Preliminary Analysis of Nuclear-Powered Data Center Scenarios

Nuclear Fuel Cycle and Supply Chain

Prepared for

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Systems Analysis & Integration Campaign

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SUMMARY

This report provides a comprehensive analysis of the potential for nuclear energy to meet the growing energy demands of data centers (DCs). It evaluates the technical, economic, and socio-environmental implications of coupling Nuclear Power Plants (NPPs) with DCs, providing initial responses to several key research questions:

What is the potential increased energy demand from DCs in the U.S., in the short, medium and long term? The U.S. is experiencing a rapid increase in energy demand from DCs, with projections indicating a total increase of 24-74 GWy(e) by 2028. Meeting this demand with nuclear energy would require 27–85 GWe of installed capacity. While this surge is expected to slow in the long term, the DC industry needs reliable, scalable, and clean energy sources.

How much nuclear capacity can be deployed to meet DC demand and in which timeframe? Several pathways for increasing nuclear capacity were identified, including uprates, restarts of recently retired reactors, power purchase agreements with existing fleet, and new construction. Approximately 20–28 GWe of nuclear capacity could be dedicated to DCs by the early 2030s.

How much High Assay Low Enriched Uranium (HALEU) would be needed to support some nuclear deployment scenarios for DCs? Meeting the deployment targets announced by Google and Amazon for the Kairos Power Fluoride-Salt-Cooled High-Temperature Reactor or KP-FHR (~500 MWe by 2035) and the Xe-100 (~1 GWe by 2040), respectively, requires ramping up 19.75% enriched HALEU production to ~6 t/yr by 2040.

What types of nuclear energy/DC coupling options exist, and what are the different benefits/challenges? Five coupling options were analyzed, ranging from grid-connected configurations to colocated, behind-the-meter setups. Key design considerations include the proximity to high- and/or medium-voltage transmission lines, the desired internal fault tolerance, and the sources of alternative/backup power during outages. Each coupling option offers unique benefits and challenges in terms of reliability, system costs, regulation, timeline, etc. A list of NPP/DC deployment scenarios was developed, considering existing or newly built NPP or DC projects. Colocated DCs with new small modular reactors or large reactors on greenfield and brownfield sites are the focus of this report.

What types of reactors, especially what size, may be incentivized by DCs? Reactor sizing optimization revealed that the ideal reactor size and number of units depend on DC demand, coupling configurations defined in this report, and other economic factors. Larger reactors are preferred for high-demand DCs and grid-connected systems, while larger number of smaller reactors are better suited for DC configurations without grid backup.

Which sites may be compatible with co-located nuclear-powered DCs? Siting those projects is a complicated evaluation factoring local water resources, grid connection availability and reliability, IT infrastructure, local work force, proximity to population zones, etc. For this effort greenfield and brownfield sites such as retired coal-fired plants were used to evaluate this question. This evaluation is not meant to recommend any particular site but it highlights key siting criteria and demonstrates large-scale site availability.

What are the socio-economic impacts of co-located nuclear-powered DCs? Those projects generate substantial economic benefits to the local economy, particularly in urban settings. Hyperscale DCs colocated with nuclear power plants (sized around 1 GW of power) can create nearly 1,700 jobs for annual operations and more than 7,300 jobs among the supply chain and local businesses as a result of increased household spending. Rural projects also provide significant benefits, but at lower magnitudes compared to urban deployments.

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ACRONYMS

ATS	Automatic transfer switch
AWS	Amazon Web Services
BOAK	Between-Of-A-Kind
BOP	Balance of plant
BPS	Bulk Power System
BTM	Behind the meter
CAPEX	Capital expenditures
CF	Capacity factor
CNSC	Canadian Nuclear Safety Commission
CONUS	Contiguous United States
COP	Coefficient of performance
CPP	Coal-fired power plant
DC	Data center
DOE	U.S. Department of Energy
EIA	Energy Information Administration
EPRI	Electric Power Research Institute
EPZ	Emergency planning zone
FOAK	First-Of-A-Kind
FHR	Fluoride salt-cooled high-temperature reactor
GIS	Geographic information system
HALEU	High Assay Low Enriched Uranium
HPC	High-performance computing
HTGR	High-temperature gas-cooled reactor
IEA	International Energy Agency
INL	Idaho National Laboratory
KP-FHR	Kairos Power Fluoride-salt-cooled High-temperature Reactor
LBNL	Lawrence Berkeley National Laboratory
LCOE	Levelized Cost of Electricity
LR	Large reactor
LWR	Light water reactor
MR	Microreactor
NE	Office of Nuclear Energy
NERC	North American Electric Reliability Corporation
NPP	Nuclear power plant
NRC	U.S. Nuclear Regulatory Commission
O&M	Operation and maintenance cost
OCC	Overnight capital cost
OR-SAGE	Oak Ridge – Siting Analysis for power Generation Expansion
PDU	Power distribution unit
PITR	Peak-IT load-to-Reactor ratio
PPA	Power Purchase Agreement
PUE	Power Usage Effectiveness
PWR	Pressurized water reactor
SaaS	Software-as-a-Service
SFR	Sodium-cooled fast reactor
SMR	Small modular reactor
T&D	Transmission and distribution
TVA	Tennessee Valley Authority

UPS	Uninterruptible power supply
VHTR	Very high-temperature reactor
WUE	Water Usage Effectiveness

SYSTEMS ANALYSIS & INTEGRATION

PRELIMINARY ANALYSIS OF NUCLEAR-POWERED DATA CENTER SCENARIOS

1. INTRODUCTION

Nuclear energy is being considered as an option for providing scalable and reliable power to meet emerging power demands. This report focuses on projecting emerging energy demands for data centers (DCs) and assessing what nuclear reactor capacity could be deployed to meet the demands. Depending on the power needs and requirements (size, reliability, proximity, etc.), different coupling configurations of nuclear reactors can be considered. This report discusses the benefits and challenges of these different options, and analyzes initial siting and socio-economic implications for a few scenarios of nuclear reactor/DC co-deployments.

1.1 Context

The U.S. is experiencing a steep growth in power demand after decades of stagnant growth. This trend is especially well documented by the North American Electric Reliability Corporation (NERC) [1]: "*Electricity peak demand and energy growth forecasts over the 10-year assessment period continue to climb; demand growth is now higher than at any point in the past two decades. Increasing amounts of large commercial and industrial loads are connecting rapidly to the [Bulk Power System]. The size and speed with which data centers (including crypto and AI) can be constructed and connect to the grid presents unique challenges for demand forecasting and planning for system behavior. Additionally, the continued adoption of electric vehicles and heat pumps is a substantial driver for demand around North America.*"

According to NERC, the aggregated peak winter and summer demand will increase by 15–18% over the next 10 years, representing up to 150 GW, putting significant pressure on the Bulk Power System (BPS) reliability. According to the Brattle Consulting Group's estimates [2], onshoring and industrial electrification are expected to grow by 36 GW by 2030, with DCs and crypto-mining together almost doubling their actual capacity by another ~30 GW. In the following, DCs and crypto-mining are usually considered together, since crypto-mining power demand comes from a particular use of DCs. The large and fast increase expected in power demand from the DC industry, together with many nuclear-DC announcements discussed next, motivate this group's focus on the DC industry. There is clear urgency in addressing this demand to avoid increase in customer electricity prices [3] and power shortages, which may result in slowing down of AI development and deployment.

1.2 Summary of Recent Nuclear-DC Announcements

Nuclear energy is generating about 20% of bulk power electricity in the U.S., with 94 Nuclear Power Plants (NPPs) currently operating. Its deployed capacity has been mostly stable for the past several decades, with a few retirements (discussed in Section 3.2) and a handful of new builds. There are wide expectations today for rapid new deployment of nuclear energy in the U.S., driven by increased energy demand and facilitated by recent actions from the U.S. administration. Table 1-1 provides a non-exhaustive list of announcements of partnerships or projects between DC companies and the nuclear industry that have taken place in the past few months. A live tracker for nuclear/DC project announcements was developed by Pillsbury [4] to keep track of the many other projects in various stages of development, with announcements almost daily. According to the International Energy Agency (IEA) [5]: "*To date, plans to build up to 25 GW of SMR capacity associated with supplying the data center sector have been announced worldwide, almost all of them in the United States, though projects are at varying stages of maturity and certainty.*"

As clearly shown by the list of announcements in Table 1-1, this trend represents an exciting opportunity for the U.S. nuclear industry, which has been preparing for a rebirth for several decades. The growth in electricity demand is finally reversing the price drops in electricity that had led to several NPP retirements in the U.S. and stalled any new deployment projects. Thanks to large capital access and financing potential, the hyperscalers (operators of large-scale data centers such as Meta, Alphabet, Microsoft, Nvidia, and Apple) bring credible new deployment projects, as evident from 1) long-term contracts (30 -year PPAs); 2) purchase of new reactor capacity; and 3) direct investment in vendors or the nuclear supply chain. These announcements are good news for the nuclear industry, which sees the opportunity to build an order book enabling it to finally reach sustained large-scale deployment.

Table 1-1. Non-exhaustive list of DC-nuclear project announcements (as of August 2025).

Date	Companies (DC/Nuclear)	Description	Ref.
Feb 2024	Green Energy Partners/Dominion	GEP plans to build a DC campus next to the Surry Nuclear Power Plant, which is operated by Dominion Energy.	[6]
March 2024	Amazon/Talen Energy	Susquehanna Steam Electric Station will supply 1.9 GW of nuclear power to Amazon Web Services' (AWS's) new DC with front-of-the-meter arrangement.	[7] [8]
Sept 2024	Microsoft/Constel-lation	20-year Power Purchase Agreement (PPA) with Microsoft to restart TMI-1.	[9]
Oct 2024	Amazon/X-energy	Amazon is backing a $500 million investment in small modular reactors (SMRs). X-energy will receive support for developing an initial 320-MW project.	[10]
Oct 2024 Aug 2025	Google/Kairos Power	Corporate agreement to bring first Kairos Power Fluoride-Salt-Cooled High-Temperature Reactor (KP-FHR) online by 2030 and 3 additional modules online by 2035. TVA signed a PPA with Kairos and Google for 50MW from its Hermes 2 reactor.	[11] [12]
Dec 2024	Meta	Meta released a request for proposal to identify nuclear energy developers to build 1–4 GW of new nuclear generation capacity in the U.S.	[13]
Feb 2025	EDF	EDF is offering land for up to 2 GW of DCs to connect to its grid.	[14]
May 2025	U.S./U.A.E. announcement	U.S. and U.A.E. administrations have announced deployment of 5GW datacenter campus in Abu Dhabi built by G42, which will be partly powered by nuclear.	[15]

June 2025	Meta/Constellation	Constellation and Meta signed a 20-year PPA for the output of the Clinton Clean Energy Center to support Meta's DCs with 1,121 MW. The agreement supports the relicensing and continued operations of the plant together with a 30-MW uprate.	[16]
June 2025	Google/Common-wealth Fusion Systems (CFS)	Google announced a partnership with CFS to buy 200 MW of clean fusion power from a grid-scale fusion power plant in the early 2030s.	[17]
June 2025	Fermi America	Fermi America submitted its NRC application for four AP1000 in Texas. Those would be built to power a large datacenter campus in Texas.	[18] [19]

DC powering is a cornerstone of the global race for development and leadership of AI technology. Other countries (France, Japan, India, etc.) also have plans for nuclear-powered DCs, leveraging ready-to-use clean capacity to attract DCs (and AI in particular) to their economies [14]. As such, the U.S. administration took several major steps toward accelerating DC deployment and powering through nuclear power. The Executive Order from May 23, 2025, "Deploying Advanced Nuclear Reactor Technologies for National Security," [20] is especially noteworthy as it [21] "*directs DOE to designate AI data centers as critical defense facilities and tasked the Secretary of Energy with utilizing all available legal authorities to site, approve, and authorize deployment of advanced reactors to power them. DOE will lay the groundwork for building and operating an advanced nuclear reactor supporting AI or other critical infrastructure no later than October 2027*". In addition to federal actions, there are many new or upcoming State initiatives that aim to encourage and enable deployments of data centers and nuclear power plants.

1.3 Why Does Nuclear-powered DC Make Sense?

Nuclear energy confers several important benefits that are especially attractive for powering DCs, namely, its reliability, dispatchability, long-term price stability, energy density, and availability or scalability [22] [23]:

- DCs require large amounts of electricity (potentially in the several 100s of MWe) with a high level of reliability. Those energy requirements are further detailed in Section 2. Nuclear energy is a prime candidate to meet DC requirements. Energy availability is a bottleneck for DC companies, which can delay DC deployment.
- Most major hyperscalers have low emission targets (net zero or even carbon-negative) with an aggressive timeline (typically by 2030) [24] [25] [26] [27] [28] [29]. Those targets are driving their choices for energy production technology toward nuclear and renewables.
- Some DCs have siting requirements (for placement close to end-users or at certain locations) which require grid connection or energy production nearby. Domestic siting of DCs is critical to fostering leadership in tech sectors while securing some data. Nuclear energy provides siting flexibility, as demonstrated in Section 7.
- Economic factors, in particular high capital cost associated with new nuclear construction, may be less a concern for hyperscaler companies. They are some of the largest corporations in the world and are able to manage a first mover's financial risks and to provide a strong signal with building of a significant order book, which eventually lowers the NPP capital cost.

- Potential use for waste heat from nuclear reactors for cooling services with absorption chillers, as highlighted in [30], may noticeably improve efficiency of the NPP/DC systems.
- Siting an NPP close to a DC may improve the socio-economic case of a DC project by bringing in additional jobs and revenues while limiting impact on local electricity prices.

There is a growing body of literature on powering DCs with nuclear energy. Especially noteworthy are a series of reports from the Electric Power Research Institute (EPRI) that project energy demand for DCs and grid implications [31], considering several capacity deployment scenarios [32]. In particular, EPRI recently published a guide to owner-operators for colocating a DC with nuclear power [33], which provides important background to this report. Several publications from the Idaho National Laboratory (INL) focus on techno-economic evaluations of nuclear/DC systems [34], and optimum sizing of NPPs to match DC power requirements [35]. Deloitte provides estimates of DC capacity that could be met by nuclear energy in the U.S. [23].

There are obviously challenges associated with the use of nuclear power, with several reports already discussing those challenges and how to overcome them [22] [33] [23]. The main potential concern DCs have with nuclear energy is with the timeline of new reactor deployment, since DC power demand is currently surging. There would need to be a transition toward nuclear because of the timeline associated with new nuclear construction. This transition would imply leveraging the current grid capacity, nuclear fleet, and technology for transition (natural gas generation) [36]. At this stage, several options are being considered for short-term access to nuclear power: 1) re-start of previously shutdown NPPs, 2) power uprates in current capacity, 3) power purchase agreement from the existing capacity, and 4) new construction, as discussed in Section 3 of this report. Other challenges include nuclear fuel supply chain development (with discussion in Section 4 of this report), and metering/transmission issues (with discussion in Section 5 of this report).

1.4 Research Questions and Report Organization

This report adds to the growing body of literature in this field. It targets policymakers (federal and state/local), DC developers who want to learn more about nuclear energy (complementing Ref. [33]), and the wider nuclear industry interested in different ways to connect NPPs to DCs. This report focuses on several research questions of interest, and responds to them through literature consolidation together with case study analyses. The following list documents the driving questions evaluated within the different sections of the report:

- What is the potential increased energy demand from DCs in the U.S., in the short, medium and long term? This topic is discussed in Section 2 on the basis of a review of the wider literature and extrapolation toward the end of the current century.
- How much nuclear capacity can be added to meet DC demand, and in what time frame? This topic is discussed in Section 3.
- How much High Assay Low Enriched Uranium (HALEU) would be needed to support some nuclear deployment scenarios for DCs? Section 4 provides preliminary assessment of HALEU requirements to support SMR deployments considered by Google and AWS.
- What types of nuclear energy/DC coupling options exist, and what are the benefits/challenges of each? This topic is discussed in Section 5. This report is not meant to provide DCs with an “optimal” solution, but to provide a range of options they can consider.

- What types of reactors, especially what size, may be incentivized by DCs? This topic is discussed in Section 6 by applying sizing optimization methodology developed at INL to assess the ability of reactor types to support various size of DCs and coupling options.
- Which site may be compatible with co-located nuclear-powered DCs? Several new-built colocated NPP/DC scenarios are analyzed in Section 7, considering greenfield and brownfield siting.
- What are the socio-economic impacts of co-located nuclear-powered DCs? Job and local economic impacts in rural and urban settings are analyzed in Section 8.

The main conclusions from this report are summarized and discussed in Section 9.

2. DATA CENTER ENERGY REQUIREMENTS AND PROJECTIONS

This section provides a technical overview of DC classifications relevant to energy system modeling and projections. The main outcome is a projection of energy demand from different types of DCs. Special attention will be given to hyperscale facilities and AI-oriented deployments because of their disproportionate influence on electricity demand and infrastructure planning, as shown in Section 2.2.

2.1 Description of Data Center Types and Their Energy Requirements

DCs vary significantly in size, operational function, reliability, and infrastructure design, all of which directly influence energy and water consumption. Key parameters include power density, Power Usage Effectiveness (PUE), Water Usage Effectiveness (WUE), and reliability requirements. These distinctions must be considered when evaluating current and future energy demands across the sector. The following sections provides summary descriptions of different types of DCs together with their energy requirements.

2.1.1 Key data center characteristics and performance metrics

DCs can be categorized based on ownership, workload, and operational role. In industry usage, categories include internal, colocation, cloud service, edge, AI training, AI inferencing, HPC, and crypto mining. For energy analysis, these map to broader functional groups:

- **Enterprise/Internal DCs**: privately owned facilities supporting an organization's in-house IT, legacy systems, and proprietary applications.
- **Colocation DCs ("Colo"):** third-party facilities leasing space, power, and cooling to customers who operate their own servers.
- **Cloud Service DCs**: provider-operated centers delivering Software-as-a-Service (SaaS), storage, and elastic compute platforms. Many are integrated into hyperscale campuses.
- **Hyperscale DCs**: extremely large facilities (often >100 MW) run by major cloud/tech firms (Amazon, Microsoft, Google, Meta, etc.) that host diverse workloads at global scale. Within hyperscale, two fast-growing subcategories are:
    - **AI Training DCs**: GPU-intensive clusters used to develop and train large AI models.
    - **AI Inferencing DCs**: facilities dedicated to deploying trained AI models for real-time applications (search, recommendations, chatbots).
- **Edge DCs**: small, distributed facilities deployed close to users or data sources for latency-sensitive applications such as autonomous vehicles, internet of things, and augmented reality.
- **High-Performance Computing (HPC) DCs**: specialized facilities supporting scientific simulations and R&D, typically with power densities of 20–30 kW/rack and advanced cooling requirements.
- **Crypto Mining DCs**: facilities dedicated to blockchain validation and cryptocurrency mining, often using ASIC-based hardware with very high energy demand but lower water use compared to AI/HPC.
- **Quantum computing**: large-scale quantum computing is still an active area of research and thus not further discussed in this report. It is expected that its energy requirements driven by cryogenic cooling requirement and qubit control will be significant while currently associated with large uncertainty [37].

Data centers (DCs) vary significantly in size, operational function, reliability, and infrastructure design, all of which directly influence energy and water consumption. Key performance metrics include power density, energy and water efficiency, hardware profile, and load characteristics. Each of these aspects contributes to the facility's total resource intensity and operational resilience. More discussion of some of these DC characteristics is provided in Section A-2.

- **Power Density:** Expressed in kilowatts per rack; typical values range from 4–6 kW/rack for edge and commercial sites to over 30 kW/rack for AI training centers. Higher power densities require more advanced cooling infrastructure, often including liquid cooling.

- **Power Usage Efficiency (PUE):** This metric reflects the efficiency of the DC infrastructure. Hyperscale and AI-focused facilities often achieve values between 1.1 and 1.2, while smaller or decentralized facilities commonly exceed 1.9.

- **Water Usage Effectiveness (WUE):** Facilities employing high-efficiency cooling systems typically exhibit increased water demand. For example, high-performance computing (HPC) and AI training facilities report water usage between 0.3 and 0.6 L/kWh, while crypto mining operations may fall below 0.2 L/kWh.

- **Hardware and Cooling:** Hardware type depends on the workload. GPU-based compute clusters for AI training generally require intensive cooling solutions, whereas CPU-based systems for commercial or colocation use often rely on conventional air cooling. Cooling strategies have direct implications for both energy and water consumption.

- **Load Profile:** Peak (rated) power capacity often differs substantially from the facility's annual average power use. Load factors vary by application—backup facilities or edge sites may operate well below peak capacity, whereas AI workloads often sustain high utilization rates. Training a large-scale language model such as ChatGPT required an estimated 10 TWh of electricity, equivalent to the annual output of a 1.2-GWe power plant. For illustration purposes, Figure 2-1 shows the fraction of server time operation for different types of servers, together with an example of daily load profile for an AI training server. Sizing NPP to meet DC requirements will depend on several factors (including peak and average DC demand, reliability requirements, grid connection, etc.), as discussed in Section 5 and 6.

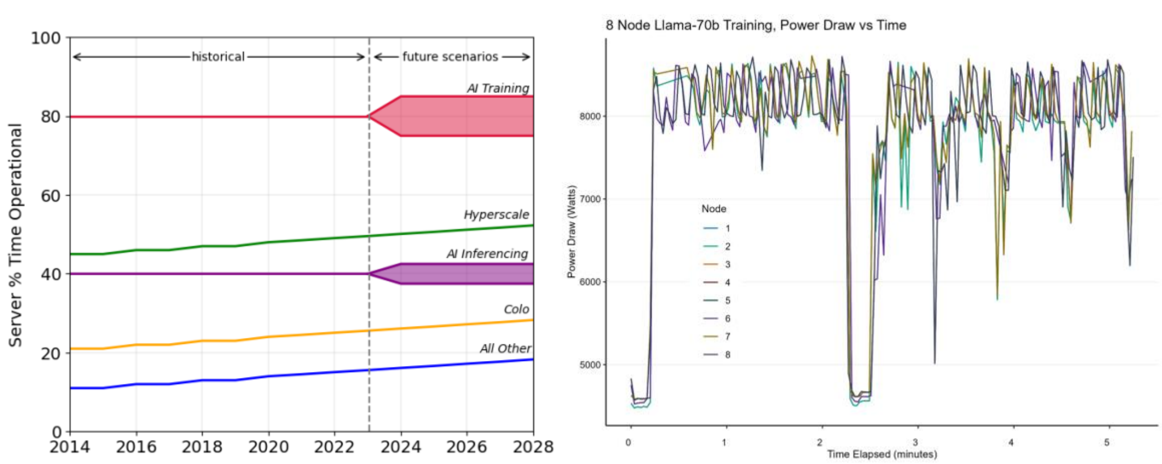


Figure 2-1. (left) Server utilization for different types of DCs (further described in Table 2-1); and (right) time series of node-level power demand during Llama-70B training across 8 nodes at Sustainable Metal Cloud; from [38].

- **Reliability Requirements:** DCs reliability requirements are based on type of mission they serve, and the types of penalty and financial losses sustained in case of service outages. Reliability is standardized through tier classifications defined by the Uptime Institute (more discussion is in Section 5.3). Each tier corresponds to specific infrastructure redundancy and expected uptime:
  - **Tier I**: Basic capacity with a single path for power and cooling. Suitable for non-critical applications.
  - **Tier II**: Includes redundant components for power and cooling. Supports moderate continuity needs.
  - **Tier III**: Supports concurrent maintenance; multiple distribution paths with one active. Common among enterprise facilities.
  - **Tier IV**: Fully fault-tolerant with multiple active paths. Required for mission-critical operations.

2.1.2 Technical summary of data center types

Table 2-1 provides a consolidated classification of major DC types, showing key technical parameters including power density, PUE, WUE, reliability tier, and expected power level. Different DC types employ varying computing architectures—such as CPU-centric setups for general-purpose workloads and GPU-intensive systems for AI/ML and HPC applications—which significantly influence both their power and cooling demands. For instance, AI training clusters often rely heavily on GPUs, leading to much higher power densities (>30 kW/rack) compared to traditional enterprise setups. These variations also drive different cooling strategies: While air cooling may suffice for lower-density environments, high-density deployments often require liquid cooling solutions, which are more water-intensive. In general, the more energy-efficient a cooling system is in terms of electricity, the more water it tends to consume, illustrating a tradeoff between PUE and WUE across DC types. The total power level is representative of today's projects, while larger gigawatt-scale campuses are also being considered.

Table 2-1. Energy and water requirements for different types of DCs.

DC types	Power density [kW/rack]	PUE [kWh/kWh]	WUE [L/kWh]	Expected demand increase to 2030	Reliability requirements [Tier]	Total power level [MW]
Telco Edge, Commercial Edge, SMB	4~6	>1.91	0.32	Low	I-II	5~10
Internal	6~10	1.68	0.67	Moderate	III	20~50
Communication service provider	6~10	1.68	0.67	Moderate	III	20~50
Colocation	6~10	1.68	0.67	High	IV	50~70
AI training (LLM, deep learning)	>30	1.1~1.14	0.3~0.6	Extremely High	IV	300~800
AI Queries/Inferencing (Edge AI)	10~20	1.18~1.22	0.4~0.8	High	IV	100~400
Cloud Service (SaaS, Storage)	6~14	1.20~1.25	0.5~1	High	IV	100~500
Crypto Mining	>20	1.05~1.1	<0.2	High	0*	200~600
HPC (Scientific Simulations, R&D)	20~30	1.12~1.18	0.3~0.7	High	II	200~600

** A "Tier 0" data center refers to a facility designed for resource-intensive operations (e.g., crypto mining) that typically delivers 75–98% uptime and does not meet the Uptime Institute's Tier I availability standard.*

2.2 Review of Data Center Energy Demand Projections

The Lawrence Berkeley National Laboratory (LBNL) report [38] released in late 2024 provides energy demand projections with a breakdown of different DC types, as shown in Figure 2-2. The DC electricity consumption in 2023 represented 4.4% of total U.S. electricity consumption. The actual energy demand from DCs amounted to 176 TWh in 2023, which represents 20 GWy(e). The largest growth is observed in the hyperscale and large-scale colocation types of DCs, with each expected to add 150–250 TWh of demand by 2028. This estimate originally excluded crypto-mining, owing to the use of a different server technology, lack of transparency from this industry, and great uncertainty in its deployment. However, energy demand estimates for crypto could still be derived from [38] (section 6) and included in Table 2-2.

Hyperscale and large-scale co-location data center energy demand is surging primarily due to the rapid growth and deployment of AI-accelerated servers and AI workloads [38]. According to a recent study from EPRI and EPOCH AI [39], energy demand to train large AI model has increased by 2.2x every year and projected AI power capacity in the U.S. could reach more than 50GW by 2030.The ranges of DC energy increases projected by LBNL [38] reach 325–580 TWh by 2028. Those are slightly more aggressive than the projection from EPRI [32], which expects the low/high to reach 250–510 TWh by 2030. The IEA estimates 290–840 TWh of added demand from DCs by 2030 [40], with about half in the U.S. (110–350 TWh).

The projected increased energy demand through 2028 from Ref. [38] is provided in Table 2-2; it represents a capacity increase from 24 to 74 GWy(e), with roughly half coming from hyperscale and half from large-scale colocation (and crypto remaining relatively small). In the "high" scenario, the electricity demand from DC accounts for 12% of total U.S. consumption in 2028.

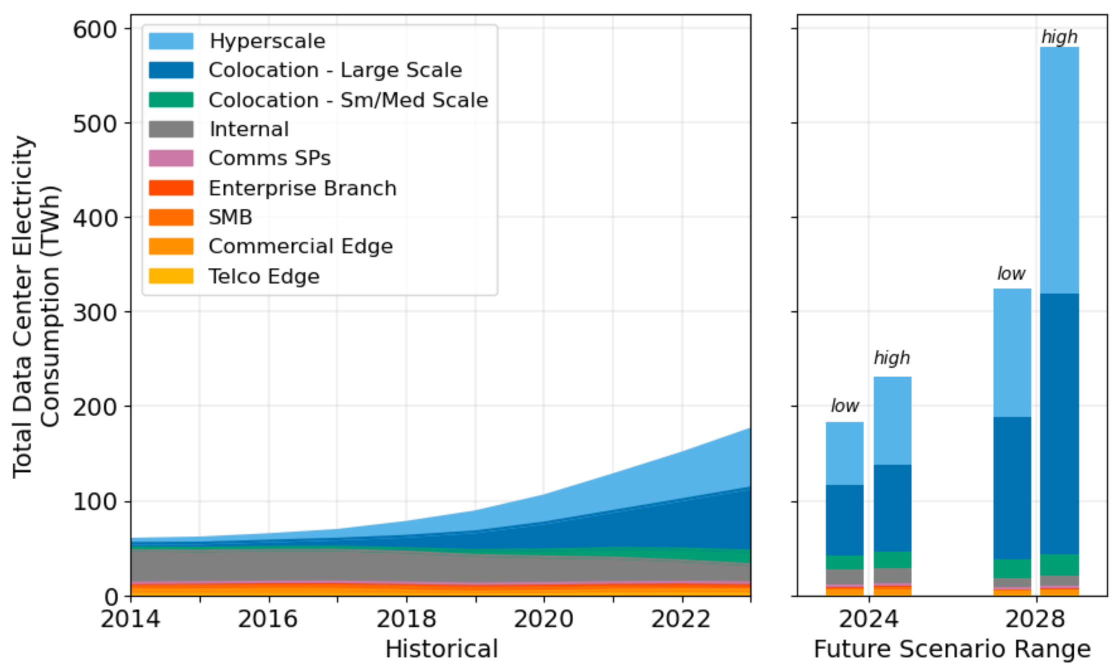


Figure 2-2. Total U.S. DC electricity demand by DC type, with historical data from 2014 through 2023 and projections through 2028 [38].

Table 2-2. DC electricity demand in the U.S. in 2023 and projected through 2028.

DC energy demand	TWh, based on [38]		Equivalent GWy(e)	Added from 2023 GWy(e)
	Hyperscale and large-scale colocation	Crypto		
Actual, 2023	176	~60	27	-
Projected, 2028 - low	325	~120	51	24
Projected, 2028 - high	580	~360	107	74

It is important to note that those estimates are based on DC annual average demand, not on rated power capacity. The idle consumption and workload can vary significantly: by 50% for hyperscale, and by 35% for colocation (based on [38]). To estimate the installed capacity that would be needed to meet this energy demand, this study assumes a Pmax/Pavg of 80% for the different DC types, which is in line with the assumptions used in [38] (page 49 and 60) and [32] (page 9). The required installed capacity is shown in Table 2-3: it ranges between 26 GWe and 79 GWe, assuming 100% capacity factor, (CF) or 27-85– GWe assuming a typical nuclear CF of 93%.

Table 2-3. Equivalent installed power capacity requirements projected through 2028 [GWe].

	Installed capacity required for each type of DC with major growth [GWe]			Total installed capacity [GWe]
	Hyperscale	Colocation (large-scale)	Crypto	CF=100% / 93%*
DC utilization	80%	80%	80%	
Projected, 2028 - low	11	11	4	26 / 27
Projected, 2028 - high	29	29	21	79 / 85

** The generation capacity values here assume a capacity factor (CF) of 100%; EPRI* [33] *estimates that for nuclear with a CF of 93%, we would need to increase this capacity by about 7.5%. For combined-cycle gas with a CF of 55%, we would need to increase this capacity by about 82%.*

This projection does show a “surge” in electricity demand from DCs in recent years, and accelerating toward the near future. Projections toward the longer term are increasingly difficult to obtain owing to uncertainty in future service demand, in DC energy efficiency (i.e., chips that consume less energy or better cooling technologies), and in process efficiency (i.e., more efficient algorithms). There are several possible scenarios to consider with stagnation or continued increase in DC demand. A drop in DC electricity demand beyond 2028 is possible but unlikely, given the historical increase in this industry (no reduction ever in DC consumption). It would be more likely that any improvement in efficiency would enable increased DC useage, leading to slowed growth in total power demand. The IEA provides long-term projections through 2035, showing slowed growth or stagnation in global energy demand from DCs [40].

Projections through the end of the century required for other SA&I energy market analyses were derived from the literature review completed in this section. Those are labeled as “SA&I – low/med/high” in Figure 2-3. After exploring a number of functional forms for regression analysis to match the near-term trends (2023–2028) from LBNL (using the min, max, and midpoint of their range for 2028 excluding crypto due to the high uncertainty associated with its energy consumption), we find that a power function provides a good combination of fit to data and continued but decelerating growth in the future.

Extrapolating the LBNL low/mid/high growth trajectories to 2100 provides a range of future DC electricity demand scenarios that vary from ~550 to 1,550 TWh in 2050 and ~775 to 3,150 TWh in 2100, encompassing the full range of LBNL and IEA scenarios in the near term except for the lowest IEA scenario ("head winds").

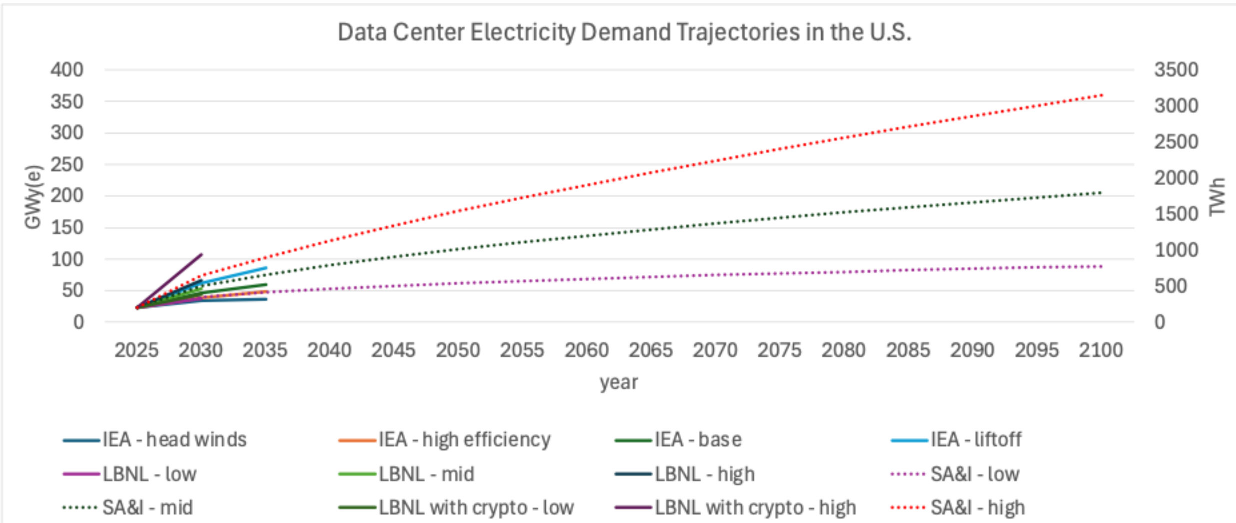


Figure 2-3. Electricity demand from DC in the U.S. – projections through 2100.

The projected DC demand distribution is shown in Figure 2-4, illustrating that two states (Texas and Virginia) are anticipating a significant rise in demand (up to 7.5GWy (e)), while most states are anticipating a more reasonable demand increase. DC are being deployed in certain regions for a wide range of reasons: to be close to the demand, to access water and energy resources, and to benefit from state and local incentives. More discussion on siting criteria for DCs is provided in Section 7.

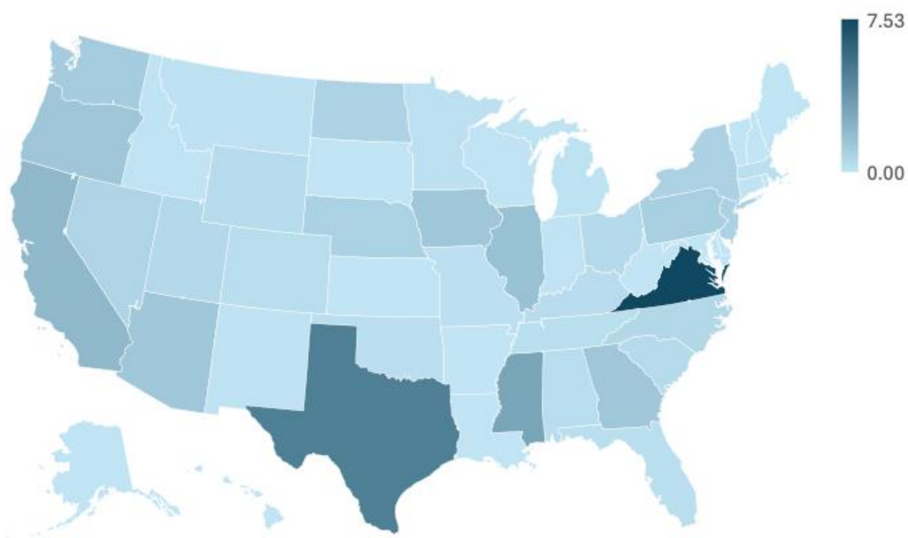


Figure 2-4. State-wide DC energy demand projected for 2030 in GWy(e), derived from the "high-growth" EPRI scenario [31].

2.3 Summary

The U.S. is currently facing a surge in energy demand from DCs, especially related to hyperscale and large-scale colocation DC, with a total projected demand by 24–74 GWy(e). If met with nuclear energy, this demand would require 27–85 GWe of installed capacity. This short-term surge is expected to be sustained at a slower rate in the following years.

Nuclear is not the only technology being considered for this market, with renewables (through grid connection or microgrids with battery storage and natural gas) providing alternative options. Economic comparisons of nuclear energy with those other options are not considered in this work, but several other studies have made such comparisons [36] [35] [32].

Obviously, nuclear energy will have a hard time meeting the short-term DC demand because of expected timeline in new construction, making alternative technologies potentially attractive. The following section focuses on assessing nuclear power capacity that can be made available in the short term to support DC demand.

3. NUCLEAR CAPACITY AVAILABILITY AND ASSOCIATED TIMELINES

The following section discusses capacity and timeline for different short-term and longer-term options for new nuclear capacity. This includes current NPP fleet, restart of recently shutdown plants, uprates, and new constructions.

3.1 Current Fleet

The current fleet of U.S. operating nuclear reactors can be leveraged to serve part of the DC demand, as shown by the decision to use the Susquehanna Steam Electric Station NPP for powering DCs for AWS through a "front-of-the meter" PPA. The current nuclear fleet employs 94 units on 54 sites, having nameplate capacity of 97 GWe and generating 89 GWy(e) (based on 2024 data from [41]), representing about 20% of total U.S. electricity production [42].

The distribution of nuclear power capacity in the U.S. is shown in Figure 3-1. Those reactors are at various stages of their lifetimes; 24 units have licenses that will expire prior to 2035 and will require license renewal to keep operating beyond that time. At this time, there are no U.S. nuclear units with upcoming announced target dates for closure.

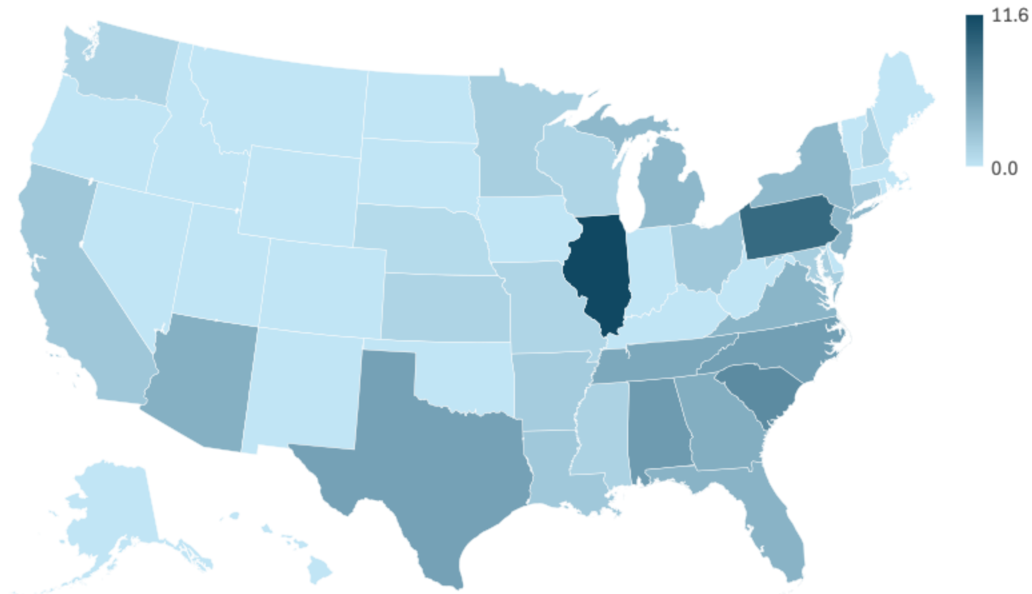


Figure 3-1. Current installed U.S. nuclear capacity in gigawatts, by state.

Two existing NPPs have announced that their existing output will be purchased by DCs (1,920 MWe to be purchased by AWS from Susquehanna by 2032 [43], and 1,130 MWe by Meta from Clinton by 2027 [44]), accounting for 3.1 GWe of installed capacity. Additional discussions [4] were reported with Calvert Cliffs, Camanche Peak, Hope Creek, and Salem; these purchases would total another 7.5 GWe if realized at their full capacity.

3.2 Recently Shut Down NPPs

Since 2013, 13 NPP units have been shut down prematurely in the U.S. The main reasons were economics (market conditions due to stagnant power demand and low-cost shale gas) or the need for expensive repairs or upgrades es [42], as shown in Table 3-1. Through these premature shutdowns, the U.S. lost about 11 GW of installed nuclear capacity.

Table 3-1. Recent premature NPP shutdowns in the U.S. (data from [42] – as of August 2025).

Reactor	State	Net capacity (MWe)	Shutdown year	Reason for premature shutdown	Restart considered?
Crystal River 3	FL	860	2013	Repairs required	No
San Onofre 2&3	CA	2150	2013	Repairs required	No
Kewaunee	WI	566	2013	Market conditions	No*
Vermont Yankee	VT	605	2014	Market conditions	No
Fort Calhoun	NE	482	2016	Market conditions	No
Oyster Creek 1	NJ	619	2018	Upgrade requested by state regulators	No
Pilgrim 1	MA	677	2019	Market conditions	No
Three Mile Island 1	PA	819	2019	Market conditions	**decided**
Indian Point 2	NY	998	2020	Market conditions and political pressure	No
Duane Arnold	IA	601	2020	Market conditions	**considered**
Indian Point 3	NY	1030	2021	Market conditions and political pressure	No
Palisades	MI	805	2022	Market conditions	**decided**

* Kewaunee is considering re-using the site (which houses a PWR under decommissioning) for building a new advanced SMR [45].

Two recently shut down NPPs (TMI-I and Palisades) are currently undergoing active re-start processes. These represent 1.6 GW of nameplate capacity that could be brought back. Those two current re-start projects are expected to be completed on a 2- to 4-year timeline:

- Holtec decided to re-start the Palisades unit in 2023 [46] and the unit is expected to be back online by the end of 2025 [47]. For this purpose, Holtec secured a $1.52B loan from the DOE Loan Program Office in 2024. On July 24, 2025, the Palisades NPP received its operating license back from the U.S. Nuclear Regulatory Commission (NRC) [48].
- Constellation decided to re-start TMI-I following signature of a 20-year PPA with Microsoft in 2024, aiming for a restart in 2027 [49] [50]. External estimates indicate that Microsoft would pay about $110/MWh under a deal announced in September 2024, with an estimated restart cost of $1.6 billion [51].

Additional NPPs may be considering a re-start, such as Duane Arnold [52] (under review at the NRC [53] and which was approved by FERC [54]), which would increase available nuclear capacity to 2.2 GWe.

Technical and regulatory challenges for re-starting an NPP under decommissioning are discussed in [55]. The decision to bring an NPP back online after shutdown needs to balance the refurbishment costs associated with a shorter remaining lifetime against the option to build a new plant with a longer lifetime.

3.3 Power Uprates

The currently operating nuclear fleet in the U.S. is generally considered to be under-utilized, and its power could be boosted through "uprates." There are different types of power uprates, ranging from smaller uprates requiring minor upgrades to larger uprates (up to 20%) requiring major balance-of-plant (BOP) upgrades, as detailed in [56].

The DOE Light Water Reactor Sustainability Program has investigated the uprate potential of the U.S. nuclear fleet [56]. The fleet has already increased its power capacity by 8 GWe when compared to its initial licensing capacity through uprates [57], and there is potential to increase it by another 16.5 GWth [56], which represents 5.5 GWe (assuming 33% thermal efficiency). The DOE liftoff report mentions 2–8 GWe of uprate potential for the current fleet [58].

Reviews of past NRC uprate application and authorization letters show that, for recent applications, authorization was obtained less than 2 years after application submittal, and in many instances, it took less than 1 year. This time estimate likely doesn't include the upgrade timeline.

According to a 2024 Nuclear Energy Institute survey [59], "*Greater than 73% of sites surveyed have a level of interest in power uprates for their units. This is significantly higher than the 50% seen in the 2023 survey. The cumulative total of these uprates could provide over 3 GWe of carbon-free nuclear energy in the coming decade and is greater than a 50% increase over the amount identified in the 2023 survey.*"

At the time of this writing, there are no expected or pending NRC uprate applications [57]. However, two utilities have announced uprates:

- In early 2025, Constellation announced its plan to uprate the power of two Illinois power plants (Byron and Braidwood) by 135 MWe combined, through an $800M investment [60]. The power output is expected to be increased in 2026, with a fully uprated output achieved in 2029.
- Energy Northwest was approved in 2025 to uprate the power of the Columbia power station (in Washington State) by 186 MWe, achieved incrementally through 2031 [61].

3.4 New Reactor Deployments

Table 3-2 provides a list of U.S.-developed advanced reactor concepts and their licensing or construction status in North America. This information is compiled to support discussion of future construction plans.

Table 3-2. Non-exhaustive list of U.S. NPP concepts and power rating, together with licensing status in North America.

Concept	Type	Construction or licensing status	Power level
AP1000, Westinghouse	PWR	2 units built and operating in the U.S.	1110 MWe
Natrium, TerraPower	SFR	Construction permit application under NRC review	345-500 MWe
Xe-100, Xenergy	HTGR	Construction permit application under NRC review	80 MWe
ENTRA1, NuScale	PWR	Design approval issued by NRC	4, 6, or 12 units of 77 MWe
SMR-300, Holtec	PWR	Licensing activities underway in Canada, U.S. and U.K.	160 MWe
KP-FHR, Kairos	FHR	Construction permit awarded by NRC for Hermes demonstration reactor	140 MWe
ARC-100, ARC-LLC	SFR	Phase 2 pre-licensing application under review by Canadian Nuclear Safety Commission (CNSC)	100 MWe
BWRX-300, GE	PWR	Design review by CNSC completed, construction permit application submitted to NRC	300 MWe
AP300, Westinghouse	PWR	Pre-licensing activities at NRC	300 MWe

FHR: fluoride salt-cooled high-temperature reactor; HTGR: high-temperature gas-cooled reactor; PWR: pressurized water reactor; SFR: sodium-cooled fast reactor

3.4.1 Ongoing projects

The U.S. has two projects underway directed at new commercial deployments of nuclear reactors (not including test projects such as Pele, Marvel and Hermes):

- Natrium demonstration reactor in Wyoming, with 500 MWe nameplate capacity, under NRC construction application [62].
- The Xe-100 demonstration reactor in Seadrift Texas, designed for 320 MWe capacity (with 4 modules of 80 MWe) [63].

The operation date for those demonstration projects funded under the U.S. DOE Advanced Reactor Demonstration Program is expected to be around 2030 [64]. The added capacity from those ongoing projects totals 820 MWe.

3.4.2 Projects under consideration

As pointed out in Ref. [58], the U.S. has experience with rapid nuclear reactor deployment: "*Over 90% of the 2024 US nuclear fleet was constructed in the 1970s and 1980s. From 1973 to 1987, the US averaged more than 6 GW of new nuclear reactors commissioned per year. At peak, in 1974, 12 reactors connected to the grid, adding 10.5 GW of capacity*."

Several other new reactor deployments are under consideration, at various stages of discussion. Here is a non-exhaustive list of announcements:

- Re-start of construction projects for VC Summer Units 2 and 3 is under consideration by the new owner, Santee Cooper [65]. These projects would bring online 2 AP1000 units, for a total rated power of 2200 MWe. The construction project was abandoned in 2017, and an expert assessment reported that construction could be completed within 5–8 years of restart [66].
- The Tennessee Valley Authority (TVA) is planning for construction of a BWRX-300 at the Clinch River site in Tennessee, with commercial operation planned for 2033 [67].
- Amazon signed three new agreements to support the development of nuclear energy projects [10]:
    - Enabling the construction of SMRs with 320 MWe capacity for the first phase and the option to increase to 960 MWe beginning in the early 2030s;
    - Investing in X-energy to develop the SMR equipment to support more than 5 GW of new nuclear energy projects; and
    - With Dominion Energy, exploring the development of at least a 300-MWe SMR near the North Anna nuclear power station.
- Google and Kairos Power entered into a corporate agreement to bring the first KP-FHR online by 2030 and additional modules later [11].
- Meta released a request for proposal to identify nuclear energy developers to build 1–4 GW of new nuclear generation capacity in the U.S. [13].
- Fermi America submitted its application for 10 CFR Part 52 combined licenses for four AP1000 (Fermi America Units 1 through 4) to be built in Texas to power large DC campus [18] [19]. The timeline and financing of the projects haven't yet been detailed.

In total, this is about 2.6 GW of new nuclear deployment that could occur in the relatively short term (around 2030), and a larger capacity of 5.5 GW that would be targeted in the longer term (2035).

Many other projects have been announced by different vendors such as LastEnergy, Aalo, Oklo, Natura, and TerraPower, and these are at different stages of discussion. Several fusion reactor projects are also moving forward, displaying very aggressive time frames [68]: Helion has started construction of its first fusion power plant in Washington state, and signed a 50-MW PPA with Microsoft, expecting power production by 2028. Google signed a 200-MW PPA with Commonwealth Fusion Systems, which is projecting to deliver its first power to the Virginia grid in the early 2030s.

The benefits/challenges of building/operating different types of NPPs (large reactors or LRs versus SMRs) are discussed in [58]. Ultimately, the utility or customer needs to assess the nuclear technology's compatibility in terms of size, flexibility, and other considerations (such as heat temperature), together with the project risks and costs.

3.4.3 New site capacity

The discussion above only considers current new-NPP deployment plans. The potential for new nuclear plants (large or small) is much greater, as highlighted in several recent publications discussed below.

The DOE advanced-nuclear liftoff report [58] assumes tripling nuclear capacity by targeting 200 GWe of added nuclear capacity by 2050, in concert with a variety of system-wide modeling efforts showing the need for this level of new nuclear capacity. The current administration has announced a target of 400 GWe of nuclear capacity by 2050 [69].

Siting new NPPs on existing nuclear sites could provide significant benefits in terms of economies of scale, community support, and access to existing site permits [58]. Previous analysis [70] found that 60–

95 GW of new nuclear capacity could be added to existing nuclear sites (including completion of the VC Summer projects).

Siting those new NPPs on coal power plant sites could also provide significant benefits by leveraging existing infrastructure and workforce [71], and providing access to inflation reduction act's (IRA) energy communities tax credit bonus [58] [72]. Previous analysis found that 120–170 GW of new nuclear capacity could be added to existing coal power plant sites [70].

3.5 Summary

Figure 3-2 summarizes the currently announced or considered new nuclear deployments. A total of 2.6 GW could be added in the coming 5 years if the current announcements are realized, with the possibility of adding 28 GW when accounting for projects under consideration (including 5.5 GW of assumed uprates for the whole existing fleet, and 3 GW of PPAs from existing plants), with about 20 GW that would be dedicated to DC demand (the other announcements may not be directly dedicated to DC demand) **by the early 2030s.** This deployment should be compared with the expected electricity demand from DCs of 27–85 GWe (assuming 93% capacity factor) by 2028 that was derived in Section 2.2. It should be re-emphasized that many more projects are being considered and may not yet be captured in these figures.

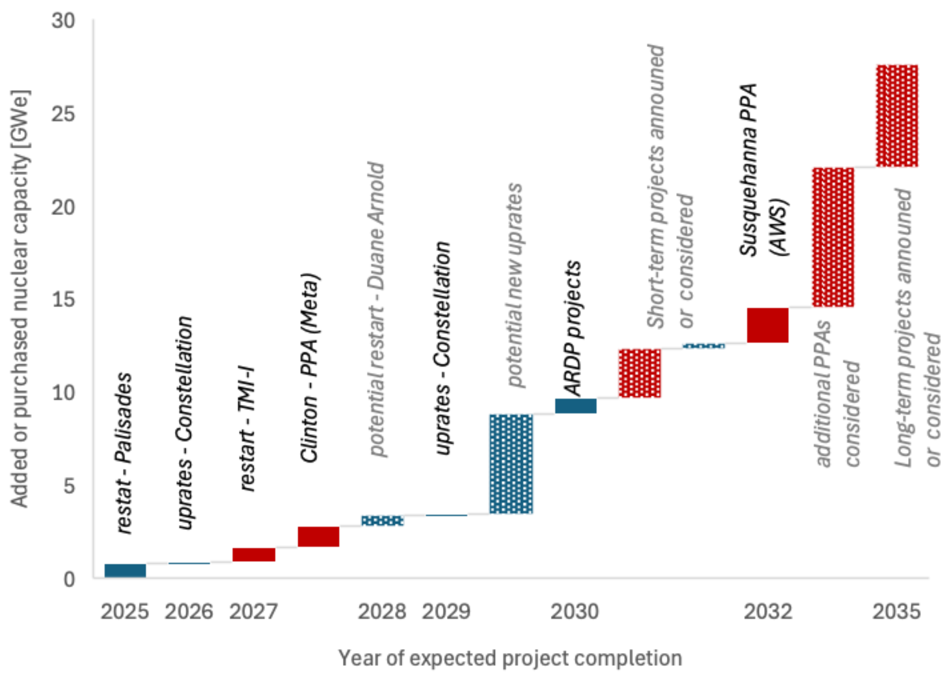


Figure 3-2. Timeline of expected and potential additions of nuclear capacity to U.S. fleet, together with PPA contracts with DCs. Dotted fills and gray labels are for considered or potential new projects; plain fills are for decided projects; red fills are for DC-specific projects.

The locations of the DC demand and potential nuclear energy production are also important to compare. The new nuclear capacity shown in Figure 3-3 corresponds to the "stretch" goal with projects that are being considered in Figure 3-2, but only shows the projects that have announced a deployment site or state (which excludes some of the long-term projects, for which sites haven't been announced). One finds distribution of the added or purchased nuclear capacity in Texas and on the East Coast, which is consistent with the location of expected DC demand shown in Figure 2-4. Since the state of Texas has its own grid with few interconnections, it is expected that increased energy demand will be supported by in-state capacity deployment. Other states (such as Virginia) may see increased energy demand from DCs while relying on increased production from neighboring states (on the East coast, for instance).

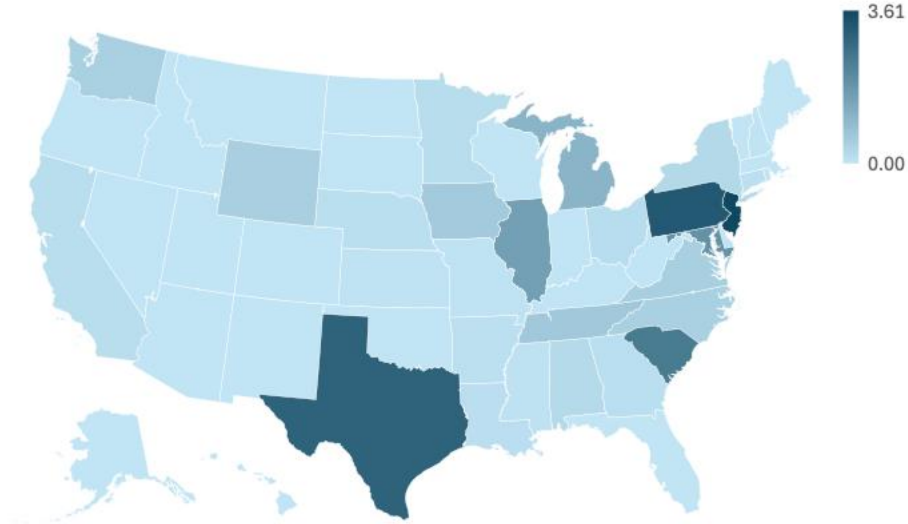


Figure 3-3. Upcoming new nuclear capacity or existing capacity that may be purchased for DCs, in gigawatts-electric.

4. ASSESSMENT OF HALEU REQUIREMENTS

Currently operating NPPs and LWR-type SMRs use low-enriched uranium (uranium enriched lower than 5 in uranium-235) which is commercially available. AWS and Google announced in 2024 partnerships with advanced nuclear reactor developers and investments in their technologies [73] [74]. They are both interested in advanced SMRs that utilize HALEU. It is noted that HALEU refers to uranium enriched greater than 5 and less than 19.75 weight percent of the uranium-235 isotope, but in this work, HALEU is considered 10 –19.75 % enriched uranium that is needed to support advanced SMRs. There is currently no domestic commercial large-scale supplier for HALEU and DOE is providing limited amounts of HALEU to support immediate needs to demonstrate advanced reactors [75] through the HALEU Availability Program (which supports the development of HALEU for civilian domestic research, development, demonstration, and commercial use). This HALEU is coming from down-blending of DOE's highly-enriched uranium stockpile, from initial HALEU enrichment production started by Centrus (900kg achieved so far) [76]. DOE has also awarded several companies (Urenco USA, Orano USA, General Matter) to help scale up domestic HALEU capacity.

Consequently, an estimate of HALEU demand was obtained in this report based on two recent announcements:

- *AWS signed three agreements to support the development of nuclear energy projects, which include enabling the construction of SMRs generating 320 MWe for the first phase and the option to increase to 960 MWe to meet the forecasted energy needs of the Pacific Northwest beginning in the early 2030s. AWS also made investments to develop the SMR equipment to support more than five gigawatts of new nuclear energy projects.*
- *Google signed an agreement to purchase nuclear energy from multiple SMRs to be developed by Kairos Power. The initial phase is intended to bring Kairos Power's first SMR online by 2030, followed by additional reactor deployments of up to 500 MWe through 2035.*

It is noted that the estimation of HALEU demand was normalized to 19.75% enriched uranium because the uranium enrichments of advanced SMRs vary depending on their design features. The work completed in this section intends to support the DOE HALEU Availability Program by estimating quantity and timeline for HALEU needs.

4.1 SMR Deployment Scenarios

Table 4-1 shows the design information on SMRs that the two tech companies are interested in. In light of the agreements, it is expected that AWS and Google will deploy an 80-MWe Xe-100 from X-energy [77] and a commercial version of the KP-FHR from Kairos Power [78], respectively. Since some design parameters are protected as proprietary information, assumptions were made to obtain the missing data.

- The missing design data on KP-FHR (the number of pebbles in the core, pebble consumption per day, etc.) were obtained from the same type of reactor: a 100-MWe Mark-I pebble-bed fluoride-salt-cooled high-temperature reactor (MK1 PB-FHR) [79]. The data from the MK1 PB-FHR were proportionally adjusted by comparing electric power levels.
- The start-up core requires relatively lower-enriched uranium than the equilibrium core because there are no parasitic absorptions by fission products, but the start-up core design information is not available. The start-up core enrichments were obtained from the reactor design studies on a pebble-bed gas-cooled reactor [80] and a pebble-bed fluoride-cooled reactor [79].

Figure 4-1 shows the deployment schedule of both SMRs to achieve the target total SMR capacities of 960 MWe for Xe-100 and 500 MWe for KP-FHR. It was assumed that four modules of Xe-100 (320

MWe) would be deployed in 2030, 2035, and 2040, and a single KP-FHR module (75 MWe) would be deployed every year from 2030 to 2036. It is noted that the total capacity of KP-FHR in 2036 is slightly higher than the target capacity of 500 MWe because a single KP-FHR module is designed to generate 75 MWe.

Table 4-1. Design information on Xe-100 and KP-FHR, and assumptions used in this study.

Tech company	**Amazon**	**Google**
SMR developer	X-energy	Kairos Power *)
Reactor model	Xe-100	KP-FHR – commercial
Power per module, MWt/MWe	200/80	177/75
Reactor CF **)	93%	93%
Uranium enrichment - Equilibrium core - Start-up core	 15.5 % [77] 5.0% [80]	 19.75 % [78] 11.9% [79]
Burnup	168.5 GWd/t [77]	180.0 GWd/t
Pebble diameter, cm	6.0	3.0
Uranium mass per pebble, g	7.0	1.5
Pebbles in core	220,000	352,500
Pebbles consumed per day	170	690
Start-up core fuel inventory, kg - LEU (5%) - HALEU (19.75%)	 1540.0 0.0	 0.0 314.5
Annual loading, kg-U/year - HALEU design enrichment - HALEU (19.75%)	 434.4 [77] 315.9	 377.8 351.3

* Several design parameters needed for mass flow evaluation are protected as proprietary information. The missing data were obtained or calculated using a similar reactor concept [79] in the present study.
** Both reactors are assumed to operate in baseload for this study, despite expected load variations from the datacenter that would likely be accommodated by the grid and by energy storage.

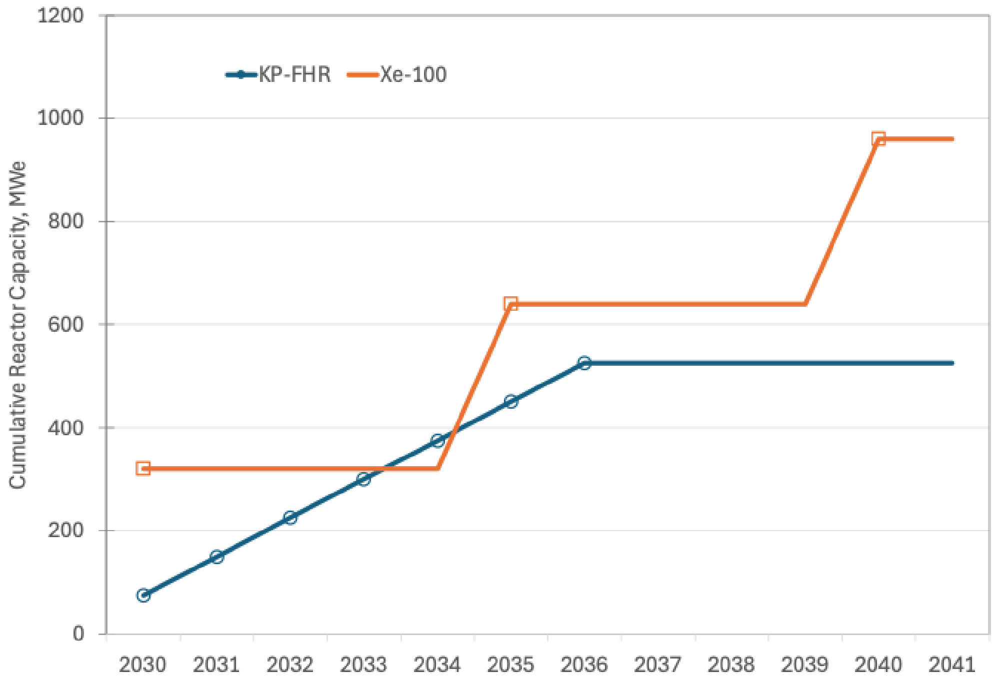


Figure 4-1. Assumed SMR deployment schedule.

4.2 Estimation of Annual HALEU Demands

Using the deployment schedule and reactor information, the demands for 19.75% enriched HALEU were estimated. The HALEU demand to support both companies' SMRs is plotted in Figure 4-2, and summarized here:

- By 2030, about 0.3 t of HALEU is needed to fill the start-up core of Google's KP-FHR. It is noted that four modules of Amazon's Xe-100 start in 2030, but HALEU is not needed at that time because it was assumed that Xe-100 starts by using 5% LEU;
- In 2031, the yearly HALEU demand will jump to 2.0 t to support the annual loadings of both SMRs and fill the new start-up of KP-FHR;
- The yearly demand increases linearly up to 3.3 t in 2035;
- In 2036, the yearly HALEU demand will jump to 5 t to support the annual loadings of the four Xe-100 modules newly deployed in 2035;
- In 2041, the yearly HALEU demand will jump to 6.3 t to support the annual loadings of the four Xe-100 modules newly deployed in 2040; and will remain constant until new units are deployed.

Once again, those HALEU estimates are normalized to 19.75% enriched uranium.

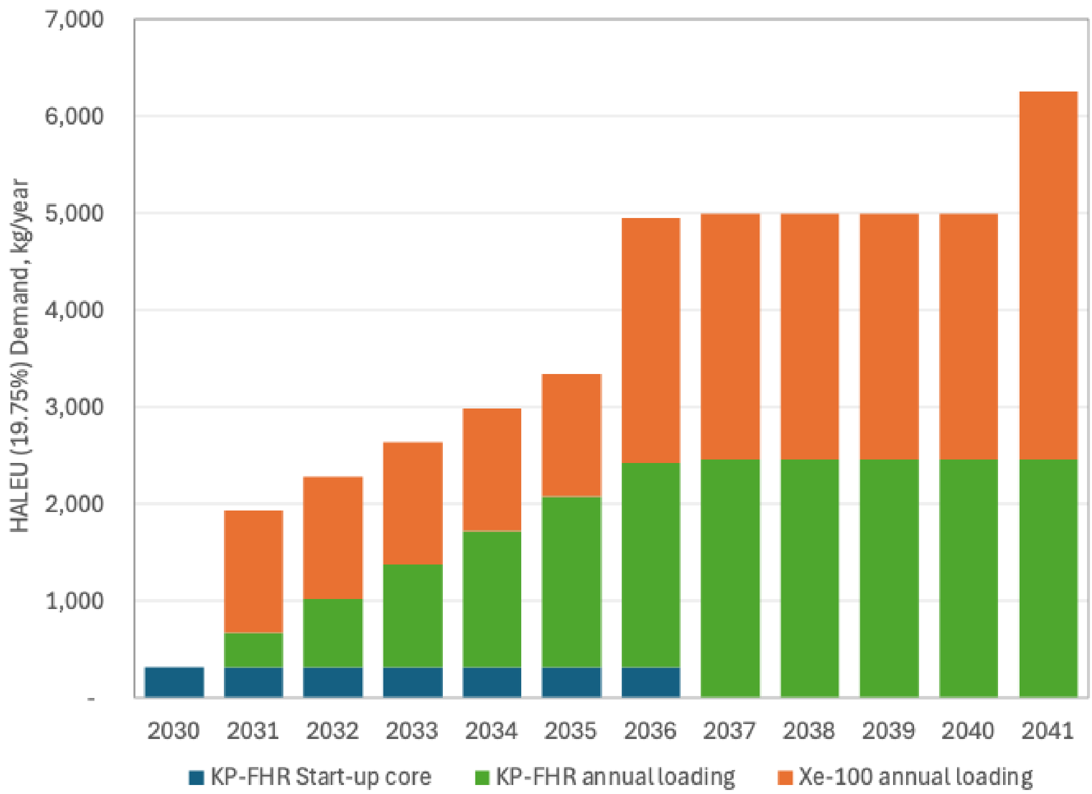


Figure 4-2. Total annual HALEU demands combining start-up core inventory and annual loading to support SMR deployment plans from Google and AWS.

4.3 Notes on Potential Variations in HALEU Estimation

Because of the assumptions applied regarding the missing design information, the HALEU demand estimation shown in Figure 4-2 could vary as described below.

- The start-up core requires a relatively lower enrichment than the equilibrium core. Because the start-up core design information is not available, it was assumed that the Xe-100 would start using 5% LEU [80]. In comparison, the uranium enrichment in the equilibrium core is 15.5%. Based on the assumptions, the HALEU demand for the Xe-100 start-up core was not counted in Figure 4-2. If the Xe-100 start-up core needs higher enriched uranium (10–20%), the HALEU demand to fill the start-up core increases.
- Amazon signed agreements to invest in X-energy to expand its equipment capacity to up to 5 GWe and to explore 300-MWe SMR development in Virginia. The HALEU demand associated with both agreements was not counted in this estimation because detailed SMR deployment plans were not discussed in the agreements. However, a sizeable increase in the demand for HALEU is expected if both agreements are implemented in the future.

Finally, one needs to re-emphasize that this analysis only considers announced SMR-deployment plans from Google and AWS. Additional DC companies or additional utilities' plans for SMR deployment were not considered and will also affect HALEU requirements.

5. REVIEW OF DIFFERENT OPTIONS FOR CONNECTING NPPS AND DATA CENTERS

A DC requires energy in the form of electricity for the IT equipment and for cooling down (generally through chilled water circulation). There are several options for NPPs to provide energy to DCs, as illustrated in Figure 5-1. Electricity can be provided directly by the NPP, either through direct connection or through the grid. This report reviews those options detailing some of their benefits/challenges. Those different options will be further evaluated in the following sections as part of a reactor sizing optimization used for siting and socio-economic studies.

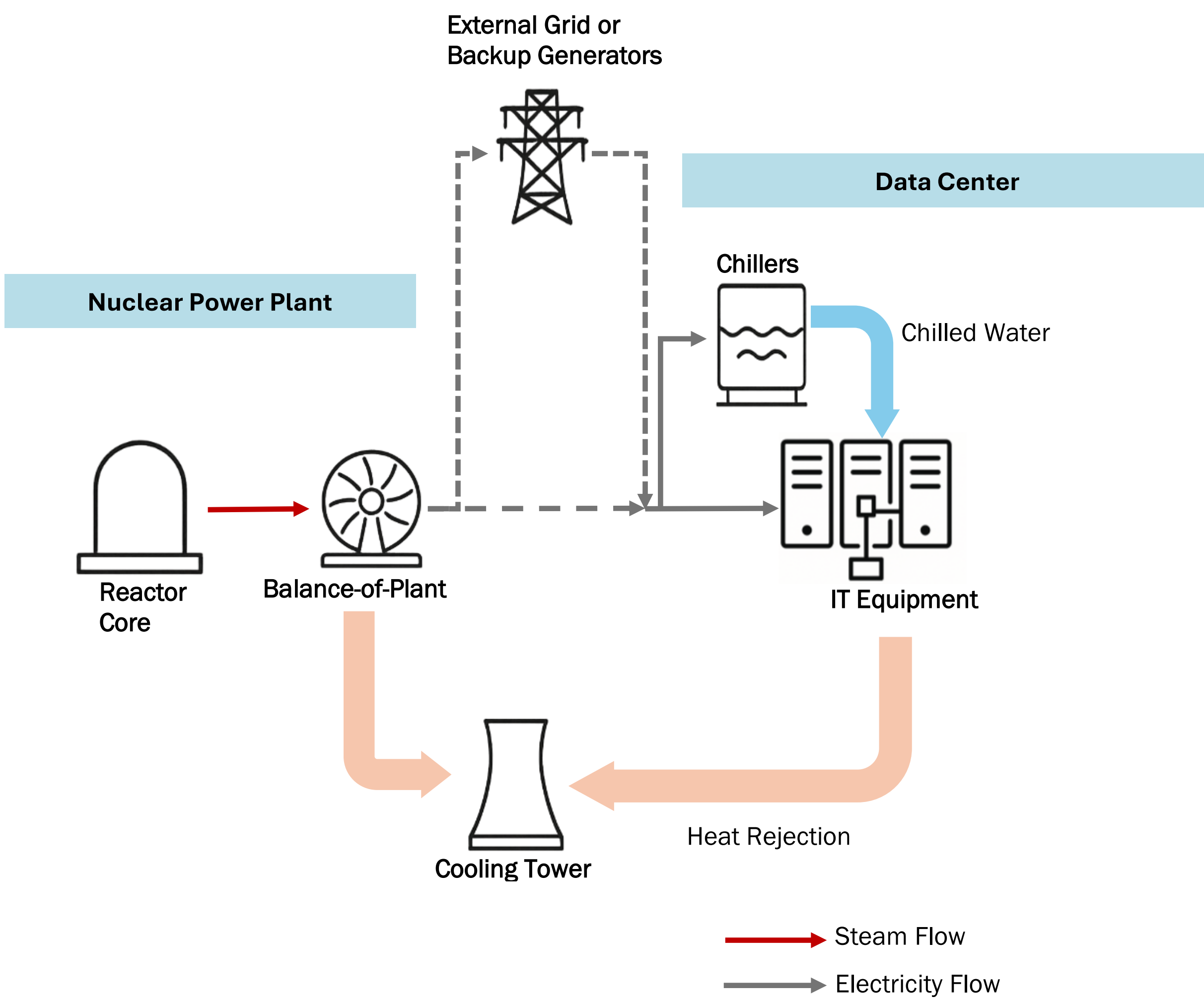


Figure 5-1. Schematic of nuclear/DC coupling options.

Different options for NPPs to connect with DCs were detailed by EPRI in [33] and are referred to as follows:

- **through the grid**: the NPP and DC are connected through the grid, without direct electrical connections between those two facilities.
- **behind the meter (BTM)**: "*the end-user facility is connected to the nuclear plant before the point where the plant is connected to the main grid and its output measured, or metered, as part*

of the overall electrical generation of the plant for use by the public on the grid" [33], allowing the NPP to sell power directly to the DC; or

- **direct connections**: the NPP and DC are directly connected, without any meaningful grid connection (although one may still be required for contingency power backup).

The different coupling options are driven by technical and economic considerations, as summarized in the following section.

5.1 Technical and Financial Considerations

5.1.1 Electrical connection and output matching

Matching the output of an NPP with a DC's demand requires precise electrical integration. As shown in Table 2-1, modern hyperscale DCs typically range from 50 MW to over 300 MW per campus, with announcements of multi-GW campuses. Nuclear power options include the following:

- **Microreactors (MRs):** <50 MWe – suitable for small or edge DCs.
- **Small Modular Reactors (SMRs):** 50–600 MWe – ideal for medium to large DC campuses.
- **Large Reactors (LRs):** >600 MWe – suitable for regional DC hubs or utility-scale supply.

NPPs are designed for specific electrical output and can generally be deployed with several modules to match site energy requirements. For instance, NuScale 77-MWe modules will be deployed in 4, 6, or 12 modules generating 308 MWe, 462 MWe, and 962 MWe. However, those may not exactly match the peak electric requirements for a specific DC site: the gap would typically be filled by the grid or by an onsite generator. Section 6 applies an optimization methodology for NPP size selection to meet DC electrical and reliability requirements. [81]

As illustrated in Figure 5-1, different types of connections can exist between the NPP, the DC, and the grid. In case the NPP and the DC have a direct power connection, step-down transformers and custom substation interfaces are needed to match DC input voltages (typically 13.8–34.5 kV). Those requirements are further discussed in Section 5.2

5.1.2 Cooling and chilled water requirements

Typical datacenter IT equipment has thermal limits around 85°C; however, industries typically set the working environment to remain at 40–45°C with a safety margin, limiting it to 60°C [81]. This translates to requiring significant energy for cooling. Cooling accounts for roughly 30–50% of a DCs's total energy consumption [82]. In choosing DC cooling methods, several factors must be considered: climate conditions, cooling medium availability (water), footprint, and datacenter load types [83]. Air cooling is generally considered for dry areas, while water cooling is considered where heat sinks like rivers and seas are nearby. If the surrounding environment temperature is low enough compared to IT equipment operating temperatures, natural air and water can be used as free-cooling media to reduce reliance on mechanical equipment such as chiller-compressors and cooling tower fans [84].

The primary source of cooling demand is heat dissipated from IT equipment loads. Under the assumption of 1 MWe of consumption generating 1 MWth of heat, a DC facility with a 100-MWe IT load requires 14–16 MW of continuous chiller cooling (direct cooling) to dissipate 100 MW_{th} of energy in the form of heat. This cooling is achieved using high-efficiency electric chillers with a coefficient of performance (COP, the ratio of cooling output to the energy input) that can reach 6–7 [85]. Final cooling consumption calculations require considering sources such as heat generation from uninterruptible power supplies (UPSs) and building-wide systems, as well as auxiliary cooling systems (fans and pumps) that operate regardless of IT load [86] [38]. Commercial DCs typically include electric chillers that operate with COP ranges of 5 [87], 6 [85], or 7 [88], often with higher COPs (8–10) [82] achieved when free cooling approaches are implemented. Nuclear facilities, which already manage substantial cooling demands, can enable synergistic infrastructure sharing:

- Shared cooling towers or chilled water loops, as illustrated in Figure 5-1.
- Steam-driven absorption chillers using waste heat from the NPP, as further discussed in Section 5.2.6.

5.1.3 Grid power availability and FERC requirements

Grid interconnection remains a key barrier to DC deployments. The FERC May 2024 rule [89] mandates that interconnection applicants (like DCs) demonstrate viable resource plans and may require self-supplied generation for large new loads due to 5+-year queue backlogs and high rejection rates (only ~19% of projects reach operation). When allowed, direct connections between nuclear generation and DCs can bypass these constraints. This approach would permit faster deployment of DCs, especially in regions like Virginia, Texas, and Georgia**,** where grid constraints are acute.

5.1.4 Reliability requirements, backup options, and demand flexibility

DCs demand various types of reliability (Tier I to IV), which are assigned to different backup requirements; those can be met by additional SMR units, grid backup, natural gas turbines (with onsite fuel storage), diesel generators, or hydrogen fuel cells.

A coupled NPP/DC system will face challenges with managing difficult-to-coordinate outages; those can be planned (such as NPP refueling and maintenance) or unplanned. When not coordinated, an outage of the NPP will require supply from backup or from the grid, while outage or load reduction from the DC will require excess NPP electricity to be sold to the grid or curtailed. Various technical solutions are considered to accommodate these power oscillations, such as grid connection with flexible PPAs or curtailment options, battery storage, hydrogen storage/fuel cells for extended backup, and workload management (shifting non-critical tasks off-peak or geographically).

In case the electrical grid is relied upon to manage the load variations from the NPP/DC system, rapid demand reduction/increase can disrupt market operations and grid stability, calling for real-time balancing or curtailment agreements with the grid operator.

Finally, it should be mentioned that datacenters may also have the ability to manage their power demand in a flexible way, as researched by EPRI through its DCFlex initiative [90]. Google announced recently it was exploring demand-response capabilities to reduce power usage during high-demand periods [91]. This is especially important as some regions such as ERCOT require all large load (typically >75 MW) to be able to curtail their demand under emergency conditions. For BTM operation, ERCOT can also request under certain emergency conditions that the generator provides its full load to the grid and curtail its power to the BTM customer [92].

5.1.5 Financial considerations

The different NPP/DC coupling strategies will be associated with various ownership options that will have a significant impact on project economics and system design requirements. Three main ownership structures are considered:

1- The DC enters into a PPA with an NPP vendor or utility. This is the most common approach, providing fixed pricing and reducing risk for the DC; however, it entails long-term dependency. Different types of PPA models are considered, such as physical PPA (power delivered and priced per MWh) or virtual PPA (carbon emission offset).

2- The DC owns and operates the NPP, in a fully vertical model. This provides enhanced control of NPP operation, which has reliability benefits (as discussed in Section 5.3), and provides potential for higher long-term economic benefits. However, it pushes risks and regulatory burden to the DC owner.

3- The DC owns the NPP and the utility operates it, with a shared control agreement. Such an approach would be complex to coordinate, but would reduce nuclear risks for the DC.

Additional discussion of financial implications is beyond the scope of this report; the reader can refer to [33] for additional information.

5.1.6 Other implications of colocating NPPs and DCs

Colocating NPPs and DCs introduces several siting requirements, such as land and water availability; these are discussed in detail in Section 7 and Appendix A. The socio-economic impact of NPP/DC colocation should also be emphasized, as discussed in Section 8.

There are also safety and regulatory implications of colocating an NPP with a DC, to account for both nuclear licensing requirements and DC operational risks. Those are discussed in more detail in [33].

While NPPs are typically built with lifetimes of 60-80 years, the lifetime of DC is expected to be much shorter. IT components are expected to be replaced every 3-6 years, and DC buildings and infrastructure are generally not designed for a long lifetime [93]. Consequently, the risks for NPP to lose its customer needs to be assessed and is typically mitigated through long-time contract agreement.

5.2 Definition of NPP/DC Coupling Options

In light of the various technical and financial considerations listed above, different options for electrical coupling of NPPs to DCs are defined in this report, as those may impact sizing, siting, and socio-economic analyses completed thereafter. Those options are further described and studied in this report, with a summary provided in Table 5-1 which is based on the 5 options derived from the most likely coupling options based on co-location and grid connections. Those options can be applied to existing or newly built NPPs or DCs. Option #1 is connection through the grid (not colocated), while Options #2, 3, and 5 are different BTM options (broken down into more options than are considered in [33] for the economic analysis performed next), and #4 is “direct connection” (no grid connection).

Table 5-1. Summary of NPP/DC coupling options.

NPP/DC Coupling Option	1	2	3	4	5
Description	No Colocation, Interconnected with BPS	Colocation with Direct Connection and Full Power Export	Colocation with Direct Connection BTM	Colocation, Islanded Microgrid	Colocation, Microgrid with Backup Interconnection
NPP and DC colocated and directly connected?	No	Yes	Yes	Yes	Yes
DC connected to the grid?	Yes	Yes	No/Limited	No	Yes
NPP connected to the grid?	Yes	Yes	Yes	No	Limited

The three main questions that drive the selection of a coupling option are the following:

- ***Are the NPP and DC colocated and directly connected?*** There is no strict definition of "colocation," but EPRI recommends assuming that a colocated DC would be within 5 miles of reactor boundaries [33]. If the DC is not colocated, grid connection would typically be required. Colocation is typically associated with direct connection. Two different types of direct connections are considered here:
    - o The BTM connection still maintains a grid connection (for the NPP to sell excess power or for the DC to access backup power). This type of arrangement may require state or regulator approval, as discussed in [33].
    - o If disconnected from the grid, the energy system will need to accommodate variations in load demand and provide sufficient backup capacity. This requirement would be met with several NPP modules or with different energy customers on a micro-grid.
- ***Is the NPP connected to the grid?*** In this case, the NPP would be able to sell its excess electricity to the grid when DC demand decreases, or to diversify its revenue sources. This means that the NPP doesn't need to be sized for the DC, as it can serve several customers. In this case, the DC can be connected to the NPP through the grid (or via a direct connection). The absence of connection from the NPP to the grid will create several challenges in terms of safety and reliability, such as response to load loss, black start, and load profile management, as further discussed in [33]. An intermediate option would be a limited grid connection to provide NPP house load and backup power during outages.
- ***Is the DC connected to the grid?*** The grid connection for the DC is used for connecting it to the NPP if it is not colocated, or for backup. Theoretically, the DC could be connected to the grid while the NPP is not: in this case, the NPP sells all its electricity to the DC, which gets additional or backup power from the grid connection.

The following provides more details on coupling options #1 through #5, describing the different types of electrical connections to the grid and between the NPP and DC (transmission and distribution; T&D), how reliability and uptime requirements influence the combined system design, and the potential for nuclear steam supply to further improve cooling efficiency. Each option is discussed separately in the subsections below. The primary differences are to what extent the NPP is connected to the bulk transmission system; to what extent the DC is connected to the bulk transmission system; and whether or not the NPP and DC are directly connected, independently of the bulk transmission system. Under each of these coupling options, DC electric distribution topologies with varying reliability features are possible. Section 5.3 discusses potential distribution designs to meet reliability requirements under each of the coupling options.

5.2.1 Coupling Option 1: No Colocation, NPP and DC Interconnected with Bulk Power System

For Coupling Option 1, the NPP and DC are not colocated on adjacent or nearby sites. Instead, they are electrically interconnected through bulk transmission lines (for North America, high-voltage [115–230 kV] or extra-high-voltage [345–765 kV]); see Figure 5-2. The greater the distance between the two facilities, the less electrical interaction they have, and the localized benefits provided by the NPP (e.g., voltage support) diminish. Since the NPP is not always producing power and power flows on the bulk transmission system can change direction, it cannot be said that the NPP is always supplying power to the DC in this arrangement. However, through a non-physical delivery PPA, the DC owner can agree to purchase power from the NPP at set prices, while physical settlement with the local utility or market operator proceeds separately.

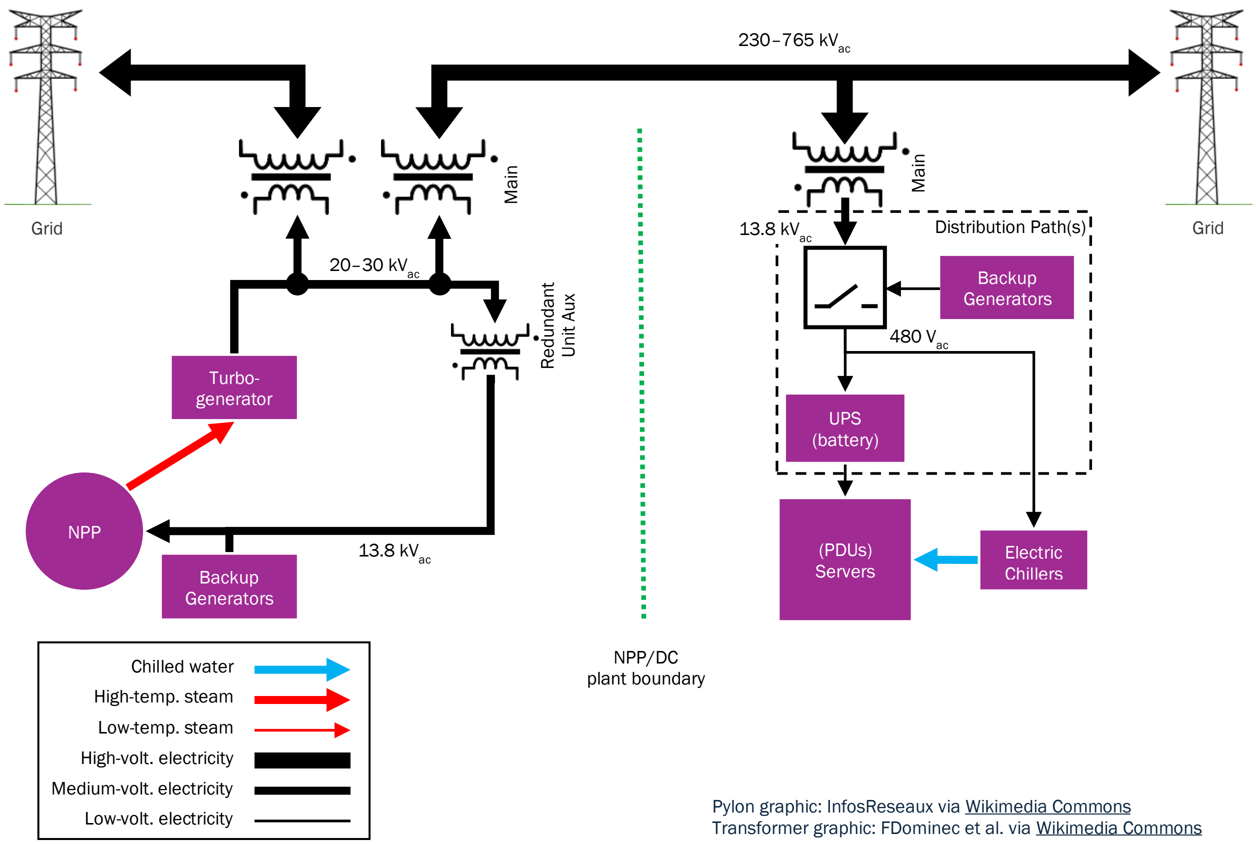


Figure 5-2. Schematic of NPP/DC Electrical Coupling Option 1: No colocation, interconnected with BPS.

An example of Coupling Option 1 is the Browns Ferry Nuclear Plant in Alabama. The first substation on one of the 500-kV transmission lines from the plant feeds the Mazda Toyota Manufacturing USA factory, a large light-duty vehicle manufacturing site.

For a DC developer, Coupling Option 1 is least reliant on the availability of an NPP, which could be advantageous for rapid construction since generator interconnection agreements typically take several years for approval in most regions. New long-distance high-voltage transmission projects also can take many years to be permitted, so siting a DC adjacent to an existing transmission line might only require the addition or expansion of a substation, which is typically much faster. Finally, Coupling Option 1 gives a DC flexibility in choosing the interconnected voltage level independent from the NPP. Depending on the load size, it might be less expensive for a DC developer to tie into a lower-voltage substation.

5.2.2 Coupling Option 2: Colocation with Direct Connection and Full Power Export

For Coupling Option 2, the NPP and DC are colocated, which in this instance means that they are physically close enough to share a substation and its interconnection(s) to the high- or extra-high-voltage transmission system. Here, a direct electrical connection can be made between the NPP and DC via medium-to-high-voltage transformers (Figure 5-3). The NPP maintains its two independent transmission circuits at high or extra-high voltage to maintain the ability to export its maximum power to the bulk power system. The DC would also maintain a connection to the BPS for times when the NPP goes offline. Depending on the relative size of the NPP compared to the DC, most or all of the DC load would be physically met from NPP output except during outages. This could simplify a PPA contract in the case where the NPP owner and DC owner are different entities. The voltage class (medium, high, extra-high) and number of circuits for the direct connection would be determined by load size and redundancy requirements while minimizing cost.

There are no known examples of Coupling Option 2 for NPPs. A potential non-nuclear example is the Baytown Energy Center, which is a natural gas combined-cycle plant in Texas that supplies both electrical power and steam to the adjacent Baytown Industrial Park. The Cedar Bayou plant on the opposite side of the park might also directly supply electrical power to the Baytown Industrial Park. Both the Baytown Energy Center and Cedar Bayou are interconnected to the BPS via 345-kV extra-high-voltage transmission lines.

For a DC developer, the colocation of Coupling Option 2 enables direct connection options to the NPP, which are beneficial from both power quality and power supply redundancy perspectives. The additional expense of the direct connection (with added direct transmission line) relative to Coupling Option 1 would have to be justified through increased power supply reliability and potentially reduced electricity prices (by avoiding bulk grid transmission and distribution costs, upon approval by the transmission regulator).

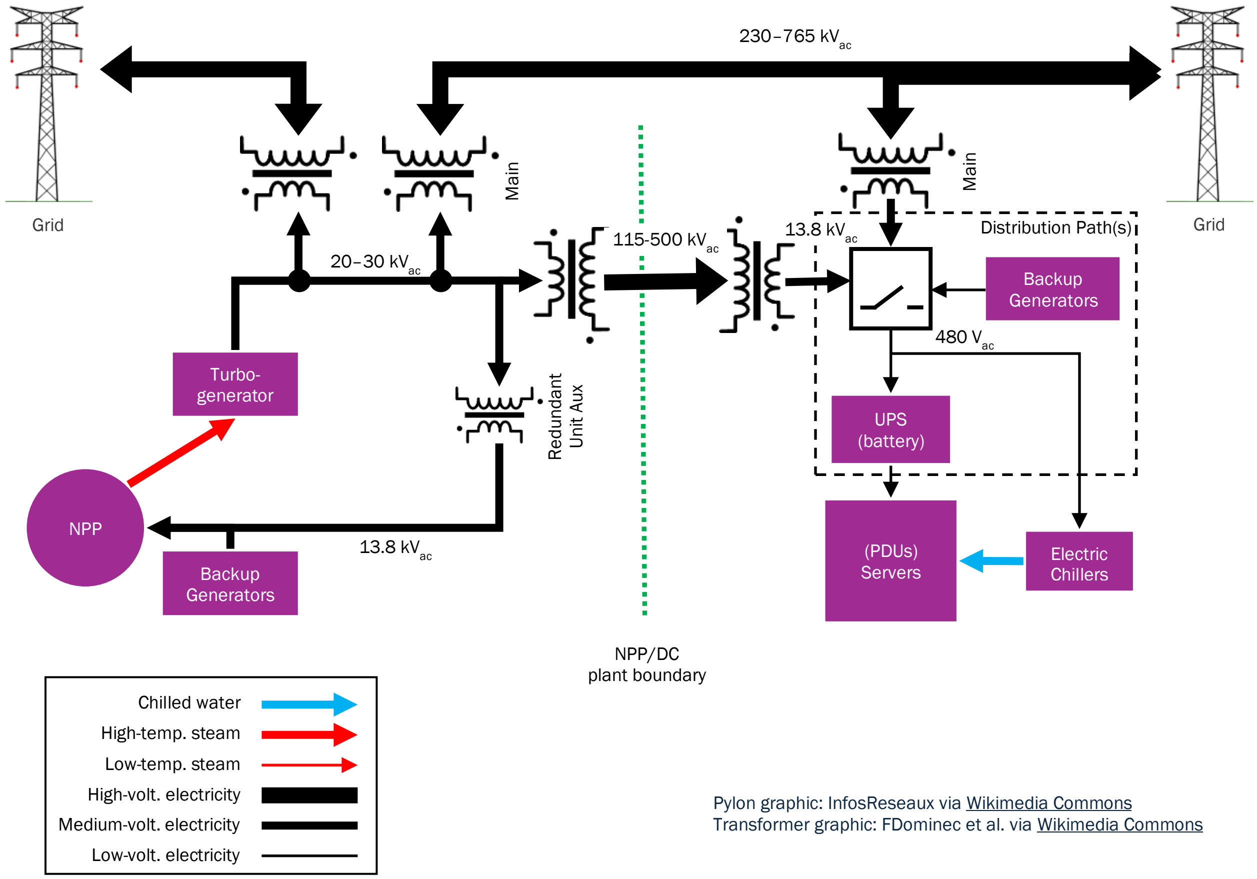


Figure 5-3. Schematic of NPP/DC Electrical Coupling Option 2: Colocation with direct connection and full power export.

5.2.3 Coupling Option 3: Colocation with Direct Connection Behind the Meter

For Coupling Option 3, the NPP and DC are colocated, and a direct connection is made between the NPP and DC as in Coupling Option 2 (Figure 5-4). The difference from Coupling Option 2 is that the DC would no longer have a separate, metered connection to the high- or extra-high-voltage transmission system. This is often referred to as a BTM design. The interconnection size for this arrangement would allow for both maximum export from the NPP and full import of power for the DC when the NPP is unavailable. In contrast to Coupling Option 2, some redundancy of grid interconnection equipment could be shared at the joint substation, potentially saving equipment costs.

However, such an arrangement creates additional energy policy and regulatory issues involving both the interconnection agreement and metering. In the main example above, the NPP would have an interconnection agreement allowing for full power export to the grid and a meter, while the DC would have a separate interconnection agreement allowing for full power import from the grid and a separate meter (only needed when grid power is used). If such an arrangement is disallowed, then the DC would not have its own interconnection agreement or meter, so it would have to disconnect from the grid connection when the NPP is offline (or outputting less than the DC demand). The DC demand would then need to be either curtailed or supplied by on-site backup generators.

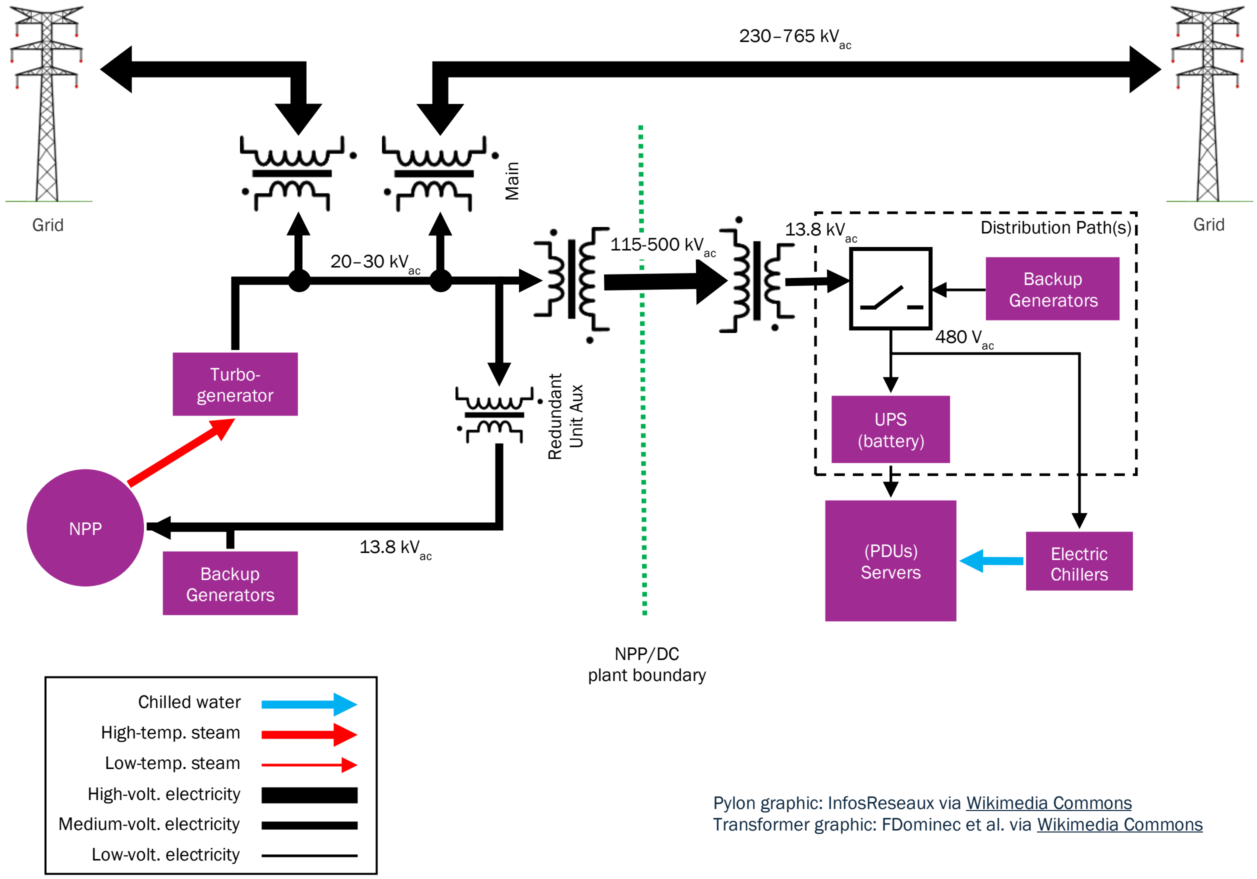


Figure 5-4. Schematic of NPP/DC Electrical Coupling Option 3: Colocation with direct connection behind the meter.

One example of Coupling Option 3 for NPPs involves the Susquehannan NPP in Pennsylvania. The Nautilus Cryptomine DC facility, jointly developed by Talen and TeraWulf, is supplied with 50 MW of power connected only to a substation fed from the Susquehanna plant [94]. Talen has proposed additional BTM DC sites adjacent to the plant that would consume up to 950 MW [95]. However, FERC rejected an amended Interconnection Service Agreement that would have allowed up to 480 MW of BTM load [96]. This particular decision was specific to PJM's transmission service rules and leaves many questions unanswered about future BTM arrangements for large loads. Separately, BTM systems are increasingly common for residential and commercial solar photovoltaic and battery installations, which are often enabled by net metering agreements with distribution service providers. Some utility-scale examples include large combined heat and power plants (e.g., petroleum refineries) and hybrid solar–battery power plants.

For a DC developer, Coupling Option 3 is desirable when interconnection can happen faster compared to Coupling Options 1 and 2, since it avoids much transmission infrastructure expansion. The close proximity to generation also reduces line losses.

5.2.4 Coupling Option 4: Colocation, Islanded Microgrid

For Coupling Option 4, the NPP and DC are colocated, and there is only a direct connection between them. Since there are no interconnections with a bulk transmission system, this is an islanded microgrid configuration. In the U.S., the NRC General Design Criteria Criterion 17 (10 CFR Part 50, Appendix A

[97]) requires at least two physically independent interconnections to a bulk transmission network for non-passive safety nuclear reactor designs (i.e., all existing light water reactor [LWR] designs). A reactor design with passive safety still requires at least one offsite power connection at present [98]. Thus, Coupling Option 4 would require regulatory changes before it could be allowed, or would be implemented with minimum grid connection to power NPP house loads (a few MW of power, depending on the reactor system).

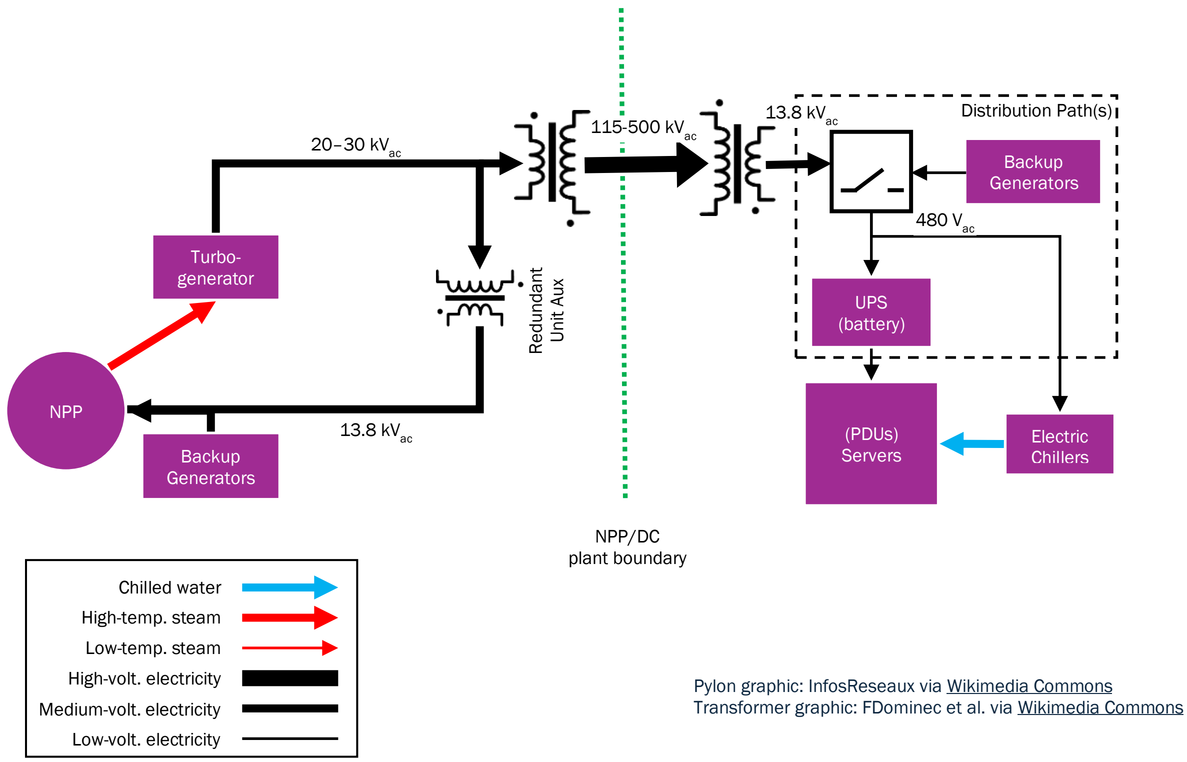


Figure 5-5. Schematic of NPP/DC Electrical Coupling Option 4: Colocation, islanded microgrid.

There are no examples of Coupling Option 4 involving a civilian NPP in the United States. However, NPPs have provided power to isolated areas in other parts of the world, such as the Russian Akademik Lomonosov nuclear power barge [99]. Military surface ships and submarines have been powered by nuclear reactors in self-contained microgrid configurations for decades. The isolated microgrid concept itself has been scaled up to 400 MW in Saudi Arabia [100].

For a DC developer, Coupling Option 4 might be desirable if speed of interconnection is of utmost importance, assuming that an NPP can be built quickly enough. It would also allow a DC to be built in an unconventional location, such as a sub-arctic region or subsea with superior cooling characteristics [101]. Power redundancy (from backup NPPs, diesel generators, or other technologies) during NPP outages would need to be provided on site as well, potentially leading to higher costs.

5.2.5 Coupling Option 5: Colocation, Microgrid with Backup Interconnection

For Coupling Option 5, the NPP and DC are colocated with a direct electrical connection between them. In contrast to Coupling Option 2, the interconnections with the BPS on the NPP side would only be sized to supply safety-critical loads (with typically two independent grid connections, depending on the regulatory requirements for the NPP), such as the reactor coolant pumps, at medium voltage. This might satisfy the NRC offsite power requirements without requiring expensive high-voltage or extra-high-voltage substation equipment. The full-size external grid connection to the DC would act as the redundant supply for the colocated NPP.

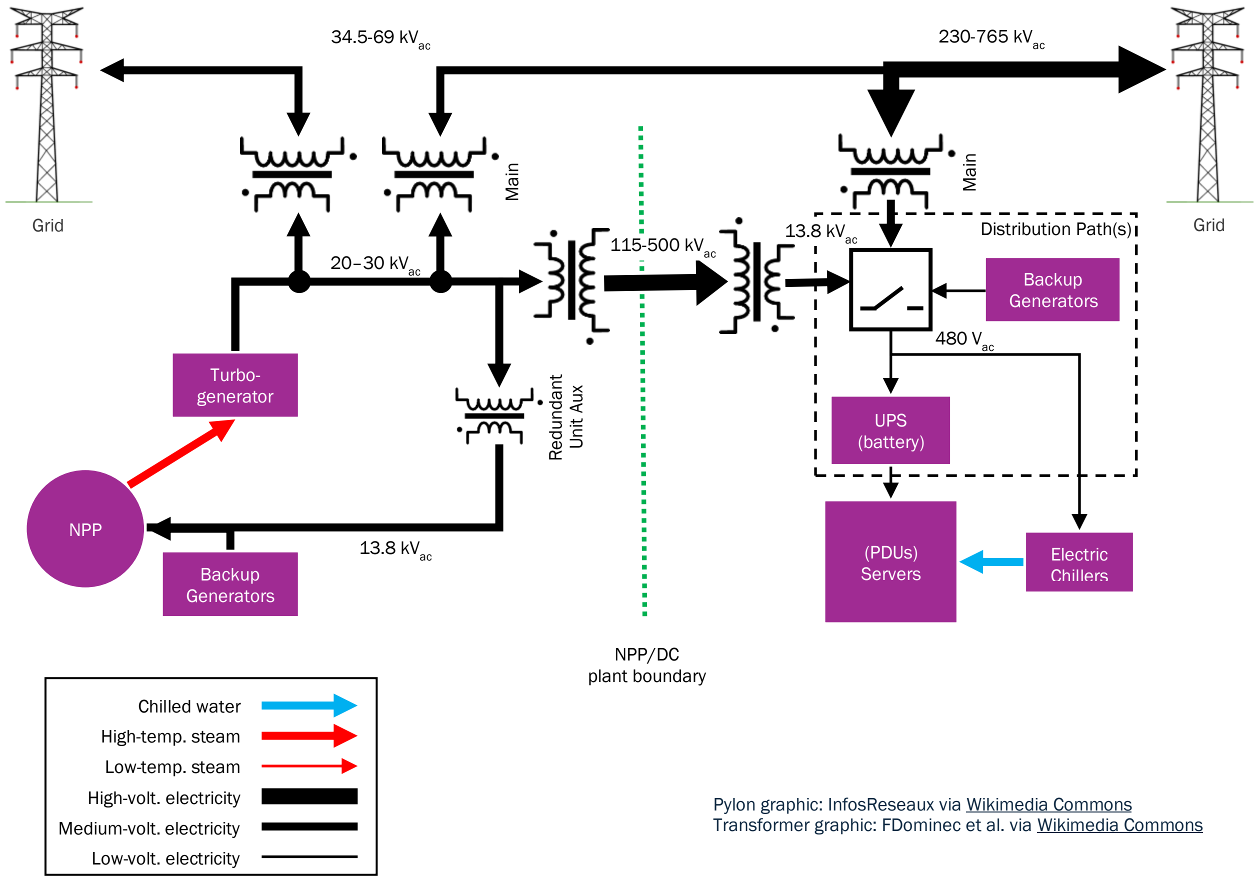


Figure 5-6. Schematic of NPP/DC Electrical Coupling Option 5: Colocation, microgrid with backup interconnection.

There are no known examples of Coupling Option 5 for NPPs. For a DC developer, Coupling Option 5 represents an intermediate step between Coupling Option 2 (which allows full export from the NPP and full import from the DC) and Coupling Option 4 (where no offsite power is available). This option would potentially enable siting in more locations than Coupling Option 2 (depending on total load), but it would still require reasonable proximity to bulk transmission, unlike Coupling Option 4.

5.2.6 Additional coupling option

A tighter integration of the NPP with DCs includes leveraging steam directly from the NPP's BOP to generate chilled water through absorption chillers [33]. This coupling configuration is only feasible under coupling options (options 2–5) and could offer significant performance advantages. Initial work demonstrated the potential to support a higher IT load than conventional cooling systems with electric chillers [30]. The methodology employed synthetic IT load profiles with varying levels of demand variability and calculated the Peak-IT load-to-Reactor ratio (PITR) metric to quantify the minimum reactor size needed and measure how effectively the nuclear asset is utilized. The analysis incorporates turbine efficiency losses from heat extraction and absorption chiller COPs ranging from single-effect (0.7–0.8) to triple-effect (1.5–1.8) configurations, providing a detailed assessment of the direct steam utilization approach.

The above study focuses on performance metrics while excluding capital expenditures (CAPEX) for reactor and chiller technologies, which can vary significantly with deployment timeline and geographic location. The key findings identify optimal combinations of absorption chiller type, COP, and heat extraction temperature when considering 4 reactor technologies: PWR, SFR, HTGR and very high-temperature reactor (VHTR). Figure 5-7 shows that absorption cooling (respective marker colors) consistently outperforms electric chiller baselines (respective dashed or solid lines) across all reactor types, and provides optimum steam extraction temperatures. This observation indicates that tight integration can benefit a diverse range of DCs, from commercial facilities to hyperscale cloud systems, with improvements of 6–16% in peak IT load support capacity. By reactor type, the improvements are: PWR 5.6–6.9%, SFR 6.2–7.7%, HTGR 6.4 (double and triple effect only), and up to 16.0% for single to triple effect configurations. The optimal PITR values for each chiller technology across different reactor designs are provided in Table 5-2.

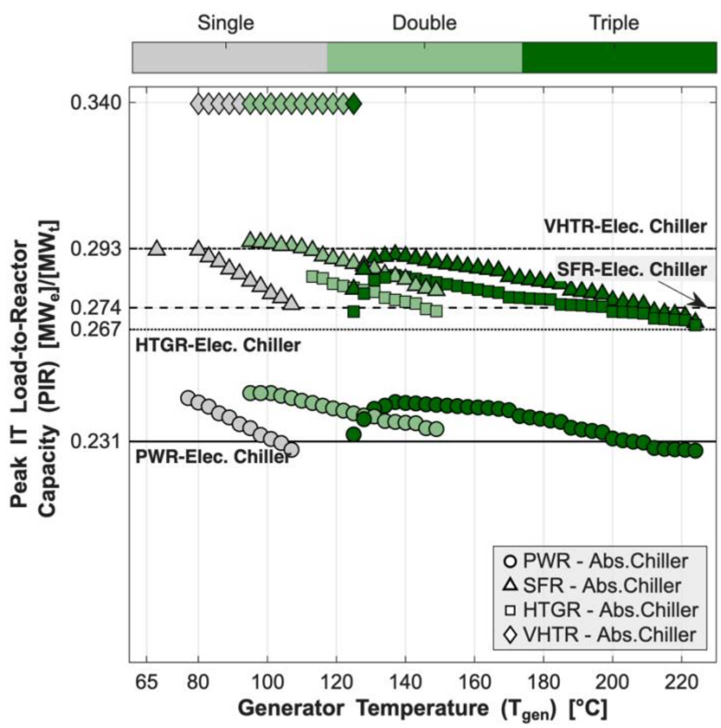


Figure 5-7. PITR across reactor types and absorption-chiller technologies: Marker shape identifies the reactor; Fill color encodes absorption-chiller (abs.). Horizontal lines are the electrical-chiller reference baselines for each reactor. The panel illustrates how PITR varies with operating temperature and chiller-type, compared to respective electrical baselines.

Table 5-2. Optimal PIRT for respective absorption chiller types across reactor designs.

Reactor	Electric chiller (Base)	Single-effect	Double-effect	Triple-effect
PWR	0.231	0.246	0.247	0.244
SFR	0.274	0.293	0.295	0.291
HTGR	0.267	-	0.284	0.284
VHTR	0.293	0.340	0.340	0.340

These heat chiller parameters are selected to minimize electricity generation drop due to turbines' off-design operations from heat extraction (assessed on the basis of BOP modeling performed in [102]), and the study minimized this drop to 7–8% for PWR, SFR, and HTGR systems. For PWR, and SFR, systems, optimal performance is achieved with double-effect absorption chillers operating at temperatures around 95–100°C. It should be noted that HTGR extraction temperatures examined are beyond the single-effect absorption chiller operating range (>110°C) and are therefore not included. VHTR systems exhibit the greatest performance gains in PITR, exceeding 15%, as they can utilize low-temperature waste heat below 125°C without incurring turbine efficiency penalties, making them particularly well-suited for tight integration strategies.

Backup chilled water will be essential for operational reliability and can be implemented through two configurations: (1) electrical chillers connected to backup generator or the electrical grid, or (2) electrical boilers connected to backup generators that supply steam to the absorption chillers during reactor maintenance periods.

EPRI also researched the case for nuclear integrated steam absorption chillers. They conclude that this is a more challenging case due to the thermal efficiency drop in nuclear BOP from high-temperature heat extraction [93]. The different results highlight the needs for transparent and comprehensive analysis, recognizing that significant optimization work may be needed to potentially allow improved performance of the NPP/DC coupling through absorption chillers.

Additional coupling options are also being researched in the community, including DC waste heat utilization in the nuclear BOP to boost system efficiency, NPP and DC sharing of cooling infrastructure, and NPP-produced H_2 that is stored and used as peak power. Those are not documented in this report, owing to the lack of published data at this time, but are currently being researched by EPRI [93].

5.3 Meeting on-site reliability requirements for different NPP/DC coupling options

Within each coupling path option, the power distribution path may be designed for varying degrees of availability by incorporating features for redundancy, maintainability without disruption, and fault tolerance. One standard that provides requirements for these in the electric power capacity and distribution paths is the *Uptime Institute Data Center Site Infrastructure Tier Standard: Topology,* which defines the widely used Tier I–IV classification based on topologies of the power and cooling systems [103]. This subsection describes—at a high level—four potential DC power distribution topologies based on the four tiers which may be used within each of the five NPP/DC coupling options described in Table 5-1. Tier IV reliability is of particular interest owing to the significant growth of DCs with this level of reliability requirements.

Table 5-3 provides a summary of the topology requirements under each tier. Each tier includes on-site generation which is able to fully support the server and cooling loads without utility power supply, including on-site fuel storage to support a minimum of 12 hours of operation at full capacity. Each of the tiers also includes a UPS with battery storage, which ensures adequate power quality under conditions including over- and under-voltage, harmonic distortion, and short-duration loss of power supply (typically, in the 15-30 min range).

The Uptime Institute standard makes a clear distinction between power sources considered as onsite generation and those considered as supplied by a utility system:

> *Services originating from outside the data center property boundary and not in full control of the data center organization are deemed and treated as a utility system… These services are not considered reliable supplies for the data center and are not considered to meet the Tier requirements for the site.*
>
> *Services to meet the Tier requirements must* ***be fully contained on the data center property and in full control of the data center organization***. [103]

This distinction has the following implication for the design of coupling of the NPP and DC: if the NPP is not fully contained on the DC property and under the full control of the DC organization, it is treated as utility supply under the Tier classification and does not contribute to the onsite generator requirements. Conversely, if the NPP is fully contained on the DC property and under the full control of the DC organization, it can contribute to the onsite generator requirements.

Table 5-3. Summary of Uptime Institute Tier Topology requirements [103].

	Tier I	**Tier II**	**Tier III**	**Tier IV**
Description	Basic Site Infrastructure	Redundant Site Infrastructure Capacity Components	Concurrently Maintainable Site Infrastructure	Fault Tolerant Site Infrastructure
Capacity	N	N+1	N+1	N after any failure (typically ≥2N)
Redundant Components	None	Backup generation, UPS, cooling, fuel tanks	All power and mechanical equipment	All power and mechanical equipment
Power Distribution Paths	Single	Single	1 Active and 1 Alternate	2 Simultaneously Active
Mechanical (Cooling) Distribution Paths	Single	Single	1 Active and 1 Alternate	2 Simultaneously Active
UPS	Yes	Yes	Yes	Yes
On-Site Generation	Yes	Yes	Yes	Yes
On-Site Generation Maintainable and Fault-Tolerant While Carrying the Site	No	No	Yes	Yes
Generators May Have Limitation on Fully Loaded Runtime	Yes	Yes	No	No
On Site Fuel Storage for Backup Generation	12 h	12 h	12 h	12 h

	Tier I	Tier II	Tier III	Tier IV
All Components Concurrently Maintainable	No	No	Yes	Yes
Compartmentalized (complementary systems and distribution paths physically isolated)	No	No	No	Yes

The example topologies in this subsection assume that the NPP does not contribute to the onsite generator requirements. However, any of these topologies may be modified to assume the nuclear plant contributes to the onsite generator requirements by connecting the nuclear plant to the onsite generation bus with appropriate transformation and protection and replacing the corresponding onsite generation capacity.

The four topologies that follow are example topologies representing one possible design structure with redundancy levels corresponding to each of the four tiers. Many variations are possible, and details such as circuit breakers and other switch elements are not shown here. The nominal voltages may differ; for example, the three-phase 480-V supply to the power distribution units (PDUs) may be transformed to a lower voltage such as 208 V in some applications. Onsite generation may output power at 480 V (typical for industrial backup reciprocating gensets up to about 3 MW) or higher voltage (larger gensets may operate at up to 13.8 kV) with a step-down transformer before the transfer switch.

5.3.1 Example Tier I Electrical Topology

Tier I represents the minimum infrastructure necessary to operate the servers and cooling system, including onsite generation, with the ability to operate for 12 hours without utility electricity and a UPS with battery storage to ensure power quality and avoid disruptions from short power supply interruptions. Tier I does not require any redundant capacity or distribution path elements, and a Tier I system must be shut down to perform preventive or corrective maintenance on elements of the distribution path. An automatic transfer switch (ATS) switches between on-site and external supply if one is disrupted.

This topology, shown in Figure 5-8, normally includes one connection to an external power supply. In Coupling Option 1, this would be the electric utility. In Options 3 and 4, this would be the NPP. Options 2 and 5 include connections to both the utility and NPP. In these cases, a second medium-voltage supply connection would be used, as shown in gray in the figure.

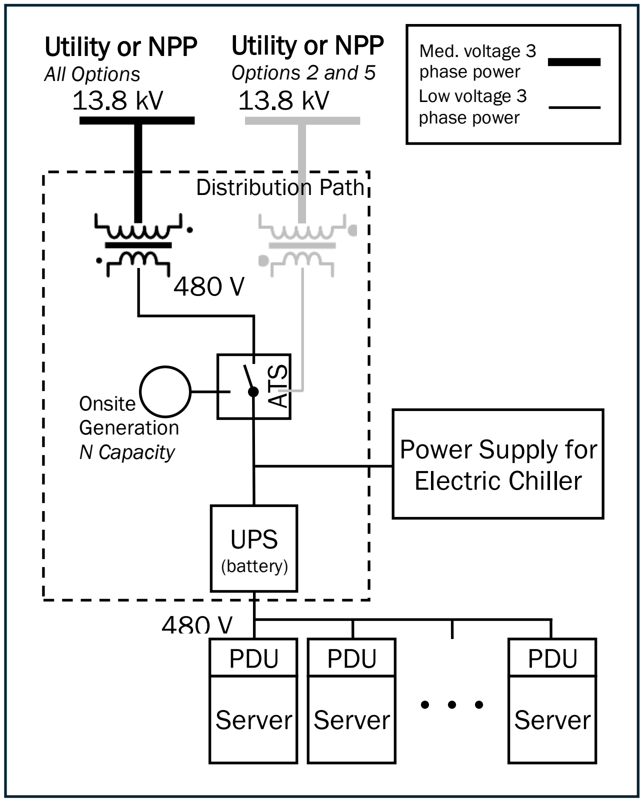


Figure 5-8. Example of a DC power distribution topology without redundant paths or capacity, corresponding to Tier I.

5.3.2 Example Tier II Electrical Topology

Building on Tier I, Tier II adds the requirement of redundant capacity in the backup generation, UPS modules and energy storage, chillers, heat rejection equipment, pumps, cooling units, and fuel tanks so that the failure of any one of these components will not cause a disruption. Tier II requirements do not include redundant distribution paths, and a Tier II system must be shut down to perform preventive or corrective maintenance on elements of the distribution path.

An example topology is shown in Figure 5-9. As with the Tier I topology, the medium-voltage supply would be an electric utility under Coupling Option 1, the NPP under Options 3 and 4, and both under Options 2 and 5.

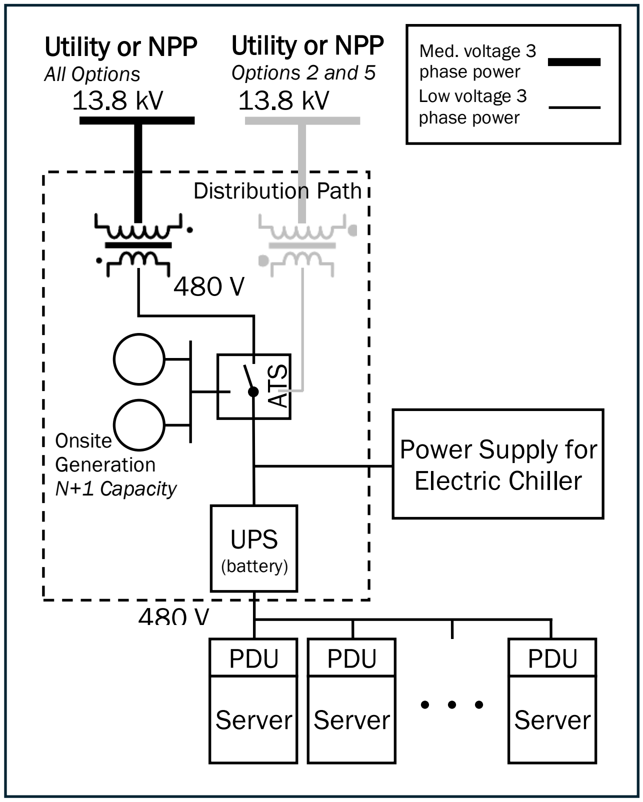


Figure 5-9. Example of a DC power distribution topology with redundant capacity but without redundant paths, corresponding to Tier II.

5.3.3 Example Tier III Electrical Topology

Tier III introduces the requirement of concurrent maintenance, enabling preventive or corrective maintenance on elements of the distribution path without disrupting DC operations. This requirement adds a redundant power distribution path to the topology, as shown in Figure 5-10. The active path, shown in blue, actively supplies power under normal operations, and the alternate path, shown in orange, only supplies power when a planned or unplanned outage impacts the active path.

This topology includes two connections to external power supplies. In Coupling Option 1, both of these are the electric utility. For increased reliability, these may be fed by different substations. In Coupling Options 3 and 4, both external connections are from the NPP. In Coupling Option 5, the active path is connected to the NPP, and the alternate path is connected to the utility supply. Finally, in Coupling Option 2, in which either the NPP or utility supply may fully support the DC needs, either branch may be active for a period of time, with switching between the branches determined not only by maintenance needs but by other criteria such as economics.

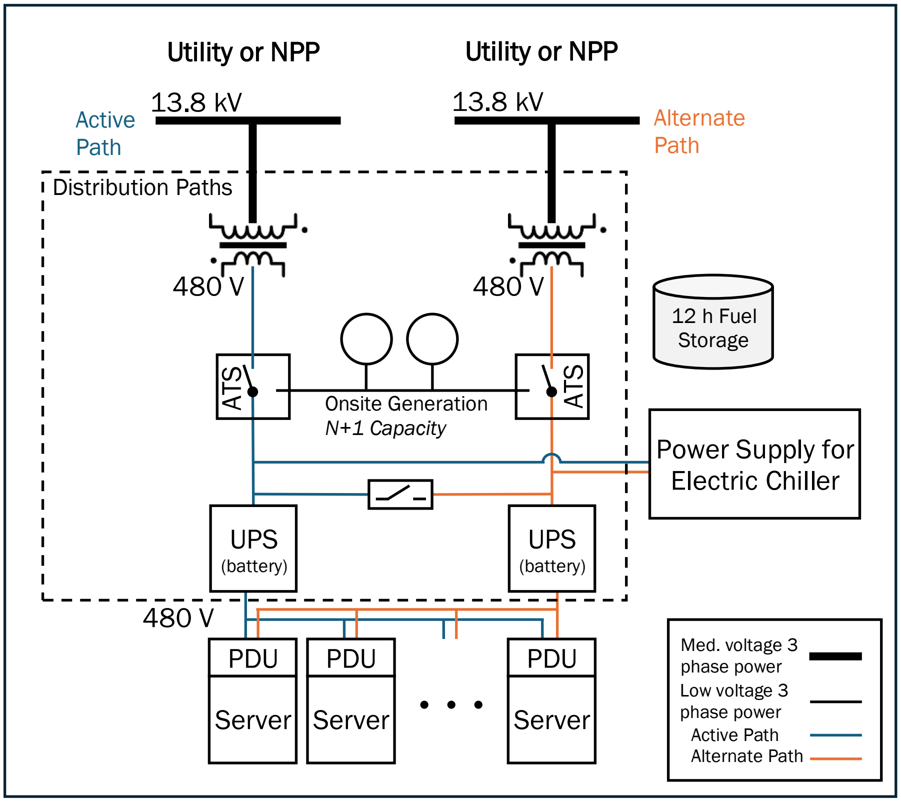


Figure 5-10. Example of a DC power distribution topology with redundant capacity and a redundant path, corresponding to Tier III.

5.3.4 Example Tier IV Electrical Topology

Finally, Tier IV introduces the requirement of fault tolerance, specifying that the outage of any capacity component or element of the distribution path will not cause a disruption of the DC operations. Compared to the Tier III topology, this adds switched connections between each point in the redundant paths and an additional set of onsite N+1 generators. In addition, the standard specifies that both paths are active during normal operations. The example topology is shown in Figure 5-11.

As in the Tier III topology, Tier IV includes two connections to external power supplies. In Coupling Option 1, both are the electric utility and again may be fed by different substations. In Coupling Options 3 and 4, both external connections are from the NPP. In Coupling Options 2 and 5, one path is connected to the NPP, and the other is connected to the utility supply. Since both distribution paths must be active under Tier IV, additional configuration may be required to allow control of the proportion of power received from the NPP and utility connection. For example, the NPP could provide both active supply connections, with a third, alternate connection providing the utility supply when necessary.

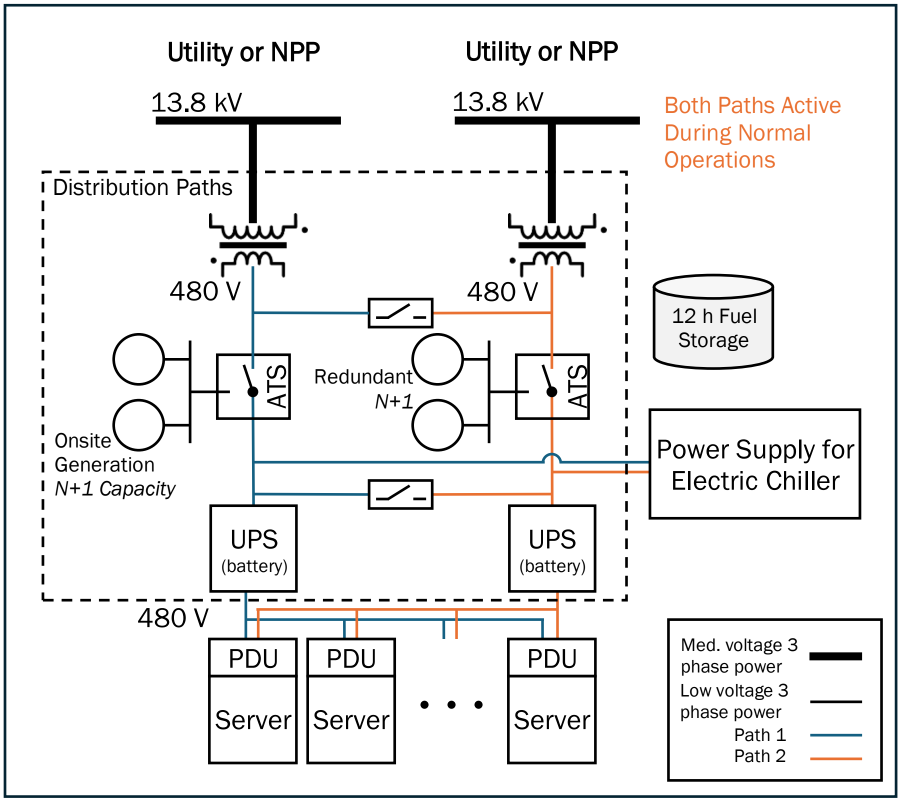


Figure 5-11. Example of a DC power distribution topology that is fault-tolerant, corresponding to Tier IV.

5.4 Summary of Nuclear/DC Coupling Options

The different coupling options discussed in Section 5 are summarized in Table 5-4, with the list of expected benefits and challenges that were discussed. Different NPP/DC scenarios were then derived on the basis of the review of deployment scenarios in Section 3, and are summarized in Table 5-5. This list is not an exhaustive list, but it illustrates the large number of potential existing scenarios together with their potential deployment timeline and capacity.

Several of these scenarios are of high interest and are being considered for deployment, in the context of existing or new NPP construction. There may be limited benefits in new nuclear deployment for an existing DC (scenario #6 of Table 5-5), unless it is planning to significantly expand its capacity.

In the remaining sections of the report, the focus is on scenarios #2 (Greenfield) and #3 (Brownfield): a new DC colocated together with a new SMR or LR (with one of the BTM coupling options) in a greenfield or a brownfield project. Reactor sizing optimization is discussed in Section 6, a siting study is presented in Section 7 and socio-economic implications are estimated in Section 8. Additional scenarios will be considered for analyses in future work.

Table 5-4. Non-exhaustive list of benefits and challenges associated with different NPP/DC coupling options.

Coupling Option	**#1**	**#2**	**#3**	**#4**	**#5**
NPP/DC Connection	No Colocation, Interconnected with BPS	Colocation with Direct Connection and Full Power Export	Colocation with Direct Connection BTM	Colocation, Islanded Microgrid	Colocation, Microgrid with Backup Interconnection
Site Availability	Medium	Lower	Lower	Higher	Lower
NPP Safety Regulatory Issues	None	None	None	Likely	Maybe
Power Market Regulatory Issues	None	Maybe	Likely	None	Maybe/Likely
On-Site Generation Capacity (NPP or other)	None	Higher (≥N)[1]	Higher (≥N)[1]	Highest (≥2N)[2]	Higher (≥N)[1]
On-Site Generation Timeline	Faster (none)	Slower	Slower	Slowest (redundant NPPs)	Slower
Local T&D CAPEX	Higher	Highest	Medium	Lowest	Medium
Local T&D Timeline	Slower	Slowest	Medium	Fastest	Medium
T&D Line Losses	Higher	Lower	Lower	Lower/None	Lower
Power Cost Certainty	Depends (indirect nuclear + wholesale purchases)	Depends (direct nuclear + wholesale purchases)	Depends (direct nuclear + wholesale purchases)	More certain (direct nuclear purchase)	More certain/Depends (direct nuclear + wholesale purchases)

[1] ≥N: At least one unit which can meet peak load.
[2] ≥2N: At least two units, each of which can meet peak load independently.

Table 5-5 Non-exhaustive list of NPP/DC deployment scenarios.

# Name	Similar to	Timeline	Potential deployment [GWe]	Coupling Option (Table 5-1)	Data Center		NPP	
					Type	Existing?	Type	Existing?
#1 PWR restart	Microsoft/ TMI-1	2025-2028	<11 GWe (likely <2.23GW)	#1	Hyperscale	No	Large PWR restart	Yes (recently shut down NPPs)
#2 Greenfield	Google/Amazon deals with Xe and KP	2030-2040	No limit	#2 through #5	Hyperscale or Gigawatt scale	No	New Large PWR SMRs	No
#3 Brownfield		2030-2040	<95 GW	#2 through #5	Hyperscale or Gigawatt scale	No	SMRs	"Brownfield": on existing NPP or coal-fired power plant (CPP) sites
#4 PWR Uprate	Constellation power uprate	2025-2030	<6 GW	#1 through #5	DC/Colocation (<100MW)	No	PWR uprate	Yes
5 Existing PWR PPA	Amazon / Talen	2025-2030	<97 GW	#3	Hyperscale	No	PWR (existing)	Yes
6 Existing DC	Existing DC looking for growth	2030-2040	No limit	#1 through #5	Hyperscale	Yes	SMRs	No
7 Giga scale DC/NPP	OpenAI plans	2035-2040	No limit	#2 through #5	Gigawatt scale	No	New Large PWR SMRs	No
8 Federal Site	Executive Orders 14141 and 14179	2030-2040	A few GW	#2 through #5	Hyperscale	No	SMRs	No (National Labs and federal land)

6. NPP SIZING FOR DIFFERENT DATA CENTER CONFIGURATIONS

The purpose of this section is to determine the optimal reactor size (that minimizes the Levelized Cost of Electricity or LCOE) of a new NPP project to meet energy demands from a DC under different coupling options (1 through 5, as described in Table 5-1). This analysis is applicable to most of the NPP/DC deployment scenarios described in Table 5-5, except for those relying on existing NPPs (scenarios #1, #4, and #5). It addresses the following questions:

Should one large reactor or multiple small reactors be built?

- How many additional reactor units are required to achieve the necessary reliability requirements for DCs discussed in Section 5?
- What is the grid connection configuration? Will the NPP be dedicated solely to powering the DC (BTM), and will any excess electricity be exported to the grid?
- How does the optimal reactor size depend on changes in demand, electricity prices, and interest rates?

This analysis intends to help DCs down select the sizes of NPPs to consider. It is important to note that this section does not consider the specifics of reactor design. Instead, it focuses on evaluating the trade-offs between economies of scale and mass production to identify the most promising reactor sizes for DC demands. The findings emphasize the variability in ideal reactor power output, which is based on several factors. Also, this section does not consider the costs associated with T&D or load flattening through batteries.

6.1 Methodology

A framework for identifying the optimal reactor size for DCs is presented in detail in [35]. A summary of this framework is shown in Figure 6-1. This framework uses data from the literature on overnight costs, O&M costs, and construction durations for various reactor sizes. These data are used to model the cost dependence on reactor size. The power demand of datacenters can fluctuate on short timescales (down to seconds and minutes, as shown in Figure 2-1). However, this model assumes a fixed demand value, ignoring these fluctuations. It is assumed that these load fluctuations will be addressed on the datacenter side, and that the load profile will not affect the optimal reactor size for the datacenter.

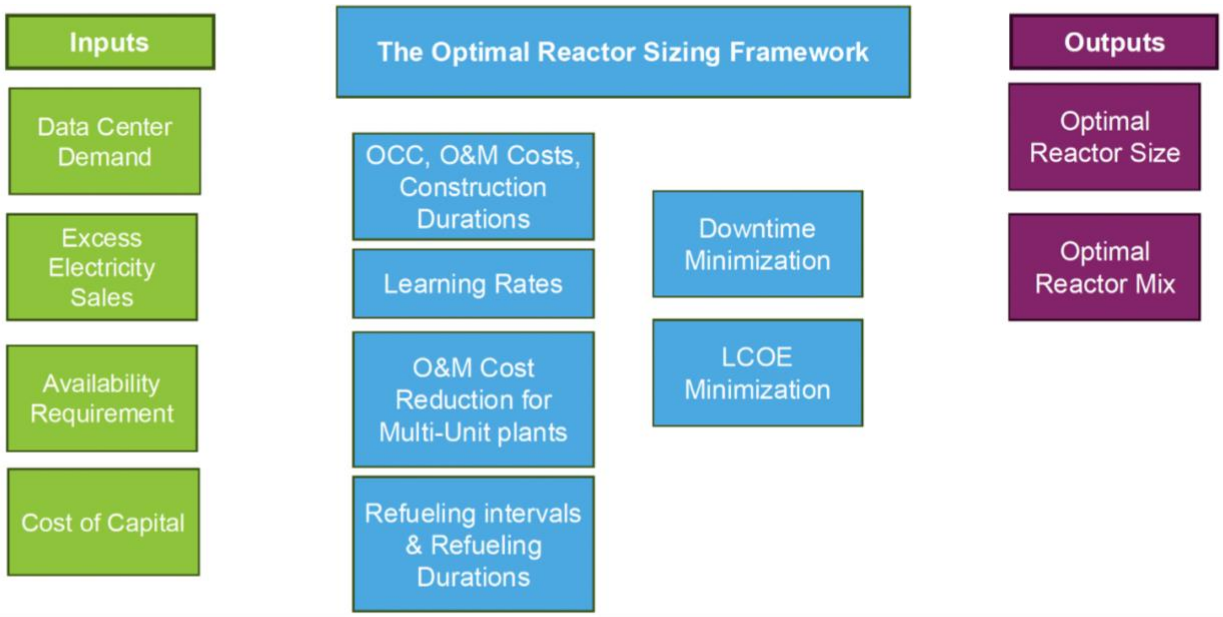


Figure 6-1. A framework for estimating the optimal reactor size for a DC. OCC: overnight capital cost O&M: operation and maintenance costs (includes fuel costs); LCOE: levelized cost of electricity.

Similarly, the framework models the learning rate dependence on reactor size, the O&M cost reduction when building more units, and the dependence of refueling interval and refueling duration on reactor size. The framework also aims to minimize downtime due to refueling. For example, if the DCs are powered by multiple small reactors, it is necessary to ensure that the reactors are not down for refueling simultaneously. Finally, the framework estimates the optimal reactor size that minimizes the total LCOE for the nuclear reactor(s).

While the details of this methodology can be found in [35], the data (costs, construction duration, learning rate, refueling interval) are summarized in Figure 6-2 and Table 6-1. Note that the costs here are Between-of-a-Kind (BOAK) costs, sometimes referred to as the “next commercial offering.” These costs do not include the costs specific to a First-of-a-Kind (FOAK) reactor but still exceed the Nth-of-a-Kind cost. Because the FOAK demonstrations are already well underway, the BOAK estimates were deemed suitable for the purposes of this study. The equations that were developed on the basis of data from the literature are listed in Table 6-1. Learning across multiple sites is not considered in this model, which focuses on a single site project.

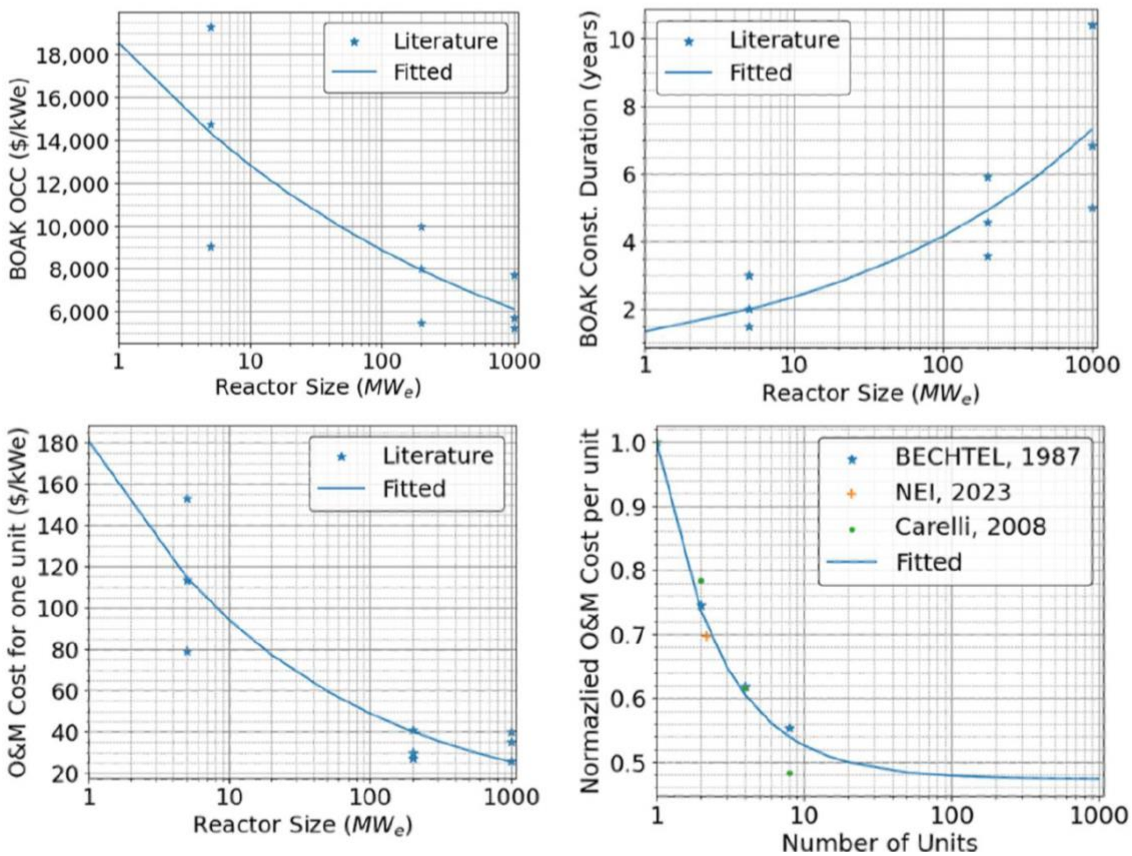


Figure 6-2. Curve fitting based on literature data for the OCC, O&M cost (2022 USD), and construction duration.

Table 6-1. Summary of the economies-of-scale curves used in this study. The OCC, O&M costs, construction duration, and refueling interval depend on the reactor size (i.e., the electric power (P) in MW_e).

	Equation	**Value at 1 GW**	**Value at 300 MW**	**Value at 5 MW**	**Refs.**
BOAK OCC (USD/kWe)	$18562 \times P^{-0.16}$	6145	7451	14,347	[104, 105]
O&M (USD/MWh) for one unit	$181 \times P^{-0.28}$	25	36	115	[104, 105]
Normalized O&M cost reduction with more units	$\frac{0.53}{num\ of\ units} + 0.47$	0.74 (2 units), 0.61 (4 units), 0.54 (8 units)			[106, 107, 108, 109]
BOAK construction duration (months)	$16 \times P^{0.25}$	90	65	24	[104, 105, 110]
Learning rate	$0.145 \times P^{-0.083}$	8%	9%	12.7%	[104, 105, 111]
Refueling interval (years)	$5 \times P^{-0.17}$ (2 years if P >= 200)	2	2	3.8	[112, 113]

When determining the ideal reactor size with a minimum LCOE, the following assumptions are made:

- The DC requires a reliability criterion of 99.995% (Tier IV). To meet this high standard, additional units (reactors) may be built to ensure such reliability, or there must be a backup power source (e.g., the NPP connected to the grid). If the NPP is connected to the grid, it is assumed that the annual power availability from NPPs needs to be only 90%. This availability is considered sufficient to classify the DC as powered by an NPP, even if it relies on other energy sources when the NPP is offline.
- Calculating the LCOE requires determining the annual and capital investment costs. The capital investment cost includes the cost of interest, assuming an interest rate of 6%. The levelization period is assumed to be 40 years.
- When selecting the ideal reactor size for the DC's needs, a wide variety of reactor sizes are available. However, in this section, it is assumed that the available reactor unit sizes are limited to 1000, 900, 800, 700, 600, 500, 400, 300, 200, 100, 50, 20, 10, 5, and 1 MWe.
- The LCOE is estimated using a simplified version of the net LCOE, as follows:

$$LCOE = \frac{\sum_{t=1}^{T} \frac{C_t + O_t - R_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}}$$

where

- C_t is the capital investment costs in year t.
- O_t are O&M costs in year t.
- R_t is the revenue generated by selling electricity to the grid in year t (if the electricity generated from the NPP is not solely used to power the DC but excess electricity is sold to the grid).
- E_t is the electricity produced during the lifetime of the project.
- r is the discount rate.
- T is the levelization period.

6.2 Results

As discussed in Section 5.2, there are several options for the power connection or NPP/DC coupling. Depending on the connection option, the LCOE of the NPP powering the DC may vary. The characteristics of these connection options are listed in Table 6-2. For each connection option, the optimum reactor size is determined (see the following subsections).

Table 6-2. Different characteristics of NPP/DC coupling that affect sizing study.

Grid Connection Option	Option #1	Option #2	Option #3	Option #4	Option #5
Grid connection	Through the grid	Direct connection to the DC with option to sell excess electricity to the grid and get backup from grid	Direct connection to DC, with option to sell excess to the grid	Direct connection to DC without connection to the grid	Direct connection to DC with backup from the grid
Excess electricity exported to the grid?	Yes	Yes	Yes	No	No
Extra units needed (n+1)?	No	No	Yes	Yes	No
Power availability required from NPPs per year	90%	90%	99.995% (for Tier IV)	99.995% (for Tier IV)	90%
Proximity requirement	>Site boundary <50 miles	>Site boundary <1 mile	>Site boundary <1 mile	>Site boundary <1 mile	>Site boundary <1 mile

6.2.1 Options #1, 2, & 5

Option #1 is likely the most common coupling option, where the DC is powered by the electricity grid, which receives electricity from multiple sources, including an NPP. In this option, there is no need to add extra nuclear units since the DC's connection to the grid guarantees the availability of electricity even when the NPP is down for refueling or maintenance. The Tier IV compliance will also require onsite backup generators, as discussed in Section 5.3. Since the NPP is connected to the grid, it does not need to achieve a reliability of more than 99%, as required by the DC. It is assumed that an NPP reliability of 90% is sufficient for the DC to be considered a nuclear-powered DC.

In this option, it is assumed that the total power output of the reactor(s) will match the DC's demand, resulting in minimal excess electricity. The primary factor determining the ideal reactor size in this option is the trade-off between economies of scale (larger reactors have a lower cost per MWh) and economies of learning (smaller units can be constructed more quickly, allowing for faster accumulation of experience and learning).

Figure 6-3 shows the estimated LCOEs at various reactor capacities for different levels of DC demand. When the DC demand is 50, 500, or 1000 MWe, the minimum LCOE is achieved by building one reactor whose capacity matches the demand. For demands of 2000 or 6000 MWe, the minimum LCOE is achieved by building 2 or 6 units of 1000-MWe reactors, respectively, as it is assumed that the largest reactor size is 1000 MWe. When the demand is 100 MWe, the minimum LCOE is achieved by building 2 units of 50-MWe reactors. However, the cost difference between 2 units of 50 MWe and 1 unit of 100 MWe is negligible, especially considering the uncertainty associated with LCOE estimation. Therefore, it can be concluded that for this grid connection option (Option #1), building one unit, or the minimum number of units required to match the demand, will achieve the minimum LCOE. It is worth pointing out that the larger reactor project may only be slightly cheaper than the multi-unit SMR project.

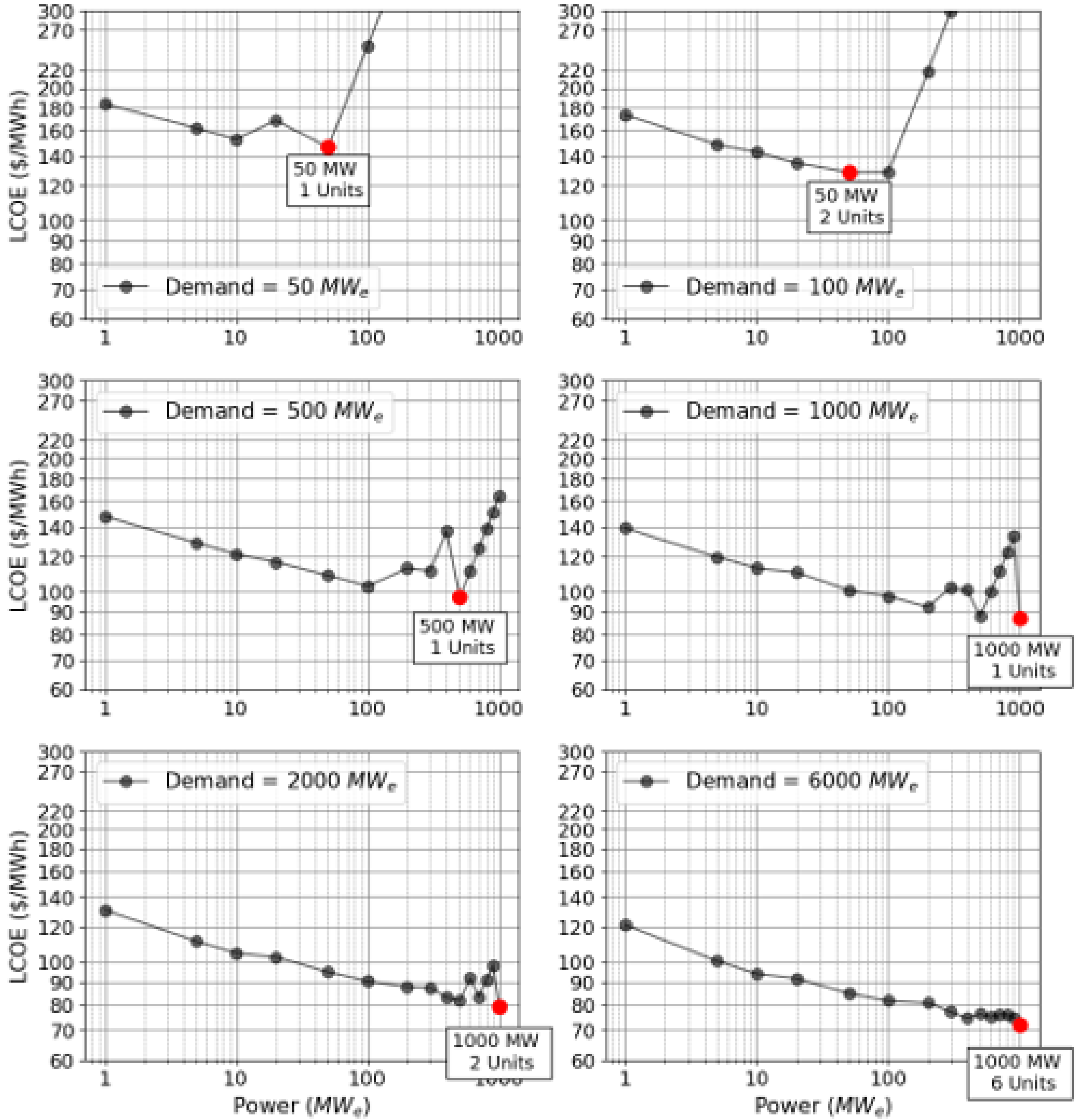


Figure 6-3. Estimation of LCOE at various reactor power levels for different DC sizes (demands) under grid connection option #1 (both the NPP and the DCs are connected to the grid). The red dot in each figure represents the minimum LCOE.

For the second grid connection option (Option #2) in Table 6-2, the reliability required by the DCs is still guaranteed by connecting the NPP to the grid. Therefore, the "Option #2" is considered the same as "Option #1" in terms of the ideal reactor size. The primary difference lies in the proximity of the NPP to the DCs, which impacts the transmission cost. However, the transmission cost was not considered in this work.

Option #5 in Table 6-2 is the same as Option #2, except that excess electricity is not exported to the grid. Although this specific option was not modeled, it is expected that the results will not differ significantly from Option #2, given that the excess electricity is minimal.

6.2.2 Option #3

The BTM connection (Option #3 in Table 6-2) has several advantages. DCs with a BTM connection are less susceptible to power outages, particularly those caused by downed transmission lines on the grid. Additionally, BTM connections provide DCs with greater control over their power sources, offering reliability benefits despite the challenges associated with implementation. In this option, the DC does not receive electricity from the grid. Therefore, extra reactor units must be available to guarantee the high reliability requirements of the DCs. Building these additional units means that there is excess electricity that is not used throughout the year. Hence, the NPP can also make profits by exporting excess electricity to the grid.

The need to build additional units for reliability favors relatively smaller reactors. For example, constructing additional LR units, which may not be used frequently, increases the LCOE significantly. In contrast, adding additional MRs may not significantly impact the LCOE. Another factor to consider is that a significant amount of excess electricity might be exported to the grid, influencing the LCOE estimation and the ideal reactor size (refer to the LCOE equation in Section 6.1).

Although the wholesale electricity prices can vary significantly by location and season. Factors such as regional demand and weather conditions can influence electricity prices. For this analysis two values are used to represent medium and low wholesale prices, which are \$60/MWh and \$10/MWh

Figure 6-4 and Figure 6-5 show the selection of the NPP with the minimum LCOE for the BTM option. For example, with a DC demand of 50 MWe and an electricity price of \$10/MWh, it is recommended to build 11 units of 5-MWe reactors. Conversely, if the electricity price is \$60/MWh, it is advisable to construct 6 units of 10-MWe reactors. The higher electricity price offsets the additional unit's cost, resulting in a lower LCOE.

For DCs with relatively low demand (<500 MWe), there is a minimum LCOE that corresponds to an optimal reactor size that balances the economics of learning and economies of scale. However, for higher demands (2,000 or 6,000 MWe), economies of scale dominate, making larger reactors preferable. Additionally, higher electricity prices (Figure 6-5) make larger reactors more likely to achieve a lower LCOE.

In general, at a low electricity price (\$10/MWh), the ideal reactor size is between 1/10 and 1/20 of the DC demand. At a high electricity price (\$60/MWh), the ideal reactor size is between 1/2 and 1/6 of the DC demand. The number of units can be calculated using this formula: $1 + \frac{datacenter\ demand}{reactor\ size}$

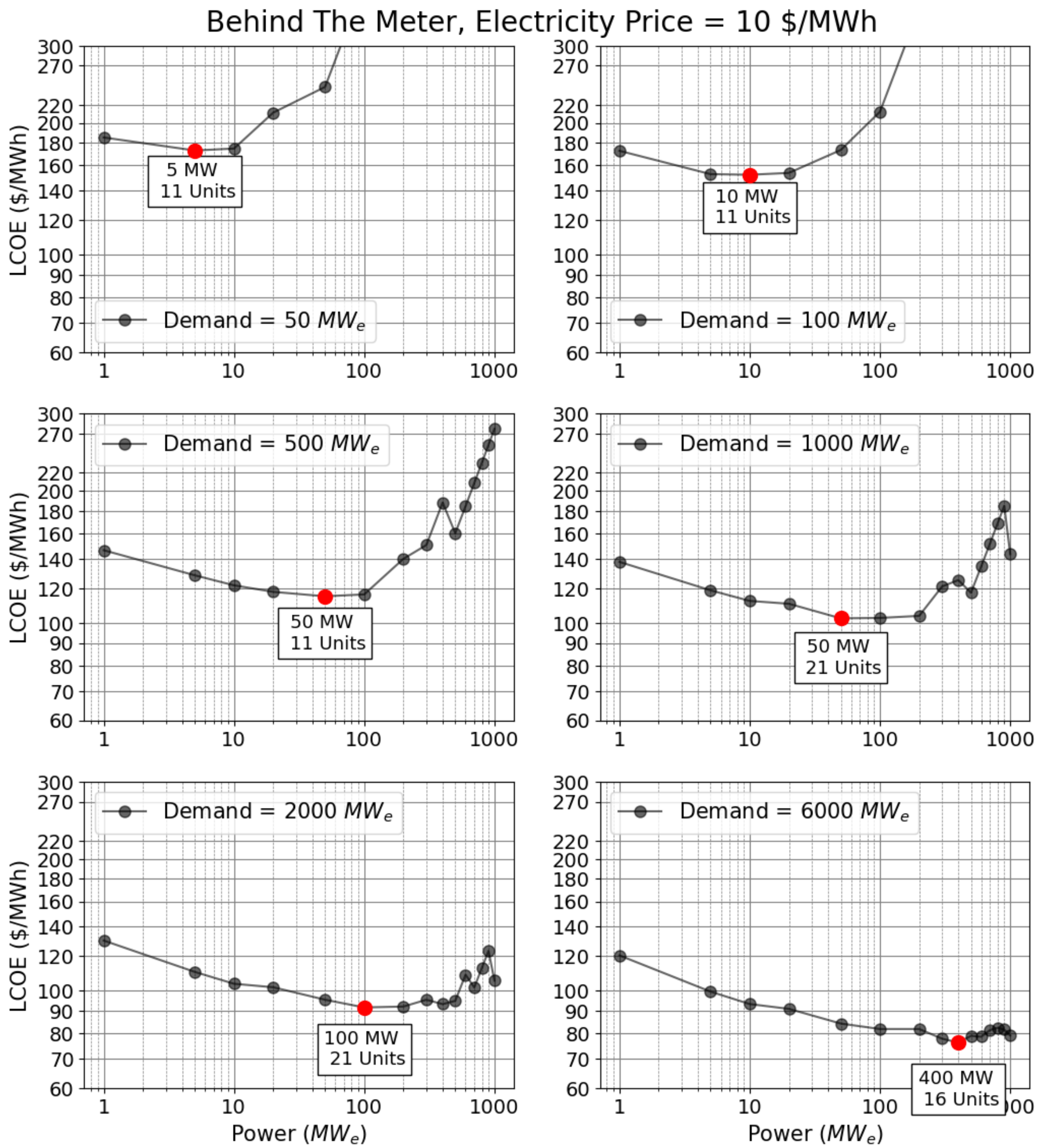


Figure 6-4. Estimation of LCOE at various reactor power levels for different DC sizes (demands) under grid connection option #3 (the DC is connected to the NPP behind the meter, with the option to sell excess electricity to the grid). A low wholesale electricity price of $10/MWh is assumed. The red dot in each figure represents the minimum LCOE.

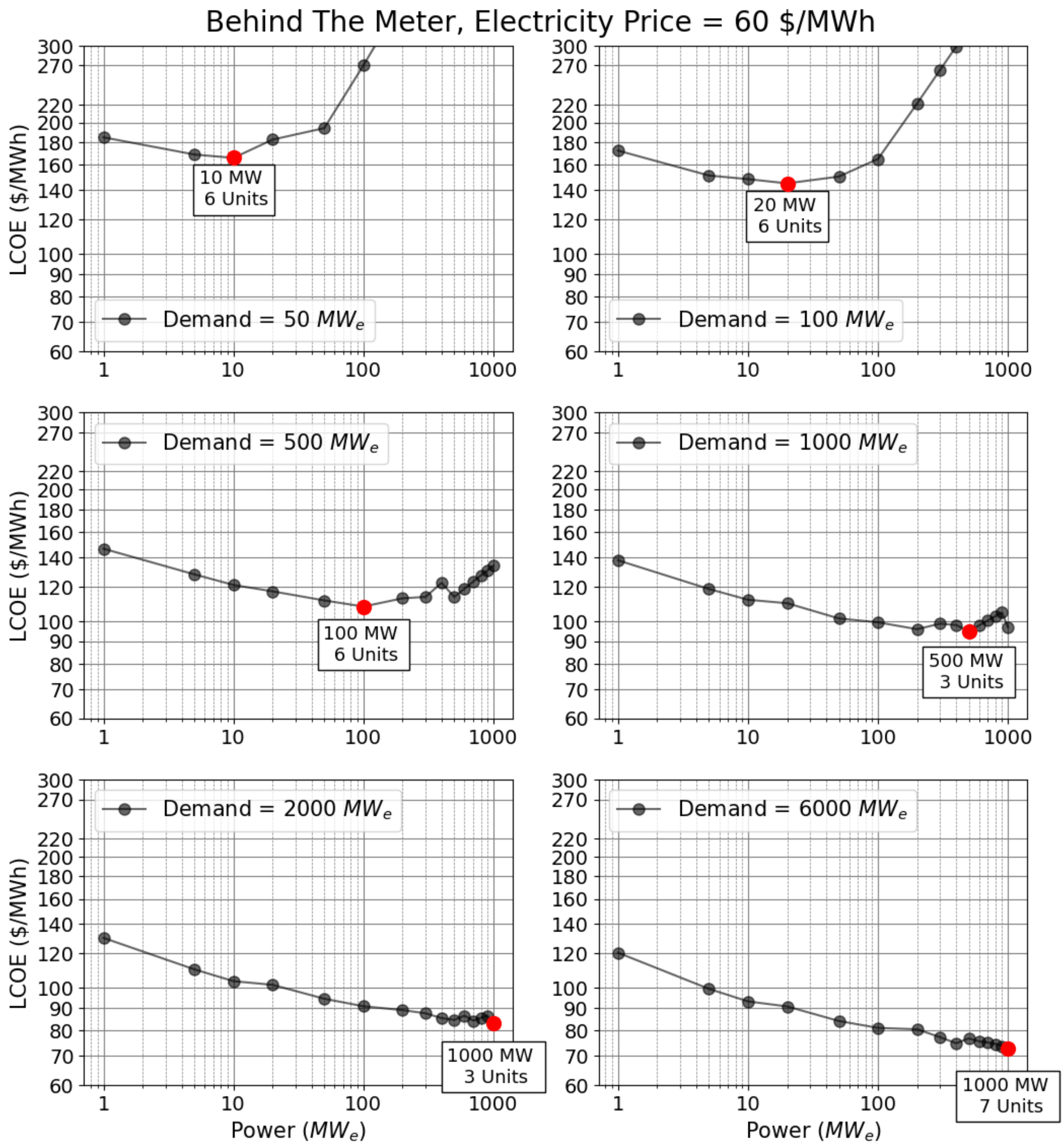


Figure 6-5. Estimation of LCOE at various reactor power levels for different DC sizes (demands) under grid connection option #3 (the DC is connected to the NPP behind the meter, with the option to sell excess electricity to the grid). A high wholesale electricity price of $60/MWh is assumed. The red dot in each figure represents the minimum LCOE.

6.2.3 Option #4

In this option, both the DC and the NPP are totally independent from the grid, which can be an advantage in isolated areas and if the transmission and distribution costs are high. This option is relatively similar to Option #3 since additional reactor units are required for reliability, except that the excess electricity is not exported to the grid. Hence, the results in this section (Figure 6-6) are similar to those for Option #3 when the electricity price is low (Figure 6-4), except that the values of the LCOEs are slightly different (see the LCOE values in Table 6-3).

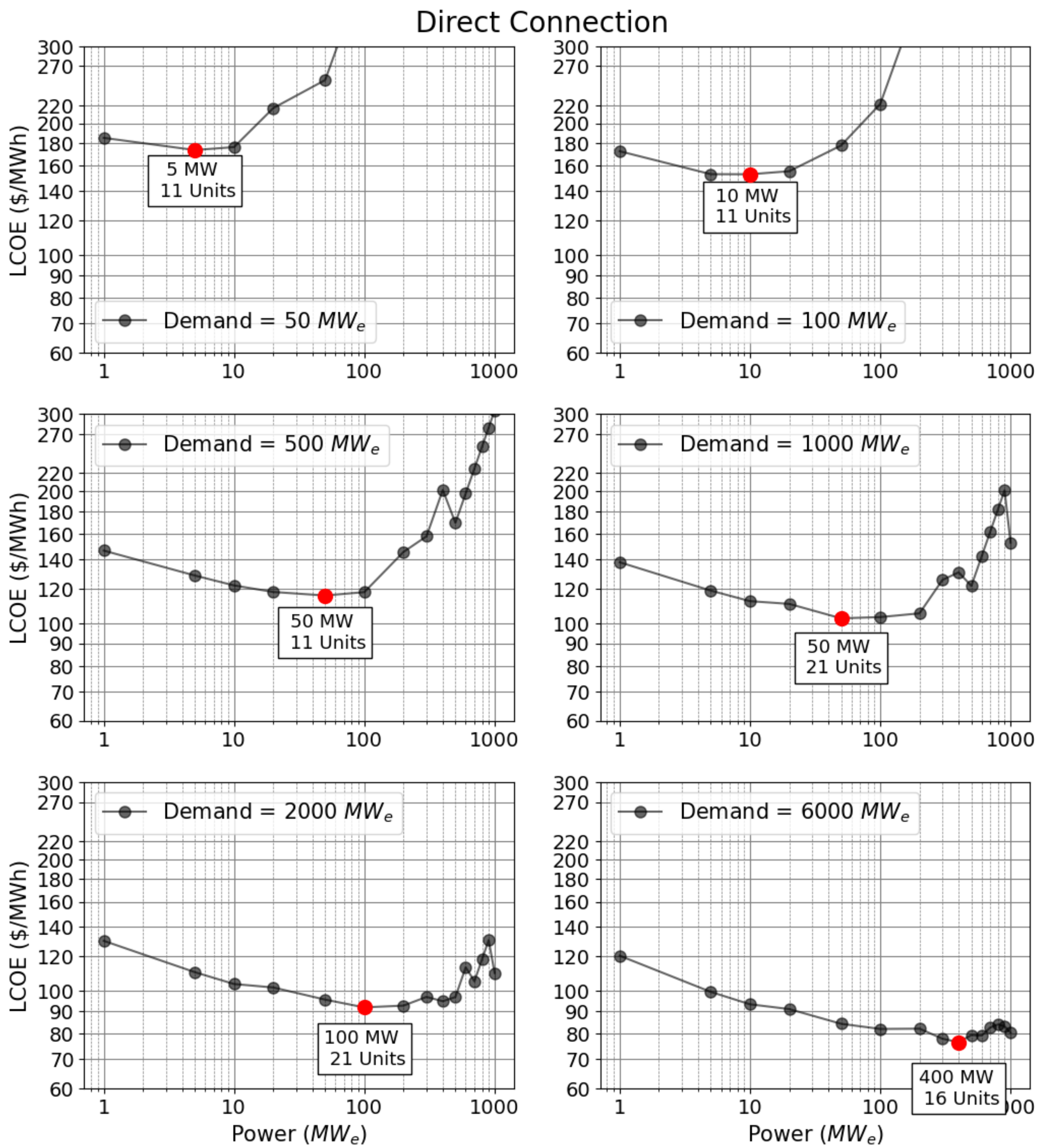


Figure 6-6. Estimation of LCOE at various reactor power levels for different DC sizes (demands) under grid connection option #4 (the NPP is directly connected to the DC without connection to the grid). The red dot in each figure represents the minimum LCOE.

6.3 Summary

This section highlights the factors influencing the decision to build larger or smaller reactors for powering DCs. The findings indicate that there is no universal solution. Depending on the DC-NPP configuration, total demand, economies of scale, and electricity price, the ideal reactor size varies for each application. A summary of the results in this section is presented in Table 6-3, which outlines the key trends noted when selecting reactor size for minimum LCOE:

- Larger reactor sizes are ideal for higher DC demand.
- Higher DC demand enables economies of scale and reduced LCOE.
- In the absence of grid backup, additional reactor units are needed to meet reliability requirements, leading to smaller ideal reactor sizes.
- With grid connection ensuring reliability, larger reactors are preferred and lower LCOE is achieved through economy of scale and reduced over capacity buildup.
- When excess electricity can be exported to the grid, higher electricity prices favor larger reactors and vice versa.
- Higher interest rates have a more significant impact on larger reactors, owing to longer construction times. For the sake of brevity, the interest rate impact was not shown in this section but the reader can refer to previous work [35].

Future work will need to consider higher-fidelity cost modeling of these different options (transmission costs, battery, etc.). Comparison with non-nuclear options would be valuable as well.

Table 6-3. Summary of reactor sizing optimization analysis for different NPP/DC coupling options.

DC Demand (MWe)	**Option #1 (should be mostly similar to #2&5)**			**Option #3 (for assumed electricity price of 60 $/MWh)**			**Option #4**		
	Through the grid (or direct connection with grid backup)			Direct connection to DC, with option to sell excess to the grid			Direct connection to DC without connection to the grid		
	Optimum Reactor Size (MWe)	# Units	Optimum LCOE ($/MWh)	Optimum Reactor Size (MWe)	# Units	Optimum LCOE ($/MWh)	Optimum Reactor Size (MWe)	# Units	Optimum LCOE ($/MWh)
50	50	1	147	10	6	166	5	11	174
100	50	2	129	20	6	145	10	11	153
500	500	1	97	100	6	108	50	11	116
1000	1000	1	87	500	3	95	50	21	103
2000	1000	2	79	1000	3	83	100	21	92
6000	1000	6	72	1000	7	73	400	16	77

7. SITING ANALYSIS

Siting new DCs together with their energy source, in particular nuclear energy, is a complex problem because of the large energy and water requirements of these systems, together with the complex regulatory and environmental requirements. In this section, a siting analysis is completed using a geographic information system (GIS) siting tool known as Oak Ridge – Siting Analysis for power Generation Expansion (OR-SAGE). It is applied to hypothetical newly built and co-located NPP/DC greenfield (scenario #2 from Table 5-5) and brownfield (scenario #3 from Table 5-5) projects. The brownfield project is considering 1) existing NPP sites with room for added nuclear capacity and 2) existing CPP sites that are operating or recently retired and are candidates for coal-to-nuclear transitions.

The different DC siting parameters compiled from numerous sources are listed in Appendix A. The DC siting parameters compiled within this report were incorporated into the OR-SAGE tool. This integration provides the opportunity to evaluate stand-alone siting of DCs and to evaluate DC siting co-located with a small or large NPP, on existing nuclear or CPP sites.

7.1 Siting Analysis for Data Centers

The compilation of siting parameters discussed from Section A-3.2 to A-3.9 is summarized in Table 7-1.

Table 7-1. OR-SAGE exclusion parameters for hyperscale data center.

	DC Type	
OR-SAGE Screening Criteria	**Large Hyperscale (100 MW on 200-acre site)**	**Gigawatt DC (1,000 MW on 2,000-acre site)**
Safe shutdown earthquake (ground acceleration)	> 0.75g Excluded	
Wetlands/open waters	Excluded	
Slope	>30% grade Excluded	
Landslide risk	Flag High Risk Excluded	
100-year floodplain	Excluded	
Streamflow – cooling water makeup (X gallons/minute; closed cycle cooling; limited to 10% of resource). Note that this water requirement could come from city-water supply or fresh water.	**< 5,000 gpm Excluded**	**< 15,000 gpm Excluded**

The result of applying the criteria for a hyperscale DC within the OR-SAGE framework is displayed in Figure 7-1. Given the comparatively relaxed set of constraining criteria established for DC technology, it is foreseeable that most of the contiguous[a] United States (CONUS) has some base-level viability for a city-water cooled DC. As such, the primary barrier to siting for this technology seems to be landslide risk, which applies to very few regions around the country. The fresh-water cooled DC siting regime is significantly more restrictive in the Western half of the United States, though it does still allow for large swaths of suitable land in the Northwestern-most states, as well as Northern and Central California. Even the difficult terrain of Western Colorado seems to have some level of viability for both DC configurations. An overlay of existing DC locations and fiber networks is shown in Figure 7-1. According to these results, the majority of existing data centers are situated within the "green" areas on these figures, thereby confirming the validity of our current DC siting criteria.

Another metric for assessing the feasibility of DC siting is the percentage of suitable land (i.e., no criteria conflicts) in a region. Figure 7-2 displays this metric broken down by state and county across the U.S. for the fresh-water cooled DC siting regime. These maps make evident the practical impact of the addition of the streamflow siting constraint on overall viability. Where the city-water cooled siting map in Figure 7-1 shows broadly high suitability in the Mid- and Southwestern U.S., Figure 7-2 shows that many of the counties in these regions have less than 25% viable land when cooling relies on naturally occurring water sources. This results in a state-level viability of less than 25% in both Nevada and New Mexico, with most other West/Midwest states having between 25 and 50% suitable land.

[a] Future work will consider expending the results to Alaska and Hawai (those OR-SAGE models need updates).

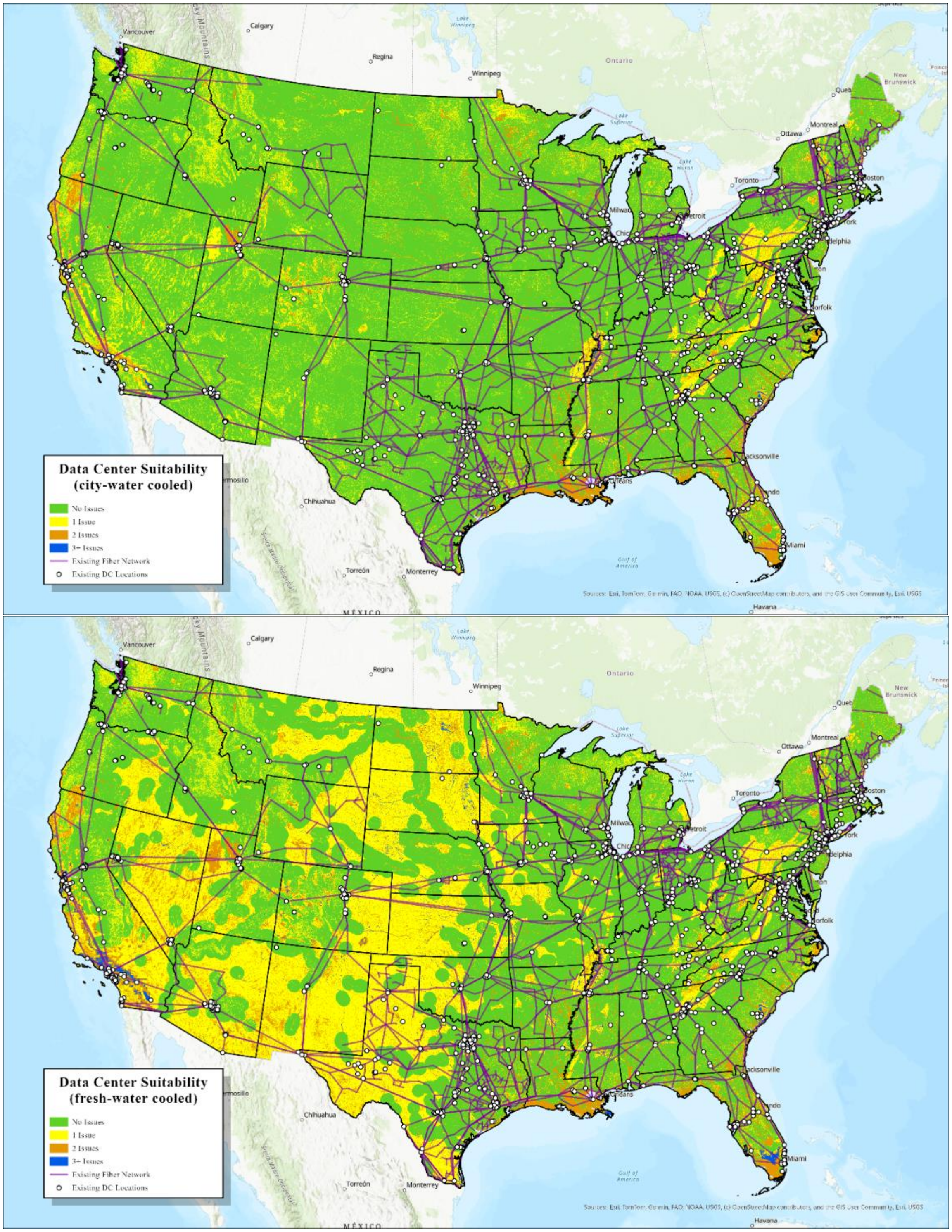


Figure 7-1. Suitability maps for city-water (top) and fresh-water (bottom) cooled DCs.

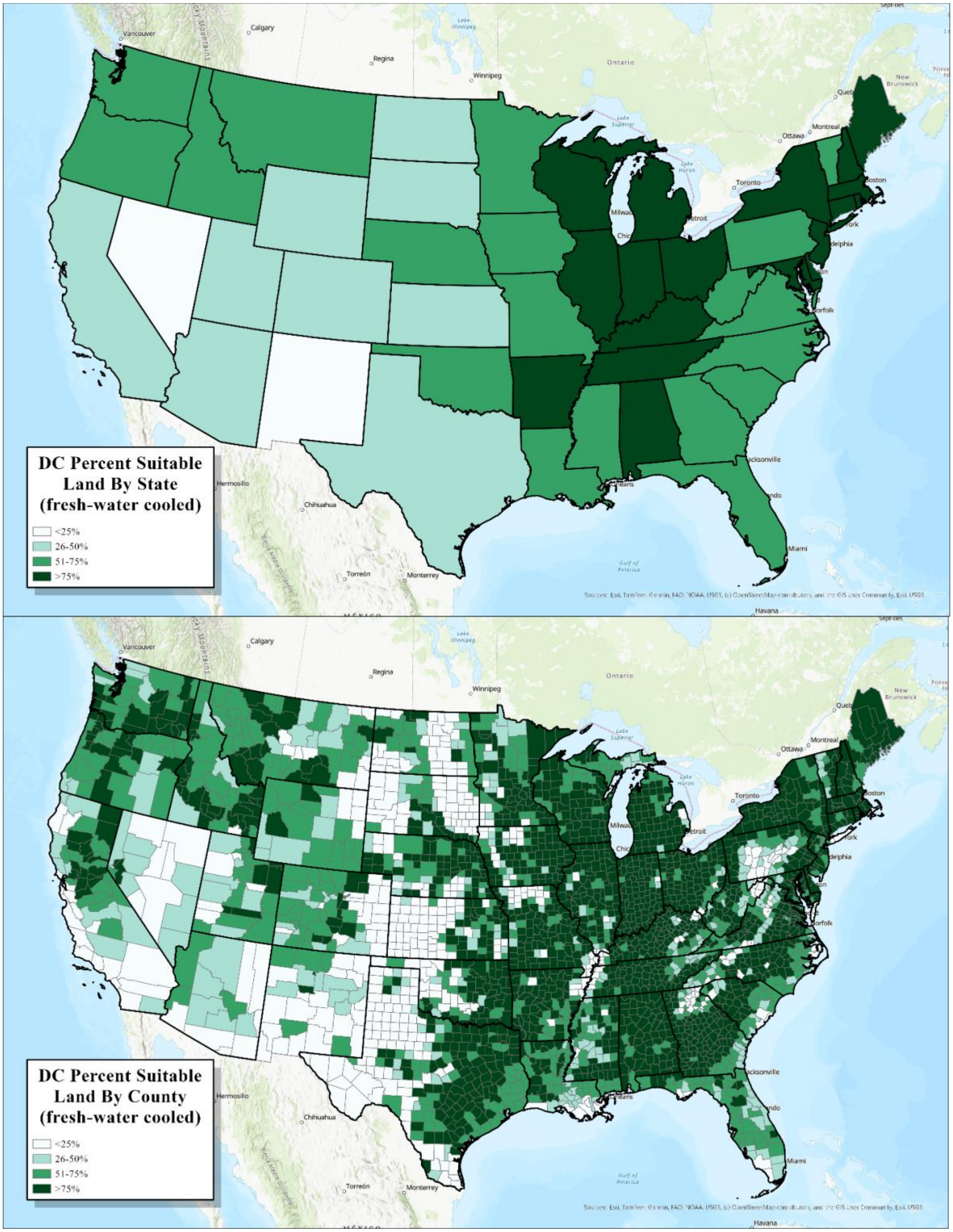


Figure 7-2. Percent of suitable land for DC siting, broken down by state (top) and county (bottom).

7.2 Greenfield Siting Analysis for Data Centers Colocated with NPPs

In this analysis, the feasibility of colocation for newly developed DCs and NPPs is measured for three reactor technology configurations: a fresh-water cooled large LWR[b], a fresh-water cooled SMR, and a city-water cooled SMR. This analysis covers scenario #2 (greenfield) from Table 5-5. The OR-SAGE screening criteria for each of these technologies can be seen in Table 7-2. These screening criteria are based on publicly available info from reactors' vendors about their design parameters and other sources (e.g., [114]). This table also contains the compiled criteria for siting a hyperscale DC, which is the technology of interest for the colocation analysis. The DC criteria also have different configurations, depending on the source of the requisite cooling water.

The differences in criteria thresholds/standing-off distance between the different reactor technologies are ostensibly minimal, and include only the population density, slope, and cooling-water requirements.

[b] Due to the high water requirements of large LWRs, one would need to know the city-water supply limit/availability to consider it as an option. We are not aware of any existing LWR with city-water supply.

Table 7-2. OR-SAGE exclusion parameters for nuclear reactor technologies and DCs

OR-SAGE Screening Criteria	Large Reactor (e.g., AP1000)	Small Modular Reactor (e.g., Xe-100)	DC: Large Hyperscale (Gigawatt DC)
Population density (people/square mile – ppsm)	>500 ppsm within 20 miles EPZ* – 10 miles	>500 ppsm within 1 mile EPZ* – site boundary	Not currently applicable
Footprint	~500 acres	~13 acres (for 4-unit package)	~200 acres (~2,000 acres for Gigawatt DC)
Output	1117 MWe	300 MWe	100 MWe (1,000 MWe)
Safe shutdown earthquake (ground acceleration)	>0.3g Excluded	>0.5g Excluded	>0.75g Excluded
Wetlands/open waters	Excluded	Excluded	Excluded
Protected lands	Excluded	Excluded	Not currently applicable
Slope	>12% grade Excluded	>18% grade Excluded	>30% grade Excluded
Landslide hazard	Flag High Risk Excluded	Flag High Risk Excluded	Flag High Risk Excluded
100-year floodplain	Excluded	Excluded	Excluded
Streamflow – cooling water makeup (X gallons/minute; closed cycle cooling; limited to 10% of resource)	< 130,000 gpm Excluded	Not applicable for Xe-100 since it requires little water for cooling (for AP300: < 36,000 gpm Excluded)	< 5,000 gpm Excluded (< 15,000 gpm for Gigawatt DC)
Proximity to hazards (buffer distance)	Flag 1-10 miles	Flag 1-10 miles	Not currently applicable
Proximity to fault lines (buffer distance)	Depends on length of fault	Depends on length of fault	Not currently applicable

* EPZ: emergency planning zone

7.2.1.1 Siting analysis for a new NPP

The maps displayed in Figure 7-3 and Figure 7-4 showcase the spatial distribution of land suitable for siting the reactor configurations from Table 7-2. The following analysis of these maps establishes a baseline to contextualize the results of colocation. It also allows for a more thorough inspection of the underlying reasons behind a region's lack of suitable land.

A suitability map for the city-water cooled SMR can be seen in Figure 7-3, in which the color corresponds to the number of criteria that are not met within a given area. This configuration is the least restrictive of the three, owing primarily to the fact that it does not require natural cooling water. The largest swath of suitable land extends from eastern Montana down to Texas, and across the vast majority of the Midwestern U.S. Notable exceptions include sizeable Native American reservations in Montana and the Dakotas, as well as the New Madrid Seismic Zone, a region of increased seismic activity along the Mississippi River that occupies 43,000 sq mi (~110,000 sq km) of land in seven states. Excluding areas within and around the Appalachian Mountain chain, the Southeast has adequate suitability for a city-water cooled/dry-cooled SMR, as does Maine. Though much of the Western U.S. is unsuitable owing to a combination of prolific fault lines, mountain ranges, seismic zones, and protected areas, smaller patches of suitable land can still be found. Specifically, Eastern Washington and Oregon as well as Southern Idaho have some suitable regions. While many regions are comparatively small against the overall scale of CONUS, all regions have more than enough land to site the technology of interest.

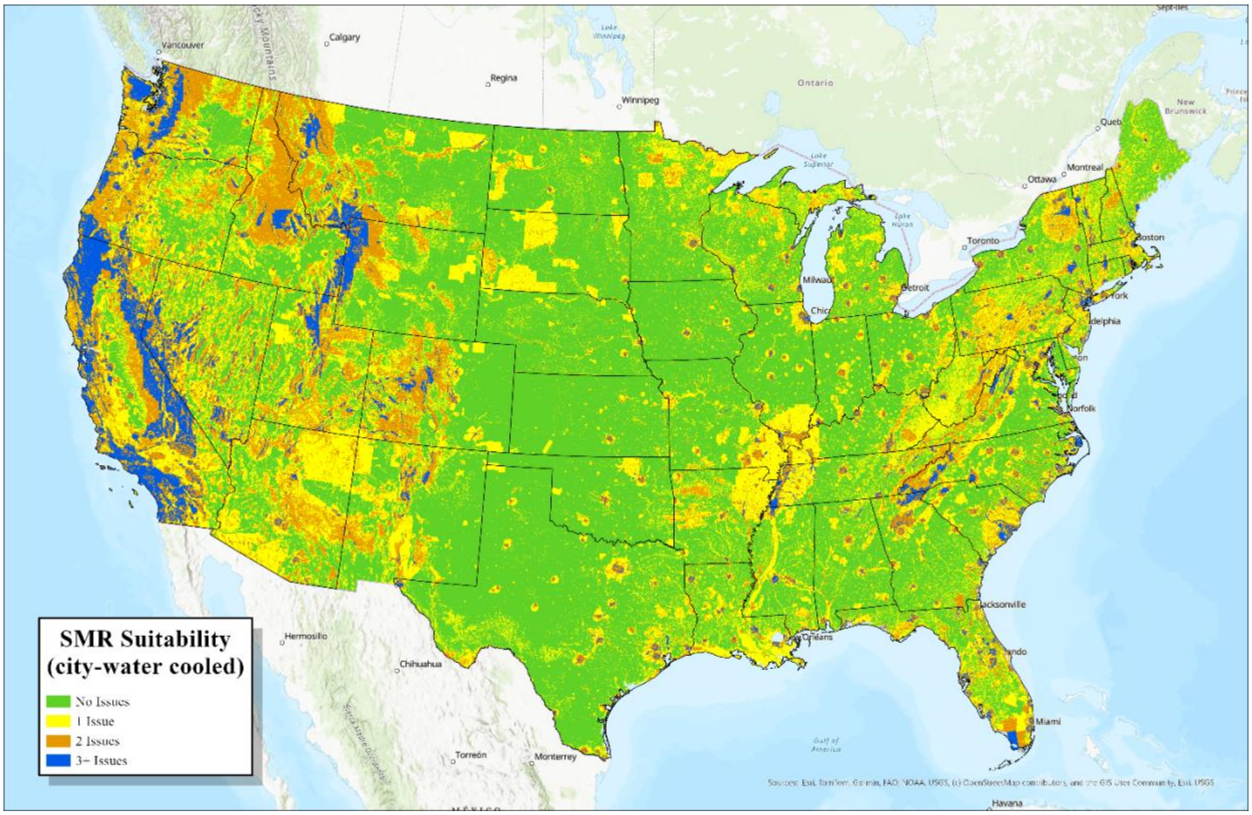


Figure 7-3. Map of suitability scores for city-water cooled/dry-cooled SMR technology. Color corresponds to the number of barriers to potential siting. Some of those barriers may have engineering solutions to alleviate their restrictions.

Comparatively, the maps of fresh-water cooled reactor suitability in Figure 7-4 are significantly more restrictive, especially in the Western half of CONUS past the 100th Meridian, which traditionally marks the transition to a more arid climate. Consequently, the potential for fresh-water cooled reactor development is severely limited to infrequent bodies of water and the major river systems in the Western U.S. While a much more subtle difference, it is also notable that the SMR technology seems to have larger clusters of suitability than those of the large LWR. The increase in water consumption for the large LWR eliminates viability around some river systems, and the lower tolerance for slope narrows the suitability in and around the Appalachian Mountains. A summary of the percentage of suitable land in each U.S. state can be seen in Table 7-3.

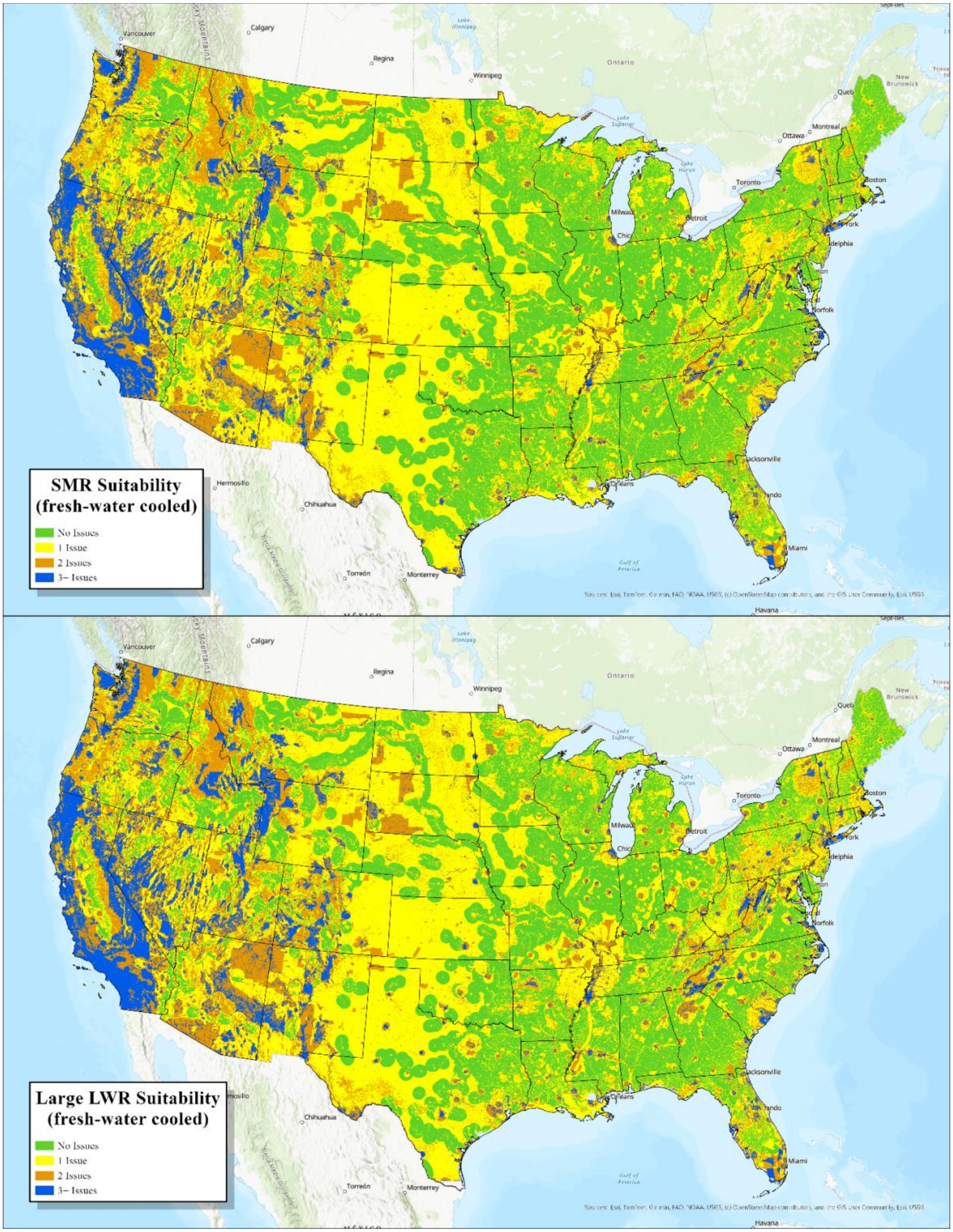


Figure 7-4. Map of suitability scores for fresh-water cooled SMR (top) and LWR (bottom) technologies.

As anticipated, the city-water cooled SMR technology generally outperforms both fresh-water cooled reactors in terms of percentage of suitable land by state, particularly in the Midwestern U.S. states. The states with the largest percentage of suitable land for city-water SMR, fresh-water SMR, and large LWR technologies are Kansas (93.14%), Indiana (76.09%), and Alabama (70.31%), respectively. In that same vein, the least viable states for reactor development are California (10.3% for city-water SMR, and 6.98% for large LWR), and Arizona (8.2% for fresh-water SMR)

The results of the DC suitability analysis are another story. Every state has at least 50% suitability for city-water cooled DCs. This also holds true for Eastern states and all but 11 states in the Midwest, Southwest, and West with respect to fresh-water cooled DCs.

Table 7-3: Percent of suitable land by state for individual reactor technologies and DC types. Color corresponds to percent suitability value.

Color legend: 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100

Region	State	Reactor Technologies			DC Types	
		SMR (City-water cooled)	SMR (Fresh-water cooled)	Large LWR	DC (City-water cooled)	DC (Fresh-water cooled)
Midwest	Indiana	78.37	76.09	66.34	97.36	93.71
	Wisconsin	64.54	67.8	62.12	82.24	81.8
	Illinois	68.95	62.22	57.29	93.81	83.45
	Iowa	89.64	62.57	55.87	95.81	71.36
	Ohio	65.48	66.78	53.72	90.14	87.27
	Michigan	55.33	54.2	50.01	78.11	75.17
	Minnesota	66.26	53.37	47.27	81.33	68.67
	Missouri	68.89	49.82	43.33	90.51	72.56
	Nebraska	87.23	50.41	31.49	93.84	62.9
	North Dakota	79.67	25.28	22.32	91.56	33.86
	Kansas	93.14	25.33	22.09	96.92	33.08
	South Dakota	65.86	14.99	14.45	94.44	26.93
Northeast	Maine	65.09	71.71	64.98	80.33	80.28
	Delaware	51.4	57.92	49	79.77	79.16
	New York	43.68	50.05	40.17	83.15	80.75
	New Hampshire	41.82	55.95	39.51	83.85	83.84
	Maryland	44.12	49.48	32.07	76.52	75.14
	Vermont	31.97	47.06	31.95	66.2	66.22
	Pennsylvania	29.1	36.97	23.96	58.05	57.26
	Connecticut	33.75	48.13	20.98	84.83	84.77
	Massachu-setts	28.77	41.04	18.4	81.81	77.17
	New Jersey	24.97	32.54	12.74	78.37	77.65
	Rhode Island	35.74	42.65	12.29	81.3	81.08

Region	State	Reactor Technologies			DC Types	
		SMR (City-water cooled)	SMR (Fresh-water cooled)	Large LWR	DC (City-water cooled)	DC (Fresh-water cooled)
Southeast	Alabama	72.64	75	70.31	86.91	86.92
	Georgia	62.64	63.89	61.23	74.17	74.05
	Mississippi	61.88	57.79	53.54	72.36	68.43
	Louisiana	49.99	48.08	46.95	60.22	58.85
	Arkansas	49.49	49.97	45.47	81.19	76.82
	North Carolina	47.24	49.5	43.08	66.58	66.2
	Kentucky	51.02	52.01	42.52	84.25	79.34
	South Carolina	43.77	45.04	42.09	68.46	68.17
	Virginia	44.06	46.03	39.53	70.18	68.1
	Tennessee	43.56	49.12	38.73	78.25	77.5
	Florida	38.22	38.88	34.43	56.56	54.62
	West Virginia	24.47	36.26	20.88	73.31	68.26
Southwest	Oklahoma	84.81	50.6	46.23	96.05	59.56
	Texas	81.95	38.62	32.65	93.52	45.67
	New Mexico	59.18	11.15	9.44	95.77	20.64
	Arizona	29.92	8.2	7.32	90.33	29.97
West	Montana	52.44	31.35	27.73	85.41	58.39
	Wyoming	59.11	30.75	25.05	88.85	49.51
	Idaho	30.61	26.77	22.38	75.59	66.7
	Washington	24.01	25.61	21.75	73.79	71.35
	Oregon	26.49	18.6	15.03	83.8	64.34
	Utah	33.88	17.79	14.39	82.73	49.83
	Colorado	48.33	17.7	11.75	81	45.51
	Nevada	33.14	9.16	8.1	90.07	22.5
	California	10.3	9.63	6.98	67.45	40.38

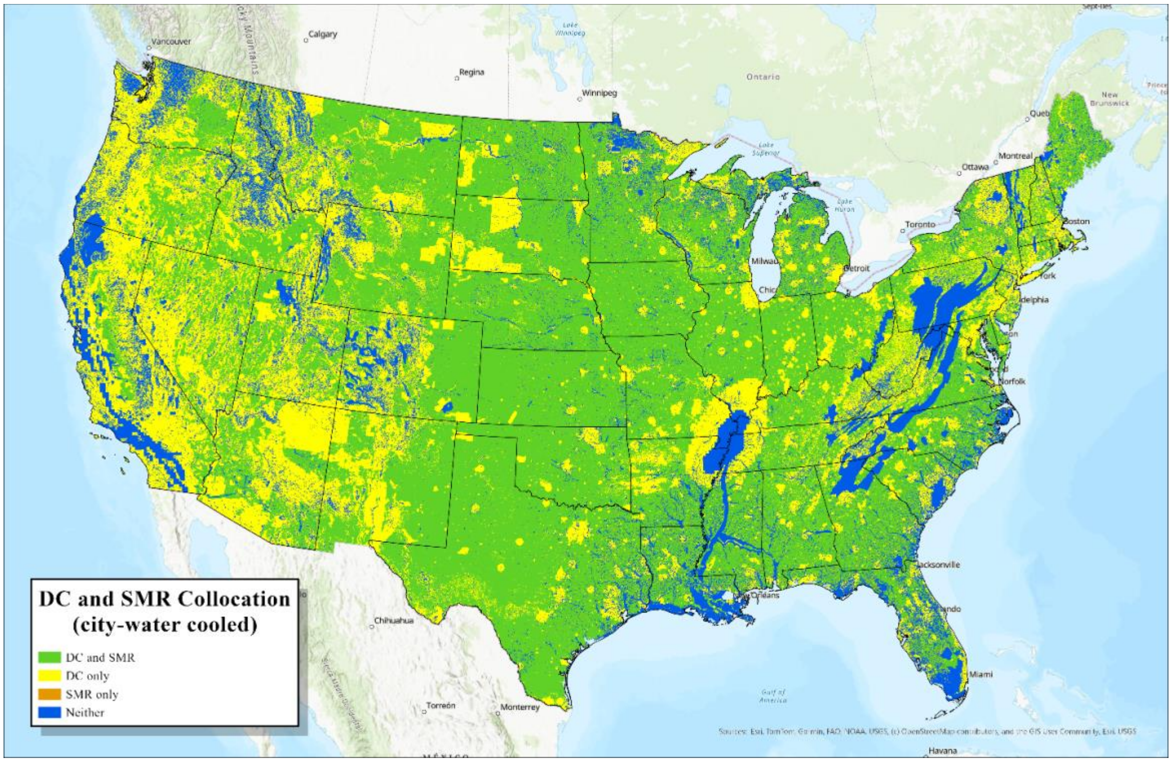
7.2.1.2 Colocation with a new NPP

Working down from the configuration with the most suitable land, Figure 7-5 displays the co-location results for the city-water cooled SMR and both city-water and fresh-water cooled DCs. Here again it becomes evident that cooling water requirements present the most significant barrier to siting, especially moving west across CONUS. It is notable that, in the city-water cooled DC colocation map, the vast majority of CONUS is viable for development of at least one of the two technologies, primarily the DC. Aside from water usage, it seems the primary barriers to colocation are landslide risks in the east and significant sloped terrain in the west.

The results displayed in Figure 7-6 are comparatively straightforward. The colocation between the fresh-water cooled SMR and the city-water cooled DC does not differ greatly when the additional restriction is introduced for the fresh-water cooled DC. Also, while it is not visually apparent, the two mixed-coolingmethod colocation maps are remarkably similar. Further analyses of the results in Figure 7-6 require numerical metrics and are presented after the remainder of the visual analysis.

The co-location of the large LWR technology with the established DC cooling configurations can be seen in Figure 7-7. In this siting regime, the outsized water requirement for the large LWR is the largest determining factor for suitability anywhere west of the Mississippi River. This is evidenced by the significant discrepancy between regions of colocated suitability and fresh-water DC-only suitability situated in the western riparian zones. For this reason, the amount of colocated suitability is largely unaffected by the additional water requirement added by the fresh-water cooled DC.

Finally, Table 7-4 shows the breakdown of percent suitability by state for each of the configurations described previously. Notable trends include the high suitability in the Midwest for city-water cooled DC and SMR colocation, as well as the fact that the majority of the land in nine states—Indiana, Wisconsin, Illinois, Iowa, Ohio, Maine, Alabama, Georgia, and Mississippi—is suitable for the colocation configurations presented. For the purpose of DC and SMR colocation, it should be noted that a combination of city-water and fresh-water cooling regimes have equivalent suitable percentages despite the disparity in cooling water requirements. Similarly, the high cooling water needs of the large LWR cause the impact of a fresh-water vs. city-water cooled DC to be nearly negligible, every state but Florida having a less than 1% reduction in overall suitability between the two configurations. One final caveat that should be noted: because it is not possible to model the availability and distribution of city-managed water resources across CONUS, it should not be automatically assumed that a given location has enough water on hand to support a city-water cooled SMR or DC. This is especially true for many parts of the Southwest and Western U.S, where the primary source for city water is commonly the nearby rivers or lakes. These regions regularly face water use restrictions, and diverting more water for any kind of industrial infrastructure may present significant challenges.



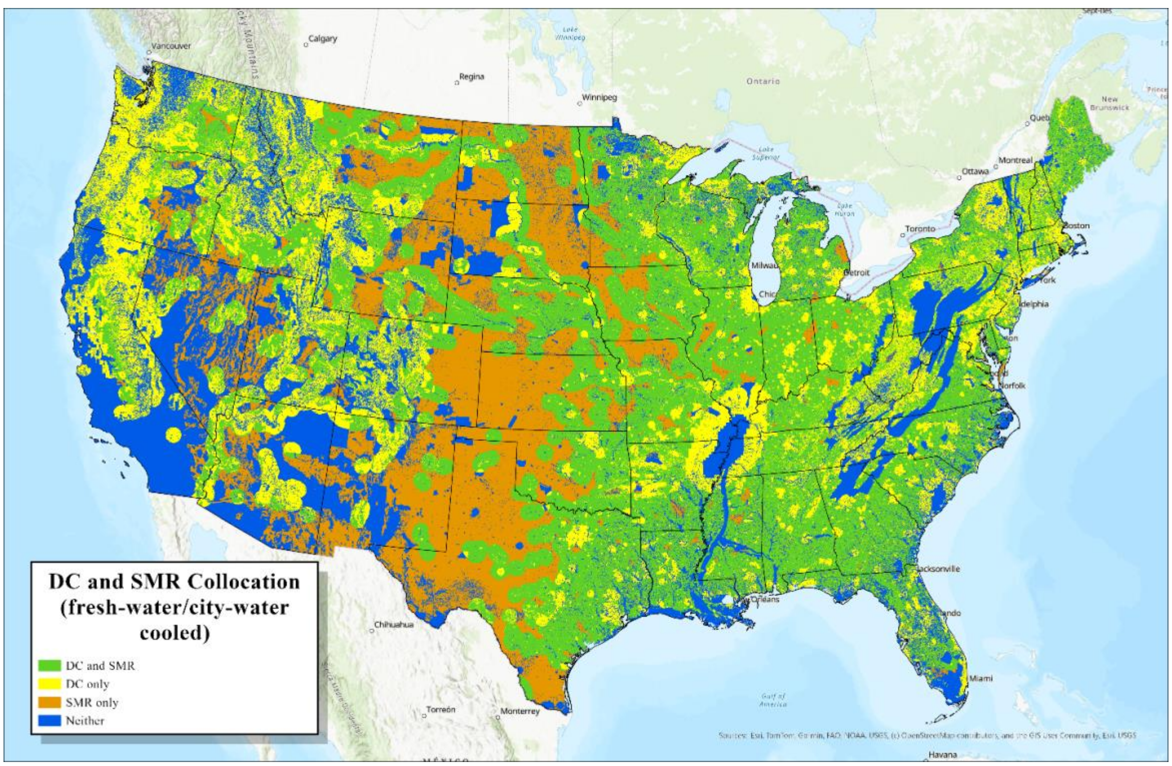


Figure 7-5. Co-location maps for city-water cooled/dry-cooled SMR technology with city-water (top) and fresh-water (bottom) DCs.

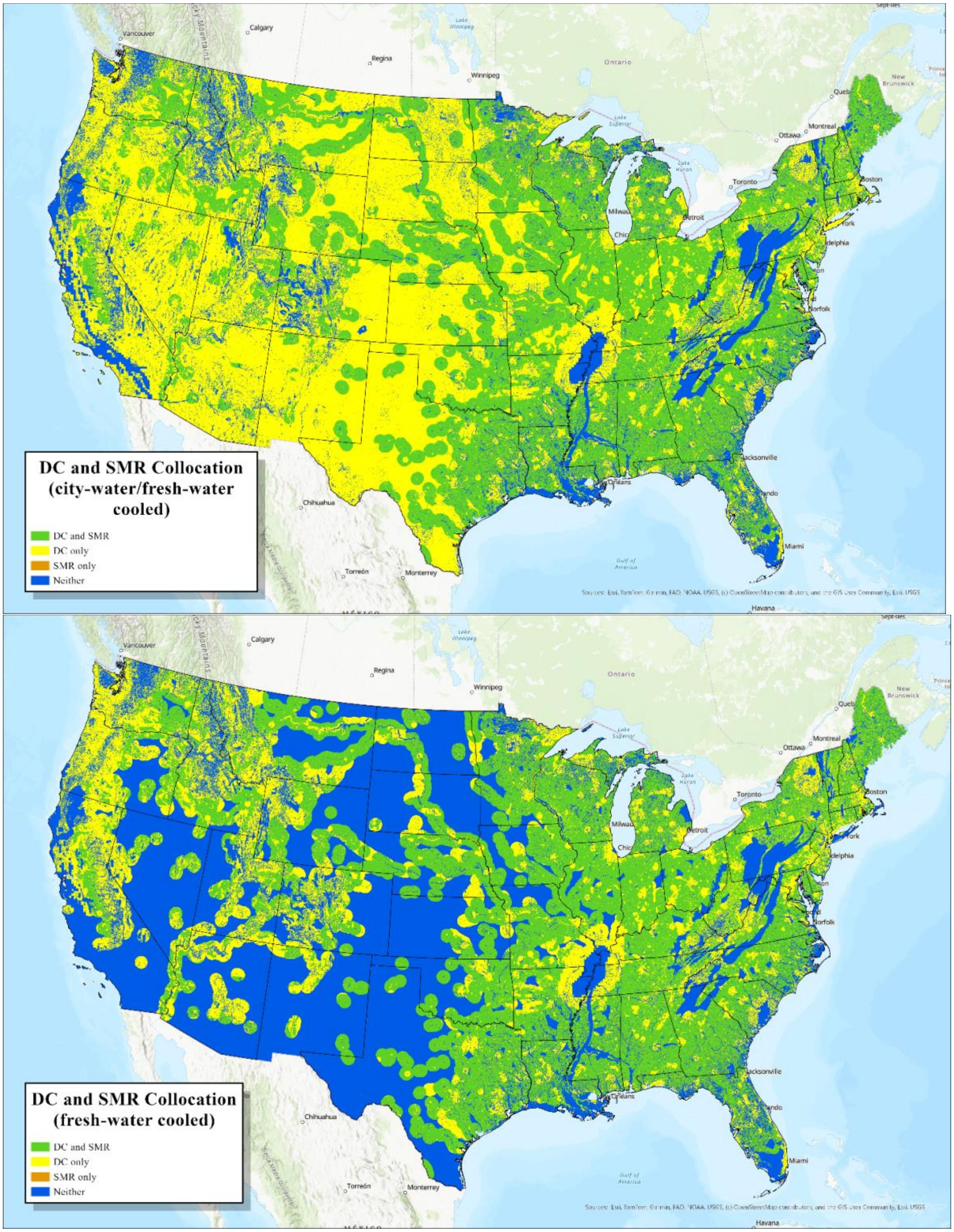


Figure 7-6. Co-location maps for fresh-water cooled SMR technology with city-water (top) and fresh-water (bottom) DCs.

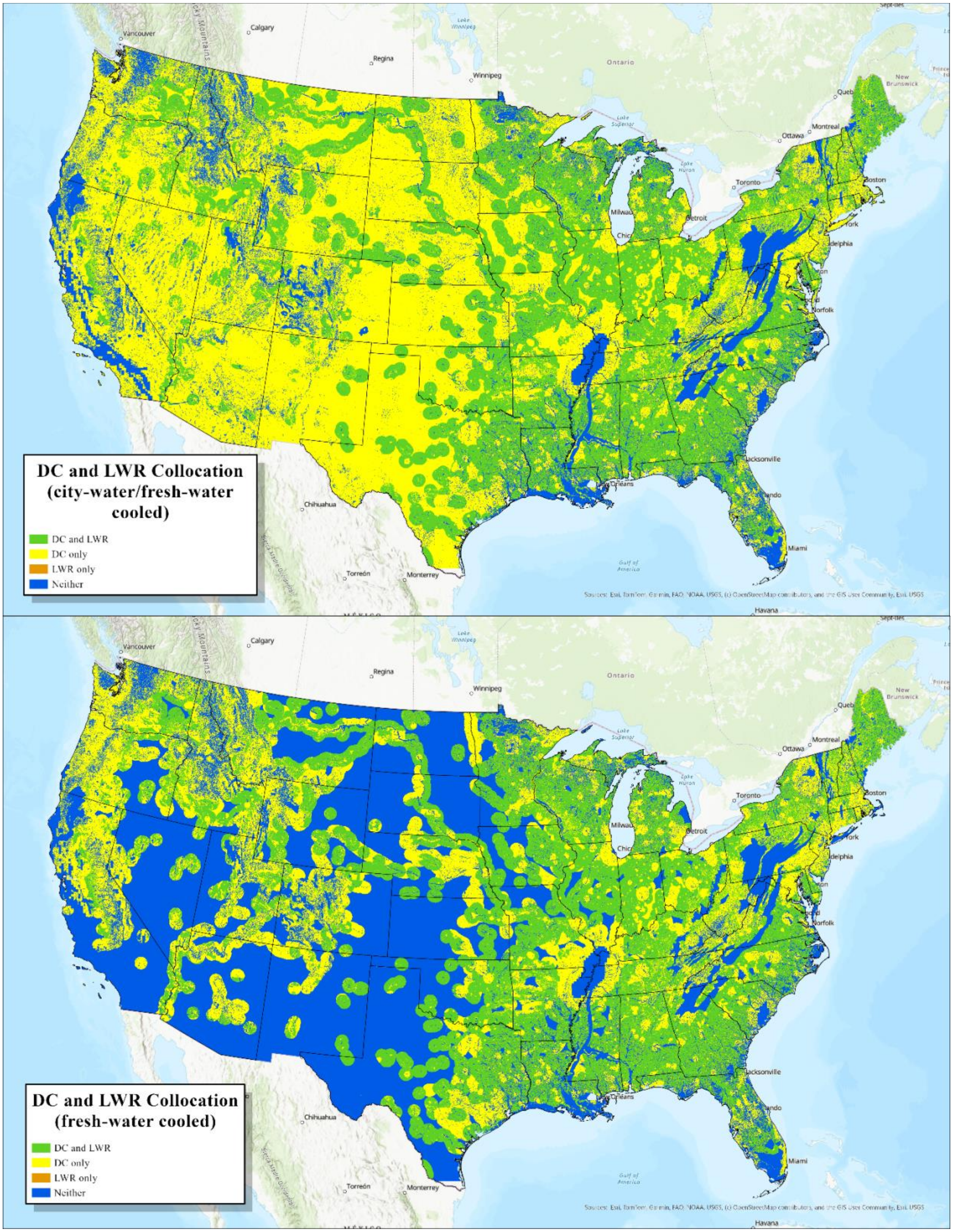


Figure 7-7. Co-location maps for large LWR with city-water (top) and fresh-water (bottom) DCs.

Table 7-4: Percent suitability by state for six DC and reactor colocation configurations. Color corresponds to percent suitability value.

Color legend: 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100

Region	State	City-water DC and SMR	Fresh-water DC and SMR	City-water DC, Fresh-water SMR	Fresh-water DC, City-water SMR	City-water DC, Large LWR	Fresh-water DC, Large LWR
Midwest	Indiana	77.87	75.55	74.28	74.28	65.87	65.8
	Wisconsin	62.49	65.63	62.2	62.2	60.01	59.78
	Illinois	68.65	61.87	60.95	60.95	57.04	56.97
	Iowa	89.16	62.08	65.11	65.11	55.54	55.48
	Ohio	65.09	66.31	62.33	62.33	53.42	53.37
	Michigan	52.96	51.82	50.45	50.45	47.69	47.42
	Minnesota	64.06	51.37	52.93	52.93	45.29	45.11
	Missouri	68.33	49.32	51.72	51.72	42.98	42.92
	Nebraska	86.49	49.84	57.56	57.56	31.23	31.18
	North Dakota	78.08	24.89	26.44	26.44	21.94	21.89
	Kansas	92.6	25.08	30.3	30.3	21.91	21.88
	South Dakota	65.18	14.87	16.11	16.11	14.34	14.32
Northeast	Maine	62.85	69.38	62.82	62.82	62.64	62.4
	Delaware	50.27	56.07	49.78	49.78	47.88	47.77
	New York	42.44	48.65	41.78	41.78	38.98	38.87
	New Hampshire	40.89	54.7	40.75	40.75	38.62	38.55
	Vermont	31.41	46.24	31.32	31.32	31.35	31.28
	Maryland	43.13	48.3	42.11	42.11	31.22	31.15
	Pennsylvania	28.8	36.48	28.39	28.39	23.72	23.67
	Connecticut	32.59	46.57	32.57	32.57	20.16	20.09
	Massachusetts	27.75	39.62	27.12	27.12	17.89	17.84
	New Jersey	23.94	31.1	23.75	23.75	12.17	12.13
	Rhode Island	34.06	40.4	33.91	33.91	11.56	11.46

Region	State	City-water DC and SMR	Fresh-water DC and SMR	City-water DC, Fresh-water SMR	Fresh-water DC, City-water SMR	City-water DC, Large LWR	Fresh-water DC, Large LWR
Southeast	Alabama	70.93	73.09	70.78	70.78	68.59	68.41
	Georgia	60.48	61.57	60.28	60.28	58.99	58.7
	Mississippi	59.73	55.66	56.22	56.22	51.53	51.29
	Louisiana	47.8	45.91	46.58	46.58	44.83	44.58
	Arkansas	48.53	48.96	46.05	46.05	44.55	44.45
	Kentucky	50.72	51.49	47.93	47.93	42.24	42.19
	North Carolina	45.98	47.79	45.43	45.43	41.82	41.6
	South Carolina	42.33	43.46	42.2	42.2	40.62	40.44
	Virginia	43.36	45.14	42.08	42.08	38.87	38.79
	Tennessee	43.27	48.58	42.62	42.62	38.44	38.38
	Florida	35.59	35.82	34.28	34.28	32.1	31.76
	West Virginia	24.27	35.8	23.21	23.21	20.69	20.62
Southwest	Oklahoma	84.42	50.29	50.25	50.25	45.96	45.91
	Texas	81.21	37.94	38.52	38.52	32.09	32.02
	New Mexico	59.1	11.11	10.91	10.91	9.41	9.4
	Arizona	29.82	8.13	8.18	8.18	7.29	7.28
West	Montana	52.1	31.13	29.44	29.44	27.54	27.5
	Wyoming	58.78	30.53	29.52	29.52	24.87	24.85
	Idaho	30.52	26.64	25.03	25.03	22.27	22.27
	Washington	23.86	25.41	21.94	21.94	21.61	21.6
	Oregon	26.41	18.53	17.43	17.43	14.97	14.96
	Utah	33.77	17.68	17.4	17.4	14.32	14.29
	Colorado	48.07	17.48	19.05	19.05	11.62	11.6
	Nevada	33.06	9.12	8.29	8.29	8.08	8.07
	California	10.26	9.55	8.1	8.1	6.95	6.94

7.3 Brownfield Siting Analysis for DCs Colocated with NPPs

In this section, a previous study from the DOE-NE Systems Analysis and Integration Campaign [115] was expanded to evaluate the feasibility of co-locating DCs at existing NPP and large CPP sites. This analysis covers scenario #3 (brownfield) from Table 5-5. The 2024 report [115] documents the results of an evaluation of existing NPPs and CPPs for the potential to establish new nuclear capacity at those sites. The evaluation focused on available areas at the sites and provided a good basis for the consideration of constructing a hyperscale DC of 100-MWe capacity that would require approximately 200 acres, or a gigawatt-scale DC of 1,000 MWe capacity that would require approximately 2,000 acres, at the existing NPP and CPP sites.

7.3.1 Siting at a current nuclear power plant

As the 2024 report [115] documents, there are 54 current NPP sites in the US hosting 94 reactors. In addition, there are 11 recently retired NPP sites in the US that formerly hosted 14 reactors. At three of the retired sites, restart of the existing reactors is being considered. According to the 2024 report, 13 sites have plans for additional reactors, 17 sites have space for an additional large LWR, and 41 sites have space for an additional 600-MWe reactor.

For this analysis, we evaluate potential DC sites within a 5-mile radius of the centroid of the existing NPP site, on the assumption that a DC can be sited within this 5-mile radius. We consider two DC types: a gigawatt-scale and a hyperscale DC.

Using the area results from the 2024 DOE study [115] as the basis and applying the OR-SAGE analysis for DCs, 13 of the 54 current NPP sites (24%) appear to have the potential land to host a gigawatt-scale DC on approximately 2,000 acres. These sites are distributed over 8 states.

For the option of siting a hyperscale DC on an approximately 200-acre site, 47 of the 54 current NPP sites (87%) appear to have the potential land to host a hyperscale DC within a 5-mile radius. These sites are distributed over 27 states. Most of the NPP sites can host more than one DC.

All the above analyses are based on an evaluation of the suitable land area based on the OR-SAGE criteria for DC siting and take into account additional factors not considered in the siting analysis, including access to power and fiber networks.

7.3.2 Siting at a coal-fired power plant (CPP)

Retiring CPPs are prime candidates for backfitting SMRs to enable reuse of infrastructure and workforce [115]. Those sites may also accommodate DCs, since they have both power and water connectivity. The 2024 DOE-NE report [115] only considered CPPs with greater than 600 MWe of combined retired and operating capacity. This capacity was considered overly limiting for a complete evaluation of CPP sites. Therefore, the entire DOE-EIA CPP source dataset used for the 2024 DOE-NE report was evaluated. The data, from April 2024, considered operating and recently retired CPPs. While some CPPs may have retired in the period from April 2024 until today, the source data should still provide a valid list of CPP sites.

All CPPs operating and retired since 2014 were initially included on the source data list. There were 420 CPP sites included on this list. CPPs with a combined retired and operating capacity of less than 100 MWe were removed from consideration. These plants were typically older and deemed to be too small to support consideration for hosting a DC. Next, CPP sites that were considered population-limited [71] for hosting an advanced-reactor backfit were eliminated from consideration. These sites may be considered for use with a fossil-fueled or other power source but were removed from this study since the use of reactor power at the site may encounter more hurdles to establish than other sites. Finally, CPP sites that were shown by OR-SAGE evaluation [71] to be surrounded by significant wetlands and open water were eliminated, reducing the count to 294 CPP sites. Moreover, we considered only CPP sites with a projected retirement year of 2025 or later (for previously retired sites, we assume that infrastructure such as access to transmission and water rights has already been lost) and those that have not announced any retirement year. This left 146 CPP sites available for further DC siting evaluation. These assumptions were used to reduce the number of CPP sites to be evaluated for this report and should not be considered binding if a particular CPP site is of interest to a DC vendor and was not evaluated by this study.

From the results of the analyses of the CPPs considered, 136 of the 146 CPP sites (93%) appear to have the potential land area to backfit an advanced reactor (at least one type of SMR) and host a hyperscale DC on approximately 200 acres within a 5-mi radius of the plant. Likewise, 70 of the 146 CPP sites (48%)

appear to have the potential land to backfit an advanced reactor (at least one large LWR) and host a gigawatt-scale DC on approximately 2,000 acres within a 5-mi radius of the plant. The results of the brownfield analysis are summarized in Table 7-5. From the table, the top three states for colocation of a hyperscale DC and an NPP are Illinois, South Carolina, and Pennsylvania. Similarly, the top three for colocation of a hyperscale DC and a NPP at a former CPP site are Wyoming, Indiana, and Kentucky.

Table 7-5. Summary of brownfield analysis for NPP and CPP sites (see Sections A-4 for definition and explanation of unique sites).

	NPP Sites		CPP Sites	
State	[SMR+hyperscaleDC on 200 Acres] # of plants (# of unique sites)	[LWR+giga-scale DC on 2000 Acres] # of plants (# of unique sites)	[SMR+hyperscaleDC on 200 Acres] # of plants (# of unique sites)	[LWR+giga-scale DC on 2000 Acres] # of plants (# of unique sites)
IL	6(780)	5(29)	6(671)	5(19)
SC	4(266)	0(0)	3(7)	0(0)
PA	3(259)	1(5)	1(13)	0(0)
NY	3(33)	0(0)	0(0)	0(0)
NC	2(96)	0(0)	4(267)	0(0)
GA	2(82)	0(0)	2(158)	1(1)
VA	2(79)	0(0)	2(157)	1(1)
OH	2(69)	0(0)	4(445)	3(7)
MI	2(60)	0(0)	2(41)	0(0)
AL	2(46)	0(0)	2(154)	1(1)
TN	2(209)	2(2)	3(209)	1(3)
TX	2(161)	1(2)	13(1346)	6(43)
LA	2(15)	0(0)	3(77)	0(0)
MN	2(128)	1(2)	1(48)	0(0)
CT	1(9)	0(0)	0(0)	0(0)
KS	1(89)	1(1)	2(354)	2(10)
NE	1(82)	0(0)	5(578)	5(15)
MO	1(66)	0(0)	5(510)	2(5)
CA	1(5)	0(0)	0(0)	0(0)

State	NPP Sites		CPP Sites	
	[SMR+hyperscaleDC on 200 Acres] # of plants (# of unique sites)	[LWR+giga-scale DC on 2000 Acres] # of plants (# of unique sites)	[SMR+hyperscaleDC on 200 Acres] # of plants (# of unique sites)	[LWR+giga-scale DC on 2000 Acres] # of plants (# of unique sites)
MS	1(47)	0(0)	1(58)	0(0)
FL	1(3)	0(0)	3(15)	0(0)
MD	1(29)	0(0)	0(0)	0(0)
WA	1(185)	1(12)	1(57)	0(0)
WI	1(16)	0(0)	4(104)	0(0)
AZ	1(150)	1(6)	4(462)	2(12)
AR	1(103)	1(1)	4(324)	2(2)
NH	1(1)	0(0)	1(1)	0(0)
CO	0(0)	0(0)	6(778)	6(30)
DE	0(0)	0(0)	1(50)	0(0)
IA	0(0)	0(0)	4(445)	3(7)
IN	0(0)	0(0)	9(1026)	5(22)
KY	0(0)	0(0)	9(923)	7(22)
MT	0(0)	0(0)	1(118)	1(3)
ND	0(0)	0(0)	6(354)	1(1)
NJ	0(0)	0(0)	0(0)	0(0)
NM	0(0)	0(0)	1(138)	1(3)
NV	0(0)	0(0)	2(349)	2(24)
OK	0(0)	0(0)	6(688)	4(9)
SD	0(0)	0(0)	1(31)	0(0)
UT	0(0)	0(0)	4(625)	3(41)
WV	0(0)	0(0)	3(244)	2(6)
WY	0(0)	0(0)	8(1083)	6(19)

7.4 Summary

7.4.1 Greenfield

The greenfield analysis using OR-SAGE, illustrated in Figure 7-3 and Figure 7-4, underscores the diverse suitability of U.S. land for various reactor configurations. City-water cooled SMRs emerge as the most flexible option, with widespread siting potential—especially throughout the Midwest, from eastern Montana to Texas, and in parts of the Southeast and Northwest—largely due to their independence from natural water sources. In contrast, fresh water-cooled reactors face notable constraints, particularly west of the 100th Meridian, where arid conditions and limited water resources restrict viable siting. Overall, SMRs are more site-flexible than large LWRs, which require more water and are sensitive to terrain slope. State-level suitability rankings place Kansas, Indiana, and Alabama at the top for city-water SMRs, fresh-water SMRs, and large LWRs respectively, while California and Arizona rank among the least suitable. Similarly, DC siting appears broadly feasible, with city-water cooled configurations achieving over 50% land suitability in every state, and strong performance also seen for fresh-water cooled DCs, except in water-constrained western and southwestern regions.

The co-location analysis on greenfield presented in Figure 7-5, Figure 7-6, and Figure 7-7 further highlights cooling water availability as the main constraint for joint siting of SMRs and DCs, especially west of the Mississippi River. City-water cooled combinations offer the broadest siting potential, particularly in the Midwest, with primary challenges arising from landslide risks in the East and steep terrain in the West. While fresh-water cooled systems face more constraints, the difference between city- and fresh-water cooled DCs becomes minimal when paired with large LWRs, given the LWR's already high-water consumption. Notably, city- and fresh-water SMR-DC pairings show comparable suitability percentages in key states such as Indiana, Illinois, and Georgia.

7.4.2 Brownfield

The brownfield analysis builds on and broadens the scope of the 2024 DOE-NE study [115], which identified 54 operational NPP sites across the U.S. hosting 94 reactors, along with 11 recently retired sites—three of which are evaluating reactor restarts. The study also highlights future expansion potential: 13 sites have plans for new reactors, 17 can accommodate large LWRs, and 41 have capacity for 600 MWe reactors. Within a 5-mile radius of each of these 41 NPP sites, this study assessed land suitability for DC development and found that 13 sites (24%) could support gigawatt-scale (2,000-acre) facilities, while 47 sites (87%) across 27 states are suitable for hyperscale (200-acre) DCs, with many capable of hosting multiple installations. These findings, based on OR-SAGE siting criteria, consider only land availability and do not include land ownership and other infrastructure requirements such as power and fiber access.

Similarly, the analysis identifies retiring CPPs as strong candidates for repurposing with SMRs and DC development, leveraging their existing infrastructure and utility connections. While the original study focused only on CPPs with over 600 MWe of combined capacity, a more comprehensive evaluation included 420 CPPs operating or retired since 2014. After excluding plants under 100 MWe, population-constrained locations, and those near significant wetlands, 146 CPP sites remained. Of these, 136 sites (93%) are suitable for co-locating an SMR and a hyperscale DC, and 70 sites (48%) can accommodate a large LWR and a gigawatt-scale DC within a 5-mile radius. Among the most promising states for NPP-based hyperscale co-location are Illinois, South Carolina, and Pennsylvania, while top candidates among CPP sites include Wyoming, Indiana, and Kentucky. These results reflect land suitability alone and do not preclude other factors that may be of interest but were not included in this analysis.

7.4.3 Study limitations

This study does not consider the availability or sourcing of utility water resources in the city-water cooled co-location criteria - an especially critical factor in arid western regions where limited supply and competing demands could pose significant barriers to deployment. As such, additional analyses should be performed before siting city-water cooled SMR and DC technology in otherwise water-constrained regions. Besides using city water, DCs in locations more than 20 miles from rivers and oceans may consider using gray water or some engineering solution for closed cooling; however, the closed-cooling option has a power demand requirement that will increase the power demand by the affected DC.

There are plenty of additional opportunities for further consideration for DCs to be sited across the country at both NPP sites and CPP sites. According to Figure 7-1, there are many pieces of suitable land across the country that are not within a reasonable distance of the existing fiber network, so there is a need to investigate the feasibility of deploying fiber cable to these areas. Furthermore, since population exclusion was not a factor for DC siting, some of the suitable areas throughout the country contain existing buildings. While DCs could be placed in existing buildings, there is also a need to use building outline data to further classify the suitable areas into suitable areas with existing buildings and suitable areas with no existing buildings.

8. SOCIO-ECONOMIC ANALYSIS

In this section, the socio-economic impact of a newly built gigawatt-scale DC facility together with its colocated NPP is evaluated. This assumes a greenfield project representative of scenario #2 described in Table 5-5. Both urban and rural settings are considered, with two types of NPPs: large LWRs and multi-unit SMRs.

8.1 Model Description

An input-output model was used to quantify the impacts of NPP and DC operations scenarios. Input-output models are created by combining regional economic data with industry-level transaction data for a specific period, usually one year. Using mathematical formulas, the impact of new economic activity observed in a specific industry can be traced as it is absorbed by other industries throughout the region. These industry-to-industry transactions create opportunities for increased revenue, job creation, and income growth. These models can be calculated manually or can be processed using advanced applications that are available from multiple software developers. The model used in this report was produced using the IMPLAN input-output modeling application [116].

As shown in Figure 8-1, input-output model results are based on three main drivers: employment, revenue, and labor income. As input data for the input-output model, revenue from electricity generation was calculated using annual megawatt hours (MWh) multiplied by the wholesale price of electricity, which is an approach that more closely reflects the value added by the generating station. Wholesale electricity prices were obtained from the EIA [117]. Retail electricity prices were not used for revenue estimation, to more properly account for the value created by the plant only. Using retail electricity prices would overstate the value of the generating station, since there is additional value added by activities during the transmission and distribution process performed at the utility level.

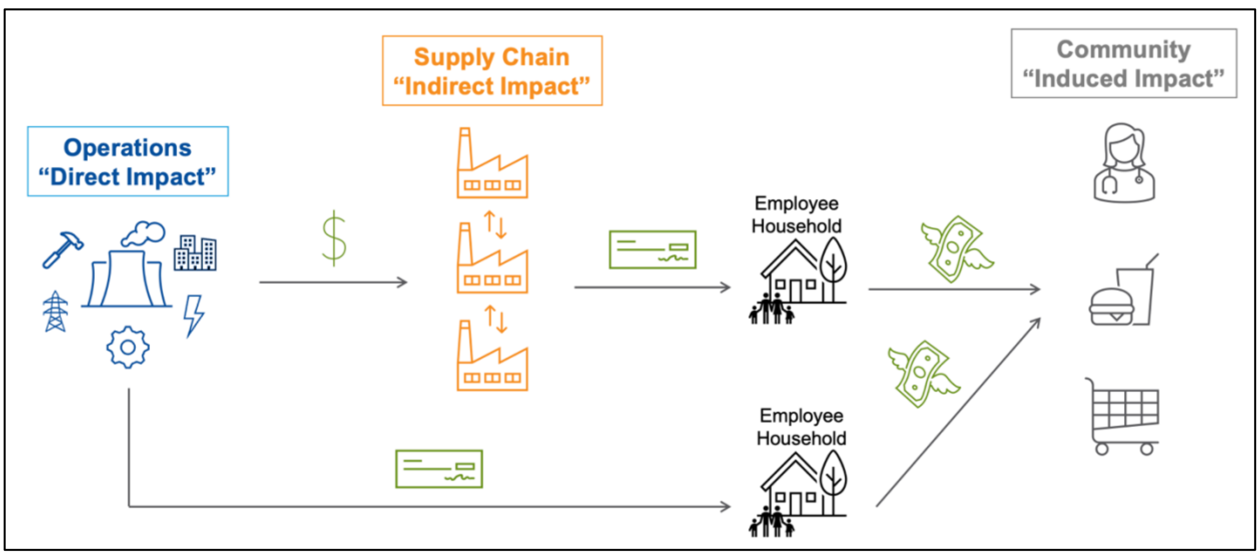


Figure 8-1. Illustration of types of local economic impact considered.

8.1.1 Data center options

DC revenue values were obtained through a meta-analysis of existing DC economic impact evaluations [118] [119]. Economic output per worker calculations were performed and the results were applied to the DC scenario in this report. These results appear as the "direct output" impact for the one-gigawatt DC. This analysis returned an average amount of $1,295,000 in revenue per worker. The actual amount of revenue earned from operating a DC is proprietary information. Revenue streams could include hosting services, cloud computing, data storage, managed services, and colocation services. These revenue streams can be complex because of the different pricing models, customer bases, and service levels involved. Each stream may have its own set of challenges and opportunities, making revenue estimation a multifaceted task.

Employee compensation for DCs and the nuclear reactor is based on the default values in the most recent IMPLAN datasets without any adjustment. The employment numbers for the NPP and DC scenarios were based on a meta-analysis of news reports and previous economic impact reports. The DC reports were analyzed to identify the number of workers needed per square foot of facility space. This returned an average value of 15.7 employees per 100,000 square feet.

Each economic impact scenario was modeled in a small and large economic region. The large region is based on a metropolitan area that has more than 4 million residents. The large economic region scenario was selected to show how the economic impact of a DC and a nuclear facility would differ from the impact in a smaller, more rural location. Large economic regions have a more diverse economy with greater access to local supply chains that could support NPP and DC operations. This results in a larger economic impact for local businesses as they support facility operations by supplying goods and services. The smaller region used in this analysis consisted of an economic region in a non-metropolitan area with around 30,000 residents.

8.1.2 Nuclear power plant options

The nuclear reactor options were selected on the basis of the availability of data required to operationalize the input-output model. Various public reports from reactor vendors have identified employment estimates for SMRs. So far, those reactor vendors include NuScale Power [120], XEnergy [121], and TerraPower [122]. These reactor vendors have published or announced employment estimates that help increase the accuracy of model results.

8.2 Economic Impact Scenarios

8.2.1 Data center scenario

The DC scenario consisted of a hypothetical newly built hyperscale facility. This scenario assumes the DC facility would span more than 6.4 million square feet with an estimated load capacity of one gigawatt. It was also assumed that the facility would require around 1,000 employees to operate. Total wages and benefits for the DC employees would be more than $113.5 million annually. Total costs for operating the facility were not estimated, but Uptime Institute suggests that labor would account for around 28% of the operating costs [123]. Power would be the largest cost, at 58% to 64% of total operating costs. The estimated annual economic output for the facility is $1.3 billion per year.

8.2.2 Nuclear reactor scenarios

Two nuclear reactor scenarios were evaluated to provide sensitivity regarding multiple options for powering a large-scale DC. A gigawatt scale nuclear reactor like a Westinghouse AP1000 would have more than enough generating capacity to support a one-gigawatt DC. The AP1000 nuclear reactor produces a net output of up to 1,110-megawatt electric (MWe) [124]. These reactors are usually operated in pairs, which would allow for some economies of scale during construction and while in operation. Judging from an analysis of 16 different gigawatt-scale nuclear facilities, a facility like an AP1000 would require around 0.54 employees per MWe. This equates to more than 650 employees to operate a single AP1000. This number is probably low, considering that most of the comparison reactors are operating with multiple units and have the opportunity to share some of the staffing across units.

A SMR scenario was analyzed to illustrate how the economic impact could change if a SMR is used as a power source. This scenario uses 80-MWe units, like an X-Energy Xe-100, arranged in clusters of four power modules for a total power output of 320 MWe. To achieve a power output similar to that of a LR, the SMR reactors would need to be combined into four power plants, each producing 320 MWe for a combined total power output of 1,280 MWe. Employment projections from SMR developers reveal their expectation that these types of reactors will be operated with less workers per MW of installed generating capacity. For this reason, the combined staff requirements of a SMR configuration of 1,280 MWe would be around 412 employees. Total wages and benefits for the SMR scenario would be around $71 million. Information from EIA suggests that the average CF for existing nuclear facilities is 92.3% [125]. If the SMR scenario reactors maintained this CF, they would produce 10.3 million MWh of electricity annually. Applying an average wholesale price for electricity of $62.02/MWh would result in an annual revenue of $642 million. This estimate is based on average wholesale prices in the U.S., which is reasonable for this initial analysis. Future work should focus on improved revenue profile estimations, in case the DC enters a long-term purchase agreement with the NPP, or in case of different ownership structures of the DC and NPP facilities.

In the analysis proposed here, the NPP is oversized (~1.2 GW) when compared to the DC (1-GW demand), and the excess electricity is supposed to be sold to the grid (coupling option #2 or #3).

8.3 Employment Impact Results

NPPs provide a valuable economic impact in the communities where they are located and are often a major employer in the region. In the case of a large 1,200-MWe reactor, the power plant would likely employ between 600 and 1,000 workers based on observations of existing large reactors currently operating. For comparison purposes, a 2010 study estimated the direct employment of around 2,550 workers for the 4,000-MWe Palo Verde NPP in Arizona [126]. The Columbia Generating Station in Richland, Washington, had a generating capacity of 1,207 MWe and reportedly had 990 workers in 2018 [127]. Reports from SMR developers have indicated that these types of NPPs will use fewer workers per GW than LRs would. The SMR scenario used in this report assumes that a 1,280-MWe SMR would employ around 412 workers. After conducting the meta-analysis of employment statistics, results show that a 1-gigawatt DC could directly employ around 1,000 employees by itself. This is based on a 6.4 million square foot facility employing 0.000157 jobs per square foot. See Table 8-1 for a detailed list of data points used to estimate jobs and MW per square foot of DC facility space.

Table 8-1. List of DC with associated reported size and jobs.

Company	Datacenter Name	Status	Location	Reported Sq. Ft.	Reported Electricity Use (MWe)	Calculated MWe/Sqf	Reported Operations Jobs	Calculated Operations Jobs/Sqf
Stack	NVA01A	Operating	Ashburn, VA	180,000	17	0.00009		
Stack	NVA02A	Operating	Manassas, VA	227,000	40	0.00017		
Stack	NVA02B	Operating	Manassas, VA	227,000	40	0.00017		
Stack	NVA02C	Operating	Manassas, VA	15,000	2	0.00013		
Stack	NVA02D	Operating	Manassas, VA	280,000	36	0.00012		
Stack	NVA02E	Operating	Manassas, VA	280,000	36	0.00012		
Stack	NVA05	Operating	Manassas, VA	262,000	36	0.00013		

Stack	NVA06	Operating	Leesburg, VA	620,000	72	0.00011		
Point One	(Unknown)	Announced	Richmond, VA	3,250,000	600	0.00018		
Cloud HQ	CloudHQ MDC1	Announced	Manassas, VA	599,198	84	0.00014		
Evo Switch	EvoSwitch Manassas (WDC1)	Operating	Manassas, VA	235,000	20	0.00008		
Iron Mountain	Iron Mountain Data Centers VA-1	Operating	Manassas, VA	168,000	12	0.00007		
Iron Mountain	Iron Mountain Data Centers VA-2	Operating	Manassas, VA	221,500	36	0.00016		
Cloud HQ	CloudHQ MCC4	Announced	Manassas, VA	382,538	60	0.00015		
Digital Realty	(Unknown)	Operating	Ashburn, VA	206,100	20	0.00009		
Switch	(Unknown)	Operating	Grand Rapids, MI	225,000	110	0.00048	26	0.000116
5C Data Centers	(Unknown)	Announced	Springfield,	214,000	200	0.00093	100	0.000467
Microsoft	Quincy	Operating	Quincy, WA	800,000			50	0.000063
Meta	(Unknown)	Announced	Richland Parish, LA	4,000,000			500	0.000125
Meta	(Unknown)	Announced	Aiken County, SC	715,000			100	0.00014
(Unknown)	Crusoe	Announced	Abilene, Texas	998,000			100	0.00010
Meta	(Unknown)	Announced	Montgomery, AL	715,000			100	0.00014
(Unknown)	(Unknown)	Announced	Hanover County, VA	257,176			28	0.00010
Average						**0.000155**		**0.000157**

By performing an economic impact analysis using an input-output model, it is possible to see the additional economic contributions that come from supply chain activity and employee spending. The results of the analysis, as shown in Figure 8-2 show that DCs produce a very high economic multiplier, as measured by dividing the total economic impact by the direct impact that comes from facility operations. The employment multiplier for DC operations was 6.3, which means that for every one job at the DC, an additional 5.3 jobs are created at businesses that are suppliers to the DC or at businesses where employees are spending their paychecks. For comparison purposes, the large and small nuclear reactors had employment multipliers of 4.0 and 5.6 respectively. A vast majority of the jobs created by DCs come from the supply chain needed to support facility operations. In total, a 1-gigawatt DC would create or sustain nearly 6,400 jobs if placed in an urban setting, as seen in Figure 8-2. More than 3,600 of those jobs would come from supply chain activity; the remaining 1,745 jobs would be the result of employee spending at local businesses. In a rural setting, the DC total employment impacts are estimated at 3,495 jobs, a 45% decrease from the employment impact in an urban setting. See Figure 8-3 for detailed impacts for rural settings. The largest portion of the employment impact is still expected to come from supply-chain activity.

The employment impacts of large nuclear reactors and SMRs are also influenced by their location. A LR is expected to create or sustain 2,600 workers in an urban setting. The same reactor would produce an employment impact of around 1,360 jobs in a rural setting; a 47% reduction compared to an urban setting.

The total employment impact of the SMR scenario in an urban setting would be to create or sustain nearly 2,300 workers. This impact is reduced to around 1,050 workers in a rural community.

Compared to nuclear reactor facilities, DCs have a much larger impact on local supply chains. DC supply-chain impacts made up 60% of the total economic impact, compared to 30% for nuclear facilities. The largest number of supply chain related jobs supported by DC operations were located in industry sectors like administrative support services, professional services, transportation and warehousing, and real estate including rental and leasing. The supply chain's share of the total employment impact decreases in rural settings, especially for large nuclear reactors.

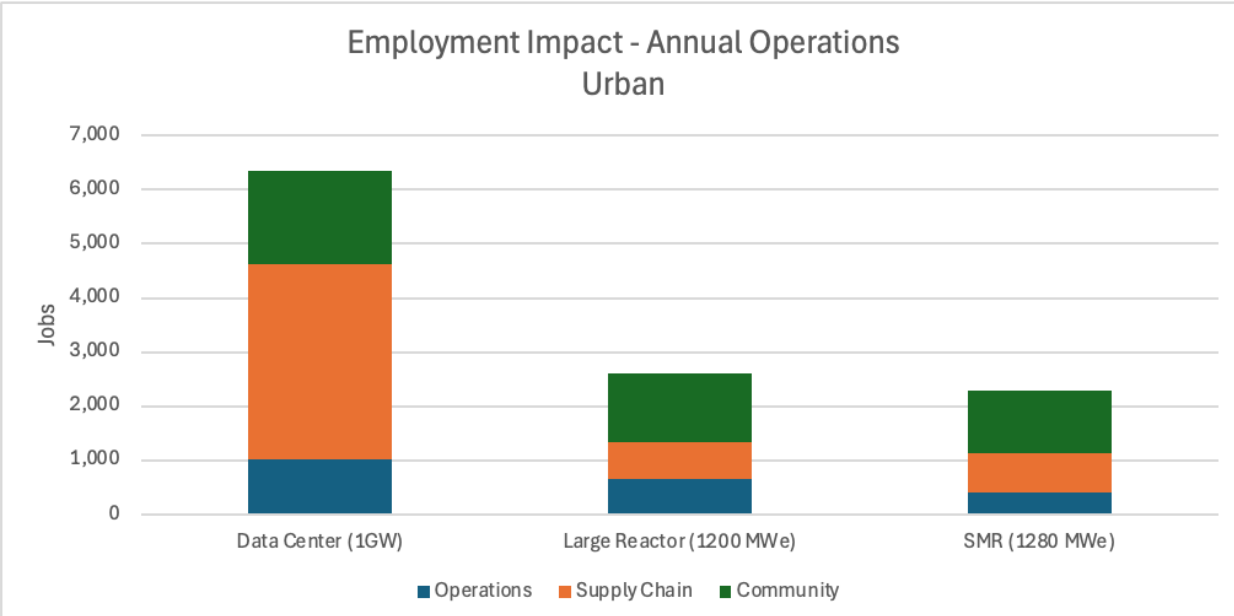


Figure 8-2. Employment impact of annual operations in urban settings.

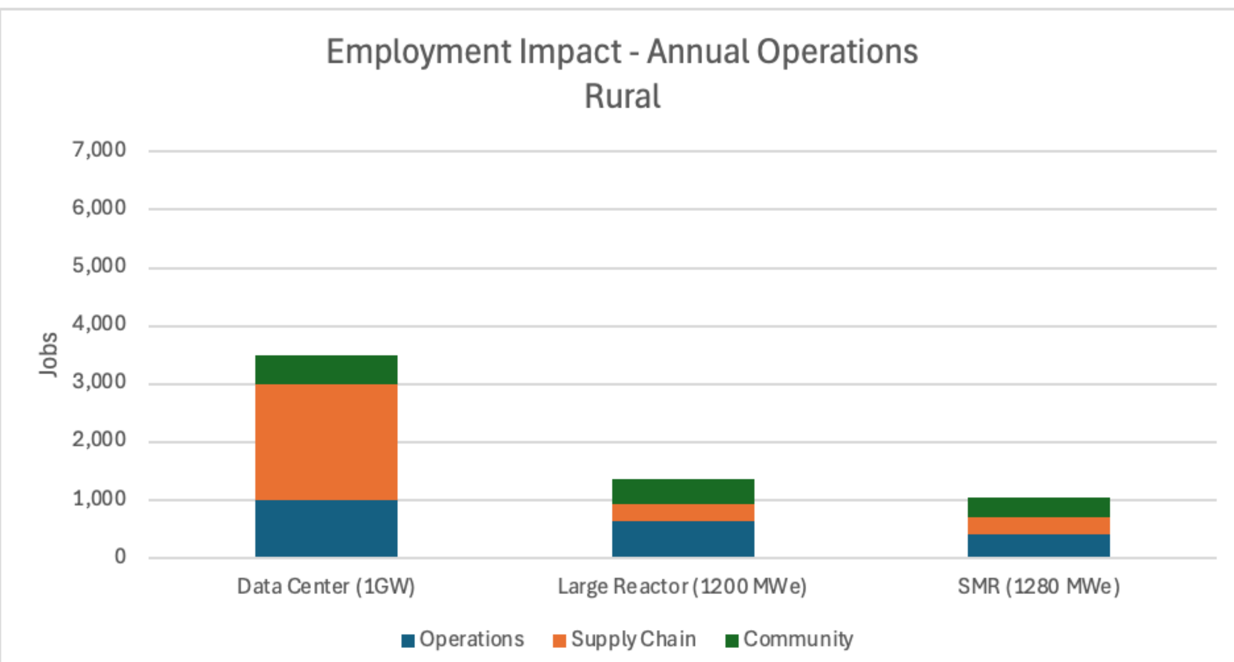


Figure 8-3. Employment impact of annual operations in rural settings.

8.4 Labor Income Impact Results

Labor income impacts represent the total value of wages, salaries, taxes, and benefits paid to workers. Wages for nuclear reactor employees are higher than for other grid-scale electricity generating technologies. Even with a relatively smaller number of workers for operating facilities, the operations portion of labor income impacts are higher for the large and small modular reactor compared to the DC. In an urban setting, the LR is expected to cost $208 million in labor income for reactor operations. The SMR nuclear facilities would likely have fewer employees, so labor income levels would drop to around $174 million. A 1-gigawatt DC would cost around $144 million. It should be noted that some of this labor income is accounting for some amount of proprietor income that is outside of the employment costs for operating the facilities. In rural settings, the operations-specific labor income impacts are reduced somewhat because there would be less likelihood for local business proprietors; this was especially evident for nuclear reactor operations.

The added impact from new supply chain and employee spending activities elevates the total labor income impact for DCs above both nuclear power scenarios in both population settings. The DC total labor income impact in the urban setting reached $519 million annually, compared to $221 million in a rural area. Because of the lower supply chain and community spending, the large nuclear reactor scenario yielded an operations labor income impact of $208 million in the urban setting and $146 million in the rural setting. The SMR configuration, because of lower staffing, had a total labor income impact of $174 million and $81 million in the urban and rural settings, respectively.

See Figure 8-4 and Figure 8-5 for detailed labor income impact results for urban and rural DC and nuclear reactor locations.

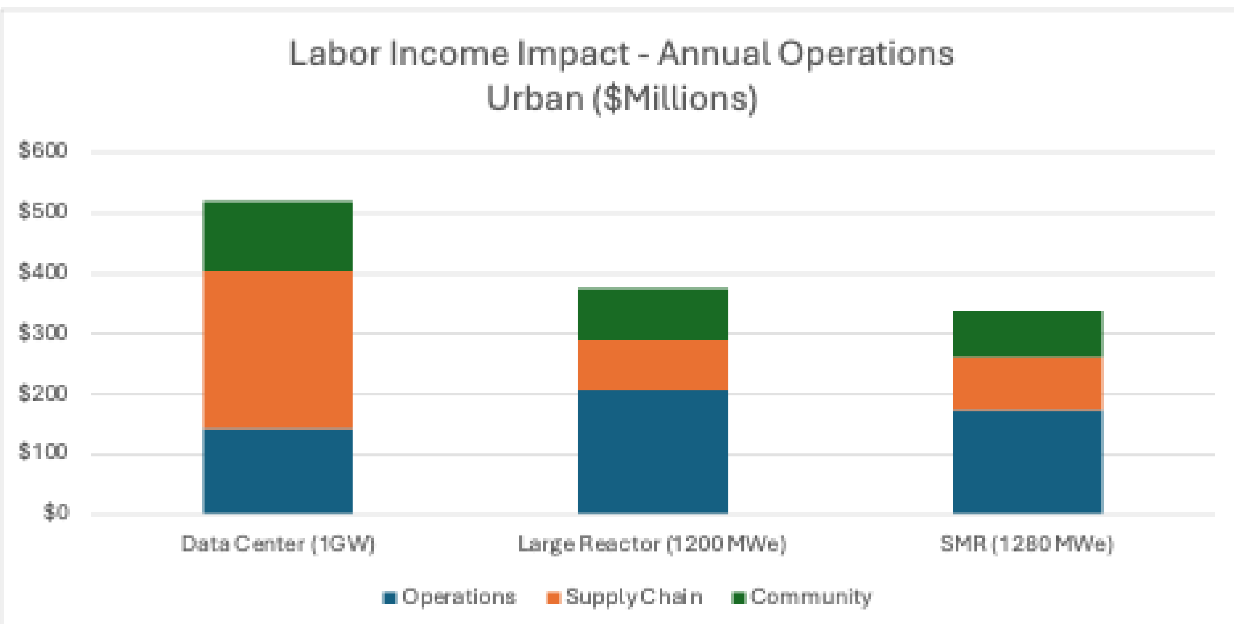


Figure 8-4. Urban labor income impacts.

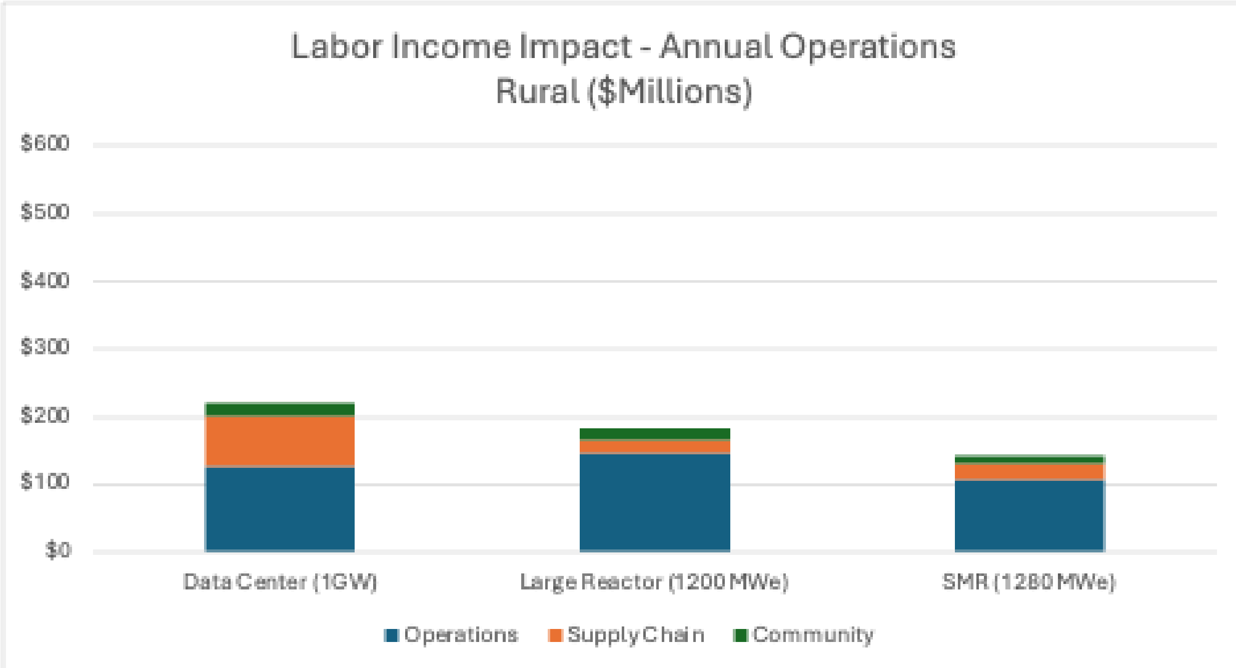


Figure 8-5. Rural labor income impacts.

8.5 Value Added Impacts

By using economic impact models, value added impacts can be quantified, providing a comprehensive view of the economic benefits associated with DCs and nuclear reactors. These value-added impacts are equivalent to the value of new production that occurs within the economy. Employee wages can be a large component of the value-added impact along with any activity that transforms an intermediate good, like raw materials, into a final good. In the case of an NPP, value is created by transforming nuclear fuel into usable electricity.

Total value-added impacts for an urban setting range from $634 million for operations of a SMR to over $1 billion for the DC. The LR is expected to produce $664 million in value added. These numbers decrease by around 25% for the nuclear reactors if operating in a rural area. Operating a DC in a rural area reduces the value-added impact by 42%. As explained previously, it is likely that moving to a rural area would result in a reduction in the local supply chain that would be capable of supporting a DC.

See Figure 8-6 and Figure 8-7 for detailed DC and nuclear reactor value-added impacts for urban and rural locations.

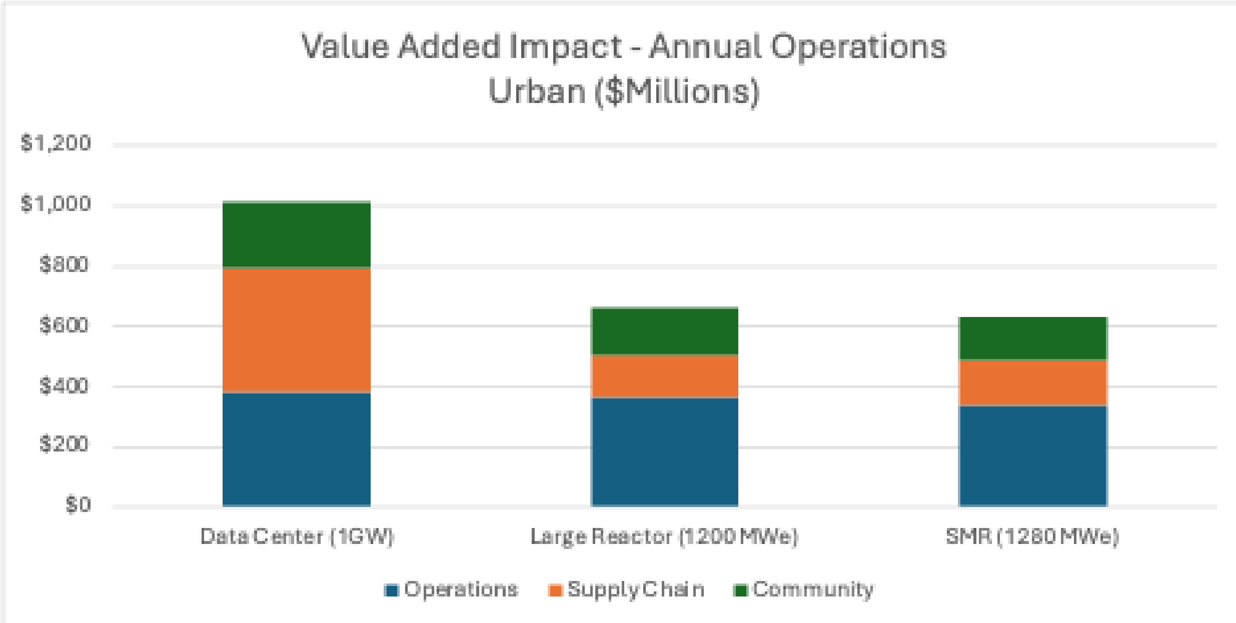


Figure 8-6. Urban value-added impacts.

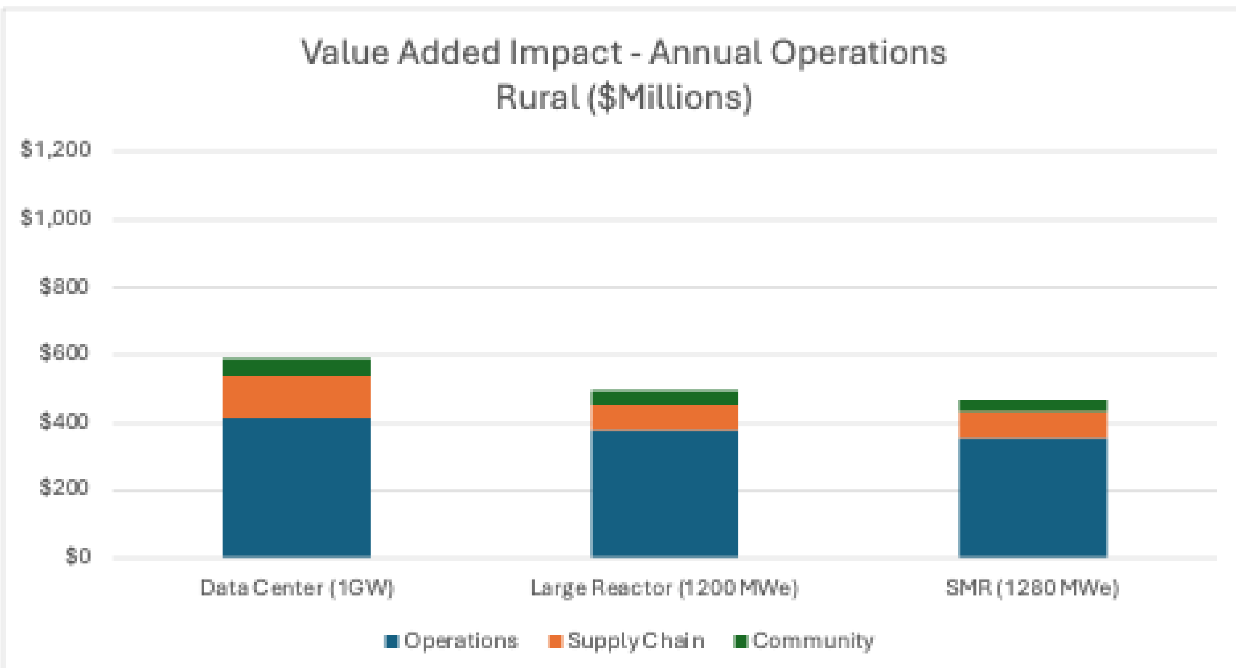


Figure 8-7. Rural value-added impacts.

8.6 Output Impacts

Output impacts are the equivalent of revenue earned through the lease or sale of DC services and electricity sales in the case of nuclear reactors. It should be noted that in this analysis the economic impact model treats the power plant output the same as the production of electricity for grid purposes. If the power plant is not sending electricity to the grid, it would still have operating costs similar to other power plants and have a similar impact on local supply chains. In a case where the power plant is mainly providing power to the DC through a power purchase agreement or other means, the cost of that electricity could be at levels above or below wholesale electricity prices. So, there is some possibility that output impacts could vary under different scenario. Details about how revenue calculations were accomplished were discussed in the Data center scenario (8.2.1) and Nuclear reactor scenarios (8.2.2) sections of this report.

Similarly to other economic impact measures, the distinction between urban and rural locations is a determining factor in the magnitude of total output impacts. It is possible that in actual applications of DCs and nuclear reactors (or other types of electricity generating technology), regionality could have some influence over electricity prices. Supply and demand conditions for DC services or electricity would ultimately determine the price and quantity of goods and services offered by both types of businesses. Electricity prices and the market price of DC services were held constant in the rural and urban scenarios. For that reason, the output impact for operations is identical in the rural and urban scenarios. The change in total output impact is therefore impacted by changes in the supply chain and community output values.

The nuclear reactor scenarios all produced a very similar amount of electricity on an annual basis. This results in an almost equivalent total output impact for the LR and SMR scenarios. The nuclear reactor scenarios produced around $800 million in total output in the rural location and around $1.2 billion in the urban location. The DC scenario is expected to produce nearly $1.7 billion in a rural location compared to $2. billion in an urban setting. Again, the increase in output impact between the rural and urban setting is the result of increased supply chain and community spending activities. Overall, the total output impact is reduced by around 30% if a DC or nuclear reactor is located in a rural location compared to an urban one. It should be noted that even though the total output impact is reduced in a rural location, the overall impact of the DC or nuclear reactor operation would be a significant portion of overall economic activity for the area.

Detailed total output values for rural and urban locations are given in Figure 8-8 and Figure 8-9, respectively.

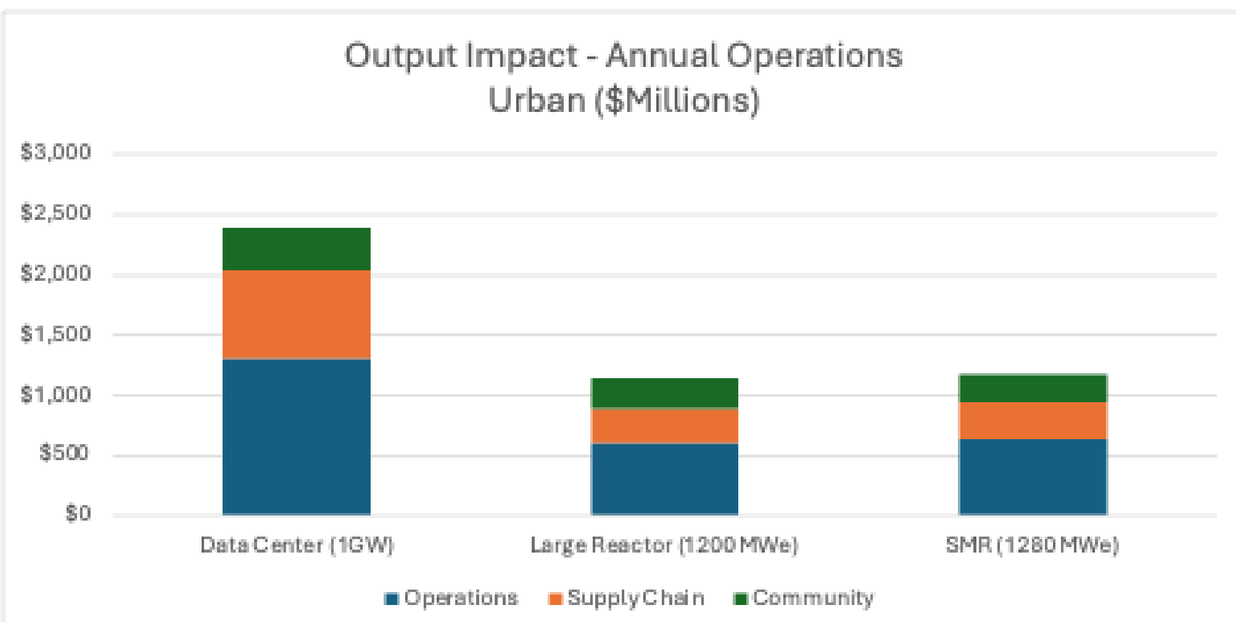


Figure 8-8. Total output impacts of urban annual operations.

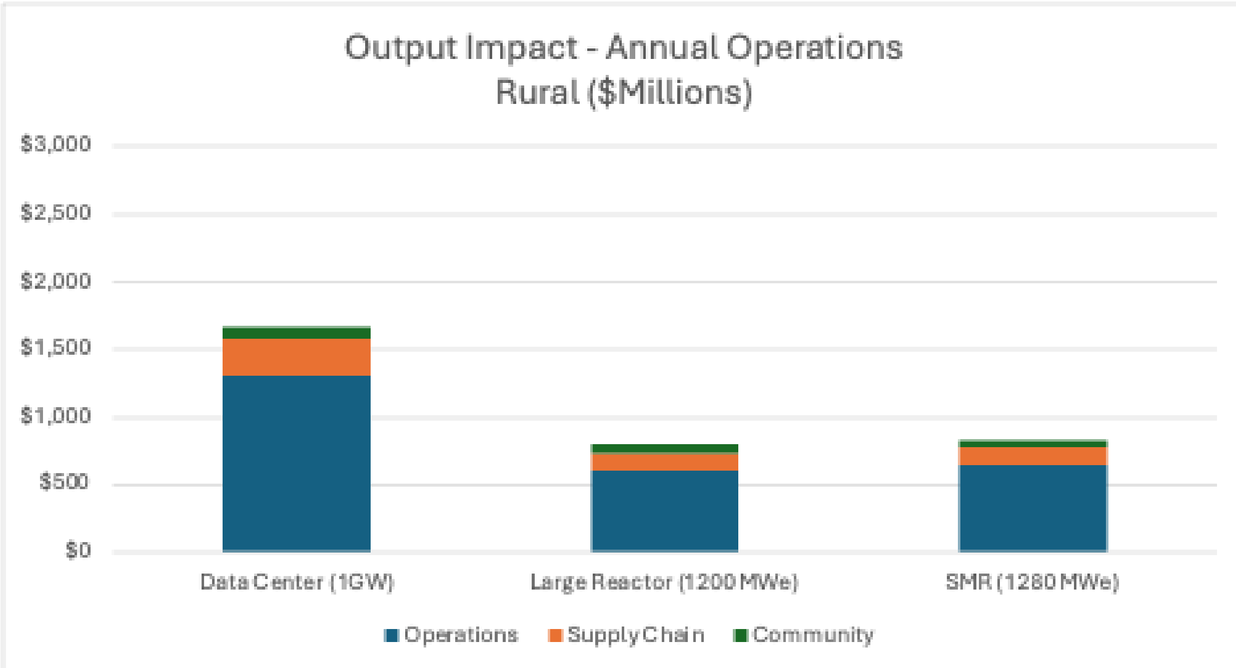


Figure 8-9. Total output impacts of rural annual operations.

9. CONCLUSIONS AND SUMMARY

9.1 Summary

This report provides a comprehensive analysis of the potential for nuclear energy to meet the growing energy demands of DCs, particularly hyperscale and large-scale colocation facilities. It evaluates the technical, economic, and socio-environmental implications of coupling NPPs with DCs. The key findings are summarized as follows:

- **Projected long-term DC energy demand:** The U.S. is experiencing a rapid increase in energy demand from DCs, with projections indicating a total increase of 24-74 GWy(e) by 2028. Meeting this demand with nuclear energy would require 27–85 GWe of installed capacity. While this surge is expected to slow in the long term, the DC industry needs reliable, scalable, and clean energy sources.
- **Plans and timelines for new nuclear capacity:** Several pathways for increasing nuclear capacity were identified, including uprates, restarts of recently retired reactors, power purchase agreements with existing fleet, and new construction. Approximately 20–28 GWe of nuclear capacity could be dedicated to DCs by the early 2030s.
- **HALEU fuel requirements:** Meeting deployment targets for the KP-FHR (assuming 7 modules of 75 MWe are deployed for a total of ~500 MWe by 2035) and Xe-100 (assuming 12 modules of 80 MWe are deployed for a total of ~1 GWe by 2040) announced by Google and Amazon requires ramping up HALEU production to around 6 t/yr (with 19.75% enrichment equivalent) by 2040.
- **NPP/DC coupling options and deployment scenarios:** Five coupling options were analyzed, ranging from grid-connected configurations to colocated, behind-the-meter setups. Key design considerations include the proximity to high- and/or medium-voltage transmission lines, the desired internal fault tolerance (Tier I–IV), and the sources of alternative/backup power during outages. Each coupling option offers unique benefits and challenges in terms of reliability, system costs, regulation, timeline, etc. A list of NPP/DC deployment scenarios was developed, considering existing or newly built NPP or DC projects. Scenarios #2 and #3 (colocated DCs with new SMRs or LRs on greenfield and brownfield sites) were the focus of this report.
- **Optimized reactor sizes for DCs:** Reactor sizing optimization revealed that the ideal reactor size and number of units depend on DC demand, coupling configurations defined in this report, and other economic factors. Larger reactors are preferred for high-demand DCs and grid-connected systems, while more units of smaller reactors are better suited for DC configurations without grid backup.
- **Siting analysis for NPP/DC projects:** Using the OR-SAGE tool, greenfield and brownfield sites were evaluated for colocated NPP/DC projects. This evaluation is not meant to recommend any particular site, but it highlights key siting criteria and demonstrates large-scale siting feasibility. Water availability emerged as a critical factor, with abundant resources in the Eastern and far Western U.S. but constraints in the Southwest and Midwest.
    - For greenfield sites, city-water cooled combinations offer the broadest siting potential, particularly in the Midwest. While fresh-water cooled systems face more constraints, the difference between city- and fresh-water cooled DC becomes minimal when paired with large LWRs, given the LWR’s already high-water consumption. Notably, city- and fresh-

water SMR/DC pairings show comparable suitability percentages in key states such as Indiana, Illinois, and Georgia.

- For brownfield sites:

  1. Among the 54 operation NPP sites across the US, 13 sites (24%) could support additional nuclear capacity together with gigawatt-scale (2,000-acre) facilities, while 47 sites (87%) are suitable for hyperscale (200-acre) data centers. Among the most promising states for NPP-based hyperscale co-location are Illinois, South Carolina, and Pennsylvania.

  2. For CPPs operating and retired since 2014 Of these CPPs, 93% are suitable for co-locating an SMR and a hyperscale DC, and 48% can accommodate a large LWR and a gigawatt-scale DC within a 5-mile radius. Top candidates states for CPP sites include Wyoming, Texas, Indiana, and Kentucky.

- **Socio-economic impacts:** Colocated NPP/DC projects generate substantial economic benefits to the local economy, particularly in urban settings. A one-gigawatt DC coupled with a large reactor is expected to create nearly 1,700 jobs for annual operations. The NPP/DC could support an additional 7,300 in an urban setting and nearly 3,200 jobs in a rural location.

The findings highlight the transformative potential of nuclear energy in addressing the growing energy demands of DCs. The growth of DCs provides an important opportunity to the nuclear industry, by providing strong incentives to accelerate new projects. However, meeting short-term DC demand will require transitional energy sources, such as natural gas, owing to the long lead times associated with new nuclear construction. As shown in this report, new nuclear capacity can also supply part of the short-term (before 2030) DC energy requirements.

9.2 Recommended Next Steps

To build on the findings of this report and help address the identified challenges, the following next steps are proposed:

- **Update projections and deployment plans:** Regularly revise energy demand projections and nuclear deployment timelines to reflect evolving market conditions, technological advancements, and project announcements.

- **Extend analyses across all scenarios:** Conduct comprehensive techno-economic, socio-economic, and siting analyses for all NPP/DC coupling scenarios listed in Table 5-5 to develop a detailed list of case studies for stakeholders, including different sizes and types of NPP and DC.

- **Explore additional coupling options:** Investigate innovative approaches such as 1) nuclear heat utilization in absorption chillers for DC cooling, 2) DC waste heat utilization in nuclear BOP systems to boost efficiency, 3) shared cooling infrastructure between NPPs and DCs, and 4) hydrogen production and storage for peak power applications.

- **Enhance techno-economic models:** Incorporate additional factors in the NPP/DC economic model, such as battery storage, transmission costs, and absorption chillers to improve cost modeling accuracy.

- **Analyze natural gas to nuclear transition:** rapid deployment of DCs is requiring deployment of natural gas powered units. Transition to nuclear energy may be strategized to leverage potential infrastructures and workforce from the natural gas plants.

- **Extend siting studies:** Perform siting analyses for Alaska and Hawaii, and consider additional criteria including climate change impacts, noise, local zoning requirements, distance to fiber networks, city water availability, etc.

- **Extend socio-economic studies:** Review the construction-related impacts, complete additional analysis of new supply-chain-related activity for DC and NPP, improve revenue modeling for behind-the-meter type connections, and perform detailed analysis of occupations and education needed to operate DCs and NPP. One can also review potential for shared occupations within the co-located nuclear and datacenter facilities (security personal, etc.).

- **Review financing and contract models:** Explore different partnership models, such as power purchase agreements (PPAs) and joint ventures, to reduce financial risks and attract investment. Assess revenue and risk profiles for asset owners to ensure financial viability.

By addressing these recommendations, future work can provide a more comprehensive understanding of the opportunities and challenges associated with nuclear energy deployment for DCs. This effort will enable policymakers, DC developers, and the nuclear industry to make informed decisions that balance economic, environmental, and societal priorities.

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Appendix A – Siting Methodology

A-1. SITING TOOL AND METHODOLOGY

A-1.1 OR-SAGE Tool Background

The OR-SAGE tool is designed to use industry-accepted practices in screening sites and then employ the proper array of data sources through the considerable computational capabilities of GIS technology available at ORNL. The tool was developed to screen the potential for NPP siting on a national and regional basis. However, because of the tool's granularity, it is often focused specifically on the immediate area around user sites of interest. If DC siting parameters can be added to OR-SAGE, the ability to evaluate DC siting on a localized scale will be beneficial.

More than 60 data sets have been collected and processed by ORNL to develop exclusionary, avoidance, and suitability criteria for screening sites for a variety of power generation types, including NPPs. Available site evaluation parameters include population density, slope, seismic activity, proximity to cooling-water sources, proximity to hazard facilities, avoidance of protected lands and floodplains, susceptibility to landslide hazards, and many others. All siting parameters should be considered as flags to inform siting decisions and should not be used to rule in or rule out any NPP site. Once DC siting parameters are identified, appropriate data sets will be collected and processed.

The OR-SAGE process is very versatile. Essentially, OR-SAGE is a visual, relational database. The database partitions the contiguous United States, a total of 720 million hectares (~1.8 billion acres), into 100- by 100-m (1 hectare or ~2.5 acre) cells. The database is tracking just under 700 million individual land cells. Successive suitability criteria are applied to each cell in the database. User-specified thresholds can be applied to each siting parameter data layer. In this manner, a variety of scenarios can be quickly and thoroughly evaluated. Data can be added and/or revised within OR-SAGE to address user interests.

Siting security assessment capability is currently being added to OR-SAGE. Security is expected to be of concern at DCs whether they are co-located with a nuclear power generating technology or not. If a DC is co-located with a nuclear power generating source, the security threat attractiveness level of both will likely increase. It will be of additional benefit if a potential DC site is also assessed for security vulnerability.

A-1.2 Methodology

OR-SAGE is essentially a dynamic visualization database that has matured with support from the Electric Power Research Institute (EPRI) and the U.S. Department of Energy (DOE) Office of Nuclear Energy (NE). Specifically, the DOE-NE Systems Analysis and Integration Campaign enabled additional functionality and supported a broad application of OR-SAGE to the potential for backfit of advanced reactors at aging coal plants [71]. This DOE report demonstrated the versatility of OR-SAGE and serves as a good reference for the OR-SAGE methodology.

Power reactor siting in the United States is based on limiting dose to individuals on the site exclusion area boundary and on the boundary of a low-population zone as defined in Title 10 to the Code of Federal Regulations, Part 100 (10 CFR 100). There is also well-defined U.S. Nuclear Regulatory Commission (NRC) guidance [128] for siting an NPP in the U.S. in NRC Regulatory Guide 4.7 (RG 4.7), "*General Site Suitability Criteria for Nuclear Power Stations*." Furthermore, the EPRI siting guide [114] for Nuclear Energy Generation Facilities provides siting criteria for consideration and is updated periodically. Approximately 50 potential site selection evaluation parameters are identified in the various sources related to public health and safety, environment, socioeconomic, and engineering factors. The selected advanced non-light-water reactor siting factors for a nominal small NPP provide a high level of discrimination and readily available data. The default small, advanced NPP siting criteria can be found in Appendix A of reference [71].

A similar approach is envisioned for the development of DC siting parameters. However, DC siting is not as highly regulated as NPP siting and operation. Therefore, a more flexible set of parameters to consider for DC siting is envisioned because of this effort.

A-2. LITERATURE REVIEW OF DATA CENTER SITING PARAMETERS

Numerous sources provided insight on parameters to consider for DC siting. This section includes all DC siting considerations identified across the various available sources. Power and cooling energy requirements were consistent across all sources. Some recommended considerations will be more amenable to OR-SAGE and available data sources than others. It should be noted that the siting analysis completed considers only commercial DCs while additional siting requirements would need to be considered for federal DCs:

> *Companies that handle US federal government data are held to more stringent IT infrastructure standards, established with the Federal Information Security Management Act (FISMA). The National Institute of Standards and Technology (NIST) provides technical and operational details that can help fulfill the FISMA directive. This often impacts decisions like facility location, levels of data security, data access, frequency of monitoring and reporting* [129].

A-2.1 Power

As further discussed in Sections 2 and 3 of this report, DCs are estimated to consume between 3 and 4 percent of the world's electricity, requiring robust electricity usage to power similarly robust processing and computing needs [129]. The power required to operate one DC can equal the power required to sustain tens of thousands of households [130].

Therefore, reliable power at a reasonable cost is a primary factor in DC site selection. Primary power can be delivered from the grid via an agreement with a utility or power can be supplied behind the meter from an onsite power source. The primary power source can be backed up by a secondary onsite source such as a diesel generator. Power considerations include power capacity, quality, redundancy (grid diversity), regional power infrastructure, scalability, cost, efficiency, and uninterruptable power supply availability [129] [130], [131].

Except for small DC projects, a new DC using power provided by a utility will require an onsite substation. Developers of very large DCs, or hyperscale DCs, are considering investing in reliable onsite power resources such as nuclear power [132].

A-2.1.1 Data center types

As discussed in Section 2, there are various types of DCs. Small onsite DCs are typically supporting a specific entity. These enterprise DCs are an integral part of the entity complex, and the power demand is typically manageable from the existing grid.

Mid-sized DCs include core DCs, Colocation DCs, managed DCs, and edge DCs. These centers are separate from the entity and are differentiated by the specific service they are offering. According to the 2024 LBNL DC report [38], a typical high-end 8-processor server will draw an average of 1.2 kW. A 2017 LBNL report [133] suggests that a mid-sized DC could have up to 500 servers. This would suggest a power requirement of 0.6 MW for the servers. Even with a power usage effectiveness (PUE) of 1.5, a mid-sized DC would have a power requirement of approximately 1 MW.

Hyperscale DCs support extremely large data service providers. Hyperscale DCs represent a significant capability increase above mid-sized DCs. Hyperscale DCs have at least 5,000 servers [134] [135]. At 5,000 servers, a DC would require approximately 10 MW. Current building trends are toward more hyperscale DCs. If it is assumed that economies of scale also apply, including room for center expansion, it is not unreasonable to anticipate hyperscale DCs with 50,000 servers. This would suggest a power requirement of approximately 100 MW.

Beyond individual hyperscale DCs, developers are envisioning gigawatt-scale campuses housing multiple hyperscale facilities [136].

A-2.1.2 Energy storage

DCs and the customers they support cannot afford to experience service disruptions resulting from power outages or power spikes. Onsite renewable energy sources and a means to store the energy could be advantageous. This would allow the DC to continue operation until a backup power supply can be brought online. This could be in the form of batteries, or the heat stored in molten salts. Certain advanced reactor technologies, such as the Natrium concept, could provide the primary power source and simultaneously provide for thermal energy storage.

A-2.1.3 Energy efficiency

A metric of DC energy efficiency is PUE. The DC PUE is important to consider because the energy source providing power to the DC requires a cooling source, which is typically water. This is identified as the indirect water footprint for a DC.

PUE = Total power supplied to the DC / Power consumed by the server equipment [137].

A PUE value close to 1.0 is ideal because it signifies that most or all energy consumed by a DC is used to power the computer server devices. However, a PUE of 1.0 is unrealistic because the energy used for non-computing elements, such as lighting and cooling, increases the PUE above 1.0. Still, a DC’s PUE tends to be inversely proportional to its size, owing to economies of scale [138].

A-2.2 Cooling

DC power consumption is significantly impacted by the need to keep servers and equipment cool. Because of the amount of heat generated by the server equipment, water is a key resource in cooling the equipment, aided by air cooling.

Therefore, DC site selection is highly dependent on the continued availability of cooling water. More temperate climates may be preferred because they enhance cooling capacity and reduce the cooling water requirements. Environments that require greater mechanical cooling are less desirable because of the costs associated with keeping cooling equipment running. [129] [131]

A-2.2.1 Climate

Weather and climate can significantly impact the energy efficiency and operational costs for a DC. One simple metric to measure climate is evaluating the average temperatures in a region of interest. This will affect the DC cooling efficiency over the course of a year [139]. Building facilities in cool, low-humidity regions provides cooling technology options that may not be feasible in warmer climates. This approach will lower energy costs, improve cooling efficiency and reduce environmental impact [140].

Within a region of interest, locations at a higher altitude may be preferable to a location in a lower altitude.

A-2.2.2 Indirect and direct water use

The U.S. is a global leader in the DC industry, with more than 5,300 facilities, according to information from Statista.com, a global data and business intelligence platform. The round-the-clock operation of these DCs makes the digital world possible. In the process, DCs consume enormous amounts of resources, especially water. That water is used in two primary ways: indirectly, to generate the electricity to run the computer server equipment, and directly, as the medium to dissipate the heat generated by the servers and other DC equipment [141].

Within a DC, water is used for cooling server equipment rooms. Most DCs use a chilled water circuit to absorb the heat generated by the server equipment. The water is chilled by cooling units powered by electricity or, sometimes, by cool air from the outside using an air-cooled system [142]. It should be noted that even when air-cooled systems can replace water-cooled systems—such as in colder weather region—water-cooled technologies operate more efficiently [143]. In some locations, water usage only commences when external temperatures rise above a certain threshold, increasing the need for cooling. Under such conditions, some DCs will start a system that sprays droplets of water (adiabatic cooling) to cool down the air flow by a few additional degrees before switching to a water chiller system [142].

A metric of DC water requirements is the water usage effectiveness (WUE). The WUE is the ratio between water used at the DC and electricity delivered to the server hardware [144]. Specifically:

WUE = Annual water usage (L) / Server equipment energy (kWh) [143]

Data center cooling requirements depend on the proposed size of the project; however, the cooling water requirement is evolving. For example, according to a 2016 LBNL report, it takes about 7.6 liters of water on average to generate 1 kWh of energy in the U.S. An average DC has a WUE of 1.8 L/kWh (7.9 gpm/MW). As a result, U.S. DCs consume billions of liters of water each year, and the amount of water usage is growing [137]. For example, it was reported [145] that Google DCs in The Dalles, Oregon, consumed more than 355 million gallons of water in 2021—an amount that had tripled since 2016—representing more than one-quarter of the town's annual water consumption. Two more DCs are slated to come online in the future in that area, adding to the regional water demand [141].

Another study in 2016 by the Uptime Institute [146] put DC water usage at 12.8 gpm/MW for a standard water chiller system and cooling tower. Cooling towers require makeup water because of evaporation, blowdown, and drift. The report noted that there are techniques, technologies, and temperature tolerances that can reduce the cooling water requirement per MW of DC load.

Since 2016, DCs have committed to better tracking of water usage and improvements in efficiency. In addition, more water-neutral renewable energy sources have come online. An updated 2024 LBNL report indicates that DCs in the US have a WUE of 0.36 L/kWh (1.6 gpm/MW) through 2023. After 2023, the average DC WUE is projected to rise to a value of 0.45 to 0.48 L/kWh (2.1 gpm/MW), reflecting increasing construction of hyperscale and Colocation DCs [38].

This LBNL report notes that US DCs consumed approximately 176 TWh in 2023, using nearly 800 billion liters of water for electricity generation (a figure based on the regional electricity grid mix for DC locations). This finding translates to a national average of 4.52 L/kWh (20 gpm/MW) of indirect water consumption for DCs [38]. This figure indicates as much as 5.0 L/kWh (22 gpm/MW) total direct and indirect water consumption for new DCs. The maximum cooling water requirements for the colocated NPP and DC can be projected based on these estimates.

Direct DC water consumption occurs close to the DC site, while the associated indirect water consumption is distributed more broadly geographically. Therefore, DC site selection should consider the potential stress on the local water basin associated with the potential site [138].

DC cooling sources could be freshwater lakes and streams, freshwater aquifers, local water distribution systems, or reprocessed water (municipal gray water). Onsite purification will likely be required because of the ultrapure needed for DC cooling.

A-2.3 Access to Fiber or Connectivity

Fiber infrastructure is becoming widespread in developed areas such as urban and suburban locations. A rural site for a DC may lack easy access to fiber optic infrastructure. This situation would require planning and right-of-way approvals to bring fiber to the site. Good connectivity to the internet and other DCs ensures that data can be transferred quickly and predictably. Redundancy through multiple service providers or through a content delivery network can help prevent interruptions to operations. Therefore, proximity to an internet exchange point where multiple large networks integrate with one another should be considered. Sites that do not possess adequate telecommunication infrastructure, including the presence of multiple carriers, should be eliminated from the selection process. [138] [130] [129] [131]

A-2.4 Space

According to Bohler [147], DCs generally need at least two buildings on a site to optimize utilities and security. Bohler estimates a minimum requirement of 40 acres for a small DC. Hyperscale DC developers will require larger tracts of land. For example, a very large DC, or hyperscale DC, will require hundreds of acres with considerable energy resources [132]. Some developers are proposing hyperscale DC parks on several thousand acres [136].

A-2.4.1 Community pushback

Public concern about any construction project is inevitable. DC construction will generate concerns over:

- Noise
- Environmental impact
- Visual appeal
- Loss of land for other purposes
- Traffic
- Impact on price of local electricity supply

A-2.4.2 Real estate cost

Important factors for DC siting include the cost of rent or purchase, utilities, taxes and other operating expenses because they substantially affect the cost of providing cloud services [130]. However, in early 2022, hyperscale operators scooped up much of the available real estate in primary DC markets [140], effectively shutting out smaller DC operators. Therefore, evaluation of secondary markets may be more fruitful for future siting considerations.

One real estate caveat is that building in regions with a high potential for hurricanes, earthquakes, wildfires and other natural disasters puts data and equipment at risk. These regions are often more expensive to build in owing to added insurance and construction regulations, as well as improved structural hardening to offset risks, so there may be a point at which an area may not be worth the additional risk and expense [140] [129].

A-2.5 Security

Investment risk to the developer of the DC will require some attention to both cyber security and physical site security. This could be in the form of fences, barriers, 24/7 guarded site access, onsite security teams, and automated security. The site should be in a safe and secure area, away from high-crime areas [130]. In addition, buildings and support equipment should be protected from fire and other natural disaster risks. A generic DC site with proposed physical security measures as designed by Senstar is presented in Ref. [148]. Note that this proposed layout does not include the additional requirements that will exist if a power generating source is colocated with the DC. If a small, advanced NPP is included as the power source, the DC could be included in the site security plan for the NPP.

A-2.6 Risk

As noted, when considering the real estate cost, the risk of natural and man-made hazards to the site must be evaluated. A loss of the DC or a loss of access to the DC could negatively impact the user base or force the operator to rely on a backup DC. By choosing a secure location, businesses can mitigate the risk of data loss and ensure the continuity of their operations [149]. Risks could include:

- Commercial airports
- Chemical or energy facilities (fire, missile, or toxic gas)
- Seismic zones
- Faults
- Volcanic activity
- High water (including future projected impacts)
- High wind (including future projected impacts)
- Fire threat (including future projected impacts)

These and other identified risks should be flagged if they are within a certain distance of the proposed site or if they engulf a proposed site, so that the siting decision is better informed.

DC siting should also consider any planned inter-connectivity with other DCs. An organization that offers a nationwide network of DCs can promise more reliability than one that has sites all within a short distance of one another. The ability of a DC to failover to another location after a disaster is an important siting consideration. From the user perspective, if an organization is choosing to house data in more than one DC, choosing facilities that are far enough apart means selecting centers that are not prone to the same risks. While there’s no hard and fast requirement, 100 miles is a good rule of thumb for DC separation for one organization [150].

A-2.7 Accessibility

The selected site should be near adequate roads and within proximity of a transportation hub, such as an airport, for ease of shipping DC hardware. Transportation will be a factor to consider for employees, visitors, and hardware upkeep whether an urban, suburban, or rural site is selected.

Remote locations may be less expensive, but they can also be difficult to reach. Before constructing a new facility, consider the logistics of building, maintaining and staffing a DC that isn’t easily accessible [140].

A-2.8 Labor Pool

The skill level and technical knowledge of the local labor pool should be part of the evaluation because DCs require educated, skilled professionals to support the computer equipment and the associated support equipment, and provide for facility and infrastructure maintenance. The site selection also impacts the ability to attract and retain employees with appropriate skill sets [140] [129] [151]. Locating a DC near a university or a computer training school may be a siting consideration that helps to ensure the availability of staff with appropriate skills [152].

A-2.9 Zoning

A secondary site decision criterion could include zoning and other ordinances. Once the siting options are narrowed to a small list, site zoning restrictions could indicate that some locations are more favorable than others. Zoning restrictions could affect the type, size, or height of the planned facility. In addition, periodic operations such as running diesel generators for backup power may be restricted [152]. Obtaining a zoning variance or rezoning a property can be a time-intensive process and may ultimately not be possible.

A-2.10 Tax Incentives

Many states and communities want to attract employers and jobs to their region. This motivation often leads to tax incentives to locate a facility in the region. Tax incentives will vary by state and county depending on the industry, the number of associated jobs, and the payroll. As with zoning, this is a parameter that may be more pertinent to a comparison of available sites when a developer is weighing options.

Remote and secondary markets may be more likely to offer incentives and tax breaks to attract new DC construction projects and jobs to their communities [140].

A-3. PROPOSED DATA CENTER SITING PARAMETERS FOR OR-SAGE

A-3.1 Advanced Reactor Siting

The standard advanced reactor siting parameters applied within the OR-SAGE model are used for the DC power source as shown in Table A-10-1. The values in the red cells in Table A-10-1 depend on the NPP technology selected. The OR-SAGE model uses publicly available water projections for various advanced reactor technologies, which can be added to the average DC cooling water requirement. If the DC property is large, the OR-SAGE parameters only need to apply to the reactor site footprint. A standard large DC could be set at 100 MW.

Table A-10-1. OR-SAGE advanced reactor exclusion criteria.

OR-SAGE Screening Criteria for Reactor Technologies	Advanced Reactors
Population density (people/square mile)	**>500 ppsm within 1 mile**
Safe shutdown earthquake (ground acceleration)	**>0.3, >0.5, >0.75**g
Wetlands/open waters	Not allowed
Protected lands	Not allowed
Slope	>18% grade excluded
Landslide hazard (moderate or high)	Flag
100-year floodplain	Not allowed
Streamflow – cooling water makeup (X gallons/minute; closed cycle cooling; limited to 10% of resource)	**Potentially 0 or very small**
Proximity to hazards (buffer distance)	Flag 1–10 miles
Proximity to fault lines (buffer distance)	Depends on length of fault

A-3.2 Data Center Cooling

DC cooling requirements depend on the proposed size of the project. A 2024 LBNL study projected direct DC cooling requirements at 0.48 L/kWh. This translates to 0.0021 gallons per minute (gpm) for each kilowatt of demand. A large DC could consume 100 MW, and would thus require 210 gpm of purified freshwater cooling. If this were limited to no more than 10% of the available water source, then a source providing at least 2,100 gpm would be necessary. This figure would be added to the water-cooling requirements of a colocated advanced NPP and subject to the same 10% limitation. Reports from 2016 put the DC makeup water at 12.8 gpm/MW. A 100-MW DC at this value would require 12,800 gpm in cooling, with the local water source capable of providing at least 128,000 gpm. New DCs certainly trend toward the lower water demand. A reasonable bound on new DC makeup water is 5 gpm/MW from a local water source capable of providing at least 50 gpm/MW. Therefore, a 100-MW facility would need a local water source capable of providing at least 5,000 gpm just for DC cooling to adhere to the recommended 10% limit on available water.

To address the amount of cooling water required, a site may decide to source the water on site via a borehole or artificial lake rather than relying on a stream or river. This variation can also be modeled in OR-SAGE, although a water source to account for evaporation and drought must be considered. As a result, most DC operators rely on local potable water resources because access to rainfall, gray water and surface water is seen as unreliable [153].

A-3.3 Access to Fiber

Data maps of fiber lines should be used to show the proximity of such lines. This map will provide an indication of the distance and diversity of fiber lines available. Rules of thumb for cost and distance can be generated for ranking suitable sites.

A-3.4 Footprint and Security

Mid-sized DCs require a footprint as small as 40 acres [147], while a hyperscale DC may require up to 200 acres [132]. Therefore, 200 acres seems to be a reasonable bounding value for the DC alone. However, additional land will be required to accommodate a colocated advanced NPP. Fifty acres or less will typically accommodate SMR. However, a database site may want to seek more than 250 acres combined to allow for additional separation. Of course, if security is to be combined for the facilities, then a smaller footprint is more efficient. The NRC has additional siting requirements regarding NPP proximity to population centers that colocated facilities will need to consider. These are incorporated in the OR-SAGE site requirements for advanced NPPs.

A-3.5 Data Center Types

Available literature suggests that there are 4 to 6 different types of DCs [134] [135] [154]. On one end of the spectrum are small onsite DCs supporting a specific entity. Such enterprise DCs are an integral part of the entity complex and are not feasible for site modeling using GIS techniques.

Mid-sized DCs include core DCs, Colocation DCs, managed DCs, and edge DCs. These service providers are separate from the entity and are differentiated by the specific service they are offering. While the footprint for such DCs can be much smaller, a reasonable GIS bounding value is 40 acres, as noted in Section A-3.4. According to the 2024 LBNL DC report [149], a typical high-end 8-processor server will draw an average of 1.2 kW. A 2017 LBNL report [133] suggests that a mid-sized DC could have up to 500 servers. This would suggest a power requirement for the servers of 0.6 MW. Even with a PUE of 1.5, a mid-sized DC would be bound by a power requirement of 1 MW. Such a DC would require a local water source capable of providing at least 50 gpm to cool the DC and adhere to the recommended 10% demand limit on the available water supply.

Hyperscale DCs support extremely large data service providers. Companies with such needs include Amazon, Apple, ByteDance, Google, Meta, and Microsoft. Hyperscale DCs represent a significant capability increase above mid-sized DCs. These DCs have a much larger footprint, exist on their own campus, and generally fit within an upper bound of 200 acres including all support buildings. Hyperscale DCs have at least 5,000 servers [134] [135]. Current building trends are toward more hyperscale DCs. If it is assumed that economies of scale also apply, including room for center expansion, it is not unreasonable to anticipate hyperscale DCs with 50,000 servers. At 1.2 kW per server and a PUE of 1.5, this size would suggest a power requirement of 90 MW. For bounding purposes, a smaller hyperscale DC with 5,000 servers would be bound at 10 MW and an extremely large hyperscale DC with 50,000 servers should be bound at 100 MW. The cooling water requirements would be 500 gpm and 5,000 gpm, respectively.

Beyond individual hyperscale DCs, developers are envisioning gigawatt-scale campuses housing multiple hyperscale facilities [136]. Two-thousand-acre campuses are proposed, requiring as much as 10 GW. Projects at this scale would require multiple generators for support.

A-3.6 Risk

It was noted in Section A-2.5 that two DCs supporting the same organization should be at least 100 miles apart [150]. This preference may be incorporated into DC siting.

Other DC risks were identified in Section A-2.5, including:

- Commercial airports
- Chemical or energy facilities (fire, missile, or toxic gas)
- Seismic zones
- Faults
- Volcanic activity
- High water (including climatic impacts)
- High wind (including climatic impacts)
- Fire threat (including climatic impacts)

All these parameters serve as flags in the siting decision process. Airports, volcanic activity, chemical, and energy facilities, not including the colocated NPP, could be flagged if located withing 5 miles of the proposed DC site. These risk factors are currently not included in this analysis. A typical building code limit for seismic activity is to build for 0.75 g, so values above this limit can be flagged; this value is used in this analysis for assessing suitable sites. A conservative flag for faults would be to use the same standoff distance as for the colocated advanced NPP. Parameter flags for water, wind, fire, and any other identified threats to a proposed site will need to be developed for secondary analysis or to rank suitable sites depending on data availability and the perceived threat.

A-3.7 Accessibility

Road infrastructure can be overlaid on any DC siting parameter results. This overlay can inform the cost to make a proposed site accessible.

A-3.8 Labor Pool

Pending available data, multiple data sets could provide college/training availability, economic diversity, labor rates, etc. While none of these factors will directly influence how adequate a proposed site might be, they will provide good information to differentiate between proposed sites.

A-3.9 Zoning and Tax Incentives

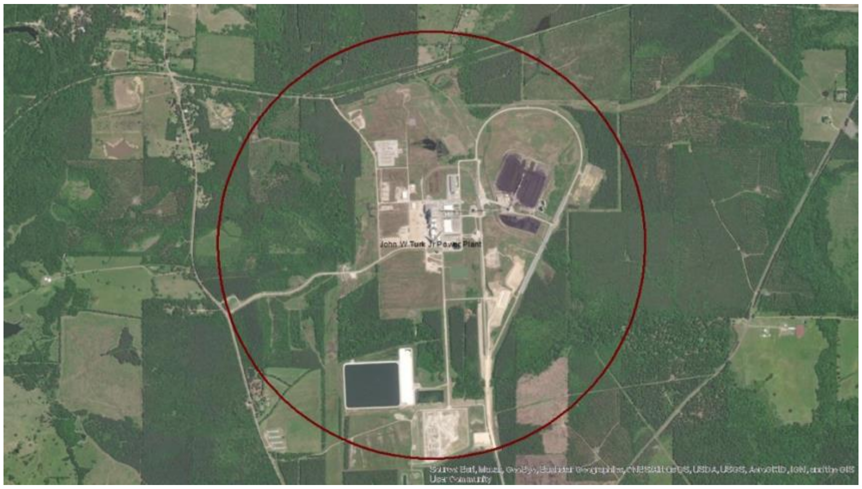
Zoning and tax incentives are likely to be significant drivers in a DC siting decision. However, data to visually influence a decision using GIS technology may be limited. For example, there may be some zoning information that could be used to flag residential areas, but this may be difficult to translate into areas that could be rezoned for commercial plus nuclear use. Likewise, tax incentives to lure business to an area are not routinely tracked in a database. However, proprietary data available to a potential DC builder may be available for visualization.

A-4. EXAMPLES OF BROWNFIELD SITE ANALYSES

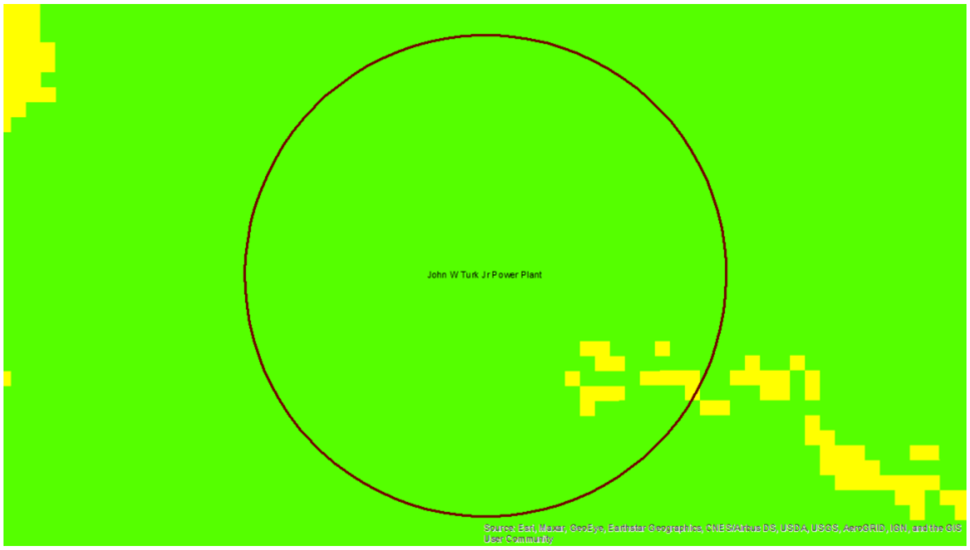
To illustrate how the results in Section 7.3 are obtained, we describe two cases using visual analysis. Note that the plants used for this visual analysis were randomly selected to convey some of the distinctive situations in the results shown in Section 7.3.

A-4.1 John W. Turker Jr. Power Plant

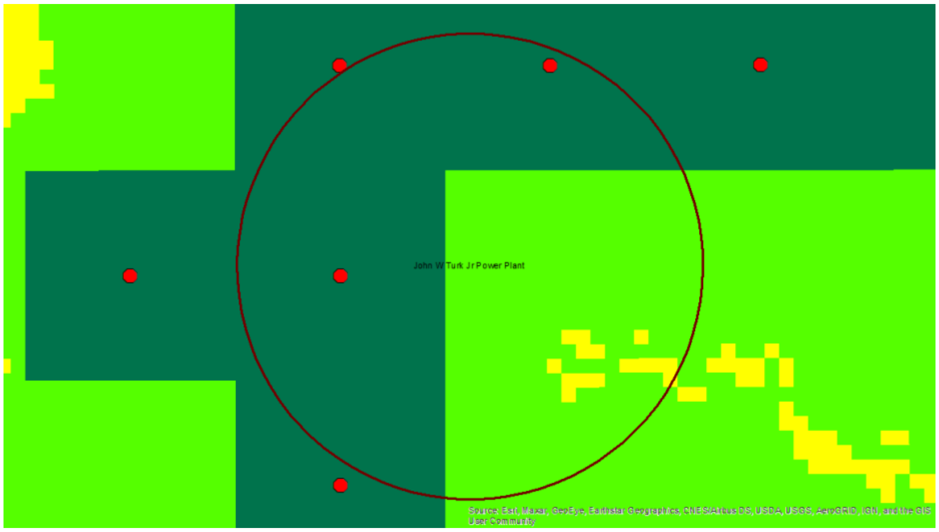
For the first case, we consider the John W. Turker Jr. Power Plant located in Hempstead County in Arkansas. This is an example of a site where a CPP plant could be backfitted with an NPP and also host DC(s).



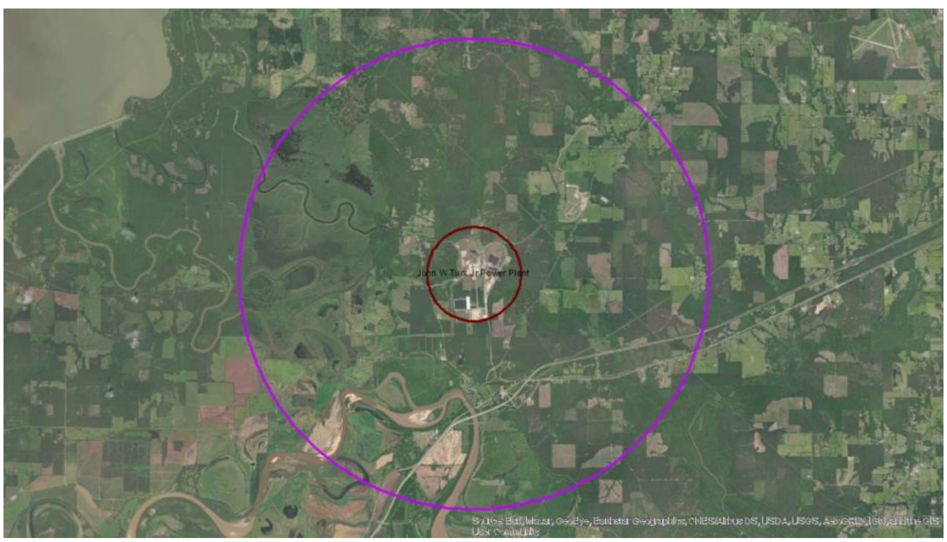
This figure shows an aerial view of the power plant. The red circular outline represents the 1-mi radius around the centroid of the plant.



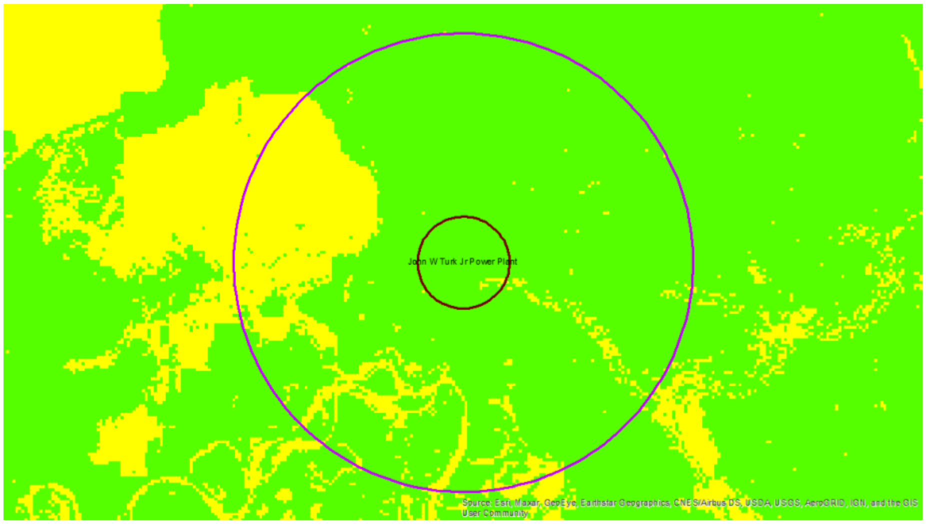
On the basis of OR-SAGE analysis, the power plant is suitable for a large LWR, since almost the entire 1-mi radius is light green, as shown in the above figure. The cell size for the OR-SAGE analysis is 100 m by 100 m (about 2.5 acres).



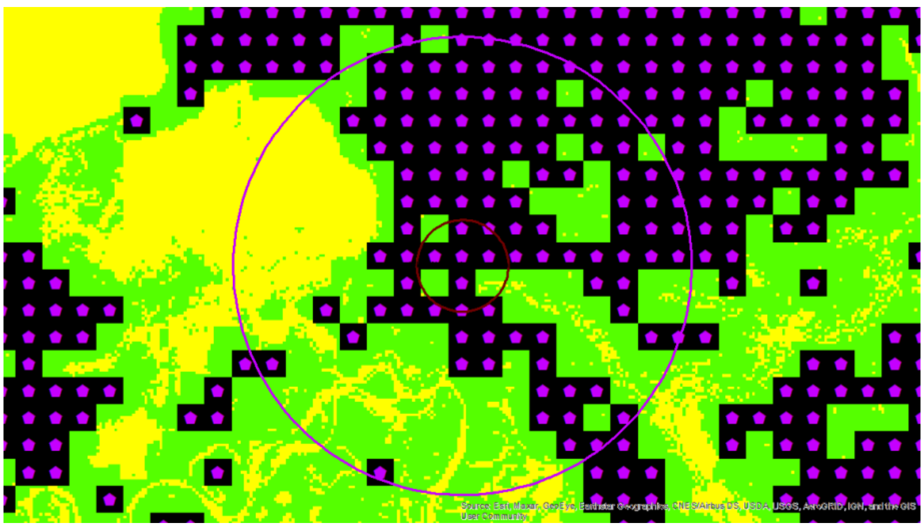
This figure shows an overlay of the aggregation of individual 2.5-acre cells to obtain the ~500-acre cell (that is, 1450 m by 1450 m) required for a large LWR plant. The 500-acre cells are shown in dark green. We can see that there are many yellow(“orphan”) 2.5-acre cells that are not contiguous enough to make a 500-acre cell. The red dots represent the centroids of the 500-acre cells. According to this result, there are two red dots within the 1-mi radius, therefore, we concluded that this plant could backfit at least 2 NPP units. Consequently, there is an opportunity for those units to host a hyperscale or gigawatt DC within a 5-mi radius.



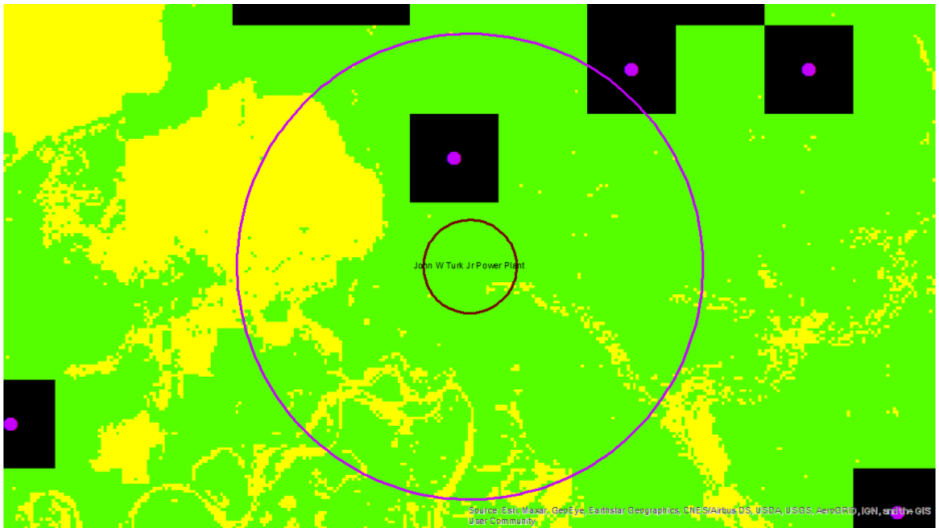
This figure shows an aerial view of the plant with a 1-mi radius outlined in dark red and a 5-mi radius outlined in purple.



This figure shows the OR-SAGE analysis for the 5-mi radius. Most of the area within the 5-mi radius is viable for siting a DC and is shown in light green.



This figure shows the result of the aggregation of the suitable area for a hyperscale DC that requires a footprint of 200 acres (that is, a 900-m by 900-m cell). The purple dots represent the centroids of those aggregated cells. The number of dots between the boundaries of the 1-mi and 5-mi radii represents the minimum potential number of hyperscale DCs that could be sited around this plant.

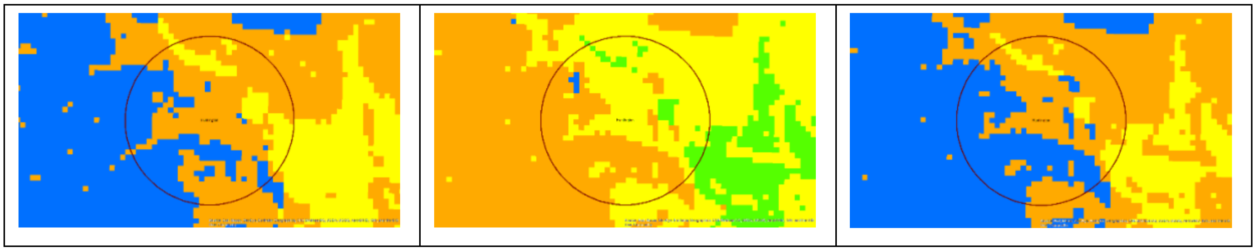


This figure shows similar results for the gigawatt DCs that require a footprint of 2000 acres (that is, 2900-m by 2900-m cells). According to this result, only one gigawatt hyperscale DC could be sited within the boundaries of the 1-mi and 5-mi radii. However, there are opportunities for smaller DCs, even, hyperscale DCs colocated with the gigawatt hyperscale DC, since at least two units of large LWR plants could fit within the 1-mi radius of the CPP site.

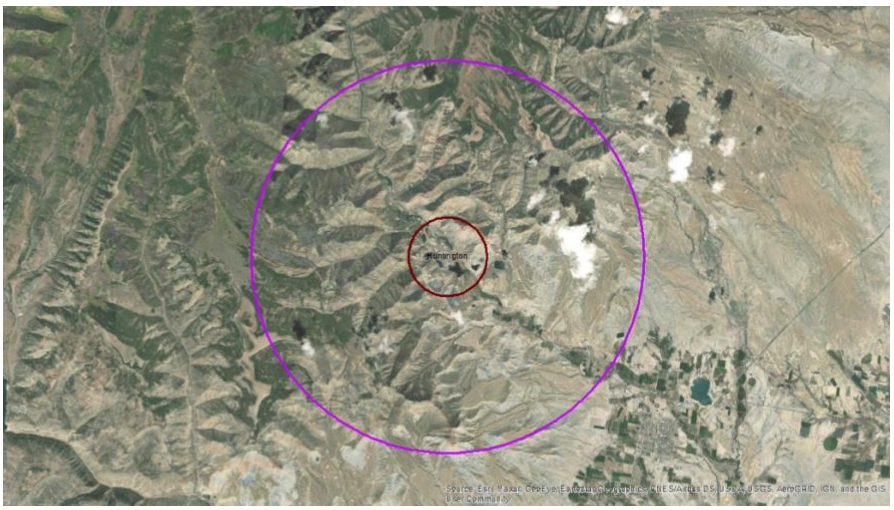
A-4.2 Huntington Power Plant

For the second case, we consider the Huntington Power Plant located in Emery County in Utah. This case illustrates a CPP site that cannot backfit an NPP even though there are viable land areas within the 5-mi radius that could support the siting of DCs.

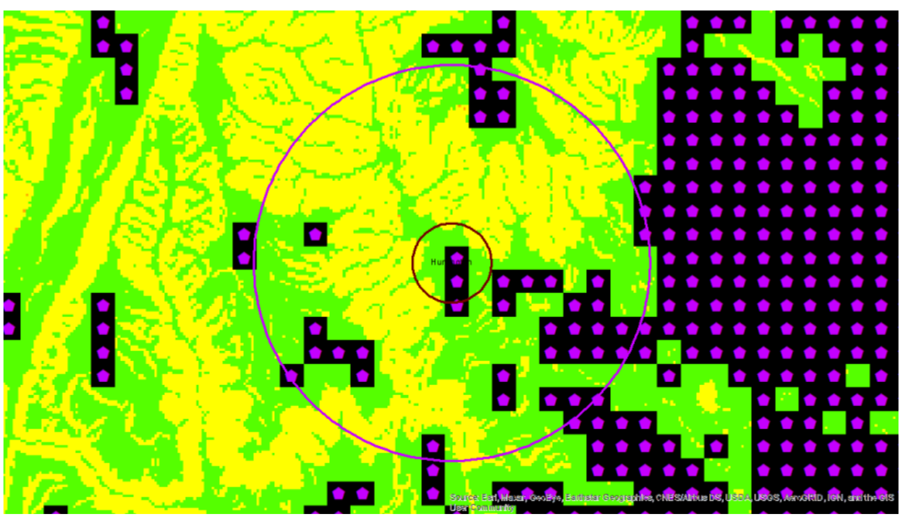
This figure shows the aerial view of the power plant. The red circular outline represents the 1-mi radius around the centroid of the plant.



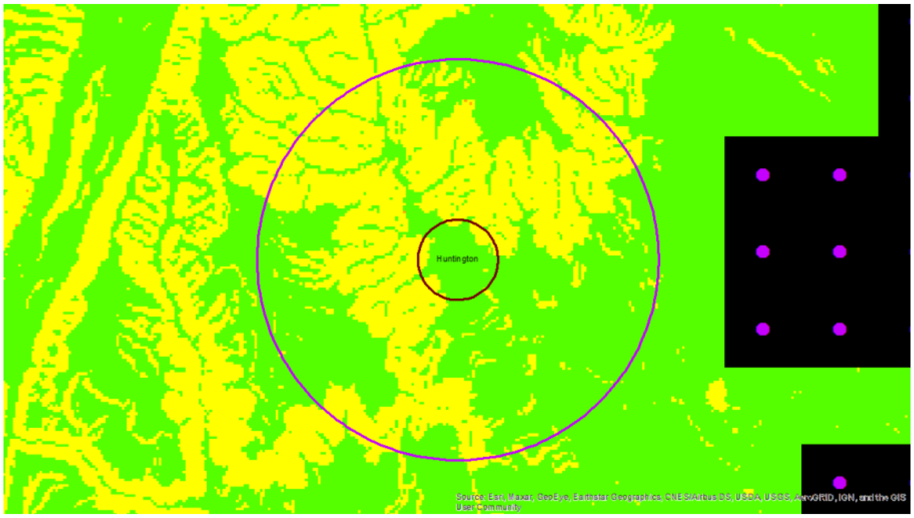
The figures in this box show the OR-SAGE analysis for three classes of NPP plants (left to right) a SMR plant that requires fresh water for cooling; a SMR plant that does not require fresh water for cooling; and a large LWR plant. In this figure, the following color coding is used: green – meets all criteria; yellow – single issue; orange – two issues; and blue – 3+ issues. According to these results, only the SMR that does not require fresh water for cooling has patches of light green, denoting suitable cells within the 1-mi radius. However, there are not enough light green patches to meet the footprint requirement for a SMR plant. Therefore, there is no potential for backfitting an NPP plant at this site, even though there may be opportunities for siting DCs within the 5-mi radius of this site, as we will show below.



This figure shows an aerial view of the Huntington plant with a 5-mi radius outlined in purple and the 1-mi radius outlined in dark red.



This figure shows that there is enough viable land within the boundaries of the 1-mi and 5-mi radii for siting a hyperscale DC with a 200-acre footprint.



However, this figure shows that there is not enough contiguous land area for a gigawatt hyperscale DC that requires 2000 acres. Therefore, in our analysis, we did not include this plant in the list of viable CPP sites that could backfit an NPP plant and host a DC.