/National Renewable Energy Laboratory. "Accelerating Speed to Power." https://maps.nrel.gov/speed-to-power/data-viewer?vL=6834e82591241decedd4ef8c%2C682746c9d58843cf7876093e%2C6838ae2891241decedd4ef8f%2C685c736d77a7c73f0a473a5d&b=%5B%5B-80.01874%2C38.464018%5D%2C%5B-75.119437%2C39.6613%5D%5D

[35] Kleyman, Bill. "Data Center Rack Density Has Doubled. And It's Still Not Enough." Data Center Knowledge, April 15, 2024. https://www.datacenterknowledge.com/cooling/data-center-rack-density-has-doubled-and-it-s-still-not-enough

constraints in "Data Center Alley." First, they needed to get power from the existing Loudoun north/south main transmission line to "Data Center Alley" to relieve the constraint. Then, they needed to bring additional power into Loudoun County from the north and south and connect it to the main north/south line to address the rapid growth in aggregate Loudoun County power demand.

To tackle the first and more urgent challenge, Dominion announced it would build a closed loop connecting the north/south main transmission lines to "Data Center Alley" in eastern Loudoun. Dominion is now planning a new 500/230 Kv line from the Wishing Star to Mars substations in the southern part of the county and a 500/230 Kv line between the Aspen and Golden substations in the northern part of the county. The loop will be completed with the addition of a third 500/230 Kv line connecting the Golden substation in the northern portion of the loop to the Mars substation in the southern part of the loop. Again, these three lines don't add new power from outside the county, and they won't be built until 2028 at the earliest. They do not, by themselves, address the enormous future increase in demand projections expected for all of Loudoun County as a result of our high concentration of data centers.

To address this future demand and bring more power into the county, in December 2023 PJM accepted a proposal from NextEra, a Florida-based power company, to run a new 500 Kv line from an existing east/west line in West Virginia south through the heartland of western Loudoun County agriculture to connect to the north/south main transmission line. This proposal encountered fierce resistance from Loudoun citizenry, the BOS and environmental groups. As a result, in August 2024, PJM announced it would route the new line through the existing north/south right-of-way.[36] Dominion later announced it would build a second 500 Kv line in the existing right-of-way and is also planning to run a new 500 Kv line from the south to connect to the main Loudoun County line. These three new lines will increase the aggregate size of the Loudoun power grid. In December 2025, Dominion Energy announced it planned to build a 525 Kv underground High Voltage Direct Current (HVDC) line bringing power into Loudoun grid from the south ending at Mosby substation.[37]

The table below provides an inventory of the main transmission lines entering the current Loudoun grid and then adds the four new entry lines to the mix. To understand the table, one must understand how much power each type of line can deliver. According to several sources, as a rough planning factor, depending on distance, a 500 Kv line can normally deliver between 1.0-1.5 Gw of power and a 230 Kv line can deliver about 500 Mw of power.[38] However, I've revised these power estimates based on recent conversations with Dominion Energy. According to their team, they've increased the amperage to 5,000 amps on 500 Kv lines and 4,000 amps on 230 Kv lines. Watts=Volts x Amps, so, by increasing the amps on these lines, more power can be delivered. With the increased amps, a 500 Kv line can now deliver an average load of about

[36] Ferguson, Sheila. "Western Loudoun Power Line." Loudoun Wildlife Conservancy. Aug. 28, 2024. https://loudounwildlife.org/2024/08/western-loudoun-power-line/

[37] Underground Infrastructure. "Dominion proposes 186-mile underground HVDC power line across Virginia." Dec. 17, 2025. https://undergroundinfrastructure.com/news/2025/december/dominion-proposes-186-mile-underground-hvdc-power-line-across-virginia

[38] Power Engineers. "500 kV AC/DC Extra-High Voltage Transmission Project." Power Engineers. 2024. https://www.powereng.com/library/500-kv-acdc-extra-high-voltage-transmission-project

2.1 Gw, and a 230 Kv line can deliver about 750 Mw. The table below shows the estimated power now being delivered into Loudoun County and projected with the new lines:

Current Lines Bringing Power Into Loudoun County:[39]

- From the north: (1) 500 Kv line = 2.1 Gw; (2) 230 Kv lines = 1.5 Gw
- From the south: (2) 500 Kv lines = 4.2 Gw; (2) 230 Kv lines = 1.5 Gw
- Total currently coming into Loudoun = **9.3 Gw**, but not to "Data Center Alley"

Planned new lines by 2028 at the earliest:[37,40]

- Aspen/Golden (north E/W line; planned completion date June 1, 2028), Wishing Star/Mars (south E/W line), Golden/Mars line (eastern N/S connector for Aspen/Golden and Wishing Star/Mars). These constitute the closed loop to "Data Center Alley" but add no new power to the Loudoun grid
- New power from the north, Mid Atlantic Resiliency Link (MARL): (1) 500 Kv line = 2.1 Gw; Doubs/Aspen (1) 500 Kv line = 2.1 Gw
- New power from the south, Morrisville-Wishing Star line: (1) 500 Kv line = 2.1 Gw (1) 525 Kv underground HVDC line to Mosby substation
- Total new Loudoun grid power planned: **17.9 Gw** (existing 9.3 Gw + 8.6 Gw new lines)

Yet as we saw earlier, with the advent of AI, Loudoun could easily see its power demand rise to as much as 20-30 Gw by 2030, far more than will be available through the above buildout schedule. While Dominion and PJM will likely assert this demand can be met by more infrastructure construction, I believe the data indicates these new transmission lines will not keep pace with the rapid increase in future demand in Loudoun County.

Nor have we addressed the 30 million sq. ft. of data centers recently approved in Prince William County immediately adjacent to Loudoun County's southern border. If we assume a 1 million sq. ft. data center will request from Dominion about 150 Mw of power, the Prince William County campus will require about 4.5 Gw of power. And the lines delivering this added power will almost certainly come through Loudoun County.

3. Increasing Demand for Water With the growth of Artificial Intelligence (AI).

Because water cooling is much more efficient than the air cooling historically used by many data centers before 2022—the year marking the rapid increase in the use of power-intensive AI following COVID—data centers are shifting to water cooling. The amount of water a medium-sized data center uses even before the widescale use of AI is staggering:

"A medium-sized data center can consume up to roughly 110 million gallons of water per year for cooling purposes, equivalent to the annual water usage of approximately 1,000 households. Larger data centers can each "drink" up to 5 million gallons per day, or about 1.8 billion annually, usage equivalent to a town of 10,000 to 50,000 people. Together, the nation's 5,426

[39] Open Infrastructure Map. https://openinframap.org/#13.17/39.07107/-77.5192

[40] Tesfa, Nebiat. "PJM Regional Transmission Expansion Planning (RTEP) Process." PJM. December 8, 2023. Slide presentation, slide 17. https://www.pjm.com/-/media/committees-groups/stakeholder-meetings/ipsac/2023/20231208/20231208-item-02-1-pjm-regional-transmission-expansion-planning-process.ashx

data centers consume billions of gallons of water annually. One report estimated that U.S. data centers consume 449 million gallons of water per day and 163.7 billion gallons annually (as of 2021)."[41] (Note: this citation references 2021 a year before the use of AI rapidly expanded.)

A Recent Washington Post article illustrates the impact AI is having on water consumption:

"Roughly a quarter of Americans have used ChatGPT since the chatbot's 2022 release, according to the Pew Research Center — and every query exacts a cost.... According to scientists at the University of California, Riverside, each 100-word AI prompt is estimated to use roughly one bottle of water (or 519 milliliters). This may not sound like much, but billions of AI users worldwide enter prompts into systems like ChatGPT every minute. Large language models require many energy-intensive calculations, necessitating liquid cooling systems."[42]

Types of Cooling[43]

Air Cooling: High power use/No water use. Generally used in older and smaller data centers. Basically, this is air conditioning to cool the data racks. Chilled air gathers the heat then is exhausted. This system uses no water but lots of power. Best for cold climates with constrained water supply.

Evaporative Cooling, Open Loop: Low power use/High water use. Used by the majority of large data centers today. Outside water is used to cool the data rack then is run through a cooling tower or evaporative cooler where it evaporates. Between 60-90% of the water used historically has been potable water. That means these systems have lower power consumption but use a large amount of water from municipal sources. This is changing as data centers strive to use more reclaimed or non-potable water for cooling.

"In practice, many data centers simply hook up to the local water mains. For example, Loudoun County, Virginia – the world's largest data center hub – supplied around +/-1 billion gallons of water to data centers in 2023, mostly relying on treated potable water because reclaimed water capacity was insufficient."[44] Note: Loudoun County has direct access to the Potomac River for water.

Closed Loop Water Cooling. Low power use/Low water use. Water in a closed loop system is passed through coils near the data racks and collects heat. The water is then cooled through heat exchangers or liquid-to-liquid cooling loops. Little to no water is evaporated. This system uses about 70% less water than open loop systems but it is more expensive and complex. Even more water savings can be realized if non-potable or reclaimed water is used to charge the system.

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[41] Miguel Yañez-Barnuevo. "Data Centers and Water Consumption." Environmental and Energy Study Institute. June 25, 2025. https://www.eesi.org/articles/view/data-centers-and-water-consumption

[42] Verma, Pranshu and Tan, Shelly. "A Bottle of Water per Email: the Hidden Environmental Costs of Using AI Chatbots." The Washington Post. September 18, 2024. https://www.washingtonpost.com/technology/2024/09/18/energy-ai-use-electricity-water-data-centers/

[43] Hegde, Ganesh. "Myths vs. Reality: Data Centers and Water Usage." Ketos. December 26, 2025. https://ketos.co/data-centers-water-usage-myths

[44] Ibid.

Wastewater Considerations. Data center wastewater is often contaminated with anti-corrosion chemicals, heavy metals and biocides from the data racks.[45] Wastewater contamination is seldom looked at when considering data center water use, but with the increase in water consumption for AI, wastewater disposal is fast becoming a major consideration.

Open Loop Wastewater. Used water is disposed after one use into the municipal sewage system or into open water sources.

Closed Loop Wastewater. Water is recycled through a closed loop system multiple times, but eventually it too becomes contaminated and must be purged and the system recharged. As in open loop systems, this wastewater, much more contaminated than open loop wastewater, is then disposed of in the municipal water system or open water sources.

Decontamination. Very little attention is being paid to data center wastewater decontamination. Even worse, EPA contamination limits only address a portion of the contaminants typically found in data center wastewater:

"However, one crucial input – water usage for equipment cooling – has attracted far less attention. Even less attention has been paid to the issue of data center wastewater discharge into public waters.... Not all contaminants listed are regulated and required to be reported by the EPA. For instance, while copper, chromium, and zinc have EPA Maximum Contaminant Levels (MCL - of 1.3 mg/L, 0.1 mg/L and 0.5 mg/L, respectively), phosphates, molybdates and biocides have no such MCL requirements."[46]

4. Increasing, Negative Impacts on Climate Change Initiatives

A disturbing, unintended consequence of this growth has also emerged. A recent New York Times article addressed an industry trend to slow or shelve plans to decommission legacy fossil fuel power plants in an effort to meet demand. According to this article, by 2030, power demands by the nation's data centers could triple. A February 2023 report by PJM shows the RTO planning to retire about 40 Gw of old power plants by 2030 while expecting about 11 Gw of new orders by that same date. Obviously much higher demands for power could significantly alter this plan.

These trends have very serious implications for our efforts to meet our climate change goals established by the Paris Agreement in 2016. These global efforts are plainly failing based on the most recent climate change data. In 2024, the World Meteorological Organization reported that global temperatures increased 1.55 degrees centigrade. "The year 2024 was the warmest year in the 175-year observational record, clearly surpassing the previous warmest year, 2023 at 1.45 °C ± 0.12 °C above the 1850–1900 average. For global mean temperature, each of the past

[45] Tozzi, Christopher. "4 Strategies for Eliminating Data Center Water Pollution." Data Center Knowledge. November 11, 2025. https://www.datacenterknowledge.com/sustainability/4-strategies-for-eliminating-data-center-water-pollution

[46] Ketos. "White Paper: Data Center Wastewater Discharge Trends: Crisis or Opportunity?" Ketos. https://ketos.co/wp-content/downloads/White%20Paper%20-%20Data%20Center%20Wastewater%20Discharge%20Trends.pdf

ten years, 2015–2024, were individually the ten warmest years on record." Six global tipping points will be reached at a ten-year, 1.5-degree rise.

It is fair here to note the data center community is pursuing very aggressive sustainability goals, goals that are far more aggressive than many other business enterprises. Unfortunately, by relying on power provided exclusively by the utility companies, their lofty sustainability goals are going to be negatively impacted if the utility companies continue this trend of postponing or even reversing the decommissioning of fossil-fuel power plants.

5. Increasing Community Resistance

Prior to 2022, the proliferation of data centers in Loudoun County was largely confined to land parcels intended for data center construction, and they were largely accepted by our citizens. The BOS received occasional complaints about the loss of green space, the visual impact of massive data center buildings, the noise these facilities made both with cooling fans and backup diesel generators, and the environmental impact associated with extremely large power consumption, but this pushback was largely generalized. Our citizens also understood and accepted that Loudoun County data centers kept our real property tax rates about 25% lower than our Northern Virginia neighboring jurisdictions.

But in 2022, the Board of Supervisors began sensing real community resistance to more data centers in Loudoun County. At about that time, data center companies had started running out of industrial land to build on and had begun to exercise their "by right" options to build on parcels they had bought years earlier zoned for office parks, research and development parks and industrial parks, many of which are located near residential neighborhoods. This began to create real tensions between communities, Supervisors and the data center sector. For example, in 2019, there were no data centers in Ashburn District (the community of Ashburn actually encompasses two districts: Ashburn and Broad Run). As of this date, four hyperscale data centers are being planned or constructed in the Ashburn district, all "by right" and all across the street from residential communities.

Community resistance increased dramatically when in 2023, Dominion Energy announced it would need to construct four new overhead transmission lines to relieve the power constraints in the county and specifically in "Data Center Alley." The previously mentioned Aspen/Golden line would run along Rte. 7, a heretofore unthinkable routing Loudoun County Boards for the previous 25 years had sworn would never happen. Earlier in 2023, Dominion Energy had already announced development of the Wishing Star/Mars line in southern Loudoun, but that line would run through a flood plain away from houses and drew little community response. Then a new line would connect the new Golden substation in the north to the new Mars substation in the south to close the loop to "Data Center Alley." Finally, a fourth line, a so-called "green field" transmission line—the previously mentioned MARL line—would run through western Loudoun County between the Potomac and Leesburg cutting across active farmlands, wetlands, tree conservation areas and through the historic village of Waterford. The public outcry was both immediate and predictable. As a result of that outcry, communities along Route 7 launched a year-long resistance movement to force Dominion to bury the 500/230 Kv line along Route 7, and a western coalition of citizens successfully pressured PJM to relocate the route of the new MARL line into the existing right-of-way coming into the county from Maryland. In October 2024,

the State Corporation Commission announced it would not require Dominion to bury the Aspen/Golden 500/230 Kv line along Route 7.

Thus, between 2022-2024, community resistance to more data centers, more overhead transmission lines, more substations and more consumption of fossil fuel energy reached unprecedented levels and began to have a major impact on BOS decision-making. In March of 2024, for the first time, the BOS voted 5-4 to deny a major data center application to build a 2.9 million sq. ft. data center. The applicant resubmitted the application scaled down to 1.3 million sq. ft., the "by right" permitted size, and, to their credit, retained a substantial environmental package in the application. That scaled down application passed by a vote of 6-3. But that application marked the first time a major, new data center application was denied by the BOS.

The "by right" growth of data center construction since 2022 in Loudoun County has proven to be particularly problematic for the BOS. As a result, in late 2023, the BOS took steps to require BOS review of some of these types of parcels. Yet since 2022, "by right" construction has proliferated as land specifically intended for data centers became scarce.

This trend came to an abrupt end on March 18, 2025 when the Board of Supervisors, in a 7-2 bipartisan vote, ended all "by right" data center development in Loudoun County. With the exception of 22 data centers "grandfathered" with the vote, all new data center development in Loudoun County must now receive Board of Supervisors approval.[20]

To be clear, no one is to blame for this confluence of these five conflicting trends. The speed with which the entire data center environment has evolved is staggering, and each of the stakeholders has, heretofore and understandably, responded to that change largely within their respective silos and process paradigms.

BOS Focus. From the BOS point of view, prior Loudoun County Boards and the Department of Economic Development saw an opportunity to get in on the ground floor of revolutionary technology likely to bring enormous economic growth to our community. It enabled us for almost 20 years to lower taxes even though our population growth was the highest in Virginia for that entire period.

Data Center Focus. Similarly, the data center community was and is simply responding to revolutionary changes in the market and historic demand for data.

Utility Focus. That demand for data has now translated into an insatiable demand for power and, to an increasing extent, water. In Virginia, the energy utilities are required by law to provide sufficient power to their customers even if demand for that power is increasing at an unprecedented rate. Asked at public meetings, including Board of Supervisors meetings, if they will be able to meet growing demand, they always assure their audiences they will—because the law requires them to. Concurrently, Loudoun Water is also having to respond to a historic increase in demand:

"Collectively, all data centers in Northern Virginia consumed close to 2 billion gallons of water in 2023, a 63% increase from 2019. Loudoun County, with approximately 200 operational data centers, used around 900 million gallons of water in 2023. This has led Loudoun Water, the county's water authority, to rely heavily on potable water for data centers rather than reclaimed water."[40]

Facing the New Realities

Beginning in 2025, opposition to data centers has grown dramatically nationwide. Much of this sentiment is the product of mis- and disinformation, but it also seems clear the rapid growth of data centers has often occurred with little local governmental oversight or control. This has led to widespread distrust of the data center community and a growing number of egregious examples of a complete disregard for the welfare of the community in the placement and operation of data centers. Local communities must assert more control over data center development if we are to more effectively manage this historic trend.

Going forward, it is incumbent upon all stakeholders—the data center community, Dominion Energy/PJM and the Board of Supervisors—to develop a strategy based on the new realities we face, a strategy that protects the quality of life of every Loudoun County citizen and reflects the tough choices we are clearly going to have to make. Based on the facts thus far presented, I believe the following are some obvious new realities we, as a Board, must address:

1. **Artificial Intelligence (AI) will change, but not substantially diminish, the unique and critical role "Data Center Alley" plays within the world data center market.**

   As mentioned previously, AI's demand for power will continue to grow exponentially, a reality we are experiencing every day. But going forward, we must also understand the changing functionality of Loudoun County's "Data Center Alley" with the advent of AI.

   AI operates in two general modes: training and inference. In the training mode, the AI model is "learning" its principal function, and in the inference mode, AI is executing its learned process to meet customer demand. In recent years, we have seen the development of "AI data centers," specialized data centers designed specifically to process AI. However, practically speaking, when the average person talks about "AI data centers," s/he is lumping all data centers under that general category.

   In practice, the term "AI data centers" most often refers to data centers focused almost entirely on AI processing in the training phase. These data centers tend to be very large, consume very large amounts of power, occupy very large campuses and require large amounts of water to cool the AI data racks. They also don't depend heavily on latency, the speed at which data can be transferred across fiber optic cable. This allows them to locate in isolated, rural areas where land is relatively cheap.

   Data centers performing AI inference calculations, on the other hand, are using AI to meet consumer demand and are therefore heavily dependent on low (faster) latency rates. Loudoun County has one of the largest underground fiberoptic networks in the world and therefore extremely low latency rates. This is what attracted data centers to Loudoun County beginning in 2000. While these types of data centers are also evolving to include more advanced and more energy intensive chips, they are more traditional data centers using much less power overall.

   Given the maturity of the Loudoun County data center market and the fact that its data centers are traditional, latency dependent, cloud-based data centers, our data centers will

likely function as AI inference data centers in the future. Given the higher power and land area needs, Loudoun County is not likely to see any AI training data centers locate here.[47]

2. **In the author's opinion, as evidenced by PJM documents citing load violations existing since 2022 and Dominion's establishment of a "constrained area," the Loudoun County electric grid is now significantly oversubscribed, and planned new powerline construction will likely lag behind rapidly increasing power demand for years to come. This conclusion was also reached by the JLARC study released in December 2024.**

   To be clear, "oversubscribed" does not mean the power grid is insecure; it means large customers with existing Electric Service Agreements (ESAs) will be power constrained—likely for years—by Dominion Energy until sufficient grid infrastructure is built to handle the contracted load. In December 2025, Dominion Energy lifted the Loudoun County "constrained area" with the completion of the Wishing Star/Mars 500/230 Kv circuit. However, the six remaining transmission line projects are not slated to be built until at least 2028, and projected demand continues to grow. In its 2024 Integrated Resource Plan,[48] Dominion Energy illustrates how it constrains customer load below the contracted ESA amount for as much as seven years. In a letter to at least one large customer on August 22, 2024, a senior Dominion official confirmed this by stating, "However, the size and quantity of large scale requests requiring supporting backbone expansion results in an extension of planning analysis and project execution lead times. Therefore, we expect the typical duration of the planning and execution process for large (greater than 100 MW) DP [Delivery Point] requests within the Dominion Energy transmission zone (DOM Zone) to increase by 12 to 36 months [from the current 3-4 years to 4-7 years]."[49]

3. **Halting new data center construction will not solve the problem.**

   Even if all new data center construction is halted immediately, the oversubscription of the power grid in Loudoun County will continue as our dependence on AI—requiring up to a tenfold increase in processing power within existing data centers—proliferates throughout the world.

4. **"Data Center Alley" rapidly rising power demand will slow the retirement of fossil fuel power plants throughout the PJM/Dominion service area.**

   This is the only way PJM/Dominion can meet the increasing demand, because the majority of power being delivered to Loudoun County data centers is derived from fossil fuels. This could be slowed somewhat if PJM/Dominion accelerate their conversion to carbon-net-zero fuels in response to aggressive data center programs demanding the utilities do just that, but the net result of these competing trends is difficult to predict.

5. **Community resistance has rapidly increased and will likely worsen.**

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[47] Iron Mountain. "AI training vs. AI inference data centers: What's the difference and why does it matter?" Iron Mountain. April 27, 2026. https://resources.ironmountain.com/blogs-and-articles/d/data-centers-ai-training-vs-ai-inference-data-centers-whats-the-difference-and-why-does-it-matter

[48] "Virginia Electric and Power Company's Report of Its 2024 Integrated Resource Plan." Case No. PUR-2024-00184; Docket No. E-100, Sub 204. Pg. 14

[49] August 22, 2024 email from Dominion Energy official to a large Delivery Point customer. Available upon request.

Thus far proposed are the new 500 Kv MARL line entering Loudoun from the north along the existing north/south corridor, a second 500 Kv line from Doubs to Aspen in the north, a new Morrisville/Wishing Star 500 Kv line and a new underground 525Kv HVDC line coming into Loudoun from the south, and the closed loop to "data center alley" comprising the new Aspen/Golden line proposed along Rte. 7 in the north, the new line from Golden-Mars through "Data Center Alley," and the Wishing Star/Mars line closing the loop in the south. But as previously stated, this loop adds no new power. If any new lines are proposed, community resistance will build accordingly. If incumbent elected officials are then voted out of office, they will be replaced by other elected officials with a mandate to vehemently oppose the data center and utility sectors.

Even without new lines, in 2026 strident opposition to all data centers has grown across the nation, and that opposition is manifesting itself in Loudoun County. County Supervisors are under increasing pressure to deny all data center applications, and this presents serious challenges to the Board of Supervisors. Because Virginia is a regulated monopoly commonwealth, meaning the power utilities are required by law to provide power to all consumers, no local Board can legally deny an application based on insufficient power.

6. **Burying 500 Kv transmission lines delivering AC power is possible but challenging and expensive; burying 500 Kv High Voltage DC (HVDC) lines is much easier and more efficient, however historically, HVDC lines have only been used to transmit power over long distances. Loudoun County may offer an excellent opportunity to develop the nation's first underground HVDC regional grid for exclusive use by data centers.**

   In October 2024, the Virginia State Corporation Commission denied the citizens' petition to underground the new 500/230Kv line from Aspen to Golden substations. Undergrounding a 500 Kv AC line has only been done once in the U.S. In 2013, an underground 500 Kv line was constructed traversing 3.7 miles through Chino Hills, CA. The project took three years and cost $224 million (not including the seven years of court battles).[50] Underground lines transmitting AC power must be insulated, usually with oil, and buried in a concrete tunnel, require much higher power transmission to deliver the same energy due to energy losses underground, are much harder and take longer to repair, and are not practical over long distances.[51]

   Undergrounding HVDC is now a viable alternative, loses very little power when buried, is used in many locations around the world and accepts renewable energy additions to the grid more easily.[52] While HVDC generally only makes sense for transmission over very long distances, the unique circumstances in Loudoun County, with its very high concentration of data centers within a relatively small geographic area, may offer an opportunity to develop a

[50] Nisperos, Neil. "Edison about to flip the switch on controversial power line project through Chino Hills." Daily Bulletin. October 30, 2016. https://www.dailybulletin.com/2016/10/30/edison-about-to-flip-the-switch-on-controversial-power-line-project-through-chino-hills/

[51] XcelEnergy. "Overhead vs. undergrounding. Information about burying high-voltage transmission lines." XcelEnergy Information Sheet. 2021. https://www.transmission.xcelenergy.com/staticfiles/microsites/Transmission/Files/PDF/Projects/CO/Avery/Transmission-CO-Avery-Substation-Overhead-Vs-Underground-Info-Sheet.pdf

[52] NextGen Highways Fact Sheet. "Buried High-Voltage Direct Current (HVDC) Transmission is Cost Competitive." November, 2022. https://nextgenhighways.org/wp-content/uploads/2023/01/NGH_Buried-HVDC-Cost-Competitive.pdf

separate HVDC regional grid for the exclusive use of Loudoun County data centers. This would offer two, major advantages: 1) it would create an entirely separate grid for data centers enabling a separate Dominion billing structure for data center users exclusive of residential and other commercial users, and 2) because HVDC is a more efficient means of transmitting carbon net-zero power, it would facilitate the transmission of carbon net-zero power (solar, wind, etc.) from numerous sources directly to "data center alley." With the recent addition of an underground 525 Kv HVDC transmission line coming into southern Loudoun County, such innovation appears to be much more feasible. Indeed, recent conversations with Dominion Energy officials suggest such a concept is now being considered.

7. **Solar and wind, by themselves, are not viable alternatives for Loudoun County data centers.**

    a. **Solar.** The average solar panel has a capacity factor (explained below) of about 24%. This means, due to clouds, darkness and other external factors, solar panels only deliver an average of about 24 percent of their "nameplate" (maximum rated power) per hour during a year. While estimates vary between 5-10 acres required per 1 Mw of nameplate power based on the topography and support structure layout, a reasonable planning factor for a commercial solar field using state-of-the art technology is about 7 acres of land per Mw.[53] Loudoun County had about 250 data centers in 2026. Assuming a 100 Mw data center average, and a capacity factor of about 24%, that usage level would require 700,000 acres of solar panels. Loudoun County's entire land mass is 333,000 acres. If power demand in Loudoun County for the next five years grows at the same rate as the previous five years (this does not account for AI growth), the county will be using 14.2 Gw of power in 2030. Solar power alone is simply not a viable answer for Loudoun County.

    b. **Wind.** As an illustrative, Vineyard Wind, a 62-turbine wind farm being built off the coast of Martha's Vineyard, will generate 806 Mw (nameplate) of electricity when complete, but only 193 Mw per hour on average after applying a 34.3% capacity factor.[54] At completion, this offshore wind farm theoretically will generate enough power to power 400,000 homes in the local area at nameplate power. But in practice, at an average of only 193 MW/hour, it would meet the power needs of about two of Loudoun County's 250 data centers.

8. **The 135-yr. old paradigm of power generated by large, remote power plants and transmitted across hundreds of miles of transmission lines will no longer work for Loudoun County's globally unique needs.**

    Given the above power demand projections and the time required to build new power infrastructure, it seems highly unlikely our traditional approach of delivering power to a

[53] Community Solar Authority. "How Much Land for 1 Mw Solar Farm: A Quick Guide." Community Solar Authority. May 31, 2024. https://communitysolarauthority.com/how-much-land-for-1-mw-solar-farm-a-quick-guide/

[54] Vineyard Wind. "Avangrid, CIP Announce First Power from Nation-Leading Vineyard Wind 1 Project." Vineyard Wind. January 3, 2024. https://www.vineyardwind.com/press-releases/2024/1/3/cip-avangrid-announce-first-power-from-nation-leading-vineyard-wind-1-project

consumer market as large and growing as Loudoun County can safely and effectively serve our needs.

Only Three Possible Scenarios Exist to Reduce or Stabilize Future Data Center Power Demand

If, as this paper and the JLARC study predict, the power grid infrastructure in Loudoun County—even with its planned expansion—will be insufficient to meet the future energy demand of the county's data center market, there are only three possible future scenarios by which that demand can be stabilized to manageable levels:

Scenario #1: Government-Imposed Energy Use Constraints. In this scenario, the Commonwealth of Virginia, the power utilities or both artificially constrain the energy consumption of high-energy consumers to ensure grid stabilization for all Virginia energy consumers. Such constraints were in place in Loudoun County from 2022 until 2026. As stated earlier, Dominion Energy has already extended the planning and execution time for delivering requested power to large consumers from 3-4 years to 4-7 years. In the author's opinion, this extended delay for full-power access will likely only increase. The JLARC study tacitly acknowledges this trend in its recommendation #2:

> "The General Assembly my wish to consider amending the Code of Virginia to clarify that electric utilities have the authority to delay, but not deny, service to customers when the addition of customer load cannot be supported by the transmission system or available generation capacity. (Chapter 3)"[55]

Like many aspects of the Loudoun County data center environment, I believe this de facto power constraint is a harbinger of what's to come globally for the data center market. We are the "canary in the mine." Data center power constraints were hardly mentioned in large data center conferences I attended in 2023. Now, they are a key topic in virtually every major data center conversation. Artificial caps on available power for data centers will likely become the norm as utilities struggle to achieve their core mission mandate, grid resiliency for all customers. A recent article in AP highlights this growing trend throughout the country.[56] This reality establishes the foundational argument for two subsequent market evolutions: 1) continuing technological advancements requiring less power within data centers, and 2) the development of microgrids to reduce data center dependency on the grid.

Scenario #2: Reduced Demand Through Technological Breakthroughs, Submerged Data Racks and Closed-Loop Water Systems. Technological breakthroughs are now on the near horizon that are likely to significantly reduce the power needed by AI and cloud-based computing. Such developments will initially reduce strains on the power grid and give the power utilities time to adjust to meet the growing infrastructure needs of the industry. (Note: this scenario could lead to significant stranded costs as discussed in atch. 1). However, such technological breakthroughs would likely be iterative and provide only temporary relief. Data centers will adjust, increase data processing density to fill the space created by

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[55] Joint Legislative and Audit Review Commission. "Data Centers in Virginia, Commission Draft." Report to the Governor and the General Assembly of Virginia. December 9, 2024, pg. xi. https://jlarc.virginia.gov/pdfs/reports/Rpt598-2.pdf

[56] AP. "US electric grids under pressure from energy—hungry data centers are changing strategy." AP. September 13, 2025. https://apnews.com/article/big-tech-data-centers-electricity-energy-power-texas-pennsylvania-46b42f141d0301d4c59314cc90e3eab5

the efficiencies, and once again operate at maximum capacity using all the power available to them. In the JLARC study (atch. 1), one data center representative succinctly captures the phenomenon known as Jevon's Paradox[57]:

"Consequently, any energy saved from efficiency gains is likely to be used to perform more computing activity. One company representative noted 'at the end of the day, a 200 MW data center is going to be a 200 MW data center.'"[58]

Similarly, as AI demand grows, existing and new data centers will move to water-use innovations such as submerged data racks and closed-loop water systems to reduce power demand as water cooling is far more energy efficient.

Scenario #3: Microgrids Develop to Provide Onsite Power. Faced with exponential market demand and possessed with almost unlimited resources to meet that demand, the data center industry will likely develop the capacity to generate onsite power through microgrids for its operations and, in so doing, significantly reduce its reliance on the regional power grid. Such developments could eventually stabilize the grid by allowing an industry-wide, distributed energy, demand response system to develop.

Likely Future: All Three Scenarios Occur Simultaneously and Energy Demand Still Grows

And so, in its continuing quest for more power, the data center industry will evolve to meet market demand. The utilities will begin to artificially cap that demand, as they eventually must do to preserve grid resiliency (scenario #1), the data industry will produce ever more energy-efficient chips and reduce their energy consumption through various water cooling mechanisms (scenario #2), and data centers will strive to become less reliant on grid power by developing microgrid, onsite baseload, backup and stored power (scenario #3).

However, of the three scenarios, I believe the development of onsite microgrid power is the most likely to reshape the national power grid going forward, though due to geographic constraints and our very dense data center market, its applicability in Loudoun County will be limited. As access to grid power becomes increasingly constrained and chip efficiencies constantly evolve, a comprehensive demand-response system will become the core of a regional and even nationwide distributed energy system. This is the heart of the new energy paradigm. Local, regional and national demand-response systems will enable onsite power sources to stabilize hourly grid operations.

Strategies for the Future

Clearly there is no "silver bullet" to meet these complex challenges, especially in Loudoun County. Any approach will require the thoughtful integration of a range of options to meet the growing demand for more power from the data center sector in ways that do not drastically and negatively impact the quality of life of our residents or the stability of our economy. Obviously whatever

[57] Wikipedia. "Jevon's Paradox." https://en.wikipedia.org/wiki/Jevons_paradox
[58] Ibid, pg. 41.

strategies are developed will be policy decisions for the Board of Supervisors to make by a majority vote.

Offered below are some suggested options by the author and as such are entirely subjective and debatable. They will likely generate considerable discussion, hopefully based upon the factual foundation thus far provided. It seems clear however that, over the next ten years, unless the data center industry undergoes a major technological transformation enabling it to significantly reduce its power consumption permanently, the Board of Supervisors will likely be faced with a repeating binary choice:

1. Accept the traditional paradigm of AC power generated at massive, remote power plants, transmitted over hundreds of miles of overhead transmission lines, then delivered to customers, including Loudoun's data centers with their historic demand for power. The likely result will be a significant threat to Loudoun County's power grid resiliency and a lattice of overhead transmission lines throughout Loudoun County, or;

2. Reject that 135-yr. old power infrastructure paradigm and facilitate the data center sector's market-driven move to a radically new power delivery model and market environment. Large power consumers will find ways to reduce their power needs while simultaneously generating low or carbon-net-zero power onsite or locally to enable them to participate in a demand response system and deliver surplus power onto the regional power grid as part of a nationwide distributed energy network. This is precisely the model the Department of Defense (DoD) has adopted. In a recent update to Title 10, DoD has directed all Services to make select military bases and critical installations energy independent and resilient through the use of onsite, sustainable energy generation, including long-term energy storage and nuclear and hydrogen power generation. This program is now being implemented worldwide.[59]

1. Utilities: Increase Transmission Capacity Through Reconductoring.

The 2025 session of the Virginia General Assembly passed a law requiring all new transmission lines in Virginia to use advanced conductors (transmission lines). Dominion has advised they now plan to replace their existing lines with advanced conductors and use advanced conductors for all new lines in Loudoun County. They will use Aluminum Conductor Steel Supported (ACSS) line. Depending on other upgrades, this will cost about 35% more than the cost of the current type of conductor in use for the past 100 years. ACSS conductors can increase line capacity by 50-100%, are the cheapest of the new alternatives and are proven technology. This type of conductor has been in use since the 1970's but is still considered an "advanced conductor" option because of the capacity increase.

While there are several other advanced reconductor options, the most common new alternative to ACSS is Aluminum Conductor Carbon Core (ACCC) conductors. Developed around 2003, this would also increase capacity by about 100%. It's a lighter line and delivers increased capacity, but is prone to breakage during installation, has

[59] TITLE 10 / Subtitle A / PART IV / CHAPTER 173 / SUBCHAPTER I / § 2911. May 31, 2024. https://uscode.house.gov/view.xhtml?req=(title:10%20section:2911(b)%20edition:prelim)

had some recent, unforeseen challenges, has challenges in icing conditions and costs about three times more than ACSS conductors.[60]

The newly reconductored lines would eventually be overtaken once again by rising demand, but, if combined with other measures, could be a valuable tool in building a new energy transmission paradigm.[61]

2. Utilities: Reduce HVAC Grid Load by Creating an HVDC Parallel Grid.

Create an Underground, High Voltage Direct Current (HVDC) Parallel Power Grid in the Existing Dominion HVAC Transmission Line Rights of Way in Loudoun County. The National Renewable Energy Laboratory (NREL), a Department of Energy laboratory, is exploring the expanded use of HVDC transmission lines in more multiple connection environments.[62] Recent technological advances now make the use of HVDC transmission lines a real alternative to the present AC-power dependent U.S. power grid. HVDC transmission lines are currently used in many countries. An HVDC transmission line is far more efficient in transmitting high-voltage power across long distances, experiences much less power loss through transmission, can be buried underground much more easily and with little loss of power, and is much better suited to allowing a grid to accept power from renewable and onsite sources.[63] There are currently three underground HVDC projects in the U.S.: Soo Green, IA, Champlain Hudson Power Express, NY, and Clean Path, NY.[64]

What if PJM, Dominion Energy, the data center community in Loudoun County, the Commonwealth of Virginia and Loudoun County government collaboratively proposed to DoE and NREL the creation of a national pilot project to create a separate, underground, HVDC power grid in Loudoun County specifically to deliver HVDC power directly to Loudoun County data centers, the highest concentration of data centers in the world? This entire HVDC grid, capable of delivering 2 Gw of of HVDC power, could be placed underground in a five-foot underground trench within the existing Dominion HVAC overhead transmission line rights of way. TenneT Netherlands is a company specializing in underground HVDC transmission projects and is engaged in several of these types of projects in Europe.[65] Data centers could begin planning to fully convert to internal DC power by 2028, the projected completion date for some of the new lines. At

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[60] Idaho National Laboratory. "Advanced Conductor Scan Report." Idaho National Laboratory. Dec. 2023; revision April, 2024. https://inl.gov/content/uploads/2024/02/23-50856_R8_-AdvConductorszScan-Report.pdf

[61] Plumer, Brad. "The U.S. Urgently Needs a Bigger Grid. Here's a Fast Solution." The New York Times. April 9, 2024. https://www.nytimes.com/2024/04/09/climate/electric-grid-more-power.html

[62] NREL. "On the Road to Increased Transmission: High-Voltage Direct Current." NREL.gov. June 12, 2024. https://www.nrel.gov/news/program/2024/on-the-road-to-increased-transmission-high-voltage-direct-current.html

[63] Berthou, Andreas. "The Benefits of High-Voltage Direct Current (HVDC) Power." EE Power. October 19, 2020. https://eepower.com/technical-articles/the-difference-that-dc-makes/#

[64] NextGen Highways. "Buried High-Voltage Direct Current (HVDC) Transmission is Cost Competitive." NextGen Highways. November, 2022. https://nextgenhighways.org/wp-content/uploads/2023/01/NGH_Buried-HVDC-Cost-Competitive.pdf

[65] TenneT. https://www.bing.com/videos/riverview/relatedvideo?q=underground+hvdc&mid=CBFAD8D2D54C82255EC5CBFAD8D2D54C82255EC5&FORM=VAMTRV

completion of the pilot project, Loudoun County would have two separate power grids, an HVAC grid for residences and normal-sized commercial customers, and an HVDC grid exclusively for data centers.

If PJM and Dominion must build the new HVAC lines anyway, why not make the project a national pilot project and incorporate state-of-the-art technology throughout the pilot project? This would include using all advanced conductors to double overhead HVAC line capacity supplemented by a buried HVDC transmission grid to distribute DC electricity directly to data centers.

The advantages of this admittedly bold concept would be significant:

1) The existing HVAC power grid and associated consumer rates in Loudoun County would immediately stabilize as data centers were moved off that grid;

2) A large infusion of DoE funding would relieve PJM and Dominion Energy of the burden of financing the currently planned infrastructure upgrades, a burden existing residential and commercial customers will undoubtedly have to bear;

3) Two separate grids would facilitate two separate billing systems for Dominion Energy, thereby relieving residential/small commercial customers from having to help pay the added infrastructure costs associated with the growing power consumption by the data centers;

4) The new HVDC power grid could be buried within existing rights of way;

5) The new HVDC grid would be much more adaptable to the incorporation of onsite data center microgrids with multiple DC power sources such as natural gas, battery backup, hydrogen fuel cells and distant solar/wind inputs.

3. Loudoun County: Create New Performance Standards

We must insist new data centers adhere to rigorous energy-conserving performance standards while incorporating essential microgrid elements into their campus designs enabling them to significantly lower their projected power load on the regional grid.

4. Loudoun County: Create an Incentive/Disincentive Program to Encourage/Require Existing Data Centers to Operate More Sustainably and Reduce Community Impact.

While retrofitting existing data centers to incorporate microgrids may, at present, be impractical, steps can be taken to reduce emissions, reduce noise levels and improve viewsheds. It may also be possible in the near future to incorporate several microgrid elements on existing data center campuses.

The planning objective for both new and existing data centers should be to demonstrate a commitment to the people of Loudoun County to reduce their load on the grid and their impact on the surrounding community over time.

Loudoun County's highly dense data center environment is unique in the data center world today. This means we are literally on the frontier of a new digital age. The county's key stakeholders are now faced with a simple binary choice: lead, through innovation and imagination, or wait and react too little, too late to a rapidly expanding traditional

power grid infrastructure inappropriate for Loudoun County's needs and unable to solve our unique demand challenges.

What is a Microgrid?

A microgrid generally consists of five elements: 1) a major power "load" or consumer such as a data center, 2) an onsite or nearby communal baseload power source (power delivered continuously to sustain normal, daily operations), 3) a backup power source to supplement the baseload power source during times of grid instability or to store excess power, 4) connections to the utility power grid enabling upload of excess power or operation of the microgrid independently in "island" mode, and 5) a system to manage all elements of the microgrid and determine if, when and how the microgrid should interface with the regional power grid.[66]

If we accept the premise the traditional power grid infrastructure serving the nation, by itself, will ultimately not be able to meet the unprecedented aggregate nationwide increase in demand for power—and some may not accept that premise—then the only viable national-scale alternative is a distributed energy network. Such a distributed energy network would offer nationwide power grid resiliency and redundancy in much the same way information stored in "the cloud" is continuously available through any smart device and not susceptible to any single device failure.

A distributed energy network would comprise thousands of microgrids around the country continuously generating baseload power for their onsite customers, storing energy for periods of grid instability, and uploading excess energy to the national grid when available to increase grid resiliency. These microgrids could be as large as data-center scale microgrids generating hundreds of megawatts of power, smaller scale microgrids to provide backup power to large consumers or even tiny, point source microgrids such as individual electric vehicle charging stations whereby your personal vehicle, once fully charged, begins to discharge onto the local power grid.

The Challenges of Developing Microgrids in Loudoun County

Though the solution for the national power grid may be the development of a nationwide distributed energy network through microgrids, such a solution has limitations for widespread deployment in Loudoun County for one reason: land. Our 250+ data centers are packed into about 30 square miles of real estate in eastern Loudoun County, and "data center alley" is literally a zero-lot-line checkerboard of data centers built on just about every square meter of space. My research suggests microgrids capable of generating the baseload power many of our data centers would require would likely need land that simply isn't available.

However, despite limitations such as land availability, our data centers are already actively exploring various microgrid options in response to grid limitations. For example, the Board recently learned of a natural gas microgrid operating in Loudoun County in "island" mode (not connected to the power grid but operating autonomously) that has been under development for the past two years. The application was approved by the Board of Supervisors with an "accessory use" included in the site plan at a time when the applicants assumed they would have access to grid power. No mention was made of gas turbines.

In August 2022, the company was forced to develop this microgrid when, after signing a billion-dollar land lease for its property, Dominion Energy informed the landowner it would not be able to provide power for several years. The applicants modified their approved site plan—a modification

[66] NREL. "Microgrids." https://www.nrel.gov/grid/microgrids.html

that did not need to come back before the Board of Supervisors—and changed "accessory use" to "turbines." The applicants very likely assumed the turbines would be a temporary solution, and county staff likely assumed "turbines" meant backup power, which did not need Board approval.

Unfortunately, the grid connection has still not been made, and the site is now operating continuously (24/7) using eight natural gas turbines with Selective Catalytic Reduction (SCR; see below) units attached. The turbines are producing about 52 decibels of continuous noise at the neighboring property lines (our zoning ordinance limit is 55 decibels), and this author has since learned there is currently no technology to filter out PM2.5, an especially harmful particulate matter pollutant, from the turbine exhaust. The Board has been receiving serious, continuous complaints from nearby residents about noise and pollution for over a year. Our Zoning Administrator has since ruled such islanded gas turbine installations require Board approval, but we have no current mechanism to retroactively address the one continuously operating islanded microgrid which is in compliance with our current zoning ordinance.

This is only one example. At present, there are four applications coming to the Board that include microgrid elements: two proposing gas turbines, one proposing blue hydrogen fuel cells and one proposing long duration energy storage.

Thus, while fully autonomous, carbon-net-zero, baseload microgrids may not be immediately feasible for many Loudoun County data centers, several microgrid elements could be adapted and applied to our existing data centers as transitional steps moving us to a distributed energy, fully carbon-net-zero data center environment in the future. However—and this is a critical point—local governing bodies must preemptively implement strict performance standards for each microgrid element before approving these data centers.

The natural gas generators in the example above have SCR units attached. According to site operators, these SCR installations reduce Nitrogen Oxides (NOX), Carbon Monoxide (CO), and unburned Hydro-Carbons (HC) to Tier IV Final EPA emission standards, the strictest standards in the industry. Unfortunately, I have since learned these are far more problematic than we thought. They remove about 95% of NOX and over 85% of CO. But there is currently no technology to filter PM2.5 emissions from gas turbines and, if not properly tuned, natural gas turbines with SCR can actually increase PM2.5 emissions. Moreover, turbines burning natural gas always emit CO_2, and the continuous noise levels are clearly too high.[67, 68] This first microgrid test case, however well-intentioned, has shown that Loudoun County will have to implement much more stringent noise and PM2.5 pollution standards going forward.

The problem is even more challenging for our existing data centers with their 4,000+ Tier II backup diesel generators (not gas turbines; traditional diesel fuel generators). Unlike gas turbines, a much quieter, cleaner solution is possible. By attaching SCR units and Diesel Particulate Filters (DPF),

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[67] Power. "Could SCR Catalyst Technology Adoption Be a Roadmap for Power Plants Seeking Economical and Efficient CO2 Point-Source Solutions?" Power. August 8, 2023. https://www.powermag.com/could-scr-catalyst-technology-adoption-be-a-roadmap-for-power-plants-seeking-economical-and-efficient-co2-point-source-solutions/

[68] Jiang, Binfan and Dehong, Xia. "Potential PM2.5 generation mechanism induced by ammonia-based SCR: Nucleation of SO3, H2O and NH3." Science Direct. May 15, 2024. https://www.sciencedirect.com/science/article/abs/pii/S0016236124002606#:~:text=As%20a%20main%20precursor%20for%20the%20PM2.5%2C,gas%2C%20which%20may%20induce%20heavier%20particle%20pollutions.

Tier II generators can be made much cleaner though no quieter.[69] An even better solution: Tier IV diesel generators, the current, highest EPA standard for diesel generators, are much quieter and filter out more than 90% of all pollutants, including PM2.5, other than CO_2.[70] If Loudoun County were to create incentives or require, through new performance standards, existing data centers to replace their 4,000 Tier II diesel generators with Tier IV diesel generators, the county would experience a significant reduction in NOX, CO, HC and PM2.5 emissions and noise levels. With this in mind, let's examine the various onsite power generation options either available now or being developed in the near future.

In researching this paper, I encountered a common theme among many I talked to when I raised the issue of carbon-net-zero onsite power production. Many believe such onsite power production is still purely theoretical and that practical demonstrations of this technology are years away. I was one of those people. What I have learned, however, is that there are several working installations delivering reduced carbon onsite power with the potential to provide the Loudoun County data center sector with various options for a viable way forward.

Potential Onsite Power Sources for Loudoun County

Given the current state of our technology, here are the six sources of onsite power available now or within five years for microgrid use. I include Small Modular Reactors (SMR) which are 2-3 years away from licensing because they are the only true baseload, dispatchable (max power is always available), noiseless, emission-free, carbon-net-zero power source option:

Power Source Type	Baseload Capacity	Carbon-Net-Zero	NOX, CO, PM2.5, CO_2
Tier IV Diesel or Tier II w/SCR and DPF			No (CO_2)
Batt./Long-Duration Storage		✓	✓
Natural Gas Turbine w/SCR	✓		No (PM2.5, CO_2)
Green Hydrogen Fuel Cells		✓	✓
Blue Hydrogen Fuel Cells	✓		No (CO_2)
Small Modular Reactor (*Future)	✓*	✓	✓

Below are the pros and cons of each power source:

> **Diesel Backup Generators.** Virtually all current data centers have diesel backup generators. The vast majority of Loudoun backup generators are Tier II generators which is dated, off the shelf technology. They are dirty and noisy. SCR units can be attached which

[69] Sustainability Directory. "How Do Diesel Particulate Filters (DPFs) Reduce PM2.5 Emissions, and What Is the Challenge of Filter Regeneration?" Sustainability Directory. Nov. 23, 2025. https://pollution.sustainability-directory.com/learn/besides-dpfs-what-is-another-technology-used-to-reduce-nox-emissions-from-diesel-engines/

[70] JC Davis Power. "How to Reduce Noise Pollution with Tier 4 Mobile Jobsite Generators." JC Davis Power. 2026. https://www.jcdavispower.com/how-to-reduce-noise-pollution-with-tier-4-mobile-jobsite-generators/

can raise them to Tier IV emission standards, including reducing over 90% of PM2.5 emissions, if Diesel Particulate Filters (DPF) are attached. Tier IV backup generators are the highest current EPA standard, are more expensive, and supply lines are very long, however they are much quieter and significantly reduce all emissions, including PM2.5.

Advantages: Enable data center "99999" reliability (data center is operational 99.999% of the time.)

Disadvantages: If Tier II, highly polluting, noisy; with SCR/DPF, cleaner but still noisy. If Tier IV, much cleaner/quieter but still emits CO_2.

Battery Energy Storage Systems (BESS).[71] A lithium battery energy storage system captures energy from various sources and stores it for later use. These are most often used to capture renewable energy produced, for example, from solar or wind installations, but they can be used to store energy from any source. They are typically used as backup power to augment a continuous power supply.

Advantages: Carbon-net-zero; no pollution; no noise.

Disadvantages: Not a source of sustainable, baseload power; lithium for batteries is becoming scarcer, and the fire hazard requires new suppression methods. These batteries only store about four hours of energy, must retain 20% of their charge to preserve the life of the battery, only have about a 10-yr. operational life, and have only one discharge rate.

Long-Duration Energy Storage.[72] While definitions vary, LDES typically refers to energy storage systems capable of delivering power for at least 8–12 hours or longer—well beyond the limits of conventional lithium-ion Battery Energy Storage Systems (BESS). LDES solutions step in where lithium leaves off, offering safer, more sustainable, and more scalable options.

Advantages: No fire hazard; versatile charge/discharge options.

Disadvantages: New technology; not a source of baseload power; requires an energy generation source which, in turn, determines its climate change impact. Not yet to scale.

Natural or Renewable Gas Turbines.[73, 74] Natural gas (local pipeline) onsite power generation is not carbon-net-zero and is a fossil-fuel derived energy source. If used to generate baseload power without active emission controls, it has significant CO_2, NOX, PM2.5, HC and CO emissions. These can be somewhat mitigated through the use of Selective Catalytic Reduction (SCR) mentioned earlier, a modification that should be mandatory in Loudoun County. It removes about 95% of NOX but still produces CO_2, and

[71] ABB. "What Are Battery Energy Storage Systems?" https://electrification.us.abb.com/battery-energy-storage-systems-bess-basics

[72] Mullendore, Seth. "Long-Duration Energy Storage: What Is It, Why Do We Need It, and When Will It Get Here?" Clean Energy Group. May 5, 2025. https://www.cleanegroup.org/what-is-long-duration-energy-storage/

[73] https://enchantedrock.com/the-advantages-over-diesel/

[74] https://www.sapphiregassolutions.com/renewable-natural-gas/

can actually increase PM2.5. My research could not find any gas turbine equivalent to Diesel Particulate Filters (DPF) used to remove PM2.5 from diesel engine exhaust.

Renewable natural gas (RNG or "biomass" gas) is waste gas produced by organic waste, captured, and delivered to the microgrid gas turbines. Since the waste gas would otherwise be released into the air, using waste gas to run generators can reduce the net CO_2 emissions even considering the CO_2 released in burning the gas. It too may use SCR to reduce emissions.

> **Advantages:** Biomass or renewable natural gas turbines may reduce total CO_2 emissions by capturing and using waste gas that would otherwise be released into the atmosphere; natural gas has lower carbon emissions than diesel and these are somewhat reduced by the use of SCR; it can provide sustained, baseload power; it can rely on existing gas lines; a gas microgrid design could easily accommodate a different energy source (hydrogen fuel cells, nuclear) in the future.
>
> **Disadvantages:** Even with SCR, gas turbines run on fossil fuel and emit very harmful PM2.5 pollutants. They also create sustained noise levels requiring mitigation; they could easily oversubscribe the gas grid with widespread use; natural gas power plants are notorious for leaking methane—up to 80-100 times more harmful to global climate than CO2—when extracting the natural gas and preparing it for pipeline delivery.[75]
>
> However, Loudoun County's single example of an islanded, onsite bank of eight gas turbines has created a major noise hazard and PM2.5 pollution for nearby residences and will likely cause the Board of Supervisors to prohibit their use as onsite power without major noise/PM2.5 mitigation from now on.

Hydrogen Production and Blue Hydrogen Fuel Cells.[76] Hydrogen is present in abundance throughout nature and can be used as a fuel source, but it is rarely available in free form. Instead, it is usually part of the chemical makeup of other energy sources such as oil, gas, biomass or even water.

> **Utility Scale Hydrogen Production.** To produce industrial scale hydrogen to be used for fuel, a process called reforming is accomplished at a separate facility. The process strips hydrogen molecules off an energy source. The source of the hydrogen and the method used to strip off the hydrogen molecules determine the classification of the type of hydrogen. "Green hydrogen" uses renewable energy sources (solar/wind) to strip hydrogen molecules from water. "Blue hydrogen" reforms natural gas at a reforming plant and theoretically uses carbon capture and sequestration to capture CO_2. "Gray hydrogen" reforms the natural gas but doesn't capture the carbon dioxide. About 95% of hydrogen production in the U.S. is accomplished through natural gas reforming[77]. **Note:** Only green hydrogen is

[75] Climate Portal. "How much does natural gas contribute to climate change through CO2 emissions when the fuel is burned, and how much through methane leaks?" Ask MIT Climate. July 17, 2023. https://climate.mit.edu/ask-mit/how-much-does-natural-gas-contribute-climate-change-through-co2-emissions-when-fuel-burned

[76] https://www.energy.gov/eere/fuelcells/hydrogen-and-fuel-cell-technology-basics

[77] U.S. Department of Energy. "Hydrogen Production Natural Gas Reforming." https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming

carbon-net-zero and fully pollutant free. Blue hydrogen and gray hydrogen produced at utility scale reforming plants "reform" natural gas (primarily methane) to obtain the hydrogen molecules. The industrial-scale process leaks highly potent methane (see natural gas disadvantages above) and releases carbon dioxide during hydrogen production.[78] Additionally, Carbon Capture and Storage (CCS) used in large-scale blue hydrogen production is a nascent technology with significant infrastructure obstacles and environmental impacts.

Blue Hydrogen Fuel Cells. Blue hydrogen fuel cells do not require a reforming plant. They use natural gas obtained directly from any community gas utility pipeline fed directly to each fuel cell. The fuel cell conducts the reforming process internally within each sealed cell, and each cell generates electricity. The fuel cells are arranged in arrays, and the size of the array determines the maximum amount of power available from the array.

Each fuel cell array is essentially noise-free and only produces relatively small amounts of CO_2 and water. The amount of carbon dioxide released is significantly less than that of diesel generators or natural gas turbines. For this reason, an array of blue hydrogen fuel cells offers an excellent source of noise-free, emission-free (except for low amounts of CO_2), baseload power.

Small Modular Reactors (SMR). A micro nuclear reactor is a small nuclear reactor capable of producing up to 20 Mw of electricity independently. An SMR is similar but is capable of producing 20-300 Mw of electricity.[79] There are more than 50 designs for SMRs. These reactors can be cooled by light water, the existing technology, or by gas, liquid metal or molten salt.[80]

Advantages: Carbon-net-zero; 93 percent capacity factor (see below); essentially noiseless; no pollutants; relatively small footprint

Disadvantages: Unlike the few traditional, light-water SMRs being developed, the majority of new SMRs produce a more enriched form of nuclear waste not yet fully evaluated for its storage risk.[81] While all current nuclear reactors in the country use 5 percent enriched uranium, the new SMRs propose using High Assay Low-Enriched Uranium (HALEU) which enriches the uranium 5-19.75 percent, a largely untested and unproven level of enrichment. However, a reactor expert at Idaho National Labs told this author the nature of the new waste is not a major issue. He did note there is no national repository for nuclear waste, meaning the waste produced by these new SMRs would be stored locally. Community resistance would be extreme; there is an

[78] Schlissel, David and Juhn, Anika. "Blue Hydrogen: Not Clean, Not Low Carbon, Not a Solution." Institute for Energy Economics and Financial Analysis. September, 2023. https://www.energy.gov/sites/default/files/2024-02/090.%20David%20Schlissel%20and%20Anika%20Juhn%2C%20IEEFA%2C%20Blue%20Hydrogen%20Not%20Clean%20Not%20Low%20Carbon.pdf

[79] Idaho National Laboratory. https://inl.gov/trending-topics/microreactors/

[80] DoE, Dept. of Nuclear Energy. https://www.energy.gov/ne/advanced-small-modular-reactors-smrs

[81] Krall, Lindsay, McFarlane, Allison, Ewing, Rodney. "Nuclear Waste from Small Modular Reactors." PNAS. May 31, 2022. https://www.pnas.org/doi/full/10.1073/pnas.2111833119?trk=public_post_comment-text

extended licensing process; SMRs are at least two years from construction; they are extremely expensive.

Nuclear Fusion. On December 17, 2024, Commonwealth Fusion System, associated with the Massachusetts Institute of Technology, announced plans to build the world's first nuclear fusion power plant in Chesterfield County, VA. The plant is planned to produce 400 Mw of power by the early 2030's.

Nuclear fusion has been largely theoretical for decades. It combines atomic nuclei from isotopes of hydrogen derived from sea water or lithium to release enormous amounts of energy. This is the process our sun uses. The energy released is completely clean, and the process produces no nuclear waste. The singular disadvantage of fusion is that it requires enormous heat to combine the isotope atomic nuclei. In 2022, after 70 years of experimentation, scientists were able to create a fusion reaction for the first time that produced more energy than it needed to create the reaction.

Given the developmental timeframe, I believe the data center sector will be well along the way to meeting its energy needs long before nuclear fusion becomes a practical reality.

Capacity Factor: Choosing A Microgrid Energy Source

A key metric used to determine what type of microgrid is appropriate for any given application is the capacity factor of the power source used in the microgrid. The U.S. Energy Information Administration (EIA) defines the capacity factor of an energy source as:

> **Capacity factor:** The ratio of the actual electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full power operation during the same period. [82]

An example illustrates this ratio. Suppose we have an energy source that can generate a maximum of 100 Mw of electricity at its peak operating power. If that energy source operates at peak power for one hour, it is generating 100 megawatt hours (100 MWh) of electricity. There are 8,760 hours in a year. We determine that energy source's historic capacity factor by dividing how many hours in a year that energy source actually operated at full capacity by the total hours in the year. If that 100 Mw energy source actually only delivered an average of 50 Mw per hour for 8,760 hours in a year, it has a capacity factor of 50%: (50 Mw x 8,760 hours) / (100 Mw x 8760 hours) = .50 or a 50% capacity factor. Similarly, if that same energy source delivered its maximum power for only 4,380 hours in a year, that too would be a capacity factor of 50%.

U.S. EIA keeps track of the average capacity factors associated with each of the various types of energy sources now available for use in microgrids. The higher the capacity factor, the greater the amount of time that energy source can deliver its maximum possible power. Below is a chart depicting the annual capacity factors for various energy sources in 2024:[83]

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[82] U.S. Energy Information Agency. "Glossary." U.S. EIA. https://www.eia.gov/tools/glossary/index.php?id=Capacity_factor#:~:text=Capacity%20factor%3A%20The%20ratio%20of,operation%20during%20the%20same%20period.

[83] U.S. Energy Information Administration. "Table 6.07.B. Capacity Factors for Utility Scale Generators Primarily Using Non-Fossil Fuels" Electric Power Monthly. https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_b *An email

2024	Geothermal	Hydroelectric	Nuclear	Biomass	Gas	Solar	Wind
Capacity Factor	65%	34.5%	92.3%	59.0%	59.7%*	23.4%	34.3%

As shown, nuclear power is, by far, the most efficient power source presently available for use in microgrids. It's capable of delivering its maximum power 92.3 percent of the time throughout any given year. It is not weather dependent and not subject to significant external constraints. Also, it is carbon-net-zero, produces no noise and has no emissions.

Solar, on the other hand, only delivers its maximum rated power about 23.4% of the time due to night, weather, length of day, and many other external factors. Thus, a utility-scale solar farm rated at 100 MW will only be able to deliver 100 Mw about 24 percent of the time throughout the year. Here's another way to look at capacity factor in this example: A 100 Mw solar field (nameplate) will actually deliver only an average of about 24 Mw every hour over one year.

Natural gas microgrids using SCR probably have a fairly high capacity factor, well over the 59.7% shown in the chart, because the chart capacity factor applies to natural gas plants. The functional capacity factor for onsite natural gas turbines is actually higher because that power is dispatchable at the site. When turned on, the gas turbines immediately deliver maximum power. This is why data centers are turning to gas turbines as a grid alternative. It's currently the only onsite energy source capable of delivering dispatchable power at baseload levels. Unfortunately, as mentioned earlier, it also has very serious noise and emission issues that must be addressed.

Geothermal microgrid applications have heretofore been largely geographically dependent, but recent advancements are making them a more viable option.

Possible New Paradigms for Loudoun County

Based on the foregoing analysis, what then might a new data center paradigm for Loudoun County look like? At present, diesel generators, BESS, and possibly hydrogen fuel cells are only best suited for backup power. Given the large number of diesel backup generators being used in the county, we should, in the near term, incentivize or require a sector-wide transition to Tier IV diesel generators or Tier II generators with SCR units and Diesel Particulate Filters attached. This is one of the recommendations of the JLARC study.[84]

Natural gas turbines incorporating SCR and significant noise mitigation could operate as either backup or baseload power and represent a very viable microgrid option for data centers facing power grid constraints. But the industry must find a way to filter out at least 90% of PM2.5 from the emissions. Loudoun County should immediately develop performance standards and zoning requirements for all of the above microgrid component systems.

Nationally, SMRs are the only viable long-term option for carbon-net-zero, baseload, onsite power generation, but they are simply not viable for county property in Loudoun County until the nuclear waste storage issue is addressed and resolved.

exchange with EIA suggested the appropriate gas capacity factor is in Table 6.07.A. Also, the gas capacity factor applies to natural gas plants, not onsite natural gas turbines.

[84] Op. Cit., pg. 60

That said, a very real possibility would be a scenario whereby the federal government begins to place SMRs on federal property without seeking local governing input. Dulles Airport is federal property, and it is situated immediately adjacent to "Data Center Alley." An installation of 20-30 SMRs generating 1 Gw of carbon-net-zero, noise-free, emission-free energy 95% of the time could be a gamechanger for the county. Obviously, such a development would initially face significant community resistance, but over time, a stable, carbon-net-zero, noiseless, emission-free energy source operating adjacent to Loudoun County might reduce community resistance. Given that the only alternatives to SMRs will be more power lines, gas turbines or a continuously constrained power grid, the greater Loudoun County community—and indeed, the Commonwealth of Virginia—have some very challenging discussions ahead.

A New Paradigm for All Counties: Creating a "Best Practices" Template

There are simply too many unknowns to predict which of these scenarios—or others not yet even being considered—will gain traction in the years ahead. But given the practical near-term constraints on microgrid development here in Loudoun County, I believe our best immediate strategy going forward is to establish a set of data center "best practices" both to guide the Board of Supervisors as it considers new data center applications and also to either incentivize or mandate adherence to these best practices within our existing data center sector. This is a tall order, but by establishing such a tool and codifying it in our zoning ordinance, the Board will have at its disposal a template to guide all future decision-making related to data centers.

An added benefit of creating such a list is that it can serve as a universal decision-making template for all counties in the nation based on the lessons learned here in Loudoun County over the past 26 years. We are the most mature and consolidated data center market in the world, and a great many counties throughout the nation are going to have to make many of the same decisions we've had to make for almost three decades. There is only one way to effectively respond to the current national debate about data centers, and that's with facts. Our list of "best practices" will empower local elected officials by providing them with the tools they need to make smart choices and good decisions about data center development in their communities.

Towards this end, my staff and I have developed a set of "15 Best Practices for Communities Considering Data Centers." This one-page primer, found at Atch. 2, establishes six critical factors that must be addressed before data centers are approved in any community. The 15 best practices then offer specific actions associated with each of the six factors.

The six factors listed below are listed in descending order of priority for Loudoun County. Each county will likely have different priorities based on local circumstances. For example, right now noise is the top priority in Loudoun County, and power is second. But for Mesa, AZ, with its high concentration of data centers, water would probably be the top priority. Here are the six factors:

- **Noise**
- **Power**
- **Water**
- **Emissions**
- **Setback**
- **Appearance**

Effectively addressing each of these factors prior to approving a data center application will provide a decision-making road map for communities not familiar with the complex, rapidly evolving data center environment.

Opportunities and Challenges

Over the course of the past year, the data center sector has become the new "wild west," with enormous amounts of revenue and extraordinary enticements being offered to local elected officials to just say "yes" to new data centers. The advantages to communities of properly planned data centers can be both significant and lasting. Yet, as we are seeing in so many cases across the nation, poorly planned data centers can be an enduring disaster for communities, permanently harming their quality of life.

The 15 best practices provided in Atch. 2 offer a set of criteria enabling local elected officials to precisely assess whether these enticements make sense for their community. In fact, the list can be used to quickly discern which offers are from speculative developers looking for quick wins and paths of least community resistance, and which are from serious companies seeking to establish deep and lasting roots in the community.

The list of challenges is no doubt long and complex. But the stakes of the game have never been higher for Loudoun County and for counties everywhere. Our task is not to fight the changing environment. Our task as Loudoun County's elected governing body—indeed, the task of local elected officials across the nation—is to learn how our environment is changing and adapt to the changes in a way that preserves our communities and protects the people we work for. I believe we're up to the task.

Attachment 2.

Assessment of the 2024 JLARC Data Center Study[85]

The 2024 JLARC study concurs with the basic premise of this white paper, namely that it will be either "very difficult" or "difficult" to build sufficient infrastructure to meet the projected energy demands of the data center industry. Unfortunately, the study's underlying premise and all its recommendations and policy options represent a tacit acceptance of scenario #1 above as the only possible way to reduce the energy demands of the data center sector.

Of the study's eight recommendations, six deal with data center siting or locally imposed performance standards to improve energy efficiencies. Yet the study plainly states improved performance measures would have a limited impact on decreasing data center sector energy demand:

> "Improving data center efficiency makes better use of energy but is likely to have only a marginal impact on demand."[86]

One recommendation suggests allowing utilities to delay but not deny data center construction to protect the grid. This is already occurring; the change would simply legally codify the practice. It also doesn't reduce increasing energy demand.

Finally, the one remaining recommendation addresses stranded costs (see below).

Of the study's ten policy options, eight suggest the General Assembly should use the state sales tax exemption as an incentive to encourage data centers to use less energy. The study acknowledges such actions could have significant, unintended consequences on the data center sector. In fact, this option would have a devastating impact on Loudoun County's economy:

> "If the General Assembly wishes to slow down the data center industry's growth in Virginia…it could allow the sales tax exemption to expire…. While it is difficult to gauge the exact effect this would have, it is likely industry growth would slow and could eventually stop or even contract.[87]

In short, the entire study essentially recommends two broad approaches: 1) local governments should use performance standards to improve energy efficiency, measures it acknowledges will have only a limited impact on reducing sector energy consumption, or 2) state government should use the state sales tax exemption to incentivize greater energy efficiency, precisely the type of artificial government intervention described in scenario #1, to reduce sector energy demand. Very brief mention is made of either technological breakthroughs (scenario #2) or onsite/communal power generation through microgrids (scenario #3) as ways to significantly reduce demands on the regional power grid.

Stranded Costs

As mentioned above, scenarios #2 and #3 could easily result in what the utility industry refers to as "stranded costs." Stranded costs occur when a regulated utility, required by law to meet the energy demand of its customers, is forced to build new infrastructure to meet predicted, future demand for

[85] Joint Legislative Audit Review Commission. "Data Centers in Virginia, 2024: Report to the Governor and General Assembly of Virginia." https://jlarc.virginia.gov/pdfs/reports/Rpt598-2.pdf

[86] Ibid, pg. 40

[87] Ibid, pg. 88-89.

energy, and, at some time during the infrastructure buildout process, that predicted demand is not realized. The regulated utility has incurred the costs of the buildout, but the consumer demand no longer justifies those costs. The utility must then absorb the costs or pass them on to residential and small commercial customers.

Normally, this is not a major challenge as historically, energy demand has been both relatively stable and predictable over time. For example, PJM charts illustrate that energy consumption between 2007-2017 in the Dominion service area decreased slightly, presumably due to realized efficiencies.[6] In such a stable market, predicting future energy demand, while a complex process, is relatively straightforward.

Since 2022, however, energy demand in Northern Virginia and particularly in Loudoun County, has increased rapidly and exponentially making it extremely difficult to accurately predict future power demand. Despite the turbulence in the marketplace, because Virginia is a regulated state, the investor-owned utilities must plan to build that infrastructure even though the predicted demand may never be realized.

Such is the case with scenarios #2 and #3. If PJM and Dominion Energy build billions of dollars of new generation and transmission infrastructure to meet what at present appears to be enormous future demand, and data centers subsequently find a way to process data using far less energy or move heavily towards microgrids and onsite power generation, the costs to the utility companies of that new infrastructure become "stranded" because demand for grid energy has dropped. The Virginia State Corporation Commission specifically addressed the issue of stranded costs at its December 16, 2024 technical conference.[88]

One way to insulate utility companies from stranded costs is to allow the utilities to charge major energy consumers an upfront tariff to absorb the cost of the infrastructure development should demand suddenly drop. This tool was used in May, 2024, when AEP Ohio filed a plan with the Public Utilities Commission of Ohio (PUCO) to require data centers to commit to a 10-year plan to make monthly payments equal to 90% of the cost of the energy they said they needed even if they ultimately didn't use that much energy.[89] In July, 2025, over strong objection from the data centers, PUCO approved a modified version of AEP's request and imposed a data center tariff requiring data centers to pay for 85% of the power they contracted for whether or not they use that much power. The tariff would be in effect for twelve years.[90] The Virginia State Corporation Commission is considering just such a tariff structure.

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[88] Pamploni, Hanna. "State Leaders Grapple with Infrastructure, Generation Costs." Loudoun Times Mirror. December 31, 2024. https://www.loudounnow.com/news/state-leaders-grapple-with-infrastructure-generation-costs/article_ebb47fac-c7b1-11ef-808d-df584e150bf9.html?utm_source=loudounnow.com&utm_campaign=%2Fnewsletter%2Foptimize%2Fdaily-headlines%2F%3F-dc%3D1735676910&utm_medium=email&utm_content=read%20more

[89] AEP Ohio. "AEP Ohio Files Plan to Secure Grid Resources for Data Centers, Protect Residential Customers." AEP Ohio news release, May 13, 2024. https://www.aepohio.com/company/news/view?releaseID=9539

[90] Wolfe, Sean. "Ohio utility regulators approve AEP's contested data center tariff proposal." Power Engineering. Factor This. July 10, 2025. [link proprietary]

Attachment 2.

Six Critical Issues for Any Community Considering Data Centers (Descending Priority):

Noise, Power, Water, Emissions, Setback, Appearance

15 Best Practices for Communities Considering Data Centers:

- Make sure your Land Use Plan addresses data center performance standards such as the ones listed below and make sure your Zoning Ordinance aligns with the Land Use Plan. Make sure both are current.
- Never allow data centers to build "by right" without governing body specific approval.
- Never sign a Non-Disclosure Agreement.

Noise

1. Conduct a pre- and post-construction noise study (dBA and dBC). dBA is audible noise; dBC measures specific frequencies and can measure tonal/narrow band low-frequency humming.

2. Pass a noise ordinance/zoning ordinance that limits noise to a maximum of 50 dBA (audible sound) perceived noise at the sending property line and reduces any dBC Tonal/Narrow band noise to background noise levels. (Option: Limit post-construction to a % of pre-construction noise).

Power

3. Require utilities to specify, in writing, the maximum power requested by the data center, how the utility plans to deliver power (routing, overhead, substations, etc.)(500 Kv = 2.1 Gw; 230 Kv = 750 Mw), and require Board approval to exceed the maximum.
4. Build data centers near existing power lines but no closer than 2x the ROW.
5. Require substations to be onsite or adjacent and included in the application. Never allow "by right" utility substation development or allow them as an "accessory use" to a data center.
6. For energy storage, use long duration storage systems (10 hours of storage minimum), not lithium-ion batteries which are not long duration systems.

Water

7. Require the data center and water utility to specify in writing how much water the data center will use annually.
8. Determine whether the data center will use air cooling, open loop water cooling or closed loop water cooling.
9. Determine whether the data center will use potable water or reclaimed water.
10. Determine how the data center will purify its wastewater and whether the local water treatment facility can adequately process the wastewater.

Emissions

11. Require Tier IV backup generators or Tier II generators with Selective Catalytic Conversion (SCR) attached. If using natural gas turbines, require SCR using ammonia as the catalyst.

Setback

12. If near residential now or in the future, require a 500’ setback; 1,000’ is ideal.

Appearance

13. Require natural screening, berms, fenestration (windows) on principal facades.
14. Limit building height, Floor Area Ratio (FAR) to ensure compatibility with surrounding structures.
15. Encourage microgrid design within the data center campus for future use (Microgrid: large power consumer, baseload power source, backup power source, long-duration storage, grid connection).

Data Center Pros:

1. Very high tax revenue (depending upon your tax structure).
2. Strong support for community initiatives.
3. Very low impact on infrastructure (no kids in schools; no cars on roads).
4. Good construction jobs when building.

Data Center Cons:

1. Visually unappealing (60-100’ high; concrete walls). This can be somewhat mitigated by setback, berms, greenery, fenestration (faux windows).
2. Noise, both dBA (normal hearing range) and dBC (tonal, narrow band noise; low frequency hum).
3. High power consumption and growing (rule of thumb: 150 Mw per every 1 mill. Sq. ft.).
4. Water consumption.
5. Light pollution.
6. Power transmission lines.
7. Power substations.