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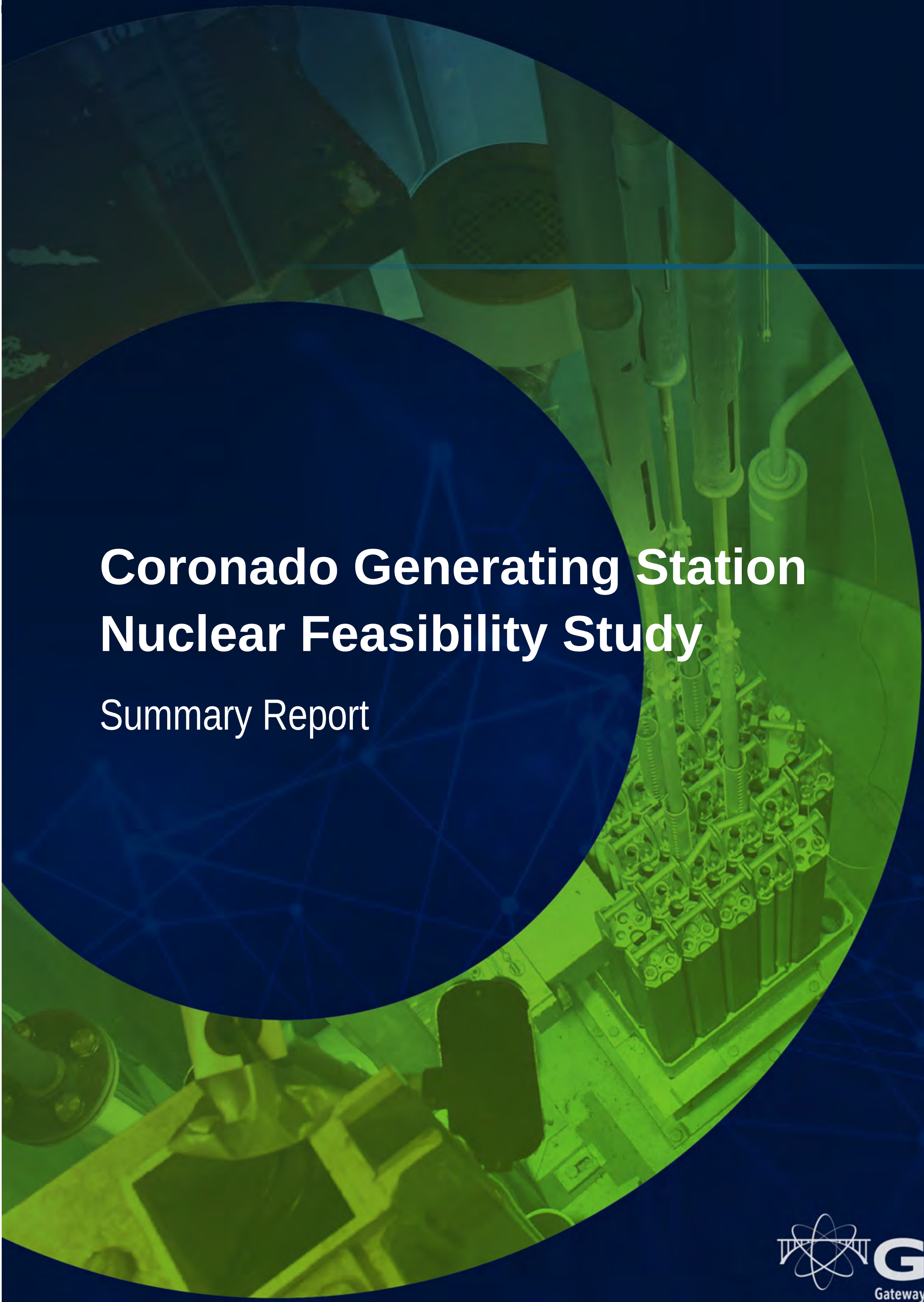

Coronado Generating Station Nuclear Feasibility Study

Summary Report

GAIN
Gateway for Accelerated
Innovation in Nuclear

Coronado Generating Station Nuclear Feasibility Study

Summary Report

Revision 1

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ACRONYMS / ABBREVIATIONS

APS	Arizona Public Service Company
BWR	Boiling Water Reactor
CCR	Coal Combustion Residual
CFR	Code of Federal Regulations
CGS	Coronado Generating Station
DOE	Department of Energy
EIR	Energy Infrastructure Reinvestment
EPRI	Electric Power Research Institute
ESP	Early Site Permit
FOAK	First of a Kind
GAIN	Gateway for Accelerated Innovation in Nuclear
HALEU	High-Assay Low-Enriched Uranium
HTGR	High Temperature Gas Reactor
ISFSI	Interim Spent Fuel Storage Installation
INL	Idaho National Lab
IRA	Inflation Reduction Act
IRP	Integrated Resource Plan
ITC	Investment Tax Credit
LCOE	Levelized Cost of Electricity
LEU	Low Enriched Uranium
LMFR	Liquid Metal Fast Reactor
MPR	MPR Associates, Inc.
NEA	Nuclear Energy Agency
NIA	Nuclear Innovation Alliance

NRC	Nuclear Regulatory Commission
O&M	Operations and Maintenance
PPE	Plant Parameter Envelope
PTC	Production Tax Credit
PWR	Pressurized Water Reactor
SCR	Selective Catalytic Reduction
SRP	Salt River Project Agricultural Improvement and Power District

CONTENTS

EXECUTIVE SUMMARY

As the power industry moves to achieve carbon emission reduction goals and shifts to a clean energy economy, coal plant retirements are on the rise. Increasing the share of nuclear power in the energy mix is one pathway to achieving emissions reductions, and 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 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 to establish a broad foundation and framework for successful nuclear feasibility studies. The Coronado Generating Station (CGS), owned and operated by Salt River Project Agricultural Improvement and Power District (SRP) is one of several sites being evaluated by GAIN.

CGS is a two-unit, coal-fired power plant located in Apache County near Saint Johns, Arizona. Unit 1 and Unit 2 have net capacities of 382 MW_e and 380 MW_e, respectively. Units 1 and 2 are scheduled to begin seasonal operation in 2025 and to retire no later than year-end 2032. Saint Johns is situated in the White Mountains and in a semi-arid climate region which is subject to cold winters and warm to hot summers. The population was estimated to be 3,388 in 2021 based on the U.S. 2020 census (Reference 11). The City of Saint Johns is also near native land; the Navajo Nation, Fort Apache Indian Reservation, Hopi Reservation, and the Zuni Indian Reservation all have a significant presence in Apache and surrounding counties.

The objective of GAIN's CGS nuclear feasibility study is to inform SRP's decision-making process about future generation options and reduce the uncertainty associated with the potential deployment of nuclear technology at this site. This three-part feasibility study includes (1) a siting evaluation, (2) a nuclear technology assessment, and (3) an economic impact assessment. GAIN worked collaboratively with SRP and the City of Saint Johns to complete the feasibility study and identify potential next steps. Results are summarized below and expanded upon in this report. While each coal plant, energy community, and utility is unique, certain results from the CGS study could apply to coal plants that possess similar characteristics to CGS and utilities with missions and business objectives similar to those of SRP.

The siting evaluation assesses the suitability of the CGS site and surrounding SRP-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 CGS 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). Based on a review of publicly available information and data provided by SRP, no exclusionary or avoidance factors were identified at CGS. CGS has ample land to host a nuclear reactor and has supporting infrastructure (e.g., rail access, electricity grid interconnection access, water delivery/pumping infrastructure, etc.) in place to support deployment. As SRP pursues redevelopment of the site, the following siting considerations could change over time and should be monitored: water availability, ecological impacts on endangered or threatened species, and continued engagement with native and local communities. The siting evaluation is publicly available (Reference 1).

The nuclear technology assessment identifies candidate nuclear technologies and potential designs that align with SRP's current mission and business objectives. GAIN's efforts relied on publicly available information and input from SRP. SRP identified electricity production at utility-scale (400-1200 MW_e) as their main priority for any potential replacement technology at CGS. Small and medium-sized advanced reactors,[1] with generating capacities on the order of hundreds of megawatts, were therefore selected as the nuclear technology grouping that best aligns with SRP's objectives. Out of the small and medium advanced reactor grouping, several potential designs could meet SRP's generation needs, timeline requirements, and risk profile. If SRP decides to continue the nuclear technology selection process, direct engagement with vendors will be required to gain additional insights into candidate designs and enable down-selection.

The economic impact assessment, completed by researchers at Idaho National Lab (INL), evaluates socio-economic data and estimates the economic impacts to the region surrounding the plant (Apache County and the neighboring Navajo County) under two main deployment scenarios: a baseline economic impact assessment of current CGS operations, and one in which the CGS site is operated as a nuclear generation plant (four discrete cases with different levels of generation capacity are assessed under the nuclear generation scenario). The study indicates that the retirement of the coal plant with no replacement generation would have significant negative impacts on the regional economy. This study also concludes that several potential nuclear deployment scenarios would have a net positive effect on the regional economy. The economic impact associated with nuclear deployment is dependent on generating capacity and reactor design. The full economic impact assessment is publicly available (Reference 2).

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[1] 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 16).

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 to establish a broad foundation and framework for successful nuclear feasibility studies. Coronado Generating Station (CGS), owned and operated by the Salt River Project Agricultural Improvement and Power District (SRP) and located near the City of Saint Johns, Arizona, is one of several sites undergoing a GAIN nuclear feasibility study.

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

The three-part CGS nuclear feasibility study includes (1) a siting evaluation, (2) a nuclear technology assessment, and (3) an economic impact assessment. The objective of the CGS nuclear feasibility study is to inform SRP's decision-making process about future power generation options and reduce the uncertainty associated with the 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, input from SRP and the City of Saint Johns, and nuclear domain expertise within GAIN, MPR Associates, Inc. (MPR), and the 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 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 generation 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 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 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 task for any power company. Such projects require the development of the right partnerships to ensure that the appropriate nuclear technology options and licensing 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 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.

SALT RIVER PROJECT

SRP, an agricultural improvement district organized and existing under the laws of the State of Arizona, is a community-based, not-for-profit organization that provides affordable water and power to more than two million people in central Arizona. SRP has a diversified set of electricity generation assets, and coal-fired plants supply a little over 25% of SRP’s delivered energy (Reference 4). SRP owns shares in the coal-fired power plants listed in Table 1, and is the sole owner and operator of CGS.

Like much of the industry, SRP is planning on and acting to significantly reduce its carbon footprint while maintaining the ability to provide reliable and affordable power. SRP anticipates retiring its coal plants in the coming years as part of its decarbonization strategy (as highlighted in Table 1).

Table 1. SRP Owned or Partially Owned Coal Generating Plants.

Plant Name	Location	Planned Retirement	Total Capacity [MW_e] (1)	SRP Role
Coronado Generating Station	Saint Johns, AZ	December 2032	762	Owner and Operator
Craig Generating Station	Craig, CO	Unit 1 2025 Unit 2 2028 Unit 3 2029	1283	29% share of Units 1&2 only
Four Corners Power Plant	Farmington, NM	2031	1500	10% share of all remaining Units
Hayden Generating Station	Hayden, CO	Unit 1 2028 Unit 2 2027	446	50% share of Unit 2 only
Springerville Generating Station	Springerville, AZ	Unit 1 2027 Unit 2 2032 Unit 3 2031 Unit 4 TBD	1560	100% share of Unit 4 off-take of 100MW via PPA with Tri-State for Unit 3

Note:

1) Total capacity is the net generating capacity for each plant. SRP receives a share of the total capacity based on total percentage of units owned.

To continue to meet the electricity needs of their customers, SRP is investigating alternative low-carbon and carbon-free generating sources to replace retiring coal plants and is considering nuclear power as one such alternative. While GAIN’s study is focused on evaluating nuclear power as a replacement technology, SRP is considering non-nuclear alternatives via a separate work scope conducted by Kiewit (Reference 5).

CORONADO GENERATING STATION

CGS is a two-unit, coal-fired power plant located in Apache County near the City of Saint Johns, Arizona, as shown in Figure 1 (Reference 4). Unit 1 and Unit 2 have net capacities of 382 MW_e and 380 MW_e, respectively. At the time of this report, Units 1 and 2 are scheduled to begin seasonal operation in 2025 and to fully retire no later than year-end 2032.

According to Apache County (Reference 6), SRP owns approximately 7,000 acres of land around and including the CGS site. The CGS site itself occupies roughly 700 acres. The plant is equipped with emission controls including electrostatic precipitators to reduce particulate emissions, scrubbers to remove sulfur dioxide, and a water reservoir to recover and contain process waste. Unit 2 has a Selective Catalytic Reduction (SCR) system, which uses a catalytic chemical reaction to convert nitrogen oxides into nitrogen, water, and small amounts of carbon dioxide. An SCR system is planned for Unit 1 by the end of 2025 (Reference 4).

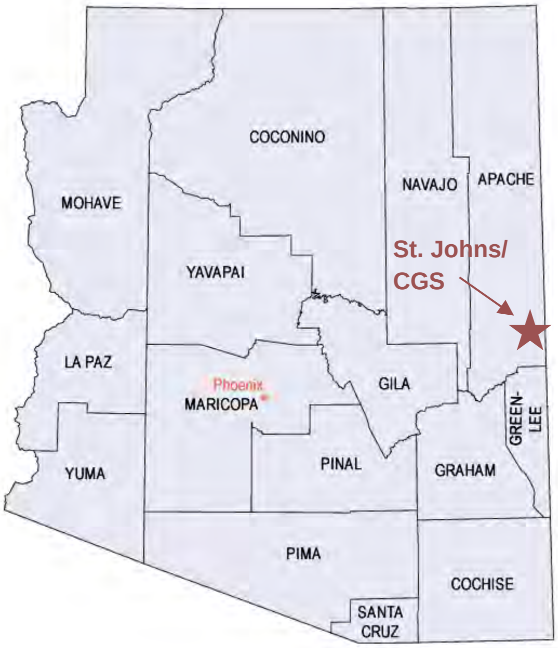

Figure 1. Map of Arizona Counties and Saint Johns / CGS.

In 2021, SRP released an updated timeline for reducing the workforce at CGS in preparation for the plant’s 2032 retirement (Reference 17). CGS employed 211 workers at the end of 2019; SRP expected to reduce total employment to 128 by the end of 2025, however, numbers have increased to 132, with additional hires the near future. Most workers reside in Apache County or the adjacent Navajo County. Other coal plants in the region have shut down or are planning to close soon. Before the closures began, the coal industry and its spinoffs provided up to 4% of the jobs in Navajo County and up to 8% of the jobs in Apache County (Reference 18).

SRP is developing plans for a phased approach to repurposing the CGS site, as shown in Figure 2. Phase 1 is intended to start immediately following coal plant retirement; technologies being considered for this phase are those which have demonstrated sufficient development maturity to support a commitment to build by 2028. The technologies under consideration include battery storage, biomass power, photovoltaic solar power, certain long-duration energy storage options, and wind power. Technologies being considered for deployment in Phase 2 include nuclear power, hydrogen-fired power, long-duration energy storage, and natural gas as a bridge to hydrogen or with carbon capture and sequestration (Reference 5).

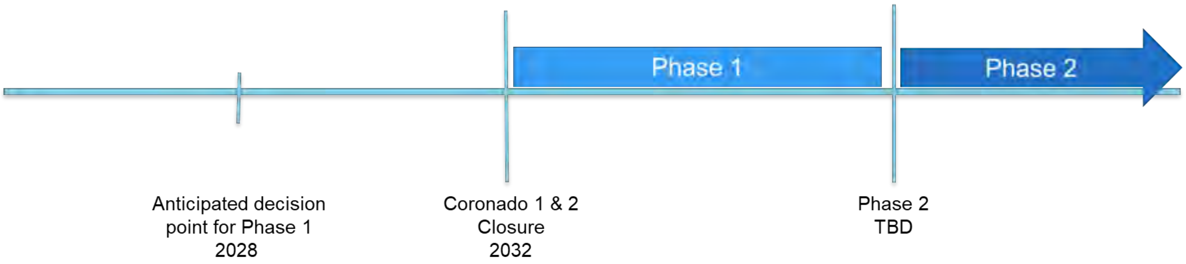

Figure 2. SRP's Phased Approach to Powering the CGS Site (further detail available in Reference 5).

STATE OF ARIZONA

Arizona's commercial nuclear generation has historically and continues to consist solely of the Palo Verde Generating Station. Palo Verde is the largest existing U.S. nuclear power plant, with a net summer capacity of 3,937MW_e (Reference 7). In 2022, Palo Verde supplied 29% of Arizona's power, with most of the remaining generation supplied by natural gas (42%), coal (12%), solar (10%), hydroelectric power (5%), and wind (1%). Biomass, hydroelectric pumped storage, and petroleum supplied the rest (Reference 8). The Arizona Public Service Company (APS) partially owns and fully operates Palo Verde. In 2017, legislation was adopted which recognizes that members of the Arizona legislature support nuclear generation as a safe and efficient means of energy production (Reference 10).

While no clean energy targets or requirements exist at the state regulatory level, between 2019 and 2021, Arizona's three largest electric utilities, APS, Tucson Electric Power, and SRP committed to carbon emission reduction targets and announced coal plant shutdowns (Reference 9).

SAINT JOHNS AND SURROUNDING NATIVE LANDS

Saint Johns is the nearest city to CGS, located within ten miles of the plant, and is the county seat for Apache County in Eastern Arizona. Saint Johns is situated in the White Mountains, and in a semi-arid climate region which is subject to cold winters and warm to hot summers. The population was estimated to be 3,388 in 2021 based on the U.S. 2020 census (Reference 11).

Saint Johns is close to native land; the Navajo Nation, Fort Apache Indian Reservation, Hopi Reservation, and the Zuni Indian Reservation all have a significant presence in Apache and surrounding counties.

SITING EVALUATION

The purpose of the CGS siting evaluation is to consider the suitability of the SRP-owned land at and near CGS 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 CGS 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 SRP, best in class technology assessment guidance, and insights from GAIN, INL, and MPR.

The full siting evaluation is publicly available (Reference 1). The approach and results 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 CGS 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 12).

As recommended in the EPRI Siting Guide, the CGS siting evaluation leverages a graded approach when assessing the suitability of the plant site and nearby SRP-owned land for a nuclear power plant.[2] The siting criteria identified in available industry guidance (References 12 and 13) can be grouped into three stages of assessment, described below. The focus of the CGS

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[2] The NRC typically requires the consideration of multiple sites in a region prior to ultimate selection for a nuclear generating station. (There are no specific requirements for the size of this region; typically for regulated utilities, the region of interest is defined by the utility service territory.) The CGS siting evaluation is focused on a site of interest (i.e., the CGS site) versus a region of interest due to the unique opportunities associated with adding nuclear to the energy mix at the CGS site. As a result, to satisfy NRC requirements, SRP will need to evaluate alternative sites to justify the selection of CGS during future stages of the siting evaluation process (see Reference 15).

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 whether 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 12) 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., being situated in a high probability flood plain or the presence of high slope that may incur large costs to backfill/excavate).

    Sites that do not have any exclusionary nuclear siting factors should be studied further in the subsequent stages. Typically, Exclusionary/Avoidance Factor Assessments can rely on publicly available data and 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, a utility has confirmed that the site(s) of interest does not have any exclusionary factors and the utility also has plans to assess risks associated with any avoidance factors identified during the Exclusionary/Avoidance Factor Assessment. While criteria addressed in this stage are not exclusionary factors, the assessed criteria 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 Decision Planning criteria. Decision Planning criteria will require further investigation in subsequent siting evaluations if SRP decides to pursue future stages.

3. **Licensing**: During this stage, a utility has selected the site for hosting a nuclear plant, has developed a deployment schedule, and is applying for either an ESP[3] or construction permit from the U.S. 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 are 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 14). For the CGS

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[3] 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.

siting evaluation, Decision Planning criteria for which relevant data either publicly exists or was provided by SRP is included in the evaluation.

Table 2 identifies the considerations evaluated as part of the CGS siting evaluation and summarizes the associated exclusionary and avoidance factors described in the EPRI Siting Guide (Reference 12). The EPRI Siting Guide also contains Decision Planning and Licensing considerations utilities can leverage when pursuing more detailed investigations. If SRP 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 12)

Siting Consideration	Exclusionary/Avoidance Factor Assessment
Geology Seismology	Exclude areas where seismic activity exceeds typical nuclear design specifications, as noted in Reference 12.
Cooling Water Supply	Ensure water availability for potential technology.
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.

Table 2. Exclusionary / Avoidance Siting Considerations (Reference 12)

Siting Consideration	Exclusionary/Avoidance Factor Assessment
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	Do not exceed the maximum pumping distance (do not select a location that is too far away from the source of cooling water such that pumping water from that distance is cost-prohibitive.)

RESULTS

No exclusionary or avoidance factors were identified at CGS. Construction of a nuclear power plant at CGS is feasible based on GAIN's initial screen.

Overall, CGS is favorable from a nuclear siting perspective, given the large amount of suitable land that SRP owns adjacent to CGS, as well as the existing supporting infrastructure (e.g., rail access, interconnection access, access to pumping stations, etc.) at the site. Additionally, the large amount of suitable land means that if nuclear power is selected as a generation source, it could complement additional replacement generation sources located at the site (e.g., could be co-located with generation sources from Phase 1 of SRP's plan to power the CGS site).

Several siting characteristics require additional investigation by SRP if nuclear siting is to be pursued at CGS. Key siting characteristics to consider include:

1. **Water Availability:** CGS currently draws from wellfields to supply CGS with water. Given the scarcity of water in the southwestern region of the United States and SRP's water reduction goals, special consideration of different cooling options is recommended at CGS. Many reactor designs are moving away from conventional, once-through cooling systems in favor of less water-intensive cooling (e.g., closed-loop cooling, air-cooled cooling, etc.). However, there are tradeoffs associated with cooling options (i.e., water usage vs. overall thermal efficiency) which can impact economic considerations of the plant and compete with community needs (e.g., agriculture, local industries, etc.). SRP should evaluate water consumption needs and impacts on overall plant efficiency before selecting a cooling option.

2. **Ecological Impacts on Endangered or Threatened Species:** The NRC stipulates that potential impact on endangered or threatened species should be evaluated before nuclear power construction and operation. Though CGS is not currently situated on land reserved for endangered or threatened species, Arizona is home to over 72 endangered, threatened, or candidate species. SRP coordinates with state and federal agencies to track species distributions and recovery efforts across Arizona, and currently monitors and comments on proposals by the U.S. Fish and Wildlife Service to list species as threatened or endangered or designate critical habitat. SRP should continue to track federal listing proposals and work to minimize regulatory impacts to current operations or future generation options at CGS.

3. **Adjacency to Native Lands and Nearby Communities:** CGS is sited on privately-owned land but is situated near the community of Saint Johns and in the same county as the Fort Apache Indian Reservation, Hopi Reservation, the Zuni Indian Reservation, and the Navajo Nation. SRP has and should continue to engage with local community and tribal leaders on decisions related to siting a nuclear power plant at CGS. Community engagement is an essential part of nuclear plant site selection, project planning, and execution. Local communities, including nearby native populations, should be engaged early and often to allow the local communities to provide input and ask questions to influence decisions.

Based on the findings from the CGS siting evaluation, SRP may want to continue to consider nuclear as a viable replacement technology at CGS. If SRP pursues the next steps in the nuclear technology siting process, SRP should continue to engage with local stakeholders and focus on developing a site layout and deployment timetable. This includes identifying reusable infrastructure (e.g., switchyards, cooling towers, etc.), determining the effect of construction on CGS operations, and assessing environmental liabilities.

APPLICABILITY TO OTHER COAL PLANTS AND ENERGY COMMUNITIES

Many elements of the CGS siting evaluation apply to other coal plants and energy communities beyond CGS and Saint Johns. GAIN’s siting evaluation approach is fully transferrable; utilities and other stakeholders can follow the steps laid out in the GAIN CGS 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 CGS siting evaluation are more broadly applicable as well. The considerations outlined previously, namely water availability, ecological impacts on endangered or threatened species, and adjacency to native lands and nearby communities are anticipated to be applicable to most candidate sites in Arizona and New Mexico with similar characteristics, as these siting considerations are relevant throughout the region. Power plants in Colorado will have some overlap with power plants in

Arizona and New Mexico but will require an additional assessment to demonstrate nuclear siting feasibility.

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

- **Physical Footprints –** The existing CGS physical footprint (i.e., the plant itself) occupies roughly 700 acres on an open, relatively flat 7,000-acre site. This allows for ample space to support the construction of a nuclear power plant.
- **Climate/Environment –** CGS and Saint Johns are located in a semi-arid climate. CGS is also situated on a low-risk floodplain, reducing the need for potential flood mitigation structures (Reference 6).
- **Water availability –** Given the scarcity of water in the southwestern region of the United States and SRP's water reduction goals, special consideration to different cooling options is recommended for CGS (e.g., wet-cooled, dry-cooled, hybrid cooling).
- **Seismic conditions –** Seismic activity in the region surrounding CGS is low. No exclusionary or avoidance factors were identified related to seismic considerations. However, this should be further assessed by SRP during later stages of evaluation.

Additional topics related to siting which were considered during the CGS siting evaluation process and have relevance to a wider audience of utilities and energy communities include the remediation of coal combustion residuals and existing location-dependent federal funding opportunities for nuclear technology investment. These are discussed in greater detail below.

Remediation Considerations

Coal combustion residuals (CCRs) are an important siting consideration when assessing the repowering of a coal plant with nuclear generation, 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[4] 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 21).

SRP owns sufficient land at the CGS site to avoid this potential conflict between existing or future CCR storage and the construction of a nuclear plant. SRP also has existing remediated

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[4] "Boundary" in this case refers to the nuclear plant physical footprint, and could include former coal station infrastructure (e.g., switchyard, pumping infrastructure, etc.). Depending on the extent of infrastructure reuse from the coal station, a clear distinction between what the nuclear station is accountable for and what the former coal station is responsible for is required.

CCR storage infrastructure on the site. However, if a utility is space-constrained at a given coal site where they are considering siting nuclear and there is a threat that CCRs could escape from where they are contained, CCRs become a relevant siting consideration, and 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 22). 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.

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 26):

- 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 26). 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 23).

Another program included in the IRA for supporting energy communities is the Energy Infrastructure Reinvestment (EIR) Financing Program at the Department of Energy (Reference 24). 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 (Reference 25). 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 26). 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 CGS nuclear technology assessment is focused on identifying candidate nuclear technologies and potential designs that are suitable for the CGS site and align with SRP's current mission and business objectives.

The GAIN team used both publicly available information and input from SRP. Information gathered and input from SRP 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 next-generation nuclear designs. Each vendor and respective design are at different stages of development and have different attributes that lend themselves better to some use cases over others. For example, smaller-scale microreactors (i.e., less than 50 MW_e) are well suited for remote applications in energy-scarce regions, while reactors that operate at higher temperatures are a good match for non-electrical applications, such as process heat and hydrogen production. Because of the number of different technologies and designs under development, utilities need to define business objectives and goals before selecting a design.

GAIN leveraged EPRI's "Advanced Nuclear Technology: Owner-Operator Reactor Technology Assessment Guide" (i.e., EPRI Technology Assessment Guide) (Reference 15) as a framework to conduct the CGS nuclear technology 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 and design options are evaluated against. At this stage, the envisioned owner/operator should agree upon and document key criteria such as need dates, target budgets, use cases, required output, etc. Mission and business objectives should be categorized as either Requirements (i.e., must-have features) and Considerations (i.e., nice-to-have

features). Requirements will be used in Steps 2 through 6, whereas Considerations will be used in Steps 4 through 6.

2. **Technologies of Interest** – Following the development of mission and business objectives, prospective owners should identify technologies of interest by surveying the nuclear technology landscape and compare these technologies against Requirements. This relates to the type of technology reactor 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 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 against the owner/operator's business objectives and needs.
4. **Potential Designs** – Following the screening to candidate technologies, potential designs are a set of specific designs offered by nuclear technology vendors that leverage the candidate technologies (e.g., PWR vendors, BWR vendors, HTGR vendors, LMFR vendors, etc.) in its design, and meet the identified Requirements.
5. **Candidate Designs** – Once potential designs have been identified, candidate designs are the potential designs that pass owner/operator screening criteria and can meet the Requirements and Considerations identified in Step 1. During this stage, the owner/operator begins 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 design which best meets the business objectives and mission of the owner/operator and identify potential alternatives should the proposed design no longer be viable.

The goal of the CGS technology assessment is to identify candidate technologies and potential designs for SRP's consideration (Steps 1 through 4 in the EPRI Technology Assessment Guide, as outlined above).

The next step of screening (Step 5 in the EPRI Technology Assessment Guide) requires direct interaction between SRP and vendors to gather more detailed information. Figure 3 illustrates the selection process as laid out in the EPRI Technology Assessment Guide, with the scope of the CGS technology assessment highlighted in blue. GAIN's approach may be used as a framework by utilities and other stakeholders interested in identifying candidate technologies and potential designs for a nuclear power plant.

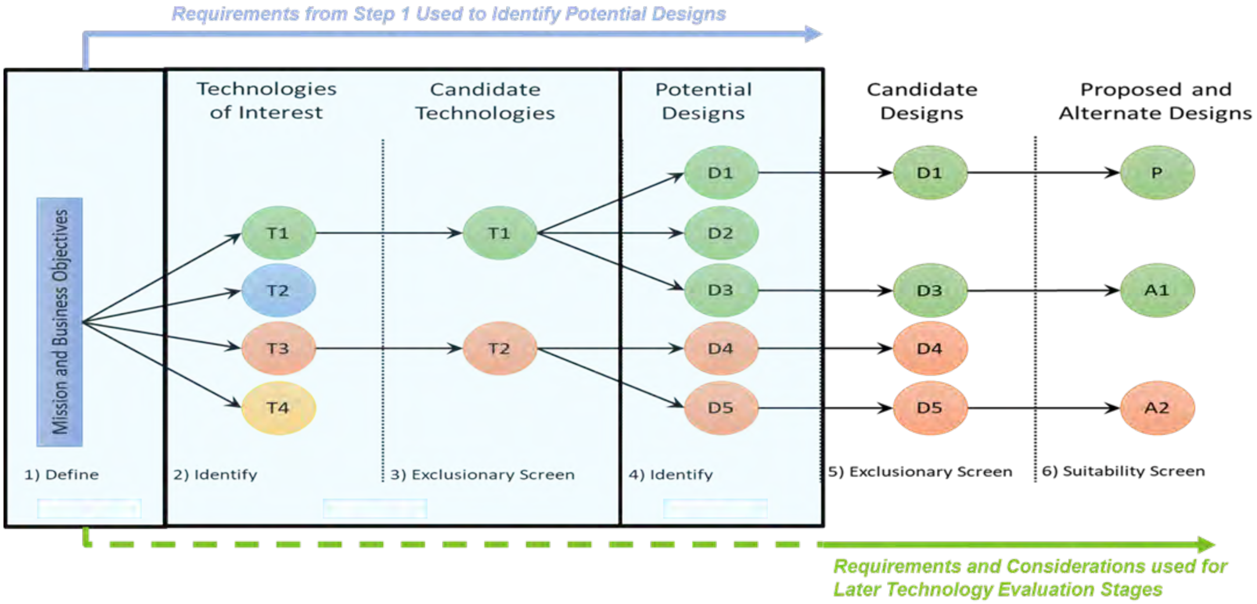

Figure 3. EPRI Technology Selection Steps with the Scope of GAIN's Assessment Highlighted (Reference 15).

DEVELOPMENT OF REQUIREMENTS

To begin the technology assessment, GAIN worked closely with SRP to document their mission and business objectives. SRP answered several questions derived from the EPRI Technology Assessment Guide and provided insights on their priorities and needs. SRP responses were leveraged to develop a list of Requirements and Considerations that align with their mission and business objectives.

Table 3 shows the list of SRP Requirements that all potential designs must satisfy. SRP Considerations are discussed in a later section on applicability to other coal plants and energy communities, to highlight their relevance to a broader audience.

Table 3. SRP Nuclear Technology Requirements.

Category	SRP Requirement
Capacity	Capable of delivering 400-1200 MW_e[5]
Primary Purpose	Electricity
Site Compatibility	Technology is compatible with CGS site attributes
Budget	The cost of the project is predictable and aligns with SRP's Integrated Resource Plan (IRP).
Operating life	Can operate at least 30 years, 60-80 years desired
Long-Term Owner/Operator Goals	• Can scale to meet needs of SRP • No unique desire to be a first mover • SRP will select a single design for CGS
Need Dates	Technology, supply chain, and regulatory maturity support SRP's Phase 2 deployment timeframe at CGS.

RESULTS

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 SRP's Requirements. 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 Requirements.

Most of SRP's Requirements (defined in Table 3) do not favor one technology type over another. SRP has indicated that the primary purpose of any replacement technology at CGS would be to generate electricity and highlighted their need for utility-scale generating capacity. In SRP's case, the technologies' fundamental methods for generating heat are less important than the power output of the technology. As a result, the technologies of interest were grouped based on their power output.

GAIN's Taxonomic Guidance on Advanced Reactors (Reference 16) defines the term 'advanced nuclear reactor' as a nuclear fission reactor with significant improvements, including additional inherent safety features, compared to reactors operating on December 27, 2020, in the United States. GAIN's Taxonomic Guidance also classes advanced reactors based on electric power

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[5] The Kiewit study investigates non-nuclear options sized at 800 MW. This technology assessment investigates nuclear options up to 1200 MW. SRP has yet to determine which technologies will be deployed at CGS.

output. Table 4 summarizes these classes (i.e., micro, small, medium, and large reactors). These reactor classes are considered the technologies of interest.

Table 4. Reactor Classes Based on Size (Reference 16).

Category	Electric Output (MW_e)
Micro	≤ 50
Small	> 50 and ≤ 300
Medium	> 300 and ≤ 600
Large	> 600

Small and medium-sized reactors have the flexibility to meet SRP's range of capacity requirements with a reasonable number of reactors. Due to their power output, it is unrealistic for microreactors to meet SRP's highest potential capacity needs given the large number of microreactors that would be required. Similarly, selecting a large reactor would limit SRP's ability to meet capacity needs in all scenarios under consideration, and may result in an overbuild (excess of capacity) scenario. Small and medium-sized advanced reactors are therefore considered the candidate technologies for this evaluation.

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. This step of the process identifies potential designs and vendors within the candidate technologies grouping that meet a utility's Requirements and align with its mission and business objectives.

Within the small and medium-sized groups of advanced reactors, multiple vendors are pursuing different reactor designs, and these designs are at varying stages of maturity. Given the number of different designs being developed and SRP's deployment timeline, GAIN established CGS-specific screening criteria in addition to SRP's Requirements to refine the aperture of this study.

The first criterion 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 criterion hinges on the vendor's ability to demonstrate that (a) the vendor is actively seeking regulatory buy-in on key design features that may be unfamiliar to the NRC (reducing regulatory risk), and (b) the vendor has a financial stake in licensing their design.

Based on these screening criteria, several potential designs were identified that could meet SRP's mission and business objectives. Potential designs are all capable of generating electricity at a utility-scale, have a maturity that could support SRP’s deployment window, and can support a range of capacities, providing SRP with desired flexibility. 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 SRP 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 SRP

Several potential designs align with SRP's mission and business objectives and are suitable for the CGS site. However, the technology monitoring and evaluation process for any utility should be considered a living process given the rapidly changing nuclear landscape. The technology assessment concludes that if SRP wishes to continue the nuclear technology selection process, SRP should:

- Engage with the vendors of potential designs. All information compiled in the CGS technology assessment is publicly sourced. Direct engagement with vendors will help SRP gain additional insights from information not publicly available.
- Refresh and refine the screening and evaluation on a semi-regular basis, leveraging insights from vendors. This will assist in planning efforts highlighted in this section by ensuring that 1) mission and business objectives are aligned with current SRP needs and that 2) any industry changes (i.e., new potential designs) can be identified and monitored appropriately. Semi-regular refreshments should continue until either a proposed design is selected, or SRP elects to discontinue nuclear evaluation efforts.
- Continue to engage with local community and tribal leaders on decisions related to technology selection and siting nuclear at CGS. Items such as workforce development and training and supporting infrastructure improvements will help ensure a smooth deployment. Community engagement is an essential part of project planning and execution.
- Outline a deployment plan, leveraging both SRP internal and external expertise. The deployment plan should cover topics contextualized by the GAIN studies (e.g., siting, technology selection, economic impact) and other topics listed in this section. Time and due diligence spent developing and implementing a deployment plan will reduce the overall risk and uncertainty surrounding nuclear deployment.

APPLICABILITY TO OTHER COAL PLANTS AND ENERGY COMMUNITIES

Similar to the CGS siting evaluation, the approach leveraged for the CGS 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 CGS may be relevant to other utilities and energy communities. 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 Requirements and Considerations. Requirements and Considerations can vary from utility to utility, and the specific Requirements 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 15) for examples of mission and business objectives and consult Table 4 and Table 5 to see how these mission and business objectives were converted and applied as Requirements and Considerations.

Considerations for Design Selection

As previously discussed, Considerations are 'nice-to-have' features that can aid in down-selecting to candidate, proposed, and alternative designs. Considerations in the CGS technology assessment are listed in Table 5. 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 5. Nuclear Deployment Considerations.

Consideration	Description
Modular Constructability	An organization may desire a better understanding of the modular construction and design scope for each technology, and which benefits are potentially realized by leveraging modular construction and design.
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.
Water Usage	Reduction in water usage is a common concern among potential power generation owners. Organizations may be interested in identifying technologies and designs that do not require a significant amount of water to operate. Water usage and potential cooling options from vendors should be well understood.
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 28). The other main option is for the owner (or one of the owners) to be the

Table 5. Nuclear Deployment Considerations.

	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 O&M model.
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 following section on "HALEU Fuel Availability" for further details.

HALEU Fuel Availability

One technological Requirement/Consideration that must be evaluated against deployment timetables is a potential technology's fuel type, and the enrichment level in particular. 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., 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. Because there is currently no commercial demand for HALEU, fuel suppliers have not invested in the required infrastructure to make HALEU at commercial scale. 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 June of 2023, the DOE issued a draft request for proposal (RFP) for commercial suppliers to supply HALEU enriched uranium hexafluoride (UF_6) for the industry (Reference 46). Additionally, the DOE issued an RFP for deconversion services, where HALEU-enriched UF_6 would be deconverted from UF_6 gas to different chemical forms (e.g., metals, oxides) for fuel fabrication (Reference 47).

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 44 and 45).

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 45). 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 has demonstrated enrichment of UF_6 gas to produce 20 kg of HALEU with plans to increase HALEU production capacity in the near future (References 44 and 48).

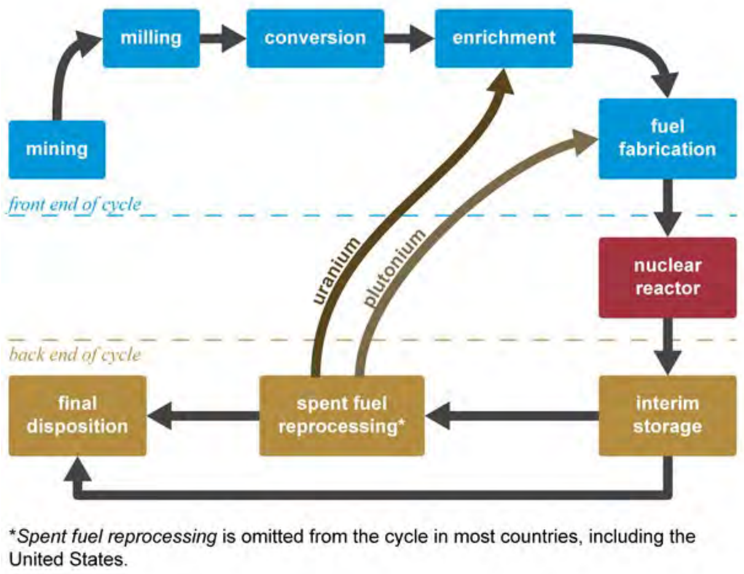
If a prospective nuclear technology owner identifies a HALEU-fueled potential design with favorable characteristics, the organization should inquire about HALEU fuel supply and monitor industry status in developing the required HALEU fuel infrastructure.

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. Also note, this used fuel is known as ‘High-Level’ waste (Reference 37).

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 4.



*Spent fuel reprocessing is omitted from the cycle in most countries, including the United States.

Figure 4. Front and Back-End of the Once Through and Closed Loop Nuclear Fuel Cycle (Reference 43)

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 37). 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 41).

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 40).

ECONOMIC IMPACT ASSESSMENT

The purpose of the CGS economic impact assessment report is to present potential regional, economic impacts of CGS coal plant retirement and of the deployment of nuclear generation onsite as replacement generation. This is done by analyzing the economic impact of the coal plant assuming continued operation (thereby showing the potential loss to the economy if the plant is retired with no replacement), and separately analyzing impacts to the economy should a nuclear power plant be deployed at CGS.

The results of this assessment are not intended to be used for financial forecasting or to replace accounting practices but should be used to compare socioeconomic impacts of various nuclear power replacement options. The full CGS economic impact assessment is publicly available (Reference 2).

Independent of this assessment, the community in Saint Johns is actively working to expand economic opportunity in the town; with funding from a Rural Innovation Stronger Economy (RISE) grant from the U.S. Department of Agriculture (USDA), the City of Saint Johns is developing an Innovation Center to aid local businesses and strengthen rural regional economies. The project is intended to support 21 distressed energy communities (as defined by the USDA) in Apache County and neighboring Navajo County (Reference 42).

APPROACH

Researchers at INL developed an economic model to estimate regional impacts associated with two different deployment options: one in which the CGS coal plant continues to operate (the baseline case) and one in which nuclear is deployed at CGS, replacing the coal plant. To enable a direct comparison between the two scenarios, the transition phase of the nuclear deployment option (which includes construction and associated economic impacts), is not included in the model Within the analysis of the nuclear deployment option, four discrete cases with different levels of generation capacity (320, 462, 616, and 924 MW_e) were evaluated. Note that these cases do not consider any potential transmission-level constraints on the deliverability of power.[6]

The region of analysis for this effort is the Apache and Navajo Counties. CGS and Saint Johns are located in Apache County, and Navajo County is a neighboring county. Most workers at CGS reside in Apache County or the adjacent Navajo County. Both counties are economically impacted by decisions made at CGS.

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[6] Transmission-level constraints could impact the economics of especially the case in which nuclear generating capacity exceeds the existing capacity of CGS. It is unknown whether the transmission system would require upgrades to deliver more power than it currently does.

To aid in comparing the two scenarios, an input-output model is used to quantify economic impacts. Input-output models enable the user to trace the impact of new economic activity observed in a specific industry 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. The model developed for this report was produced using the IMPLAN input-output modeling application (Reference 19).

The analysis of each scenario estimates the impact on overall economic output (the value of industry production), employment (the number of jobs created or sustained in the region), labor income (employee compensation and proprietor income), and value-added (the difference in monetary value between raw material and final goods). These metrics are assessed at three different levels:

- **Direct impacts** are at the level of the power plant.
- **Indirect impacts** are assessed within the supply chain supporting the power plant.
- **Induced impacts** are those which occur in the community surrounding the power plant.

The combination of all three of the above levels of assessment comprises total impact.

The baseline analysis of continued coal plant operations at CGS is based on average plant business volumes over multiple years to smooth fluctuations that typically occur. In recent years, electricity prices have fluctuated throughout the United States and in Arizona. For this analysis, SRP provided a long run wholesale electricity price that is intended to represent typical pricing during normal operation. To calculate total direct economic output for the baseline case, the amount of energy produced in a typical operating year was multiplied by the wholesale price of electricity. To determine direct employment and labor costs, the most recent annual plant values were used as the basis. All direct impacts were used as inputs to the economic model to obtain estimates for indirect and induced impacts, as well as for direct, indirect, and induced impacts associated with value-added.

The analysis of nuclear deployment at CGS is based on employment and wage information provided by reactor vendors in publicly available reports and on estimates of labor income and plant revenue values by the INL research team. Labor income was estimated by using industry wage and benefits data from the U.S. Bureau of Labor Statistics. Total plant output was calculated by multiplying the wholesale price of electricity by the annual electricity production estimates. Capacity factors were applied to determine an expected annual electricity production value. Similar to the baseline case, these direct impacts were input to the model to assess indirect and induced impacts, as well as direct, indirect, and induced impacts associated with value-added.

RESULTS

The results of the study show that the closure of the CGS coal plant would have significant negative impacts on the regional economy. The study also concludes that several potential nuclear deployment scenarios would have a net positive impact on the regional economy.

In the baseline case, combining plant operations with additional indirect and induced impacts, CGS is estimated to add $304 million of total economic output and more than 448 jobs to the region. The coal plant is estimated to contribute nearly $130 million to the Apache and Navajo Counties' gross regional product through value-added impacts, and nearly $40 million to the region's total labor income. Table 6 summarizes the projected losses for the region should CGS close with no replacement.

Table 6. Economic Impact Summary – Projected Losses from CGS Plant Closure.

Impact Type	Employment	Labor Income	Value Added	Output
Direct Effect	149	$21.9	$89.9	$212.7
Indirect Effect	208	$14.2	$32.6	$77.7
Induced Effect	91	$3.7	$7.5	$13.8
Total Impact	448	$39.7	$129.9	$304.2

Note: Dollar values are in millions of $.

The economic impact analysis of the nuclear alternatives shows that the potential for improving the economic conditions of the region is substantial. Scenarios C and D show a potential $150 million to $370 million in new economic activity, spurred on with 260 to 540 new jobs. Table 7 provides an overview of key characteristics of the nuclear capacity replacement options and economic impacts estimated for each scenario as compared with the baseline case.

Table 7. Power Plant Comparison Values.

Plant (Technology) (2)	Plant Capacity [$\mathrm{MW_e}$]	Capacity Factor	Employment	Labor Income (1)	Value Added (1)	Output (1)
CGS Coal Plant	762	49%	448	$39.7	$130	$304
Scenario A	320	93%	353	$31.3	$92.3	$233
Scenario B	462	93%	576	$53.4	$142	$340
Scenario C	616	93%	705	$63.3	$181	$450
Scenario D	924	93%	989	$86.4	$262	$673

Notes:

(1) Dollar values are in millions of $.

(2) Scenario A represents a 4-pack of the X-Energy Xe-100 80MW reactor. Scenarios B-D represent a 6-, 8-, and 12-pack of the NuScale VOYGR reactor (this design is only officially being sold as a 4-, 6-, or 12-pack; the values for the 8-pack are estimated based on the 6- and 12-module versions.)

APPLICABILITY TO OTHER COAL PLANTS AND ENERGY COMMUNITIES

Though the focus of the CGS economic impact assessment is one particular plant, the results can be translated to nearby coal plants, especially those in the Apache and Navajo Counties. In addition, the results may translate well to coal plants that employ a similar number of workers to CGS. Beyond impacts to economic metrics including employment, labor income, value added, and output, social justice and workforce transition implications for CGS may provide insights for coal plants and energy communities with similar socioeconomic conditions.

Social Justice Implications

Socioeconomic statistics show that the region under study is facing economic challenges Unemployment in the region exceeds the state average of 3.8%, with a 7.7% unemployment rate in Apache County and 5.2% in Navajo County.[7] The median income for the region is 36% lower than that of the state. These statistics play into the energy burden facing the region. Relative to the state average, the regional energy burden[8] is more than four times greater than that of the state (Reference 20). The region is experiencing existing economic challenges that would be exacerbated if generation capacity at CGS is not replaced (particularly with a resource associated with a similar operational workforce) when the coal plant is retired.

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[7] These counties are comprised of tribal and non-tribal lands. For the purposes of this report, employment, education, and income data is an aggregate of all residents and does not differentiate between tribal and non-tribal populations.

[8] A household may be categorized as having a high energy burden when energy bills consume more than 6% of the household's income (Reference 22).

As shown in the economic impact analysis results, the siting of a nuclear power plant can have beneficial impacts on local populations and economies. However, it can also place strain on local communities. For example, during construction, construction personnel may increase traffic in local communities, or limit short-term housing/hotel availability, and influence business. As is indicated in NRC regulatory guidance (Reference 14), the consequences and effects on the surrounding population from a socioeconomic perspective should be evaluated and accounted for when siting a nuclear plant. When engaging with local communities, including nearby native populations, it is important to understand the needs and perspectives of community members as well as the community's experience with the nuclear industry (e.g., power generation, waste management, uranium mining, etc.). The engagement model and overall approach should be catered to individual groups and their interests and needs.

The City of Saint Johns, AZ, is relatively small and geographically isolated. To ensure that the increase in population that may come with the construction or operation of a nuclear power plant is managed properly, careful planning and collaboration between the city and SRP is needed. Many coal communities have similar characteristics (smaller and somewhat geographically isolated) to Saint Johns. In all cases, it is essential that the community and utility engage and work closely with one another at each stage of a coal to nuclear transition.

Workforce Transition

The goal in a workforce transition is to minimize (or improve upon) the overall impact on the community's workforce. In any energy transition, some percentage of jobs will require minimal retraining, while other positions will necessitate significant retraining of existing workforce (or the movement of appropriately trained/experienced workers to the job location). To develop an estimate of this split in a transition from coal to nuclear generation, the CGS economic impact assessment leverages data from the Bureau of Labor Statistics to compare average national staffing patterns for fossil fuel and nuclear facilities. Ultimately, transitioning the CGS coal plant to nuclear generation while matching energy output is likely to result in more jobs in the community. Also, the majority of existing jobs at a coal fired station can be transferred to the new nuclear station with minimal retraining. Approximately 74% of the existing jobs are relatively similar and potentially require minimal retraining. The remaining 26% could also be preserved but would require more extensive retraining. Alternatively, trained workers could move to the community (Reference 2). The overlap (i.e., 74% of jobs which would require minimal retraining) and gap to be filled (i.e., 26% of jobs which would require more extensive retraining) when transitioning a coal plant workforce to nuclear positions are visually represented in Figure 5.

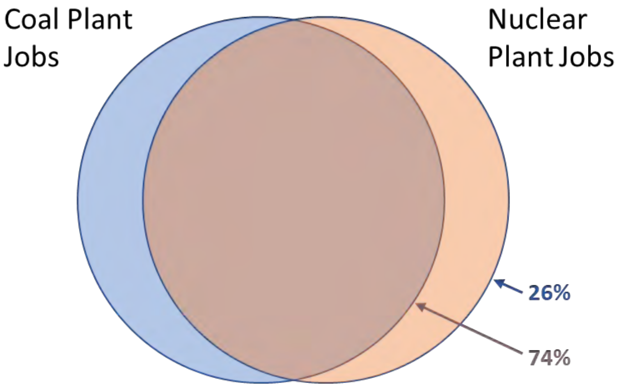

Figure 5. Illustration of Skill/Expertise Overlap between Coal and Nuclear Plant Jobs (Reference 2).

The above estimate of the percentage of positions requiring minimal versus significant retraining is based on national averages as reported by the US Bureau of Labor. As a result, it is roughly applicable to similarly sized U.S. coal plants. Where workforce training is required, energy communities can access retraining by partnering with local colleges, the utility or plant owner, regulators, and other non-governmental agencies.

USEFUL RESOURCES

The following resources are leveraged as part of the CGS 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 29): This document published by the Nuclear Innovation Alliance (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 (including the CGS economic impact report, as well as a majority of the resources listed below). 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 12): 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 13): 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 14): 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 30): 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 early site permits (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 31).

"Advanced Nuclear Technology: Owner-Operator Reactor Technology Assessment Guide" (i.e., EPRI Technology Assessment Guide) (Reference 15): 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 32): 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 16): 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 33): 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 34): 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 35): 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 36): This guideline, published by the Nuclear Energy Institute, discusses how utilities can develop a plant parameter envelope (PPE[9]) to support early site permit (ESP) activities. A PPE allows siting activities to continue while keeping multiple technology options open. Specifically, the guideline details what information will be needed

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[9] 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.

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 49): 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 power 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.

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