Powering Pennsylvania's Data Centers: Nuclear Energy as the Cornerstone to an All of the Above Approach

Pennsylvania's energy landscape is rapidly evolving in response to economic growth, electrification trends, and the accelerating demand for data center infrastructure. Long-term signals consistently point toward a future defined by sustainable energy choices, regardless of the changing political landscape. Insights shaping this trajectory include:

- **Nuclear energy is poised to play an increasingly central role** in an all of the above energy approach due to its zero-emissions profile and ability to provide firm power.
- **Energy demand is rising across all scenarios,** fueled in part by AI-driven growth in high-capacity, energy-intensive data centers–where nuclear power could offer a viable, sustainable solution.
- **Strategic, long-term collaboration will be essential**, requiring engagement across the public and private sectors, academia, and local communities.
- **The path forward is complex**, but clear signals suggest that innovation and coordinated investment can position Pennsylvania as a leader in clean, resilient energy infrastructure.

Recently, Team Pennsylvania convened a diverse group of energy stakeholders to develop three hypothetical futures for our energy system in 2050. The exercise brought together executives representing Pennsylvania's prominent energy sectors, including natural gas and coal, environmental nonprofit leaders, public sector representatives, and academia to discuss the possibilities. Despite differing policy frameworks and strategic assumptions, all scenarios identified nuclear energy as a critical component of Pennsylvania's all of the above approach to its future energy mix.

Further, as the demand for supercomputing increases with widespread adoption of AI, we need an influx of data centers. Powering these data centers requires thoughtful consideration from policymakers and the public about the environment, affordability, and reliability.

Behind the Meter vs. In Front of the Meter

Behind the Meter (BTM) energy solutions are not connected to transmission or distribution systems. They involve generating or storing energy on-site, often through renewable sources like solar panels or backup systems such as natural gas generators and battery storage. BTM commercial and industrial solutions offer significant benefits, including reducing reliance on the grid and potentially lowering long-term costs. They often allow for faster time to market because users do not have to wait in transmission queues. BTM configurations also shield local ratepayers from electricity scarcity because the data center brings its own generation instead of consuming energy from the grid. However, they often face high upfront investments, ongoing maintenance, and regulatory challenges. Moreover, while BTM solutions can contribute to environmental goals, their environmental impact may vary based on the specific technologies used and the materials involved.

On the other hand, In Front of the Meter (FTM) energy solutions are directly supplied from the grid or centralized providers, for example, by purchasing energy from an energy generator that is supplied by a utility or a competitive supplier. FTM solutions are easier to scale and provide access to a broad range of energy sources, making them a convenient option for large operations like data centers. The grid connection provides reliability and backup generation. However, transmission queues often mean technology cannot be deployed immediately. Additionally, they create a dependency on grid infrastructure and can be subject to higher energy costs during periods of peak demand. Further, large energy consumers may increase overall power prices in FTM configurations. As the demand for data center services continues to grow in Pennsylvania, understanding these energy choices is crucial. The commonwealth's policymakers and the public must grasp the implications of these options for cost management, grid reliability, and sustainability, ensuring that the energy needs of data centers are met without compromising our broader energy system.

Energy Sources for Data Centers

Nuclear Energy: Clean, Firm Power Requiring Time and Investment to Scale

The first option to power data centers is with nuclear energy, which creates energy by splitting (or fission of) uranium atoms. This process releases energy, which is used to heat water, creating steam that drives a turbine to produce electricity. Nuclear energy has much lower land use per megawatt hour than other sources.

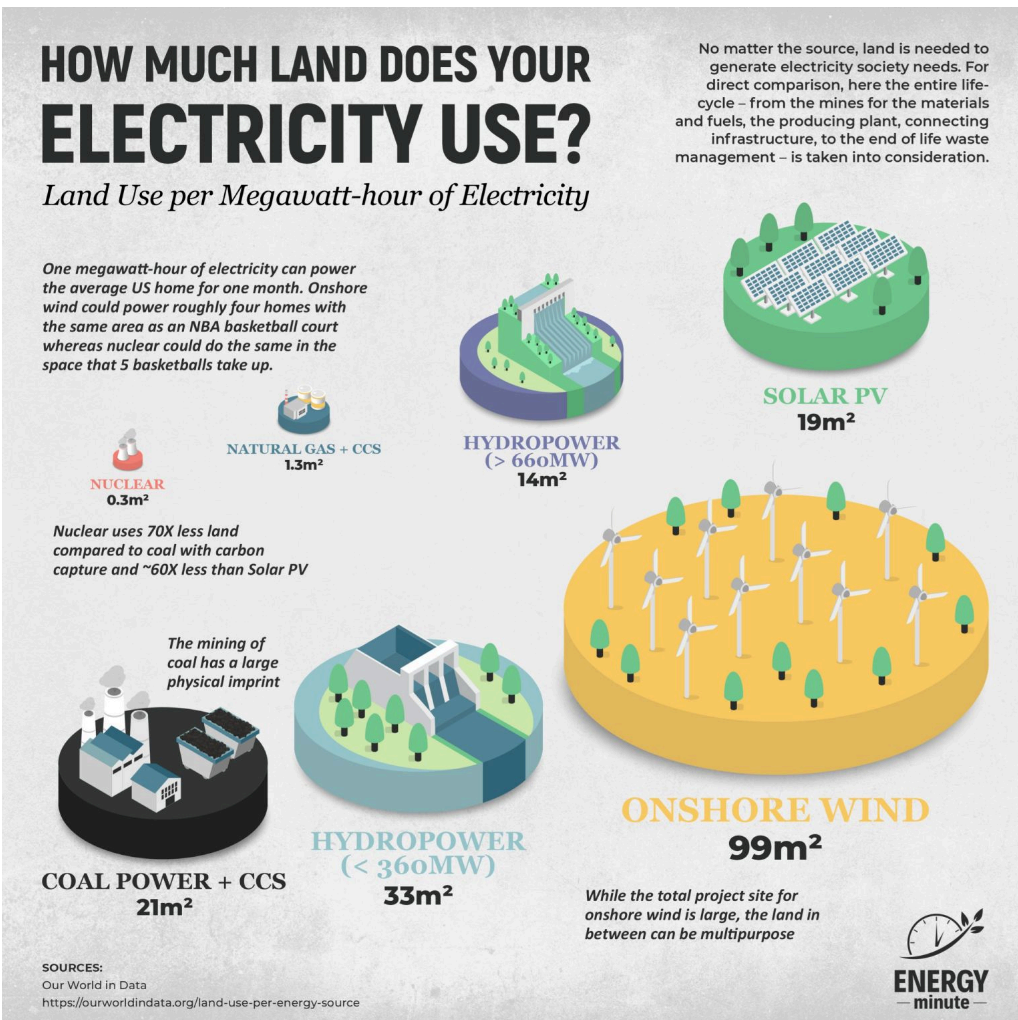

Figure 1

Nuclear energy's main advantage is that it provides clean, firm power that supplies electricity to homes and businesses, including data centers. Clean, firm power refers to power sources that are carbon-free and can be relied on regardless of weather conditions. Nuclear energy is expected to meet power needs for hyper-scalers such as Amazon, Google, and Microsoft. What's more, nuclear energy can be co-located with a data center and provide onsite BTM power, further reducing its land footprint, which is already the smallest of energy sources per MWh of energy produced. Pennsylvania signaled its interest for such use of nuclear energy, with Talen's approval for a 300 MW BTM solution at its Susquehanna nuclear station, and Constellation's FTM solution to restart of Three Mile Island to power data centers. Opportunity also exists for nuclear energy to power small- and medium-sized data centers through technologies like Westinghouse's eVinci™ Microreactor. The "modular" aspect of small, modular reactors lends itself to replicability and scalability, which is a more cost-effective way to approach project development compared to conventional nuclear energy.

Challenges exist due to the high capital cost of developing nuclear energy projects, which makes them difficult to justify economically. Over their lifetime, however, nuclear power plants often provide a good return on investment due to low operating costs, well-paying jobs, and broader downstream economic impacts. Yet advanced nuclear technologies may not be ready in time for the scaling of data centers, with the first small modular reactor (SMR) projected to come online in 2030. Finally, an additional consideration is waste management. Despite the safe management of spent nuclear fuel at nuclear power plants, there are ongoing concerns about establishing a permanent disposal solution.Overall, powering data centers with nuclear energy is a viable option for Pennsylvania in the long term because nuclear provides clean, firm energy, creates high-paying, long-term jobs, and offers other economic benefits for local communities. Currently, Pennsylvania remains the second largest producer of nuclear energy in the United States. Pennsylvania has a storied legacy as the birthplace of nuclear energy, an existing nuclear supply chain, and manufacturing capabilities to bolster acceleration of nuclear energy commercialization and deployment.

Natural Gas: Firm Power with Emissions and Rising Costs for New Construction

The second option to power data centers is natural gas. Pennsylvania has substantial natural gas supply and infrastructure, making it an ideal candidate to power data centers.

The primary advantage of natural gas is that, like nuclear energy, it provides firm power that is not affected by changes in the weather. Natural gas plants can also support peak demand, which is essential during periods of high electricity consumption. Additionally, costs and timelines have been well understood in Pennsylvania due to its longstanding history with natural gas dating back to 1881, though this phenomenon has been shifting due to supply chain issues for components like turbines in recent years leaving concerns about scalability.

Burning natural gas to produce power emits greenhouse gases such as CO_2 and methane, both of which contribute to climate change and air pollution. As Pennsylvania acts on its Climate Action Plan, adding natural gas plants to power data centers will make achieving an 80% reduction in greenhouse gas emissions by 2050 more difficult. Burning natural gas also produces air pollutants such as CO_2, nitrogen oxides, and methane due to pipeline leaks. Several technology options could close the loop on these emissions, like hydrogen or carbon capture utilization and storage (CCUS), but many of these technologies have not yet reached commercial viability. Given its prevalence in Pennsylvania, natural gas can serve as an interim energy solution until sustainable options become more prevalent.

Overall, while the use of natural gas to provide the electricity needs of data centers is convenient in the short term, longer-term environmental and human health impacts require consideration. Natural gas, when paired with other technologies, could provide a near-term solution for powering data centers if supply chain costs of timelines could be addressed for necessary component parts.

Renewables: Zero-Emissions Requiring Increased Land Footprint

The third approach to powering data centers is with 100% renewable generation including wind, solar, hydropower and geothermal.

The advantage of powering data centers with renewable energy sources is zero carbon emissions. Renewable energy is becoming more cost-competitive, with operational costs often lower than fossil fuels because as renewable energy increases in installed capacity, the costs decline commensurately. This phenomenon is also known as a learning curve. Overall, renewable energy generation is sustainable and has negligible climate, environmental, or public health impacts, and is becoming increasingly cost-competitive with fossil fuels.

However, some renewable energy sources like wind and solar are "variable" because they only generate electricity when specific conditions are met. Without proper storage mechanisms sited with renewables, meeting the energy needs of data centers will be difficult. Wind and solar energy are also location-dependent, meaning that the availability of renewable energy depends on areas where the wind is stronger, or sunlight is more available, meaning low scalability compared to other energy sources. Additionally, renewables, particularly wind and utility-scale solar photovoltaic, need large amounts of land to produce large amounts of electricity. Solar energy, for example, requires approximately 19 m^2 of land per MWh of energy produced (see Figure 1). Furthermore, a build-out of renewable energy would require a commensurate increase in transmission lines and other grid infrastructure due to connectivity required for FTM utility-scale renewables. Renewables such as wind and solar also have shorter lifetimes than other sources of energy, as wind turbines and solar panels typically require replacement every 20-25 years. Replacing renewable energy equipment with a higher frequency than other energy sources can contribute to a higher long-term cost.

Pennsylvania has existing renewable capacity and infrastructure, yet under a 100% renewable energy scenario for data centers, storage options must account for variability. Additionally, other important considerations include energy density, land use, and infrastructure expansion.

All of the Above: Hybrid or Mixed Energy Sources to Support Transition

The last scenario for powering data centers entails a mix of energy sources. A hybrid approach uses renewables, nuclear energy and natural gas to meet the power needs of data centers.

A mix of energy sources reduces reliance on a single source. Using a diverse mix and transitioning to lower-emission sources over time allows space for Pennsylvanians to use its natural resources while incorporating new technologies when they become available.

The disadvantages of a hybrid or mixed energy approach to powering data centers, particularly with BTM solutions, involve the complexity of managing a system with different types of energy sources. Integrating different energy generation sources into a single system requires different infrastructure, which creates high upfront capital costs. Sophisticated systems will be required to balance supply and demand, and as renewable energy fluctuates, nuclear energy or natural gas plants must be carefully operated to meet demand, which creates complex grid management and operation. Similarly, the operating costs of this system can be higher due to the complexity of the system and the need for backup systems like natural gas. Data centers must ensure that their energy supply is optimized for cost and efficiency.

On the environmental front, the continued use of natural gas in this scenario will contribute to greenhouse gas emissions and air pollution. While natural gas would function as a backup system to compensate for other energy sources to power data center operations, the expansion of natural gas will make it more difficult for Pennsylvania to meet its climate goals. The broader impact on Pennsylvania is the opportunity to create economic growth through data centers, increase sustainable and clean energy generation, while leveraging existing natural gas generation and infrastructure as Pennsylvania moves forward to reach its economic, energy, and environmental goals. This approach provides clean, firm power from nuclear, lower emissions from renewables, and flexibility from natural gas to meet fluctuating demand. It supports energy security efforts and helps Pennsylvania achieve its climate goals while reducing variability by using backup energy when renewable sources are unavailable

Commentary on Pennsylvania's Energy Mix for Data Centers

Pennsylvania's energy landscape is characterized by a diverse mix of energy sources. In 2023, natural gas was the primary energy source for electricity generation in the state. Nuclear power also played a significant role, with Pennsylvania as a leader in the nation for nuclear electricity generation. Coal contributed a smaller portion to the energy mix, and renewable sources accounted for a modest share of the generation.

Over the past decade, there has been a notable shift toward natural gas-fired electricity generation in Pennsylvania. In October 2024, natural gas-fired generation accounted for 57% of the state's electricity production, more than doubling its share since October 2013. This increase is attributed to the state's abundant natural gas resources and advancements in extraction technologies. Additionally, investments in efficient natural gas technologies have enhanced its role in power generation.

Looking ahead, integrating more renewable energy sources while maintaining grid reliability presents both challenges and opportunities. Leveraging Pennsylvania's natural gas resources can serve as a transitional bridge, providing a stable energy supply as renewable infrastructure expands. Investments in nuclear energy also offer a low-carbon, reliable power source to complement renewables. Developing an energy strategy that balances economic growth, environmental sustainability, and energy security is crucial for Pennsylvania's future, ensuring that the state's energy infrastructure can meet the demands of emerging industries while addressing climate change.

Public Policy and Regulatory Tradeoffs

Low | Medium | High

	Environmental Impact	Land Use	Operating Costs	Long-term Cost	Upfront Costs	Scalability
Nuclear	Low	Low	Low	Low	High	High
Natural Gas	High	Low	Medium	Medium	Medium	Medium
Renewables	Low	High	Low	Medium	Medium	Low
Hybrid/Mix (e.g., renewables, gas, nuclear)	Medium	Medium	Medium	Medium	High	Medium

Figure 2

Conclusion: All of the Above Approach with Nuclear Cornerstone

As Pennsylvania charts its energy future, policymakers and stakeholders must consider the environmental impact, affordability, and reliability of powering data centers. Understanding the value proposition of each energy source is key to shaping effective policy and making financing decisions. Using a variety of sources to power Pennsylvania's data centers will be critical to supporting Pennsylvania's energy future, but nuclear energy must be a cornerstone of this strategy. Employing existing nuclear energy assets while planning an expansion of nuclear energy generation in Pennsylvania will support the clean energy transition, promote grid reliability, and ensure energy security. Continued research, open dialogue, and collaboration are essential to ensuring the commonwealth remains at the forefront of energy innovation while meeting the growing demands of the digital economy.