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The University of Texas at Austin / IC² Institute

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Economic Impacts of Texas Small Modular Reactor Industry Development, 2024–2055

Final Analysis Report

SUBMITTED TO

PUBLIC UTILITY COMMISSION OF TEXAS
TEXAS ADVANCED NUCLEAR REACTOR WORKING GROUP
COMMISSIONER JIMMY GLOTFELTY

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Introduction

The Public Utility Commission's Texas Advanced Nuclear Reactor Working Group invited the Bureau of Business Research (BBR) of the IC[2] Institute at The University of Texas at Austin to conduct a study evaluating the economic impact of the creation of a Small Modular Reactor (SMR) industry in the State of Texas as well as an analysis of the economic impact of deploying SMRs in Texas.

Types of Analyses

This report contains 5 sections:

1. **ERCOT Grid Modeling** – To estimate the necessary cost reduction to make new nuclear generation capacity competitive under current market conditions and future trends.
2. **Estimated Economic Impact** – The total employment, gross domestic product, and disposable income that would be generated by building and deploying SMRs in Texas across 3 investment scenarios (Low, Medium, and High investment). Analysis uses the leading REMI tool for dynamic impact analysis and its E3 package for analyzing specific investments in the energy sector.
3. **Supply Chain Potential** – To characterize the relative potential of Texas businesses based on the number of businesses currently present in Texas industry sectors germane to SMR manufacture and deployment in the context of numbers nationally, comparing Texas to other states with arguably similar potential in the SMR industry. Analysis uses the North American Industry Classification System or NAICS.
4. **Business Surveys** – Findings from two BBR surveys: (1) a survey of Texas Economic Development Council professionals from across the state and (2) a separate survey of manufacturing businesses in Texas. The manufacturers' survey gauged business' interest in participating in the supply chain for SMRs being built in and deployed in and beyond Texas.
5. **Workforce** – A review and findings from an analysis of whether the Texas economy currently has, or can generate in the future, the workforce necessary to manufacture, construct, and operate SMRs in the state. This analysis also presents possible next steps in filling anticipated workforce gaps that might emerge.

Highlights and Key Findings

ERCOT Grid Modeling

SMR nuclear capacity is built when capital expenditures or CAPEX are at or below $3 million per megawatt (MW) and fixed operating expenses or OPEX (fixed) are below $105,000 per megawatt-year. Additionally, nuclear capacity is built under all OPEX scenarios ($150,000 to $75,000 per megawatt-year) when CAPEX is at $2 million per megawatt. Currently, there are federal tax credits that could lower the capital or operating cost of new nuclear power plants.

Modeling results indicate that Houston and Dallas are load centers, likely to receive the most SMR capacity because of their industrial needs and growing populations. (SMR deployment may avoid having to meet growing electrical demand by transporting wind and solar power across Texas at peak hours.)

Estimated Economic Impact

We modeled three economic impact scenarios using a range of estimates of 300MW units built and deployed in Texas. Considering that there are no SMRs yet in operation, we acknowledge the wide range of estimates among nuclear energy experts of SMR units expected to be deployed in the next few decades. In addition, we assume SMRs will add to the state and national energy generation mix, not replace or displace existing legacy electrical energy generation.

Of the three scenarios we model in this report (Low, Medium, and High investment), the Medium assumes 37 300MW units built and deployed just in Texas, and 771 built in Texas and deployed across the U.S. over 26 years by 2055, representing 242 gigawatts (GW) of SMR generation in Texas and the U.S. This scenario (a mid-range number of units built and deployed, using mid-range CAPEX and OPEX estimates and a moderate learning rate) results in significant economic impacts. On average, over the next 26 years there could be:

- An annual average of 148,000 people employed directly and indirectly by the new SMR industry (construction, operations, manufacturing).
- $50.6 billion in new economic output in Texas.
- $27.3 billion in income to Texas workers.

Supply Chain Potential in Texas

By categorizing NAICS codes into segments and subsegments, we identify existing industries with the potential to participate in the SMR supply chain in Texas, and we highlight areas of weakness at the state level. The analysis is based on business count location quotients (LQs) for 10 SMR segments and approximately 30 subsegments.

Texas is strong across the SMR supply chain compared to the nation, yet there are other states also competitive with Texas in their ability to support an advanced nuclear energy plant supply chain.

Business Survey

Approximately 35% of participants in our survey expressed interest in participating in an SMR supply chain. Based on this survey, industrial manufacturers are more likely to participate in certain segments and subsegments of the industry (e.g., balance of plant, inputs, and support services), though incentives are necessary to realize participation of these and other industry segments. Optimistically, about half of businesses are interested in using SMR power, including from the grid or private ownership.

Texas Economic Development Council Survey

More than 90 economic development officials with the Texas Economic Development Council (TEDC) responded to our survey with approximately 80 having experience in the past five years with siting or expansion of industrial plants and facilities. We received responses from city, county, and economic development entities in all 12 regions of Texas (Comptroller's official regions).

Electric power capacity is the single most important factor currently impacting (expansion or siting of) new industrial projects in their areas with "water supply," "access to talent," "access to development ready sites," and "taxes and incentives" next in priority.

Officials rated the importance of the following energy characteristics in this order:

- Certainty of electricity being available when facility begins operation
- 24/7 electricity without interruptions
- Amount of time before electricity would be available at the facility
- Cost of electricity
- Decarbonized source (green) of electricity

Officials surveyed cited numerous specific examples of instances in their areas in which insufficient energy/electricity availability had negatively affected a siting decision.

Workforce Analysis

We utilized multiple data sources and methodologies in reviewing a range of workforce issues. The analysis collected information and data through interviews about current nuclear workforce challenges, anticipated operational and construction employment from a 300 MW SMR, and forecasts of operational and construction/manufacturing employment from the REMI economic impact model, using the Medium scenario of 37 SMRs deployed in Texas and 771 manufactured in Texas.

Our analysis concluded that the state should not have any major issues supplying an operational workforce. Initial employment from operations occurs in 2033 with approximately 1,000 workers, ramps up slowly, and peaks in 2055 at approximately 46,000 workers. Manufacturing and construction employment would begin in 2030 with more than 11,000 employees. The ramp-up is much faster and peaks in 2046 at approximately 250,000 workers. The major uncertainty and potential workforce challenge appears to be with a number of production-oriented occupations for manufacturing SMRs. We suggest a future monitoring function regarding workforce issues. A monitoring unit could perform a series of tasks to ensure adequately trained operational and manufacturing employees would be available if, and when, SMRs move forward.

Despite the uncertainties inherent in estimating the economic impacts of an SMR industry that is in its earliest stages, the research team has used the most reliable modeling and other methodological approaches available to present policymakers, local leaders, and industry experts with up-to-date information about the potential economic benefits that may accrue to the state from manufacturing and deploying SMRs in Texas.

ERCOT Grid Modeling Trends and Observations

Key Findings

We examined the potential for nuclear power adoption in the ERCOT at various prices of nuclear generator capacity. The goal of this work is to define the capital expenditures (CAPEX) and operating expense (OPEX) price points which make small modular nuclear reactors (SMRs) competitive compared to existing technologies such as wind, solar, and natural gas. The study explores 36 scenarios by varying CAPEX and OPEX values for building capacity from 2020 to 2050. These build periods occur in seven stages, ranging in length from 3–5 years for each stage. Results indicate that it is economically feasible to build nuclear capacity when CAPEX drops to $3 million/megawatt (MW) and OPEX (fixed) falls below $105,000/megawatt-year (MW-year), with most capacity concentrated in the Houston region due to its industrial demand. However, these cost thresholds are significantly lower than forecasts by the National Renewable Energy Laboratory in the Annual Technology Baseline (ATB),[1] which projects CAPEX values between $2.9 million and $10.1 million per MW and OPEX between $118,000 and $216,000 per MW-year by 2040. The ATB data suggest that nuclear power is unlikely to become cost-competitive in the ERCOT before 2040 without major technological advancements, regulatory improvements such as the Nuclear Regulatory Commission's (NRC's) Part 53 initiative, and/or significant upfront investments to reduce CAPEX.

How the Model Operates

There are numerous questions by grid planners and policymakers about the potential for nuclear power to meet growing demand for electricity. This portion of the report is focused on possible SMR adoption in the ERCOT based on different CAPEX and OPEX prices for new nuclear generators. For this analysis, we utilize the GenX electricity grid capacity expansion model—which was developed to optimize future electricity generation by quantifying the most cost-effective portfolio of resources to build—to support the ERCOT grid.[2,3] The model finds the optimal (lowest cost) path for how the grid will evolve given assumptions around future technology cost and fuel prices. In our analysis, we aim to provide clarity on prices that make new nuclear generation capacity competitive under current market conditions and future trends. To that end, we developed a suite of GenX scenarios with a variety of CAPEX and OPEX combinations.

The GenX model was used to estimate market adoption of new nuclear in the ERCOT for each of the 36 technology cost combinations. The GenX model is also given inputs of CAPEX and OPEX for the existing fleet and new power plants from natural gas, wind, and solar, but these were all held constant. Because the model chooses the least-cost pathway, nuclear would only be chosen when it's cost competitive compared

[1] National Renewable Energy Laboratory. (2024). *Electricity Annual Technology Baseline (ATB) data download*. Retrieved August 28, 2024, from https://atb.nrel.gov/electricity/2024/data

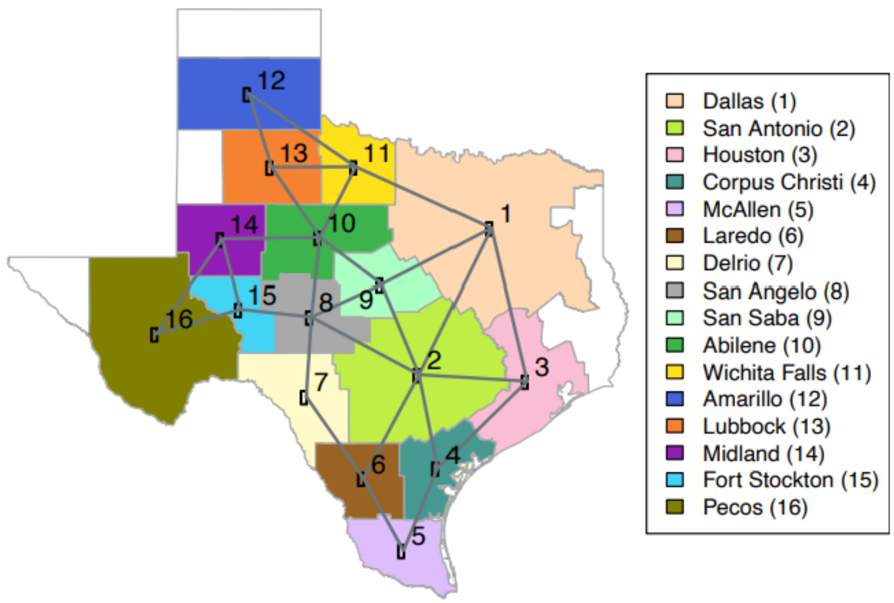
[2] Jenkins, J.D., & Sepulveda, N.A. (n.d.). *Enhanced decision support for a changing electricity landscape: The GenX Configurable Electricity Resource Capacity Expansion Model.*

[3] Lohse, C., Abou Jaoude, A., Larsen, L., Guaita, N., Trivedi, I., Joseck, F., Hoffman, E., Stauff, N., Shirvan, K., & Stein, A. (2024). *Meta-analysis of advanced nuclear reactor cost estimations* (No. INL/RPT-24-77048-Rev000, 2341591; p. INL/RPT-24-77048-Rev000, 2341591). https://doi.org/10.2172/2341591

to the other technologies. If the total cost of building and operating nuclear is below the other options, the GenX model will choose to build nuclear in greater numbers. The goal of this work is to find the point at which the model determines nuclear to be the cheaper option to build. The GenX model used in this analysis was developed and vetted for previous studies of ERCOT.[4] This model consolidates ERCOT into 16 regions which are shown in Figure 1. The regional lens provides clarity on which areas of Texas are optimal for nuclear development.

Figure 1. ERCOT 16 Region Map

This map illustrates the different areas within ERCOT that must be served electricity.
The largest load centers are urban areas such as Houston, Dallas, San Antonio, and Austin.[5]



Setup

The GenX model requires input files that define the parameters for building new power plant capacity. Generator data includes fuel pricing and generator costs. Transmission constraints are used as inputs for analysis; expected load is scaled based on historical ERCOT data and other variables.

The load data projections are based on numerous areas of growth that will require expansion of the ERCOT grid. The growth of electric vehicles (EVs), data centers, oil and gas operations, and liquefied natural gas (LNG) export terminals will all increase the demand on ERCOT. Future weather trends will also affect projections as they relate to renewable energy performance. After the Texas House Bill 5066 and the 2023 legislative session, the ERCOT now considers all "unsigned" loads which may encourage further investment

[4] Skiles, M.J., Rhodes, J.D., & Webber, M.E. (2024). *Assessing the potential for building sector retrofits to mitigate ERCOT electricity shortfalls during Winter Storm Uri* (No. arXiv:2403.01027). arXiv. https://doi.org/10.48550/arXiv.2403.01027

[5] Rhodes, J.D. (2023). *A roadmap for modernizing Texas' electricity infrastructure.* https://www.texasadvancedenergy.org/hubfs/2023%20Reports/ERCOT%202040%20Roadmap%20Transmission%20Study_Ideasmiths_2023.pdf

in transmission and grid infrastructure. Based on this new forecasting process, there are 41–43 additional GWs of load forecasted by the ERCOT in their *Large Load Interconnection Status Update*.[6] We utilized the ERCOT Long Term System Assessment[7] to inform decisions on predicting transportation charging profiles and adoption timelines. With the combination of charging profiles and an adoption timeline, the expected demand from EVs could be projected into 2050. Another area of large load growth is Permian Basin oil and gas operations. A 2023 electrification study found that 11.9 GWs of new load are needed by 2032.[8] The final large load area considered in these load projections is LNG exports. LNG exports are not exclusively driven by electricity, but seven projects with construction approvals in Texas plan to use electricity for liquefication operations.[9] Lastly, future population projections were modeled using the Texas 2022 projections in the 0.5 migration scenario.[10] By accounting for all these growing sectors of demand, we generated load input files for the GenX model.

For this analysis, seven stages of modeling represented the 30 years between 2020 and 2050. Within the expansion model, one year is representative of each stage or "time-step." These "time-steps" estimate the average expected cost of fuel, new generation, and new transmission as defined by the Annual Technology Baseline and Annual Energy Outlook for the range of years covered.[11] Table 1 defines the breakdown of the multi-stage approach.

Table 1. Load Data for 2020–2050 in the ERCOT

Year	Stage 1 2020–2022	Stage 2 2023–2025	Stage 3 2026–2030	Stage 4 2031–2035	Stage 5 2036–2040	Stage 6 2041–2045	Stage 7 2046–2050
Average Demand (GW)	47	64	81	95	110	126	142
Peak Demand (GW)	78	98	115	130	157	186	214

We calculated fuel costs based on the Annual Energy Outlook (AEO) from the U.S. Energy Information Administration. AEO runs numerous fuel-level scenarios. The reference fuel cost cases from the AEO were utilized for coal and uranium, while the Low resource scenario was utilized for natural gas. See fuel costs in Table 2. The Low resource scenario increases the cost of natural gas due to the expectation that supply may not meet demand, while coal prices will decrease because supply may surpass demand. Nuclear fuel costs

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[6] Neel, E. (2024, May 6). *Large load interconnection status update.* ERCOT. https://www.ercot.com/files/docs/2024/05/05/LLI%20Queue%20Status%20Update%20-%202024_5_2.pdf
[7] ERCOT. (2023, March 22). *2024 Long-Term System Assessment (LTSA) Planning*. https://www.ercot.com/files/docs/2023/03/20/2024_LTSA_Planning_March22_2023.pdf
[8] ERCOT. (2023, March 22). *Electrifying the Permian Basin*. https://www.ercot.com/files/docs/2023/03/17/Presentation%20to%20ERCOT%20planning.pdf
[9] Federal Energy Regulatory Commission. (2025, January 2025). *U.S. LNG export terminals: Existing, approved not yet built, and proposed*. https://www.ferc.gov/media/us-lng-export-terminals-existing-approved-not-yet-built-and-proposed
[10] Texas Demographic Center. (2022). *Texas Population Projections Program*. https://demographics.texas.gov/Projections/2022
[11] U.S. Energy Information Administration. (2020). *EIA annual energy outlook 2020 - issue in focus.* https://www.eia.gov/outlooks/aeo/section_issue_policies.php

increase over time, which may be due to increased demand and a lack of supply. Currently, the Department of Energy is addressing this concern with the Fuel Availability program[12] to accelerate fuel fabrication facility construction.

Table 2. Multi-Stage 2020–2050 Fuel Costs

Fuel Type	Stage 1 2020–2022	Stage 2 2023–2025	Stage 3 2026–2030	Stage 4 2031–2035	Stage 5 2036–2040	Stage 6 2041–2045	Stage 7 2046–2050
Natural Gas ($/MMBtu)	3.66	2.99	3.56	3.71	6.51	6.62	6.86
Coal ($/MMBTU)	1.81	1.95	1.9	1.88	1.85	1.79	1.77
Uranium ($/MMBTU)	0.72	0.72	0.73	0.74	0.75	0.76	0.77

As noted earlier, the National Renewable Energy Laboratory conducts an Annual Technology Baseline or ATB,[13] which compares capital and other costs on a capacity basis for ease of comparison among technologies. The ATB data provide advanced, moderate, and conservative projections by year from now to 2050. Based on these data, the OPEX costs range from $118,000 to $216,000 per MW-year for SMRs. For our current analysis, the highest OPEX cost is set at $150,000 per MW-year and then is decreased by $15,000 per MW-year. The ATB CAPEX values range from $5.5 million to $10 million per MW for SMRs. The starting CAPEX value is set at $7 million per MW and is decreased by $1 million per MW for each iteration. (See Tables 3 and 4.)

[12] Office of Nuclear Energy. (n.d.) *HALEU Availability Program*. Retrieved August 28, 2024, from https://www.energy.gov/ne/haleu-availability-program

[13] National Renewable Energy Laboratory. (2024). *Electricity Annual Technology Baseline (ATB) data download*. Retrieved August 28, 2024, from https://atb.nrel.gov/electricity/2024/data

Table 3. New Build CAPEX Generator Cost 2020–2050 From NREL's Annual Technology Baseline

Technology	CAPEX Stage 1 (million $/MW)	CAPEX Stage 2 (million $/MW)	CAPEX Stage 3 (million $/MW)	CAPEX Stage 4 (million $/MW)	CAPEX Stage 5 (million $/MW)	CAPEX Stage 6 (million $/MW)	CAPEX Stage 7 (million $/MW)
Battery	0.18	0.15	0.14	0.14	0.14	0.13	0.13
Wind	1.57	1.36	1.03	0.94	0.89	0.84	0.79
Natural Gas With Carbon Capture Conservative	1.06	1.05	1.03	1.00	0.98	0.96	0.94
Natural Gas Combined Cycle	2.68	2.62	2.55	2.45	2.34	2.24	2.14
Natural Gas Combustion Turbine	0.94	0.90	0.87	0.85	0.82	0.80	0.78
Solar	1.36	1.17	0.89	0.77	0.74	0.70	0.67
Nuclear	2-7	2-7	2-7	2-7	2-7	2-7	2-7

Note: Nuclear CAPEX values include the range used in the current Texas analysis.

Table 4. New Build OPEX Generator Cost 2020–2050 From NREL's Annual Technology Baseline

Technology	OPEX Stage 1 (thousand $/MW-year)	OPEX Stage 2 (thousand $/MW-year)	OPEX Stage 3 (thousand $/MW-year)	OPEX Stage 4 (thousand $/MW-year)	OPEX Stage 5 (thousand $/MW-year)	OPEX Stage 6 (thousand $/MW-year)	OPEX Stage 7 (thousand $/MW-year)
Battery	6.20	5.30	4.99	4.93	4.83	4.73	4.63
Wind	42.79	41.67	40.18	38.54	37.06	35.59	34.11
Natural Gas With Carbon Capture Conservative	27.64	27.64	27.64	27.64	27.64	27.64	27.64
Natural Gas Combined Cycle	65.90	65.90	65.90	65.90	65.90	65.90	65.90
Natural Gas Combustion Turbine	21.16	21.16	21.16	21.16	21.16	21.16	21.16
Solar	22.99	20.92	18.20	16.59	16.16	15.75	15.33
Nuclear	150-75	150-75	150-75	150-75	150-75	150-75	150-75

Note: This table shows the range of nuclear OPEX values utilized for the Texas analysis.

In our analysis, we held constant other technical parameters constant for new nuclear generators, such as the heat rate of the generator (defined as the amount of heat in Metric Million British Thermal Unit or MMBtu consumed per MWh of electricity generated). We also held constant the ramp rates of all new nuclear generators. Ramp rates describe how quickly a generator can increase or decrease supply to meet demand; 25% means the generators can increase or decrease power supply by 25% per hour, which is typical of historic nuclear reactor characteristics.

Results

The modeling team produced 36 scenarios including six different CAPEX values and six different OPEX values for new nuclear generators. It was hypothesized that, as advanced nuclear became cheaper, more nuclear capacity would be built. For all CAPEX values at or above $4 million per MW, no nuclear capacity was built. Therefore, there are no data on those scenarios provided in the tables/figures that follow. The model built nuclear capacity after CAPEX fell to $3 million per MW thus we only show results for those scenarios.

Table 5 and Table 6 illustrate how much capacity is built under the different OPEX and CAPEX levels while Tables 7 and 8 show capacity built by region at those same levels.

Figure 2. Capacity Built by 2050 in the ERCOT Grid for CAPEX Values of $3 Million/MW and All OPEX Values

The model builds nuclear capacity when the CAPEX is $3 million per MW and OPEX is below $105,000 per MW-year. However, this CAPEX price point is not projected to be attainable by the ATB data until 2040, which indicates that further investment in nuclear technologies and licensing must be made for nuclear capacity to be built on the grid.

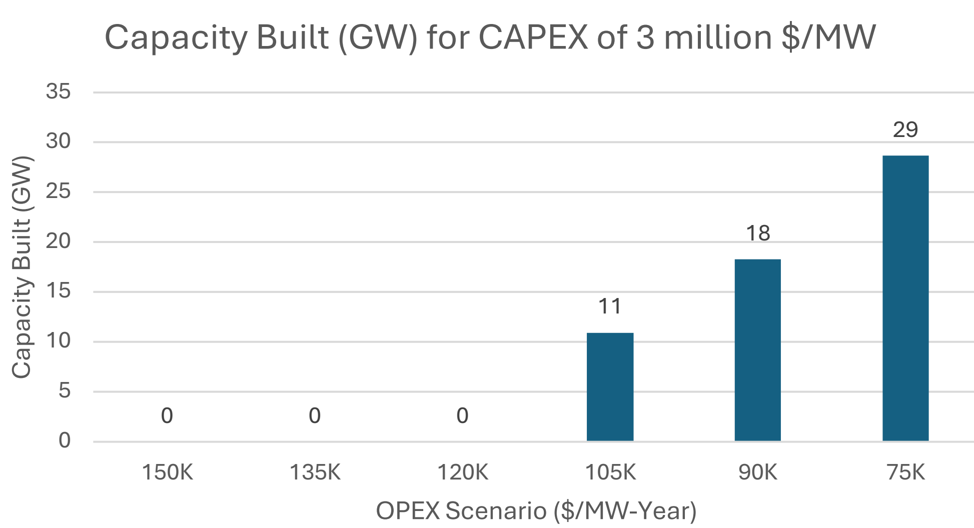


Figure 3. Capacity Built by 2050 in the ERCOT Grid for CAPEX Values of $2 Million/MW and All OPEX Values

Compared to Figure 2, when CAPEX is reduced to $2 million per MW, capacity can be built under any OPEX value. This figure may signify the importance of reducing the upfront costs of nuclear, those related to a lack of resilient construction which is flexible to design changes and permitting complexity.[14]

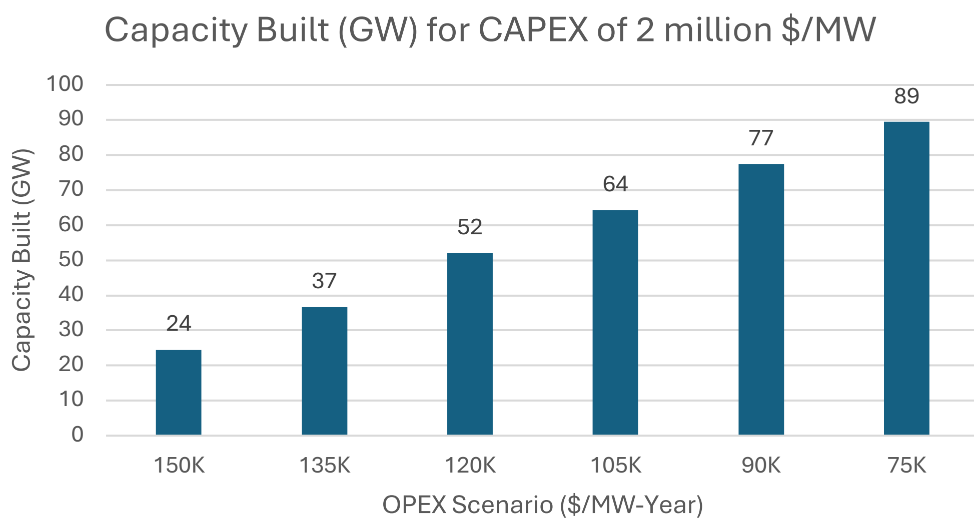


Table 5. Total Capacity Built by 2050 at $3 Million per MW

Once CAPEX is reduced to $3 million per MW, capacity is built under multiple OPEX values below $105,000 per MW-year.

CAPEX (million $/MW)	OPEX (thousand $/ MW-year)	Capacity Built (GW)
3	150	0
3	135	0
3	120	0
3	105	11
3	90	18
3	75	29

[14] Jenkins, J.D., & Sepulveda, N. A. (2017). *Enhanced decision support for a changing electricity landscape: the GenX configurable electricity resource capacity expansion model.* MIT Energy Initiative Working Paper Revision 1.0 November 27, 2017. https://dspace.mit.edu/handle/1721.1/130589

Table 6. Total Capacity Built by 2050 at $2 Million per MW

Capacity is built under all OPEX values once the CAPEX value is decreased to $2 million per MW. This table may imply that the reduction in upfront costs is more important than the lifetime operational costs.

CAPEX (million $/MW)	OPEX (thousand-$/ MW-year)	Capacity Built (GW)
2	150	24
2	135	37
2	120	52
2	105	64
2	90	77
2	75	89

The first scenario in which we saw capacity built was deployed in the Houston area (model region 3 as shown in Figure 1). This result is likely because Houston is the largest demand center primarily because of industrial needs (see the Houston region in the map in Figure 4). Additionally, as coal power plants are retired, transporting electricity to the Houston region may be difficult due to congestion. Once the nuclear costs decrease further, nuclear is built in other regions such as Dallas and San Antonio, as shown in the map in Figure 5.

Table 7. Regional Capacity Built by 2050 at $3 Million per MW CAPEX

Houston has the largest capacity built, which may be due to the large industrial load concentrated in that region of Texas.

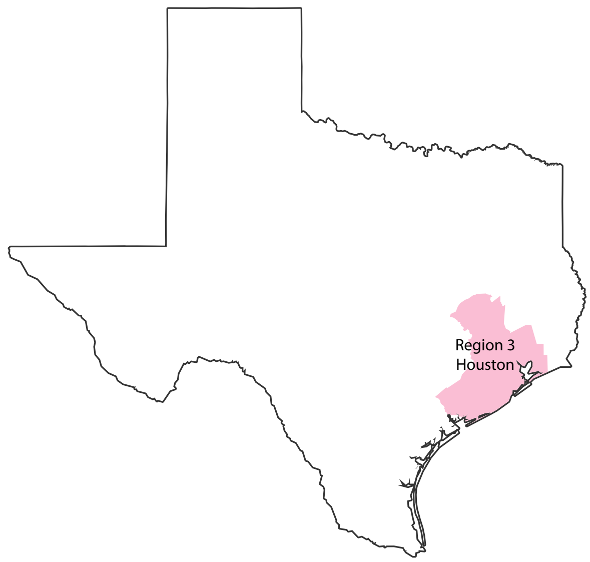
Region	Zone	Capacity Built (GW) at Each OPEX Value ($/MW-year)					
		$150k	$135k	$120k	$105k	$90k	$75k
Dallas	1	0	0	0	0	3	8
San Antonio	2	0	0	0	0	0	2
Houston	3	0	0	0	11	15	18
Corpus Christi	4	0	0	0	0	0	1
McAllen	5	0	0	0	0	0	0
Laredo	6	0	0	0	0	0	0
Del Rio	7	0	0	0	0	0	0
San Angelo	8	0	0	0	0	0	0
San Saba	9	0	0	0	0	0	0
Abilene	10	0	0	0	0	0	0
Wichita	11	0	0	0	0	0	0
Amarillo	12	0	0	0	0	0	0
Lubbock	13	0	0	0	0	0	0
Midland	14	0	0	0	0	0	0
Fort Stockton	15	0	0	0	0	0	0
Pecos	16	0	0	0	0	0	0

Table 8. Regional Capacity Built by 2050 at $2 Million per MW CAPEX

As costs decrease, there is larger adoption of nuclear; multiple Texas regions can benefit from building nuclear capacity.

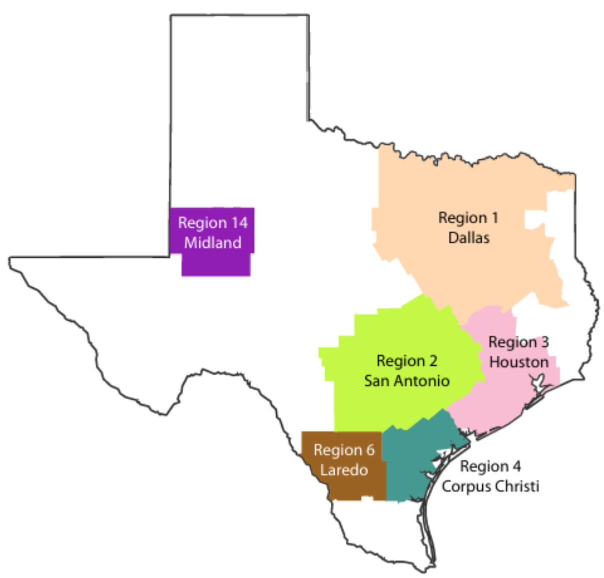
Region	Zone	Capacity Built (GW) at Each OPEX Value ($/MW-year)					
		$150k	$135k	$120k	$105k	$90k	$75k
Dallas	1	6	11	20	24	26	29
San Antonio	2	0	3	7	11	14	17
Houston	3	18	21	22	24	26	27
Corpus Christi	4	1	2	1	2	2	1
McAllen	5	0	0	2	2	3	4
Laredo	6	0	0	1	1	1	1
Del Rio	7	0	0	0	0	0	0
San Angelo	8	0	0	0	0	0	0
San Saba	9	0	0	0	0	0	0
Abilene	10	0	0	0	0	0	0
Wichita	11	0	0	0	0	0	0
Amarillo	12	0	0	0	0	0	0
Lubbock	13	0	0	0	0	0	0
Midland	14	0	0	0	1	5	10
Fort Stockton	15	0	0	0	0	0	0
Pecos	16	0	0	0	0	0	0

Figure 4. Demand in Houston Region – High Investment Scenario



For the most expensive scenario with capacity built, CAPEX of $3 million per MW and OPEX of $105,000 per MW-year, all of the capacity is built within the Houston region.

Figure 5. Demand in Houston and Dallas Regions – Medium and Low Investment Scenarios



For the remaining scenarios, CAPEX of $2 million per MW and variable OPEX of $150,000-$75,000 per MW-year, capacity is built in numerous regions including Dallas, San Antonio, Houston, Corpus Christi, Laredo, and Midland. The largest capacity is built within Dallas, San Antonio, and Houston.

While the CAPEX and OPEX cost of nuclear is higher than competing new generators, the overall lifecycle cost may be lower due to the inexpensive fuel. The model chose to build nuclear power because, over the 60-year lifecycle, it projects nuclear to be the most cost-effective option when costs decline enough. It should be noted that the nuclear prices used in this analysis are well below any ATB price forecast that is expected before 2040. The NREL ATB projects that nuclear CAPEX values are expected to be between $2.9 million and $10.1 million per MW. In 2040, the expected OPEX costs range between $118,000 and $216,000 per MW-year. This wide range of OPEX costs may be attributed to the numerous SMR designs with different operational requirements, such as fuel storage, heat management, and environmental conditions. Conversely, the NRC is currently working on Part 53 which aims to streamline the construction and permitting of new nuclear plants and could decrease the complexity of permitting numerous reactors.[15] Part 53 is a new nuclear reactor license; the NRC has held public meetings on it already in November 2024 to gain more public insight.[16] Through increased efficiency in permitting, the capital expenses for reactors will decrease. We find that the CAPEX cost may be more important than OPEX cost, as shown in Table 6 and Table 8. Once the CAPEX drops below $2 million per MW, the GenX model builds nuclear capacity under all OPEX costs. These results show that, unless further investment is made to reduce CAPEX through financial tools, permitting reform, and construction efficiency increases, SMR development may be limited in Texas.

[15] The Breakthrough Institute. (2024, March 4). *Nuclear Regulatory Commission charts a path forward on Part 53*. https://thebreakthrough.org/issues/energy/nuclear-regulatory-commission-charts-a-path-forward-on-part-53

[16] Patel, S. (2024, March 4). *NRC Sets Stage for Advanced Nuclear with New Part 53 Rule*. POWER Magazine. https://www.powermag.com/nrc-sets-stage-for-advanced-nuclear-with-new-part-53-rule/

Estimated Economic Impact

The REMI economic impact model presented here offers a comprehensive analysis of the potential effects of new SMR manufacturing in Texas for deployment both in Texas and the rest of the U.S. Our analysis results demonstrate how this investment could influence the state's economy by estimating changes in employment, income, and gross state product (GSP). The model evaluates both short-term benefits, like construction activity, and long-term impacts, such as increased energy production capacity and regional competitiveness. Additionally, the model assesses and incorporates supply chain effects from this added investment.

To estimate the number of SMR units built and deployed in Texas, the research team made several assumptions:

- The first SMR will not come online producing heat or electricity until 2031, even though the model has SMR investment beginning in 2025.
- 300MW units built and deployed in Texas in 2025–2055, range: 12–61 units
- 300MW units built in Texas, deployed elsewhere in U.S. in 2025–2055, range: 451–1090 units.
- We model 3 manufacturing and deployment scenarios as follows.
  - Low - low number of units built and deployed, high cost, low learning curve, fewer economies of scale
  - Medium - mid-range number of units built and deployed, lower cost, higher learning curve, more economies of scale
  - High - highest estimate of units built and deployed, lowest cost, highest learning curve
- Figures are presented in current (non-adjusted) dollars.
- Texas captures 100% of the advanced nuclear manufacturing market—i.e., all units deployed in Texas and the U.S. will be manufactured in Texas.
- SMRs will add to the state and national energy generation mix and will not replace or displace existing legacy electrical energy generation.

Advanced nuclear CAPEX and OPEX cost estimates were based on a widely cited and reputable meta-analysis of dozens of academic and industry reports containing estimates of nuclear costs released in 2024 from a team of energy economists at Idaho National Laboratory.[17] Our research team shared the report's assumptions with other experts before using them in the REMI model to broadly assess their validity. We were satisfied that these cost assumptions represent the most accurate data available that estimate the cost to build and operate SMRs in a nascent industry. Table 9 presents the cost assumptions by scenario. Table 10 displays the 300MW units manufactured in Texas but deployed in other states, and units built and deployed in Texas, for each of the 3 investment scenarios.

[17] Abou-Jaoude, A., Lohse, C.S., Larsen, L. M., Guaita, N., Trivedi, I., Joseck, F.C., Hoffman, E., Stauff, N., Shirvan, K., & Stein, A. (2024). *Meta-analysis of advanced nuclear reactor cost estimations* (No. INL/RPT-24-77048-Rev001). Idaho National Laboratory (INL), Idaho Falls, ID (United States). https://doi.org/10.2172/2371533

Table 9. CAPEX & OPEX Dollar Inputs by Scenario, for 300MW SMR

	CAPEX Input	OPEX Input
Low	$5,500/MW	$27/MW
Medium	$7,750/MW	$30/MW
High	$10,000/MW	$41/MW

Table 10. 300MW SMR Units Built in Texas and Deployed in Other States by Scenario

	TX Manufactured	TX Deployed
Low	451	12
Medium	771	37
High	1,090	61

We present the three modeling scenarios in detail in Table Set 11. The Low scenario represents low capital expenditure or CAPEX and low operational expenditure or OPEX; the research team anticipates this is the most conservative number of units expected to be built in Texas and deployed both in Texas and the U.S. 2030–2055. The Medium and High scenarios use higher numbers of units built with lower CAPEX and OPEX estimates and higher learning rates.

Key Findings

Of the 3 scenarios in Table Set 11, the likeliest scenario is the Medium estimate, which assumes 37 300MW units built and deployed in Texas and 771 units built in Texas and deployed in the U.S., and together capable of generating 242 GW of electricity. This scenario results in significant economic impacts. On average, over 26 years:

- An annual average of 148,000 people employed directly and indirectly by the new SMR industry (construction, operations, manufacturing).
- $50.6 billion in new economic output in Texas.
- $27.3 billion in income to Texas workers.

Figure 6 illustrates the Texas regions our study team believes will receive the first set of SMRs deployed in the state.

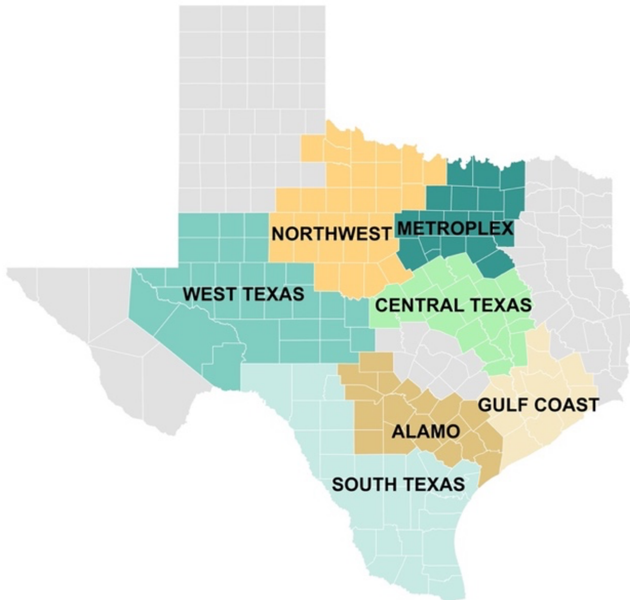
Table Set 11. Economic Impact of Three SMR Manufacturing and Deployment Scenarios

Low		**Average**						**Sum**
Category	**Units (12 in TX; 451 in U.S.)**	**Year 1-5**	**Year 6-10**	**Year 11-15**	**Year 16-20**	**Year 21-25**	**2030-2055**	**2030-2055**
Total Employment	Jobs	36,576	65,865	86,957	149,914	157,075	101,279	-
	% Change	0.18%	0.31%	0.40%	0.68%	0.69%	0.47%	-
Gross Domestic Product	Dollars (Current, Thousands)	7,695,688	16,770,060	25,724,524	51,835,279	64,802,794	34,740,578	324,013,969
	% Change	0.24%	0.44%	0.55%	0.93%	0.97%	0.71%	0.97%
Disposable Personal Income	Dollars (Current, Thousands)	3,809,091	8,628,253	13,763,338	27,561,763	35,937,878	18,748,464	487,460,076
	% Change	0.15%	0.28%	0.37%	0.60%	0.64%	0.47%	0.47%

Medium		**Average**						**Sum**
Category	**Units (37 in TX; 771 in U.S.)**	**Year 1-5**	**Year 6-10**	**Year 11-15**	**Year 16-20**	**Year 21-25**	**2030-2055**	**2030-2055**
Total Employment	Jobs	50,473	103,770	139,579	215,522	219,389	148,345	-
	% Change	0.25%	0.49%	0.65%	0.97%	0.97%	0.69%	-
Gross Domestic Product	Dollars (Current, Thousands)	10,561,216	26,180,571	41,379,243	74,195,000	91,137,730	50,597,629	455,688,651
	% Change	0.33%	0.68%	0.89%	1.33%	1.36%	1.03%	1.36%
Disposable Personal Income	Dollars (Current, Thousands)	5,243,096	13,450,633	22,031,935	39,880,953	50,465,013	27,324,159	710,428,128
	% Change	0.21%	0.44%	0.59%	0.87%	0.90%	0.69%	0.69%

High		**Average**						**Sum**
Category	**Units (61 in TX; 1090 in U.S.)**	**Year 1-5**	**Year 6-10**	**Year 11-15**	**Year 16-20**	**Year 21-25**	**2030-2055**	**2030-2055**
Total Empoyment	Jobs	51,111	111,877	152,493	229,611	235,595	159,055	-
	% Change	0.25%	0.53%	0.71%	1.04%	1.04%	0.74%	-
Gross Domestic Product	Dollars (Current, Thousands)	10,638,900	28,180,926	45,407,823	79,541,060	99,294,846	54,769,537	496,474,230
	% Change	0.33%	0.73%	0.98%	1.42%	1.48%	1.12%	1.48%
Disposable Personal Income	Dollars (Current, Thousands)	5,303,373	14,438,038	24,038,880	42,580,470	54,262,467	29,347,355	763,031,227
	% Change	0.21%	0.47%	0.64%	0.93%	0.97%	0.74%	0.74%

Figure 6. Expected Texas Regions for First SMRs



Analysis of Supply Chain Potential

Background

To develop a framework for the potential SMR supply chain, we outlined all the necessary components and services required to build and maintain an SMR. These components and services are divided into 10 categories, referred to as "segments." Each segment is subdivided into 2–5 "subsegments," providing additional specificity. Each subsegment consists of 2–4 NAICS codes. The North American Industry Classification System or NAICS was established in 1997 and classifies businesses by economic activity in the U.S., Canada, and Mexico. Each business is assigned a five- or six-digit code, with the latest update in 2022. To determine the appropriate segments and subsegments, we referenced the E4 Carolinas report *Economic Impact of the Nuclear Industry in the Southeast United States*, which analyzes the economics of larger-scale nuclear reactors in Tennessee.[18] This report used all 9 segments and their respective subsegments. To tailor this framework to the SMR supply chain, we added a 10th segment, a "SMR Specific" segment, to account for differences in SMR manufacturing compared to traditional reactors. We identified a total of 58 NAICS codes to be categorized into the 31 subsegments. Table 12 shows the schema developed at the segment and subsegment level.

Table 12. Supply Chain Schema[19]

Segment	Subsegment
INPUTS	Construction Materials
	Metals & Alloys
	Nuclear Fuel
NUCLEAR ISLAND	Containment Structure
	Infrastructure & Operations (I&O)
	Nuclear Reactor
CONVENTIONAL ISLAND	Service Water System
	Turbine Generation System
BALANCE OF PLANT	Auxiliary Facilities
	Auxiliary Systems
	Cooling Tower
	HVAC
END USER	Power Generation
	Transportation

[18] Von Nessen, J. & Brun, L. (2024, February). *The economic impact of the nuclear industry in the Southeast United States: A regional and state-level analysis.* E4 Carolinas. https://www.commerce.virginia.gov/media/governorvirginiagov/secretary-of-commerce-and-trade/va-nuclear/E4_Carolinas_Economic_Impact_Report_Final.pdf

[19] The supply chain schema includes 9 segments, 28 subsegments derived from "The Economic Impact of the Nuclear Industry in the Southeast United States" (TN). Segments and subsegments taken from "The Economic Impact of the Nuclear Industry in the Southeast United States" (p. 13–14). We added one additional "SMR Specific" segment consisting of 3 subsegments: Transportation of Pre-Built SMRs and Modules; Modular Fabrication & Assembly; and Rapid Deployment & Redeployment.

Segment	Subsegment
POST-SALES SERVICE	Life-Extending Modifications
	Operations & Maintenance (O&M)
	Training & Simulations
END OF LIFE	Decommissioning
	Fuel Storage & Disposal
	Materials Recycling & Disposal
SUPPORT SERVICES	Engineering, Procurement, & Construction
	Financial
	Legal
	Siting
	Strategy & Market Info
SUPPORTING I&O	Education & Training
	Governments & IGOs
	NGOs
SMR SPECIFIC	Modular Fabrication & Assembly
	Rapid Deployment & Redeployment
	Transportation of Pre-Built SMRs & Modules

Goals or Research Questions

By categorizing NAICS codes into segments and subsegments, we can identify existing industries with the potential to participate in the SMR supply chain in Texas, as well as highlight areas of weakness at the state level. The unit of analysis we used is the number of firms in a category. Thus, the assessment of potential is based on the number of firms in Texas that have the potential to participate in an SMR supply chain.

Methodology

All data collected is publicly accessible online and was gathered between June and August 2024. The primary source for economic and business data was the Census Business Builder (CBB), an interactive tool hosted by the U.S. Census Bureau.[20] The CBB interface allows users to view economic and business data by state, county, and city. We used these data to generate statistics such as location quotients and the percentage composition of American firms/businesses. We also utilized the U.S. Bureau of Labor Statistics[21] to cross-check data collected from the CBB. Although there were slight differences between the two sources, they reflected similar areas of strength and weakness.

[20] U.S. Census Bureau. (n.d.). *Census Business Builder (CBB)*. Census.Gov. Retrieved September 20, 2024, from https://www.census.gov/data/data-tools/cbb.html

[21] U.S. Bureau of Labor Statistics. (n.d.). *U.S. Bureau of Labor Statistics*. Bureau of Labor Statistics. Retrieved September 20, 2024, from https://www.bls.gov/

The location quotient is a statistic that indicates a sector's level of specialization compared to the rest of the United States. The equation for the location quotient for NAICS data in Texas is:

$$\textbf{Location Quotient} = \frac{\text{State Counts by Sector}/\text{Total State Counts}}{\text{U.S Counts by Sector}/\text{Total U.S.Counts}}$$

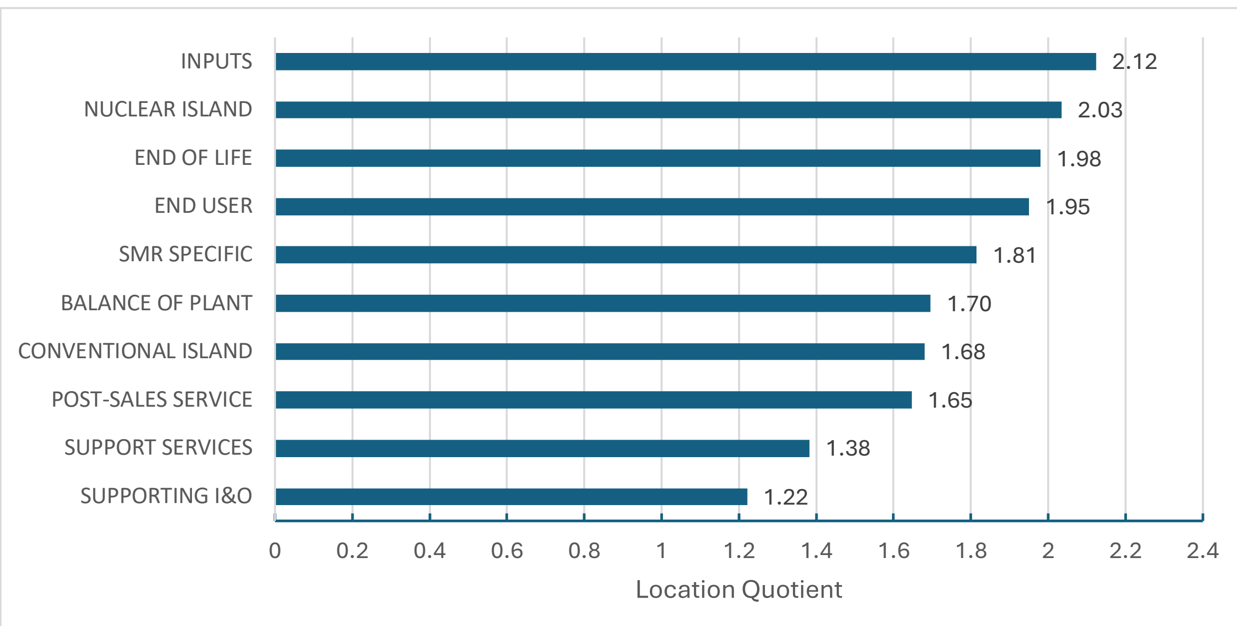
A location quotient greater than 1 indicates strength for a given NAICS code in Texas in the supply chain, and a location quotient less than 1 indicates weakness. All location quotients were generated with data from the CBB. Specifically, the location quotient is a way of assessing the potential of businesses in Texas to participate based on how many are in Texas compared to how many might participate nationally.

Analysis

For a concise view of the areas of strength and weakness in the potential SMR supply chain in Texas, we average the NAICS location quotients by their segments. As shown in Figure 7 for Texas, all supply chain segments in the model are greater than 1, thus have greater potential than the U.S. overall; nuclear inputs and nuclear island components are even stronger with location quotients greater than 2.

Figure 7. Average Location Quotient per Segment in Texas

A location quotient greater than 1 indicates that Texas is a specialist in that segment.



Discussion and Next Steps

The data our team collected and the statistics we generated suggest that Texas has a sufficient number of businesses across all categories necessary to support an SMR supply chain. However, it is important to note that this analysis indicates potential, but does not confirm active participation in the supply chain. Additionally, we compared these data to six other states known for their ability to support an advanced nuclear energy plant supply chain: Tennessee, Michigan, Pennsylvania, South Carolina, Virginia, and Illinois. Qualitatively, Texas ranks in the middle of the pack among these top contender states, further suggesting that Texas may be poised to pivot toward an SMR supply chain. Further data collection is needed to assess Texas' potential involvement in an SMR supply chain. Gathering city and county-level data would provide greater insight into the state's strengths and weaknesses. Additionally, comparing Texas to more states with established SMR supply chains could offer valuable insights and best practices.

Business Surveys

Survey of Local Economic Development Officials in Texas

The research team conducted a survey of members of the Texas Economic Development Council about their familiarity with SMRs and the role and importance of electricity availability in siting decisions for new and expanding industrial facilities in Texas.

We sent surveys to approximately 800 economic development professionals who represent around 500 discrete local governments in Texas: cities, economic development corporations, counties, regional councils of governments, chambers of commerce, and regional economic development entities.

The goals for this survey were to:

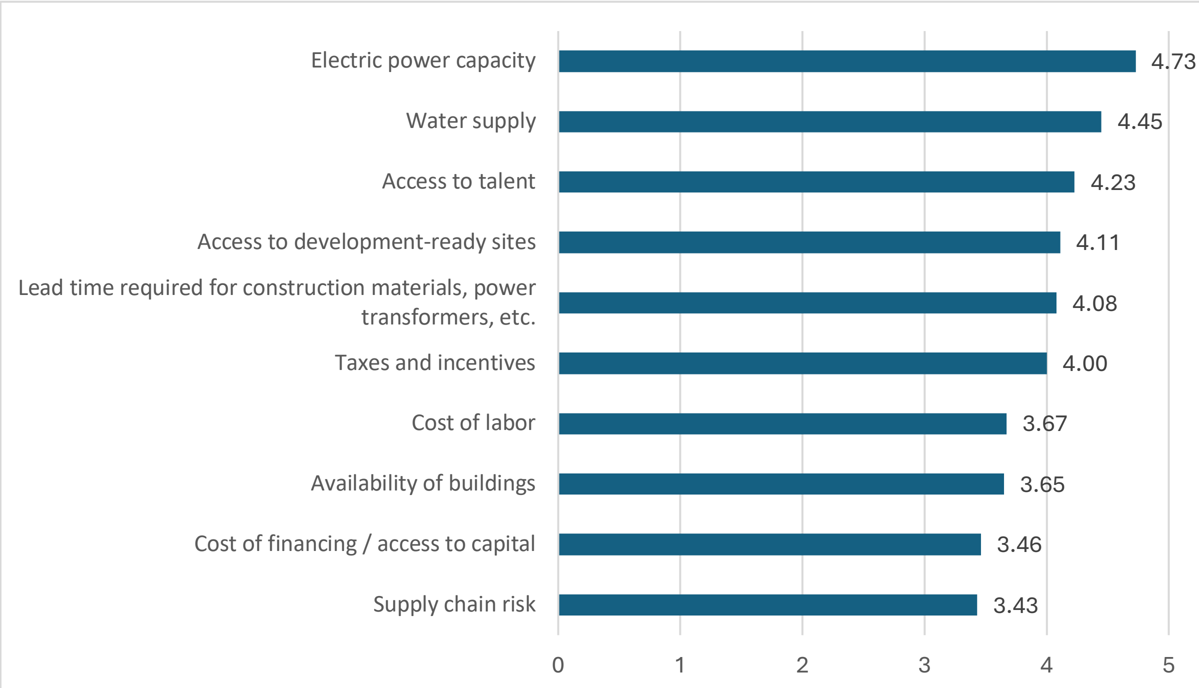
- Determine the relative importance of energy/electricity as a factor in decision-making about expansion of existing industrial facilities and siting of new industrial facilities throughout Texas.
- Determine the relative importance of different characteristics/factors of electricity, such as availability, reliability, 24/7, clean source, and cost.
- Capture current perceptions of nuclear power and awareness of small modular reactors as a future source of electricity.
- Identify specific examples in which insufficient electricity availability had negatively impacted siting or expansion of an industrial facility.

More than 90 economic development officials responded, and approximately 80 officials had experience in the past five years with siting or expansion of industrial plants and facilities. We received responses from economic development entities in all 12 Texas Comptroller regions (the regional geographic division used by the study team in Figure 1).

Key Findings

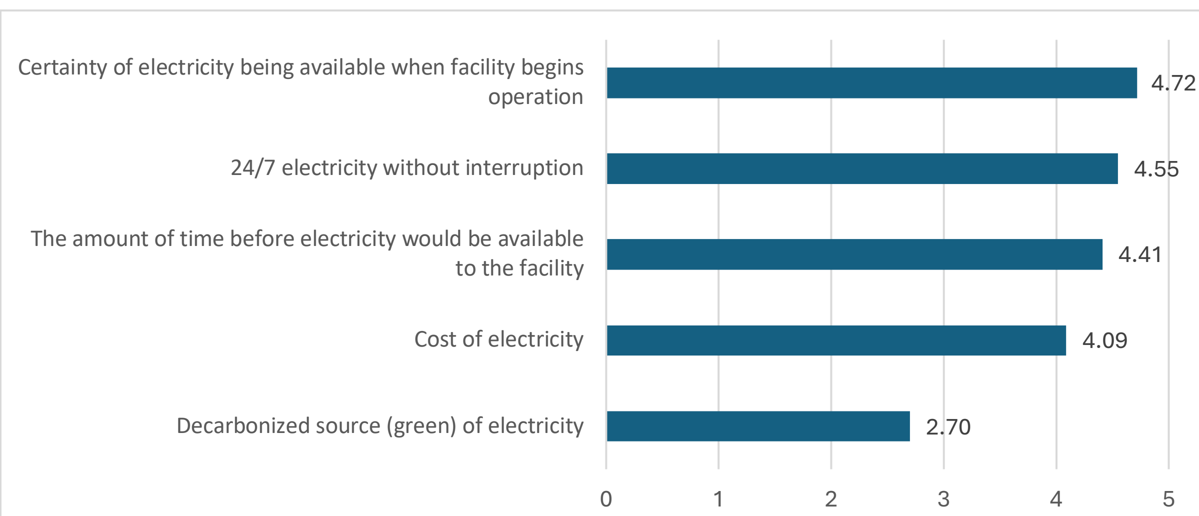
Electric power capacity is the single most important factor currently impacting (expansion or siting of) new industrial projects in their areas, with "water supply," "access to talent," "access to development-ready sites," and "taxes and incentives" ranked next in importance. See Figure 8.

Figure 8. Site Selection Factors by Average Importance Rating (on a scale of 1 to 5)



Officials indicated how their industrial clients would rate the importance of various energy characteristics, as shown in Figure 9 next. Notably, a green source of electricity was substantially less important than high availability, high reliability, and low cost.

Figure 9. Energy Characteristics by Average Importance (on a scale of 1 to 5)



Thirty-five (35) survey respondents cited specific examples in their areas in which insufficient energy/electricity availability or reliability had negatively affected a siting decision. See Appendix B for their verbatim comments.

Survey of SMR Supply Chain

Our study team conducted a second survey to gain baseline insights and investigate how firms in Texas perceive the opportunities associated with participating in an SMR supply chain in some capacity, either participating as a consumer of energy, a member of the SMR supply chain, or an owner/operator of a corporate-owned SMR to supply energy to their industrial operations.

The survey included questions about the importance of certain features when considering the manufacturing and deployment of SMRs, interest by participants in various SMR use cases, and (among those with interest in supply chain participation) a measure of interest in participating in specific supply chain segments. As such, the insights from this survey complement our analysis of SMR supply chain potential with information about current levels of propensity to participate. Participants also had the opportunity to give their qualitative ideas about how their interest might further increase if SMR incentives become available.

Participant Background

We promoted the survey with the support of several relevant organizations and groups, including Texas Association of Business, Texas Association of Manufacturers, Texas Chemistry Council, and Texas Oil and Gas Association. Additionally, we used a commercial research panel, Dynata, to expand participation more broadly across the state among industrial manufacturers. Table 13 summarizes the industries represented by the 85 survey participants who completed the survey as of September 12, 2024.

Table 13. Industry Sectors of Survey Participants[22]

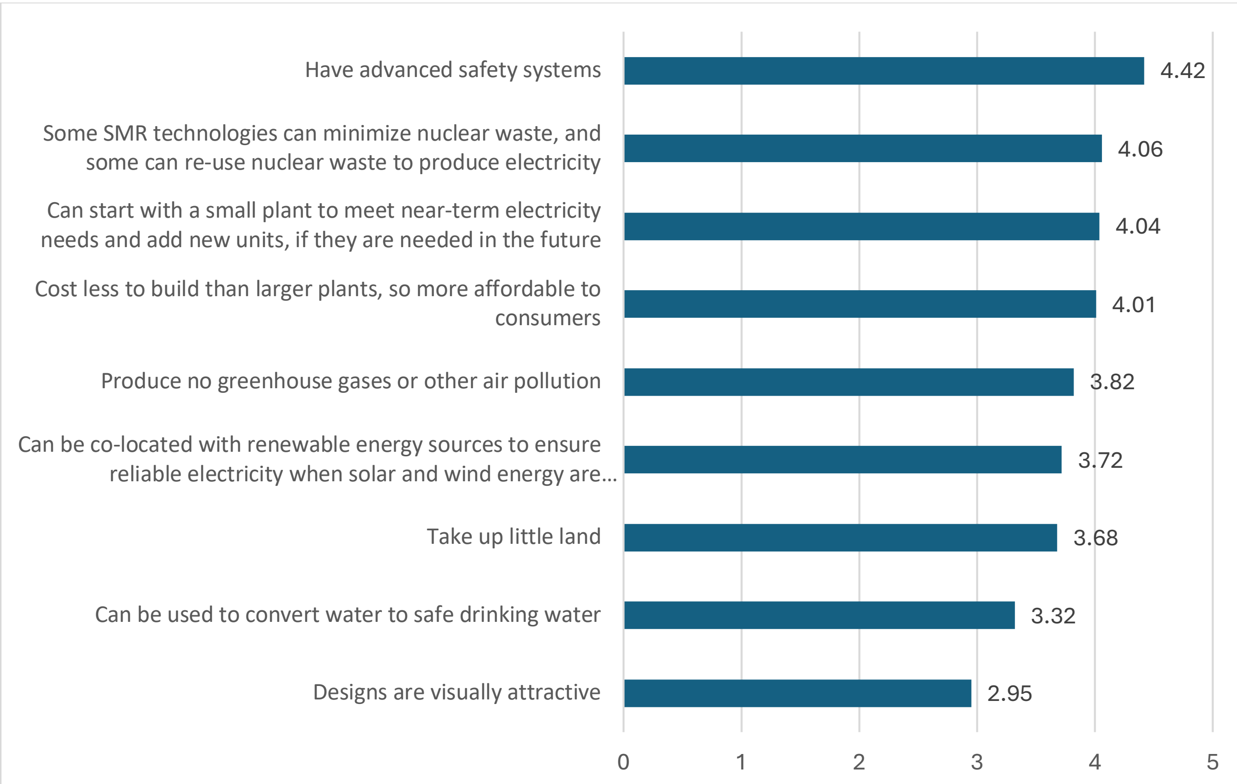
Sector	% of Survey Participants
Manufacturing	65.90%
Mining, Quarrying, and Oil and Gas Extraction	20.00%
Construction	7.10%
Other	7.10%
Utilities	5.90%
Agriculture, Forestry, Fishing and Hunting	2.40%
Wholesale Trade	2.40%
Transportation and Warehousing	2.40%
Professional, Scientific, and Technical Services	2.40%
Retail Trade	1.20%
Information	1.20%
Management of Companies and Enterprises	1.20%
Other Services (Except Public Administration)	1.20%

[22] Analysis of responses to survey question Q2: Which of the following best describe your organization's industry sector? (select all that apply)

SMR Feature Importance

Of the factors evaluated by participants when considering the development and deployment of SMRs, these were viewed as the most important: safety systems, minimizing nuclear waste, expandability, and lower cost to build (Figure 10).

Figure 10. SMR Feature Average Importance (on a scale of 1 to 5)[23]

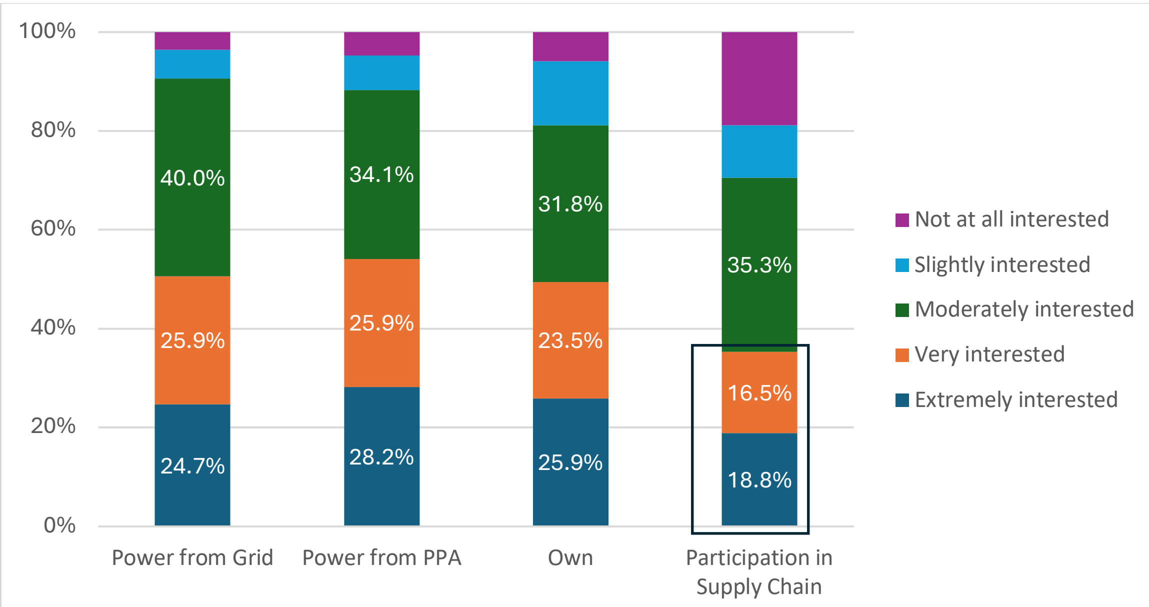


[23] Analysis of responses to survey question Q7a: Significant technology development, cost, and licensing risks remain in bringing advanced SMR designs to market. However, based on what you know today, how important to you are the following features of small modular reactors? Rate each on a scale from 1 to 5 where 1 is not all important and 5 is extremely important.

Interest in SMR Usage

Approximately 35% of participants in our survey expressed interest in participating in an SMR supply chain. Based on this survey, industrial manufacturers are more likely to participate in certain segments and subsegments of the industry (e.g., balance of plant, inputs, and support services), though incentives are necessary to realize participation of these and other industry segments. Optimistically, about half of businesses are interested in using SMR power, including from the grid or private ownership (Figure 11).

Figure 11. SMR Interest Among Firms Surveyed[24]



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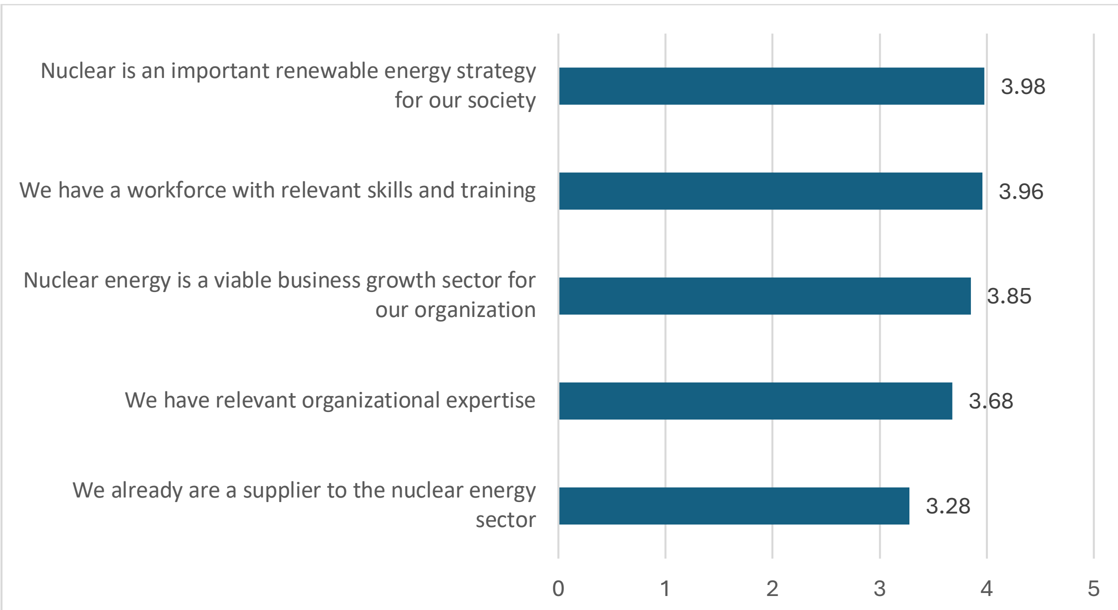
[24] Analysis of responses to survey question Q8: Based on what you know today, how interested do you think that your organization is in utilizing SMRs in each of the following ways? Rate each on a scale from 1 to 5 where 1 is not all interested and 5 is extremely interested. Use case definitions:

- As a source of energy provided to your organization via the grid for your operations and processes (Power from Grid)
- As a source of energy for your organization's operations and processes via a power purchase agreement (PPA) (Power from PPA)
- As a corporate-owned source of energy used exclusively for your corporate operations and processes (Own)
- As a business opportunity to participate in the manufacture, construction, or supply of components or services for SMRs (Participation in Supply Chain)

Relevance of Criteria When Considering SMR Supply Chain Participation

We also asked survey participants to consider the relevance of certain factors in their SMR supply chain participation. Among those interested in SMR supply chain participation (n=53), firms found all of the factors or criteria we tested to be relevant when considering participation in the supply chain. Interestingly, the least relevant criteria, already being a supplier in the nuclear energy sector, is only modestly less relevant (see Figure 12).

Figure 12. SMR Supply Chain Participation Criteria, Average Relevance of Criteria[25]



Among those interested in SMR supply chain participation (n=53), firms surveyed identified where they may fit into the supply chain, specifically which supply chain segments and subsegments are most relevant to their organizations. Table 14 displays the percentage of interest at the segment and subsegment level. Nearly all interested firms indicated that balance of the plant aspects are relevant to them. Approximately two-thirds found supporting services relevant, and one-half of participants found post-sales service and SMR-specific participation relevant to their organizations.

[25] Analysis of responses to survey question Q10: How relevant are the following factors when you think about participating in the manufacture, construction, or supply of components or services for SMRs?

Table 14. Relevance of Supply Chain Segments[26]

Supply Chain Segment / Subsegment	Relevance
BALANCE OF PLANT	98.2%
Auxiliary Facilities	15.1%
Auxiliary Systems	20.8%
Cooling Tower	32.1%
HVAC	30.2%
CONVENTIONAL ISLAND	35.9%
Service Water System	20.8%
Turbine Generation System	15.1%
END OF LIFE	18.9%
Decommissioning	1.9%
Fuel Storage & Disposal	3.8%
Materials Recycling & Disposal	13.2%
END USER	39.6%
Power Generation	22.6%
Transportation	17.0%
INPUTS	75.5%
Construction Materials	34.0%
Metals & Alloys	26.4%
Nuclear Fuel	15.1%
NUCLEAR ISLAND	45.3%
Containment Structure	11.3%
Infrastructure & Operations (I&O)	18.9%
Nuclear Reactor	15.1%
POST-SALES SERVICE	52.8%
Life-Extending Modifications	11.3%
Operations & Maintenance (O&M)	24.5%
Training & Simulations	17.0%
SMR SPECIFIC	52.8%
Modular Fabrication & Assembly	26.4%
Rapid Deployment & Redeployment	9.4%

[26] Analysis of responses to survey question Q12: Please review the following list of SMR component technologies and services. They are organized by major segment (e.g., INPUTS) and subsegment (e.g., Nuclear Fuel). Which, if any, are relevant categories for your organization to provide as part of the manufacture, construction, or supply of components or services to SMRs? Select all that apply.

Supply Chain Segment / Subsegment	Relevance
Transportation of Pre-Built SMRs & Modules	17.0%
SUPPORT SERVICES	64.1%
Engineering, Procurement, & Construction	17.0%
Financial	17.0%
Legal	13.2%
Siting	7.5%
Strategy & Market Info	9.4%
SUPPORTING I&O	37.8%
Education & Training	13.2%
Governments & IGOs	5.7%
NGOs	18.9%

Suggestions to Incentivize Participation in an SMR Supply Chain

The survey concluded with an open-ended question soliciting high-level feedback about the kinds of incentive programs that participants thought would motivate their organization to participate in an SMR supply chain. While more research is needed to assess and evaluate SMR incentives, the feedback received in this survey provides a starting point, and preliminary themes are apparent in this high-level reflection. Not surprisingly, tax-based incentives were commonly mentioned as were incentives directed at offsetting startup, retooling, and certification costs. A third incentive theme that emerged centered on the idea of providing evidence to potential supply chain participants that the advanced nuclear technology is viable (e.g., reliable, safe, cost effective, etc.).

Workforce Review

We utilized multiple data sources and methodologies in reviewing a range of workforce issues. The analysis collected information and data through interviews about current nuclear workforce challenges, anticipated operational and construction employment from a 300 MW SMR, and forecasts of operational and construction/manufacturing employment from the REMI economic impact model, using the Medium scenario of 37 SMRs deployed in Texas and 771 manufactured in Texas. Our analysis concluded that the state should not have any major issues supplying an operational workforce. Initial employment from operations occurs in 2033 with approximately 1,000 workers, ramps up slowly, and peaks in 2055 at approximately 46,000 workers. Manufacturing and construction employment would begin in 2030 with more than 11,000 employees. The ramp-up is much faster and peaks in 2046 at approximately 250,000 workers. The major uncertainty and potential workforce challenge appears to be with a number of production-oriented occupations for manufacturing SMRs. We suggest a future monitoring function regarding workforce issues. A monitoring unit could perform a series of tasks to ensure adequately trained operational and manufacturing employees would be available if, and when, SMRs move forward.

Data Collection, Analysis, and Findings

To identify appropriate, available strategies for ensuring a sufficient supply of workforce talent to meet the demands of potential SMRs in the next several decades, we obtained data from the REMI economic forecasting model as well as reviewed multiple public reports and economic analyses. To supplement these data, we conducted qualitative interviews with executives at SMR developers, utilities, companies in the nuclear industry supply chain, and state and federal government researchers and workforce officials.

See also Appendix D for additional workforce information and analyses.

Current Nuclear Workforce Challenges

Several near-term workforce challenges were identified by utility executives, federal laboratory researchers, and state government workforce officials in this research:

- Well-known shortages of personnel with trades and crafts occupations with acute problems in recruitment of welders and electricians.
- Continuing shortages of personnel in radiation physics, radiation protection, and other low-volume occupations as the established talent pipelines for these job titles produce an insufficient number of entry-level employees.
- More separations due to retirements and anticipated retirements, a trend mirrored in national demographic statistics and workforce trends in other industries.
- Lack of awareness by potential employees about nuclear energy employment opportunities and a reluctance of some younger workers to consider any type of nuclear position.

Because of current challenges and anticipated future workforce challenges, two major utilities in the southeast United States recently have created multi-person workforce development and planning divisions.

Single SMR: Projected Employment Estimates for Operations and Construction

Based on multiple reports and analyses, there are no foreseeable, significant challenges in having a well-trained SMR operational workforce. Operational workforces have been confirmed within a reasonable range, at least for Gen III+ SMRs. While there is some variation in the estimate for a referent 300 MW reactor, the number was estimated to be approximately 100 operational employees. That level of operational staffing would be lower than staffing for existing large, light water reactors on a per MW basis. Gen IV SMRs based on new technologies present more variation in operational employment estimates.

Similarly, based on multiple reports and interviews, there are no foreseeable construction workforce challenges, unless there would be an abnormally high number of large industrial facilities built in any Texas region. Even if that were to occur, this problem is likely to be temporary, given the history of very large site-based construction workforces at new industrial facilities in Texas.

Multiple SMRs: Projected Employment Estimates From REMI Model

As described more fully in the Estimated Economic Impact section of this report, our team ran multiple scenarios with multiple assumptions about impacts from SMRs through 2050. While all of the scenarios are hypothetical and uncertain, if the Medium scenario occurred (771 manufactured in Texas and 37 deployed, with first SMR becoming operational in 2033), the employment impacts would be significant.

Note that OPEX employment include operations employees at the SMRs, employees working for suppliers to the SMRs, and employees working in businesses that are financially dependent on expenditures at the plant and the suppliers.[27] CAPEX employment is from manufacturing and construction of SMRs, employees working for suppliers of construction and manufacturing products and services, and employees working in businesses that are financially dependent on expenditures at the construction and manufacturing sites.

OPEX Employment = Employment impacts from operational expenditures. CAPEX Employment = Employment impacts from manufacturing and construction expenditures.

Major findings from this analysis are presented next. The REMI model produced the following estimates of **total employment** in Table 15.

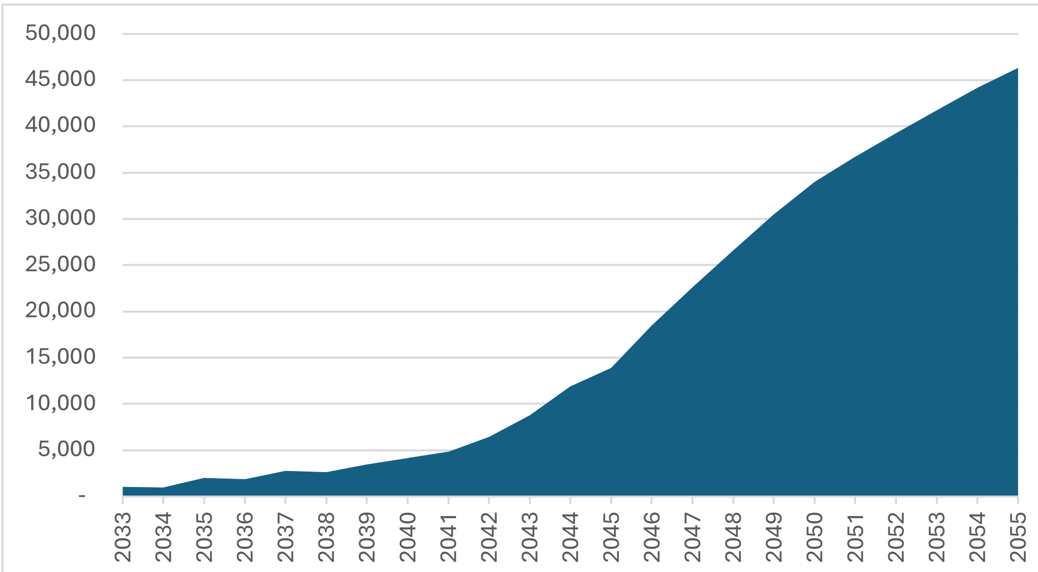
Table 15. Total OPEX and CAPEX Employment, Medium Scenario

Category	Units	Average					
		Year 1–5	Year 6–10	Year 11–15	Year 16–20	Year 21–25	Yearly Average 2030–2055
Total Employment	Jobs	50,473	103,770	139,579	215,522	219,389	148,345

[27] Employment includes both full-time and part-time workers.

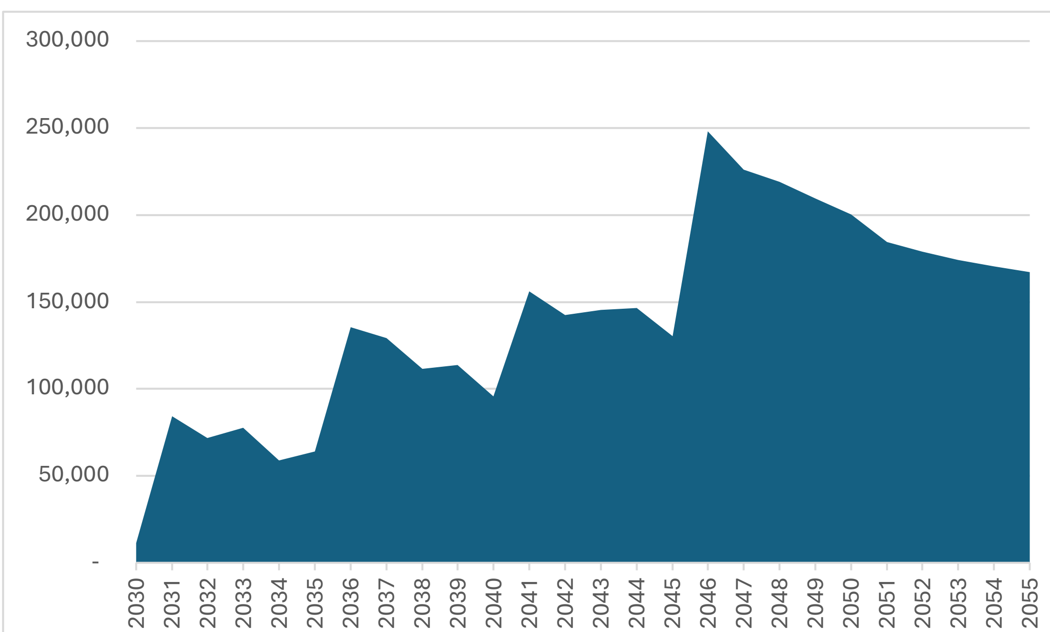
For OPEX employment, initial employment occurs in 2033 with approximately 1,000 workers, ramps up slowly, and peaks in 2055 at approximately 46,000 workers as shown in Figure 13.

Figure 13. OPEX Employment, Medium Scenario Impacts, 2033–2055



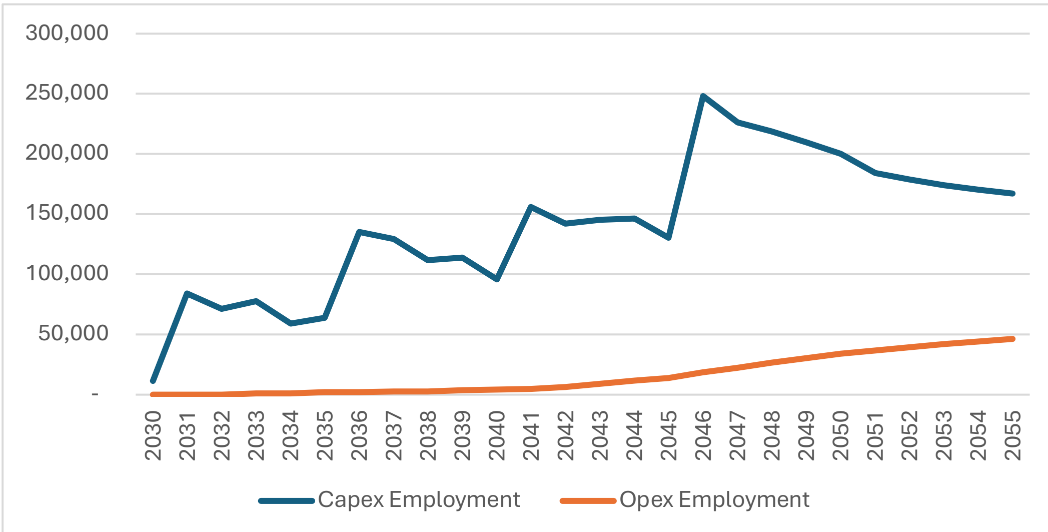
For CAPEX employment, because manufacturing and construction are involved, initial employment occurs in 2030 with more than 11,000 employees. The ramp-up is much faster and much larger than with OPEX and peaks in 2046 at approximately 250,000 workers. See Figure 14.

Figure 14. CAPEX Employment, Medium Scenario Impacts, 2033–2055



The next chart (Figure 15) shows the longitudinal forecasts and relative sizes of OPEX and CAPEX workforces for the hypothetical Medium scenario.

Figure 15. OPEX and CAPEX Employment Projections, Medium Scenario, 2033–2055[28]



OPEX Employment by Occupation: Demand for specific occupations from SMRs would not be significant, even in 2035 when about 2,000 employees are forecast. Only three occupations would have demand of more than 100 workers, and only 32 additional engineers and 20 additional plant operators would be needed.

CAPEX Employment by Occupation: There could be challenges to meet demands from SMRs for select occupations as early as the 2030s. Table 16 has the estimated number of additional employees needed by type of occupation for the initial decade of construction and manufacturing. Metalworkers and plastic workers would be in high demand as would several other production-oriented occupations. For several other select occupations shown in Table 17, the demand would be much less.

[28] CAPEX employment is from manufacturing and construction of SMRs. OPEX employment is from operating SMRs. Estimated employment is from a "medium scenario" of 771 manufactured and 37 deployed and operated in Texas.

Table 16. CAPEX Employment Projections for Select Occupations, 2030–2040

	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Metal workers and plastic workers	1,016	7,560	7,327	7,286	6,965	6,919	14,656	14,422	14,005	13,826	13,418
Construction trades workers	645	4,766	4,390	6,141	3,002	4,452	6,239	7,639	4,702	5,912	3,009
Material moving workers	639	4,749	4,049	4,229	3,406	3,557	7,834	7,367	6,563	6,559	5,743
Other production occupations	475	3,522	3,287	3,273	2,985	2,968	6,420	6,211	5,877	5,770	5,449
Business operations specialists	474	3,515	2,959	3,235	2,405	2,628	5,583	5,320	4,531	4,623	3,815
Other installation, maintenance, & repair occupations	472	3,512	3,142	3,436	2,687	2,929	5,981	5,926	5,217	5,363	4,644
Motor vehicle operators	415	3,117	2,714	2,933	2,304	2,462	5,228	5,037	4,427	4,482	3,840
Assemblers and fabricators	338	2,474	2,288	2,244	2,015	1,969	4,291	4,095	3,816	3,688	3,426

Table 17. CAPEX Employment Projections for Other Select Occupations, 2030–2040

	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Top executives	306	2,262	1,899	2,075	1,540	1,689	3,579	3,411	2,904	2,970	2,455
Health diagnosing and treating practitioners	245	1,795	1,335	1,450	1,025	1,135	2,714	2,356	1,972	2,012	1,598
Computer occupations	236	1,771	1,488	1,589	1,235	1,298	2,862	2,657	2,312	2,303	1,934
Engineers	201	1,503	1,389	1,427	1,216	1,241	2,642	2,580	2,355	2,333	2,111

Priority Next Steps to Consider

Most workforce best practices emphasize the importance of (1) immediate placements for those being trained and educated and (2) actions that are demand-driven by employers. There are few immediate job openings for SMR operational personnel, and no certain schedule for when such jobs would become available to any degree. The REMI workforce estimates for employment and specific occupations are based on a hypothetical Medium scenario for numbers manufactured and deployed. Depending on many future actions, investments, and developments, workforce estimates could be higher or they could be minimal if SMR costs exceed the thresholds described in the ERCOT Grid Modeling section earlier in this report.

If Texas state government officials wish to establish an SMR economic cluster, inaction is not an option. There are continuing shortages of several nuclear occupations, there is a need to focus on possible manufacturing/occupational personnel who would build SMR components, and there are questions about the ultimate nuclear workforce that may be needed for the next 25–30 years.

Active Monitoring

As a first step, consider a strategy of "active monitoring" of SMR workforce issues. The Texas Workforce Commission or a state government entity, such as the Texas Advanced Nuclear Reactor Working Group's proposed Texas Advanced Nuclear Authority, could undertake a series of SMR workforce tasks such as:

- Perform an in-depth, initial analysis about the labor availability and necessary training needed, if any, for manufacturers with potential to become part of the SMR supply chain.
- Conduct several analyses on nuclear-oriented training and curricula at junior and community colleges, such as (1) the timing to expand such programs and increase teaching staff; (2) options for increasing financial aid for students in those institutions interested in nuclear jobs; and (3) the need for additional resources to expand educational sessions about advanced nuclear energy and employment opportunities in high school science classes and in middle school programs.
- In conjunction with appropriate other Texas state agencies, assess the benefits and costs of obtaining an energy education curriculum designation from the U.S. Department of Education for career and technical education, similar to that obtained by the Commonwealth of Virginia.
- Prepare a Texas energy industry cluster report similar one produced by Michigan, and produce another state-level report that identifies nuclear-oriented occupations in surplus and deficits similar to that prepared by Virginia.
- Collect nationwide data developed by the nuclear industry, academic researchers, and federal laboratory researchers about the long-term personnel demand and supply of key nuclear occupations and job titles (e.g., nuclear engineers) and how any shortages will be distributed across nuclear professional job titles and craft/trades job titles at nuclear facilities.
- Engage nuclear workforce executives about their current staffing needs/pain points; determine how well the demand-driven pipeline functions and how to improve it, if necessary, in coming years when more clarity exists about the timing of SMR manufacturing and deployments.
- Monitor SMR-related workforce policies and programs in other states, provinces, and Europe.

All of the suggested active monitoring tasks can be performed in a resource-efficient manner with limited investment of time, funds, and staff for now. If and when there is a "demand signal" such as multiple SMR orders, then additional resources could be allocated to address any identifiable workforce challenges. Texas state officials in concert with industry, associations, and educational institutions generally should have sufficient time to increase the supply of personnel given the likelihood that the number of manufactured and deployed SMR units will be distributed over a period of 25 years.

Study Limitations and Important Considerations

While funded by the Public Utility Commission of Texas (PUCT), this estimate and analysis of the economic impact of building and deploying SMRs in Texas was conducted independent of the PUCT's Texas Advanced Nuclear Reactor Working Group and its subcommittees. BBR researchers coordinated with the Working Group and observed many of its meetings to collect background information, but the BBR was not charged with reviewing or commenting on their November 2024 report or recommendations.

This report has highlighted the considerable economic potential of manufacturing small modular nuclear reactors in Texas and deploying them both "behind the meter" and onto the state's electric grid. With the understanding that SMRs have yet to be fully permitted, built, and deployed anywhere in the U.S., this study has used modeling, business surveys, interviews, and supply chain analysis to highlight future commercial impacts of adding heat and power generated from SMRs to the state's energy supply.

There are several important limitations to estimating the potential economic impact of building and deploying SMRs in Texas.

Number of SMRs to Manufacture and Deploy: This study used conservative projections of the number of SMRs expected to be built over the next 30 years, but it should be noted that there is tremendous uncertainty among experts, especially given the existing nuclear regulatory regime, the early stage of SMR and advanced nuclear technology, evolving federal nuclear waste policy, and public opinion around safety issues with nuclear power.

REMI Model Limitations: While REMI is among the most dynamic, robust economic impact modeling software available, its E3 energy package (the one used in this study) lacks the ability to generate fiscal impacts. The study team also took advantage of the model's flexibility to adjust nuclear inputs and customized REMI's investment multiplier so as not to overstate the economic impact of a new SMR industry in Texas.

Competition From Other States: Unlike many economic modeling forecasts, such as the impacts of a major new plant in a specific geography, additional uncertainty occurs because actions of other governments (incentives, etc.) are unknown and may very well affect the number of SMRs manufactured and/or deployed in Texas. Development of a Texas SMR nuclear cluster depends in part on unknown future actions by other states and provinces.

Forecast Period: The 30-year study period, and 25-year construction period, while an attribute of the REMI model, is much longer than that commonly used in many models. Occupational workforce forecasts usually are for 10 years, for instance. The longer forecast period is likely to introduce more variables and more variation in possible impacts.

Cost Projection Uncertainty: SMR technology is still in developmental stages, with no deployments completed as of 2024. Costs related to construction, operation, and maintenance are mostly based on the costs of building large nuclear facilities, with some adjustments for the smaller physical plant needed for SMRs. Cost overruns, common in nuclear projects, could skew economic forecasts. What is more, the economies of scale that might be expected to accrue as the industry lands on a standard design, routinizes the construction process, and produces more and more reactors do not appear in the modeling forecasts.

Regulatory Hurdles: The nuclear industry is subject to stringent regulations, and Texas would need to navigate federal and state approval processes. Uncertainties around timelines, regulatory costs, and potential delays complicate economic estimates.

Market Demand Uncertainty: Texas has a deregulated energy market with significant investments in renewables like wind and solar. As this report showed in the ERCOT Grid Modeling section, predicting how SMRs would fit into this energy mix and compete with cheaper renewable sources or natural gas is challenging.

Public Perception and Political Factors: Nuclear energy has a contentious public image, with concerns about safety and waste disposal. In the future, researchers could begin to analyze the public's willingness to support new, safer advanced nuclear power technologies; until then, these social factors could affect political support, land acquisition, and/or local opposition to impact economic forecasts.

Supply Chain and Workforce: Survey results presented here show an interest among Texas manufacturers in joining the supply chain for building SMRs in the state, but more certainly needs to be done to educate firms on the market opportunity before the state can unlock the potential among nuclear-adjacent industries like chemical manufacturing and oil and gas production. On the other hand, this study has shown that there do not seem to be gaps in the current workforce to support and supply this new industry with a qualified workforce in the short term. In the longer term, 2-year and 4-year institutions of higher education in Texas will have to be ready to communicate with the SMR industry to understand the industry's workforce gaps and meet its future workforce needs.

Appendices

Appendix A: Organizations Consulted

Representatives from many organizations in the nascent SMR industry, academia, and federal labs contributed to this analysis by meeting with the research team, answering our questions, suggesting other research to review, and recommending other experts with whom to meet. Without identifying specific individuals, for reasons of confidentiality, we would like to thank the following organizations for their help and cooperation with this study.

Argonne National Laboratory	REMI
Breakthrough Institute	Southwest Research Institute
Clean Energy Buyers Association	Tennessee Valley Authority
Constellation Energy	Texas Association of Business
Dominion Energy Inc.	Texas Association of Manufacturers
Dow Inc.	Texas Chemistry Council
E4 Carolinas	Texas Comptroller of Public Accounts
HII Nuclear	Texas Economic Development Council
Idaho National Laboratory	Texas Oil and Gas Association
Information and Communications Technology Council of Canada	University of Texas at Austin Nuclear and Radiation Engineering Program
Jacobi Consulting	University of Wyoming
Kairos Power	Virginia Nuclear Council
Last Energy	Wharton County Junior College
Natura Resources	X-Energy
National Renewable Energy Laboratory	Xcel Energy
Nuclear Energy Institute	Zachry Group
NuScale Power	
Oak Ridge National Laboratory	
Paragon Energy Solutions	
Port of Corpus Christi	
Princeton University	
Pueblo Economic Development Council	

Appendix B: Select Comments - TEDC Survey

We include these responses to an open-ended question in the survey of Texas Economic Development Council members to illustrate the importance to Texas businesses of reliable sources of electricity. The survey question is reproduced below. Quotes are grouped into two themes that emerged from all responses: Specific Losses and Insufficient Power Capacity.

Please provide information about any specific instances in your area in which insufficient energy/electricity availability has negatively affected a siting decision.
SPECIFIC LOSSES
We have multiple providers in our area which are divided into electric service territories. We recently met representatives of a large $400+ advanced manufacturing facility. Our community met all of the requirements for this project to locate, but the electric provider that served the sites which were under consideration in our city was not able to instill confidence that we could serve the 48 MW capacity of the project that would be needed within the next 10 years. *We are seeing larger and larger demands for power on both manufacturing projects and data center projects. Data centers do utilize a significant amount of energy, but are also a significant benefit for the communities where they locate due to the very sizable amounts of property taxes generated by these projects at the city, county, and school district level. These help to pay for needed services at the local level. Improving the capacity of the grid would allow Texas communities to continue attracting high quality projects to our areas which create new economic opportunities for residents and ensure that our communities remain resilient.*
We have passed on multiple data center projects due to lack of power. Power outages in recent areas have led our existing companies to consider looking for redundant sites.
We serve a small rural area and we have lost developers because of the cost to bring electricity to an area to support multiple single-family homes.
Only delays in providing the required amount of electricity for server farms, but expansion of traditional service power line grids are trying to meet the demands, but falling behind on the construction due to supply chain issues and in some cases right-of-way acquisition.
We recently lost a $550M project that is a key industry in manufacturing components for electric motors. It went to S. Carolina. We have lost several over the years and it's impossible to know the impact to the community, but it happens fairly often for larger facilities.
A plastic board building plant in [redacted] .
After winter storm URI, every industrial client required an explanation of the grid situation. Additionally, we had a client that had large electricity needs. It required transmission level service. Even though the site under consideration was in a developed business park, new lines needed to be extended. The time and cost associated with right of way acquisition, line construction and delivery was not clear and may have been placed on the client. The uncertainty tipped the choice to a site in Ohio. $1 billion investment.

INSUFFICIENT POWER CAPACITY
I am currently working on a $650M Electric Arc Steel Mill. The Steel Mill requires significant power, in my conversations with [redacted], the project will require an onsite substation with cost exceeding $25M and a two-year project build out, which is causing the site selector and company to explore moving the project out of the State of Texas. An SMR would provide the necessary power and the Steel Mill Ownership Team has expressed interest in partnering on such a project. A project of this scope will create over 350 high paying jobs for the City [redacted], [redacted] County, and Region.
We have had some businesses not locate to our area because of the electrical shortage
• *Insufficient existing electrical infrastructure in rural communities* • *Lack of electrical infrastructure near tracts large enough for major manufacturers* • *Rural electric cooperatives not having the capacity to serve nor maps to show service areas* • *Having sites just outside of major electrical provider's service area* • *Lack of substations and transmission capacity* • *Time to market for electrical transmission development* • *Lack of natural gas supply despite being a major production area for it*
I am in [redacted], and we have over $12B in data center projects in the works (already secured power, permitting, purchased the land, and in some form of construction / completion). When and if we can secure more power, I think we will see a greater investment for potentially five to eight more projects. Power demand is growing and now the availability of power is stalling projects.
Two coal plants are being shut down, which will limit the power available for our area. Additionally, transmission infrastructure is limited in the area. Multiple 10-250 MW developments have been proposed, and will require planning and high dollar upgrades to provide the power requirements of facilities such as these.
Inability to site large MW users
We are disqualified from 95% of all leads from the Governor's Office because of a lack of electrical capacity.
The speed to market and ERCOT keeping up with the massive demand is the biggest challenge. We are working with data center developers that could invest upwards of $1+ billion in a rural community with upwards of 500 MW of demand. This has a significant impact in lowering the property tax rate for other residents and businesses in the area. If the speed to market in getting through the ERCOT regulatory process is too confusing or not clear to a developer, then it causes us to lose deals.
Inability to access transformers timely has been the biggest setback for us.
In [redacted], while we do not have specific instances of industries being negatively affected by insufficient energy availability, it is crucial to address this issue proactively to prepare for future growth. Reliable energy infrastructure is a key factor in attracting new businesses and investors to our town.
Data centers of any size
Our max service to both of our industrial parks (400 acres total) is 5 MW. The majority of leads we've seen the past couple of years have wanted 50MW or more.

Appendix C: Fiscal Impacts Associated With SMR Manufacturing and Deployment in Texas

Tax Methodology

We sourced state and local finance data from the U.S. Census Bureau to estimate the state and local tax revenue associated with SMR manufacturing and deployment in Texas. For the high-level estimates, we sourced data from the components of property, sales, and other taxes, found in the Census Bureau's "General revenue from own sources" section of that source's "Table 1: State and Local Government Finances by Level of Government and by State: 2022."[29] To estimate an effective sales and gross tax receipts tax rate, we divided the taxes from the Census estimates by personal consumption expenditures (average for 2021 and 2022, since the REMI data is calendar year and the Census data is fiscal year). We estimated the effective tax rate for other taxes by dividing other taxes from Census by REMI's data on value added. Likewise, we estimated the effective rate for property taxes by dividing property taxes from Census by the sum of gross private domestic fixed investment and regional actual capital stock from REMI. We then multiplied these effective tax rates by the change in the respective factors in Texas for the Low, Medium, and High scenarios. This is not an exhaustive estimate of the changes in tax revenues, but a sampling of major sources.

Tax Revenue Estimates

In Table A1, we present the average annual fiscal impacts from sales, property, and other taxes associated with the cumulative manufacturing and deployment of SMRs in Texas. For the Medium scenario, we estimate that state and local taxes would be $382 million per year in the first five years, growing to nearly $3.8 billion per year in the last five years of the study period 2024–2055.

Table A1: Yearly Average State, Property, and Other Tax Revenue From SMR Manufacturing and Deployment in Texas, 2024–2055

		Average					
Category	**Units**	**Year 1-5**	**Year 6-10**	**Year 11-15**	**Year 16-20**	**Year 21-25**	**2030-2055**
Low	Dollars (Current, Thousands)	278,475	652,611	1,037,424	2,024,876	2,658,208	1,389,803
Medium	**Dollars (Current, Thousands)**	**382,597**	**1,011,217**	**1,660,688**	**2,944,459**	**3,750,325**	**2,031,898**
High	Dollars (Current, Thousands)	390,840	1,084,499	1,812,716	3,153,345	4,047,809	2,188,720

[29] See "U.S. Summary and State Estimate" Excel table from https://www.census.gov/data/datasets/2022/econ/local/public-use-datasets.html, retrieved November 18, 2024.

Appendix D: Supplemental Information on SMR Workforce Issues

In this appendix, we present additional details and data that supplement the Workforce Review section of the main report. The first section here examines estimates of the number of operational employees that may be required for SMRs. We then compare those estimates to the current nuclear workforce at existing large light water reactor plants and estimate the number of construction-related jobs. Next, we present qualitative information obtained from numerous interviews about current and anticipated nuclear workforce supply and demand imbalances over the near- and long-term. Finally, we suggest other workforce issues identified during data-gathering for future analysis.

Quantitative Workforce Estimates for SMRs

This review examines estimates of the number of operational employees based on referent SMR at a 300 MWe plant. We focus on estimates for permanent operations jobs at SMR facilities (construction employment will be intense, but temporary).

Estimates of SMR Operations Workforce

While there is some variation in the estimated operational employment for a referent 300 MWe reactor, we found a fairly consistent estimate to be approximately 100 operational employees. We obtained data for this finding from a detailed economic impact analysis of a proposed Canadian SMR and from a compilation of employment estimates by Idaho National Laboratory (INL) researchers.

PricewaterhouseCoopers (PwC) estimated in 2021 that there would be 101 direct (operational) jobs for each of the 60 years of operations for an Ontario SMR based on proprietary information provided to them by General Electric Hitachi for their BWRX-300 reactor. [30]

Independently, INL researchers compiled the data in Figure A1 based on public releases of information by three SMR companies[31] in 2021 and 2022.

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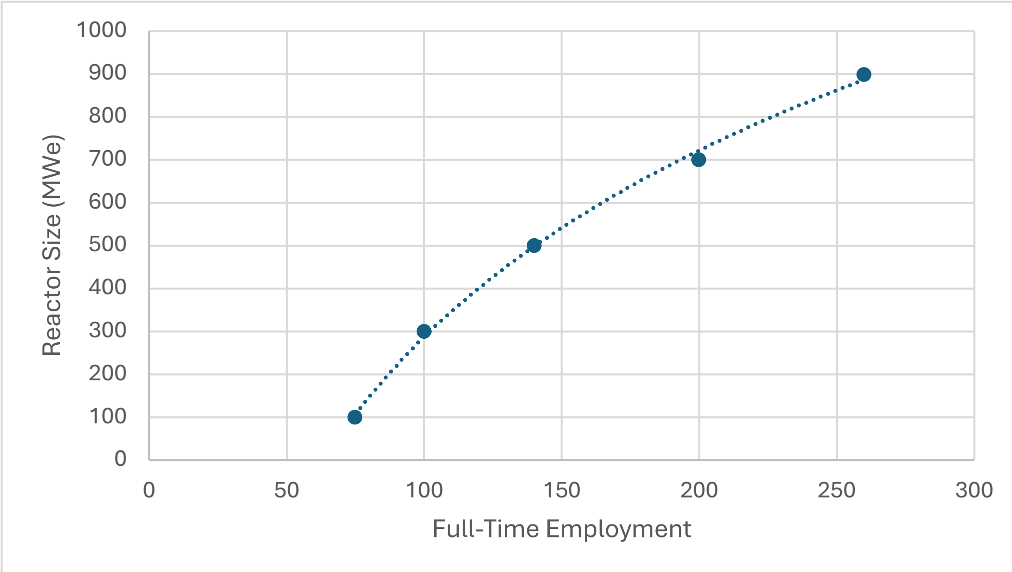
[30] See PricewaterhouseCoopers (PwC)'s *Transforming Canada's energy future: The socio-economic impact of GE Hitachi SMRs. 2021.*

[31] The three companies are NuScale, TerraForm, and X-Energy. The GE Hitachi BWRX-300 reactor analyzed for the Ontario plant was not included in the INL compilation. See page 66 in: J. Hansen, W. Jenson, B. Dixon, L. Larsen, N. Guaita, N. Stauff, K. Biegel, F. Omitaomu, M. Allen-Dumas, & R. Belles. *Stakeholder guidebook for coal-to-nuclear conversions.* (INL/RPT-23-75136). Idaho National Laboratory, Idaho Falls, ID (United States). https://fuelcycleoptions.inl.gov/SiteAssets/SitePages/Home/C2N_Guidebook_2024.pdf

Figure A1. Employment Estimate by Reactor Size (MWe)



Another earlier analysis in 2018 by a researcher at the Pacific Northwest National Laboratory estimated that 166 full-time operational staff would be required for a 625 MWe reactor, an estimate that conforms approximately to the INL compilation of estimates.[32]

It should be noted, however, that not all operational employment estimates are similar. The exceptions are noted below, with several having larger ratios of full-time equivalents (FTEs) to MWe and at least one other having a very low expected full time employment complement.

<u>Michigan</u> - A December 2023 study by Veritas Economics for the Michigan Public Service Commission expected there would be 360 operating personnel for a plant array of 12 SMRs with each SMR rated at 60 MWe or a total of 720 MWe.[33]

<u>Pueblo, Colorado</u> - One detailed analysis of replacement options for a retiring coal plant estimated 200–300 permanent jobs for a 500 MWe advanced generation reactor. The lower estimate of 200 would be higher than the INL estimate for that size reactor, and the 300-person job estimate would be quite high.[34]

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[32] See Short, S.M., and Schmitt, B.E., (2018*). Deployability of small modular nuclear reactors for Alberta applications – phase II.* Alberta Innovates, Edmonton, CA. https://albertainnovates.ca/wp-content/uploads/2020/07/Pacific-Northwest-National-Laboratory-Deployability-of-Small-Modular-Nuclear-Reactors-for-Alberta-Applications-Phase-2.pdf

[33] See Michigan Public Service Commission (2023). *Michigan nuclear study feasibility report*. East Lansing, MI. Draft for public review, December 11. 2023. https://www.michigan.gov/mpsc/-/media/Project/Websites/mpsc/workgroups/nuclear-feasibility-study/Michigan-Nuclear-Feasibility-Study_030124.pdf

[34] See Pueblo Innovative Energy Solutions Advisory Committee Report: https://www.xcelenergy.com/staticfiles/xe-responsive/Archive/PIESAC%20Written%20Report.pdf

Not site-specific - One utility executive gave two very different staffing figures based on the number of reactors at a particular site. He said they were estimating 200–300 employees for a four-module array of 300 MWe reactors, or for a total of 1200 MWe. And for a single low-pressure SMR of 300 MWe, they were estimating 150 operators and another 50 security personnel.

Southeast U.S. - One utility human resource executive said they were estimating SMR operational employment for a 300 MWe to be between 66–70, which is fewer than the range cited above.

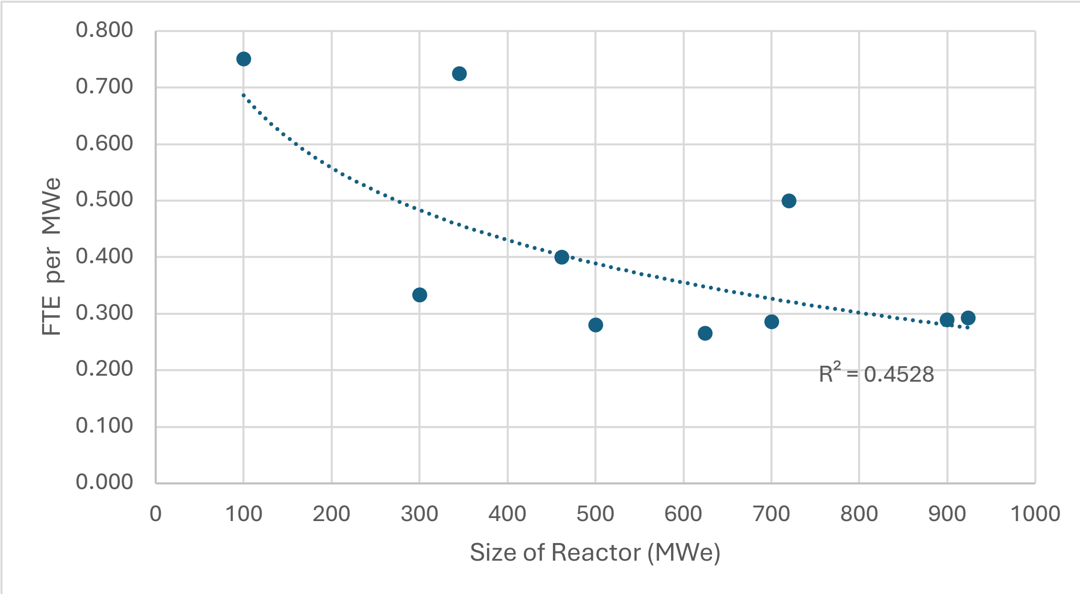
The staffing estimates exhibit more variation when smaller reactors are considered. For a demonstration reactor by one company in Tennessee, an operational workforce of 101 (59 on weekdays and 42 on weekends) was estimated for two 28 MWe reactors, or a total of 56 MWe. An executive noted these estimates were extraordinarily high and said there were two primary reasons: (1) the reactors are a demonstration project; (2) the staff at the demonstration project will be trained for other sites when the SMR reactor is approved and commissioned.

Finally, one of the microreactor companies estimated that their reactor could be operated with fewer than 10 individuals on-site. Their plan is to utilize autonomous control systems to the maximum extent possible, which would enable minimal on-site personnel while also having more backup personnel in a central location for multiple sites.

In summary, while the operational staffing is clearly dependent somewhat on reactor design and size, there is a reasonable range that has been estimated for operating a referent, 300 MWe SMR.[35] On a per-MWe basis, staffing shows a declining trajectory based on the size of the SMRs. For a referent 300 MWe SMR, the staffing ratio is anticipated to be on the order of 0.33 to 0.40 jobs per MWe. (See Figure A2.)

[35] Another compilation of operational workforces for each plant design appears on page 8-6 in Lenowisco Planning District Commission, 2023. *SMR Site Feasibility Study for Lenowisco by Dominion Engineering*. Duffield, VA. https://energy.virginia.gov/renewable-energy/documents/FINAL%20LENOWISCO%20SMR%20Feasibility%20Study%20-%20DEI%2020230520%20.pdf

Figure A2. Full-Time Operational Staff per SMR MWe



Source: Compiled by BBR staff from INL GAIN report and other reports cited.

Staffing Ratios for Existing Light Water Reactors

Employment and staffing ratios for existing light water reactors are mostly higher on a per MWe basis than estimates for SMRs. We show a number of comparisons next.

Internationally, the number of direct jobs, which are operational positions at a nuclear power plant, falls in the range of 0.4 to 1.0 jobs per MWe, or 400 to 1,000 employees per GWe[36] (see Table A2.) For the U.S., with 98 GWe and 70,000 jobs, that would translate to 714 jobs per GWe or 0.71 per MWe. For an SMR with 300 MWe, that ratio of 0.714 would yield 214 direct jobs, a number that is about twice that estimated for SMRs immediately above.

[36] See Clean Energy Ministerial. (2022). *Nuclear energy—providing power, building economies*. NREL/TP—6A50-82419. Original sources of data are shown below the table.

Table A2. Countrywide Job Creation From Nuclear Programs[37]

Country	Nuclear Capacity (GWe) (at the time of the study)	Direct	Indirect	Induced	Total Estimated Jobs
France	63	125,000	114,000	171,000	**410,000**
South Korea	18	29,400	36,700	27,400	**93,500**
United States	98	70,000		430,000	**500,000**

Another set of data comes from a December 2015 report by the Nuclear Energy Institute.[38] Based on the ratio of employees to MWe at each facility, the direct jobs (full-time) are:

Comanche Peak:

Direct full-time: 908
MWe: 2,400
Ratio: 0.378 direct jobs per MWe

South Texas Project:

Direct full-time: 1153
MWe: 2,560
Ratio: 0.45 direct jobs per MWe

The two ratios for full-time employees are on the low end of the average for the U.S. of 0.714 per MWe (714 per GWe). The combined ratio of direct jobs to power generated would be:

Total direct jobs from Comanche Peak and STP: 2061
MWe from both facilities: 4960
Ratio: 0.414 per MWe or 414 per GWe.

[37] Original data sources:

- International Atomic Energy Agency (IAEA). 2021. *Assessing national economic effects of nuclear programmes*. IAEA-TECDOC-1962. Vienna.
- Nuclear Energy Agency (NEA) and International Atomic Energy Agency (IAEA). 2018. *Measuring employment generated by the nuclear power sector*. OECD Publishing. Paris. https://doi.org/10.1787/9789264305960-en
- Nuclear Energy Institute (NEI). 2020. *Nuclear energy in a low-carbon energy future.* https://www.nei.org/resources/reports-briefs/nuclear-energy-in-a-low-carbon-energy-future

[38] See Nuclear Energy Institute. (2015). *The economic benefits of Texas' nuclear power plants.* https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/economic-benefits-texas-nuclear-plants-201512.pdf

A more recent example comes from 2024 report *The Economic Impact of the Nuclear Industry in the Southeast United States: A Regional and State-Level Analysis*, by researchers at E4 Carolinas.[39] For South Carolina, the ratio of direct jobs to power was 0.411. For the other states in the region, a slightly higher ratio was computed to be 0.448.

Also, a PwC economic impact analysis of four AP-1000 pressurized water reactors in Canada estimated a ratio of 0.400 per MWe or 400 employees for each of the four units.[40] And in a very detailed analysis, McQuade of Atomic Energy of Canada gave current staffing for existing Candu 700 MWe plants and an estimate for a newer version of the size plant. The ratios were about the same, 0.68 staff per MWe.[41]

The conclusion from all of these studies is that existing light water reactors are more labor intensive than estimated staffing needs for SMRs.

Estimates of SMR Construction Workforces

The construction of a nuclear power plant requires a much larger labor force than its operation. That has been the case for large light water reactors and will be the case for SMRs. Several estimates of SMR construction workforces have been published.

In Michigan, Veritas Economics estimated construction workforce requirements for a 12-module array totaling 720 MWe at a specific site. Over four years, construction employment each year was estimated as follows:

Year:	2032	2033	2034	2035
Full-time employment:	1815	908	2285	2992

The differences in annual construction employment are based on the sequence of on-site activities.

> *The first year of construction covers site improvement activities including major excavating work for all buildings, structures, and employee parking lots as well as a vast majority of the concrete work used in construction of foundations for building, structures, and onsite waste storage facilities. The second year of construction covers structural steel erection and exterior finishing for the primary buildings included on the site. The third year of construction covers interior finishing of the onsite buildings as well as physical security measures used to prevent thefts and sabotage relating to special nuclear material that will be housed at the site during the operation of the plant. The fourth year of construction is when the SMR reactor will be delivered and installed. The final year of construction covers materials and machinery used to finish the facility construction and functionality as it is tied into the grid.*[42]

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[39] See Von Nessen, J. & Brun, L. (2024, February). *The economic impact of the nuclear industry in the Southeast United States: A regional and state-level analysis.* E4 Carolinas. https://www.commerce.virginia.gov/media/governorvirginiagov/secretary-of-commerce-and-trade/va- nuclear/E4_Carolinas_Economic_Impact_Report_Final.pdf

[40] See Westinghouse Nuclear, (2023). *The economic impact of a Westinghouse AP1000 Reactor Project in Canada*. https://westinghousenuclear.com/media/3nrbtsc0/the-economic-impact-of-a-westinghouse-ap1000-reactor-project-in-canada.pdf

[41] See McQuade, D. (2001). *Staffing requirements for future small & medium reactors (SMRs) based on operating experiences and projections*. IAEA-TDCDOC-1193. International Atomic Energy Agency (IAEA). https://www-pub.iaea.org/MTCD/Publications/PDF/te_1193_prn.pdf

[42] Quote from page 38 in: Michigan Public Service Commission (2024). *Michigan nuclear study feasibility report*. https://www.michigan.gov/mpsc/-/media/Project/Websites/mpsc/workgroups/nuclear-feasibility-study/Michigan-Nuclear-Feasibility-Study_030124.pdf

Two recent estimates about construction periods and employment are slightly different. One from an engineering, procurement, and construction company suggests that a typical SMR would require only three years and have a peak construction employment of between 1,500 and 2,000 employees. A reactor company executive also suggested a maximum construction period of three years and maximum construction employment of 1,500.[43]

Construction employment estimates by PwC for the Ontario SMR plant are lower than for Michigan or the confidential estimates. In the Canadian analysis, a four-year period covering both manufacturing and construction was computed for the Province of Ontario. For that time-period and for both major tasks, full-time employment was estimated to average 1,140 employees.[44] The Conference Board of Canada also has estimated employment impacts for a four-module array to be deployed in Saskatchewan from 2032 to 2041. Unfortunately, only summarized employment estimates were available.[45]

Qualitative Findings

In this section, we review several current nuclear workforce issues, anticipated future gaps in meeting SMR nuclear workforce demand, and potential strategies for addressing those gaps.

Shortages, Pain Points, and General Lack of Supply

Interviews with utility executives and federal laboratory workforce researchers identified multiple challenges:

- Well-known supply and demand issues with trades and crafts and some engineering fields.
- Long-term problems with shortages of some such radiation physics, radiation protection.
- More separations due to retirements, a trend mirrored in national demographic statistics and workforce trends in other industries.
- Lack of awareness by potential employees about nuclear energy employment opportunities.
- A reluctance of some younger workers to consider any type of nuclear position.

Less common reasons also cited were:

- Lower pay than available with other employers, especially on construction projects and for those in the trades/crafts who already are making a good wage.
- More clearances and background checks than at other similar projects.
- Inconsistency of jobs due to periodic interruptions and layoffs.
- More voluntary separations by younger employees.

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[43] Both estimates were provided by individuals who were promised confidentiality for their respective interviews.

[44] Put differently, the average annual number of full-time direct employees for manufacturing and construction was estimated at 11 times the number for operational employees. However, the manufacturing and construction would occur over seven years while operations would occur over a 60-year period.

[45] See The Conference Board of Canada. (2021). *A new power: Economic impacts of small modular nuclear reactors in electricity grids, summary for executives*. https://www.conferenceboard.ca/product/a-new-power-economic-impacts-of-small-modular-nuclear-reactors-in-electricity-grids/

In general, there is concern about most trades, with especially acute shortages among electricians and welders. In nuclear job titles, the supply and demand of operational workers is generally in balance, with the exception of some shortages of radiation protection employees. One utility executive said their most difficult recruiting challenges are and will continue to be for low-volume occupations in health physics, radiation health, and radiation protection. They do not have well-established pipelines for these job titles as they do for operators, technicians, and engineers.[46]

And one nuclear supply chain company has had difficulty recruiting for nuclear architects, logic design engineers, and nuclear personnel with particular experience and has had to recruit nationally instead of in their headquarters region.

Possible Remedies for Current and Near-Term Challenges

Larger, expanded, and new pipelines of talent are being built or planned to address current and near-term shortages. Examples of initiatives at educational institutions include:

- Establishing new nuclear curriculums such as a nuclear minor concentration in an engineering department or a new nuclear engineering program.
- Establishing new and expanded internships and apprenticeships as well as scholarships for students.

Other remedies being tried by utilities and other state governments:

- Recruiting from non-nuclear industries such as oil and gas, concrete, petrochemicals, aerospace, and defense.
- Utilizing training programs that exist at federal labs for radiation technicians or company training programs for welders and project managers.
- Attempting to reduce the voluntary separation rate of employees by smoothing out the peaks and valleys for trades and crafts employees so they have a sustainable workforce without interruptions and layoffs.
- Establishing new outreach and recruitment activities for separating military personnel in particular and at Historically Black Colleges and Universities.

Longer-term forecasts add more complexity. One analysis of SMR staffing from 2018 to 2050 focused on Nigeria and emphasizes staffing and training at a national level.[47] Several items are worth mentioning. First, the top three functions to be recruited are maintenance/construction (18%), operations (9%), and management (8%). Second, different skill sets need to be recruited at different time periods, and none of them show a real increase until 2034 based on an initial SMR being added to their grid in 2027.

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[46] For an extensive and in-depth analysis of nuclear-related occupations in one-region see TIP Strategies. (2015). *regional workforce study. Savannah River site community reuse organization*. https://srscro.org/wp-content/uploads/2019/10/2015-Regional-Workforce-Study.pdf .

[47] See Egieya, J., Amidu, M.A., & Hachaichi, M. (2023). Small modular reactors: An assessment of workforce requirements and operating costs. *Progress in Nuclear Energy, 159*. https://doi.org/10.1016/j.pnucene.2023.104632

A more relevant and important article reviewed the nuclear engineering (NE) workforce in the United States.[48] Because the multiple authors are from numerous institutions, and due to the recency of the analysis, its findings deserve serious consideration. Recommendations were consensus expert opinions on actions needed to ensure that the nuclear engineering profession will be able to meet the nation's future needs. The authors recommended the following items:

> *1. The profession should carefully monitor for a potential lack of experienced engineers to fill the mid-level positions as older personnel retire, especially within the nuclear utility employment sector. Although, currently, there appears to be an adequate supply of entry-level workers, the sector may need to implement professional development activities to ensure a sufficient cohort of adequately prepared mid-level engineers.*
>
> *2. Employers should continue to take steps to preserve their corporate knowledge and experience bases as the wave of retirements of older workers continues.*
>
> *3. Sufficient support should be available to maintain an appropriate capacity of academic NE programs. Although student enrollment in NE departments and programs is currently robust, a contraction of the nuclear engineering job market could jeopardize academic NE programs, for example, following the shuttering of additional nuclear plants in the United States in the future. Reduced employment opportunities for graduating students would eventually reduce the numbers of students in the training pipeline and likely result in a reduction in the number of remaining NE degree programs, as occurred in the 1980s and 1990s.* [49]

A third longer-term workforce estimate also has appeared in some publications. According to this analysis, an additional 375,000 workers will need to be trained or retrained to support the deployment and operation of 200 GWe by 2050. Despite that analysis being prepared under contract to the U.S. Department of Energy, there is no original document that has been released or is available for review by academic researchers or researchers at federal laboratories. Without the ability to review, it will be omitted from further consideration.[50]

In summary, the inferences for the near-term and longer-term are somewhat mixed. Near-term, there will be an increasing need for nuclear personnel as many of those in nuclear positions now are on the verge of retirement. However, the initial focus may need to be on training existing nuclear personnel rather than building more capacity for new personnel. Longer-term, there is general agreement that a larger nuclear workforce will be required, but how much larger is yet to be based on solid projections and clearly dependent on the additional nuclear generation that would be deployed.

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[48] Townsend, L.W., Brady, L.; Lindegard, J., Hall H.L., McAndrew-Benavides, E. & Poston, J.W. (2022). Nuclear engineering workforce in the United States. *Journal of Applied Clinical Medical Physics*. https://doi.org/10.1002/acm2.13808

[49] Quote from pages 6 and 7 in: Townsend et al., 2022).

[50] See pages 31, 45, 57 of U.S. Department of Energy. (2023). *Pathways to commercial liftoff—advanced nuclear*. https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Advanced-Nuclear-vPUB.pdf
This report shows that building 13 GW of new nuclear capacity per year would require 375,000 workers by 2050 for construction, manufacturing, and operations. Roughly 100,000 would be required to operate the 200 GW of reactors in 2050 and 275,000 would be required for construction and manufacturing.

Other Workforce Issues

Although operational and construction-related workforce problems do not appear to be imminent, there are some workforce issues that may need to be addressed in the near future.

Manufacturing Workforce - There are unknown challenges regarding the workforce needed to produce the estimated number of SMRs that could be manufactured in Texas and deployed outside the state. That has received scant attention and until there are actual orders for SMRs, any workforce issues are unlikely to be identified as high priority by state workforce officials or researchers. Although many larger manufacturers have project management experience to smooth out peaks and valleys on orders that overlap for the same type of product, how much of a challenge it will be for them cannot be determined now. Also, as construction of SMRs will require dedicated modular assembly capabilities that either do not exist or are constrained, there may well be problems with establishing efficient manufacturing processes with the initial SMRs.[51]

Contractors (EPCs) - There is likely to be an increased workload on administrative staff responsible for record-keeping and materials management. That will also apply to human resources staffs that have responsibility for checks and screening of workers. Quality assurance (QA), quality controls, and QA training will receive more emphasis to meet NRC standards.

Timing of New Government Workforce Investments - Because of the extreme uncertainty about the timing of SMR progress, there should be a "demand signal" before significant investments are made. That demand signal should come from private sector employers as new investments should be developed with employers. The timing issue is one that all states are facing and can be summarized by what appeared in a November 2023 report in Kentucky:[52]

> *Nuclear development in Kentucky will require timely, accurate, and precise coordination with educational systems and existing workforces. This will allow the next generation to learn, practice their trade, and gain the experience necessary in a*

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[51] The modular assembly issue was cited on page 49 of the U.S. Department of Energy Pathways to Commercial Liftoff—Advanced Nuclear. Modularization also was analyzed in Stewart, R., Gregory, J., & Shirvan, K. (2022, October). Impact of modularization and site staffing on construction schedule of small and large water reactors, *Nuclear Engineering and Design.* 397: 111922.

[52] See Kentucky Office of Energy Policy. (2023). *Report to the Kentucky Legislative Research Commission Pursuant to 2023RS SJR 79.* Frankfurt, KY. https://eec.ky.gov/Energy/Documents/Final%20Report%20SJR79_11.17.23.pdf
Noteworthy other recent reports from state governments regarding SMRs are:

Commission to Investigate Next-Generation Nuclear Reactor Technology in New Hampshire. (2023). *Final report*, Concord, NH. https://nuclearnh.energy/wp-content/uploads/2023/12/NH-Nuclear-Study-Commission-2023-Final-Report.pdf
Connecticut Department of Energy and Environmental Protection, 2024. Draft Report on Select Connecticut Energy Supply Issues. Hartford, CT. https://www.dpuc.state.ct.us/DEEPEnergy.nsf/c6c6d525f7cdd1168525797d0047c5bf/edfbba1211ab2e0c85258ad0005400d9/$FILE/PA%2023-102,%20Section%2035%20-%20Study%20Draft%20Report.pdf

Pennsylvania Joint State Government Commission. (2024). *Benefits of nuclear energy and development of small modular reactors.* Harrisburg, PA. http://jsg.legis.state.pa.us/resources/documents/ftp/publications/2024-02-08%20(HR238)%20Small%20Modular%20Power%20Final%20Report%20FEB%208%202024.pdf

State of Washington Legislature. (2016). *Small modular reactors: An analysis of factors related to siting and licensing in Washington state.* https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=SMRFinalReport_7ba0bec6-1c34-4f92-a601-c9df0806a70e.pdf *variety of skills and at a pace that will match the deployment of different energy projects across Kentucky. The Working Group expressed concern for the lack of accredited nuclear engineering or nuclear technician programs within Kentucky, but also expressed concerns about the viability, cost and timing of any programming for these career paths. The Working Group also recognized the importance of K-12 education in helping expose young students to different career pathways that could lead them to a career in energy, and potentially nuclear energy. However, the Working Group was resolute in the importance of timing and pacing of workforce development activities. This is classified as an area where an initiating event would require the development of any workforce development activity. The workgroup expressed concerns over premature workforce development activities relating to nuclear energy development that would result in trained workers having to look for employment outside the state.*[53]

[53] For one example of a premature recommendation involving Texas, see Krieger, K., & Morris, L. (2011). *Texas' efforts to increase nuclear technology workforce.* [conference session]. WM2011 Conference, February 2011, Phoenix, AZ. https://archivedproceedings.econference.io/wmsym/2011/papers/11407.pdf Quote is from pages 30-31.