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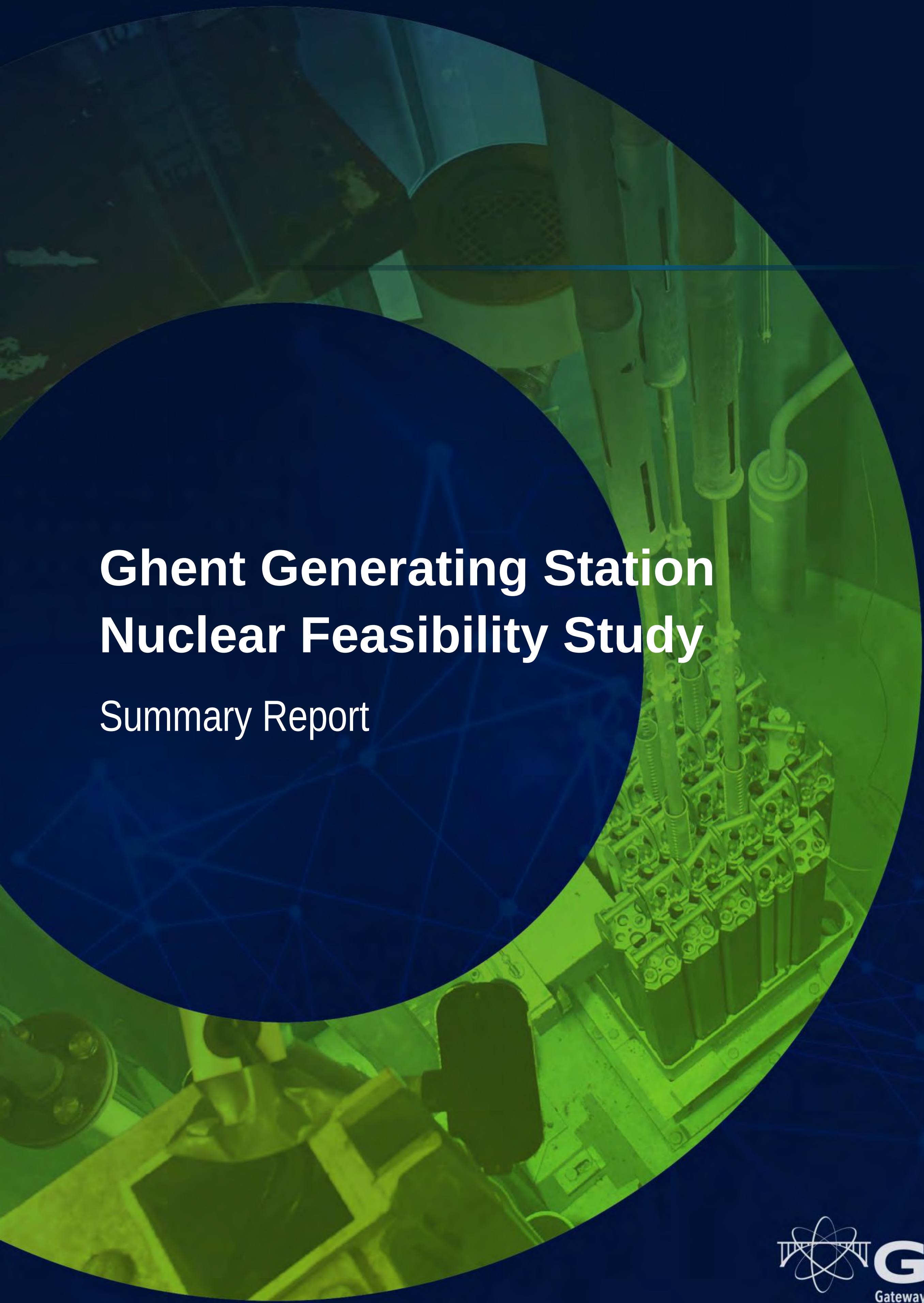

Ghent Generating Station Nuclear Feasibility Study

Summary Report

GAIN
Gateway for Accelerated Innovation in Nuclear

Ghent Generating Station Nuclear Feasibility Study

Summary Report

Revision 0 – Initial Release

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ACRONYMS / ABBREVIATIONS

BWR	Boiling Water Reactor
CCR	Coal Combustion Residual
CFR	Code of Federal Regulations
CGS	Coronado Generating Station
COL	Combined Operating License
DOE	Department of Energy
EIR	Energy Infrastructure Reinvestment
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	Early Site Permit
FOAK	First of a Kind
GAIN	Gateway for Accelerated Innovation in Nuclear
GGS	Ghent Generating Station
GW	Gigawatt
HALEU	High-Assay Low-Enriched Uranium
HTGR	High Temperature Gas Reactor
ISFSI	Interim Spent Fuel Storage Installation
INL	Idaho National Laboratory
IRA	Inflation Reduction Act
ITC	Investment Tax Credit
KU	Kentucky Utilities
LCOE	Levelized Cost of Electricity
LEU	Low Enriched Uranium
LG&E	Louisville Gas and Electric
LMFR	Liquid Metal Fast Reactor
MPR	MPR Associates, Inc.

MW	Megawatt
NEA	Nuclear Energy Agency
NIA	Nuclear Innovation Alliance
NRC	Nuclear Regulatory Commission
O&M	Operations and Maintenance
PGDP	Paducah Gaseous Diffusion Plant
PPE	Plant Parameter Envelope
PPL	PPL Corporation
PSC	Public Service Commission
PTC	Production Tax Credit
PWR	Pressurized Water Reactor
RFP	Request for Proposal
SRP	Salt River Project
TRISO	TRi-Structual ISOtropic

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EXECUTIVE SUMMARY

Coal plant retirements are on the rise as the power industry moves to achieve carbon emission reduction goals and shifts to a clean energy economy. Increasing the share of nuclear power in the energy mix is one pathway to achieving emissions reductions. Siting nuclear generation projects on the same property or nearby land as retiring coal plants is one deployment option being evaluated. Using such locations would enable these new nuclear deployments to utilize some of the coal plant sites' infrastructure and would create high-paying jobs in existing energy communities.

The Gateway for Accelerated Innovation in Nuclear (GAIN) is working with a diverse group of participants to evaluate coal plant sites in different regions across the United States and establish a broad foundation and framework for successful nuclear feasibility studies. Ghent Generating Station (GGS), owned and operated by Louisville Gas & Electric (LG&E) and Kentucky Utilities (KU), a part of the PPL Corporation (PPL) family, is one of several sites being evaluated by GAIN.

GGS is a four-unit, coal-fired power plant located near Ghent, Kentucky in Carroll County. The four units have a net generating capacity of 1,919 MWe and are planned for phased retirement, with Units 1 and 2 retiring first and Units 3 and 4 retiring afterwards. GGS is located within five miles of several industrial companies that consume large amounts of electricity and may be potential process heat customers.

The objective of the overall GGS nuclear feasibility study is to enable PPL's decision-making process about future generation options and reduce uncertainty associated with potential deployment of nuclear technology at the site. The two-part GGS nuclear feasibility study includes (1) a siting evaluation, and (2) a nuclear technology assessment. GAIN worked collaboratively with PPL to complete the studies and identify potential next steps for PPL. Results are summarized below and expanded upon in this report. While each coal plant, energy community[1], and utility is unique, certain results from the GGS study could apply to coal plants that possess similar characteristics to GGS and utilities with missions and business objectives like those of PPL.

The siting evaluation assesses the suitability of the GGS site and surrounding PPL-owned land for nuclear generation. While the formal siting process for a nuclear reactor requires a significant amount of time (i.e., multi-year), effort, and detail, the siting evaluation provides an initial assessment of whether the GGS site has characteristics that could preclude nuclear deployment (i.e., exclusionary factors) or characteristics that could present challenges leading to increased cost and risk (i.e., avoidance factors). No exclusionary factors were identified based on a review

[1] The Inflation Reduction Act (IRA) provides specific definitions for what is designated as an "energy community". For more detail, see Reference 2.

of publicly available information and data provided by PPL. Two avoidance factors were identified at GGS related to land availability. The first avoidance factor is that the existing PPL property has challenging, higher slope terrain, which could require significant grading to flatten land suitable for nuclear deployment. The second is the potential proximity to coal combustion residual (CCR) storage that could limit available land for siting. These avoidance factors can be addressed during potential nuclear deployment. Impacts on the local community, including potential for new jobs and increased economic output, should also be considered during the nuclear siting process. Local communities should be engaged early and often to allow community members to provide input and ask questions to influence decisions.

The nuclear technology assessment identifies candidate nuclear technologies and potential designs that align with PPL's current mission and business objectives. GAIN's efforts relied on publicly available information and input from PPL. This nuclear technology assessment identified small and medium advanced nuclear reactors[2] as the candidate technologies that best align with PPL's mission and business objectives. Out of the small and medium advanced reactor grouping, several potential designs could meet PPL's mission and business objectives.

GGS is a viable location to site one of several potential nuclear reactor designs. However, if PPL decides to pursue this direction, they would need to balance the cost of land preparation (e.g., grading, CCR remediation, additional land acquisition) against other options. Other options include siting at an alternate site or reducing a potential nuclear facility's footprint to fit on the GGS site (therefore reducing power output of the site).

[2] The term "advanced nuclear reactor" refers to a nuclear fission reactor with significant improvements, including additional inherent safety features, compared to reactors operating on December 27, 2020, in the United States. When defining reactors by size, small reactors have an electrical output between 50-300 MWe and medium reactors have an electrical output between 300-600 MWe (Reference 46).

INTRODUCTION AND PURPOSE

The Gateway for Accelerated Innovation in Nuclear (GAIN) is working with a diverse group of participants to evaluate several coal plant sites in different regions across the United States and establish a broad foundation and framework for successful nuclear feasibility studies. Kentucky Utilities' Ghent Generating Station (GGS), located in Carroll County, Kentucky, is one of several sites undergoing a GAIN nuclear feasibility study. GGS is owned and operated by PPL Corporation (PPL) companies[3].

The purpose of this report is to summarize the approach taken and the results obtained in the two-part GGS nuclear feasibility study. GAIN's approach to the GGS study is intended to be applicable and repeatable for other coal plants. While every coal plant, energy community, and utility is unique, certain results from this study may apply to coal plants that possess similar characteristics to GGS and to utilities with similar missions and business objectives to PPL.

The two-part GGS nuclear feasibility study includes (1) a siting evaluation, and (2) a nuclear technology assessment. The objective of the overall GGS nuclear feasibility study is to inform PPL's decision-making process about future generation options and reduce uncertainty associated with potential deployment of nuclear technology at this site. GAIN's efforts relied on industry-recognized siting and nuclear technology selection guidance, publicly available information from vendors and researchers, information from PPL, and nuclear domain expertise within GAIN, MPR Associates, Inc. (MPR), and Idaho National Laboratory (INL).

BACKGROUND AND MOTIVATION

The electric power industry is undergoing a significant transition driven by changes in technology, economics, and customer demands. Between 2015 and 2020, the United States retired an average of 11 Gigawatts (GW) of coal capacity each year (Reference 3). Coal retirements are expected to continue as the power industry moves to achieve carbon emission reduction goals and shifts to a clean energy economy. Communities, government, utilities, and researchers across the United States are seeking options to reduce carbon emissions, and adding more nuclear power to the energy mix is one pathway to achieving this reduction. Siting nuclear projects on the same property or nearby land as retiring coal plants is one option that is being considered and evaluated. This would enable these new nuclear deployments to utilize the coal plant sites' infrastructure (depending on the age and condition) while supporting a just energy transition by supporting high-paying jobs in existing communities, contributing to a greener energy portfolio, and reducing local pollution. Deployment of nuclear technology in general also

[3] For this report, any references to "PPL Corporation" include their subsidiaries, such as Louisville Gas & Electric (LG&E) and Kentucky Utilities (KU).

contributes to the resilience of the electric grid through the siting of firm, dispatchable sources of electricity generation.

Evaluating, planning for, and successfully completing the deployment of a nuclear power plant is a complicated and challenging task for any power company. Such projects require the development of the right partnerships to ensure that the appropriate nuclear technology options and deployment pathways are available to meet business and community goals. Critical to evaluation and planning for a coal to nuclear transition is engagement with the community to understand and incorporate their vision for a successful transition of the coal plant.

GAIN serves as an independent resource for nuclear innovation and deployment, without bias towards site location or technology selection. As an initiative from the Department of Energy's (DOE's) Office of Nuclear Energy, GAIN engages with industry, communities, and decision-makers on a regular basis to strengthen and optimize the program and resulting products.

GAIN is working with a diverse group of participants to evaluate several specific sites in different regions and establish a broad foundation and framework for successful nuclear technology implementation across the United States. GAIN has previously participated in studies with Coronado Generating Station (CGS), located near the City of Saint Johns, Arizona (Reference 4).

PPL CORPORATION

PPL is the parent company of several utilities serving the states of Kentucky, Pennsylvania, Rhode Island, and Virginia. In Kentucky, PPL's holdings include two regulated utilities based in Louisville, Kentucky: Louisville Gas and Electric (LG&E) and Kentucky Utilities (KU). Combined, LG&E and KU serve more than 1.3 million customers with 7500 Megawatts (MWs) of capacity (Reference 5).

PPL is committed to reducing its carbon emissions. PPL has published goals to achieve net-zero carbon emissions by 2050 and is targeting a 70% reduction from 2010 levels of carbon emissions by 2035 and an 80% reduction by 2040 (Reference 6). PPL is taking an all-of-the-above approach in investigating alternative low carbon or carbon-free generating sources to add to the energy mix in Kentucky and is considering nuclear power as a viable alternative. Table 1 provides a list of PPL owned and operated coal-fired power plants in Kentucky.

Table 1. PPL Coal Generating Assets in Kentucky (Reference 7).

Station Name	Location	Total Capacity [MWe]
E.W. Brown Generating Station (one coal-fired unit)	Harrodsburg, KY	457
Ghent Generating Station (4 units)	Ghent, KY	1919
Mill Creek Generating Station (4 units)	Louisville, KY	1465
Trimble County Generating Station (2 coal-fired units)	Bedford, KY	1274

GHENT GENERATING STATION AND SURROUNDING AREA

GGS is a four-unit, coal-fired power plant located near Ghent, Kentucky in Carroll County (see Figure 1). The four units have a net generating capacity of 1,919 MWe (Reference 7) and are planned for phased retirement based on discussion with PPL, with Units 1 and 2 retiring before Units 3 and 4.

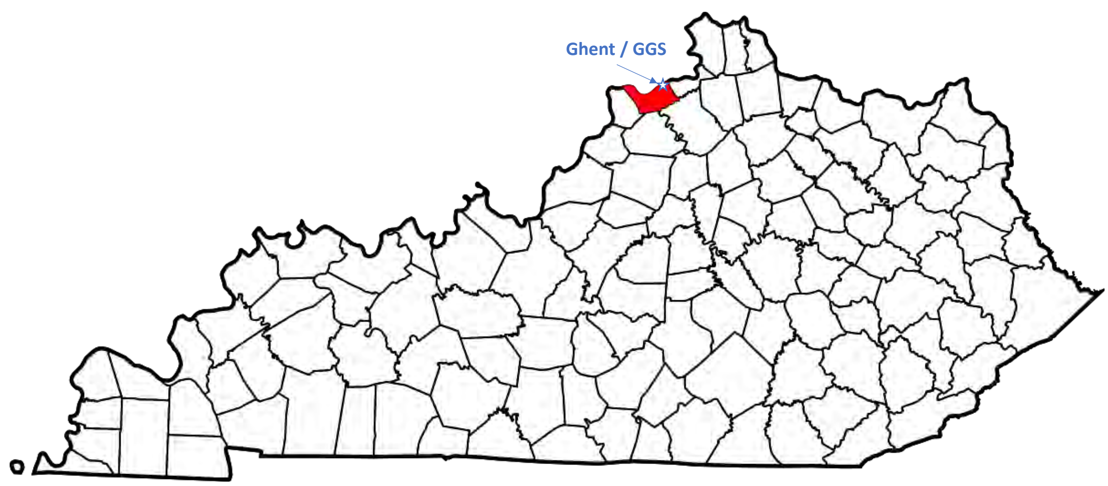


Figure 1. Map of Kentucky Counties and Ghent / GGS

PPL owns approximately 2,300 acres of land around and including the GGS site (Reference 8). GGS is situated on the Ohio River which provides cooling water to the plant.

GGS is also located near to the town of Ghent which, as of the 2020 census, has a permanent population of 360 people (Reference 9). Census data also shows that an estimated 2,400 workers commute to Ghent on a normal basis (Reference 10).

The site is located within five miles of an industrial area next to steel and chemical manufacturers. These manufacturers (as well as the town of Ghent) could be potential end-users of carbon free electrical power and process heat provided by a nuclear power plant.

STATE OF KENTUCKY

In 2022, Kentucky electricity generation was supplied primarily by coal (68%) and natural gas (25%), and other sources (such as hydroelectric, biomass, and solar) supplied the rest. Kentucky is the fifth-largest coal-producing state in the United States (Reference 11).

Kentucky's history with nuclear involves the Paducah Gaseous Diffusion Plant (PGDP) which was constructed in 1952 to produce enriched uranium. Operations ceased at the facilities in 2013. The DOE office of Environmental Management is currently deactivating the plant facilities and continuing the cleanup activities at the site (Reference 12).

In 2017, Kentucky repealed its nuclear moratoriums, removing bans or restrictions on nuclear energy (Reference 13). In 2023, the Kentucky Senate passed a resolution to create a working group to examine the barriers to developing nuclear power generation in Kentucky (Reference 14). The working group published a report in November 2023 concluding that while there are challenges that must be mitigated, "there are no insurmountable barriers to nuclear energy development in Kentucky" (Reference 15).

The Kentucky Senate legislators continued the conversation of bringing nuclear to the state by passing Senate Bill 198 in February 2024, which would establish the Kentucky Nuclear Energy Development Authority (Reference 16). The bill has been delivered to the Kentucky Secretary of State for implementation (Reference 57). Additionally, the Governor of Kentucky has signed a resolution signaling to the state's Public Service Commission (PSC) to prepare for nuclear energy as part of an "all-of-the-above" energy strategy (Reference 54).

SITING EVALUATION

The purpose of the GGS siting evaluation is to consider the suitability of the PPL-owned land at GGS for a nuclear power plant (Reference 1). While the formal siting process for a nuclear reactor requires a significant amount of time (i.e., multiple years), effort, and detail, the siting evaluation provides an initial assessment of whether the GGS site has characteristics that could preclude nuclear siting (i.e., exclusionary factors) or characteristics that could present challenges leading to increased cost and risk associated with nuclear deployment (i.e., avoidance factors).

The siting evaluation leverages publicly available information, input from PPL, industry recognized technology assessment guidance, and insights from GAIN, INL, and MPR.

The full siting evaluation is publicly available (Reference 1). The approach and results of the siting evaluation are summarized herein.

APPROACH

As industry interest in nuclear generation grows, numerous siting guidance documents are being made available to assist utilities and communities in evaluating site suitability to host a nuclear reactor. These guidance documents are best used early in the siting process and provide high-level overviews of exclusionary and avoidance criteria, as well as guidance on more detailed nuclear siting considerations. The GGS siting evaluation closely follows the steps laid out in the Electric Power Research Institute's (EPRI's), "Advanced Nuclear Technology: Site Selection and Evaluation Criteria for New Nuclear Power Generation Facilities" (i.e., the EPRI Siting Guide). The EPRI Siting Guide provides siting guidance to prospective nuclear owner-operators throughout the siting process, combines regulatory guidance with business-related considerations, and is a comprehensive starting point for any siting activity (Reference 17).

As recommended in the EPRI Siting Guide, the evaluation leveraged a graded approach when assessing the suitability of the GGS site and nearby PPL-owned land for a nuclear power plant[4]. The siting criteria identified in available industry guidance (References 17 and 18) can be grouped into three stages of assessment, described below. The main focus of this siting evaluation is the first stage, the Exclusionary/Avoidance Factor Assessment, and incorporates selected Decision Planning criteria.

1. **Exclusionary/Avoidance Factor Assessment**: During this stage, a utility determines if the site(s) of interest have any exclusionary factors or nuclear siting-related criteria that would preclude the construction of a nuclear reactor. The Exclusionary/Avoidance Factor Assessment will also identify any avoidance factors that should be considered and further assessed as part of Decision Planning (see Stage 2). The EPRI Siting Guide (Reference 17) defines exclusionary and avoidance factors as:
    - **Exclusionary** – Factors that preclude nuclear construction (e.g., located within 10 miles of a major airport, situated on federally protected land, etc.),
    - **Avoidance** – Factors that are not exclusionary, but may present challenges during licensing, construction, or operation that could lead to undesirable costs or risks (e.g., presence of high slope that may incur large costs to backfill/excavate).

    Sites that do not have any exclusionary siting factors should be studied further in the subsequent stages. Typically, Exclusionary/Avoidance Factor Assessments can rely on

[4] This initial siting evaluation is focused on a site of interest (i.e., the GGS site) versus a region of interest due to the unique opportunities associated with adding nuclear to the energy mix at the GGS site. As a result, to satisfy NRC requirements, PPL will need to evaluate alternative sites to justify selection of GGS during future stages of the siting evaluation process (see Reference 19).

publicly available data, or limited utility information (e.g., water usage rights, insights on community support, etc.).

2. **Decision Planning**: During this stage, more investigation is required to assess siting considerations and develop a deployment schedule to coordinate information gathering and siting activities. At this point in the process, utilities have confirmed that the site(s) of interest do not have any exclusionary factors and have plans to assess risks associated with any avoidance factors identified during the Exclusionary/Avoidance Factor Assessment. The criteria assessed will help a utility down-select to the "best" site and preferred site layout, from regulatory and business perspectives. Where information is available, this initial siting evaluation qualitatively assesses selected Decision Planning criteria. Note that Decision Planning criteria will require further investigation in subsequent siting evaluations if PPL decides to pursue future stages.

3. **Licensing**: During this stage, a utility has selected the site for hosting a nuclear power plant, has developed a deployment schedule, and is applying for either an Early Site Permit (ESP)[5] or construction permit from the Nuclear Regulatory Commission (NRC). Activities during this stage often involve site specific work, such as geotechnical assessments, meteorological and environmental monitoring, and stakeholder engagement.

Criteria were assessed on a pass/fail/more investigation required basis. Note that the Decision Planning criteria spans a wide range of the siting process and will likely involve a more formal siting evaluation process as outlined in NRC Regulatory Guide 4.7 (Reference 19). For this initial siting evaluation, Decision Planning criteria where data either publicly exists or was provided by PPL is included in this report. Insights regarding future stages (e.g., later stages of Decision Planning and Licensing) are also provided for PPL's consideration. Potential risks were explored in greater detail to provide PPL with additional insights to support Decision Planning.

Table 2 lists the scope of siting considerations to be evaluated at each stage, by order of appearance in the EPRI Siting Guide (Reference 17). Criteria from these references are suitable for conducting an Exclusionary/Avoidance Factor Assessment and early Decision Planning investigations. However, the licensing criteria in Table 2 are highly condensed. If PPL advances to a licensing stage of planning, siting-related industry experts should be consulted for further clarity on specific requirements for licensing.

Table 2. Exclusionary / Avoidance Siting Considerations (Reference 17)

Siting Consideration	Exclusionary/Avoidance Factor Assessment
Geology Seismology	Exclude areas where seismic activity exceeds typical nuclear design specifications, as noted in Reference 17.
Cooling Water Supply	Ensure water availability for potential technology.

[5] An Early Site Permit (ESP) is a siting permit granted by the NRC and can be technology agnostic. Once approved, an ESP is valid for 10-20 years, and can be renewed for an additional 10-20 years.

Table 2. Exclusionary / Avoidance Siting Considerations (Reference 17)

Siting Consideration	Exclusionary/Avoidance Factor Assessment
Ambient Air Requirements	Evaluate ambient air temperatures as they relate to cooling options (i.e., water-cooled, air-cooled, or hybrid methods) to support more detailed analyses later in the siting process.
Flooding	Avoid high-probability floodplains.
Nearby Hazardous Land Uses	• Exclude Department of Defense reserved land. • Ensure no major airport is within 10 miles of the plant. • Avoid areas that may incur additional liabilities to a nuclear reactor.
Extreme Weather Conditions	Quantitatively assess extreme weather conditions on site, and effects of climate change increasing frequency of extreme weather events.
Population	• Exclude areas with greater than 300 persons per sq. mile. • Minimize nearby population centers (>25,000 persons per sq. mi)
Emergency Planning	No exclusionary/avoidance factors are associated with this category.
Atmospheric Dispersion	Subjectively characterize nearby topographical features that effect atmospheric dispersion (e.g., hills, valleys, etc.)
Radionuclide Pathways	Exclude siting on and avoid siting near Environmental Protection Agency (EPA) Class I (special groundwater) sources.
Transportation Safety	No exclusionary/avoidance factors are associated with this category.
Effects on Surrounding Ecology	• Exclude areas designated as critical habitats for endangered/ threatened species. • Exclude major, high-quality wetlands. • Exclude areas where cooling water/other operational impacts may affect endangered/threatened species. • Avoid ecologically sensitive and special designation wildlife/wetland/aquatic areas.
Socio-economic Considerations	• Exclude public amenity areas established by federal, state, and local agencies. • Exclude national parkland. • Exclude national wildlife refuges. • Exclude wilderness areas. • Exclude National Marine Sanctuaries. • Exclude cultural resources, such as American Indian lands, national/historic landmarks, etc. • Maximize distance, to the extent practical, to the above areas.
Engineering and Cost-Related Considerations	• Exclude areas beyond maximum practical pumping distance. • Avoid areas of high slope. • Avoid areas that may incur high costs for remediation for site suitability (e.g., coal ash ponds).

RESULTS

No exclusionary factors were identified at GGS. However, some avoidance factors were identified and warrant additional consideration and investigation.

Key desirable factors at GGS include the following:

- **Ohio River Access** – GGS is situated on the Ohio River and has ample cooling water for a nuclear power plant.
- **Potential Nearby Industrial Customers** – GGS is near several chemical and steel manufacturers that may be industrial customers for nuclear-powered and carbon-free process heat or hydrogen, depending on their carbon-emission goals.
- **Later Coal Plant Retirement Date** – The coal units at GGS are planned to retire in the next few decades, which allows time for advanced nuclear technologies to mature and deploy other projects, reducing risks in estimating cost, schedule, and supply chain.

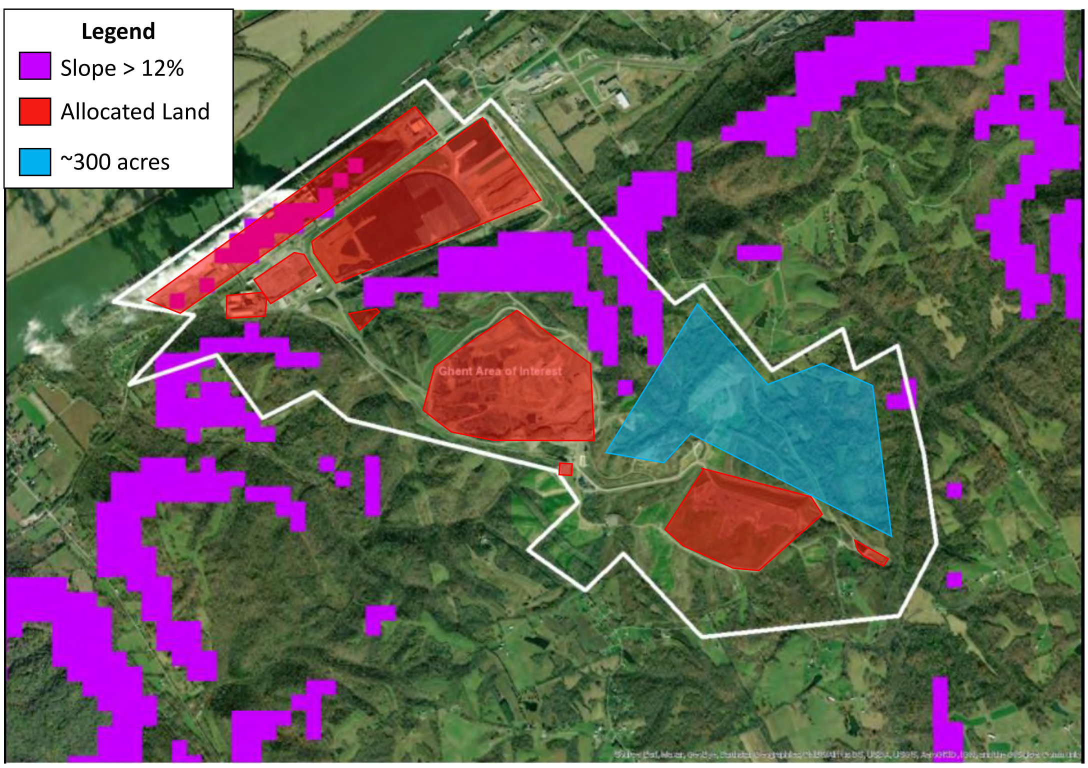


Figure 2. Slope and Allocated Land Around GGS (Reference 1).

The primary challenge associated with the GGS site (albeit not exclusionary) is the amount of land suitable for future development activities. For the GGS site, the current property has large amounts of land that either have high slope (greater than 12%) or are used to store coal combustion residuals (CCRs) (See Figure 2) (Reference 1). High slope and CCR allocated areas that limit land for development could increase site preparation costs in future development activities and must be considered. These constraints limit the amount of contiguous land for development on the existing site property to approximately 300 acres, which limits the number of reactors that could be sited. Ideally, PPL wishes to match the generating capacity of GGS (See Table 4), and 300 acres may not be able to host a large enough nuclear power plant to do so.

Based on these findings, PPL could:

1. Evaluate the costs associated with grading high slope areas/ remediating CCRs (See the Remediation Considerations section) against the benefit of increasing GGS site hosting capacity.
2. Evaluate if additional land is required outside of the GGS site for future nuclear development.

APPLICABILITY TO OTHER COAL PLANTS AND ENERGY COMMUNITIES

Many elements of the GGS siting evaluation apply to other coal plants and energy communities beyond GGS and Ghent, especially for sites with similar slope, CCR, and land constraint challenges. GAIN's siting evaluation approach is fully transferrable; utilities and other stakeholders can follow the steps laid out in the GAIN GGS Siting Assessment and EPRI Siting Guide. For a high-level investigation of siting feasibility, an interested party may screen a site based on the characteristics listed in Table 2. Certain results of the GGS siting evaluation are more broadly applicable as well.

More generally, the results of the GGS siting evaluation may apply to sites with similar:

- **Physical Footprints** – The largest continuous area at GGS that avoids CCR, and highly sloped areas is approximately 300 acres. A new nuclear power plant's capacity may be limited if the physical footprint allowed to support construction is limited.
- **Climate/Environment** – GGS is located next to the Ohio River which allows easy access to ample cooling water. A small amount of PPL-owned land near GGS is classified within a probability floodplain that should be considered when developing a nuclear site layout/plot plan (Reference 1).
- **Seismic Conditions** – Seismic activity in the region surrounding GGS is well below the design limit (Reference 1). No exclusionary or avoidance factors were identified related to seismic considerations. However, this should be further assessed by PPL during later stages of evaluation to quantify credible threats in the area.

Regional economic impacts, the remediation of coal combustion residuals and existing location-dependent federal funding opportunities for nuclear technology investment are also important considerations. These are discussed in greater detail below.

Regional Economic Impacts

Impacts on the local community should be considered during the nuclear siting process. Local communities should be engaged early and often to allow community members to provide input and ask questions to influence decisions.

Regional economic impacts (e.g., jobs and income) associated with energy transitions are dependent on several factors including the population of the local community, the capacity and technology associated with the asset being retired, and capacity and technology associated with the asset being deployed. The DOE recently published the Stakeholder Guidebook for Coal-to-Nuclear Conversations (Reference 52) that quantifies regional economic impacts associated with coal and nuclear power plants with varying capacities in different sized communities.

Communities and utilities can leverage Reference 52 to estimate anticipated economic impacts associated with coal retirements and nuclear deployments. For example, GGS is located in Carroll County, Kentucky. Carroll County has a population of approximately 11,000 people (Reference 53). Leveraging Table A-6 from Reference 52 and the population of Carroll County, one could estimate potential economic impacts associated with deployment of different sized (i.e., MWe) nuclear power plants at GGS.

Table 3 below summarizes applicable economic impacts from Reference 52 based on the population of Carroll County, KY. Direct impacts are equivalent to values for power plant operations. Indirect impacts are associated with supply chain activity. Inducted impacts are a result of employ spending throughout a community. Note that the data below is agnostic of specific locations and should be considered for informational purposes only.

Table 3. Nuclear Economic Impact Data for Counties with Populations Under 20,000 Residents (Reference 52)

		Nuclear Power Plant Size (MW_e)				
		100	300	500	700	900
Employment (# of Jobs)	Direct	75	100	140	200	260
	Indirect	25	75	125	174	224
	Induced	21	33	48	68	88
	Total	121	207	313	443	573
Labor Income ($Million)	Direct	$12.10	$16.10	$22.60	$32.30	$41.90
	Indirect	$1.70	$5.10	$8.50	$12.00	$15.40
	Induced	$0.70	$1.20	$1.70	$2.40	$3.10
	Total	$14.60	$22.40	$32.80	$46.60	$60.50
Value-Added ($Million)	Direct	$24.60	$53.50	$84.90	$119.50	$154.10
	Indirect	$4.20	$12.50	$20.80	$29.10	$37.50
	Induced	$1.70	$2.60	$3.90	$5.50	$7.20
	Total	$30.40	$68.60	$109.60	$154.10	$198.70
Total Output ($Million)	Direct	$45.60	$136.70	$227.80	$318.90	$410.10
	Indirect	$8.60	$25.90	$43.20	$60.40	$77.70
	Induced	$3.20	$5.00	$7.30	$10.30	$13.40
	Total	$57.40	$167.50	$278.30	$389.70	$501.10

- Employment is the number of jobs created or sustained.
- Labor income is the amount of employee compensation.
- Value added is equal to contributions to gross domestic product from the region.
- Output is the dollar value of domestic production or revenue from sales.

Remediation Considerations

Coal combustion residuals (CCRs) are an important siting consideration when assessing the potential deployment of a nuclear power plant at a coal plant site, as CCR storage can introduce complexity to the siting and construction process of a nuclear plant due to potential environmental liabilities for the nuclear plant. CCRs can contain radionuclides that can trigger a nuclear plant's radiological detectors and monitoring programs. Without a clear boundary for new-build nuclear, the nuclear plant may be accountable for radionuclides and contamination that originally resulted from coal plant operations. Additionally, construction activities for new-build nuclear may have effects on existing CCR storage post-closure requirements. If construction activities for a new nuclear power plant are situated near a closed-in-place CCR storage facility, then the CCR storage facility's post-closure care plan may require amendment (Reference 20).

PPL is limited by the available land at GGS to build a nuclear power plant. Since PPL is space constrained, CCRs become a relevant siting consideration. Additional remediation may be required beyond what is currently included in the existing coal site's plans.

The additional remediation could serve multiple purposes: 1) to increase the land available for siting a nuclear power plant and 2) to reduce the potential risks of CCR effects on the plant siting process. The amount of investment may differ depending on the scope and purpose of the remediation (e.g., remediation to increase available land may cost significantly more than smaller scope efforts to reduce environmental risks). Additional remediation options include:

- Removing CCRs from a site through recycling or reuse (i.e., beneficial use) of the CCRs
- Transporting CCRs offsite to a permitted landfill by truck, rail, or barge

Costs for removing CCRs from a site may be significant, as shown by an assessment prepared for Dominion Energy by AECOM in 2017 (Reference 21). The report estimated CCR remediation costs may range from tens of millions of dollars to several billion dollars, depending on the size of CCR storage, closure and CCR transport option, time frame for closure, and the site's proximity to permitted landfills or CCR end-users. There are also additional considerations for removal, such as transportation increasing the risk of spills or CCR dust exposure.

For a more detailed discussion regarding CCRs and nuclear siting, see Reference 22. If CCR removal is pursued, a utility may choose to leverage existing funding opportunities from state or federal resources.

Funding Opportunities for Nuclear

There are several federal funding options for investment in nuclear technologies, some of which are dependent on the location of a facility. The Inflation Reduction Act (IRA), for example, includes funding opportunities and incentives for the private sector to invest in and pursue clean energy technologies. Provisions include both Production Tax Credits (PTCs) and Investment Tax Credits (ITCs) that are available to developers and owners of future advanced reactor projects. It is important to note that these tax credits are applied after the facility is constructed and operating. Both the PTCs and ITCs are associated with criteria that will affect not just eligibility for the credit, but also the amount of credit that will be available when claimed. These criteria include (Reference 23):

- Facilities deployed in energy communities (e.g., coal communities) receive larger credits.

- Facilities deployed with significant U.S.-produced content can capture larger credits.
- Credits can be dependent on overall U.S. progress in achieving target greenhouse gas reductions.
- There are options for tax credits as well as direct payment from the Treasury (albeit with a reduction in credit amount).

Energy communities, including areas economically reliant on coal-fired power plants, are one of the areas targeted for support by the IRA. For clean energy projects and facilities (e.g., nuclear projects) located in energy communities, developers can receive a bonus of up to 10 percentage points on top of the ITC or an increase of 10 percent for the PTC (Reference 23). In addition to the previous credits , new reactor developers can also leverage production tax credits for up to ten years to generate clean hydrogen, which, depending on nearby industrial customer needs, may be useful for a utility siting new nuclear (Reference 24).

Another program included in the IRA for supporting energy communities is the Energy Infrastructure Reinvestment (EIR) Financing Program at the Department of Energy (Reference 25). The EIR includes funding for projects that:

1. Retool, repower, repurpose, or replace energy infrastructure that has ceased operations, or
2. Enable operating energy infrastructure to avoid, reduce, utilize, or sequester air pollutants or anthropogenic emissions of greenhouse gases.

The EIR also includes the remediation of environmental damage associated with energy infrastructure under its scope (e.g., CCRs) (Reference 26). The program appropriates $5 billion in credit subsidies through September 30, 2026, to support loan guarantees of up to $250 billion for eligible projects (Reference 23). This provides projects with low-cost loans and includes the ability to refinance higher-cost debt and equity (Reference 27).

TECHNOLOGY ASSESSMENT

Nuclear reactor design selection is arguably the most important decision a utility will make in the process of deploying a nuclear reactor. The chosen technology and design must meet the overall business objectives of the utility, but the decision to be made is not purely technical in nature. Selecting a vendor forms a multi-decade relationship in which the vendor is trusted to ensure that a facility continues to meet the utility's business needs throughout the operating life of the reactor.

The GGS nuclear technology assessment is focused on identifying candidate nuclear technologies and potential designs that are suitable for the GGS site and align with PPL's current mission and business objectives.

The GAIN team used both publicly available information and input from PPL to conduct the assessment. Information gathered and input from PPL including their mission, business objectives, and priorities were assessed leveraging industry-recognized technology assessment guidance and insights from GAIN, INL, and MPR.

APPROACH

There are dozens of developers working to commercialize advanced nuclear designs. Each vendor and respective design are at different stages of development and have attributes that may increase their effectiveness in some use cases (e.g., electricity or process heat) compared to other vendors/designs. For example, some reactor technologies operate at higher temperatures, which can enable a larger selection of non-electrical applications (e.g., process heat and hydrogen production) than reactors that operate at lower temperatures. Because of the number of different technologies and designs under development, it is important for utilities to define business objectives and goals before selecting a design.

To identify candidate technologies and potential designs for PPL, GAIN leveraged the EPRI Technology Assessment Guide (Reference 28) as a framework to conduct this assessment. The EPRI Technology Assessment Guide includes six steps, outlined below.

1. **Define Mission and Business Objectives –** A utility's mission and business objectives serve as the framework for the assessment and establish the criteria that all technology options are evaluated against. At this stage, the envisioned owner/operator should be identifying key criteria such as need dates, target budgets, use cases, required output, etc.
2. **Technologies of Interest** – Following the development of mission and business objectives, prospective owners/operators should identify technologies of interest by surveying the nuclear technology landscape and compare these technologies against mission and business objectives. This relates to the "type" of reactor technology under

consideration. For example, Pressurized Water Reactors (PWRs), Boiling Water Reactors (BWRs), High Temperature Gas Reactors (HTGRs), and Liquid Metal Fast Reactors (LMFRs), would all be distinct “technologies of interest.”

3. **Candidate Technologies –** Prospective owners/operators should use identified requirements to screen technologies of interest to a list of candidate technologies. Candidate technologies are the set of technologies of interest that pass the first stage of screening and are considered acceptable for the owner/operator’s business objectives and needs.
4. **Potential Designs –** Following the screening of candidate technologies, prospective owners/operators should identify potential designs, which are a set of specific designs offered by vendors which leverage the candidate technology (e.g., BWR vendors, PWR vendors, etc.) in their design and meet identified objectives.
5. **Candidate Designs –** Once potential designs have been identified, prospective owners/operators should narrow them down to candidate designs, which are the potential designs that pass owner/operator screening criteria and are capable of meeting business objectives and needs. During this stage, the owner/operator has begun conversations directly with vendors to solicit more information and assist with the technology selection process.
6. **Proposed and Alternate Designs –** This is the last stage of the EPRI technology assessment guide. The goal is to identify the technology which best meets the business objectives and mission of the owner/operator and identify alternatives should the proposed design no longer be viable.

The goal of this nuclear technology assessment is to identify candidate technologies and potential designs for PPL’s consideration (Steps 1 through 4 of the EPRI Technology Assessment Guide as outlined above).

The next step of the screening (Step 5 in the EPRI Technology Assessment Guide) requires direct vendor interaction. Should PPL decide to continue the nuclear technology selection process, PPL should confirm their mission, business objectives, resulting Criteria (i.e., Technology Criteria and Design Screening Criteria), and continue to reflect their needs before engaging in detailed discussions with vendors.

Figure 3 illustrates the selection process as laid out in the EPRI Technology Assessment Guide, with the scope of the GGS technology assessment highlighted in blue. GAIN’s approach may be used as a framework by other utilities and stakeholders interested in identifying candidate technologies and potential designs for a nuclear power plant.

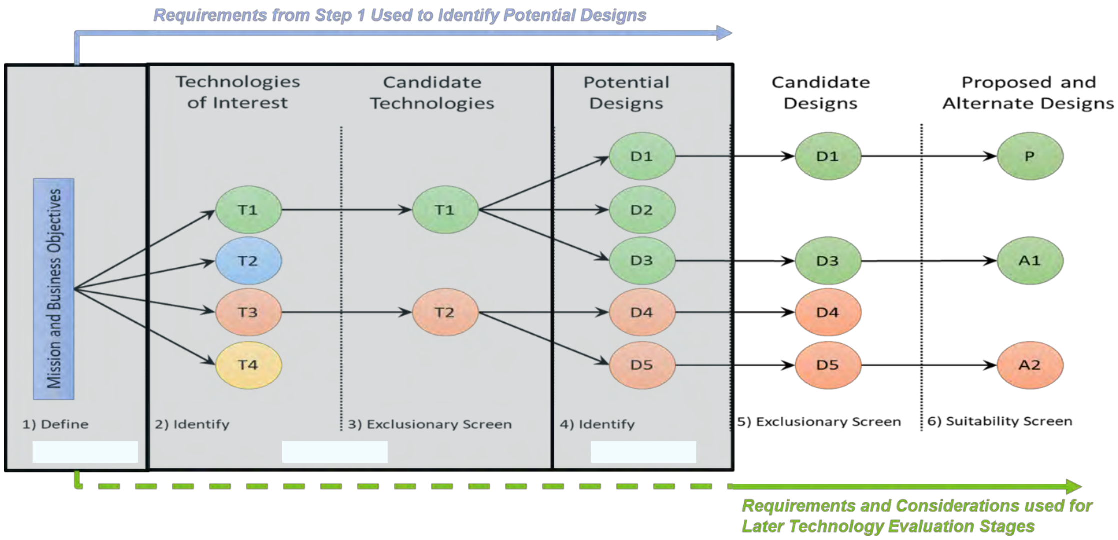


Figure 3. EPRI Technology Selection Steps with the Scope of GAIN's Assessment Highlighted (Reference 28).

DEVELOPMENT OF CRITERIA

To begin the nuclear technology assessment effort, GAIN worked closely with PPL to document key Criteria such as need dates, target budgets, use cases, and required output related to nuclear deployment at GGS. PPL's mission and business objectives and the results of the GGS siting evaluation serve as the basis for this nuclear technology assessment and were used to establish the Criteria against which all technology and design options were evaluated.

Table 4 shows the list of PPL Technology Criteria that all candidate technologies (and therefore, potential designs) must satisfy. Design Screening Criteria that all potential designs must satisfy are discussed in the Potential Design subsection. To highlight their relevance to a broader audience, PPL Considerations are discussed in a later section on applicability to other coal plants and energy communities.

Table 4. PPL Nuclear Technology Criteria.

Category	PPL Technology Criteria
Capacity	Preferred to meet GGS's current capacity (2,226 MWe nameplate, 1,919 MWe net) with multiple generation units for availability during outages
Purpose	• Electricity • Potentially high temperature process heat for industrial customers
Site Compatibility	The technology must fit within the GGS site
Operating Life	Can operate at least 30 years
Long-Term Owner/Operator Goals	• Be scalable to meet PPL's capacity needs • No unique desire to be a first mover
Need Dates	Prefer the replacement technology to be available by late 2030's to enable availability for broader energy goals

RESULTS

The results of the Ghent nuclear technology assessment and potential next steps PPL could take are discussed in the following subsections.

Technologies of Interest and Candidate Technologies

To identify technologies of interest and ultimately candidate technologies, GAIN surveyed the nuclear technology landscape and compared available technologies against PPL's mission and business objectives. The EPRI Technology Assessment Guide notes that technologies can be grouped based on mission and business objectives (e.g., power output size). Once technologies of interest are identified and grouped, candidate technologies are selected based on the technology's ability to meet the identified Technology Criteria.

Technologies of interest for GGS include micro, small, medium, and large advanced nuclear reactors. The term advanced nuclear reactor refers to a nuclear fission reactor with significant improvements, including additional inherent safety features, compared to reactors operating on December 27, 2020, in the United States (Reference 46). The EPRI Technology Assessment Guide (Reference 28) provides further information related to the technology groupings. The size and output level groupings are summarized in Table 5.

Table 5. Reactor Classes based on Size and Output (Reference 28)

Size	Output (MWe)	Plant Footprint (acres)[(1)]	Site Footprint (acres)[(2)]
Micro	< 50	0.1 to 4	1 to 8
Small	50 - 300	25 to 200	50 to 500
Medium	300 - 600	60 to 250	250 to 800
Large	> 600	100 to 400	500 to 2000

Notes:

1. Plant footprint refers to the area needed to support the operating plant.
2. Site footprint refers to the plant footprint and any additional area declared as part of the site. The GGS siting evaluation provides further information on the footprint definitions (Reference 1).

Utility-scale generation and footprint constraints exclude the use of microreactor and large reactor technologies at GGS. Therefore, small and medium advanced nuclear reactors were identified as candidate technologies that could meet PPL's mission and business objectives. Direct vendor engagement is recommended to provide further insight on design-specific land requirements.

PPL's Technology Criteria (defined in Table 4) do not exclude any reactor technology types (e.g., PWRs, BWRs, etc.) because PPL's primary purpose for nuclear deployment is to generate electricity. However, PPL's current Technology Criteria include a preference for technologies capable of producing process heat. As such, process heating[6] capabilities and technology maturity were considered when examining reactor types available. Nuclear technology process heating capabilities are discussed further in the Process Heat section. The following advanced reactor types as defined by the Nuclear Innovation Alliance (NIA) Primer (Reference 29) were included in the technology assessment:

- Water Cooled Reactors (e.g., BWR, PWR)
- Gas Cooled Reactors (e.g., HTGR)
- Molten Salt Cooled Reactors
- Liquid Metal Cooled Reactors (e.g., LMFR)

Potential Designs

After identifying small and medium advanced reactors as the candidate technologies, the next step of the EPRI Technology Assessment Guide is to identify potential designs and vendors

[6] Consistent with Reference 31, "process heating" refers to the use of nuclear power to generate process steam, hot water, or another heat transfer medium as a heat carrier. Process heat can be used by subsequent processes as-is or in combination with electricity.

within the candidate technologies grouping that meet a utility's Criteria and align with its mission and business objectives.

Within the small and medium sized grouping of advanced reactors, there are multiple vendors pursuing different designs, and at varying levels of maturity. Given the number of reactor designs being developed and PPL's deployment timeline, additional screening Criteria (i.e., Design Screening Criteria) were applied to determine a list of potential designs.

The first of the Design Screening Criteria is related to the vendor's ability to demonstrate the design, licensing, supply chain, construction, and operational maturity of their respective design. This reduces the level of uncertainty and risk associated with future deployments. The second of the Design Screening Criteria hinges on the vendor's ability to demonstrate that they are actively seeking regulatory buy-in on key design features that may be unfamiliar to the NRC (reducing regulatory risk). For a design to be considered a potential design, both Design Screening Criteria must be met, demonstrating a level of maturity and remaining effort commensurate with PPL's ideal deployment timeline.

Several potential designs were identified that could meet PPL's mission and business objectives. Potential designs are all capable of generating electricity at a utility-scale, have a maturity that could support PPL's deployment window, and can support the capacity needs in which PPL is interested. Technologies represented in the selection of potential designs include a boiling water reactor, pressurized water reactors, a liquid metal fast reactor, and a high temperature gas reactor.

The list of potential designs shared with PPL is utility- and site-specific. Other utilities and energy communities will need to follow the steps outlined in the EPRI Technology Assessment Guide and described herein to develop their utility- and site-specific list of designs that align with their mission and business objectives.

Potential Next Steps for PPL

PPL's decision on whether to pursue nuclear technology at GGS should be informed by the following actions and potential next steps. The actions can be pursued individually at a smaller scale to inform PPL's decisions, or together as part of a larger coordinated effort depending on PPL's level of investment.

1. **Determine the minimum acceptable capacity for a nuclear deployment at GGS:** PPL has stated that an ideal deployment capacity is similar to current GGS capacity (1,919 MWe). However, as discussed in the GGS Siting Evaluation (Reference 1) and based on EPRI reactor size estimates (Reference 28), there could be challenges with land constraints. Without further investigating candidate technologies' footprint requirements and GGS site specific details, it is unclear if PPL's ideal capacity will be attainable at

GGS without expanding the available footprint with land acquisition or additional CCR storage remediation.

2. **Determine estimated footprint requirements of the potential designs that meet minimum capacity requirements and compare against achievable capacity at GGS:** PPL may choose to leverage an ESP submitted to the NRC by other utilities and information obtained from vendors to determine the estimated footprint of each design. Comparing footprint requirements of potential designs and achievable capacity at GGS will inform whether additional remediation or land acquisition is needed at GGS.
3. **Assess cost and schedule for nuclear deployment and determine feasibility in PPL portfolio:** In addition to the nuclear deployment itself, costs and schedule expectations may be affected by remediating CCR, addressing high slope, or acquiring additional land. PPL will need to determine the amount of investment and their associated timeline needed to meet capacity requirements.
4. **Make decision to pursue next steps at GGS and/or invest in alternative options:** If PPL decides to move forward with nuclear deployment at GGS, PPL should be aware of additional implementation Considerations (e.g., NRC licensing pathways, nuclear waste storage, etc.). PPL may also choose to pursue an alternative option at this point, which may include exploring other sites for nuclear feasibility.

APPLICABILITY TO OTHER COAL PLANTS AND ENERGY COMMUNITIES

Similar to the GGS siting evaluation, the approach leveraged for the GGS technology assessment and the EPRI Technology Assessment Guide can be used by other utilities and energy communities. Beyond the applicability of the general technology selection approach, the Considerations for design selection at GGS may be relevant to other utilities and energy communities. Industrial heating, fuel availability, and nuclear waste storage are additional topics related to technology selection which may be of interest to a larger audience.

As mentioned, the first step in evaluating nuclear technologies is for a utility to define overarching mission and business objectives, and from this list create a set of Criteria and Considerations. Criteria and Considerations can vary from utility to utility, and the specific Criteria and Considerations will directly affect technology identification and selection. For any potential new nuclear owner/operator wishing to screen technologies, the owner/operator should reference the EPRI Technology Assessment Guide (Reference 28) for examples of mission and business objectives and consult Table 5 and Table 6 to see how these mission and business objectives were converted and applied as Criteria and Considerations.

Considerations for Design Selection

Considerations aid in down selecting the potential designs to candidate, proposed, and alternative designs. These Considerations may be assessed by organizations seeking to select a nuclear technology design and can form the basis for inquiries when contacting vendors for information.

Table 6. Technology and Nuclear Deployment Considerations.

Consideration	Description
Flexible Power Output	Organizations are expressing interests in designs that can both provide firm, dispatchable power, and can also adjust output based on grid load on a day-to-day basis. While this is not traditionally how nuclear reactors operate in the United States, market forces are necessitating vendors provide technologies that are capable of quickly adjusting output. Some designs are explicitly publicizing their ability to do this.
Owner/Operator Model	There are two main options that utilities are considering for the ownership/operation model of a nuclear project. One option that some lead demonstration projects are pursuing is having a separate utility with nuclear experience serve as the operator, while the applicant utility (/utilities) serves as the owner(s) (as exemplified in Reference 30). The other main option is for the owner (or one of the owners) to be the operator of the facility. This would mean the owner is responsible for developing all operational processes, polices, and procedures for the plant.
First-of-a-Kind (FOAK) Content and Risks	Related to maturity, some of the technologies of interest will have more FOAK design features than others. The extent of a vendor's understanding and qualification of FOAK components in their respective design should be well understood. To qualify FOAK components takes significant time and cost for a vendor. The intent of many vendors is to demonstrate and qualify these FOAK concepts with lead demonstration projects and/or extensive qualification testing. Not only can lead projects be used to assess the credibility of vendor schedules, but they can provide insight on what might be 'at risk' to an organization, should the organization wish to deploy a similar technology.
Fleet-Based Benefits	Should an organization wish to expand its nuclear capacity beyond a single site, it should consider the fleet-based benefits that some technologies of interest may offer. These benefits may include items such as ease of scalability, training programs, outage support staffing, etc.
Vendor Partnership Suitability	A selected technology vendor will be a partner to a prospective nuclear technology owner for decades. An organization should understand the key stakeholders and vendors associated with a technology of interest and determine if the existing relationship with proposed vendors (if applicable) is favorable to meeting relevant needs and objectives.
Potential Plant Downtime	Some technologies of interest consist of multiple modules, meaning that the entire plant will not be required to go offline for activities such as refueling. Further, some technologies of interest can be refueled while running. The effect of potential downtime should be evaluated on the envisioned operations and maintenance (O&M) model.

Table 6. Technology and Nuclear Deployment Considerations.

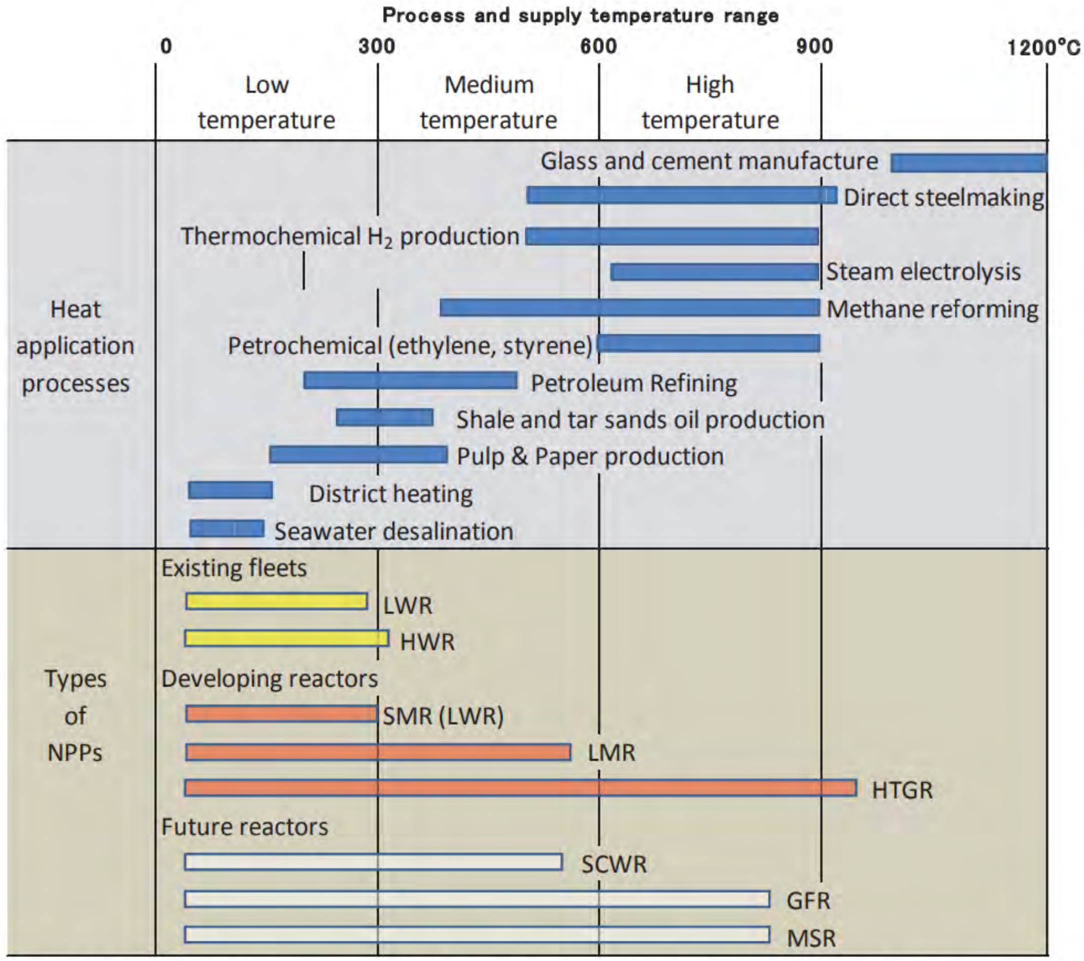
Consideration	Description
Licensing Pathways and Considerations	The NRC has two main licensing pathways for commercial power nuclear reactors are outlined in the Code of Federal Regulations (CFR): 10 CFR 50, known as the ‘two step’ process, and 10 CFR 52, also known as the ‘one step’ or combined operating license (COL). Both processes have distinct advantages and disadvantages and involve public hearings on licensing activities. Depending on the technology selection and deployment timeframe, both pathways should be assessed against deployment needs.
Availability of Fuel	Technologies of interest use different fuel forms at varying enrichment levels. Some designs utilize High-Assay Low-Enriched Uranium (HALEU) fuel (fuel enriched up to 19.75 wt.% U-235). As of writing, the U.S. HALEU fuel supply chain is not well established. While efforts to improve the maturity of this supply chain are ongoing, HALEU fuel availability should be assessed at the time of technology selection. See the section on “HALEU Fuel Availability” for further details.

Process Heat

Industrial process heat is the use of thermal energy to produce, treat, or alter manufactured goods. Process heat is the most significant source of energy use and greenhouse gas emissions in the industrial sector, accounting for about 50% of all onsite energy use and 30% of greenhouse gas emissions (Reference 31).

One of the key advantages to nuclear provided process heat is that nuclear can provide high quality, carbon-free steam, and process heat. Because GGS is situated near process heat off-takers, PPL may wish to consider providing process heat to these off-takers in the future. The proximity of GGS to these potential process heat users may improve the feasibility and project economics of nuclear deployment. This is because shorter distances between heat source (e.g., the nuclear reactor) and end user reduces the amount of transport infrastructure and heat loss from transport.

The number of use cases for nuclear process heat depends on process heat temperature, compatibility with heat supply method, energy demand, and coordinated lifetime of the nuclear and industry processes (Reference 32). Figure 4 compares several temperature requirements for industrial processes against temperatures for existing, developing, and future reactor technologies.



Note: GFR — gas cooled fast reactor; HTGR — high temperature gas reactor; HWR — heavy water reactor; LMR — liquid metal reactor; LWR — light water reactor; MSR — molten salt reactor; NPP — nuclear power plant; SCWR — supercritical water reactor; SMR — small modular reactor.

Figure 4. Temperature ranges of heat application processes and types of nuclear power plant (Reference 33)

Depending on the desire to provide process heat, technology selection has a significant effect on potential end-users. For example, liquid metal, molten salt, and high temperature gas reactors can provide the highest temperatures of the potential designs. Whereas light water designs, such as PWRs, and BWRs operate at lower temperatures, and therefore may have fewer potential off takers if providing process heat is a Consideration. Therefore, if prospective owners determine that providing process heat is a Consideration, technology selection will influence how many potential process heat off-takers are available.

HALEU Fuel Availability

One technological Consideration is that the technology must be evaluated against deployment timetables is a potential technology's fuel type, and the enrichment level. Fuel enrichment level refers to the amount of Uranium-235 (U-235) present (by weight percentage) in nuclear fuel. Traditional nuclear plants use Low-Enriched Uranium (LEU). LEU fuel is enriched up to 5 wt. % U-235 and has a readily established supply chain.

Some advanced reactors use HALEU fuel. HALEU fuel is enriched anywhere between 5 and 19.75 wt.% U-235. Reactors that use HALEU can utilize new fuel types (e.g., TRi-structural ISOtropic (TRISO) fuel), extract more energy per unit volume of fuel, and operate longer between refueling. However, there is no commercial scale HALEU supply chain currently available in the United States.

The reason a HALEU supply chain is not well established in the United States is not technical in nature but is rather a result of market forces. Fuel suppliers have not invested in the required infrastructure to make HALEU at commercial scale because there is currently no commercial demand for HALEU. Conversely, reactor designs which use HALEU fuel cannot be easily deployed in the United States due to the lack of fuel. The Department of Energy is aware of this challenge and is actively pursuing multiple pathways to produce HALEU. In January 2024, the DOE issued a final request for proposals (RFP) for enrichment services to help establish a HALEU supply chain for future reactors (Reference 55).

The Energy Act of 2020 directed the establishment of the HALEU Availability Program to ensure access to HALEU for civilian domestic research, development, demonstration, and commercial use. The HALEU Availability Program will acquire HALEU through purchase agreements with domestic industry partners and produce limited initial amounts of material from DOE-owned assets. The HALEU Availability Program is intended to spur demand for additional HALEU production and private investment in the nation's nuclear fuel supply infrastructure – ultimately removing the federal government's initial role as a supplier (References 34 and 35).

Projects are actively underway to mature the supply chain. For example, in November of 2022, the DOE announced an approximately $150 million cost-shared award with American Centrifuge Operating, LLC of Bethesda, Maryland, a subsidiary of Centrus Energy Corp, to demonstrate the nation's ability to produce HALEU (Reference 35). Centrus is responsible for manufacturing advanced centrifuges for use at an enrichment facility in Ohio. In November of 2023, the company's AC-100M machine demonstrated enrichment of hexafluoride gas to produce 20 kg of HALEU with plans to increase HALEU production capacity in the near future (Reference 34 and 56).

If a prospective nuclear technology owner identifies a HALEU-fueled potential design with favorable characteristics, the organization should inquire about HALEU fuel supply and monitor industry status in developing the required HALEU fuel infrastructure.

Nuclear Waste Storage

Nuclear waste storage is a relevant Consideration in the process of selecting a nuclear reactor design. When obtaining information from vendors, an owner/operator should evaluate each potential design in terms of waste generation and interim storage plans and footprints. This section is not design-specific and is instead intended to provide context for the topic of nuclear waste storage at a more general, design-agnostic level.

The nuclear fuel supply chain may be described in terms of the 'front end' and 'back end.' The front end of the nuclear fuel cycle includes the mining, milling, conversion, enrichment, and fabrication of nuclear fuel. From there, the nuclear fuel is loaded into a reactor until it can no longer support fission and is considered 'depleted' or 'spent.' Used nuclear fuel is radioactive and must therefore be handled accordingly. Used nuclear fuel then enters the back end of the nuclear fuel cycle. The back end of the fuel cycle is considered either a once-through or a closed-loop (Reference 36).

Once-through back-end fuel cycles take the used fuel from nuclear reactors, keeping it first in temporary or 'interim' storage. Used fuel in interim storage is then shipped to longer-term storage for final disposition, where the used fuel will safely decay. A closed-loop fuel cycle will take the used fuel from the temporary or interim storage after some time, reprocess the fuel (a process that separates fissile material from waste products in the fuel), and reuse a significant portion of the fuel. The front and back end of a once-through and closed-loop fuel cycle are shown in Figure 5.

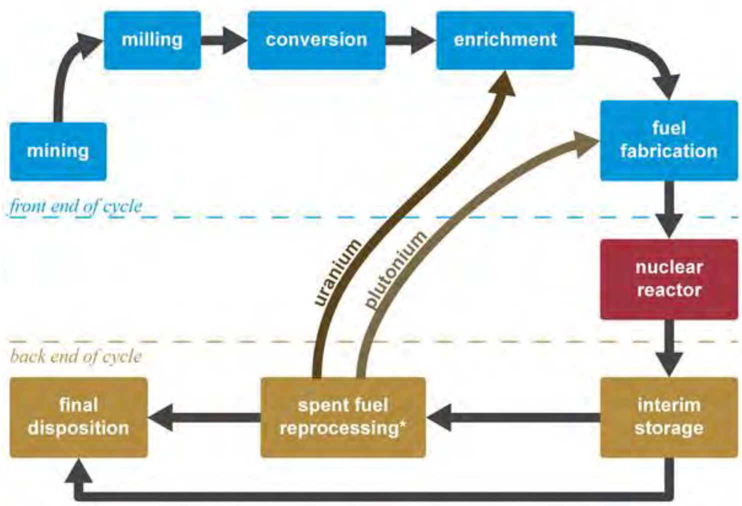


Figure 5. Front and Back-End of the Once Through and Closed Loop Nuclear Fuel Cycle (Reference 37).

All commercial nuclear reactors in the United States use a once-through fuel cycle. There are many reasons for this, both political and economic, but the total amount of used fuel generated by all commercial nuclear reactors in the United States is relatively small. In fact, all the used fuel ever produced by the United States commercial nuclear industry since the late 1950s would only cover a football field to a height of approximately 10 yards (Reference 36). Some countries, like France, the United Kingdom, and others leverage a closed fuel cycle, where used fuel is reprocessed and reused. This significantly reduces the amount of waste generated by their nuclear power plants (Reference 38).

In the United States, efforts to construct a long-term geological repository are suspended. This means that the majority of used nuclear fuel is in dry storage on-site at nuclear plants. The DOE is expecting to provide clarification for the management and disposition of these materials (Reference 39). The DOE is currently evaluating multiple options for spent fuel disposition, including a centralized interim storage facility, continued storage at nuclear sites, reprocessing and waste treatment technology, and development of alternative long-term repositories (Reference 40).

Until a long-term repository in the United States is established, reactor operators are storing used fuel on site in Interim Spent Fuel Storage Installations (ISFSIs). ISFSIs are a part of standard plant design and are built to hold dry casks which contain the used nuclear fuel. To date, all used nuclear fuel in the United States has been stored without incident. Additionally, recognizing the need for longer interim storage, suppliers are offering dry casks with design lives greater than 100 years and that are built to the highest quality and safety standards (Reference 41).

USEFUL RESOURCES

The following resources are leveraged as part of the GGS nuclear feasibility study, which may be useful to coal communities, utilities, and other stakeholders interested in siting advanced nuclear technology.

"Resources for Coal Repowering with Nuclear Energy" (Reference 42): This document published by the NIA serves as a high-level introduction to coal repowering with nuclear energy and a directory of useful resources for those looking to dive deeper into the topics discussed. It presents the key concepts, opportunities, and challenges associated with this energy transition, and provides readers with solid foundations and condensed information, facilitating a comprehensive understanding of this subject matter.

"Advanced Nuclear Technology: Site Selection and Evaluation Criteria for New Nuclear Power Generation Facilities" (i.e., the EPRI Siting Guide) (Reference 17): This guide was published by EPRI and provides siting guidance to prospective utilities throughout the lifecycle of the siting process. This guide combines regulatory guidance with business-related considerations for siting purposes and is a comprehensive reference and good starting point for any siting activity.

Coal Repowering – A White Paper Series (Reference 18): This white paper series published by EPRI discusses some of the high-level benefits, drawbacks, and considerations for repowering coal-fired power plants with nuclear power. Information in the whitepaper series complements siting considerations in the EPRI Siting Guide.

Nuclear Regulatory Commission (NRC) Regulatory Guide 4.7 (Reference 19): This NRC guidance document provides explanations of the NRC's specific siting criteria and defines specific requirements for siting a nuclear reactor. This guide is limited in scope to NRC related requirements.

The DOE's "Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants" (Reference 43): This report specifically considers the transition of coal-fired power plants to nuclear power plants and addresses some of the key pros and cons associated with converting. This report also highlights some of the economic aspects to consider when converting a coal plant into a nuclear plant.

Previous Early Site Permit Applications: To date, six ESPs have been approved by the NRC to utility companies considering building nuclear power plants. The ESPs themselves are the end-product to siting related work and can be leveraged to (1) identify and scope the level of effort required related to siting a nuclear power plant, and (2) provide inputs to use for scoping purposes for early siting activities when leveraging the above guidance documents. ESPs can be viewed on the NRC website directly (Reference 44).

"Advanced Nuclear Technology: Owner-Operator Reactor Technology Assessment Guide" (i.e., EPRI Technology Assessment Guide) (Reference 28): This guide was published by EPRI and outlines a nuclear technology and design selection process for owner-operators, including prospective utilities. This guide provides a general selection process, as well as recommendations on how to compare technologies and designs against one another.

"Advanced Nuclear Reactor Technology – A Primer" (Reference 29): This primer was published by the NIA and provides an overview of several advanced nuclear technologies and their specific design features. The guide also discusses some general advanced nuclear topics, such as passive safety systems and fuel types.

GAIN Taxonomic Guidance (Reference 46): This document, provided by GAIN, seeks to standardize advanced nuclear terminology. The definitions developed in this document are used throughout this report.

Laying the Foundation for New and Advanced Nuclear Reactors in the United States (2023) (Reference 45): This comprehensive report from the National Academies of Sciences is a compendium of various recommendations regarding successful commercialization of advanced reactors and provides a thorough discussion on multiple advanced nuclear topics.

Advancing Nuclear Energy – Evaluating Deployment, Investment, and Impact in America's Clean Energy Future (Reference 47): This study, prepared and published by the Breakthrough Institute, develops advanced reactor levelized cost of electricity (LCOE) models for different advanced reactor deployment strategies. Insights on key assumptions made in this report can help utilities develop different LCOE models and support planning.

"The NEA Small Modular Reactor Dashboard" (Reference 48): This dashboard was published by the Nuclear Energy Agency (NEA) and provides a summary of deployment status for 21 different nuclear designs. The dashboard uses publicly available information to assess deployment status in terms of licensing, siting, financing, supply chain, engagement, and fuel.

"Industry Guideline for Developing a Plant Parameter Envelope in Support of an Early Site Permit" (Reference 49): This guideline, published by the Nuclear Energy Institute, discusses how utilities can develop a plant parameter envelope (PPE[7]) to support ESP activities.

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[7] A Plant Parameter Envelope (PPE) is used by an ESP applicant who does not specify one technology. It is possible to obtain an ESP without selecting a technology via a PPE.

A PPE allows siting activities to continue while keeping multiple technology options open. Specifically, the guideline details what information will be needed from multiple vendors to develop a PPE, and how to combine vendor feedback to develop a "bounding" envelope. This guideline is particularly helpful for highlighting specific data a utility will need to collect to apply for an ESP.

"From Coal to Nuclear: A Practical Guide for Developing Nuclear Energy Facilities in Coal Plant Communities" (Reference 22): This report, developed by EPRI, provides owner-operators and other stakeholders with practical guidance for the deployment of a nuclear power plant on or near an existing coal plant site. The report provides a regulatory-agnostic process for repowering and reviews the many options and concerns that must be evaluated and resolved in this process, including technical, workforce-related, and community engagement-related considerations.

"Mass Acquisition of Early Site Permits for Coal-to-Nuclear Repowering" (Reference 50): Published by the Breakthrough Institute, this report cites regulatory uncertainty as a key barrier to repowering coal plants with nuclear power plants. The report specifically addresses the challenge associated with acquiring an early site permit and proposes that the U.S. DOE lead a program to assess retiring coal plant sites around the U.S. for viability as nuclear plant sites. Under this program, the DOE would then mass-acquire ESPs for multiple eligible sites, and subsequently transfer those permits to utility companies and developers.

"Estimating Economic Impacts of Repurposing the Coronado Generating Station with Nuclear Technology" (Reference 51): GAIN conducted an economic impact analysis for the town of St. Johns, Arizona where the Salt River Project (SRP) has announced CGS's retirement. The report evaluates local economic impacts if CGS were to continue to run as a coal plant or to be replaced with nuclear deployment option. It also includes an evaluation on job and skill overlap between coal plant jobs and nuclear plant jobs.

"Stakeholder Guidebook for Coal-to-Nuclear Conversions" (Reference 52): Published for the DOE, the guidebook provides stakeholders (energy communities and electric utilities as the primary audience) guidance for coal-to-nuclear transitions. Areas of focus in the guidebook include economic impact, workforce transition, siting, and policy considerations.

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