PWG CASE STUDY ON NUCLEAR AND SMRS

The iMasons Climate Accord (ICA) is a coalition of Hyperscalers, data center developers/operators, and energy providers committed to reducing carbon emissions across digital infrastructure. Our mission is to achieve global carbon accounting for digital infrastructure to influence market-based decisions and drive the industry towards carbon neutrality.

The ICA Power Working Group aims to decarbonize data center power worldwide. We focus on enabling real-time transparency of the carbon content of power and creating market-based incentives to source zero-carbon power 24/7.

INTENT

The data center industry is seeking energy solutions to reach its goal of increasing power capacity to 1,000 TWh by 2026 while maintaining high standards of scale, efficiency, speed-to-market, and emission-free generation.

This case study first reviews the history of nuclear development and energy industry data before diving into a real-world scenario originally outlined in Last Energy's Data Center Case Study, *Rapidly Scaling Enterprise Data Center Demand and Accelerating Timeline* (Last Energy, n.d.). It has been adapted to include the expertise and thought leadership of the ICA Power Working Group in data centers, power, and independent research into small modular reactors (SMRs).

The following case study examines the power hurdles faced by developers and hyperscalers, by exploring the benefits and challenges of implementing nuclear power as a primary power source for data centers.

THE HISTORY OF NUCLEAR & THE CONVERGENCE WITH AI

WHY NUCLEAR, WHY NOW?

Nuclear development has begun to see a global resurgence, in both the private and public sectors, due to the reliable and clean power it can provide.

In the private sector, Amazon recently acquired a data center campus (Swinhoe, 2024) next to an existing gigawatt-scale, nuclear power plant in Pennsylvania on a 10-year Power Purchase Agreement (PPA), and Google and Microsoft executives have been quoted discussing their support for the technology. (Jennetta, 2024)

In the public sector, the ADVANCE Act was recently passed in the US, encouraging the acceleration of nuclear licensing. Great British Nuclear (GBN), the government-owned energy company, is driving the deployment of new advanced reactor technology in the UK.

However, the US and Europe already rely on nuclear energy for clean baseload power. Nearly 20% of America's electricity and 50% of its carbon-free electricity is generated by 94 nuclear reactors across 28 states. (NEI, 2023). In Europe, 22% of the European Union's (EU) power supply comes from 100 nuclear power plants, with over half of that generated in France. Non-EU countries have a 30% nuclear energy share from 67 nuclear reactors located in the UK, Belarus, Russia, Ukraine, and Switzerland. (World Nuclear Association, 2024)

The majority of these power plants were built between 1970 and 1990, as shown in *Figure 1*.

Major closures occurred after the Chernobyl disaster in 1986 and the Fukushima disaster in 2011, leading to significant shutdowns, most notably in Germany, where eight nuclear reactors were shut down permanently. (BASE, 2024)

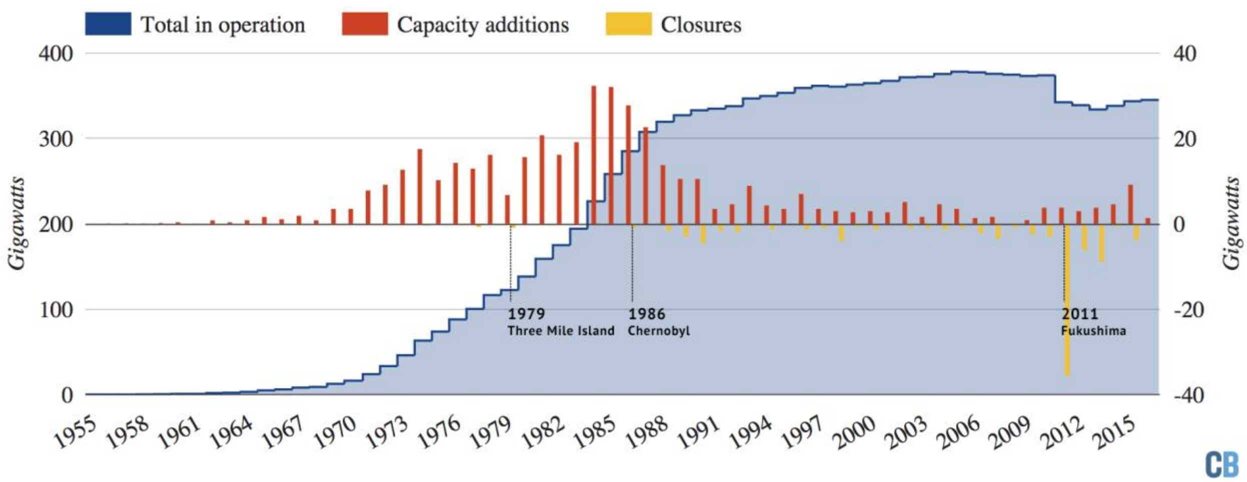

Figure 1: Global nuclear power generating capacity (Carbon Brief, 2016)

These closures were largely due to public sentiment rather than actual data, as the total death toll from Chernobyl is estimated to be less than 100, and the death toll from Fukushima is 0 (Ritchie 2017).

The long-term climate results of these hasty decisions are clear when comparing France to Germany and the total fossil fuel consumption of each country.

Country	Nuclear	Renewable	Fossil	Other
France	65%	25%	8%	2%
Germany	< 2%	42%	46%	10%

The prevailing obstacle to nuclear power plant development since 1975 has been time to deployment. In the US and UK, construction timelines jump from 5 years to 20+ years (See Figure 2). Excessive construction times on these government funded mega projects led to higher costs, which were passed down to the taxpayer. Meanwhile, countries like France and South Korea reduced costs, standardized deployment, and maintained 5-10 year construction times (Evans and Pearce, 2016).

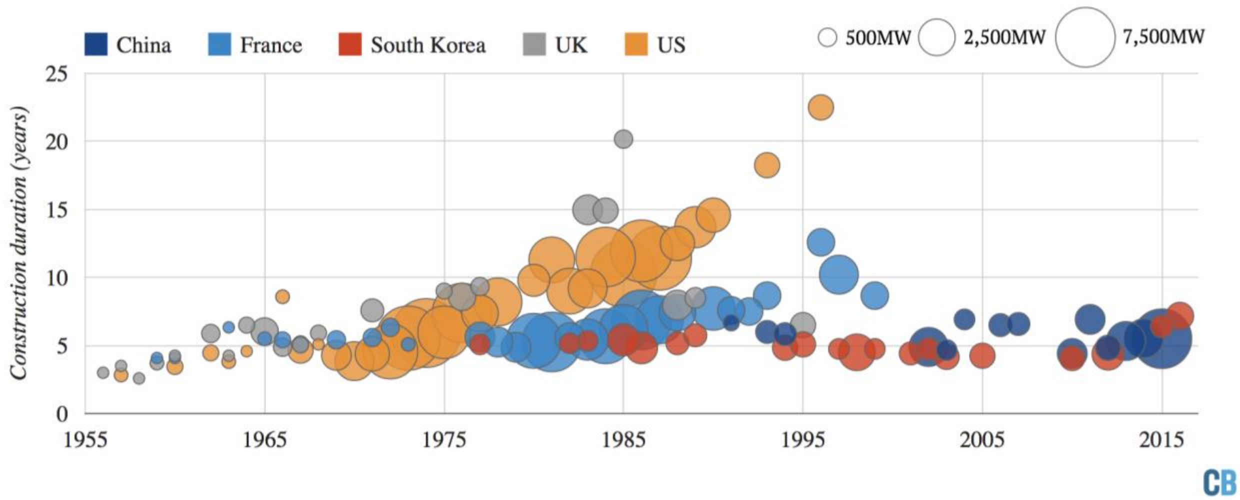

Figure 2: Annual capacity additions and construction times (Carbon Brief, 2016)

Today, companies are focused on reducing costs and construction timeline by reducing the size of the nuclear reactor or power plant. These next gen reactors are called small modular reactors, which range from 20 to 300 MW, or micro modular reactors (MMRs), ranging from 1-20 MW.

ENERGY USAGE IN DATA CENTERS

Power consumption by the world's data centers is on the rise. The fundamental causes of this expansion are:

- The continued growth of digitization
- The increased use of cloud computing
- The recent growth of data-intensive artificial intelligence (AI) services

Increased demand for data has led to data centers growing in both size and number, with their energy demand growing to match. In 2022, data centers used an estimated 460 TWh—about 1% of global consumption. In the UK alone, data centers are approaching 10 TWh a year, bringing the total consumption to 2.5% of national electricity (Çam et al., 2024).

Despite significant and consistent energy efficiency gains over the past decade by data centers, large and growing energy loads can strain regional energy supplies and data center operations. Protests against grid power consumption from anti-data center advocacy groups have led municipalities and power utilities around the world to consider and establish restrictions and moratoriums to limit power for new data center construction, which was the case in Amsterdam (2022), Northern Virginia (2023), Singapore (2019-2023) and Dublin (2022).

Adding energy-intensive data centers to already strained infrastructure is a challenge to the grid and to the data center. To manage bottlenecks, transmission operators carefully control the entry of new generators and consumers onto the grid. In many countries, including the United Kingdom, decade-long queues for new grid connections and the related transmission upgrades are increasingly common. Data centers must guarantee their own additional sources of power to ensure their operating reliability and assuage local and municipal concerns about unsupported growth in demand.

As demand for data grows in the coming years, it will take more than just efficiency improvements to address the carbon challenge – data center developers and operators face pressure to reduce their emissions from governments, investors, and their customers.-Data centers need access to reliable clean power.

Data centers and data transmission networks are responsible for about 330 megatonnes of CO_2 equivalent emissions every year, or 1% of total energy-related carbon emissions around the world.[3] So far, efficiency improvements have held this figure relatively stable, but to reach net-zero emissions globally by 2050, data center emissions must fall 50% by 2030, even as the market grows (Rozite, Bertoli, and Reidenbach, 2023).

BENEFITS & CHALLENGES OF NUCLEAR POWER & SMALL MODULAR REACTORS (SMRS)

To better understand the implications of nuclear power data centers, we must first recognize the benefits and limitations of nuclear power.

BENEFITS

Baseload Power

Nuclear power plants generate electricity at a constant, flat load without any reliance on external factors. This is advantageous for data centers that need to be operating 24/7.

Existing Technology

Nuclear power plants use existing, proven reactor technology that has been around since the 1970's. Almost 70% of the global reactor fleet (World Nuclear Association, n.d.) is made up of Pressurized Water Reactors (PWRs), ranging from 80 MW on submarines like the NS Savannah (San Francisco Maritime National Park Association, n.d.) to over 1,000 MW (Westinghouse, n.d.).

Once constructed, nuclear power plants are able to operate for 60+ years with minimal downtime. However, as mentioned at the start, GW scale plants have been subject to substantial construction and cost overruns.

Companies focused on using - existing reactor technology, available fuel, and fully modular construction techniques - have the potential to deploy a significant amount of baseload capacity before 2030 to meet Data Centers needs.

Scalability and Resilience

Small Modular Reactors can scale accordingly with data center energy usage and provide N+1 redundancy. Ranging in size from 15 MW to 500 MW, different SMRs are able to provide different values, from grid attributes to redundant onsite loads.

Smaller MMR and SMR power plants in the 15-50 MW range such as Oklo's Aurora, or Last Energy's PWR-20, allow for on-site redundant power. For example, if you have a 100 MW load, a developer could sign a PPA for 140 MW, and export 40 to the grid. That way, when one of the 5 power plants is offline for refueling, there is still n+1 redundancy. Additionally, these reactors can grow in parallel with a data center's electricity demand. If the same campus aims to grow from 100 MW to 1 GW over the course of 5 years, accelerated on-site construction allows for staggered deployments that will meet the data center' ramping timelines.

Larger SMRs, such as New Scale's VOYGR (300-900 MW Power Plant), or Rolls Royce's 460 MW reactor, can be used to replace retiring coal assets, and provide grid stabilization.

Footprint

Next generation SMRs have a lower footprint compared to other carbon free assets. This reduces the geographic constraints that some other generation assets face. Additionally, the reduced size allows for some technologies to function without a large body of water, further enabling near-universal siting.

Technology	SMR or MMR	Solar	Wind
Footprint*	1	30x	133x
Average Capacity Factor**	93%	20%	45%
* Stevens, L., et al. (2017) ** U.S. Department of Energy (2020)			

Low Carbon Life Cycle

The chart below demonstrates that wind, solar, and nuclear have the lowest total lifecycle carbon emissions of any electricity source. While all three reduce direct emissions, a total life cycle analysis shows that nuclear has the lowest Scope 3 emissions of any other electricity source.

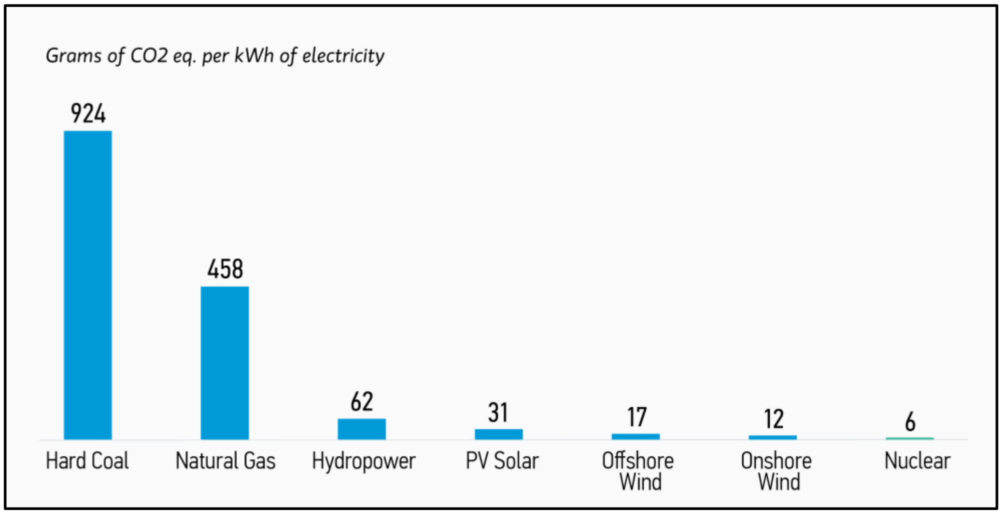

Figure 3: Nuclear Lifecycle GHG Emissions Lower Than Wind or Solar (Quattry, S., 2023)
Source: UN Economic Commission for Europe, 2021, “Life Cycle Assessment of Electricity Generation Options.”

CHALLENGES

Cost

Historically, nuclear power has been expensive. A large part of this is due to construction overruns and high CapEx requirements. 60-80% of the cost of a nuclear power plant comes from upfront construction costs. Significant schedule overruns, such as those seen during the construction of Vogtle 3 & 4, can lead to interest expenses increasing cost by another 50% or more. (Potter, 2022). Reduced construction times and streamlined designs from SMRs have the potential to significantly reduce general CapEx and delivered power costs.

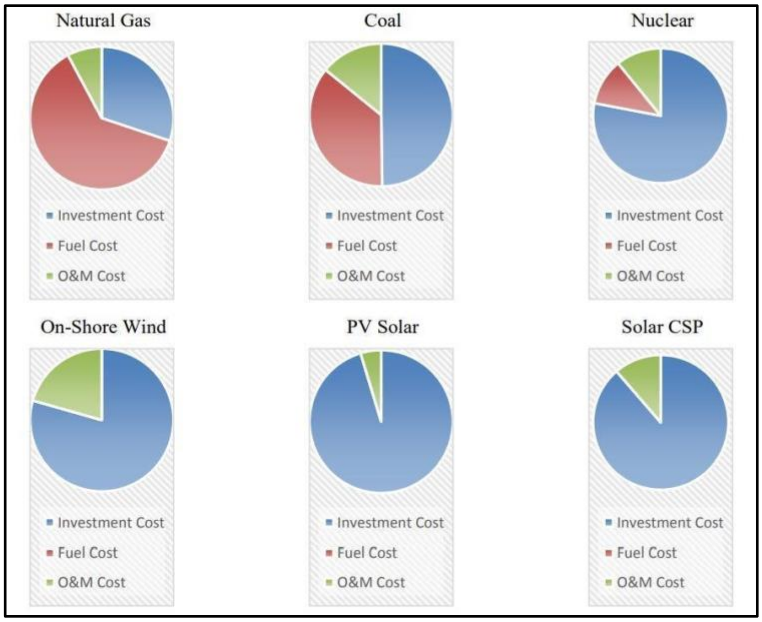

Figure 4: Percent contribution to LCOE of cost categories for coal, natural gas, nuclear, wind, PV solar, and solar CSP. Data from (Wittenstein and Rothwell 2015).

Nuclear Fuel

The process for obtaining nuclear fuel involves mining uranium, converting it to UF6 gas, enriching the UF6, and then fabricating fuel bundles.

Existing Process for Low Enriched Uranium (LEU)				
Step	1. Mining	2. Conversion	3. Enrichment	4. Fabrication
Description	Uranium ore is mined and processed into U3O8 ("Yellowcake")	Yellowcake is reacted with hydrogen fluoride to form UF4 which is then reacted with fluorine (F2) to create UF6 gas	UF6 gas is sent through hundreds of rapidly spinning centrifuges to separate U238 from U235	UF6 gas is turned into a solid powder (UO2), compressed and heated into pellets then inserted into zircaloy tubes to form fuel bundles
Supply Chain (Western)	- 55,000 Tons Annually - 13+ global companies	- Cameco (Canada) - ConverDyn (USA) - Orano (France)	- Orenco - Urano - Centrus	- Westinghouse - Framatome - Mitsubishi - Enusa - KNF - INB - DAE - NFI

There are two different notable fuel types: Low Enriched Uranium (LEU), and High-Assay Low Enriched Uranium (HALEU). Step 3 and Step 4 of the above processes have yet to be fully built out for HALEU.

LEU is used in every commercial reactor today. It is a uranium fuel with a U235 content of <5% and comes in an oxide form. This fuel source has been the industry standard for over 50 years.

HALEU is a uranium fuel with a U235 content of 5-19.99%. This fuel source can come in several forms: oxide, salt, metal. HALEU fuel can enable molten salt and lead reactors, with a higher efficiency and reduced burnup. However, HALEU fuel is not currently used in any commercial reactors.

Fuel supply will be a challenge for advanced reactors focusing on utilizing HALEU or TRISO-X fuel. However there is an opportunity for SMR companies taking advantage of the LEU fuel supply to deploy at scale in the near term.

Licensing

In the US, the licensing process for nuclear reactors is notably complex and lengthy. This intricate regulatory framework often leads to significant delays and increased costs. To advance nuclear adoption, it is crucial for the U.S. to streamline its regulatory processes, and enact legislation such as the recently approved ADVANCE Act of 2023.

European Union countries, such as France, Finland, and the United Kingdom, are leading the way in nuclear energy by adopting more flexible regulatory frameworks and engaging in robust public outreach. These nations have demonstrated that policy innovation and effective communication strategies can significantly accelerate the deployment of nuclear power. Their proactive stance serves as a valuable model for other countries aiming to enhance their nuclear energy capabilities.

The data center industry has the potential to influence and streamline the nuclear licensing process through its technological expertise and significant energy demands. For example, Microsoft's development of nuclear licensing AI software can revolutionize regulatory procedures by enhancing safety assessments and reducing approval times.

By collaborating with regulatory bodies, the data center industry can drive innovation in nuclear licensing, making the process more efficient and responsive to technological advancements, similar to successes in other power sectors/industries.

Public Perception

Public perception remains a significant barrier to the widespread adoption of nuclear energy.

However, over the past decade, public sentiment has drastically increased, maybe most notably in the US. A majority of Americans (57%) say they favor more nuclear power plants to generate electricity in the country, up from 43% who said this in 2020. (Leppert, R. and Kennedy, B. 2023)

Today, nuclear is one of the few topics in the US that has seen continued bi-partisan support, with majority support in both parties.

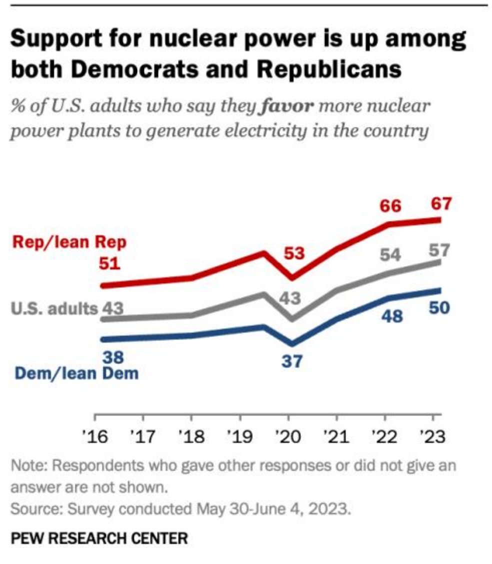

Figure 4: Support for nuclear power is up among both Democrats and Republicans. (PEW Research Center, 2023)

SCENARIO OVERVIEW

Last Energy, a member of the ICA and Power Working Group, is a developer, owner, and operator of 20MW micro modular nuclear power plants. They bring the energy-as-a-service model to the nuclear sector by streamlining the delivery of reliable baseload electricity and heat, taking end-to-end responsibility for all deployment activities from product design to operations and maintenance. This case study is applied in the following real-world scenario.

A UK-based project requires a developer to expand their existing data center facility from a peak demand of 80 MW (grid-tied) to 300 MW before 2030 to serve the planned growth of their hyperscale tenant.

In planning their expansion to 300 MW, the distribution grid operator told the developer that the earliest they could upgrade the existing 80 MVA grid supply connection would be 2033.

The Challenge

1. Insufficient grid access is delaying data center expansion.
2. Further grid congestion will only add to decade-long queues for connections.

3. Municipal and public opposition has led to data center restrictions.
4. The facility requires 24/7 up-time, as well as fully decarbonized power.
5. There are only 35 acres of industrial-zoned land available.

Power Considerations	
General Agreement	The Developer wants to sign a Power Purchase Agreement (PPA)
Power Availability	The Developer needs 99.999% reliability
Volume Required	The Developer wants to keep their 80 MVA connection
Contract Length	The Developer's Tenant has a 15-year lease
Cost Savings	The Developer's delivered, over the grid, electricity cost is £0.20/kWh ($0.26)
CO2 Reduced	The Developer is required to have net-zero electricity
Deployment Timeline	The Developer is bringing 60 MW if IT capacity online every 6 months
Grid Support	The Developer would like to contribute to grid reliability

After exploring a variety of potential solutions to bridge the gap, the developer decided that on-site nuclear power from an SMR would be the most cost-effective and environmentally friendly solution.

They will contract power, through PPAs, for (12) 20 MW power plants to meet their 240 MW demand and ramp their data center at 10MW/month, reaching full load by 2030 – they reached the following agreement.

Contract Outcome	
PPA Volume	12 PWR-20s or 240 MW (2,102,400 MWh) for N+1 Redundancy with Grid
Contract Length	15 Years to accommodate data center tenant
Delivered Price	£0.15/kWh($0.19) delivered (including all BTM transmission & distribution fees)
Cost Savings	25-35% cost savings on delivered power vs. grid power
CO2 Reduced	~4 million tonnes of CO_2 saved vs. grid over contract lifetime
Timeline	60 MW Ramp up every 6 months
Grid Support	Able to export unused power from SMR back to grid during peak hours

The decision allows for no upfront cost from the data center and a phased ramping schedule for synchronized growth between the nuclear power plants and the data center.

In the described scenario, the developer has decided to utilize 240 MW from a small/micro nuclear power plant. The development will require ~20 acres, approximately 50x less land than would be required for solar + storage, and approximately 100-200x less land than would be required for wind. This can reduce local stakeholder hesitancy towards the project, as they can maintain their agricultural land, and find additional tax benefits from the use of their industrial land.

Micro modular nuclear power plants can be sited flexibly to address the regional power shortages and limitations. Their standardized design enables delivery in 24-36 months, with construction timelines advertised between 6-24 months. Additionally, compared to traditional nuclear, operational timelines require less refueling downtime, ranging from 10-30 days every 18 months, all the way to 3 months every 6 years.

The power purchase agreement (PPA) model ensures predictable and long-term electricity pricing, reducing the data center operator's exposure to energy price fluctuations. This aligns the incentives between the data center developer and the micro nuclear power plant developer, as revenue is tied to energy production and its reliance on efficient and continuous power generation.

The data center developer benefits from a flexible financing structure and cost certainty, while maintaining their 80 MW grid connection which provides N+1 redundancy and accounts for any peaks or troughs in power consumption.

CONCLUSIONS

Nuclear energy is experiencing a resurgence in both private and public sectors, driven by its reliable and clean power production capabilities, and the impending global energy crisis.

Prominent Hyperscalers like Amazon, Google, and Microsoft have demonstrated interest by publicly endorsing nuclear PPAs, hiring nuclear development teams, and purchasing nuclear power. Similar to solar and wind, hyperscalers have the opportunity to accelerate the nuclear industry through PPAs.

Governments are also encouraging nuclear advancements through legislation like the ADVANCE Act in the US and the efforts of Great British Nuclear in the UK. Despite historical setbacks from events like Chernobyl and Fukushima, nuclear power continues to be a significant contributor to clean energy, providing nearly 20% of America's electricity and 22% of the European Union's power supply.

The nuclear industry has been historically plagued by high construction costs and lengthy deployment timelines, but SMRs and MMRs aim to address these issues by reducing the size and in turn construction times, making nuclear a more viable option for modern energy demands.

The data center industry, characterized by its growing energy consumption due to the expansion of digitization, cloud computing, and AI services, faces significant power challenges. Data centers consumed an estimated 460 TWh in 2022, about 1% of global energy consumption. As demand for data continues to grow, ensuring reliable and clean power becomes crucial. Nuclear power, particularly through SMRs, presents a compelling solution for data centers.

The benefits of nuclear power for data centers include providing baseload power, scalability, and resilience. Nuclear plants generate electricity at a constant rate, essential for the 24/7 operation of data centers. SMRs, ranging from 15 MW to 500 MW, can be scaled according to data center needs and provide redundancy, ensuring uninterrupted power supply. Additionally, nuclear power has a low carbon footprint, aligning with the industry's goals for emission-free energy solutions.

In conclusion, nuclear energy has the potential to provide reliable, scalable, and low-carbon power, making it a significant contender for meeting the energy demands of the growing data center industry. By leveraging advancements in SMR/MMR technology and streamlining regulatory processes, nuclear power can play a crucial role in supporting the expansion and sustainability of data centers worldwide.

REFERENCES

ADVANCE Act of 2023, S.1111, 118th Cong. (2023). https://www.congress.gov/bill/118th-congress/senate-bill/1111

BASE. (2024, January 31). The Nuclear Phase-out in Germany. *Federal Office for the Safety of Nuclear Waste Management.* https://www.base.bund.de/EN/ns/nuclear-phase-out/nuclear-phase-out_node.html

Çam, Eren, et al. (2024, January). Electricity 2024: Analysis and forecast to 2026. *Gas, Coal and Power Markets (GCP) Division of the International Energy Agency.* https://iea.blob.core.windows.net/assets/6b2fd954-2017-408e-bf08-952fdd62118a/Electricity2024-Analysisandforecastto2026.pdf

Evans, S., and Pearce, R. (2016, March 8). Mapped: The World's Nuclear Power Plants. *Carbon Brief.* https://www.carbonbrief.org/mapped-the-worlds-nuclear-power-plants

Jennetta, A. (2024, June 18). Google, Microsoft will not invest in new nuclear plants but support technology: officials. *S&P Global.* https://www.spglobal.com/commodityinsights/pt/market-insights/latest-news/electric-power/061824-google-microsoft-will-not-invest-in-new-nuclear-plants-but-support-technology-officials

Last Energy. (n.d.) PWR-20. https://www.lastenergy.com/technology

Last Energy. (n.d.) *Rapidly Scaling Enterprise Data Center Demand and Accelerating Timelines*. https://www.lastenergy.com/case-studies/rapidly-scaling-data-center-demand-and-accelerating-timing-for-coming-online

Leppert, Rebecca, and Brian Kennedy. (2023, August 18). Growing Share of Americans Favor More Nuclear Power. *Pew Research Center.* https://www.pewresearch.org/short-reads/2023/08/18/growing-share-of-americans-favor-more-nuclear-power/

National Grid ESO. (2022, March). *What Are Data Centres and How Will They Influence the Future Energy System?* https://www.nationalgrideso.com/document/246446/download

NEI. (2023). *U.S. Nuclear Plants.* https://www.nei.org/resources/fact-sheets/u-s-nuclear-plants#

NuScale. (n.d.). VOYGR™ Power Plants. https://www.nuscalepower.com/en/products/voygr-smr-plants

Oklo. (n.d.) Technology. https://oklo.com/technology/default.aspx

Potter, B. (2002, June 9). *Why Are Nuclear Power Construction Costs so High? Part I.* Construction Physics. https://www.construction-physics.com/p/why-are-nuclear-power-construction

Quattry, S. (2023, September 20). The Nuclear Revival: Embracing a Safe Source of Energy. *Morgan Stanley Investment Management.* https://www.morganstanley.com/im/en-us/individual-investor/insights/articles/nuclear-revival-esg.html

Ritchie, H. (2017, July 24) What Was the Death Toll From Chernobyl and Fukushima? *Our World in Data*. https://ourworldindata.org/what-was-the-death-toll-from-chernobyl-and-fukushima

Rolls Royce. (n.d.) SMR. https://www.rolls-royce-smr.com/

Rozite, V., Bertoli, E., and Reidenbach, B. (2023, July 11). Data Centres and Data Transmission Networks. *IEA*. https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks.

San Francisco Maritime National Park Association. (n.d.) Technical Information N.S. Savannah. *New York Shipbuilding Corporation.* https://maritime.org/tour/savannah/press/part2b.php

Stevens, L., Anderson, B., Cowan, C., Colton, K., Johnson, D. (2017, June). The Footprint of Energy: Land Use of U.S. Electricity Production. *Strata.* https://docs.wind-watch.org/US-footprints-Strata-2017.pdf

Swinhoe, D. (2024, March 4). AWS acquires Talen's nuclear data center campus in Pennsylvania. *Datacenter Dynamics.* https://www.datacenterdynamics.com/en/news/aws-acquires-talens-nuclear-data-center-campus-in-pennsylvania/

U.S. Department of Energy. (2020, May 1). *What is Generation Capacity?* https://www.energy.gov/ne/articles/what-generation-capacity

Wittenstein, M., and G. Rothwell. (2015). Projected Costs of Generating Electricity, 2015 Edition, Nuclear Energy Agency.

Westinghouse. (n.d.) AP1000® Reactor Design. https://westinghousenuclear.com/energy-systems/ap1000-pwr/overview/

World Nuclear Association. (n.d.) Are there different types of nuclear reactor? https://world-nuclear.org/nuclear-essentials/are-there-different-types-of-reactor

World Nuclear Association. (2024, February 1). *Nuclear Power in the European Union*. https://world-nuclear.org/information-library/country-profiles/others/european-union