Stakeholder Guidebook for Coal-to-Nuclear Conversions

Nuclear Fuel Cycle and Supply Chain

Prepared for
U.S. Department of Energy
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ABSTRACT

This guidebook provides stakeholders in communities and electric utilities with information supported by analyses and document reviews about issues pertinent to the topic of coal-to-nuclear (C2N) transitions. Economic impact analysis and workforce transition issues make up the section geared towards community stakeholders. Cost considerations, policy opportunities, technology mapping, coal remediation issues, and siting considerations make up the section geared for utility stakeholders. Community stakeholders will find aspects of the utility-focused section helpful, e.g., ash remediation. And similarly, utility stakeholders will find aspects of the community-focused section helpful, e.g., workforce transition.

Constructing a study that can be applied to a wide variety of communities with coal power plants (CPPs) is not trivial. This guidebook evaluates 300 possible scenarios of C2N transitions. The scenarios are based varying the population size of communities and varying the possible capacity size matchups of the coal power plant with the replacement nuclear power plant. Economic impacts, e.g., jobs and economic activity, are then listed for each of the possible scenarios. The guidebook also explores the implications of workforce transition. It illuminates the potential need for retraining for some job functions and describes how another set of job functions can be transferred to the nuclear power plant (NPP).

To provide economic context to the C2N proposition, results from a recent study forecasting U.S. energy supply and demand through 2050 are presented. Deployments of advanced nuclear units and displacement of fossil generation are observed, with lower nuclear capital costs driving higher deployment levels, in both a “no policy” case and a hypothetical “net-zero emissions by 2050” policy case. C2N transition projects fit into these broader trends in the U.S. energy system.

Guiding questions are provided for a utility to consider underlying the key decision drivers leading to selection of NPP design characteristics that would be most suitable for their CPP site, among the various concepts available or under development by the nuclear industry. This requires considering utility strategy, existing CPP site infrastructure compatibility, together with estimated costs and timeline of such project. Finally, the guidebook addresses issues of site remediation, site access, and site licensing.

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ACRONYMS AND ABBREVIATIONS

ACRS	Advisory Committee on Reactor Safeguards
AEA	Atomic Energy Act
ASLB	Atomic Safety and Licensing Board
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BLS	Bureau of Labor Statistics
C2N	coal-to-nuclear
CAPEX	capital expenditures
CCR	coal combustion residuals
CFR	Code of Federal Regulations
COL	combined operating license
COLA	combined license application
CP	construction permit
CPP	coal power plant
CWA	Clean Water Act
D&D	disposal and disposition
DEC	Duke Energy Corporation
DoD	Department of Defense
DOT	Department of Transportation
EIA	Energy Information Administration
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ER	Environmental Report
ESP	early site permit
FAA	Federal Aviation Administration
FERC	Federal Energy Regulatory Commission
FEMA	Federal Emergency Management Agency
FPA	Federal Power Act
FRA	Federal Railroad Administration
FSAR	Final Safety Analysis Report
FWS	Fish and Wildlife Service
FOM	fixed operations and maintenance

GAIN	Gateway for Accelerated Innovation in Nuclear
GCAM	Global Change Analysis Model
HTGR	high temperature gas reactor
IBEW	International Brotherhood of Electrical Workers
IPP	independent power producer
ISO	independent system operator
ITAAC	inspections, tests, analyses and acceptance criteria
LCOE	levelized cost of electricity
LWA	limited work authorization
MWh	megawatt-hour
MSA	Metropolitan Statistical Area
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NPC	Northland Pioneer College
NPP	nuclear power plant
NOAK	Nth-of-a-kind
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NRC	Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
O&M	operations and maintenance
OATT	open access transmission tariff
OCC	overnight capital cost
OL	operating license
OSCM	Office of Standard Contract Management
PSAR	Preliminary Safety Analysis Report
QF	qualifying facility
RTO	regional transmission organization
SA&I	Systems Analysis & Integration
SAR	safety analysis report
SER	safety evaluation report
SFR	sodium fast reactor

SMR	small modular reactor
SOC	Standard Occupational Classification
TES	thermal energy storage
USACE	U.S. Army Corps of Engineers
VOM	variable operations and maintenance
Western	Western Wyoming Community College

STAKEHOLDER GUIDEBOOK FOR COAL-TO-NUCLEAR CONVERSIONS

1. INTRODUCTION

The U.S. Department of Energy (DOE) published a report in 2022 that evaluated the potential impacts of coal-to-nuclear (C2N) transitions where coal-fired electrical power plants are retired and replaced by nuclear power plants on or near the same site (Hansen et al. 2022). The primary findings of the 2022 study include (i) a quantified estimate of the number of coal sites in the country that are amenable for hosting advanced nuclear reactors; 80% of the sites evaluated, (ii) an estimate of the range of cost savings that may be attained in repurposing infrastructure from a coal power plant (CPP) for use in the nuclear power plant (NPP); 15% - 35% of the overnight capital cost of construction[a] and (iii) for a anonymized community, an estimate of what the economic impacts where a C2N transition takes place may turn out to be; such as increases in economic growth and jobs in the region.

In the 2022 DOE report on C2N transitions, there is a summary of studies that looked at transition issues. Since then, more have emerged, as highlighted below. Given the breadth of studies that now exist on the topic, the aim of this guidebook is to provide interested stakeholders with information to provoke thinking and further inquiry on issues relevant to C2N transitions. To accomplish this, the content of the guidebook is organized around two stakeholder perspectives: communities and utilities.

The guidebook begins by focusing on community stakeholders. Section 2, titled "Community Stakeholders," includes a comprehensive analysis that can be used by those interested in a C2N transition and the associated economic impacts. The analysis allows a community with a CPP to look to this section and approximate how economic impacts such as jobs and income might change in a scenario of a C2N transition. Although the section is directed to community stakeholders, stakeholders with a utility perspective will also find useful information. The section also walks the reader through a discussion of workforce transition that examines the types of jobs at a CPP then compares these to the types of jobs at an NPP, shedding light on what retraining programs might look like.

Section 2 includes an analysis of 300 possible combinations of community population size and power plant capacity in MWe. This makes it possible for community stakeholders from any size community to find an approximation of economic impacts that may result from a C2N transition in their community. In addition to varying community populations, the analysis considers these impacts for CPPs that range from 100 MWe to 900 MWe. Larger power plants are not evaluated because of the many studies that already exist on economic impacts for larger plants. For example, a 2010 study on the Palo Verde nuclear facility in Arizona provides a view of potential economic impacts associated with large, gigawatt scale reactors (AppliedEcon 2010). Palo Verde is rated to 4,000 MWe and directly employs 2,900 workers. The economic impact model from the 2010 study suggested the employment impacts of that plant would result in a total employment impact of 8,700 jobs. Links to this and other GW scale nuclear facilities are available in Appendix A-5. Even if a community is not considering a C2N transition but is considering inviting a utility to host nuclear power, the analysis in Section 2 shows economic impacts of NPPs over a range of capacity sizes. A general takeaway from Section 2 is that C2N transitions will likely lead to increased employment opportunities and higher incomes in the community. Section 2 also addresses issues related to environmental considerations, such as changes in greenhouse gas emissions and nuclear waste.

[a] Overnight capital cost of construction is a term that refers to the cost of the project as if there were no interest charges during the construction period.

The analysis on workforce transition gives community stakeholders important points to consider when plotting out what a C2N transition might look like. For example, it asks questions such as "how many workers at the CPP will simply retire versus seek employment at the NPP?" It also addresses issues like "do we have the right training programs at the local community college to support workers in transition?" On average, more workers are needed at NPPs than at CPPs of the same size. This means that, even if all the CPP workers transition to the NPP, more workers will be needed at the NPP. So, the section points out how population growth and infrastructure to support it should be part of the community deliberations.

Section 3, "Utility Stakeholders," describes factors such as investor economics, potential cost savings, and technology matching between existing nuclear designs with features of the utility's CPP. While this section is directed to utility stakeholders, community stakeholders will find this information useful as well. Section 3 also describes points to consider with respect to coal ash remediation and site preparation. The guidebook includes a detailed appendix for in-depth results on economic impacts and on siting related issues.

Turning to the utility perspective, Section 3 gets into factors that will likely bear on a utility's decision to undergo a C2N transition. For the average CPP, most of the cost to generate electricity is in fuel costs but for the average NPP, the situation is reversed. Most of the generating cost is from operating the plant (WNA 2022).[b] This drives much of the economic impacts related to jobs and growth from Section 2, but it also impacts a change in how the utility operates the power plant. Also, if the utility pursues a one-for-one replacement (i.e., an NPP of the same MWe capacity as the CPP), due to the higher capacity factor with nuclear power over coal power, the utility will have more megawatt hours available for sale annually. Section 3 addresses economic issues like these. The section also discusses aspects of site remediation once the CPP shuts down. Section 3 also contains a detailed discussion of regulations governing environmental issues associated with remediation and the licensing aspects of nuclear technology. For utility stakeholders who do not currently have nuclear power as part of their energy portfolio, this section will be helpful for considering the level of effort involved in siting an NPP.

The Electric Power Research Institute (EPRI) published a series of technical reports that provide a high-level overview of factors on decommissioning a CPP and reusing parts of its infrastructure at an NPP, one of which is a guidebook (EPRI 2019, 2022, 2023). The EPRI guidebook aims at providing power plant owner-operators with regulatory guidance on repurposing an existing CPP. The Bipartisan Policy Center published a white paper that addresses the viability of advanced nuclear power replacing the coal capacity in the United States (Jacobs and Jantarasami 2023). It largely leverages analysis from DOE's 2022 report but places the DOE findings in the context of policy discussion oriented towards C2N transitions. The Nuclear Innovation Alliance (NIA) recently published a thought-piece on C2N transition issues (Cothron and Greenwald 2023). It provides useful insights on topics ranging from the increasing frequency of CPP retirements, to siting and screening issues, and timelines for bridging the gaps in employment for the CPP workforce. NIA's thought piece also adds useful insights to the DOE findings. Although beyond the scope of this guidebook, it is worth noting that there have been many sessions at conferences and other venues, both domestically and internationally, where C2N transitions and related issues were the major themes. Finally, The Gateway for Accelerated Innovation in Nuclear (GAIN) is leading an expansive effort to respond to community leaders' interest in C2N transitions. Some of these efforts have led to direct engagement with communities and studies to support community interest (Jenson et al. 2023). GAIN coordinates a research group (several discussed here) for information sharing and opportunities related to C2N transitions.

[b] Here generating cost refers to the unit cost of producing electricity, also sometimes referred to as the levelized cost of electricity (LCOE).

2. COMMUNITY STAKEHOLDERS

2.1 Socioeconomic Impacts

Power plants are not only important to communities as a source of electricity, but they are also major sources of economic benefit to communities, especially in rural locations. Some local businesses may benefit as suppliers of goods and services in support of plant operations. As power plant employees receive paychecks, additional benefits are distributed to other local businesses as household spending creates additional local economic activity. Besides being some of the largest employers in the region, power plants often pay wages and salaries that are above average for the region, which leads to higher standards of living and improved quality of life. The 2022 DOE report on C2N transitions evaluated economic impacts for one anonymized community with a CPP and highlighted how local governments and school districts depend on tax revenue from power plants to maintain services and infrastructure that local residents depend on (Hansen et al. 2022).

Socioeconomic impacts considered in this guidebook include information about employment, income, changes to gross domestic product, revenue, education attainment, and workforce transition. Education attainment and workforce transition are addressed in the next section, so here the focus is on economic impacts.

U.S. Energy Information Administration (EIA) data shows that CPPs are currently operating in more than 200 counties in the United States (U.S. EIA 2023b). This guidebook utilized economic data on 30 different counties where CPPs are currently operating. The representative counties included each contain at least one CPP and half of the locations in the sample have a coal mine located within the county. Aggregating economic impacts, based on combinations of various sizes of the CPP, the NPP, and the community size, results in 300 different evaluated scenarios. The economic impacts, evaluated using input-output modeling techniques (IMPLAN 2022),[c] are structured to shed light on the potential impacts for a variety of NPP and CPP sizes. These impacts are further stratified by community population size, which is a major driver behind the magnitude of impact felt by the community. This effort was undertaken to provide communities with impact estimates that are close to what a location-specific analysis would reveal. Precise economic impact results for specific geographic locations require individual economic impact models that are customized to fit local economic conditions. Economic impact models of this type require significant time and financial resources to accomplish. Communities that would like to have a customized model to identify C2N economic impacts are encouraged to seek out professional assistance in doing so. Each economy is different, and a custom impact model would yield unique results each time. The economic impacts presented here should be thought of as a reasonable approximation of what detailed, community-specific results might yield.

These economic analyses generally find that C2N transitions would typically result in increased employment opportunities and higher incomes if the nuclear replacement has a similarly sized electricity production capacity. Increased employment opportunities and higher incomes could also lead to an increased population size for communities where the nuclear plants are located. These population changes would lead to additional socioeconomic implications, such as economic development, that are not addressed in this guidebook but are important when considering a C2N transition.

Table 2-1 shows the distribution of U.S. CPPs bound by the size of the community populations where they are located. Community population is structured by tiers based on population ranges. The table also shows the average size of the CPP unit as well as the number of units at a site.

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[c] Some of the data presented in this report use IMPLAN's economic modeling platform: IMPLAN® model, 2022 Data, using inputs provided by the user and IMPLAN Group LLC, IMPLAN System (data and software), 16905 Northcross Dr., Suite 120, Huntersville, NC 28078 www.IMPLAN.com.

Table 2-1. Coal power plant community tier characteristics.

CPP Community Tier Characteristics					
Tier Number	Population Range	Count of Counties	% of Counties Located in MSAs	Avg. # CPP Generating Units	Avg. CPP Nameplate Capacity
1	< 20,000	46	19%	2.2	489
2	20,000-39,999	44	20%	2.1	452
3	40,000-89,999	40	50%	2.9	400
4	90,000-199,999	45	82%	2.8	390
5	200,000+	43	100%	2.2	422

Note: metropolitan statistical area (MSA). Data source: (U.S. EIA 2023b)

2.1.1 Guidebook Economic Impact Evaluation Methodology

The process of analyzing and establishing the five community tiers mentioned above facilitated a bulk analysis of potential economic impacts for communities interested in C2N transitions. That is, by analyzing economic impacts for the 300 combinations noted, community stakeholders can find approximations of economic impacts their community may experience if a C2N transition takes place at their local CPP. For the economic impact evaluation, six communities were selected to represent each tier for a total of 30 communities. The representative CPP communities were selected to represent the range of population within the tier and a set of possible electricity production capacities using a CPP or NPP.

Decision-makers within CPP communities considering nuclear replacements may be interested in a range of plant sizes that align with energy needs that may have changed since the CPP was initially constructed. For this purpose, economic impacts were calculated for five generating capacity increments, 100, 300, 500, 700, and 900 MWe. So, suppose there is a 250 MWe CPP set to retire in a community. The impacts listed under the results for the 300 MWe increment would approximate the community's impacts. Likewise, the CPPs represented in the economic impact model followed the same generating capacity intervals used for the nuclear scenarios. In the CPP scenarios, the average of actual industry employment data for existing facilities were used in the input-output model. The NPP scenarios used public press release information since there are no examples of operating small modular reactors (SMRs) to collect data from.

In summary, five nuclear scenarios and five coal scenarios were analyzed for each of the 30 reference communities for a combined total of 300 economic impact models. Results for each tier and electricity generating scenario were then averaged to yield economic impact results that reflect the range of CPP communities across the United States.

2.1.2 Input-Output Model Scenario Details

Estimated construction impacts are not included in the scope of this guidebook due to lack of information about SMR construction costs. The NPP and CPP scenarios were selected based on actual sizes of NPP designs that exist in the market. The scenarios were kept generic in size and description. The results are linear in nature, which means that for a given community, impact results can be scaled up or down to match the desired capacity size.

Each scenario required data inputs for the input-output model. These inputs include plant output (revenue), employment, and labor costs. The values used in the model are available in Table 2-2. Values associated with plant revenue were derived from multiplying the 2021 U.S. average wholesale price of electricity, as reported by the U.S. EIA (U.S. EIA 2023c), by the estimated annual MWh of electricity produced. Industry average capacity factors for existing fleet NPPs and CPPs from EIA were used to calculate annual MWh for coal and nuclear plants. It is possible that the modular-designed NPPs could have capacity factors that differ from the existing fleet, but operating data on those capacity factors are not available at the time of this report. Retail electricity price was not used when calculating plant revenue to more closely approximate the total revenue contribution made by the generating facility itself.

NPP employment estimates were based on press releases and public documents made available by SMR developers (TerraPower 2022; NuScale 2021; WNN 2022). Employment estimates for CPPs came from Hitachi Velocity Suite (Hitachi 2023). Per-worker labor costs, loaded with costs for benefits and taxes, were applied to total plant employment for a total labor cost for NPPs and CPPs. Information regarding the specific per-worker labor costs, wholesale electricity price, and capacity factors is available in Table 2-3.

Table 2-2. Model input values.

Model Input Values	
Nuclear Worker Annual Salary + Benefits	$161,275
Coal Worker Annual Salary + Benefits	$136,681
Wholesale Electricity per MWh (2021)	$56.17
Coal Capacity Factor	51.9%
Nuclear Capacity Factor	92.7%

Source: Author calculations based on data in (U.S. BLS 2023a, 2022; U.S. EIA 2023c, a)

Table 2-3. Replacement scenario details.

Replacement Scenario Details					
Plant Capacity (MWe)	100	300	500	700	900
NPP Jobs	75	86	140	200	257
CPP Jobs	35	55	80	115	155
Coal Plant (MWh)	454,294	1,362,881	2,271,468	3,180,055	4,088,642
Nuclear Plant (MWh)	812,052	2,436,156	4,060,260	5,684,364	7,308,468
Coal Labor Cost	$4.8	$7.5	$10.9	$15.7	$21.2
Nuclear Labor Cost	$12.1	$13.8	$22.6	$32.3	$41.5
Coal Plant Revenue	$25.5	$76.6	$127.6	$178.6	$229.7
Nuclear Plant Revenue	$45.6	$136.8	$228.1	$319.3	$410.5
$Millions. Wholesale electricity price: $56.17 per MWh					

Source: Author calculations based on data in (U.S. BLS 2023a, 2022; U.S. EIA 2023c, a)

2.1.3 Using the Economic Impact Results

Economic impact results are organized into separate matrices that identify impacts for employment, contributions to GDP (value-added), labor income, and economic output. Each matrix begins with a top row indicating the MWe capacity of a generating facility for either a CPP or NPP. Each following row of the matrix represents a population range identified through the community tier analysis.

Guidebook users first need to identify the population size for their geographic region.[d] If the location of the power plant is part of a metropolitan area, the combined population of the MSA should be used. Columns of the impact matrix are organized by power plant electricity production capacity. The top of each column indicates the plant capacity (100, 300, 500, 700, or 900 MWe).

Each impact category has three result matrices that show total economic impacts, which represent the sum of direct (impacts at the power plant), indirect (impacts in the supply chain), and induced (impacts in the community). (See Appendix A for further discussion of impact nomenclature.) The sections that follow present each impact category. Within each section, the first matrix shows the economic impact of CPPs. These values are shown as positive numbers but will be considered losses as the CPP shuts down. These CPP impacts are intended to show the result of total shutdowns although plant closures may occur in phases over various time periods. The second results matrix provides the impact results for NPPs. These impacts are reflective of fully operational plants under normal conditions. The third matrix identifies the net change in impact when comparing CPPs and NPPs of the same MWe plant capacity and same population range. If desired, guidebook users can calculate alternative net change scenarios by comparing results for columns that represent differing plant capacities.

Note that values represented in the results matrices are rounded. As a result, it is possible that net change calculations could appear incorrect due to rounding.

The following example illustrates how a results matrix is used. This example displays the employment impact for typical operations of an NPP. The process to obtain estimates for other impact types follows the same process as the following example.

[d] These population figures are accessible through the U.S. Census Bureau resources like Quick Facts, available at https://www.census.gov/quickfacts/.

Table 2-4. Example of using economic impact results.

Community Example

Location: Anytown, USA

Population: 68,500

Nuclear replacement of interest: 900 MWe

Steps

1. Locate the row that corresponds to the population size (shaded in gray in the table).
2. Locate the column that corresponds to the nuclear replacement size (also shaded in gray).
3. Note the intersection of the row and column shows the economic impact.

Matrix of Economic Impacts

Population Range	Plant Capacity by MWe – Employment Impact (Jobs)				
	100	300	500	700	900
< 20,000	121	207	313	443	573
20,000-39,999	139	253	387	547	707
40,000-89,999	144	266	408	576	744
90,000-199,999	150	283	436	616	795
200,000+	178	352	548	773	998

2.1.4 Total Employment Impact

Employment impacts show the number of jobs created or sustained by plant operations. It is important to remember the first row of these matrices indicates the plant capacity in MWe. The following rows, organized by population range, indicate the total number of jobs created or sustained by plant operations.

Table 2-5. Analysis Results: Coal power plant employment impact.

Population Range	Plant Capacity by MWe – Employment Impact (Jobs)				
	100	300	500	700	900
< 20,000	56	108	166	236	312
20,000-39,999	64	128	198	281	370
40,000-89,999	68	134	220	312	410
90,000-199,999	69	143	223	316	415
200,000+	80	171	270	382	501

Table 2-6. Analysis Results: Nuclear power plant employment impact.

Population Range	Plant Capacity by MWe – Employment Impact (Jobs)				
	100	300	500	700	900
< 20,000	121	207	313	443	573
20,000-39,999	139	253	387	547	707
40,000-89,999	144	266	408	576	744
90,000-199,999	150	283	436	616	795
200,000+	178	352	548	773	998

Table 2-7. Analysis Results: C2N transition net change* in employment impact.

Population Range	Plant Capacity by MWe – Net change in Employment Impact (Jobs)				
	100	300	500	700	900
< 20,000	65	99	147	207	261
20,000-39,999	75	126	189	266	337
40,000-89,999	75	132	188	264	334
90,000-199,999	81	140	213	300	380
200,000+	98	181	278	392	498
*Net change is calculated by subtracting the CPP impact from the NPP impact for the same population range and plant capacity.					

As mentioned previously, economic impacts are distributed across three impact types. Direct impacts are equivalent to values for power plant operations. In the case of direct employment impacts, the plant capacity to produce electricity can increase at a higher rate than the number of workers required to operate the plant. Indirect impacts are associated with supply chain activity. Induced impacts are the result of employee spending throughout the community. See Appendix A for a detailed set of tables that identify how employment impacts are distributed across the impact types for each CPP and NPP size scenario. Figure 2-1 is provided here as an example of how employment impacts for a 500 MWe are distributed across each community tier.

Model results show, as exhibited in Figure 2-1, that as the local population and its supporting economy increases in size, the local economy increasingly creates opportunities for employment in supply chain and community spending related businesses. In a Tier 1 community, the indirect portion of total impacts from a 500 MWe NPP, is responsible for 40 percent of total jobs sustained by the operations of the NPP. By comparison, for the same size NPP, the indirect share of total employment impacts is responsible for 49 percent of jobs in a Tier 5 community. This would equate to 125 jobs (313 x 40%) in a Tier 1 community and nearly 269 jobs (548 x 49%) in a Tier 5 community.

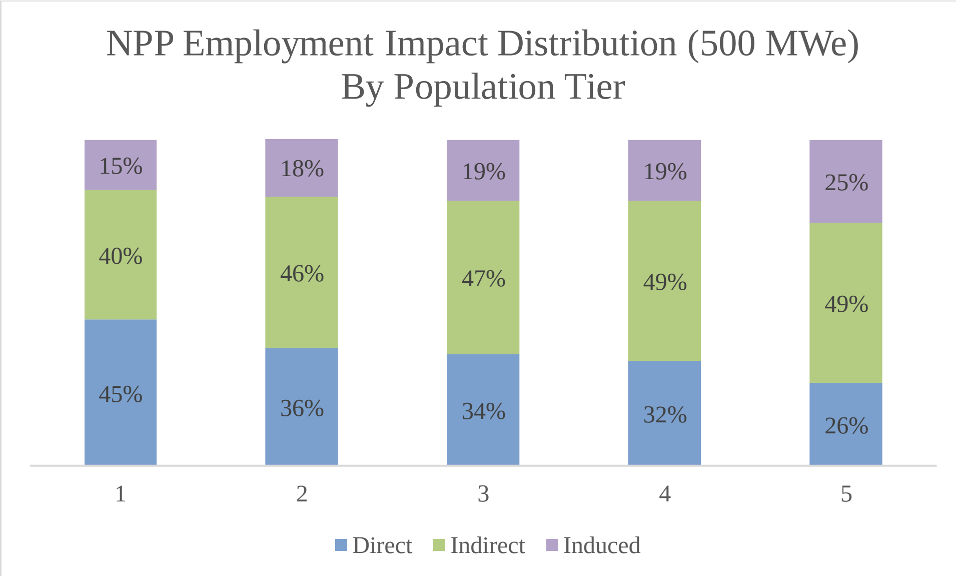

Figure 2-1. Example nuclear power plant employment impact distribution based on analysis results.

2.1.5 Total Labor Income Impact

Labor income impacts include wages, salaries, benefits, and employment taxes. All values in these matrices are presented in millions of dollars. Labor income used in these models is reflective of CPP and NPP industry wage and benefits information from the Bureau of Labor Statistics Occupational Employment and Wage Statistics program (U.S. BLS 2023b, a).

Table 2-8. Analysis Results: Coal power plant labor income impact.

Population Range	Plant Capacity by MWe – Labor Income Impact ($Millions)				
	100	300	500	700	900
< 20,000	$6.0	$10.9	$16.4	$23.5	$31.2
20,000-39,999	$6.5	$12.0	$18.3	$26.1	$34.6
40,000-89,999	$6.9	$12.8	$20.3	$28.9	$38.2
90,000-199,999	$6.8	$13.0	$20.0	$28.4	$37.6
200,000+	$8.4	$17.1	$26.7	$37.9	$49.9

Table 2-9. Analysis Results: Nuclear power plant labor income impact.

Population Range	Plant Capacity by MWe – Labor Income Impact ($Millions)				
	100	300	500	700	900
< 20,000	$14.6	$22.4	$32.8	$46.6	$60.5
20,000-39,999	$15.5	$24.9	$36.9	$52.4	$67.8
40,000-89,999	$16.2	$26.8	$40.0	$56.7	$73.5
90,000-199,999	$16.4	$27.3	$40.9	$58.0	$75.0
200,000+	$20.0	$36.5	$55.9	$79.1	$102.2

Table 2-10. Analysis Results: C2N transition net change in labor income impact.

Population Range	Plant Capacity by MWe – Net Change in Labor Income Impact ($Millions)				
	100	300	500	700	900
< 20,000	$8.5	$11.5	$16.4	$23.2	$29.3
20,000-39,999	$9.1	$12.9	$18.6	$26.3	$33.3
40,000-89,999	$9.4	$14.0	$19.7	$27.9	$35.3
90,000-199,999	$9.6	$14.3	$20.9	$29.5	$37.4
200,000+	$11.6	$19.4	$29.2	$41.2	$52.3

See Appendix A for a detailed set of tables that identify how labor income impacts are distributed across the impact types for each CPP and NPP size scenario. Figure 2-2 is provided here as an example of how labor income impacts for a 500 MWe are distributed across each community tier.

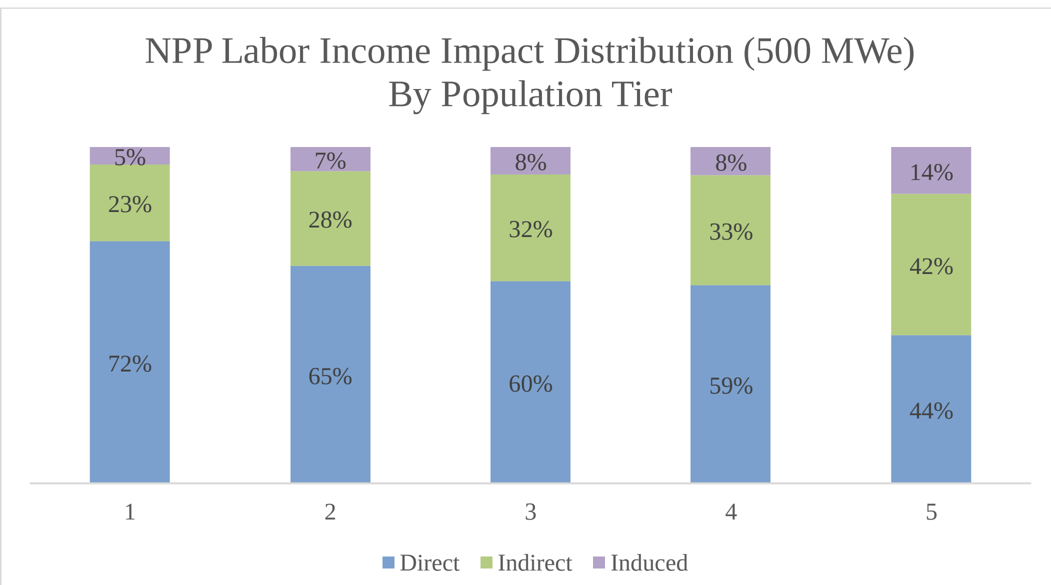

Figure 2-2. Example nuclear power plant labor income impact distribution based on analysis results.

2.1.6 Total Output Impact

Total output impacts are reflective of industry revenues from electricity production, supply chain activity, and employee spending. All values in these matrices are presented in millions of dollars.

Table 2-11. Analysis Results: Coal power plant total output impact.

Population Range	Plant Capacity by MWe – Output Impact ($Millions)				
	100	300	500	700	900
< 20,000	$29.3	$86.3	$143.5	$201.0	$258.6
20,000-39,999	$30.7	$90.2	$149.9	$210.0	$270.3
40,000-89,999	$33.2	$95.0	$162.1	$227.1	$292.3
90,000-199,999	$32.7	$96.0	$159.5	$223.4	$287.6
200,000+	$36.3	$105.6	$175.3	$245.6	$316.3

Table 2-12. Analysis Results: Nuclear power plant total output impact.

Population Range	Plant Capacity by MWe – Output Impact ($Millions)				
	100	300	500	700	900
< 20,000	$57.4	$167.5	$278.3	$389.7	$501.1
20,000-39,999	$61.0	$177.2	$294.2	$412.0	$529.9
40,000-89,999	$64.4	$187.1	$310.6	$435.1	$559.5
90,000-199,999	$64.7	$187.6	$311.3	$436.0	$560.7
200,000+	$74.1	$212.5	$352.0	$493.1	$634.3

Table 2-13. Analysis Results: C2N transition net change total output impact.

Population Range	Plant Capacity by MWe – Net Change in Output Impact ($Millions)				
	100	300	500	700	900
< 20,000	$28.1	$81.2	$134.7	$188.7	$242.5
20,000-39,999	$30.3	$87.0	$144.3	$202.0	$259.6
40,000-89,999	$31.2	$92.1	$148.5	$208.0	$267.2
90,000-199,999	$31.9	$91.6	$151.8	$212.6	$273.2
200,000+	$37.8	$106.8	$176.7	$247.5	$318.0

See Appendix A for a detailed set of tables that identify how output impacts are distributed across the impact types for each CPP and NPP size scenario. Figure 2-3 is provided here as an example of how output impacts for a 500 MWe NPP are distributed across each community tier.

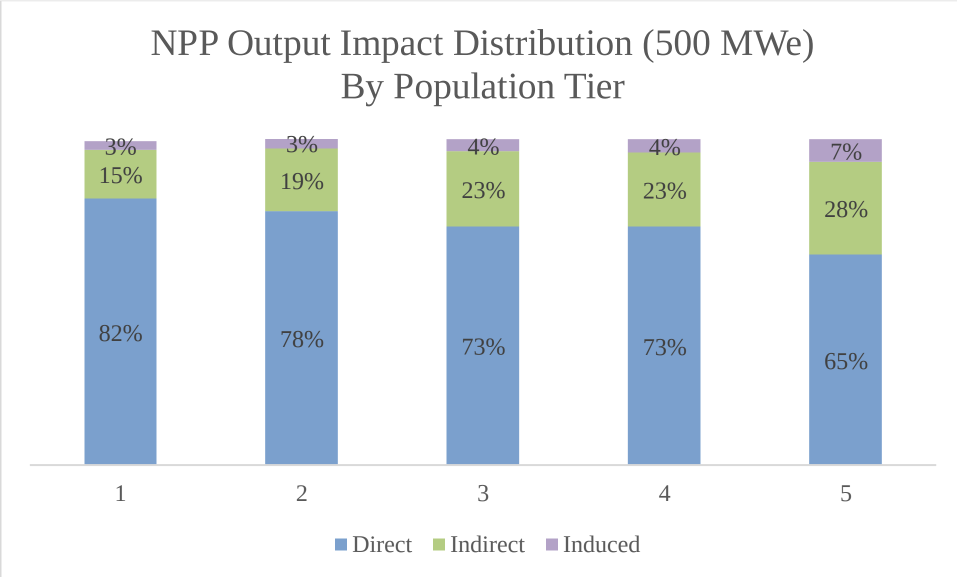

Figure 2-3. Example nuclear power plant output impact distribution based on analysis results.

2.1.7 Value-Added Impact

Value-added impacts provide insight on the total contributions to gross domestic product for the local area that can be attributed to power plant operations, which include contributions from the supply chain and businesses where employees spend paychecks. All values in these matrices are presented in millions of dollars.

Table 2-14. Analysis Results: Coal power plant value-added impact.

Population Range	Plant Capacity by MWe – Value-Added Impact ($Millions)				
	100	300	500	700	900
< 20,000	$15.0	$37.4	$60.5	$85.2	$110.6
20,000-39,999	$15.9	$39.8	$64.5	$90.8	$117.9
40,000-89,999	$16.0	$36.1	$65.0	$91.4	$118.7
90,000-199,999	$15.4	$38.1	$61.6	$86.8	$112.7
200,000+	$19.2	$48.8	$79.3	$111.6	$144.7

Table 2-15. Analysis Results: Nuclear power plant value-added impact.

Population Range	Plant Capacity by MWe – Value-Added Impact ($Millions)				
	100	300	500	700	900
< 20,000	$30.4	$68.6	$109.6	$154.1	$198.7
20,000-39,999	$32.1	$72.9	$116.5	$163.8	$211.1
40,000-89,999	$33.3	$76.5	$122.5	$172.2	$222.0
90,000-199,999	$33.1	$75.6	$120.9	$170.1	$219.2
200,000+	$39.8	$93.7	$150.6	$211.6	$272.7

Table 2-16. Analysis Results: C2N transition net change in value-added impact.

Population Range	Plant Capacity by MWe – Net Change in Value-Added Impact ($Millions)				
	100	300	500	700	900
< 20,000	$15.4	$31.2	$49.0	$68.9	$88.0
20,000-39,999	$16.1	$33.0	$51.9	$73.0	$93.2
40,000-89,999	$17.3	$40.4	$57.5	$80.8	$103.3
90,000-199,999	$17.7	$37.5	$59.3	$83.3	$106.5
200,000+	$20.6	$44.9	$71.3	$100.1	$128.0

Figure 2-4 is provided here as an example of how value-added impacts for a 500 MWe are distributed across each community tier.

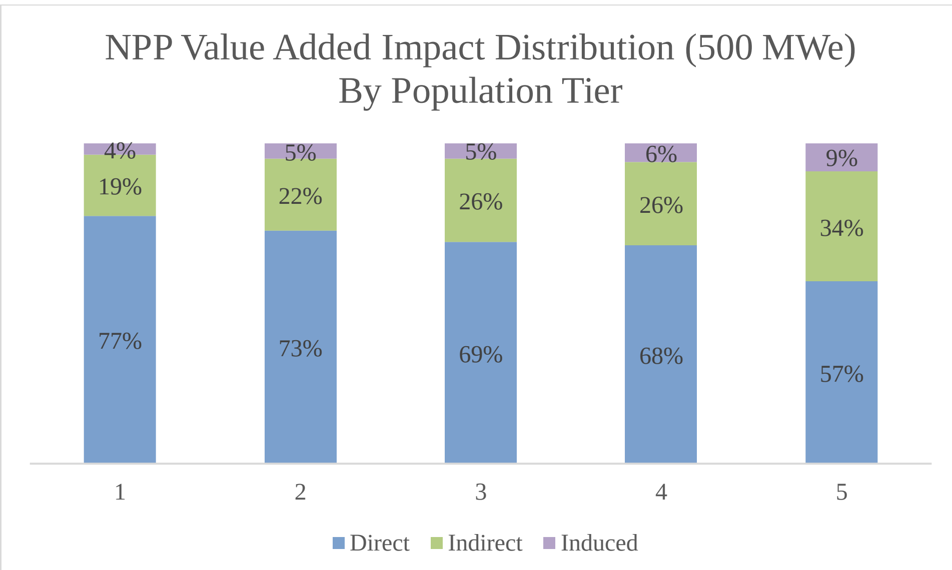

Figure 2-4. Example nuclear power plant value-added impact distribution based on analysis results.

2.2 Workforce Transition

The effective transitioning of workforces from CPPs to NPPs is vital to minimizing the impact on the communities where such changes take place. For the communities involved, an important question will be how such a change will affect workers at the CPP. Having established workforce transition practices in place will help communities navigate these changes effectively and with minimal negative impact to local workers. This section provides guidance on how workforces might be impacted and provides recommendations to minimize the negative impacts from such a transition. The three areas addressed in this section are as follows:

1. Differences in educational attainment between generation types;
2. Similarities and differences between coal and nuclear power jobs; and
3. Summary of and approaches to retraining workforces.

The discussions around areas one and two rely heavily on quantitative data from the Bureau of Labor Statistics (BLS) employment matrices (U.S. BLS 2023b). For point three, more qualitative data obtained from interviewing key leaders of communities undergoing or considering undergoing a C2N power transition is leveraged.

Data from BLS provides a look at national-level staffing patterns on a per industry basis. For example, nuclear power generation is considered a single industry while coal and other fossil fuel power generation are grouped into a single fossil fuel generation industry, and data are aggregated. It is worth noting that the data presented do not exclusively represent data patterns from coal plants, but rather from a combination of both coal and other types of fossil fuel generation stations. This approach utilizes the most granular data that is publicly available. Additionally, it is consistent with previous research on this topic (Hansen et al. 2022).

Within a given industry, data are divided into subcategories based on occupation. The data report on statistics identifies the percentage of a given industry employed in each occupation and average educational attainment by occupation. These industry-specific occupation statistics were used to determine average differences in education and staffing patterns from a CPP to an NPP. The data presented in this report are from data aggregated to a national level. It is possible that specific locations experience differences in education and staffing patterns, but national data proves more effective at determining what a C2N transition might look like at any randomly selected location in the United States.

2.2.1 Differences in Educational Attainment

To show differences in educational attainment, BLS data was aggregated across all occupations in both coal and nuclear power generation industries and plotted in histograms. Seven educational attainment categories were used: less than high school diploma, high school diploma or equivalent, some college, no degree, associate’s degree, bachelor’s degree, master’s degree, doctoral or professional degree. To aggregate the data, the distribution of educational attainment for each occupation of a given industry was weighted by what percent of persons in that industry held that occupation. Equation (1) sheds light on how this was performed,

$$IndustryValue_x = OccupationValue_x \times OccupationWeight \quad (1)$$

Where:

- X represents one of the seven educational groups listed above;
- IndustryValue represents the industry weighted average educational attainment for a given category X;
- OccupationValue represents the percentage of persons in a given occupation that obtained the educational of level X; and
- OccupationWeight represents the percentage of persons in the industry that hold that position.

The following example illustrates the differences in educational requirements for a given occupation. 14.5 percent of the persons that work at an NPP fall under the occupation of nuclear engineer and 10.3 percent fall within the occupation of security guard (U.S. BLS 2022). Both play a vital role in the safety and function of the plant, but each requires different educational backgrounds. The educational distribution of persons that work in these two occupations are shown in Figure 2-5.

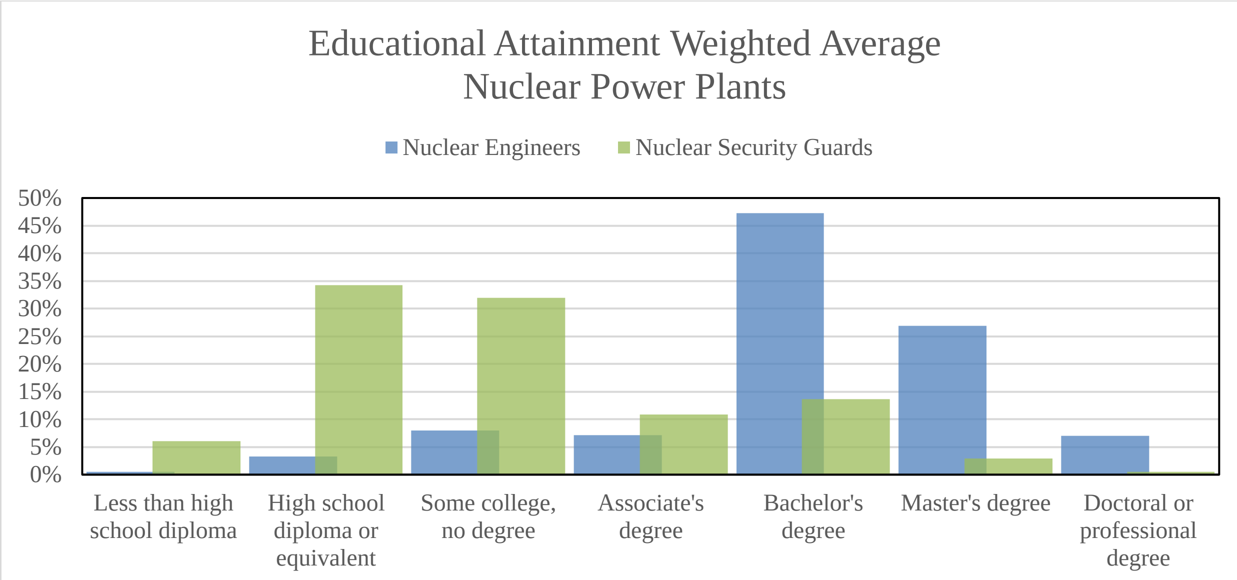

Figure 2-5. Educational distribution of nuclear engineers and security guards at a nuclear power plant.

In both CPPs and NPPs, there are positions with varying educational requirements. Understanding the aggregate differences helps to identify how much additional education might need to be obtained and when resources should be offered. Figure 2-6 provides context by showing the total jobs required by educational type. It shows that in almost every educational category the nuclear plant requires more workers than the coal plant, except jobs that require a high school diploma or less (the two leftmost categories). Despite this, the job differences are minor. In both categories, the total employment differences are less than 3 percent. Figure 2-7 shows the normalized aggregated distribution of educational attainment for both CPPs and NPPs. Comparing the histograms in Figure 2-7 with Figure 2-6 shows that nuclear roles, on average, require more education. Specifically, NPP staff have more bachelor’s, master’s, and doctoral degrees than staff at coal plants with CPP roles filled by persons with less education on average. However, note that when considering total employment changes, this becomes less significant. The aggregate net increase in jobs at the nuclear plant (when matching the electric output of a given coal plant) means that almost all workers are likely to find roles within a given educational band.

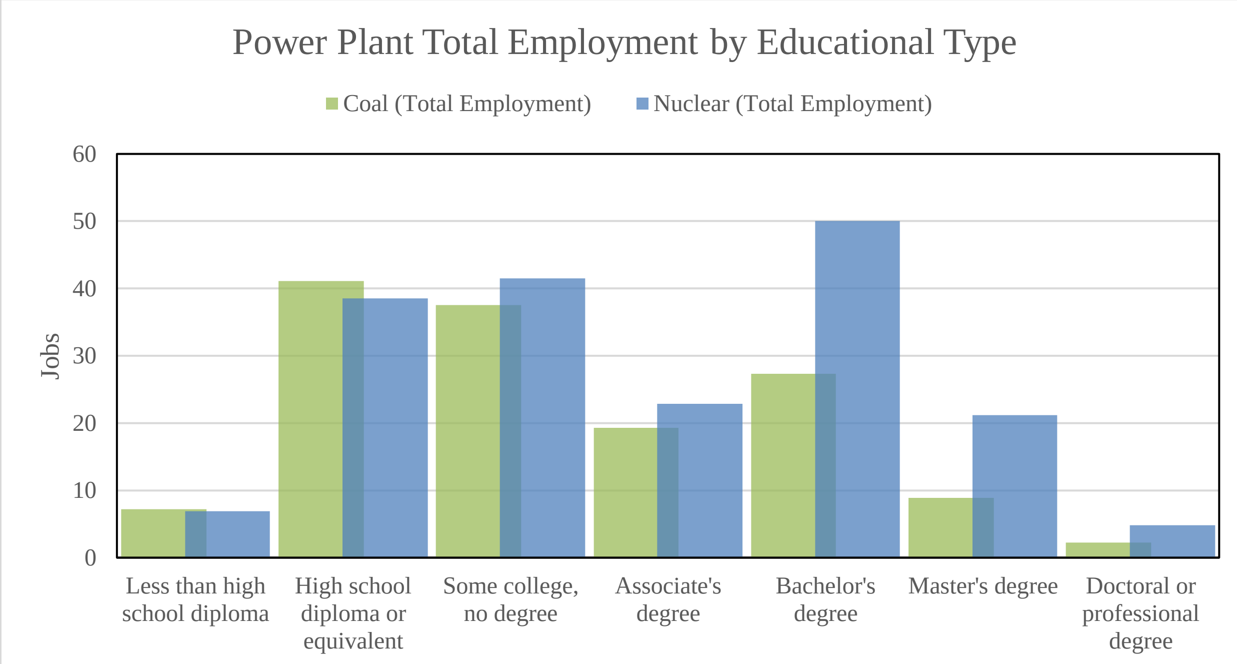

Figure 2-6. Total employment by educational requirements across all coal and nuclear plant jobs in the United States.

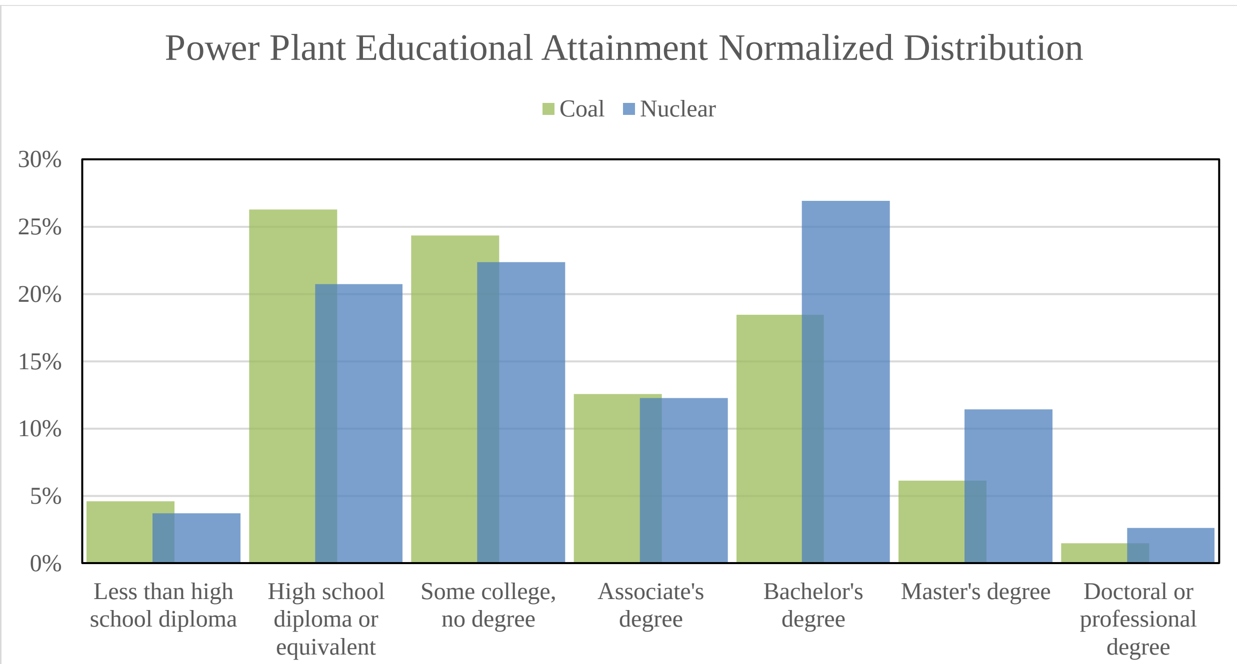

Figure 2-7. Distribution of education attainment across all coal and nuclear plant jobs in the United States.

The implications of this are clear. Should a community undergo a C2N transition, it is likely coal workers will need additional education to minimize community job losses from the transition. In some cases, this may mean simply taking a few additional classes; in others, an individual may want to pursue a bachelor's or advanced degree. In instances where the latter is required, transitioning becomes more complicated. Workers may not have access to education locally and may have to move out of the community. For those with families and established roots in the community, such a move may be even more difficult. Additionally, the costs associated with obtaining education might create added financial hardship for aspiring workers. In cases where this involves marginalized communities, this would be more pernicious. Understanding the requirements associated with changing generation technologies should be considered from a lens that includes the impacts to specific communities. Community leaders should consider how providing access or support to further education could be made so that unintended disparities do not further disadvantage marginalized communities.

Education attainment data reflects the most common education levels for each occupation based on industry surveys conducted by the U.S. Bureau of Labor Statistics. There are other workers in the data for each occupation that have lower or higher education levels and successfully perform the job. In these cases, work experience may be more valuable than a specific credential or degree. Some of this work experience may be valuable at both coal and nuclear plants.

2.2.2 Similarities and Differences in Roles

With generational technology changing at a power plant, there should still be skill overlap between jobs. One could expect there to be a crossover between the roles hired at the nuclear plant with the existing roles at the coal plant.

Overlap job similarities can be directly compared using BLS data. Within data matrices, each job is assigned to an occupation code, sometimes referred to as a SOC code. This code is a six-digit number with the first two digits identifying a major group, the third digit a minor group, and the last three digits identifying a specific occupation.[e] For example, the code 17-0000 denotes architecture and engineering occupations, 17-2000 denotes engineering occupations, 17-2160 denotes nuclear engineering, (U.S. BLS 2018).

Comparing occupation codes between coal plants and nuclear plants provides a picture of the similarity in roles from each power plant type. When modeling the transition from a 500 MWe coal plant to a 500 MWe nuclear plant, the similarities can be separated into two main areas: identical occupation codes (where all six digits match) and similar occupation codes (where up to five digits match). In this scenario, 45 percent of the added nuclear jobs share identical occupation codes with the coal plant, and 72 percent of the added share similar occupation codes. This implies that, based on the BLS occupation categorization, many occupations at the CPP have the educational background to work at the NPP. The BLS data do not account for nuclear, industry-specific training. For example, NRC-required training or other industry-specific training offered by the NPP to its employees is not reflected in this BLS comparison.

An example of two roles that are identical in the BLS occupation codes at both an NPP and a CPP is industrial mechanics (occupation code 49-9041) shown in both Table 2-17 and Table 2-18. If a 500 MWe coal plant was replaced with a 500 MWe nuclear plant, the coal plant industrial mechanics could transition to work at the nuclear plant as industrial mechanics based on the education attained for work at the CPP. The mechanic may need additional, industry-specific training at the NPP such as the NRC-required training noted above. In this example, the nuclear plant would staff four mechanics in this role while the coal plant only staffed three, meaning another mechanic would need to be brought in to fill the gap.

Other roles will also require industry-specific training to work at the nuclear plant. For example, in a CPP there are roles for electricians that work on power houses, substations, and relays. It is likely many of the skills needed to perform these functions at the CPP are like the functions at the NPP. Industry-specific training will be needed for these workers to transition to the new nuclear plant. For

[e] Codes appear in tables with a dash after the first two number as follows, XX-XXXX.

example, a person who worked as a welder at the CPP would need certifications to perform welds at the NPP. Other job functions at the NPP may require nuclear-grade qualifications.

There will also be roles created where there is no overlap with the existing coal plant. For these roles, workers from the CPP would need additional education or retraining. It could also be the case that for these positions, people from outside the community would need to fill these roles. For example, nuclear engineer (occupation code 17-2161) is a role that is not found in coal plants. As shown in Table 2-17, the nuclear plant will need about 20 workers to fill these roles, and most likely these roles will be filled by persons not working at the coal plant.

The exercise of comparing occupation codes is not exact. In application, identical codes between nuclear and coal plant jobs may still need training, and the amount of training needed could vary depending on the position. The value of this exercise is that it provides a numerical approximation of job similarities and therefore helps to better understand how a technology transition might look.

In the table below, note that while the NPP operators and CPP operators would technically be flagged as highly similar with this BLS occupation comparison method, this is an example where more extensive retraining will be needed. This is considered an outlier to the comparison method but worth noting because of the number of personnel associated with these roles.

Table 2-17. Estimated 500 MWe nuclear power plant staffing patterns (abbreviated).

500 MWe Plant - Largest Gains in Nuclear Jobs (Top 10)		
Occupation Code	Occupation Title	Jobs Gained
17-2161	Nuclear engineers	20
33-9032	Security guards	14
51-8011	Nuclear power reactor operators	14
19-4051	Nuclear technicians	14
51-1011	First-line supervisors of production and operating workers	7
49-2095	Electrical and electronics repairers, powerhouse, substation, and relay	5
49-1011	First-line supervisors of mechanics, installers, and repairers	4
49-9041	Industrial machinery mechanics	4
17-2071	Electrical engineers	4
13-1151	Training and development specialists	4

Table 2-18. Estimated 500 MWe coal power plant staffing patterns (abbreviated).

500 MWe Plant - Largest Losses in Fossil Fuel Jobs (Top 10)		
Occupation Code	Occupation Title	Jobs Lost
51-8013	Power plant operators	-14
49-9051	Electrical powerline installers and repairers	-5
49-2095	Electrical and electronics repairers, powerhouse, substation, and relay	-4
17-2071	Electrical engineers	-4
51-1011	First-line supervisors of production and operating workers	-3
43-4051	Customer service representatives	-3
49-9041	Industrial machinery mechanics	-3
49-1011	First-line supervisors of mechanics, installers, and repairers	-2
49-9012	Control and valve installers and repairers, except mechanical door	-2
47-2111	Electricians	-2

As previously explained, the examples shown in the tables above come from replacing plants at a scale of 500 MWe. If the plant size were to change, the values in the table would change. On aggregate, nuclear plants generally require more workers than coal plants, so the overall change in jobs from changing generation technology should be net positive. Figure 2-8 illustrates this point by showing the differences in plant employment between nuclear plants and coal plants as the plant size scales up or down.

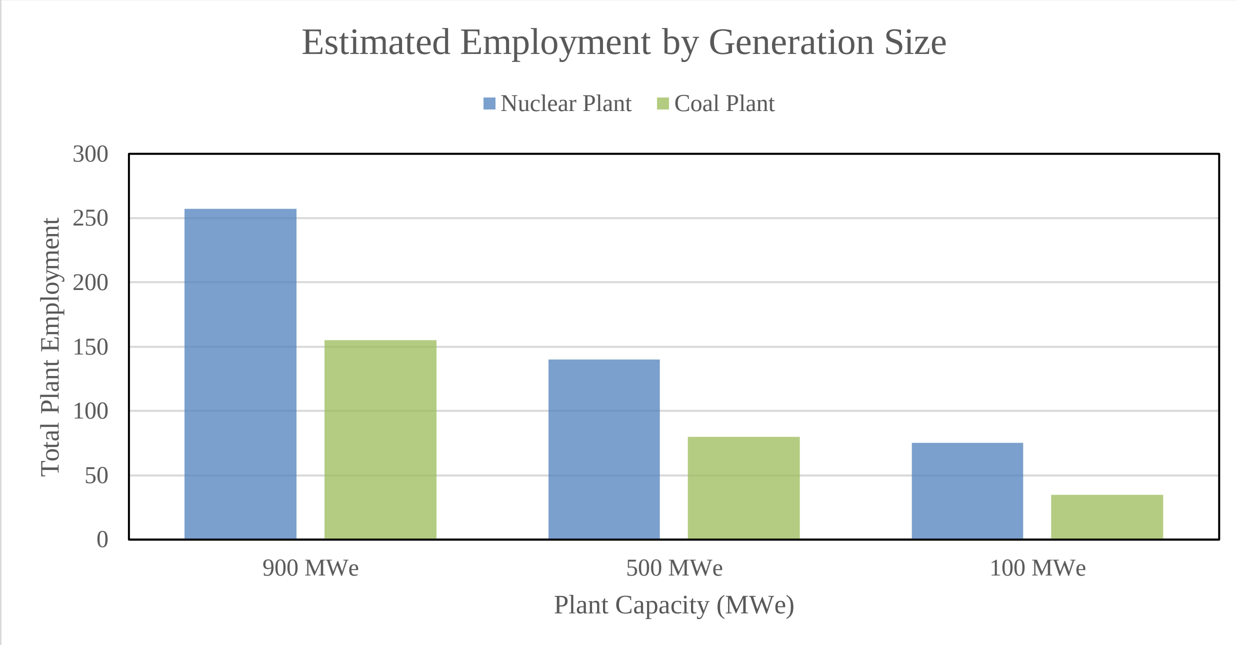

Figure 2-8. Differences in total plant employment by generation station size.

2.2.3 Risks of Retirement or Unemployment

Anytime workers experience largescale layoffs like those produced from plant closures, there is a risk that some workers will choose not to transition and instead retire. In some cases, this might mean early retirement. Finding new work and training for new roles can be daunting for potential workers and for those in proximity to retirement. Research on the displacement from plant closures of industrial workers in Switzerland found that age played a role in a workers' likelihood to retire (Oesch and Baumann 2015). Findings suggested that as age increases, the likelihood of both unemployment and retirement increases. Specifically, for those surveyed aged 55 to 59, 15 percent chose to retire and for those aged 60–64, 49 percent elected to enter retirement. Although this research is specific to Switzerland, and there are limits to its applicability in the United States, the authors suggest this trend applies to the United States and Europe. Research from 2001 in the United States confirms this trend (Kletzer 2001). It shows that for displaced workers across multiple industries, age has a negative relationship with the likelihood of reemployment post layoff. Specifically, workers aged 25–34 and 35–44 years old were 11 percent more likely to be reemployed post displacement than workers aged 45 or older.

Another risk is that workers of non-retirement age will not desire to transition nor participate in retraining programs. This may result in the worker entering long-term unemployment, relocating to a new area for work, or electing to take jobs in the same area for different employers. While the discussion above details that this is a more pervasive issue for older workers, it is also a risk for younger workers.

2.2.4 Avenues of Retraining Workforces

Retraining a coal workforce to transition into roles at a nuclear plant involves the collaboration of multiple groups. This includes the utility, or utilities involved in the transition, the local governments of the cities impacted by the loss or gain of jobs, and local colleges or educational institutions. For communities impacted, minimizing job losses will be paramount and minimizing the transition period where workers are unemployed will be a priority. To achieve this, communities should consider ongoing talks with the utilities involved to ensure training/retraining programs are implemented as soon as possible. Often nuclear utilities have training strategies and workforce acquisition tactics. Community leaders can aid in these strategies by facilitating communication between community members and representatives from programs that can assist with the process. As communities help to connect utilities to the local institutions that can help with training, the process can be accelerated.

Colleges and educational institutions are key players. In locations where an educational institution (such as university, community colleges, or trade schools) exists, it is common for there to be pipelines for training programs into the CPP. These schools likely developed programs with classes and training spaces, with close ties to the utility. In Arizona, such a transition is being considered at the Coronado Generation Station (a CPP) in St. Johns. Northland Pioneer College (NPC), a local community college, has programs in place to train workers for local coal power plants. Because of the uncertainty of the transition, the college has yet to take any action to produce retraining programs. However, the college has resources that could help community members prepare for a job change when collaborating with the utility.

To better understand the potential for education via college-driven programs in the St. Johns area, the president of NPC, Dr. Chato Hazelbaker, was interviewed (Hazelbaker 2023). Dr. Hazelbaker explained that NPC has an existing program to train workers for coal plants in the area. At its peak, the program had between 150–200 students enrolled each year, but since the announcement of upcoming coal plant closures, enrollment has decreased drastically. So much so, that the program in 2023 only had three students. However, the college is well positioned to pivot this program for nuclear training/retraining. According to Dr. Hazelbaker, the college has two 10,000 square foot buildings, one near the Coronado Generation Station, built with technical training programs in mind (Hazelbaker 2023). If a C2N transition were to take place in St. Johns, there would be resources and educational infrastructure to enable retraining though an NPC-led program.

A good example of a C2N transition happening in real time is taking place in Kemmerer, Wyoming. Kemmerer’s coal plant (The Naughton Power Plant) is undergoing a transition to nuclear power (Natrium 2023). This plant had an existing workforce pipeline from the local Western Wyoming Community College (Western). Western’s program provided workers in a variety of roles to the coal plant and upon hearing about the transition began altering the program to fit the requirement of nuclear power plants. To better understand how Western is playing a role in the ongoing transition the dean of outreach and workforce development and the vice president of student learning were interviewed to discuss changes to existing programs (Murphy 2023).

Amy Murphy, dean of outreach and workforce development at Western, explained that many of the existing programs could be augmented to meet the additional requirements for a comparable role at a nuclear facility (Murphy 2023). A specific example that Ms. Murphy gave was the conversion of an industrial safety course for coal plant workers. The course was augmented in several ways, but one change was to include three-way communication training, something the coal plant industrial safety course did not require. In this sense, the training programs were not reinvented, but gaps were filled to accommodate the change in the technology and regulation.

Labor unions can also play a role in the retraining and education of transitioning workers. For example, a labor union in the nuclear energy space is the International Brotherhood of Electrical Workers (IBEW). According to IBEW reports in 2017, more than 15,000 union members work full time in nuclear plants, and many thousand more union members work on the construction and maintenance of plants during outages (Randolph 2017; IBEW 2017). Unions like IBEW have experience in organizing workers, connecting them to resources, and interfacing with employers, politicians, and local governments on behalf of workers.

In many instances these unions span generation technologies and work in both the coal and nuclear spaces. For example, in Canada, IBEW joined a transition task force for coal workers to better understand how these workers can effectively transition into new work amid the phase out of CPPs in Canada (IBEW 2018). This task force leverages the expertise of IBEW to consider possibilities for coal workers to understand options such as retraining, relocating, or retiring. As a similar transition takes place in the United States at plants where unions have a presence, a similar approach can be taken. Engaging with union leaders and involving them early in the process of deciding how to retrain workers will likely have a very positive impact on the ability to successfully transition a CPP into an NPP.

Local educational institutions and labor unions are not the only way for retraining to take place. Some utilities will send would be workers to existing nuclear sites for training, and others leverage partnerships with universities and national laboratories. What happens in a specific community should be the result of conversations with utilities, workers, community leaders, labor unions, and any other key partners. The experience of others undergoing these transitions, such as what is taking place in Kemmerer, Wyoming, should be sought out. Such a transition is not an easy task for communities to take on. However, with impending plant shutdowns, there are ways to limit the discomfort of such a transition. By understanding key differences in education between these technologies and the types of jobs that will be lost and gained and knowing what resources exist to retrain workers, a community will be well on its way to a successful shift from a CPP to NPP.

2.3 Environmental Considerations

There are several environmental considerations related to a coal to nuclear transition. A notable result is the change in greenhouse gas emissions. Generating electricity at an NPP does not produce GHG emissions, generating electricity at a CPP does. Hansen et al. (2022) describes GHG, and other environmental outcomes connected to a coal-to-nuclear transition. That study shows that a community that experiences a coal-to-nuclear transition will experience an improvement in environmental quality because of reduced GHG emissions. But there are additional environmental considerations. This section discusses the management of used nuclear fuel and considerations of coal ash.

2.3.1 Management of Spent Nuclear Fuel

An often-asked question about nuclear power is "what about nuclear waste?" The summary below provides a narrative around this question. While there are many publications that address this in reports and peer reviewed publications, this summary provides a high-level answer to the question.

Where CPPs are fueled constantly throughout the day, today's NPPs can run for ~18 to 24 months before being refueled. During the refueling outage that typically runs a few weeks, ~1/3rd of the fuel in the core is replaced with fresh fuel[f]. The fuel that is removed is "spent"[g] as most of the fissile material in the fuel has been used up. Only ~5% of the uranium has fissioned (split into smaller atoms called fission products).[h]

Nuclear fuel in current reactors consists of uranium pellets stacked in metal tubes that are arranged in arrays called fuel assemblies[i]. These assemblies, which are 5 to 9 inches square and 12 to 14 feet long, are what is put into and taken out of the reactor. Unlike the combustion process, where coal is converted to ash, discharged nuclear fuel is in the same form as fresh fuel. However, discharged fuel is highly radioactive due to the presence of short-lived fission products that decay rapidly, so the spent fuel must be shielded to protect the workers. Fission product decay produces heat, so the fuel must also be cooled. Both functions are achieved by putting the recently discharged fuel into spent fuel pools for up to

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[f] Some advanced reactors will have on-line refueling where the reactor continues to operate during incremental refueling.

[g] Some documents may use the term "used fuel" instead of "spent fuel", especially when discussing advanced reactors where the fuel may need to be removed from the reactor before the fissile material is spent due to other constraints. "Used fuel" may also be used to refer to fuel that is planned to be recycled to recover reusable materials.

[h] Advanced reactors and fuels are being designed for higher burnup with as much as 15% or more of the fuel fissioned.

[i] The fuel forms for some advanced reactors will be different from the fuel assemblies discussed here, including fuel arranged in hexagonal arrays, in flat plates, and in small balls ("pebbles"). However, the physical management of the discharged fuels will be similar.

5 years, where the water provides both the shielding and the heat removal (see Figure 2-9). After 5 years, most of the short-lived fission products have decayed to stable isotopes and are no longer radioactive. With the lower activity and heat generation from the remaining radioactive isotopes, the fuel can either remain in the spent fuel pool or be moved into dry storage casks (see Figure 2-10). NRC regulates the storage of SNF at nuclear reactors to ensure its safe management.

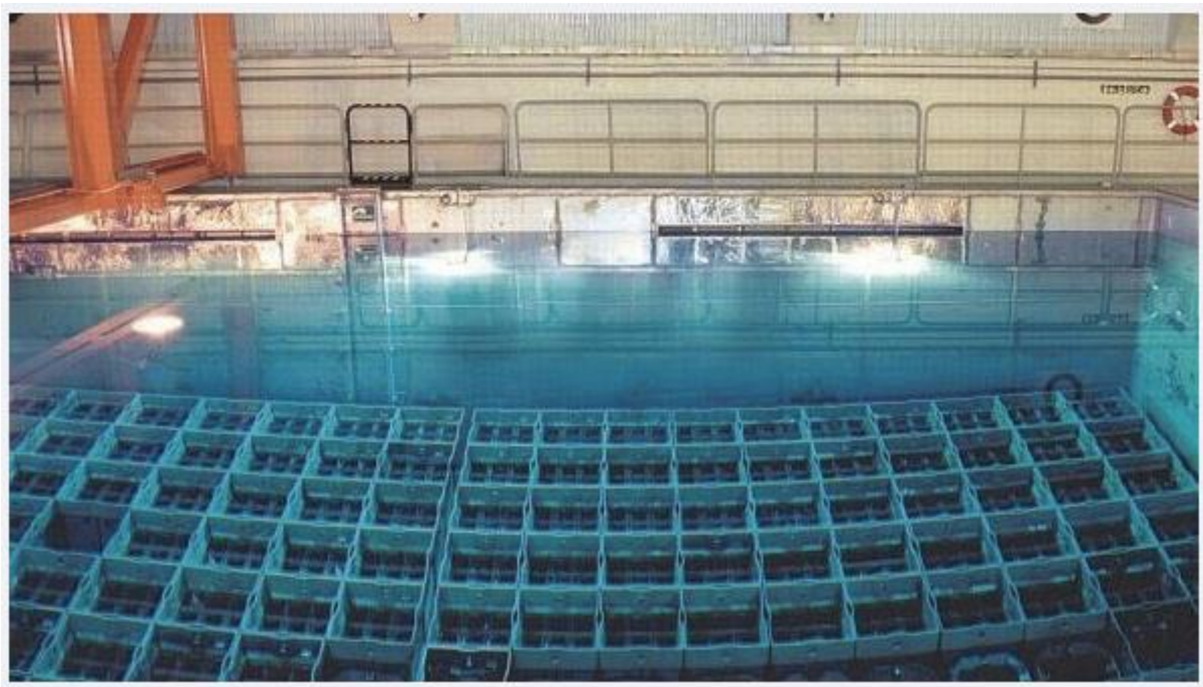

Figure 2-9. Pool storage racks. Source: (NEA 2023).

Figure 2-10. Examples of dry storage cask containers. Source: (TAM 2022)

The Department of Energy is responsible for ultimate disposal of SNF in compliance with the Nuclear Waste Policy Act. Until SNF is accepted for disposal, it will be safely stored, currently onsite at NPPs. NRC has determined that SNF can be safely stored for 100 years or more (U.S. NRC 2014). The DOE is working on siting of a federal consolidated interim storage facility using consent-based siting.

Another common question is how much waste does a nuclear power plant produce? A coal plant produces thermal energy by breaking the chemical bonds in coal during combustion. The thermal energy is then used to produce steam that powers turbines to turn electrical generators. A nuclear plant also produces thermal energy used to make steam, but it is breaking atomic bonds that are much stronger and so release many times more energy per unit mass. Because atomic bonds are so strong, each fuel pellet (smaller than a AA battery) can produce as much energy as a ton of coal. See Figure 2-11.

Because the energy density of nuclear fuel is so high, it produces very small amounts of spent fuel to manage. A typical 1,000 MWe nuclear power plant will produce about 20 metric tons of spent fuel per year.[j] By comparison, in a year a typical 1000 MWe coal power plant will produce 300 thousand metric tons of ash and 6 million metric tons of CO_2 (WNA n.d.). One dry storage cask can hold 10 to 15 metric tons of spent fuel from current reactors.

[j] Advanced reactors and fuels will produce smaller amounts of used fuel (by mass) due primarily to higher fuel burnup which results in more energy per unit of fuel mass. See the following for more information on spent fuel management of advanced reactors: https://fuelcycleoptions.inl.gov/SiteAssets/SitePages/Home/SMR_Waste_Attributes_Report_Final.pdf.

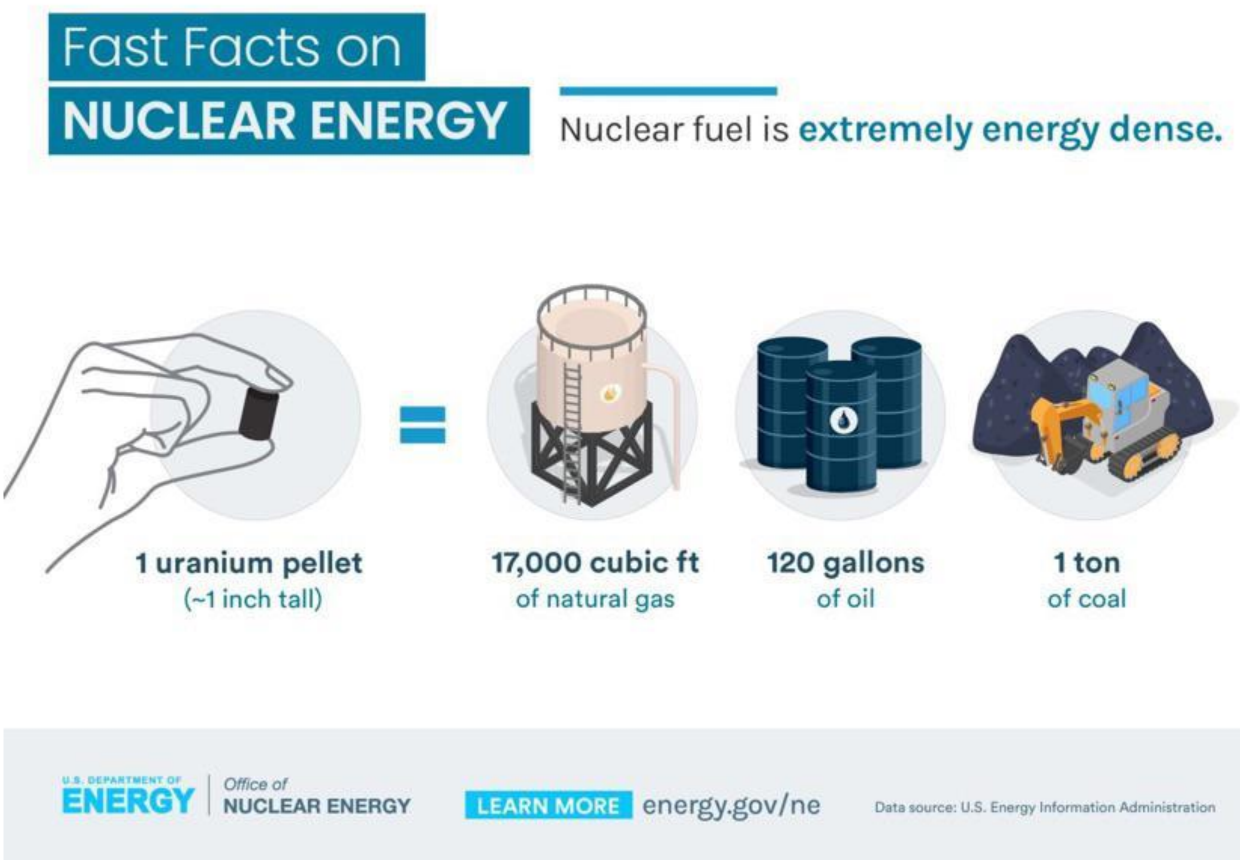

Figure 2-11. Comparison of different types of fuels used to produce electricity

In addition to spent fuel, operation of a nuclear reactor will also result in low level waste (LLW), which includes used clothing worn in radiation areas (booties, etc.), air and water filters, used equipment that has been replaced, and other operational wastes. Most of these materials are only mildly radioactive and are typically packaged in 55-gallon drums and shipped to licensed, lined landfills for disposal on a routine basis[k]. The small amounts of wastes that are more radioactive are packaged and shielded as needed to ensure safety during storage, transport, and disposal.

3. UTILITY STAKEHOLDERS

3.1 Market Opportunities

At the present crossroads of rising demand for energy, coal assets reaching their end of useful life, and interest in decarbonization, the proposition to derive fresh value from existing assets through transformation is of interest to many types of stakeholders. Utilities which have not owned or operated nuclear plants before may be interested in exploring nuclear investments for the first time, and veteran nuclear owners may find it worthwhile to expand the share of nuclear in their portfolio. C2N projects

[k] There are four commercial LLW disposal sites in the United States. They are located in Barnwell, South Carolina, and operated by EnergySolutions; in Clive, Utah, also operated by EnergySolutions; the Hanford site in Washington, operated by U.S. Ecology; and in Andrews, Texas, operated by WCS LLC. For more information, see NIH (2017).

present one pathway for this new investment, offering utilities a chance to extract more value from assets they already own while decarbonizing their portfolio.

In this context, it is useful to examine broader forecasts about deployment of advanced nuclear generation technology to help contextualize the C2N investment decision within more general trends of expanding U.S.-wide deployment of advanced nuclear. Greater deployments of advanced nuclear technology strengthen supply chains, increase the experience level of EPCs and subcontractors, and generally increase the competitiveness of the market, to the benefit of potential utility owners. This section briefly summarizes some recent research into possible deployment of advanced nuclear technology between 2025 and 2050, to give context to this topic.

A 2023 study by the U.S. Department of Energy's Systems Analysis & Integration (SA&I) Campaign (Kim 2023) models the deployment potential for nuclear energy through 2100, using the Global Change Analysis Model (GCAM). GCAM is a multi-sector economic model which can simulate the evolution of energy use, fuel demand, agriculture, land use, and greenhouse gas emissions in the United States. It can model various types of energy policies to estimate the impact of policy interventions on outcomes for the overall U.S. energy system. One goal of Kim's study was to assess the possible level of deployment for nuclear energy under various policy scenarios, using a spectrum of assumptions about nuclear capital cost. Kim (2023) provides useful estimates of expected nuclear deployment in the U.S. to meet decarbonization objectives, so the approach and results will be summarized here and discussed in the coal-to-nuclear context.

3.1.1 Relevant Assumptions

Kim's study includes a variety of scenarios. For this guidebook, only two of these will be highlighted:

1. Reference case: no energy policies (including no IRA policies)
2. Net-zero case: mandates zero net emissions for the entire US-wide economy by 2050.

Kim (2023) does not directly model C2N projects but does include a generic advanced nuclear technology option with a range of overnight capital cost (OCC) assumptions. Figure 3-1 shows the assumed evolution of advanced nuclear capital costs in the study. The study included five different cost cases. In each, the price starts high and then (except for the highest-cost case) the capital cost decreases over time. These reductions in cost are assumed to derive from improved construction outcomes for the deployed NPP units through learning by doing. The units' operating costs were the same across all cases.

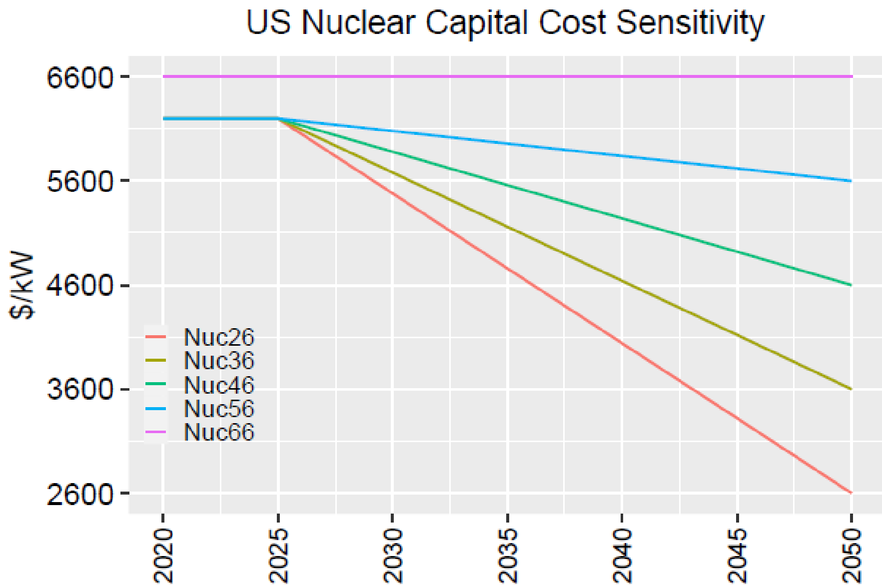

Figure 3-1. Nuclear overnight capital cost assumption profiles for five cost scenarios. The case names ("Nuc26", "Nuc36", etc.) come from the original study and indicate the final capital cost achieved by 2050 and correspond to the "nuclear capital cost scenario" labels used later in this section. Source: Kim (2022).

Those cost profiles can be compared with those described in Hansen et al. (2022) for C2N projects, as further summarized in Section 3.3. The C2N project type with the lowest baseline estimated capital cost is the SFR on-site CPP replacement (i.e., the "C2N #3 - SFR" project type) at $3398/kW. The C2N project type with the highest baseline estimated capital cost is the HTGR separate-site linked replacement (i.e., the "C2N #0 – HTGR" project type) at $6028/kW. Therefore, the long-term cost estimates used in different scenarios from Kim (2023) correspond roughly to the range of long-term cost estimates developed for the C2N project alternatives, although the GCAM model does not capture any of the secondary factors, benefits, and challenges associated with converting coal plants to nuclear plants.

Kim's study models the specific retirement dates for each currently operating nuclear reactor in the United States, using the best available data about currently projected retirement dates. All reactors except Diablo Canyon 1 and 2 are assumed to receive 80-year license extensions, so most of the current nuclear fleet retires between 2050 and 2070.

3.1.2 Nuclear Deployment Results

Table 3-1 shows the total amount of nuclear generation capacity operational in the United States in 2050 for the reference scenario (no climate/energy policies) and for the net-zero 2050 scenario.

Table 3-1. Total U.S. nuclear capacity operational in 2050, as used for electricity generation, by nuclear capital cost scenario.

	Total U.S. nuclear capacity for electricity in 2050 (GWe)	
Nuclear capital cost scenario	Reference case	Net-Zero 2050 case
$6600/kW	117	179
$5600/kW	125	207
$4600/kW	137	244
$3600/kW	156	302
$2600/kW	197	394

Lower capital costs for nuclear result in increased levels of nuclear deployment by 2050, in both the reference case and the net-zero 2050 case. The net-zero 2050 case makes greater use of nuclear capacity to replace fossil-fired generation—coal, gas, and petroleum liquids—but both cases see reduced fossil utilization in favor of nuclear (and renewables such as wind and solar).

Nuclear energy can be used to support clean generation of hydrogen (and other secondary energy products, such as process heat or ammonia) in addition to electricity. This study models the growing market for hydrogen on both the supply and the demand side, so the amount of nuclear capacity dedicated to hydrogen generation is determined separately from the amount of nuclear capacity dedicated to electricity generation. The amount of nuclear capacity deployed for hydrogen generation is tracked separately in the study; these results are shown in Table 3-2.

Table 3-2. Total U.S. nuclear capacity operational in 2050, as used for hydrogen generation, by nuclear capital cost scenario.

	Total U.S. nuclear capacity for hydrogen in 2050 (GWe)	
Nuclear capital cost scenario	Reference case	Net-Zero 2050 case
$6600/kW	4	19
$5600/kW	6	26
$4600/kW	8	35
$3600/kW	12	48
$2600/kW	18	63

The reference case assumes only a small market for hydrogen, so the “pull” from this secondary market is very weak compared to the demand arising from electricity generation. The net-zero 2050 case assumes that more U.S. industry and transportation are converted to use hydrogen, so the market is larger and more profitable, increasing the amount of nuclear generation dedicated to hydrogen.

3.1.3 Evolution of U.S. total electricity generation by technology type

The breakdown of total annual electricity generation by technology type forecasted for the reference (no policy) and net zero 2050 cases is shown in Figure 3-2. Each row containing two charts shows results for one of the nuclear capital cost cases, with the most expensive nuclear OCC at the top and the least expensive at the bottom.

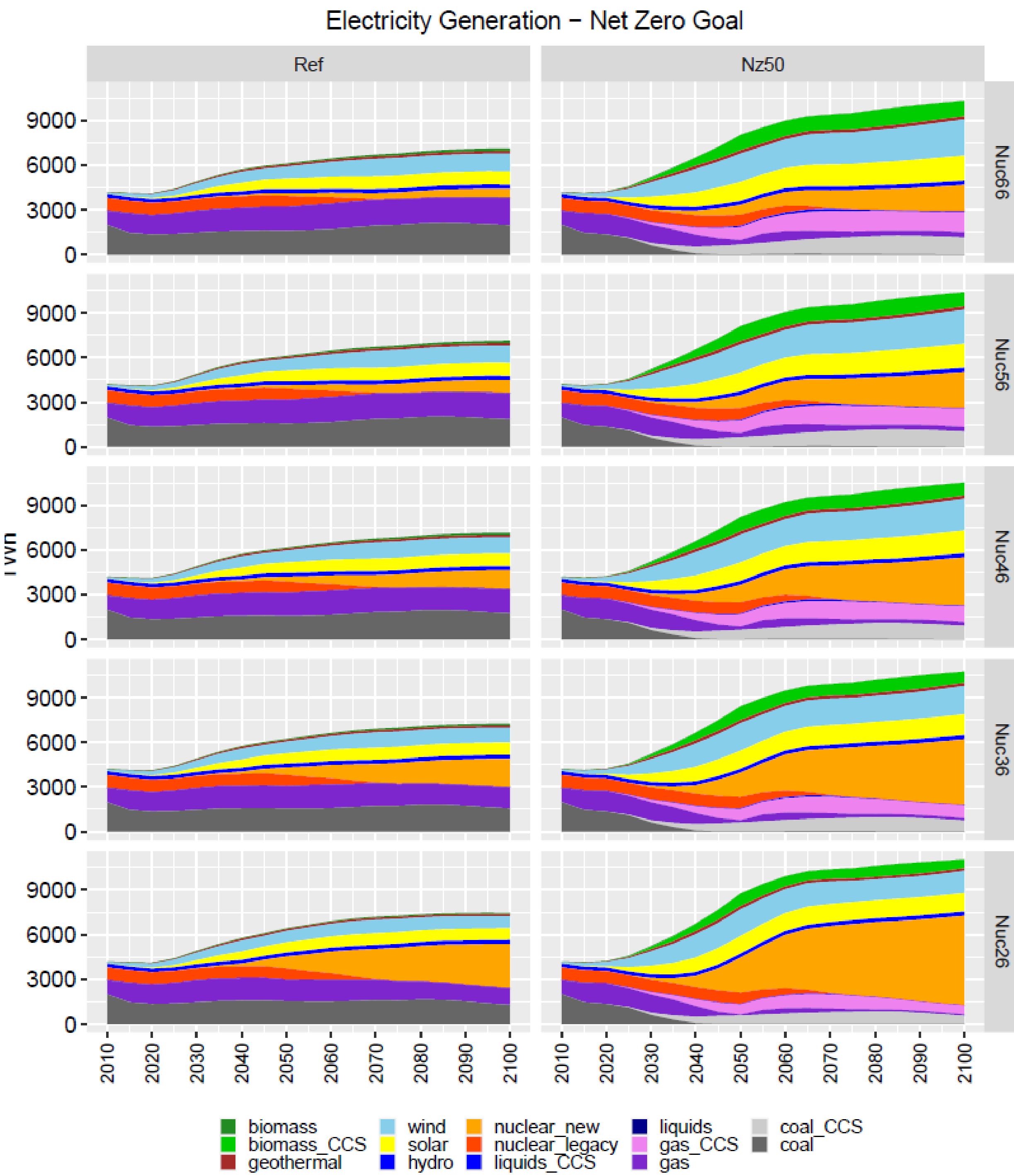

Figure 3-2. Evolution of total annual generation by technology type, 2010-2100. Source: (Kim 2022).

In the Reference case, new additions of non-emitting technologies slightly displace fossil-fuel generation from coal and natural gas, but mostly serve to supply the substantial growth in demand for electricity. Utilization of all fossil fuels remains relatively consistent across the entire time horizon in the reference case. However, lower capital costs for nuclear do translate to lower generation shares for coal as well as higher generation shares for advanced nuclear. This indicates that even without implementation of zero-carbon policies, C2N transition projects would fit into the overall shape of the U.S.'s changing energy picture.

In the net-zero 2050 case, carbon-emitting technologies are required to phase out by 2050. Natural gas (purple) is to be largely replaced with natural gas-plus-CCS in about equal quantities, but coal is only partially replaced by coal-plus-CCS. The concurrent growth of zero-carbon technologies, including advanced nuclear, indicates opportunities for C2N projects in this scenario.

3.1.4 Implications for C2N Projects

The results above indicate the possible medium- and long-term demand for C2N projects. Even in the reference case, nuclear capacity is used to partially substitute for fossil-fired generators; the possibility of directly converting CPPs into NPPs makes this process more efficient, in terms of both cost and land use. If additional energy legislation were to be enacted, such as a net-zero mandate, the additional demand for nuclear technology to provide baseload electricity and support other renewable sources would extend to nuclear projects executed via C2N as well.

Nuclear energy will be useful for both electricity generation and hydrogen generation, but its value proposition does not strictly depend on either a deep decarbonization mandate or the appearance of a lucrative market for hydrogen. Significant new nuclear capacity will be valuable in achieving net-zero policy targets, and C2N transition projects can reduce the capital costs required to implement this new nuclear capacity, so the option for C2N projects could help accelerate decarbonization goals.

3.2 Drivers of NPP Selection in C2N Transition

Utilities considering transitioning their CPPs to NPPs need to identify which NPP technologies would potentially be compatible with their CPP site, and what type of infrastructure could potentially be leveraged to reduce the C2N project's capital cost. The utility needs to identify the type of NPP in terms of power level; number of units, etc. (discussed in Section 3.3); and the type of C2N transition project that defines how the NPP would connect to legacy CPP infrastructure.

Several types of C2N projects were defined in Hansen et al. (2022) and could be applied, leading the utility to evaluate different types of NPP for compatibility with features of the specific CPP. The transition options described in Hansen et al. include:

- C2N#0: NPP built <u>near</u> the CPP site.
- C2N#1-2-3: NPP is built <u>on</u> the CPP site, to directly reuse at minimum the electrical and heat-sink components.
- C2N#2-3: NPP connects to CPP balance-of-plant. This can be done through:
  - C2N#2: direct connection (less likely scenario), where the NPP directly thermally couples with existing CPP equipment (provides heat to the CPP steam generator or steam to the CPP turbine plant equipment).
  - C2N#3: indirect connection, where the NPP uses thermal energy storage (TES) as a buffer between the NPP primary system and the CPP steam generator or turbine plant equipment.

Any type of C2N project will enable similar community economic (workforce transition) and environmental benefits. The main difference between C2N projects will be in terms of infrastructure reutilization potential (as shown in Table 3-1) and project timeline (as discussed in Section 3.3.1). This section proposes a list of questions that a utility should investigate to help select a C2N project type and compatible NPP concept.

3.2.1 What Is the Target Nameplate Capacity for the Replacement NPP?

The utility must identify the nameplate capacity of the replacement NPP unit, which could be larger or smaller than that of the original CPP. The nameplate capacity refers to the maximum amount of electric energy that a generator can produce under specific conditions, as determined by the manufacturer. Generator nameplate capacity is usually expressed in megawatts (MW), as indicated on a nameplate that is physically attached to the generator. The nameplate capacity should be decided based on the following parameters:

- **Maximum and average electrical load that the utility wants to sell on the grid**. A utility needs first to assess the capacity and flexibility of the NPP that would maximize its revenues. The different role and performance associated with NPP and CPP operations should be recognized. Even though the CPP and NPP's role on the grid is mostly for baseload operation, a CPP typically operates at lower capacity factor to better match changing demand on the grid, and such a role may be better filled among other options by a smaller (in terms of average power level) NPP associated with TES, enabling higher peak power level. Other non-electrical applications for NPP, such as hydrogen or other industrial applications, direct air capture (Stauff et al. 2023), etc., could also be considered to justify higher nameplate capacity. NPPs have historically been operated as baseload capacity (only operating at full power) in the United States, but all advanced reactor concepts claim load-following operation capability for daily power variations.
- **Maximum allowable electric load on the CPP electrical infrastructure** such as turbomachinery, electrical systems, and transmission lines (typically sized at the CPP plant nameplate capacity). This maximum allowable load sets a ceiling on the NPP's electrical power generation, unless the CPP equipment is upgraded. For C2N projects considering reuse of the CPP turbo-alternator, the power of the NPP unit should closely match the electrical power of the replaced CPP unit.
- **Maximum heat sink available and water withdrawal and discharge permits**. When considering the implications to water use, consider the differing thermal efficiencies. An NPP with the same nameplate capacity as the CPP may discharge waste heat to the heat sink (body of water or cooling tower). Therefore, it is important to verify the maximum heat-sink capacity, which means the cooling water on site at the CPP as well as the limits on water withdrawal and discharge imposed by existing permits.

Once the ideal target power level is selected, the utility may consider NPP concepts which can provide a similar capacity level. Each advanced reactor concept has its own nameplate capacity which is set by the licensed design. Depending on other requirements, the utility may consider building a single larger unit covering the full power level, or several smaller co-located units. Both approaches can provide different benefits, depending on priorities. For example, the single larger unit may reduce the lead time until the full capacity comes online, whereas with multiple smaller co-located units, installation starts may be staggered to spread out required capital expenditures (Stauff et al. 2021).

3.2.2 Is the CPP Site Compatible to Host an NPP?

For C2N#0, the NPP is located outside the CPP site, while in C2N#1-2-3, the NPP would be located at the CPP site. Answers to the following questions will help a utility determine whether a CPP site is compatible to host an NPP, as well as which types of C2N projects are best suited for the site.

- Is there sufficient land on the CPP site to host an NPP?
  - See land requirements for typical reactors from EPRI (2022). More detailed requirements may be obtained directly from the selected NPP vendors.
- Does the site meet NPP siting criteria for an SMR or for a large reactor?

  - See siting requirements for NPP from EPRI (2022). Alternatively, siting data from Hansen et al. (2022) is available by request.[1]
- What are the costs and timeline associated with CPP decontamination?
  - Those factors, together with their escalation risks, need to be accounted for in the overall C2N project cost and timeline. See discussion in Section 3.3

The responses to these questions will help the utility decide if the NPP can be built directly on CPP site (C2N#1-2-3), or if it should be built further away (C2N#0). Notably, the distinction between C2N#0 and #1 is not perfectly delineated. For example, if an NPP is built near the boundary of the CPP, it could potentially reuse more on-site CPP infrastructure (permits, grid connection, office buildings, etc.), while potentially removing some requirements for CPP decommissioning and demolition.

3.2.3 Is a Multi-year Gap in Electricity Production Financially Justifiable?

During some C2N transitions, there may be a "revenue gap" between the CPP shutdown and NPP startup during which the utility receives no operating income from either the CPP or the NPP. This duration is determined largely by how early the CPP needs to be retired to perform refurbishment and regulatory activities before construction of the NPP. For the C2N#0 project type, there is no revenue gap, as the schedule of the NPP construction project does not depend on the schedule of the CPP demolition project. For C2N#1-2-3, however, certain dependencies between the CPP demolition and/or refurbishment mandate that the CPP be shut down before certain phases of the NPP construction can proceed.

If a revenue gap is not feasible, a utility could consider building the NPP as a C2N#0 project, thereby allowing it to build the NPP near the CPP site independently from D&D operations. In that scenario, the CPP shutdown could be intentionally timed to coincide with the start of the NPP's operations.

For all other C2N project types that would involve reusing a CPP site, electrical, heat-sink, and/or steam-cycle infrastructure, the coal plant must be shut down prior to the start of the nuclear project. Some of the existing plant will need to be dismantled and the equipment being reused in situ will need to be tested, refurbished, and possibly licensed by the Nuclear Regulatory Commission (NRC) or other regulatory bodies. This is because safety-related construction on the nuclear plant can proceed only after any applicable licenses have been issued, which may require completion of D&D, remediation, and refurbishments of the CPP site and components in some types of C2N projects (C2N#1 and 2). Safety-related work comprises the most costly, complex, and expensive activities on the project schedule. Therefore, the licensing process is an important point for understanding the project timeline. Moreover, those tasks may increase the risk of schedule slippage due to unexpectedly protracted demolition or radiological remediation work associated with decommissioning the CPP.

Time gaps between CPP retirement and NPP operation may entail more than just a revenue gap, but also could result in the loss of access rights to water or transmission, as further discussed in EPRI (2022), or even reduce the potential for CPP employee retention, which is further discussed in Section 2.2. Those risks should be carefully assessed and may influence the C2N project-type selection.

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[1] At the Gateway for Accelerated Innovation in Nuclear (GAIN) website for coal transitions, there is a link to a form, which allows a request for access to the siting data performed in 2022. See the website here: https://gain.inl.gov/SitePages/Coal2Nuclear.aspx.

3.2.4 Which Existing CPP Infrastructure Can Be Reused in NPP?

For all C2N#1-2-3 projects, the following infrastructure may be reusable (Hansen et al. 2022; Griffith 2021; EPRI 2022): grid interconnections, cooling water supply, transportation access, office buildings, maintenance workshops, diesel generators, and non-nuclear licenses and permits.

Table 3-3 lists the major categories of CPP components that might be eligible for reuse. The following considerations will help a utility evaluate the tradeoff between refurbishment and replacement:

- Does the component play a role in safe operation of the NPP? If so, the component needs to be refurbished or upgraded prior to licensing of the NPP, to comply with nuclear licensing requirements. This is likely a significant endeavor, and there is no extant industry experience to serve as a guide for this process. Such re-use of CPP component licensing adds risks in timeline delays. If the component does not play a role in safe NPP operation, refurbishment may be more straightforward and similar to other applications.
- How compatible is this component with the selected NPP design? Will its reuse result in a significant reduction in plant thermal efficiency when compared to using the recommended NPP components? Typical CPPs use subcritical, supercritical, or ultra-supercritical technologies. The latter one enabling higher thermal efficiency requires steam temperature/pressure levels to be in balance-of-plant components typically exceeding those of NPP concepts.
- What is the remaining useful lifetime of the component? Will reusing this component entail significant increased outage risks or maintenance costs? How does the cost of refurbishment or upgrade compare with the cost of a new component?

Table 3-3. Potential infrastructure reuse for different C2N project types.

Infrastructure reutilization	C2N#0	C2N#1	C2N#2	C2N#3
Transportation infrastructure	Y/M (partially)	Y	Y	Y
Transmission lines, substation, generator step-up transformer, switchyard equipment		Y	Y	Y
Office buildings, utilities and easements, meteorological tower, emergency services	N	Y	Y	Y
CPP site	N	Y	Y	Y
Electrical components and grid interconnections	N	Y	Y	Y
Cooling water supply and heat-sink components	N	Y	Y	Y
Environmental permits such as water and transmission rights	Y/M	Y/M	Y/M	Y/M
Balance-of-plant systems such as turbine plant equipment and steam generators	N	N	M	M

Note: Y = Yes; M = Maybe; N = No

Responses to these questions should be discussed with selected NPP vendors to determine whether the utility may reuse and/or refurbish CPP components. Ultimately, reusing each type of CPP components will be decided based on a tradeoff between cost savings opportunity and added project risks. The following provides comments on some specific types of components:

- Steam turbine: A turbine requires precise pressure/temperature conditions and nameplate capacity, so it could be reused in an NPP only if similar steam conditions and power level to those in the CPP are maintained.
- Steam generator: for direct coupling (C2N#2), the steam generator would likely need to be replaced because it will be the reactor coolant pressure boundary which plays a critical safety role by containing the primary coolant. Thus, the steam generator would need to be qualified as a nuclear safety component, and CPP steam generator would need to go through such qualification process. For indirect coupling (C2N#3), the steam-cycle components may not need to be qualified as nuclear safety component, which may allow use of existing non-nuclear stamped steam-generator and steam-cycle components.
- Electrical connections: For NPP concepts that depend on active systems for reactor safety, class 1E electric components may be required, prompting upgrade of some components (Holcomb, Peretz, and Qualls 2011). However, none of the advanced reactors under consideration in Table 3-4 may require such 1E components as they all rely on passive safety.
- Heat-sink components: CPPs typically use mechanical draft cooling or direct cooling through dedicated channels. Those may not be usable in NPP moving forward due to changes in regulations and requirements of using the “best technology available to minimize adverse environment impact” (Griffith 2021), such as natural draft cooling towers that are more expensive but allow improved thermal efficiency and reduce the amount of heat dumped to the atmosphere.

Assessing potential for infrastructure reuse under considered C2N scenarios should be initiated early on for a utility to plan investment decisions accordingly (i.e., to keep investing in maintenance and improvements in some of the infrastructure identified for reuse even though the CPP faces shutdown).

3.2.5 Summary with Targeted C2N Project and NPP Concept

From the discussion above, the CPP owner considering a C2N project should make the following decisions:

- Select the nameplate capacity level target of the NPP resulting from the C2N project, which helps select NPP design candidates among the several types of reactors developed or under development (discussion on possible NPP candidates are listed in Section 3.3). This is based on energy production requirements and site compatibility criteria. Impact of gap in energy production between the CPP shutdown and NPP startup should then be assessed considering utility revenues, permits retention, and workforce transition. Decisions can then be made on siting an NPP on a CPP site (C2N#1-2-3) or next to it (C2N#0).
- In collaboration with the NPP vendor, the utility identifies which infrastructure could be potentially reused and decides on a C2N project type (between C2N#1-2-3), based on the tradeoff between cost saving opportunities and added project risks. From this, the C2N project timeline and costs and potential revenue gap can be estimated.

3.3 Nuclear Technology Options

This section provides additional information on nuclear technology options in terms of design characteristics that may influence C2N project types and expected costs of C2N projects. This aims at helping the CPP utility assess the compatibility of NPP concepts and potential cost of such projects.

3.3.1 Design Characteristics of NPP Concepts under Development in the United States

Advanced NPP concepts being developed by U.S. industry are expected to be compatible with some type of C2N project, but some may not be compatible with C2N #2 or #3 projects. In this guidebook, the types of NPPs considered are limited to concepts with a high technology readiness level, and which are planned or proposed for relatively near-term deployments in the United States. Those concepts are described in Table 3-4 together with the main properties that may influence some C2N project type decisions. However, this list is not intended to be extensive, and additional NPP designs should be considered as well. For example, microreactors are not considered in this report. CPP sites are typically considering > 50 MWe, except in Alaska where CPP power levels as low as 10 MWe are found (Hansen et al. 2022). The table informs on the technical aspects of technology designs that are in near term deployment. So, for example, if a utility has a 250 MWe CPP that will retire, it could be replaced with 3 modules of the NuScale design (77 MWe) or with 3 modules of the Xe-100 design (80 MWe).

As described in the previous section, the main NPP characteristics of interest are the maximum electrical power, waste heat removal, use with TES, and temperature in the steam cycle. The demonstration timeframe is important as well making an informed decision, especially for a utility that does not seek to be an early mover with regards to the deployment of specific NPP technologies. The compatibility with TES is the main differentiator between C2N#2 and 3 type of projects, as it enables decoupling of the reactor system to the steam-cycle component, facilitating reusing existing steam-cycle components. Additional NPP design considerations should be discussed with vendors, such as plant footprint, project cost and construction timeline, electrical connection requirements, compatibility with dry heat removal, maneuverability, etc.

The NPP capability to serve different industries (beyond electricity) should also be identified and discussed with the utility and surrounding community stakeholders. Such applications are typically more attractive in reactors that offer higher steam-cycle temperatures. NPP vendors have usually identified beyond the grid applications for their reactor design and established connections within the industries. Such applications may be a good match for a coal community looking at transitioning their CPP facility while diversifying their economy. Identifying such connections early on would enable building relevant training programs and attracting supply chain industries within the community.

Table 3-4. Description of various NPP concepts.

	TerraPower Natrium	NuScale VOYGR	X-Energy Xe-100	Westinghouse AP1000
Reactor type	Sodium-cooled Fast Reactor (SFR)	Integral Pressurized Water Reactor (PWR)	High-Temp. Gas-cooled Reactor (HTGR)	Pressurized Water Reactor (PWR)
Nameplate electrical power [MWe]	345 (max 500 with thermal energy storage)	308 or 924 (4 or 12 packs)	80	1117
Required waste heat removal for each NPP unit [MWt]	~520	~625 and ~1875 (4 or 12 packs)	~120	~2270
Thermal Energy Storage (TES) in baseline design	Yes	No	No	No
Temperature in steam cycle [°C]	~500	~305	~650	~270
C2N project compatibility*	#0,1,3	#0,1	0,1,2, 3?	#0,1
Demonstration timeframe	2030	2029	2029	Operating

*This is based on NPP technology. Compatibility with specific CPP site and plant technology is required to confirm project type availability.

3.3.2 Economics of Advanced Reactors

The costs of advanced nuclear reactors are uncertain, and the associated range of uncertainty is substantial. This section provides a short summary of long-term costs that are expected for nuclear reactors with a summary of potential C2N savings based on infrastructure reuse. Those costs are for construction in the United States and should be representative of both large reactors and SMRs. Cost estimates for nuclear energy are summarized in Table 3-5 coming from Hansen et al. (2022). Those costs estimates are not specific for reactor concepts described in

Table 3-4 but are representative costs of the various reactor technologies, as justified in (Dixon et al. 2017). These costs are provided for information and more detailed and updated cost information should be provided by and negotiated with NPP vendors.

The costs provided in Table 3-5 show the OCC and the operating costs for various reactor types under different C2N project assumptions. The operating costs are broken down with fuel costs: variable and fixed O&M costs (VOM and FOM). These assume cost impact of C2N projects, including decommissioning and demolition requirements for CPP (assumed for all C2N types) with some increase in O&M from added maintenance/refurbishment costs and reduced OCC based on infrastructure reuse, as justified in Hansen et al. (2022). These costs from Dixon et al. (2017) do not differentiate costs from single to multi-unit projects, while reduction in capital and operating costs (per unit of electricity produced) may be obtained in multi-unit plants construction project as those can share balance-of-plant components, office building, electrical connection, and some workforce (security, operators, maintenance, etc.).

The numbers provided in Table 3-5 are representative of Nth-of-a-kind (NOAK), assuming a successful construction project (without significant cost overruns) and some learning. Some C2N projects may be first movers (i.e., one of the first deployments of a given type of NPP) which carries increased risks of cost and timeline for reactor licensing, cost escalation due to lack of experience by the utility, reactor designer, and construction contractors. Significant cost overruns have been observed in recent U.S. projects (Kozeracki et al. 2023) and should be expected and planned for, especially if the utility decides to be an early mover. Therefore, even though C2N projects may enable savings through reusing infrastructure, these projects may increase risks of costs escalation, and their risks should be carefully weighed against their benefits.

To mitigate the risks and consequences of cost and schedule overrun, utilities should investigate a few approaches. First, different advanced reactor concepts include different levels of constructability risk. Constructability risk mitigation can involve designing to require lower quantities of commodity inputs (Eash-Gates (2020)); relying more on serial manufacturing of plant systems as modules and less on on-site labor or “stick-building” (Buongiorno et al. (2018)); a smaller nameplate capacity (Stewart and Shirvan (2023)); and other design choices that prioritize efficiency, simplicity, and repeatability of construction work. Change orders and human error also introduce significant cost risk into nuclear construction projects, as described by Stewart and Shirvan (2023). Construction contracts that attribute more risk ownership to the contractor, even if the owner pays a higher premium for the contract, cap the utility’s risk exposure. Finally, the Department of Energy’s Loan Programs Office may be able to provide loan guarantees to utilities building new nuclear plants, enabling qualifying utilities to access lower-cost financing for the project.

Table 3-5. Cost assumptions of NOAK for all C2N project alternatives in 2022 USD, from Hansen et al. (2022).

Project Type	Example Reactor Type	Assumption Set	VOM $/MWh	FOM $/kw-yr	Fuel Cost $/MWh	OCC $/kW
C2N#0	PWR	Baseline	$2.00	$80.00	$10.52	$4,799
C2N#1	PWR	Baseline	$2.00	$92.61	$10.52	$3,598
C2N#1	PWR	Conservative	$2.50	$110.05	$13.15	$4,066
C2N#0	HTGR	Baseline	$2.07	$96.64	$11.46	$6,028
C2N#2	HTGR	Baseline	$2.07	$118.78	$11.46	$3,951
C2N#2	HTGR	Conservative	$2.59	$140.33	$14.33	$4,732
C2N#0	SFR	Baseline	$2.00	$86.00	$15.38	$5,121
C2N#3	SFR	Baseline	$2.00	$104.33	$15.38	$3,398

C2N#3	SFR	Conservative	$2.50	$120.46	$19.23	$4,228

3.4 Coal Ash Remediation for Nuclear Power Development

When considering the replacement of coal power plants, no other presently available dispatchable clean energy source can seamlessly fill the role as effectively as nuclear energy, a point underscored by Griffith (2021). This section of the guidebook reviews coal ash remediation process and its implication for siting nuclear power development on retired coal plant sites. The section is aimed at providing understanding for two stakeholder groups: utilities who do not at present have coal assets as part of the energy generation portfolio and communities with a CPP.

3.4.1 Site Contamination by Coal Combustion Residuals

Coal ash or coal combustion residuals (CCR) are the byproducts resulting from the incineration of coal at power plants by both electric utilities and independent power producers. In 2012, more than 470 coal-fired electric utilities burned about 800 million tons of coal, yielding around 110 million tons of CCR across 47 states and Puerto Rico. These residuals come into being in either wet or dry forms, although their composition might change following their creation. Certain CCR are subjected to dehydration, while others are combined with water to aid in their transportation, a process referred to as sluicing. The disposition of CCR can involve sending them off site for either beneficial applications or disposal, as well as on-site placement in landfills or surface impoundments.

To put this in perspective, in 2012, approximately 40 percent of the generated CCR found beneficial utilization (such as, in wallboard, concrete, roofing materials, and bricks), leaving the remaining 60 percent to be placed in surface impoundments and landfills. Among this 60 percent, about 80 percent found their way into on-site disposal facilities. At present, more than 310 active on-site landfills are engaged in CCR disposal, averaging over 120 acres in size per disposal site and boasting an average depth exceeding 40 feet. Moreover, over 735 active on-site surface impoundments are involved in CCR disposal, with an average size of over 50 acres and an average depth of 20 feet (as defined by Environmental Protection Agency [EPA] 40 Code of Federal Regulations [CFR] Parts 257 and 261 (U.S. EPA n.d.-a, b). Figure 3-3 presents a visual representation of reported volume of coal ash at coal plant facilities.[m]

[m] Data the figures with maps were collected from owner/operator websites. A list of the websites can be found at https://www.epa.gov/coalash/list-publicly-accessible-internet-sites-hosting-compliance-data-and-information-required.

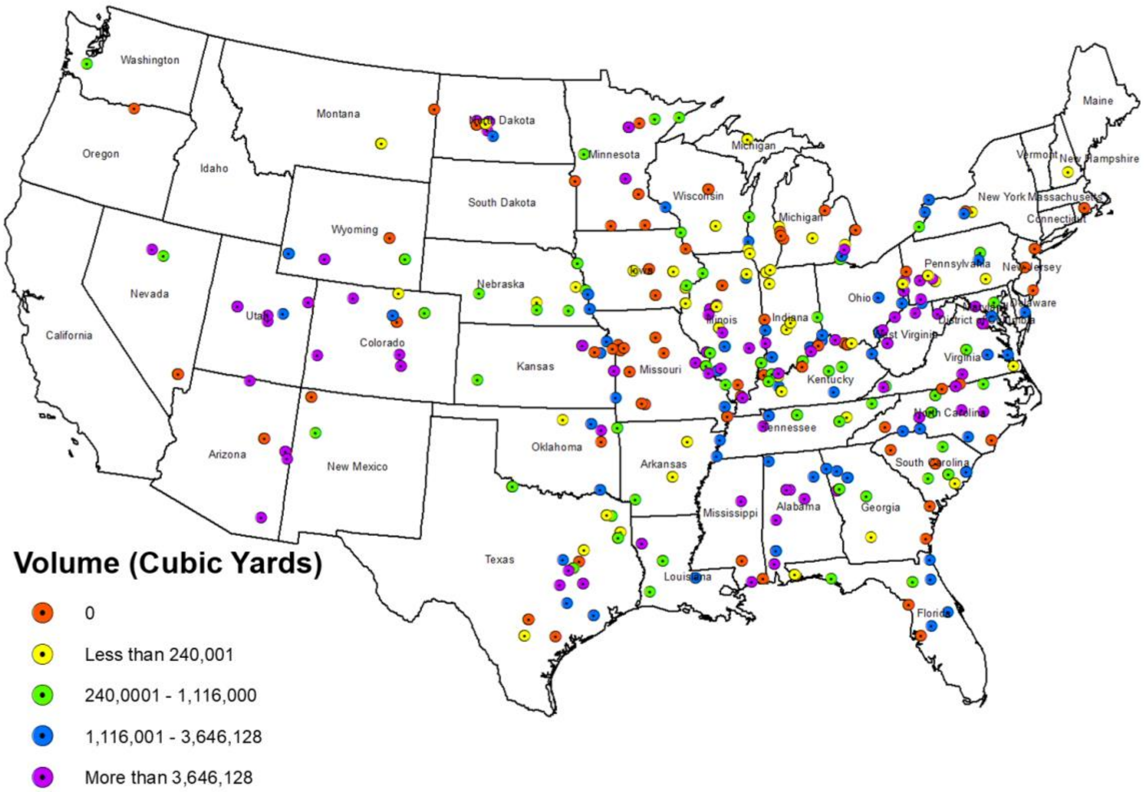

Figure 3-3. Quantity of CCR and, if applicable, water held in the unit as of 2020/2021. The data was accessed at EarthJustice (2022b).

Beginning in 2018, coal-fired electric utilities were compelled to publicly report groundwater monitoring data for the first time ever (EarthJustice 2022b). According to the published report, 94 percent of the coal ash ponds in the United States are unlined. Almost all of them contain groundwater with toxins above levels that the U.S. EPA deems safe for drinking water. Some 292 plants reported groundwater monitoring data. Based on that data, 91 percent of these plants are contaminating groundwater with toxic substances at levels exceeding federal safe standards.

Depending on whether pollutants are found in groundwater, the landfill or pond is in one of the following stages of monitoring as depicted in Figure 3-4 (EarthJustice 2022b).

- **Assessment Monitoring:** Industry is monitoring for toxic metals but has not yet been required to begin corrective action.
- **Corrective Action:** Industry has found toxic metals in groundwater above federal standards and has entered into the corrective action or cleanup process at this unit. This does not mean the plant has actually started cleanup of groundwater. A designation of “corrective action” means that cleanup is required, and the plant owner must develop a cleanup plan “as soon as feasible” and choose a remedy that restores groundwater to original conditions.
- **Detection Monitoring:** Industry is monitoring for coal ash contaminants but not the toxic metals.
- **No Recent Monitoring Report:** No recent monitoring has been conducted for this unit because the unit closed by removing all ash shortly after the CCR rule was written, or no utility posted data.

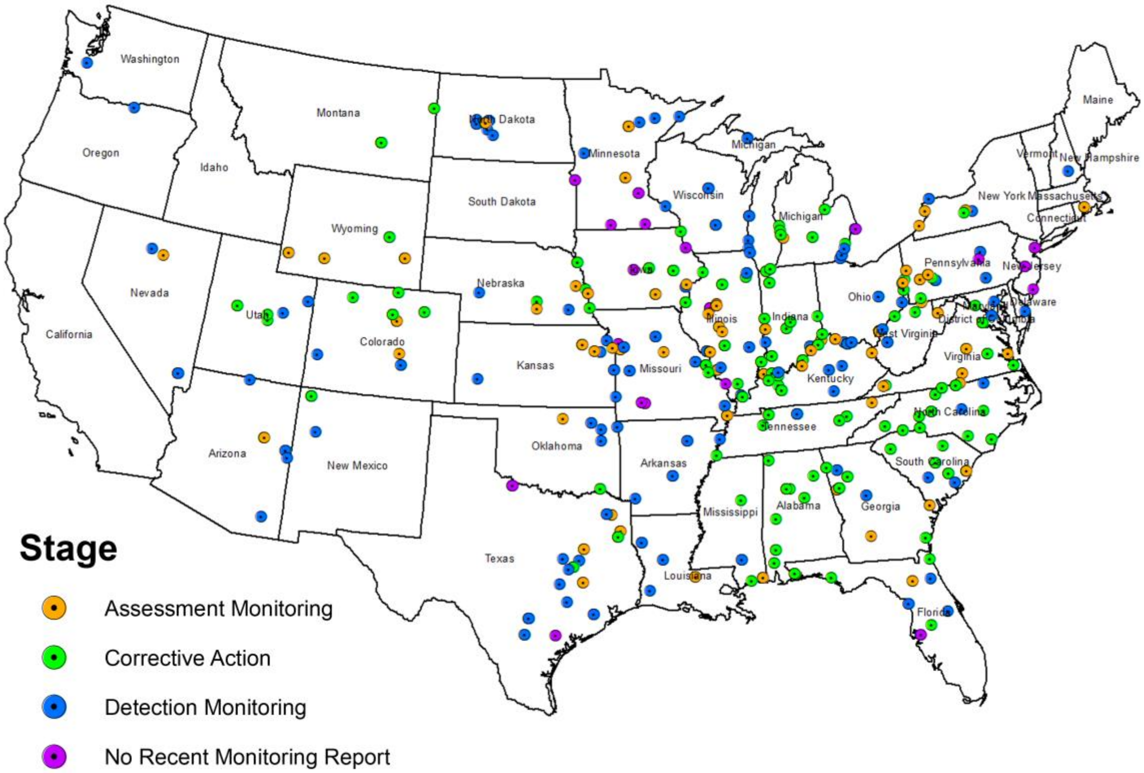

Figure 3-4. Distribution of the different stages of monitoring coal ash unit. Note: There are 170 sites with assessment monitoring; 300 sites with corrective action; 241 sites with detection monitoring; and 35 sites with no recent monitoring report.

Furthermore, Figure 3-5 summarizes the various method by which the operator intends to close the coal ash unit, according to disclosures made pursuant to the CCR rule or, if the unit is already closed, the method the operator used. Operators must include this information in a public closure plan even if the impoundment is not yet closed.

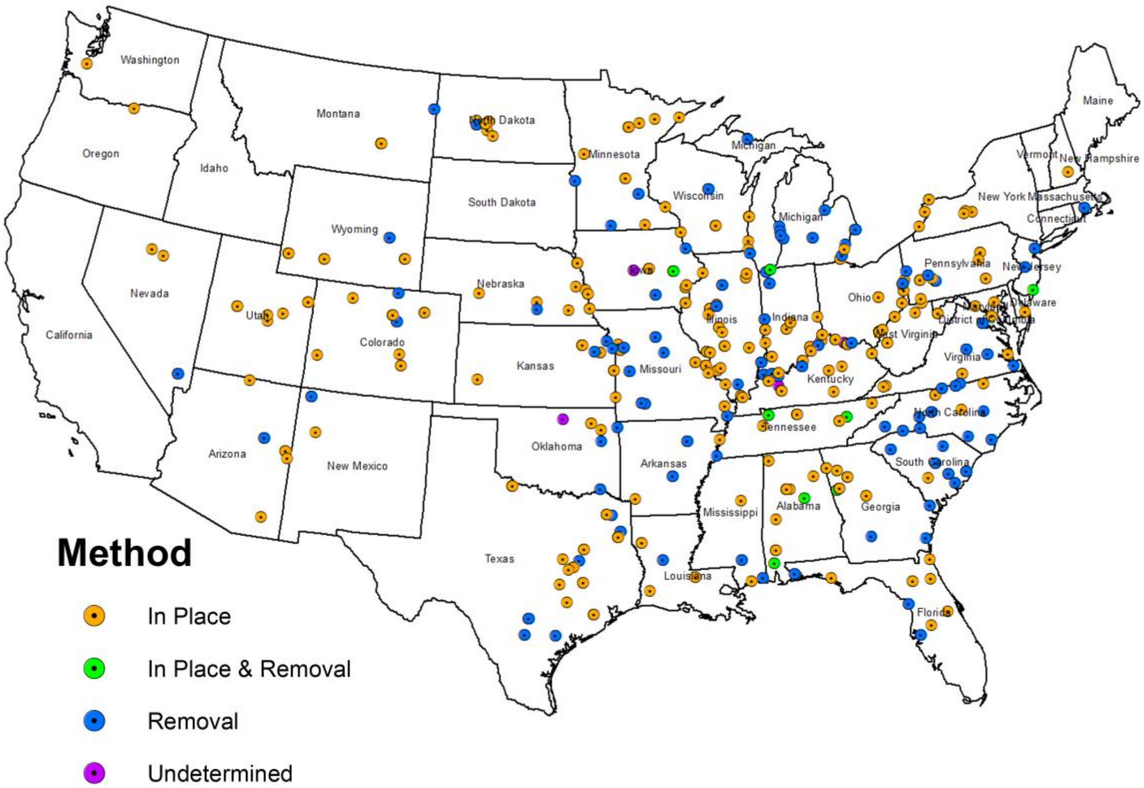

Figure 3-5. Distribution of closure methods of coal ash unit. Note: There are 446 sites with in-place closure; 23 sites with in-place and removal closure; 270 sites with removal method of closure; and seven sites with undetermined method of closure.

The description for the various closure methods in Figure 3-5 is summarized as follows (EarthJustice 2022b):

- **In Place:** Closing the coal ash site by leaving the coal ash where it is and "capping" it with a cover. If a unit is closed in place, the operator must continue groundwater monitoring and other post-closure care for the unit for at least 30 years.
- **Removal:** Excavating all the coal ash and transporting it to a different disposal unit (on site or off site) for permanent disposal.
- **In Place & Removal:** Closing the unit by partial excavation and leaving the remainder of coal ash in place. Post-closure care for 30 years, including groundwater monitoring, is required for any coal ash closed in place.
- **Undetermined:** The operator did not disclose its closure method for the coal ash disposal unit.

3.4.2 Siting Nuclear Energy Projects While Addressing Environmental Issues

Coal plant decommissioning involves abating, removing regulated materials, demolishing structures, remediating the site, and restoring it for beneficial use. According to Kopp (2020), decommissioning costs typically range from \$5 million to \$15 million (net of scrap) for a 500-MW coal-fired power plant. Factors affecting these costs include the quantity of asbestos and regulated materials, presence of buildings, labor markets, demolition methods, and proximity to scrap markets. The decommissioning schedule is typically 18 to 30 months. It should be noted that ash pond remediation can account for 70 to 75 percent of total costs, hazardous material remediation adds 5% to 7%, and structural demolition covers the remaining expenses. This section addresses environmental issues in retired coal plant sites in case the nuclear power project is responsible for the site remediation.

3.4.2.1 Indicators of Compromised Structural Integrity of CCR Surface Impoundments

It is plausible that sites previously engaged in coal power generation might experience deterioration in the structural integrity of their CCR surface impoundments. To ensure the safety and viability of such sites, owners and operators of CPPs are obligated to routinely carry out a series of structural integrity assessments, as outlined by the U.S. EPA (2015):

- Assessments involving the classification of potential hazards in the event of a failure of the CCR surface impoundment.
- Evaluations of structural stability that document alignment with recognized and universally accepted engineering best practices in terms of design, construction, operation, and maintenance.
- Appraisals of safety factors related to slope stability; wherein unmet factors lead to the closure of the unit.
- Updates to emergency action plans that outline the situations and conditions constituting emergencies regarding CCR unit safety, while also identifying the requisite actions to be taken during such emergencies.

In cases where these assessments remain unfinished or their stipulated criteria are not met before transitioning to an NPP setup, there may be a necessity for expenditures aimed at achieving compliance and ensuring the site's suitability for its new purpose.

3.4.2.2 Waste Management Procedures for CCR Disposal

The expenses linked with decommissioning a CPP site and transforming it into an NPP site are significantly influenced by the costs of coal ash removal and demolition, as outlined in Griffith (2021). The intricacies of this decommissioning endeavor are further compounded by the uncertainties revolving around potential groundwater contamination stemming from coal ash, accompanied by the associated requirements for mitigation, updates in regulations, and various other unknown factors. In 2015, the EPA introduced the Coal Combustion Residuals Rule, which came into effect in 2018, mandating coal-fired electric utilities to publicly report their groundwater monitoring data, as indicated by the U.S. EPA (2015).

Presently, a documented count of about 160 coal ash ponds with potential contamination concerns has been established (U.S. EPA 2023). Moreover, as of October 5, 2020, owners of no less than 124 U.S. plants have issued public notices acknowledging that leaking coal ash ponds and landfills on their premises have led to groundwater contamination surpassing health standards. In response to these reports, specific cleanup obligations have been delineated (EarthJustice 2022a):

1. Each plant proprietor is obliged to craft a cleanup plan, aimed at restoring contaminated areas to their original state. These cleanup plans need to be concluded within 180 days of identifying contamination and plans for over 100 plants are now publicly accessible.
2. The plant owner must engage with "interested and affected parties" sharing the outcomes of the corrective measures assessment at least 30 days before selecting a particular set of remedial actions.
3. Active participation from the public in the cleanup selection process is mandated to ensure a timely, thorough, and health-conscious remediation effort.

Among the recognized methods for properly managing CCR disposal is the conversion of CCR into a "beneficial use." Optimal practices for such conversion generally involve a technique known as "encapsulation." In fact, employing encapsulated coal ash delivers positive impacts not only on the environment but also on the economy. A prevalent form of encapsulation involves binding combustion residuals into products such as wallboard (amounting to 11.7 million tons in 2021) and concrete (totaling 12.6 million tons in 2021)—the two primary applications. Additionally, roofing materials and bricks are also utilized for this purpose. It is vital that the encapsulation process is carried out meticulously to prevent residuals from escaping into the surrounding environment, in accordance with EPA guidelines (U.S. EPA 2021a).

3.4.2.3 Regulations for the Disposal of CCR

The EPA governs the disposal of CCR. These regulations extend to both operational and non-operational facilities, regardless of the current energy source employed for electricity generation, provided that the CCR unit still contains CCR and associated liquids. To illustrate, measures must be taken to curb the seepage of contaminants into groundwater, the dispersion of pollutants into the air as dust, and the assurance of impoundment safety to prevent catastrophic containment failure. In situations where the ash remains on site, it must be encompassed within a fully intact pond lined with impermeable material. Otherwise, if removal is necessary (a notably more expensive undertaking), the ash must be completely extracted from the premises. This endeavor spans several years to accomplish (Morehouse 2020). Additionally, stipulations for recordkeeping, reporting and the availability of information on public websites have been established (U.S. EPA 2021b).

Remediation policies and their ramifications for regulatory compliance in the context of nuclear power plants

The EPA's 2015 rule concerning CCR disposal by electric utilities (U.S. EPA 2015) outlines seven fundamental national criteria for CCR landfills and CCR surface impoundments:

1. Location restrictions
2. Liner design criteria
3. Structural integrity requirements (outlined above)
4. Operating criteria (excluding scenarios where site inheritance goes beyond structural integrity prerequisites)
5. Groundwater monitoring
6. Closure and post-closure requisites
7. Recordkeeping, notification, and internet posting obligations.

The 2015 rule delineates five location restrictions that are applicable to new CCR landfills, both new and existing CCR surface impoundments, and lateral expansions of CCR units. However, existing CCR landfills are only subjected to the location restriction concerning unstable areas. NPPs taking over sites with CCR landfills should ensure a clear understanding of the site's location and the definition of unstable areas in the context of CCR landfills and confirm that these aspects follow the EPA's 2015 rule. These restrictions encompass prohibitions against CCR placement in:

1. Areas above the uppermost aquifer in the region
2. Wetlands
3. Fault areas
4. Seismic impact zones
5. Unstable areas.

For inherited CCR impoundments from decommissioned CPPs, the principal liner design consideration revolves around potential retrofitting. If the current impoundment detects significant concentrations of one or more specified toxic constituents exceeding groundwater protection standards and lacks a composite liner or at least 2 feet of compacted soil meeting EPA's hydraulic conductivity specifications, the unit must either undergo retrofitting or be closed.

Ongoing groundwater monitoring is mandated for existing CCR impoundments, even at decommissioned sites. In cases where a monitoring well system is not already in place, its installation must be accompanied by well-defined sampling procedures, comprehensive groundwater data analysis, detection of hazardous constituents (e.g., toxic metals), and an evaluation of water quality parameters (e.g., pH and total dissolved solids). The groundwater monitoring program must adhere to a consistent schedule encompassing detection monitoring, assessment monitoring, and corrective action.

The closure of a CCR unit can be accomplished by leaving the CCR in its existing location and implementing a final cover system or through the complete removal and decontamination of the CCR. While the outgoing CPP operation typically handles closure procedures, it might fall upon the incoming NPP to review, revise, or develop post-closure care plans detailing essential activities to ensure the safety of encapsulated residual CCR.

Finally, NPPs taking over sites with in-place CCR must sustain records of maintenance criteria, promptly notify relevant stakeholders of any issues, and post notifications regarding problems, planned solutions, and timelines for solutions on specified online platforms.[n]

Long-term implications of CCR management policies for nuclear power plant operations

In addition to the remediation policies, several essential long-term management requirements apply to existing on-site CCR impoundments, as laid out by the EPA in 2015:

1. Periodic assessments of hazard potential classification to determine potential adverse consequences in the event of a CCR surface impoundment failure.
2. Periodic structural stability assessments conducted by a qualified professional engineer to verify adherence to recognized and widely accepted engineering best practices in terms of design, construction, operation, and maintenance.
3. The development and maintenance of an emergency action plan.

3.5 Site Access and Preparation

As discussed in this section, site access and preparation for a nuclear plant built at a current or former coal plant site are dominated by the regulatory framework for such an endeavor. Any utility or independent power producer (IPP) seeking to repurpose a CPP site to an NPP will need to obtain several licenses and permits. Many of these agencies and the required permits will be familiar to the utility or the IPP, such as the Federal Energy Regulatory Commission (FERC) or the EPA. However, the NRC licensing process will be an unfamiliar activity to most entities that do not already own or share in the ownership of an NPP.

Some of the licenses and permits which may be needed for site access and preparation are outlined here, although this list should not be considered comprehensive because the requirements can vary by state and location. In addition to the points for consideration enumerated in this section, there may be other points that project stakeholders could consider, not discussed here. These might include factors that bear or civil infrastructure like road and waterways, or factors that have environmental implications. Factors such as these are not addressed here because these would be addressed in a formal

[n] Further information about these requirements can be accessed from the tables available on page 21306 at: https://www.federalregister.gov/documents/2015/04/17/2015-00257/hazardous-and-solid-waste-management-system-disposal-of-coal-combustion-residuals-from-electric.

environmental impact study of a proposed project. None of the information in this guidebook, including the discussions in this section and the Appendix, should be construed as authoritative advice, whether legal or otherwise, from DOE or its national laboratories.

3.5.1 Nuclear Regulatory Commission

The NRC licenses an applicant to construct, operate, and decommission a reactor through an extensive licensing process. The formal licensing process is initiated by a licensing application,[o] although the NRC staff encourages applicants to hold a series of pre-application meetings with the NRC staff so that NRC staff has a clear understanding of the applicant proposal, and the applicant has a clear understanding of the NRC staff review process. Once an application is submitted, the NRC staff reviews the submission, using standard review plans (U.S. NRC 1999, 1987), to ensure that the applicant's assumptions are technically correct, and the proposed activities will not adversely affect the environment. Depending on the quality of the application, the review process generally takes about 2 months.

3.5.1.1 Part 50 2-Step License

Applicants can opt to seek a power reactor operating license under a two-step process outlined in Title 10 of the CFR Part 50 (10 CFR 50), "Domestic Licensing of Production and Utilization Facilities." The licensing process also requires an environmental review under 10 CFR 51, "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions."

The first step is an application for a construction permit. An application for a construction permit must contain (U.S. NRC 2004):

1. Preliminary safety analyses;
2. An environmental review; and
3. Financial and antitrust statements.

NUREG-0800 (U.S. NRC 1987) provides guidance to the applicant for the organization and detailed content of the preliminary safety analysis report (PSAR). The content of the application is outlined in 10 CFR 50.33 and 10 CFR 50.34. The PSAR includes information about the plant site, the reactor systems, electrical power, power conversion, accident analyses, radioactive waste management, radiation protection, operational programs (conduct of operations), quality assurance, technical specifications, and human factors. The NRC staff will review the application in accordance with the guidance found in NUREG-0800. The NRC staff must issue a preliminary safety evaluation report (SER) finding that the PSAR is sufficient for construction to start by. The NRC goal is to issue a construction permit is 36 months following the acceptance of an application.

NUREG-1555 (U.S. NRC 1999) provides guidance to the applicant for the organization and detailed content of the environmental report (ER). The NRC staff will review the ER's site description and analysis of the environmental impacts of construction, operation, and postulated accidents. Impacts evaluated include (U.S. NRC 2004) impacts on air; water; animal life; vegetation; natural resources; and property of historic, archaeological, or architectural significance. Other items evaluated include economic, social, and cultural impacts. The NRC staff will prepare and issue a draft and final environmental impact statement (EIS). This process takes 24–36 months and runs concurrent with the safety review.

[o] An application can currently be submitted under Title 10 of the Code of Federal Regulations (CFR) Part 50 or Part 52 (10 CFR 50 or 10 CFR 52). A third application option is currently being developed for advanced reactors to be codified as 10 CFR 53.

The Part 50 process is shown in Figure 3-6. Both the EIS and the preliminary EIS must be completed prior to a public hearing and subsequent issuance of a construction permit allowing construction of the plant to be initiated.

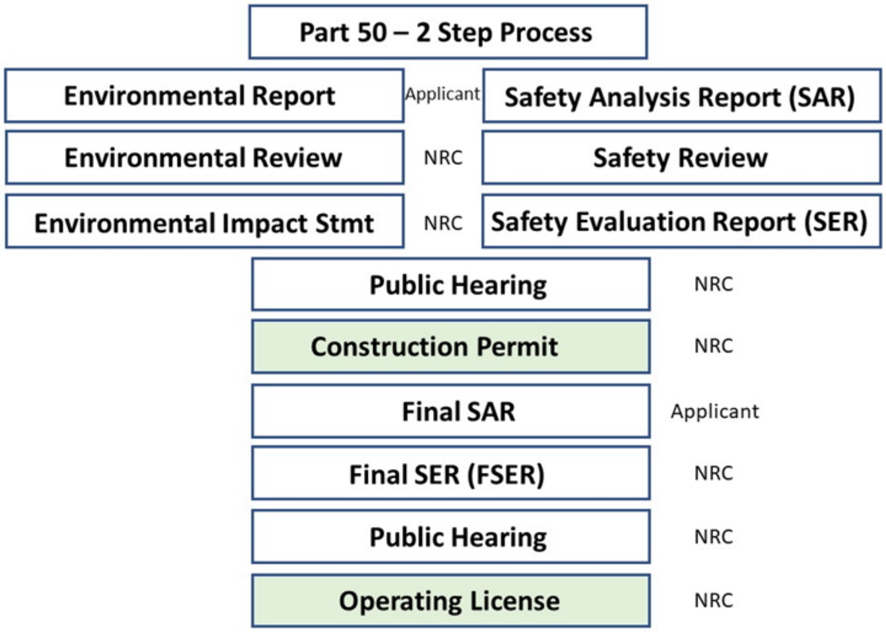

Figure 3-6. 10 CFR 50 licensing process.

During construction, under 10 CFR 50, the applicant finalizes the plant design information, and its plans for operation are developed. The applicant then submits a final safety analysis report (SAR) to the NRC for review and, after a second public hearing, if held, NRC may issue an operating license as shown in Figure 3-6. The NRC goal for the entire licensing process under Part 50 is 42 months.

3.5.1.2 Part 52 Combined License

An alternative to the Part 50 licensing process is for an applicant to apply for a combined license under 10 CFR 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants." An application for a combined license (U.S. NRC 2004) may incorporate by reference a standard design certification, an early site permit (ESP), both, or neither. This approach allows early resolution of safety and environmental issues. The content of the application is outlined in 10 CFR 52.77 and 10 CFR 52.79.

The regulations in 10 CFR Part 52 provide a pathway to obtain an ESP for approval of one or more sites separate from an application for a construction permit or combined license. ESPs are a means to bank a site, and they are good for 10 to 20 years and can be renewed for an additional 10 to 20 years. They address site safety issues, environmental protection issues, and plans for coping with emergencies, independent of the review of a specific nuclear plant design. Obtaining an ESP will speed up the process to obtain an EIS for a site when a decision is made to move forward with a combined license application. The NRC goal to issue an ESP is 24 months following acceptance of an application.

The Part 52 process is shown in Figure 3-7. Only one public hearing is required during this process. The Part 52 path is designed to speed up the process to obtain an NPP license under the assumption that a certified design is selected. The ESP and certified design steps are dashed in Figure 3-7 because they are optional. The NRC goal for the entire licensing process under Part 52 is 30 months when referencing a certified design and an ESP. Without a certified design, the licensing goal is 42 months.

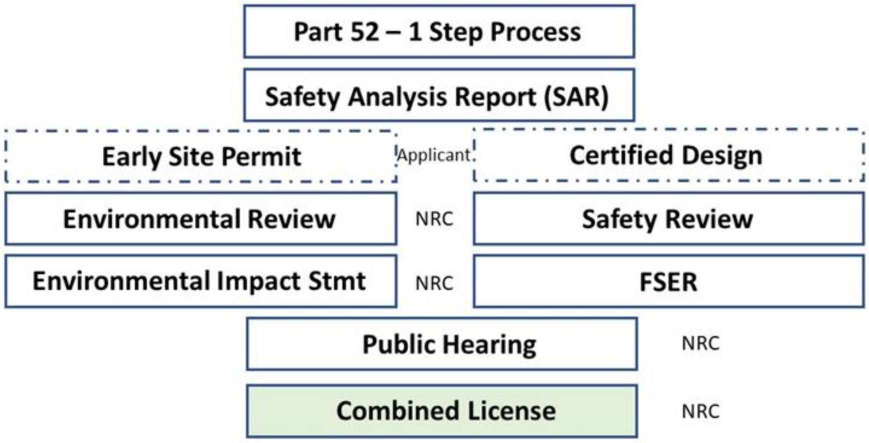

Figure 3-7. 10 CFR 52 licensing process.

3.5.1.3 Part 53 Advanced Reactor License Process

The NRC staff is currently preparing Part 53, "Risk-Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors." When approved, Part 53 will provide a third alternative for applications for advanced reactors.

3.5.1.4 National Environmental Policy Act (NEPA)

The NRC reviews all environmental impacts of its licensing activities in accordance with NEPA[p], which requires that all federal agencies consider the environmental impacts of their actions and decisions prior to making the decision. As noted in Figure 3-6 and Figure 3-7, the NRC staff will coordinate NEPA compliance with an applicant for an NPP. This includes interactions with appropriate state and local environmental agencies. The EPA reviews all EISs under Section 309 of the Clean Air Act to ensure the adequacy and the acceptability of the environmental impacts of the proposed action.

3.5.1.5 Licensing Time/Cost

The total licensing process for several recent applications for an AP-1000 reactor (an NRC certified large light-water reactor design) required 44 months following the acceptance of the application. This timeline would have followed several years of effort to prepare the licensing application. The NRC captured the Combined License Application (COLA) costs for seven separate licensee applications. Based on the NRC developed cost figures, the average cost to prepare a COLA for submittal to the NRC staff is $29.9M (South Carolina 2018) and requires approximately 2 years to prepare (U.S. DOE 2012).

After submittal of the application to the NRC staff, the NRC staff begins its formal review of the application and bills the applicant for the review time. Duke Energy (DEC) testified to the South Carolina Public Utility Commission regarding its William States Lee NPP application[q] that the NRC staff documented over 67,000 man-hours on its application. The FY-23 NRC staff charge rate is $300 per hour. DEC further testified that it is reasonable to expect that DEC expended a similar number of person-hours, if not more, developing the responses to the NRC requests for additional information and other requirements for design changes.

[p] 42 U.S.C. §4321 et seq. (1969) https://www.epa.gov/laws-regulations/summary-national-environmental-policy-act

[q] The Public Service Commission of South Carolina, *In the Matter of: Application of Duke Energy Carolinas, LLC For Adjustments in Electric Rate Schedules and Tariffs*, Docket No. 2018-319-E, November 8, 2018.

Smaller, advanced reactors with fewer systems may require less review time. In addition, the repeated deployment of identical reactor technology should bring down the review time and cost for subsequent reactor applications. Groups of utilities deploying the same reactor technology could also form an owners' group to share application resources to help drive down application costs.

3.5.2 Department of Energy

In order to receive an operating license from the NRC, an applicant must enter into a contract with DOE for the disposal of spent nuclear fuel and/or high-level radioactive waste, in accordance with the Nuclear Waste Policy Act (NWPA) of 1982, as amended.[r] Under the NWPA, DOE is responsible for the disposal of spent nuclear fuel and high-level radioactive waste of domestic origin from civilian nuclear power reactors to protect the public health and safety and the environment. However, costs associated with such disposal are to be borne by the generators or owners of such fuel or waste. In addition, DOE is required under the NWPA to collect a full cost recovery fee (for deposit into the Nuclear Waste Fund) from owners and generators for the disposal of spent nuclear fuel and/or high-level radioactive waste. In compliance with a November 2013 court ruling, the fee was adjusted to zero and payment of ongoing fees by utilities was suspended in May 2014.

Power reactor standard contracts are initiated and managed by the DOE Office of Standard Contract Management in the Office of the General Counsel. This office integrates the core requirements established by the NWPA that pertain to the Nuclear Waste Fund and the management of the Standard Contract (10 CFR 961) between a nuclear utility and the government.

DOE also manages the international transmission of electricity. Authorization must be obtained from the DOE to transmit electric energy across the international borders with Canada and Mexico.

3.5.3 Federal Energy Regulatory Commission

The FERC is an independent regulatory agency officially organized as part of DOE, that oversees that regulates the interstate transmission of natural gas, oil, and electricity. FERC is self-funding, in that Congress sets its budget through annual and supplemental appropriations, and FERC is authorized to raise revenue to reimburse the United States Treasury for its appropriations, through annual charges to the natural gas, oil, and electric industries it regulates. Additionally, FERC reviews proposals to build liquefied natural gas (LNG) terminals and interstate gas pipelines as well as licensing hydropower projects.[s]

While the FERC does not approve physical construction of electric generation facilities, it does regulate the rates, terms, and conditions of wholesale sales of electricity in interstate commerce (utility to utility) and the direct transmission of power in interstate commerce by public utilities. Under FERC Order 888,[t] all public utilities that own, control, or operate facilities used for transmitting electric energy in interstate commerce must have a FERC-approved open access transmission tariff (OATT) on file. An OATT sets out the terms and conditions under which a transmission utility must offer open, non-discriminatory transmission service to customers. This power permitting process can take 2–4 years to complete due to the backlog of applications. A recent analysis by researchers at Lawrence Berkely National Laboratory found that over 2,000 GWe of requests are in backlog for connection to the grid.[u] In

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[r] Public Law (P.L.) 97-425; 96 Stat. 2201, as amended by P.L. 100-203, Title V, Subtitle A (December 22, 1987), P.L. 100-507 (October 18, 1988), and P.L. 102-486 (The Energy Policy Act of 1992, October 24, 1992). The Act is generally codified at 42 U.S.C. 10101.

[s] https://www.ferc.gov/what-ferc-does

[t] https://www.ferc.gov/industries-data/electric/industry-activities/open-access-transmission-tariff-oatt-reform/history-oatt-reform/order-no-888

[u] https://emp.lbl.gov/sites/default/files/emp-files/queued_up_2022_04-06-2023.pdf

regions of the country where independent system operators (ISOs) or regional transmission organizations (RTOs) manage and control the transmission system (FERC Order 2000), each ISO and RTO is regulated by the FERC and is bound by the provisions established in its FERC-approved OATT.[v] Independent System Operators (ISO) grew out of Orders Nos. 888/889 where the Commission suggested the concept of an Independent System Operator as one way for existing tight power pools to satisfy the requirement of providing non-discriminatory access to transmission. [w]

An existing operational power plant will have a FERC power permit (e.g., an OATT noted previously). However, if the existing power plant permit lapses, a new FERC application goes to the back of the que, requiring 2–4 years to get a new permit. Even if the FERC permit does not lapse, timing and plant coordination matter. The new plant generating infrastructure must use the same interconnection point as the previous facility, provide roughly the same MW capacity, and the same interconnection service. In addition, there must be ownership continuity for the existing and the new generators.[x]

4. SUMMARY

Coal-to-nuclear transitions create an opportunity for utilities and communities where a coal power plant is scheduled for retirement. Many factors present themselves as issues for consideration as stakeholders evaluate the feasibility of C2N transitions. This guidebook provides stakeholders with information on some of the factors that should be part of decision making around C2N transitions.

For community stakeholders trying to understand the implications of the local CPP retiring, Section 2 provides a framework for arriving at an estimate of local economic impacts. The data in that section enable an estimate of economic impacts for replacing the CPP with an NPP of similar size, smaller size, and larger size. For communities who do not have a CPP but are yet interested in economic impacts of siting an NPP in their community, the data in Section 2 can also be used to approximate such impacts. For stakeholders interested in how the workforce at a CPP might transition to an NPP, the section describes how jobs at a CPP match up with jobs at an NPP. It shows which jobs might transfer directly, and which jobs at the NPP will likely be filled by people moving to the area. In addition to economics, a C2N transition will have environmental considerations. Section 2 also provides information about environmental implications of used nuclear fuel present in the community. The section provides a description of how used nuclear fuel is handled once it leaves the NPP.

For stakeholders at electric utilities who do not currently have nuclear power as part of their energy portfolio, and who either own a CPP and are considering an NPP for its replacement, or who are interested in adding an NPP to the utility's energy portfolio in a different way, Section 3 provides information to shed light on these considerations. As the United States increasingly works to decarbonize its economy, especially by 2050, utilities have a central role in that pursuit. Section 3 shows how nuclear technology strengthens the ability for utilities to contribute to decarbonizing the economy. Section 3 also aims to add insight to which nuclear technologies might best match the characteristics of the retiring CPP. Additionally, the section elaborates on cost implications of adding nuclear technology to the mix.

Another aspect for utilities to consider in a C2N transition is that of preparing the coal site to host an NPP. Or, if C2N is not the consideration but adding nuclear to the energy mix is, what does site access and preparation entail? Section 3 provides many points to consider. For example, repurposing a coal power plant site to an NPP will require several licenses and permits. Many of these permits and licenses will be familiar to the utility; however, the NRC licensing process will be an unfamiliar activity to most

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[v] https://www.ferc.gov/sites/default/files/2020-06/RM99-2-00K_1.pdf

[w] https://www.ferc.gov/sites/default/files/2020-06/RM99-2-00K_1.pdf
https://www.ferc.gov/power-sales-and-markets/rtos-and-isos

[x] https://www.ferc.gov/industries-data/resources/ferc-processes

entities that do not already own or share in the ownership of an NPP. Section 3 describes the existing licensing approaches and mentions a new approach the NRC is considering, Part 53, for licensing advanced reactors. The repurposing may impose additional cost if the NPP project is responsible for the site remediation. The additional costs can be avoided if the NPP projects are located at sites with no on-site coal ash storage.

Containing all the factors relevant to a C2N transition, or adding NPP to the energy portfolio mix, is not realistic for a single guidebook. Fortunately, and in addition to this guidebook, there are several other efforts underway to get information to stakeholders. Section 1 describes some of these. A main contribution of this guidebook is to inform on potential economic impacts to communities and economic considerations for utility decisionmakers. Additional contributions include issues to consider such as environmental impacts (e.g., spent nuclear fuel and legacy coal ash), and siting and permitting considerations (e.g., types of applicable NRC licenses and level of effort required).

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Appendix A

Supplementary Information on Economics and Siting

A-1. Community Tier Analysis

EIA data indicate there are more than 500 coal-powered generating units in the United States. These generating units are located at power plants across more than 200 counties. Each CPP community has unique characteristics that would influence the result of a location-specific economic impact model. After careful analysis an approach was developed to sort CPP communities into five population tiers. These tiers are evenly distributed with around 30 counties that contain CPPs. Analysis of these counties showed that it was very common for counties with populations above 100,000 to be included in MSAs.

County-based community analysis is complicated by challenges with rural CPP counties that are located close to metropolitan areas. In these cases, it might be necessary to combine the population of the rural county with the adjacent metropolitan area to evaluate economic impacts for the combined region. This is an optional step dependent on the goals of the community when trying to understand local impacts. In summary, the definition of the "community" population is subject for discussion based on guidebook user needs. In a similar fashion, multiple non-metropolitan county populations could be combined to form a larger economic region if desired.

Analysis of the community tiers revealed the average nameplate capacity for generating units ranged between 390 and 489 MWe. These generation capacities fit well withing the range of small modular reactor design configurations. (It is possible that a utility company may choose to replace existing CPPs with gigawatt scale nuclear reactors. There are many other economic impact reports on existing fleet gigawatt scale reactors. This report will provide economic impact estimates for smaller reactor configurations based on the nameplate capacities that are more prevalent among CPPs.)

Each community tier had an average number of generating units between 2.1 and 2.9. There was no significant correlation (R=-0.09) between the county population and the total sum of generating capacity. A few locations in the community tier analysis were major electricity producers, in some cases as much as 4,500 MWe. Figure A-1 provides a graphical representation showing a count of counties by total CPP generating capacity.

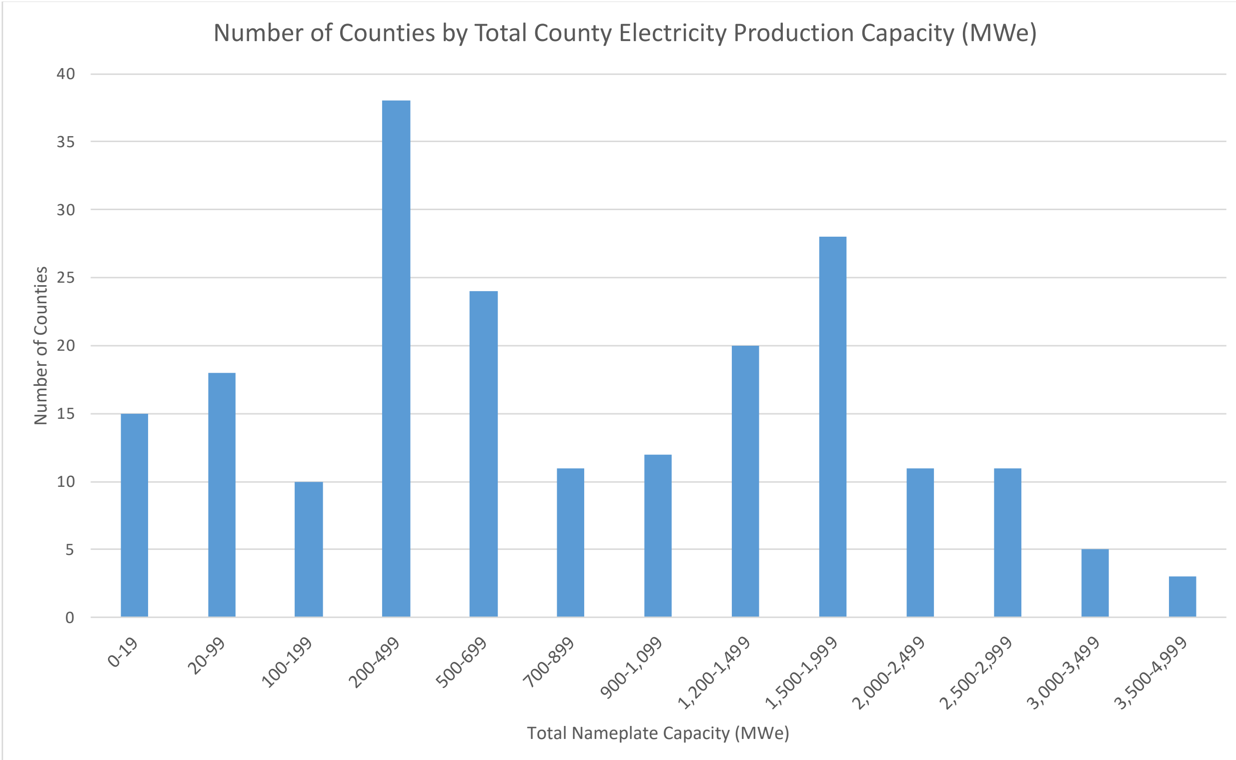

Figure A-1. Count of counties by total CPP electricity production capacity.

A-2. Overview of Input-Output Modeling and IMPLAN

Input-output modeling is an analytical framework used to study the interdependencies and interactions within an economy. It provides a way to analyze the flow of goods, services, and resources between different sectors of an economy and how changes in one sector can impact others. This modeling technique was first developed by Nobel Prize laureate Wassily Leontief in the 1930s and has since become an essential tool in economics, regional planning, and policy analysis.

The underlaying data behind input-output modeling represents the economy as a matrix of input-output coefficients. Each cell in the matrix represents the quantity of inputs required by each sector to produce a unit of output. By analyzing these coefficients, researchers can examine the linkages between sectors and predict the effects of external shocks. The input-output model can be used to estimate the plant-level, supply chain, and employee community spending effects of changes in final demand or production on the overall economy. By introducing a change in the final demand for a particular sector, such as an increase in industry spending, researchers can assess how this change ripples through the economy, affecting the dollar value of industry output, employment, and labor income. These changes in final demand are the pebble in the pond that send ripples throughout the rest of the economy.

Results of input-output modeling are specific to a defined region, based on economic data for that region. If new economic activity is introduced in the model for a specific industry, and an adequate local supply chain is not available, the model will automatically allow industry spending amounts to “leak.” For example, if a power plant fuel supplier is not available within the region, any spending for fuel would not be included in the overall economic impact. This economic leakage reduces the multiplying effects of new economic activity and would result in lower job creation and less industry production. As a result, more developed economies with greater industry diversity tend to have higher economic impacts. Thus, input-output modeling is a powerful framework for understanding the structure and dynamics of an economy.

As mentioned previously, economic impact models are usually based on defined geographic areas. The model used in this report was applied to 30 counties across the United States. The model will automatically leverage industries at each location as potential suppliers for typical power plant operations.

Multiple software and web application developers have created commercially available economic impact models. This study uses the IMPLAN economic impact modeling application. IMPLAN utilizes data from government sources like the Bureau of Economic Analysis, BLS, and U.S. Department of Agriculture combined with their own proprietary models to create industry spending patterns for over 500 industries.

A-3. Model Results Definitions

The following definitions are used when discussing the results of input-out models as they relate to C2N transitions.

A-3.1 Impact Types

DIRECT:	Values related to power plant operations.
INDIRECT:	Supply chain activity that supports power plant operations.
INDUCED:	Derived from household spending as workers receive paychecks.
TOTAL:	Combined total of direct, indirect, and induced impacts.

A-3.2 Impact Categories

EMPLOYMENT:	The number of jobs created or sustained.
LABOR INCOME:	The amount of employee compensation which includes wages, benefits, and payroll taxes.
VALUE ADDED:	This value is equal to contributions to gross domestic product from the region.
OUTPUT:	The dollar value of industry production or revenue from sales.

A-4. Disaggregated Economic Impacts

Table A-1. Detailed employment impact distribution by population tier.

Detailed Employment Impact Distribution by Population Tier (Count of Jobs)						
100 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	35	35	35	35	35
	Indirect	12	17	20	21	25
	Induced	9	12	13	13	21
	Total	56	64	68	69	81
	Nuclear					
	Direct	75	75	75	75	75
	Indirect	25	36	38	43	54
	Induced	21	28	30	32	49
	Total	**121**	**139**	**143**	**150**	**178**

Table A-1. Continued.

	Tier Size	1	2	3	4	5
300 MWe	Coal					
	Direct	55	55	55	55	55
	Indirect	37	50	55	62	74
	Induced	16	22	24	26	42
	Total	**108**	**127**	**134**	**143**	**171**
	Nuclear					
	Direct	100	100	100	100	100
	Indirect	75	108	115	129	161
	Induced	33	46	51	54	91
	Total	**208**	**254**	**266**	**283**	**352**
500 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	80	80	80	80	80
	Indirect	62	84	101	103	123
	Induced	24	34	39	40	66
	Total	**166**	**198**	**220**	**223**	**269**
	Nuclear					
	Direct	140	140	140	140	140
	Indirect	125	179	191	215	269
	Induced	48	68	76	81	139
	Total	**313**	**387**	**407**	**436**	**548**
700 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	115	115	115	115	115
	Indirect	86	117	141	144	173
	Induced	34	48	55	57	94
	Total	**235**	**280**	**311**	**316**	**382**
	Nuclear					
	Direct	200	200	200	200	200
	Indirect	174	251	268	301	376
	Induced	68	96	108	115	197
	Total	**442**	**547**	**576**	**616**	**773**

Table A-1. Continued.

	Tier Size	1	2	3	4	5
900 MWe	Coal					
	Direct	155	155	155	155	155
	Indirect	111	151	182	185	222
	Induced	46	64	73	75	124
	Total	**312**	**370**	**410**	**415**	**501**
	Nuclear					
	Direct	260	260	260	260	260
	Indirect	224	323	344	386	484
	Induced	88	124	140	149	254
	Total	**572**	**707**	**744**	**795**	**998**

Table A-2. Detailed output impact distribution by population tier ($millions).

Detailed Output Impact Distribution by Population Tier ($Millions)						
	Tier Size	1	2	3	4	5
100 MWe	Coal					
	Direct	$23.5	$23.5	$23.5	$23.5	$23.5
	Indirect	$4.5	$5.5	$7.7	$7.2	$9.2
	Induced	$1.3	$1.7	$1.9	$2.0	$3.6
	Total	**$29.3**	**$30.7**	**$33.2**	**$32.7**	**$36.3**
	Nuclear					
	Direct	$45.6	$45.6	$45.6	$45.6	$45.6
	Indirect	$8.6	$11.3	$14.3	$14.2	$20.0
	Induced	$3.2	$4.1	$4.5	$4.9	$8.5
	Total	**$57.4**	**$61.0**	**$64.4**	**$64.7**	**$74.1**
	Tier Size	1	2	3	4	5
300 MWe	Coal					
	Direct	$70.6	$70.6	$70.6	$70.6	$70.6
	Indirect	$13.4	$16.4	$20.9	$21.5	$27.7
	Induced	$2.4	$3.3	$3.6	$4.0	$7.4
	Total	**$86.3**	**$90.2**	**$95.1**	**$96.0**	**$105.6**
	Nuclear					
	Direct	$136.7	$136.7	$136.7	$136.7	$136.7
	Indirect	$25.9	$33.8	$42.8	$42.7	$60.0
	Induced	$5.0	$6.7	$7.6	$8.2	$15.8
	Total	**$167.5**	**$177.2**	**$187.1**	**$187.6**	**$212.5**

Table A-2. Continued.

	Tier Size	1	2	3	4	5
500 MWe	Coal					
	Direct	$117.6	$117.6	$117.6	$117.6	$117.6
	Indirect	$22.3	$27.3	$38.7	$35.8	$46.2
	Induced	$3.6	$5.0	$5.8	$6.1	$11.5
	Total	**$143.5**	**$149.9**	**$162.1**	**$159.5**	**$175.3**
	Nuclear					
	Direct	$227.8	$227.8	$227.8	$227.8	$227.8
	Indirect	$43.2	$56.4	$71.4	$71.1	$100.0
	Induced	$7.3	$10.0	$11.5	$12.4	$24.2
	Total	**$278.3**	**$294.2**	**$310.6**	**$311.3**	**$352.0**
700 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	$164.6	$164.6	$164.6	$164.6	$164.6
	Indirect	$31.2	$38.2	$54.1	$50.2	$64.7
	Induced	$5.2	$7.1	$8.3	$8.6	$16.3
	Total	**$201.0**	**$210.0**	**$227.1**	**$223.4**	**$245.6**
	Nuclear					
	Direct	$318.9	$318.9	$318.9	$318.9	$318.9
	Indirect	$60.4	$79.0	$99.9	$99.6	$140.0
	Induced	$10.3	$14.1	$16.2	$17.5	$34.2
	Total	**$389.7**	**$412.0**	**$435.1**	**$436.0**	**$493.1**
900 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	$211.7	$211.7	$211.7	$211.7	$211.7
	Indirect	$40.1	$49.1	$69.6	$64.5	$83.1
	Induced	$6.9	$9.4	$11.0	$11.4	$21.4
	Total	**$258.6**	**$270.3**	**$292.3**	**$287.6**	**$316.3**
	Nuclear					
	Direct	$410.1	$410.1	$410.1	$410.1	$410.1
	Indirect	$77.7	$101.5	$128.4	$128.0	$180.0
	Induced	$13.4	$18.3	$21.0	$22.6	$44.2
	Total	**$501.1**	**$529.9**	**$559.5**	**$560.7**	**$634.3**

Note: Individual values may not add to the total due to rounding.

Table A-3. Detailed value-added impact distribution by population tier ($millions).

Detailed Value-Added Impact Distribution by Population Tier ($Millions)						
100 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	$12.1	$12.4	$11.5	$11.0	$12.4
	Indirect	$2.2	$2.5	$3.4	$3.2	$4.8
	Induced	$0.7	$1.0	$1.1	$1.2	$2.1
	Total	**$15.0**	**$15.9**	**$16.0**	**$15.4**	**$19.2**
	Nuclear					
	Direct	$24.6	$24.6	$24.6	$24.1	$24.6
	Indirect	$4.2	$5.2	$6.2	$6.3	$10.3
	Induced	$1.7	$2.3	$2.6	$2.8	$5.0
	Total	**$30.4**	**$32.1**	**$33.3**	**$33.1**	**$39.8**
300 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	$29.6	$30.4	$24.7	$26.2	$30.2
	Indirect	$6.6	$7.6	$9.3	$9.7	$14.3
	Induced	$1.3	$1.8	$2.0	$2.2	$4.3
	Total	**$37.4**	**$39.8**	**$36.1**	**$38.1**	**$48.8**
	Nuclear					
	Direct	$53.5	$53.5	$53.5	$52.1	$53.5
	Indirect	$12.5	$15.7	$18.7	$18.8	$30.9
	Induced	$2.6	$3.7	$4.3	$4.6	$9.2
	Total	**$68.6**	**$72.9**	**$76.5**	**$75.6**	**$93.7**
500 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	$47.7	$49.1	$44.5	$42.0	$48.8
	Indirect	$10.9	$12.7	$17.1	$16.2	$23.8
	Induced	$1.9	$2.7	$3.3	$3.4	$6.7
	Total	**$60.5**	**$64.5**	**$65.0**	**$61.6**	**$79.3**
	Nuclear					
	Direct	$84.9	$84.9	$84.9	$82.6	$84.9
	Indirect	$20.8	$26.1	$31.2	$31.4	$51.6
	Induced	$3.9	$5.5	$6.5	$7.0	$14.1
	Total	**$109.6**	**$116.5**	**$122.5**	**$120.9**	**$150.6**

Table A-3. Continued.

	Tier Size	1	2	3	4	5
700 MWe	Coal					
	Direct	$67.1	$69.1	$62.7	$59.2	$68.7
	Indirect	$15.3	$17.8	$24.0	$22.7	$33.3
	Induced	$2.8	$3.9	$4.7	$4.9	$9.5
	Total	**$85.2**	**$90.8**	**$91.4**	**$86.8**	**$111.6**
	Nuclear					
	Direct	$119.5	$119.5	$119.5	$116.2	$119.5
	Indirect	$29.1	$36.6	$43.6	$44.0	$72.2
	Induced	$5.5	$7.8	$9.2	$9.9	$20.0
	Total	**$154.1**	**$163.8**	**$172.2**	**$170.1**	**$211.6**
900 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	$87.3	$89.8	$81.6	$77.1	$89.3
	Indirect	$19.7	$22.9	$30.9	$29.1	$42.8
	Induced	$3.7	$5.2	$6.2	$6.4	$12.5
	Total	**$110.6**	**$117.9**	**$118.7**	**$112.7**	**$144.7**
	Nuclear					
	Direct	$154.1	$154.1	$154.1	$149.9	$154.1
	Indirect	$37.5	$47.0	$56.1	$56.5	$92.8
	Induced	$7.2	$10.0	$11.8	$12.8	$25.8
	Total	**$198.7**	**$211.1**	**$222.0**	**$219.2**	**$272.7**

Note: Individual values may not add to the total due to rounding.

Table A-4. Detailed labor income impact distribution by population tier ($millions).

Detailed Labor Income Impact Distribution by Population Tier ($Millions)						
100 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	$4.8	$4.8	$4.8	$4.8	$4.8
	Indirect	$0.9	$1.2	$1.5	$1.5	$2.4
	Induced	$0.3	$0.5	$0.6	$0.6	$1.2
	Total	**$6.0**	**$6.5**	**$6.9**	**$6.8**	**$8.4**
	Nuclear					
	Direct	$12.1	$12.1	$12.1	$12.1	$12.1
	Indirect	$1.7	$2.3	$2.8	$3.0	$5.1
	Induced	$0.7	$1.1	$1.3	$1.4	$2.8
	Total	**$14.6**	**$15.5**	**$16.2**	**$16.4**	**$20.0**

Table A-4. Continued.

	Tier Size	1	2	3	4	5
300 MWe	Coal					
	Direct	$7.5	$7.5	$7.5	$7.5	$7.5
	Indirect	$2.8	$3.6	$4.2	$4.4	$7.2
	Induced	$0.6	$0.9	$1.0	$1.1	$2.4
	Total	**$10.9**	**$12.0**	**$12.7**	**$13.0**	**$17.1**
	Nuclear					
	Direct	$16.1	$16.1	$16.1	$16.1	$16.1
	Indirect	$5.1	$7.0	$8.5	$8.9	$15.3
	Induced	$1.2	$1.8	$2.2	$2.3	$5.1
	Total	**$22.4**	**$24.9**	**$26.8**	**$27.3**	**$36.5**
500 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	$10.9	$10.9	$10.9	$10.9	$10.9
	Indirect	$4.7	$6.0	$7.7	$7.4	$12.1
	Induced	$0.9	$1.3	$1.7	$1.7	$3.7
	Total	**$16.4**	**$18.3**	**$20.3**	**$20.0**	**$26.7**
	Nuclear					
	Direct	$22.6	$22.6	$22.6	$22.6	$22.6
	Indirect	$8.5	$11.7	$14.2	$14.9	$25.5
	Induced	$1.7	$2.6	$3.3	$3.4	$7.9
	Total	**$32.8**	**$36.9**	**$40.0**	**$40.9**	**$55.9**
700 MWe	Tier Size	1	2	3	4	5
	Coal					
	Direct	$15.7	$15.7	$15.7	$15.7	$15.7
	Indirect	$6.5	$8.4	$10.7	$10.3	$16.9
	Induced	$1.2	$1.9	$2.4	$2.4	$5.3
	Total	**$23.5**	**$26.1**	**$28.9**	**$28.4**	**$37.9**
	Nuclear					
	Direct	$32.3	$32.3	$32.3	$32.3	$32.3
	Indirect	$12.0	$16.4	$19.8	$20.8	$35.7
	Induced	$2.4	$3.7	$4.7	$4.9	$11.1
	Total	**$46.6**	**$52.4**	**$56.7**	**$58.0**	**$79.1**

Table A-4. Continued.

	Tier Size	1	2	3	4	5
900 MWe	Coal					
	Direct	$21.2	$21.2	$21.2	$21.2	$21.2
	Indirect	$8.4	$10.9	$13.8	$13.2	$21.7
	Induced	$1.6	$2.5	$3.2	$3.2	$7.0
	Total	**$31.2**	**$34.6**	**$38.2**	**$37.6**	**$49.9**
	Nuclear					
	Direct	$41.9	$41.9	$41.9	$41.9	$41.9
	Indirect	$15.4	$21.0	$25.5	$26.8	$45.9
	Induced	$3.1	$4.9	$6.0	$6.3	$14.4
	Total	**$60.5**	**$67.8**	**$73.5**	**$75.0**	**$102.2**

Note: Individual values may not add to the total due to rounding.

A-5. Economic Impact Studies on Large-scale Nuclear Power

The Table A-5 provides links to various economic impact reports for existing fleet U.S. based nuclear reactor facilities. These studies were performed by different authors who used different methodologies and modeling software. For these purposes it is difficult to make perfect comparisons between the results of each study. It is also important to consider currency inflation when comparing older and newer reports that range between 2001 and 2019. This list is only meant to facilitate access to other economic impact reports and not to endorse or attempt to identify all the reports that are publicly available.

A 2010 study, which can be found using the link in Table A-5, on the Palo Verde nuclear plant, provides an example of how economic impacts differ when looking at larger plants. At the time of the report, the Palo Verde plant had a capacity of 4,000 MWe and direct employment of 2,900 workers. The economic impact model suggested the employment impacts of that plant would result in a total employment impact of 8,700 jobs. The Palo Verde study was done using the IMPLAN economic impact modeling application which makes its results more comparable with the SMR impacts presented in this guidebook.

Table A-5. Examples of publicly available economic impact reports for nuclear power plants.

Study Year	Plant Name	Link
2001	Millstone Power Station	https://www.nrc.gov/docs/ML0419/ML041910428.pdf
2004	Palo Verde	http://large.stanford.edu/courses/2016/ph241/chandler2/docs/paloverde-nei.pdf
2008	North Anna Power Station	https://www.nrc.gov/docs/ML0829/ML082960083.pdf
2010	Palo Verde	http://large.stanford.edu/courses/2016/ph241/chandler2/docs/ae-2010.pdf
2013	Diablo Canyon	https://www.pge.com/includes/docs/pdfs/shared/edusafety/systemworks/dcpp/PGE_Economic_Impact_Report_Final.pdf
2014	Exelon's Nuclear Fleet	https://www.remi.com/topics-and-studies/the-impact-of-exelons-nuclear-fleet-on-the-illinois-economy/
2015	Texas Combined	https://www.nei.org/resources/reports-briefs/economic-benefits-texas-nuclear-power-plants
2015	Indian Point	http://large.stanford.edu/courses/2017/ph241/arguello1/docs/nei.pdf
2015	R.E. Ginna	http://large.stanford.edu/courses/2018/ph241/green1/docs/nei-feb15.pdf
2015	Nine Mile Point, Ginna, and Fitzpatrick	https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B7F5ED662-DA11-41BC-99EE-D6EC5ACC509E%7D
2015	St. Lucie and Turkey Point	https://www.fpl.com/clean-energy/pdf/economic-study.pdf
2017	Davis-Besse and Perry	https://d3n8a8pro7vhmx.cloudfront.net/nuclearmatters/pages/211/attachments/original/1494337829/Ohio-Nuclear-Report-Brattle-21April2017_%281%29.pdf?1494337829
2017	Hope Creek NJ	https://www.brattle.com/wp-content/uploads/2021/05/13065_11755_salem_and_hope_creek_nuclear_power_plants_contribution_to_the_new_jersey_economy1.pdf
2018	Columbia	https://www.energy-northwest.com/energyprojects/Columbia/Documents/NEI_EconomicImpacts-ColumbiaGeneratingStation-010918.pdf
2019	LaSalle, Byron, Dresden, Braidwood	https://www.remi.com/wp-content/uploads/2019/11/872-The-Impacts-of-Illinois-Nuclear-Power-Plants-on-the-Economy-and-the-Environment.pdf

Table A-6. Consolidated Economic Impacts

Power Plant Economic Impact Reference Table

(Results organized by local population size and power plant generating capacity in megawatts electric)

Population	Plant & Impact Type	Employment					Labor Income					Value-Added					Total Output				
		100	300	500	700	900	100	300	500	700	900	100	300	500	700	900	100	300	500	700	900
<20,000	**Coal Power Plant**																				
	Direct	35	55	80	115	155	$4.8	$7.5	$10.9	$15.7	$21.2	$12.1	$29.6	$47.7	$67.1	$87.3	$23.5	$70.6	$117.6	$164.6	$211.7
	Indirect	12	37	62	86	111	$.9	$2.8	$4.7	$6.5	$8.4	$2.2	$6.6	$10.9	$15.3	$19.7	$4.5	$13.4	$22.3	$31.2	$40.1
	Induced	9	16	24	34	46	$.3	$.6	$.9	$1.2	$1.6	$.7	$1.3	$1.9	$2.8	$3.7	$1.3	$2.4	$3.6	$5.2	$6.9
	Total	56	108	166	236	312	$6.0	$10.9	$16.4	$23.5	$31.2	$15.0	$37.4	$60.5	$85.2	$110.6	$29.3	$86.3	$143.5	$201.0	$258.6
	Nuclear Power Plant																				
	Direct	75	100	140	200	260	$12.1	$16.1	$22.6	$32.3	$41.9	$24.6	$53.5	$84.9	$119.5	$154.1	$45.6	$136.7	$227.8	$318.9	$410.1
	Indirect	25	75	125	174	224	$1.7	$5.1	$8.5	$12.0	$15.4	$4.2	$12.5	$20.8	$29.1	$37.5	$8.6	$25.9	$43.2	$60.4	$77.7
	Induced	21	33	48	68	88	$.7	$1.2	$1.7	$2.4	$3.1	$1.7	$2.6	$3.9	$5.5	$7.2	$3.2	$5.0	$7.3	$10.3	$13.4
	Total	121	207	313	443	573	$14.6	$22.4	$32.8	$46.6	$60.5	$30.4	$68.6	$109.6	$154.1	$198.7	$57.4	$167.5	$278.3	$389.7	$501.1
20,000-39,999	**Coal Power Plant**																				
	Direct	35	55	80	115	155	$4.8	$7.5	$10.9	$15.7	$21.2	$12.4	$30.4	$49.1	$69.1	$89.8	$23.5	$70.6	$117.6	$164.6	$211.7
	Indirect	17	50	84	117	151	$1.2	$3.6	$6.0	$8.4	$10.9	$2.5	$7.6	$12.7	$17.8	$22.9	$5.5	$16.4	$27.3	$38.2	$49.1
	Induced	12	22	34	48	64	$.5	$.9	$1.3	$1.9	$2.5	$1.0	$1.8	$2.7	$3.9	$5.2	$1.7	$3.3	$5.0	$7.1	$9.4
	Total	64	128	198	281	370	$6.5	$12.0	$18.3	$26.1	$34.6	$15.9	$39.8	$64.5	$90.8	$117.9	$30.7	$90.2	$149.9	$210.0	$270.3
	Nuclear Power Plant																				
	Direct	75	100	140	200	260	$12.1	$16.1	$22.6	$32.3	$41.9	$24.6	$53.5	$84.9	$119.5	$154.1	$45.6	$136.7	$227.8	$318.9	$410.1
	Indirect	36	108	179	251	323	$2.3	$7.0	$11.7	$16.4	$21.0	$5.2	$15.7	$26.1	$36.6	$47.0	$11.3	$33.8	$56.4	$79.0	$101.5
	Induced	28	46	68	96	124	$1.1	$1.8	$2.6	$3.7	$4.9	$2.3	$3.7	$5.5	$7.8	$10.0	$4.1	$6.7	$10.0	$14.1	$18.3
	Total	139	253	387	547	707	$15.5	$24.9	$36.9	$52.4	$67.8	$32.1	$72.9	$116.5	$163.8	$211.1	$61.0	$177.2	$294.2	$412.0	$529.9
40,000-89,999	**Coal Power Plant**																				
	Direct	35	55	80	115	155	$4.8	$7.5	$10.9	$15.7	$21.2	$11.5	$24.7	$44.5	$62.7	$81.6	$23.5	$70.6	$117.6	$164.6	$211.7
	Indirect	20	55	101	141	182	$1.5	$4.2	$7.7	$10.7	$13.8	$3.4	$9.3	$17.1	$24.0	$30.9	$7.7	$20.9	$38.7	$54.1	$69.6
	Induced	13	24	39	55	73	$.6	$1.0	$1.7	$2.4	$3.2	$1.1	$2.0	$3.3	$4.7	$6.2	$1.9	$3.6	$5.8	$8.3	$11.0
	Total	68	134	220	312	410	$6.9	$12.8	$20.3	$28.9	$38.2	$16.0	$36.1	$65.0	$91.4	$118.7	$33.2	$95.0	$162.1	$227.1	$292.3
	Nuclear Power Plant																				
	Direct	75	100	140	200	260	$12.1	$16.1	$22.6	$32.3	$41.9	$24.6	$53.5	$84.9	$119.5	$154.1	$45.6	$136.7	$227.8	$318.9	$410.1
	Indirect	38	115	191	268	344	$2.8	$8.5	$14.2	$19.8	$25.5	$6.2	$18.7	$31.2	$43.6	$56.1	$14.3	$42.8	$71.4	$99.9	$128.4
	Induced	30	51	76	108	140	$1.3	$2.2	$3.3	$4.7	$6.0	$2.6	$4.3	$6.5	$9.2	$11.8	$4.5	$7.6	$11.5	$16.2	$21.0
	Total	144	266	408	576	744	$16.2	$26.8	$40.0	$56.7	$73.5	$33.3	$76.5	$122.5	$172.2	$222.0	$64.4	$187.1	$310.6	$435.1	$559.5
90,000-199,999	**Coal Power Plant**																				
	Direct	35	55	80	115	155	$4.8	$7.5	$10.9	$15.7	$21.2	$11.0	$26.2	$42.0	$59.2	$77.1	$23.5	$70.6	$117.6	$164.6	$211.7
	Indirect	21	62	103	144	185	$1.5	$4.4	$7.4	$10.3	$13.2	$3.2	$9.7	$16.2	$22.7	$29.1	$7.2	$21.5	$35.8	$50.2	$64.5
	Induced	13	26	40	57	75	$.6	$1.1	$1.7	$2.4	$3.2	$1.2	$2.2	$3.4	$4.9	$6.4	$2.0	$4.0	$6.1	$8.6	$11.4
	Total	69	143	223	316	415	$6.8	$13.0	$20.0	$28.4	$37.6	$15.4	$38.1	$61.6	$86.8	$112.7	$32.7	$96.0	$159.5	$223.4	$287.6
	Nuclear Power Plant																				
	Direct	75	100	140	200	260	$12.1	$16.1	$22.6	$32.3	$41.9	$24.1	$52.1	$82.6	$116.2	$149.9	$45.6	$136.7	$227.8	$318.9	$410.1
	Indirect	43	129	215	301	386	$3.0	$8.9	$14.9	$20.8	$26.8	$6.3	$18.8	$31.4	$44.0	$56.5	$14.2	$42.7	$71.1	$99.6	$128.0
	Induced	32	54	81	115	149	$1.4	$2.3	$3.4	$4.9	$6.3	$2.8	$4.6	$7.0	$9.9	$12.8	$4.9	$8.2	$12.4	$17.5	$22.6
	Total	150	283	436	616	795	$16.4	$27.3	$40.9	$58.0	$75.0	$33.1	$75.6	$120.9	$170.1	$219.2	$64.7	$187.6	$311.3	$436.0	$560.7
200,000+	**Coal Power Plant**																				
	Direct	35	55	80	115	155	$4.8	$7.5	$10.9	$15.7	$21.2	$12.4	$30.2	$48.8	$68.7	$89.3	$23.5	$70.6	$117.6	$164.6	$211.7
	Indirect	25	74	123	173	222	$2.4	$7.2	$12.1	$16.9	$21.7	$4.8	$14.3	$23.8	$33.3	$42.8	$9.2	$27.7	$46.2	$64.7	$83.1
	Induced	21	42	66	94	124	$1.2	$2.4	$3.7	$5.3	$7.0	$2.1	$4.3	$6.7	$9.5	$12.5	$3.6	$7.4	$11.5	$16.3	$21.4
	Total	80	171	270	382	501	$8.4	$17.1	$26.7	$37.9	$49.9	$19.2	$48.8	$79.3	$111.6	$144.7	$36.3	$105.6	$175.3	$245.6	$316.3
	Nuclear Power Plant																				
	Direct	75	100	140	200	260	$12.1	$16.1	$22.6	$32.3	$41.9	$24.6	$53.5	$84.9	$119.5	$154.1	$45.6	$136.7	$227.8	$318.9	$410.1
	Indirect	54	161	269	376	484	$5.1	$15.3	$25.5	$35.7	$45.9	$10.3	$30.9	$51.6	$72.2	$92.8	$20.0	$60.0	$100.0	$140.0	$180.0
	Induced	49	91	139	197	254	$2.8	$5.1	$7.9	$11.1	$14.4	$5.0	$9.2	$14.1	$20.0	$25.8	$8.5	$15.8	$24.2	$34.2	$44.2
	Total	178	352	548	773	998	$20.0	$36.5	$55.9	$79.1	$102.2	$39.8	$93.7	$150.6	$211.6	$272.7	$74.1	$212.5	$352.0	$493.1	$634.3

Notes:

Dollar values in Millions.
Columns represent plant sizes in MWe.
Some totals may not add due to rounding.

Helpful Economic Impact Definitions:

Direct Impact - Economic activity specific to power plant operations
Indirect Impact - Economic activity created as suppliers provide goods and services to support power plant operations
Induced Impact - Economic activity resulting from power plant and supplier employees spend paychecks throughout the community
Total Impact - The combined total of direct, indirect, and induced impacts

Employment: The number of jobs created or sustained
Labor Income: The combined total of wages, salaries, benefits, and payroll taxes
Value-Added: Estimated contributions to gross domestic product for the region
Total Output: The dollar value of economic activity equivalent to total spending or revenue