THE UNIVERSITY OF TENNESSEE KNOXVILLE

HOWARD H. BAKER JR. SCHOOL OF PUBLIC POLICY AND PUBLIC AFFAIRS


# Economic Impacts of Construction and Operation of a Small Modular Reactor on Tennessee

Prepared for the
Tennessee Nuclear Energy Advisory Council

**Dr. Matthew N. Murray, Dr. Elis Vllasi and Dr. Jilleah G. Welch**

October 28, 2024

*Acknowledgment:* This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the State Energy Program Award Number DE-EE0009487.

# Economic Impacts of Construction and Operation of a Small Modular Reactor on Tennessee

**Prepared for the**

**Tennessee Nuclear Energy Advisory Council**

**Prepared by**

**Dr. Matthew N. Murray**

**Dr. Elis Vllasi**

**and**

**Dr. Jilleah G. Welch**

**Baker School of Public Policy and Public Affairs**

**The University of Tennessee**

**October 28, 2024**

*Thanks to David Owenby, Senior Advisor, Tennessee Department of Environment and Conservation; Charles Sims, TVA Distinguished Professor of Energy and Environmental Policy; Lou Qualls, Vice President, Boston Government Services and Tennessee State Energy Policy Council; Traci Boatner, President, East Tennessee Economic Council and Tennessee Nuclear Advisory Council; and Nicole Allen, Vice President and Director of Communications and Growth, East Tennessee Economic Council for comments, conversations, and input on this report. Special thanks to TVA for the provision of data and background information. The views expressed here are those of the authors.*

# Scope

## Economic Impacts of Construction and Operation of a Small Modular Reactor on Tennessee

The Tennessee Nuclear Energy Advisory Council (TNEAC) identified supporting TVA's deployment of a small modular reactor at the Clinch River Nuclear site as a priority in our Preliminary Report (December 2023). To that end, the TNEAC commissioned the University of Tennessee Baker School of Public Policy & Public Affairs to produce an assessment on the *"Economic Impacts of Construction and Operation of a Small Modular Reactor in Tennessee*." The findings of the Baker School's SMR Economic Impact Assessment (EIA) follow here and provide valuable information to the TNEAC as it drafts its Final Report to be delivered by October 31, 2024.

This EIA estimates an SMR (300 MW) deployed in Tennessee would generate $1.4 billion in construction spending directly sourced from within the state. Netting out employment benefits and taxes on worker payroll, $1 billion in spending would spread through supply chains and create a multiplying ripple effect across Tennessee. This would facilitate 16,440 new jobs (or 1,827 jobs per year) and increase the total production of goods and services in the state by $1.6 billion, or $175.2 million annually. Annual operational costs of the SMR would generate $98.5 million in yearly output for Tennessee and 717 jobs per year.

This EIA reflects best construction cost projection for a 60% complete SMR design. The EIA has greater confidence in the model and multiplier to estimate economic impacts to output (GDP), income, and jobs. For $1 billion in in-state construction spending on goods and services, this EIA projects Tennessee's output (GDP) grows by $1.6B. This economic impact figure is largely scalable. If actual *in-state* construction cost increases, the impact would be roughly expected to increase according to that 1.6:1 ratio, e.g., if construction cost is $2 billion, then then economic impact for Tennessee would be close to $3.2 billion.

While an increase to generation capacity would be an important net benefit of the SMR deployment, this EIA focuses specifically on economic impact of output, income, and jobs from the construction and ongoing operation of an SMR. It is important to note that this EIA is not a comprehensive evaluation of all the benefits that would arise from deploying an SMR in Tennessee, such as:

- The addition of reliable, resilient, safe, clean baseload power for 40 years or more and annual generation sales realized.
- Strategic value of building the first SMR would address "First of A Kind" (FOAK) costs and set the stage for ideal cost reduction, up to 40% per unit, as additional SMRs are built.
- Supply chain opportunities for Tier 1-3 suppliers locating or expanding in Tennessee for manufacturing or fabricating components for SMR deployment in Tennessee. EIA offers guidance in approaching GE-Hitachi and TVA to discuss opportunities and expectations for growing in-state spending on goods and services during construction of an SMR in Tennessee as well as any subsequent units.

- Potential for premium pricing schedule or agreements for SMRs' carbon-free power from particular purchasers (e.g., data centers, hyperscalers, etc.)
- Effects of first and future SMRs attracting talent, R&D/tech transfer, wraparound knowledge, capital, and community support to benefit the region's nuclear ecosystem, further demonstrating that Tennessee is a hub for nuclear development, manufacturing, and deployment.

The EIA highlights the output, income, and jobs impact from the construction and operation of an SMR in Tennessee - important aspects contributing to the overall benefits arising from such a deployment. While this EIA is not a full calculation of benefits, it demonstrates that there is significant value in deployment and provides material information for the TNEAC. It may also offer useful insights for other decision-makers, such as the TVA Board and interested stakeholders.

## Executive Summary

Tennessee has strong roots in the nuclear sector, dating back to the era of the Manhattan Project. Today, Tennesseans rely on nuclear power for a significant share of their baseload electricity generation. Nuclear related research and other activities, from nuclear medicine to legacy site cleanup and waste remediation, represent important assets of the East Tennessee economy. This foundation has the potential to support the next generation of electric power supply through the construction and deployment of small modular reactors (SMRs). SMRs and nuclear power generation have the capacity to provide clean energy and help meet the nation's ongoing decarbonization goals and energy security needs while also providing widespread economic development benefits.

This report, prepared by the University of Tennessee Baker School of Public Policy and Public Affairs, documents the potential economic impacts from the construction and operation of one SMR on the Clinch River, a joint initiative of the Tennessee Valley Authority (TVA) and GE-Hitachi. While the project remains in the planning stage with no firm commitment to move forward, all the necessary steps are being taken to prepare for the actual construction of the facility. The BWRX300 would be the first SMR to be built and operated in the U.S. Construction preparation would commence in 2024, with completion slated for 2032, at which time the facility would become operational.

The impact estimates here are based on confidential data from TVA and include $1.4 billion in construction spending incurred directly (i.e., sourced) in Tennessee, a figure that includes employment benefits and some state and federal taxes. Netting these latter components out translates to $1.0 billion in spending that would spread through supply chains and create multiplier impacts as spending ripples across the state. Operational spending would support ongoing impacts through nonpayroll spending, payroll spending, and employment. The modeling presented here captures the economic impacts on state output (gross domestic product), labor income, and jobs in Tennessee.

The analysis reveals substantial multiyear impacts from construction:

- Total production of goods and services (state gross domestic product or *output*) would increase by $1.6 billion or $175.2 million per year,
- Income accruing to workers in Tennessee would total $1.4 billion or $151.5 million a year, and
- Total person-year employment would represent 16,440 jobs or 1,827 full-time jobs per year.

The impacts from operations are expressed in terms of a representative year of facility operation using 2033 as the base year.

- Deployment would support 717 jobs, with 205 tied directly to operations,
- Income for Tennesseans tied to new employment opportunities would total $56.9 million per year, and
- Total new output for the state economy would be $98.5 million a year.

Additional benefits would accrue to Tennessee through a number of channels, including increased in-state sourcing of construction materials, multiple SMR builds and deployments, spillovers to related sectors (nuclear medicine, waste remediation), and additional research, development, demonstration, and deployment (RDD&D) and partnerships with universities and private industry.

## Introduction

Enthusiasm continues to grow regarding the prospect of a renewed domestic focus on nuclear power. Primary drivers are the energy transition and the need for a clean source of electric power to replace fossil fuels along with growing demand from sources including artificial intelligence. The primary headwind to nuclear adoption is cost and the need for a multi-decade payback period on investment. Because baseload energy demands cannot be completely met today by renewables, nuclear power offers a compelling alternative. In addition, reaching net zero (i.e., balancing emissions production with emissions removal) will require clean electricity and today there are few alternatives to nuclear power.

Enthusiasm for nuclear power is also driven by interest in potential economic development impacts, including job and income creation, support of critical supply chains, RDD&D, and synergies that spillover to related activities like nuclear medicine. R&D and spillover benefits are likely unique to nuclear power compared to other mature generating technologies. Domestic security and energy security concerns have also sparked interest in nuclear power options and alternatives.

SMRs are an important piece of the modern nuclear energy profile that appears to be emerging in the U.S. and abroad. SMRs are generally viewed as safe, capable of meeting both baseload and niche energy supply needs, offer siting flexibility, and can help balance overall loads across the distribution network. Because they are modular, they lend themselves to simpler manufacturing, production, and installation processes. Modularity is especially important to economic development impacts since multiple units and their component parts could be sourced from areas with unique expertise and capacity.

Tennessee and the Tennessee Valley Authority (TVA) are well-placed to play a leading role in America's potential nuclear renaissance. Currently under consideration is the construction and deployment of up to four SMRs through a partnership between TVA and GE-Hitachi, which owns the technology under consideration (BWRX300). The nuclear industry's existing economic impact in the state is already impressive and includes $9.8 billion in economic output, $3.2 billion in labor income, and over 40,000 jobs.[1] According to the East Tennessee Economic Council (ETEC) – a leading voice for the state's nuclear sector – there are more than 350 nuclear locations in the state, with 229 nuclear companies. While 154 are located in the Knoxville metropolitan area, the jobs are spread across the state with concentrations in all of Tennessee's major metropolitan areas.[2] The nuclear industry in the state benefits from the presence of numerous private businesses, including Kairos Power, TRISO-X, Ultra Safe Nuclear Corporation, and Type One Energy, that focus on advanced reactor technology, advanced nuclear fuel, pilot fuel manufacturing, and fusion energy technology. There is also a robust presence of federal agencies in East Tennessee (e.g., Oak Ridge National Laboratory (ORNL), Y-12 National Security Complex (Y-12), Oak Ridge Associated Universities (ORAU)) and institutions of higher education across the state (e.g., the University of Tennessee and its highly ranked Department of Nuclear Engineering, Tennessee Technological University, Chattanooga State Community College, Roane State Community College, Vanderbilt University). Together, these and other assets offer an extraordinarily strong foundation to build upon to support the state's energy independence and national energy security through the construction and operation of SMRs.

The estimates presented here indicate significant economic impacts from TVA's potential investment in SMR construction and deployment. Total employment impacts from the construction of a single SMR are estimated to be 16,440 person-year jobs or 1,827 full-time jobs per year. Operational-year direct employment by TVA of 205 workers will support 512 additional jobs through supply chains and the multiplier process, yielding a total employment of 717 for a representative year of facility activity. Substantial impacts would also be created for state gross domestic product (GDP) and income for Tennesseans.

The remainder of this report provides details on the statewide economic impact estimates associated with the construction and deployment of an SMR on a site on the Clinch River in East Tennessee. The discussion starts with a background on SMRs. Economic impact methods and impact estimates are subsequently presented. The report then discusses several unique facets of the SMR project that are important to framing the impact estimates. A brief conclusion closes the report.

---

[1] Joseph Von Nessen and Lukas Brun, "The Economic Impact of the Nuclear Industry in the Southeast United States, A Regional and State-Level Analysis," E4 Carolinas. February 2024. Estimated impacts account for direct, indirect, and induced effects that are discussed in the economic impact modeling section below.

[2] ETEC has assumed a prominent role in supporting the region's nuclear sector, with a strong emphasis on much needed workforce training and development. See, for example, https://www.eteconline.org/nuclear-industry-hub/ This link also provides a map of the nuclear companies in Tennessee.

## A Primer on SMRs

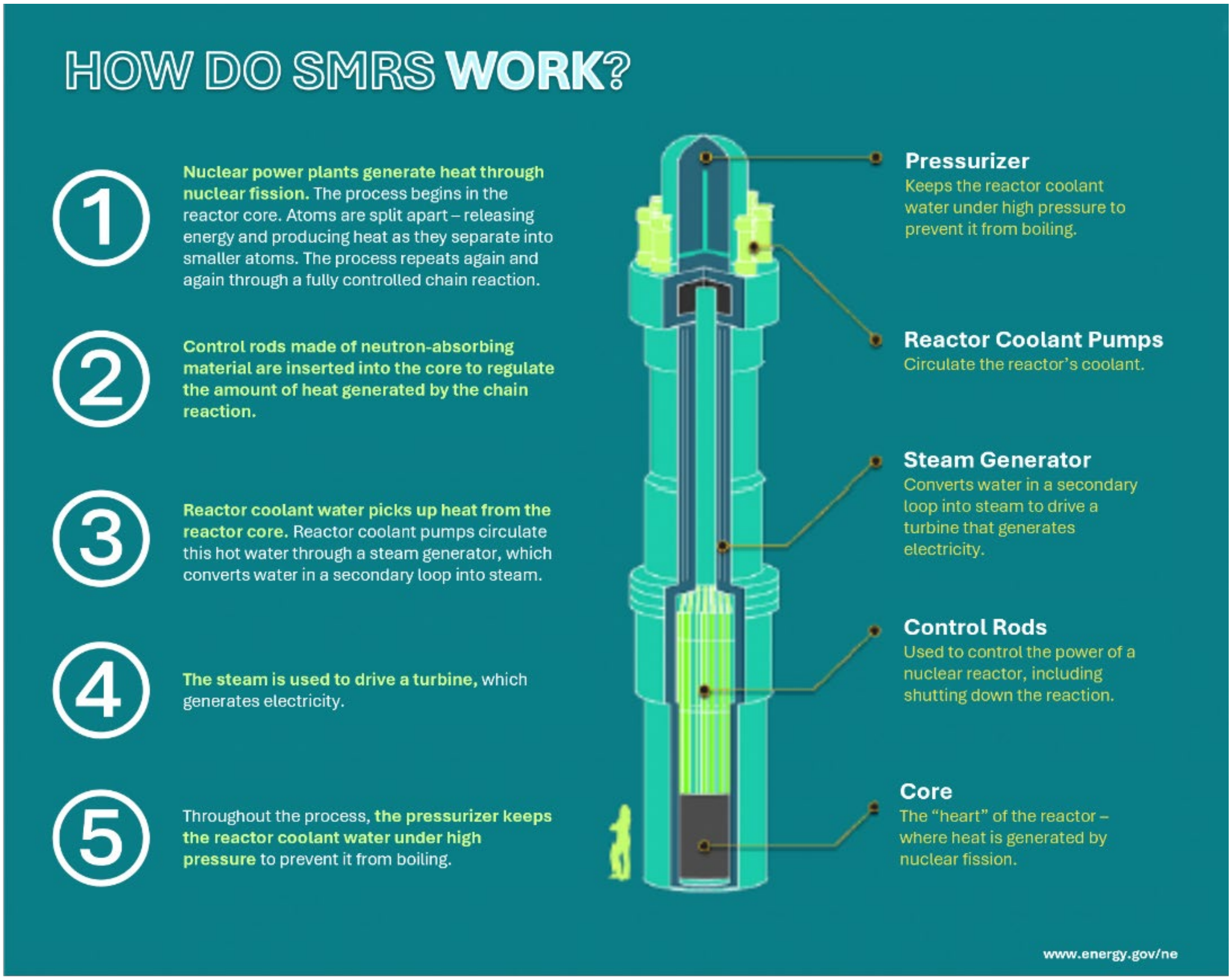
There are various definitions for SMRs that cover a range of sizes and reactor technologies. Generally, SMRs are distinguished from the very small class of reactors known as microreactors, which typically produce 10s of megawatts of electricity (MWe), but they are smaller than the traditional light water reactor, which produces around 1000 MWe. A further distinction is that the current fleet of operating reactors is used only to make electricity, whereas some SMRs can be used to produce industrial high-temperature heat in addition to making electricity. According to the International Atomic Energy Agency's definition,[3] SMRs are "advanced nuclear reactors that have a power capacity of up to 300 megawatts of electricity (MWe) production per unit." They are small as they are about one-third the size of traditional nuclear reactors; modular since their major components can be factory constructed, assembled, and transported to a site for installation; and recognized as reactors, since they use nuclear fission to produce energy. In other words, a "small modular reactor uses energy from a controlled nuclear chain reaction to create steam that powers a turbine to produce electricity."[4] Figure 1 provides one illustration, though this does not correspond precisely to the technology of the BWRX300 discussed below.

---

**3** Joane Liou, "What are Small Modular Reactors (SMRs)?", IAEA Office of Public Information and Communication. https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs

4 Idaho National Laboratory, "What are Small Modular Reactors?" https://inl.gov/trending-topics/small-modular-reactors/

**Figure 1. A Snapshot: How Do SMRs Work?**




*Source: Office of Nuclear Energy, U.S. Department of Energy*

Within the range of power generation output, SMRs can be further broken down into different sizes to serve different power needs. EnerData defines three categories[5]:

1. *5-15MW* – also known as *micro-reactors* used for off-grid applications
   - Isolated communities, military and defense use, natural disaster response
2. *15-200 MW* – for heat and/or electricity in energy-intensive industrial sites
   - Desalinization, mines, O&G extraction, hydrogen production
3. *200-400 MW* – for network-connected power generation
   - Replacement of coal-fired power plants, electrification of medium-sized cities and isolated industrial centers, networks with insufficient capacity for higher power plants

***What are the Different SMR Designs?*** In addition to varying power output, SMRs also differ in terms of design. While figures vary, EnerData lists 83 SMR designs in development, spanning Generation II (Gen II) to Generation IV (Gen IV), across 18 countries.[6] Gen II designs are older models; Gen IV models share modern features generally related to simplified design and increased passive safety. According to an American Academy of Arts and Sciences report,[7] Gen II nuclear reactors, typically known as light water reactors (LWRs), are commercial reactors designed to be economical and reliable with a lifetime of 40 years. Operating since the 1960s, they primarily include pressurized water reactors (PWR), boiling water reactors (BWR), advanced gas-cooled reactors (AGR),[8] and constitute the bulk of nuclear reactors in use today. A distinguishing feature of Gen II reactors is that they use traditional active safety features involving electrical or mechanical operations that can be initiated automatically or by the operators of the nuclear reactors.

Gen III reactors built on Gen II with state-of-the-art improvements in fuel technology, thermal efficiency, modularized construction, safety systems (especially the use of passive systems), and standardized design with a 60-year operational life. Gen III+ designs include significant improvements in "passive safety features that do not require active controls or operator intervention but instead rely on gravity or natural convection to mitigate the impact of abnormal events."

Gen IV refers to a number of nuclear reactor technologies that are still in the conceptual or prototype phase, with wide adoption and deployment still decades away.[9] Gen IV build on Gen III+ units, including

---

[5] EnerData, "An Emerging Technology Backed by Public Policies." https://www.enerdata.net/publications/executive-briefing/smr-world-trends.html
[6] Ibid. EnerData.
[7] Steven M. Goldberg and Robert Rosener, American Academy of Arts & Science, Nuclear Reactors: Generation to Generation. nuclearReactors.pdf (amacad.org)
[8] Gen II reactors also include: CANada Deuterium Uranium reactors (CANDU) and Vodo-Vodyanoi Energetichesky Reactors (VVER).
[9] There is only one Gen IV reactor (HTR-PM) that is operational and is found in China. World Nuclear News, December 6, 2023, China's demonstration HTR-PM enters commercial operation : New Nuclear - World Nuclear News (world-nuclear-news.org)

the ability to support industrial processes (e.g., hydrogen production, water desalination).[10] The designs include reactors that are gas-cooled fast, lead-cooled fast, molten salt, sodium-cooled fast, supercritical water-cooled, or very high-temperature gas. [11] The Gen IV designs must also improve on Gen III+ in terms of sustainability, economics, safety and reliability, and non-proliferation.

The reactor designs vary by fuel, coolant, use, and size:

- Land-based Water-Cooled: 25 designs
- Marine-based Water-Cooled: 8 designs
- High-Temperature Gas-Cooled: 17 designs
- Liquid Metal Cooled Fast Neutron Spectrum: 8 designs
- Molten Salt: 13 designs
- Micro-Reactors: 12 designs

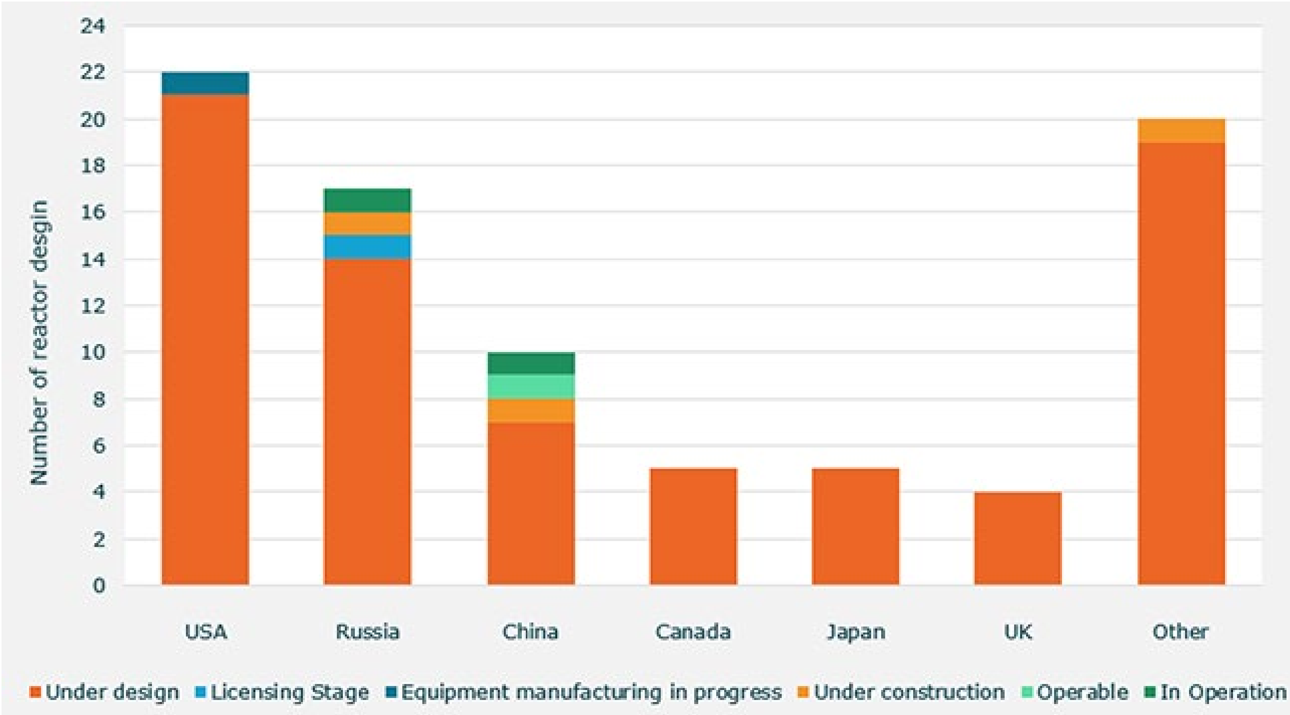
Only two SMR designs are currently operational, and both are based on older technologies. One SMR is in Russia, a 70 MW Russian KLT-40S by JSC Afrikantov OKBM, Pressurized Water Reactor (PWR), which is a Gen II design. China has built two SMRs. One is in operation, a 210 MW Chinese HTR-PM by Tsinghua University, High Temperature Gas Reactor (HTGR), which is a Gen II design, and the other one is an operable demonstration unit, the 2.5 MW HTR-10, HTGR, a Gen IV design.

Of all SMRs currently in development, "[t]he USA leads in terms of … design recorded (22 different designs), followed by Russia (17), China (10), Japan (5), Canada (5), and the UK (4)." It is not clear how this proliferation of models affects the adoption choice. On the one hand, the variety offers competition and opportunities for novel designs, but the same variety may create uncertainty about moving forward, especially for first adopters.

---

[10] Goldberg and Rosner, nuclearReactors.pdf (amacad.org)
[11] Nuclear: what is a 4th generation reactor? - Polytechnique Insights (polytechnique-insights.com)

**Figure 2. Worldwide SMR Reactor Designs by Country of Origin (2022)**




*Source: IAEA, 2022; Enerdata 2024*

The U.S. SMR designs include six land-based water-cooled, five high-temperature gas-cooled, one liquid metal-cooled, five molten salt, and five micro-reactors.[12]

***What Are the Key Advantages of SMRs?*** Small modular reactors offer key advantages relative to traditional nuclear power plants.

- *Modularity:* For some designs, modularity allows SMRs to expand the power output by adding modules, decreasing power output by shutting off modules, and making repairs without shutting down the whole plant.
- *Standardization:* The smaller size and modularity of the nuclear reactors allow for standardization and in-factory manufacturing and shipping of major components to the construction site.
- *Configurability*: SMRs can be customized depending on location, installed into an existing grid or remain off-grid, or be built on an existing coal power plant footprint.
- *Reliability and Efficiency*: SMRs can achieve the same efficiency and high reliability that the current fleet of nuclear reactors are providing.

---

[12] International Atomic Energy Agency, "Advances in Small Modular Reactor Technology Development," (2022 Edition). https://aris.iaea.org/Publications/SMR_booklet_2022.pdf

- *Functional Flexibility*: SMRs can support residential or industrial needs with district or process heating.
- *Operating Flexibility*: SMRs can complement renewables by providing load-following functions, currently performed by fossil-fueled plants, to promote grid stability.
- *Siting Flexibility*: SMRs require only 10 percent to 25 percent of the land area of a traditional nuclear plant.[13] GE-Hitachi Nuclear Energy claims that its GE-Hitachi BWRX300 – a model TVA is evaluating for potential, future deployment – achieves about 90 percent volume reduction in plant layout.[14] Moreover, some SMRs can be built near urban centers and away from large bodies of water.
- *Safeguards and Security*: Some SMRs can be installed underground, which can lower the risk of sabotage or natural hazards. As most major components are built in a factory, some SMR reactor cores (limited to microreactor designs) can be returned to the factory with the reactor vessel for defueling. The reactors are built with various passive safety features, including steam condensation and gravity, that allow cooling for extended periods (weeks to months) without power or operator action. Safety is often further enhanced by a simpler reactor design, lower core power, and/or larger fractions of coolant.
- *Lower Capital Investment and Operating Costs*: Relatively lower costs are expected due to smaller size, a shorter construction period, modular construction, and factory fabrication. SMRs may also offer economies of scale due to factory production of multiple units, easier decommissioning processes, reduced operating staff, reduced refueling needs (more operational time), and lower cooling requirements.
- *Enhanced Economic Development*: Construction and operation of an SMR produces economic impacts like new jobs and an expanded tax base that are of value to the host community and state. In addition, unlike singular large capacity generation facilities, SMRs can yield economic development benefits through *ongoing* production and parts manufacture. The attraction is the potential to produce and export multiple SMR units as well as their component parts. Additional benefits arise from related supply chains, facility deployment and management expertise, and R&D that supports nuclear advancement.

***What SMR Design is TVA Considering?*** One SMR design that TVA is evaluating is the GE-Hitachi BWRX300 small modular reactor for potential, future deployment at the Clinch River Nuclear Site.[15] The reactor is designed by GE Hitachi Nuclear Energy (GEH), under a Technology Collaboration Agreement with TVA,

---

[13] Idaho National Laboratory, "Advanced Small Modular Reactors." https://inl.gov/trending-topics/small-modular-reactors/

[14] GE Hitachi Nuclear Energy, "BWRX-300 Small Modular Reactor." https://www.gevernova.com/nuclear/carbon-free-power/bwrx-300-small-modular-reactor

[15] For more information on the TVA proposal see https://www.tva.com/energy/technology-innovation/advanced-nuclear-solutions

Ontario Power Generation (Canada) and Orien Synthos Green Energy (Poland), and will be constructed from parts and materials sourced from the U.S., Canada, and Europe. This reactor is a *Generation III+* design (a modernized version of a light water reactor, in this case, a Boiling Water Reactor with passive safety features), a land-based water-cooled reactor, and is capable of supplying electricity to the grid and electricity and/or steam for process heat applications, district heating, and hydrogen production. According to GE, the BWRX300 reactor is based on a U.S. NRC-licensed, 1,520 MWe Economic Simplified Boiling-Water Reactor (ESBWR) and incorporates the 10th evolution of boiling water reactors since GE began developing nuclear reactors in 1955.[16]

The key features of the reactor include:

- *Design Type*: Boiling Water Reactor (BWR)
- *Coolant*: Light water
- *Power*: 300 MWe (electricity output) / ~900 MWth (thermal/steam output)
- *Power Capacity to the Electric Grid*: 285 – 315 MWe / In-house use: ~15 MWe
- *Operation Cycle*: 12–24 months / 10-20 days outage per cycle
- Design (Plant) Life: 60 - 80 years
- *Building Size*: ~ 2.1 acres
- Fenced Plant Area: ~ 6.5 acres
- Total Operating Staff: ~70[17]
- *Material & Equipment Overnight Capital Costs*: $1 billion (1st unit), $750 million (nth unit), with costs continuing to change over time

To date, this reactor has been selected for pre-licensing/permit application/deployment in Canada, Poland, the UK, and the U.S. This multi-country commitment has enabled technical collaboration among GEH and multiple power providers, including TVA, Ontario Power Generation (Canada) and Synthos Green Energy (Poland), and ~ $400 million investment in the design and development of a standard reactor that is deployable in these countries and beyond.

The BWRX300 unit provides numerous advantages, according to GEH.[18]

- *Safety*: a design that mitigates large Loss-of-Coolant Accidents (LOCAs) due to "simpler passive safety systems and a more integrated Nuclear Steam Supply System compared to prior Light Water

[16] U.S. Nuclear Regulatory Commission, "Issued Design Certification – Economic Simplified Boiling-Water Reactor (ESBWR)." https://www.nrc.gov/reactors/new-reactors/large-lwr/design-cert/esbwr.html
[17] GE Hitachi Nuclear Energy, "BWRX-300 General Description," December 2023, Table 19-2. https://www.gevernova.com/content/dam/gepower-new/global/en_US/images/gas-new-site/en/bwrx-300/005N9751_Rev_BWRX-300_General_Description.pdf. Also see "Status Report – BWRX-300 (GE Hitachi and Hitachi GE Nuclear Energy)," September 30, 2019, table 2. https://aris.iaea.org/PDF/BWRX-300_2020.pdf
[18] GE Hitachi Nuclear Energy, "BWRX-300 one of the most economical SMR designs available." https://www.gevernova.com/content/dam/gepower-new/global/en_US/images/gas-new-site/en/bwrx-300/GEA34170A-GE-Hitachi-BWRX-300-Factsheet-R7.pdf

Reactor (LWR) designs." As it uses "natural circulation and passive cooling isolation condenser systems," the unit "passively cools itself for seven days without power or operator action during abnormal events, including station blackout. Indefinite cooling is achieved by the simple action of water addition to the isolation condenser pools."

- *Savings*: the scale and simplicity of the reactor (compared to larger/other SMRs) is projected to have up to "60% less capital cost per MW when compared with other typical water-cooled SMRs," as well as "significant reductions in operating staff, maintenance cost, and security requirements." It "can be constructed in 24-36 months utilizing modular and open-top construction techniques proven in Japan."
- *Supply-Chain*: The key reactor components and the systems will be manufactured across the U.S. and allied countries (Canada, Europe, Japan), offering a more secure and greater quality supply chain and the assurance of competitive pricing.

***How Secure are SMRs?*** Expectations are that SMRs offer greater physical security due to their inherent designs and reduced site area compared to large nuclear plants. However, any SMR, like all pieces of modern technology, will incorporate digital equipment that may be connected to communication networks (whether wireless or wired). Such digital and connected systems could make SMRs vulnerable to cyber threats like any generating asset. In 2022, there were more than 800,000 cyber-attacks in the U.S.,[19] with many significant breaches conducted by hostile states (e.g., China, Russia, Iran) and non-state actors against critical infrastructure.

An international workshop on SMR security convened by the World Institute for Nuclear Security concluded that "[n]o clear guidelines exist regarding SMR security. Developers are not sure where the boundaries are or how much protection is necessary for their designs." A key conclusion is that "cybersecurity risks are manageable."

***How Much Does an SMR Cost?*** The cost estimates for SMR construction vary widely because of many considerations, including variation in design and, most importantly, the fact that there is no track record to build on. Projected costs appear to be much higher today than just a few years ago. A 2021 report asserts that the first-of-a-kind (FOAK) Levelized Cost of Electricity (LCOE)[20] for SMRs is $98/MWh for investor-owned utilities and $76.7 /MWh for municipal-owned utilities, with no government partnerships. With government partnerships (for example, loan guarantees), LCOE costs fall to $48.4 and $43.4 /MWh for investor and municipal-owned utilities, respectively.[21] The same report claims overnight capital costs (OCC)

---

[19] USA Facts, "How many cyberattacks occur in the US?" https://usafacts.org/articles/how-many-cyber-attacks-occur-in-the-us/

[20] See, for example, U.S. Energy Information Agency, "Levelized Costs of New Generation Resources in the *Annual Energy Outlook 2022*," March 2022, https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

[21] SMR Start, "The Economics of Small Modular Reactors." March 2021. http://smrstart.org/wp-content/uploads/2021/03/SMR-Start-Economic-Analysis-2021-APPROVED-2021-03-22.pdf

of $3,800 kW for an SMR facility size of 600MWe with a construction period of 36 months and a deployment year of 2030.

A 2024 study by the Institute for Energy Economics and Financial Analysis finds that SMRs are expensive and that the estimated costs are rapidly rising.[22] The study examined the rising costs of traditional reactors (Georgia Power Vogtle, Units 3 and 4) as well as SMRs (NuScale, X-Energy, and GE Hitachi BWRX300) and found that the actual costs were significantly higher than the estimated costs at the design stage. For example, the projected costs for the NuScale SMR in 2015 were $9,964/kW, but by 2023, those projected costs had ballooned to $21,561/kW. The same trend holds for the GE Hitachi unit, with 2020 costs projected at $2,883/kW and the 2023 costs at as high as $12,347/kW.

A recent academic study by Asuega, Limb, and Quinn[23] shows that different studies provide a range of OCCs between $3,782 and $4,978/kW for light water SMRs. Their modeling analysis estimates the OCC to equal $4,355 /kW and an LCOE of $90 /MWh for a light-water SMR. The overall and per KW costs of TVA's proposed SMR have not been disclosed.

Newly implemented FOAK technologies commonly come at a high cost, with costs falling through subsequent deployments. This means that the economic impact of initial units will be larger than the impacts from subsequent units. The same high costs for initial units represent a significant barrier to entry for new technologies like SMRs. Because electricity prices must remain competitive to avoid adverse impacts on economic development, this is a major challenge for TVA and other utilities considering SMR adoption.

## Economic Impact Modeling: Background

Economic impact analysis is the standard tool used to estimate the consequences of changes in economic activity, from the location of a new manufacturing firm to the closure of a coal-fired power plant. The same tools are employed here to measure the effects of SMR construction and operations spending on the Tennessee economy. The following discussion starts by providing background on the methodology underlying the estimation and then briefly reviews the limited research on the economic impacts of SMRs. The next section presents the results and findings.

***Estimation methods***. The most important feature of economic impact analysis is that it is driven by expenditures. Economic impacts originate through *direct* spending, in this instance by TVA and its partners and prime contractors. This includes payroll disbursements as well as the acquisition of supplies, equipment, construction materials, aggregate, fuel, machinery, wiring, reactor materials, and so on that are tied to facility construction and operations.

---

[22] David Schlissel and Dennis Wamsted, "Small Modular Reactors, Still Too Expensive, Too Slow and Too Risky." Institute for Energy Economics and Financial Analysis. May 2024. https://ieefa.org/sites/default/files/2024-05/SMRs Still Too Expensive Too Slow Too Risky_May 2024.pdf

[23] A. Asuega, B.J. Limb and J.C. Quinn, 2023. Techno-economic analysis of advanced small modular nuclear reactors. *Applied Energy*, *334*, 120669.

Since the focus is Tennessee, it is essential that the direct spending used in the impact modeling be confined to in-state expenditures. The reason is that spending incurred outside the state generally has an inconsequential impact, if any impact at all, on the state economy. For example, precision-machined pipe fittings acquired from an out-state-vendor would have an impact on the state of origin, not Tennessee. Installation of these same fittings could impact the state and would, in principle, be captured through construction and installation spending, which is included in the analysis. Nuclear fuel is an example of a costly input that will be sourced from outside the state. Because a significant share of inputs for SMR construction would come from out of state, there are potentially large first-round direct spending leakages that create economic impacts elsewhere. This is the case for virtually all businesses since no regional economy has the capacity to produce everything it needs. While many tangible inputs to construction will come from outside the state, considerable payroll and nonpayroll spending will be incurred in Tennessee, yielding substantial economic benefits.

Direct spending on the project is the first of many rounds of economic impact for both construction and operations. Nonpayroll expenditures on goods and services initiate *indirect spending* that works through the business supply chain, from sophisticated components to mundane janitorial and landscaping services. This boosts in-state business activity, creating additional nonpayroll spending, employment, and worker payrolls in firms across the state.

Payroll tied to direct spending—construction workers and TVA oversight personnel—will largely be spent in the state, initiating *multiplier effects*. Similarly, as workers in the supply chain receive their income, most will be spent in Tennessee, creating additional multiplier effects. The ripples span business sectors, including retail trade, finance, insurance, services and so on. Multiplier effects influence virtually every sector of the state economy. For example, a TVA employee may purchase an automobile made in Tennessee, which enhances production activity in the state's automotive sector. Workers in the automotive sector expend their income on a range of goods and services, further enhancing employment and payroll across the state. These workers, in turn, expend income in Tennessee, yielding additional income, employment, and state production of goods and services. The *multiplier* measures these ripple effects. Together, the direct, indirect, and multiplier effects capture the overall economic impacts on the state.

While in-state expenditures are the impact driver, measures of economic benefit used here are wage and salary income that accrues to Tennesseans, jobs held in the state, and state gross state product. These metrics are commonly used in economic impact analysis since they reflect benefits that accrue to the state and its residents.

Each economic impact benefit measure—income, employment, and GDP—has a multiplier associated with it. The income multiplier, for example, captures the number of times a dollar turns over in the economy. The income multiplier accounts for the leakage of purchasing power that arises from out-of-state spending and savings at each round of the process. The employment multiplier indicates how many jobs would be created in total from one direct job. For example, an employment multiplier of 2.0 means that one additional job is created for each direct job tied to the project. Multipliers tend to be larger for larger regional economies because there are fewer leakages at each round of the spending process. In practice, this means that state-level multiplier impacts will tend to be larger than local-level multiplier impacts.

The analysis here uses RIMS II multipliers for the Tennessee economy that are acquired from the U.S. Bureau of Economic Analysis.[24] These data are built on actual industry data that account for business-to-business transactions and other economic linkages.

***Other SMR impact studies***. A small number of studies have explored the potential economic impacts from SMR construction and deployment, though none are specific to a potential TVA project in Tennessee. One is an analysis that considered the impacts of $1 billion in hypothetical construction spending on an SMR.[25] This study did not examine a specific input spending profile on goods, services, and payroll but simply assumed a $1 billion construction cost. Direct employment associated with construction is estimated to be 9,647, with a total employment of 16,164, including indirect and multiplier effects. The $1 billion in direct spending on the facility would create $2.1 billion in total output. Direct employment of 1,128 for operations would create 4,200 total jobs, with annual direct spending of $1.0 billion supporting $1.8 billion in total output. A similar study was released in 2010 that considered the economic impact of a "prototypical 100 MW SMR" that would cost $500 million to construct.[26] The estimates indicate a total construction impact of 7,000 jobs and $404 million in earnings for workers. Operational impacts were estimated to yield 375 jobs with $27 million in earnings. The multipliers for this second study generally range between 2.5 and 2.9.

A summary of a third report notes that a 600 MWe SMR could create $500M in output each year with an employment multiplier ranging from 1.7 for a local community and 2.4 for the host state.[27] A fourth study undertaken by the Conference Board of Canada for Ontario Power Generation considered the construction and operation of an SMR in Canada.[28] The estimates are based on lifetime returns and indicated an output (GDP) contribution of C$15.3 billion. Employment impacts would total an average of 2,000 jobs per year. Few details are provided for either of these studies.

---

[24] For an introduction and additional resources see https://www.bea.gov/news/blog/2020-08-03/bea-updates-regional-economic-tool. Alternative models include REMI (https://www.remi.com) and IMPLAN (https://implan.com/) The latter two propriety economic impacts models use the same core data to develop their modeling framework and multipliers.

[25] E4 Carolinas, "The Economic Impact of the Nuclear Industry in the Southeast United States: A Regional and State-Level Analysis," February 2024.

[26] The Energy Policy Institute, "Economic and Employment Impacts of Small Modular Reactors," June 2010. https://www.nrc.gov/docs/ML1802/ML18023A166.pdf

[27] SMR Start, "The Economics of Small Modular Reactors." March 2021. http://smrstart.org/wp-content/uploads/2021/03/SMR-Start-Economic-Analysis-2021-APPROVED-2021-03-22.pdf

[28] Conference Board of Canada, "Ontario Powe Generation: Economic Impact Analysis of Small Modular Reactors (SMRs)," 2023. https://www.opg.com/releases/opgs-smrs-will-generate-jobs-and-lasting-economic-benefits-for-ontario/

The most detailed study available evaluated the impacts of potential SMR construction on a 16-county region in eastern Idaho.[29] The proposed NuScale SMR that was evaluated would include 12 modules with 60 megawatts of capacity per unit. Total project costs were estimated to be $2.5 billion, with $1.4 billion of direct spending anticipated in eastern Idaho. The total employment impact across the four-year construction period was estimated to be 13,422 (or an average of 3,356 jobs per year), with the creation of $644.2 million in labor income. While the SMR project is similar to the TVA proposal, the regional scope of the analysis is rather different, which has implications for the magnitude of estimated impacts. Most significant is that the population of the 16-county region (389,841) is just 5.8 percent of the Tennessee population (6.8 million) in 2018. A much smaller population means far less economic diversity and far greater leakages of expenditures at each round of spending, reducing both supply chain and multiplier impacts. Worker salaries on the project were also much lower than the salaries for the TVA project, which means lower *levels* of income injected into the region to support the multiplier.

## Economic Impact Modeling: Estimates

This section provides estimates of the economic impact of SMR construction and operations based on data provided by TVA. The discussion starts with an overview of the scope of the project and input data and then turns to construction impacts, operational impacts, and overall impacts.

***Project overview and input data***. TVA has been working for several years to lay the foundation for the potential construction of one or more SMRs at its Clinch River site. TVA is currently engaged with GE-Hitachi, which owns a proposed SMR technology, and is in the process of seeking approvals from the Nuclear Regulatory Commission; pre-site approval has been granted. At this time, neither a construction permit nor an operating permit has been issued. Importantly, TVA has not made a firm commitment to move forward with the project. Based on direct communication with TVA: “Any decisions will be subject to support, risk sharing, required internal and external approvals, and completion of all necessary environmental and permitting reviews.”

Many of the costs incurred to date are one-time planning and regulatory costs that total well over $100 million. These are not included in the impact analysis presented here. The expenditure data that have been provided for both construction and operations are confidential estimates and presented at a relatively high level of aggregation. This level of detail is nonetheless more than adequate to enable economic impact analysis.

Construction activity could begin as soon as the necessary permits have been granted. Construction would continue into 2032, at which time operations and power generation could begin. The analysis of construction includes startup and commissioning activity by TVA personnel.

---

[29] Idaho Policy Institute and McLure Center for Public Policy Research, University of Idaho, “Economic Impact Report: construction and Operation of a Small Modular Reactor Electric Power Generation Facility at the Idaho National Laboratory Site, Butte County, Idaho,” January 29, 2019. https://www.rediconnects.org/wp-content/uploads/2019/02/SMR-Economic-Impact-Report-FINAL.pdf

***Construction overview***. TVA has shared some of the key assumptions underlying the data that have been provided on the construction phase. These are important to understanding what is and what is not included in the impact assessment:

- Data provided are specifically targeted at project construction-related work performed inside Tennessee;
- First of a Kind (FOAK) engineering, original equipment manufacturer (OEM) engineering to adjust the standard design to site, and any other design engineering-specific costs are not included;
- Engineering work and planning field engineering, including change engineering, is included;
- Operations and operations support development, staffing and training are included in the estimate, including staffing numbers;
- Commodities and materials cash flow include only cash flows for items that can be potentially purchased in the state of Tennessee;
- OEM equipment cash flows, long lead equipment, and specialty items are not included in the Commodities and Materials cash flow;
- Indirect craft (riggers, operators, etc.) are included as a separate line item in the Labor section;
- Contractor equipment purchases are not assumed to be acquired in Tennessee and are not in the construction estimates;
- Construction planning by project management, etc., does not include EPC (Engineering, Procurement and Construction) contractor home office support.

Because the SMR technology being evaluated for potential deployment is owned by GE-Hitachi, they will have considerable control over input sourcing for the project.

As noted above, the expenditures expected to be incurred in Tennessee are isolated from overall spending on the project. There are several assumptions embedded in the data that may lead to underestimation of impacts, including the omission of some FOAK costs, potential OEM acquisitions in Tennessee that are not accounted for, and construction equipment purchases that might take place in Tennessee. Specific items that will be purchased out of state include: Reactor Pressure Vessel (RPV), Reactor Internals, Reactor Isolation Valves, Main Steam Isolation Valves, and Turbine/Electric Generator.

The current workplan expenditure estimates have construction labor force, construction management, construction engineering, and permanent staff budgeted for the current year through 2032; construction material acquisition in Tennessee is assumed to begin in 2026 and cease in 2031.

All construction labor will be sourced from Tennessee. This is important since in-state labor will be used to assemble/install an extensive array of inputs purchased from both inside and outside the state. Startup and commissioning will be staffed by permanent TVA employees, most or all of whom reside in Tennessee.

Total project spending in Tennessee will be $1.4 billion. These data have been adjusted so that they are net of state and federal taxes, as well as employee benefits like pensions that are generally not included in impact modeling.[30] Across all years of the project, adjusted direct labor costs total $661.0 million, and commodity and materials costs total $379.2 million, for a total of $1,040.2 million in expenditures incurred in Tennessee. Estimates of *total* SMR construction costs are unknown at this time. Assuming a hypothetical cost in the range of $3 to $4 billion would imply that significantly less than one-half of the costs are being sourced in the state. Construction-person years are projected to total 4,867 or about 541 workers per year on average. Peak employment years are late in the current decade.

Workers engaged on the project will generally earn high wages and salaries, reflecting the complexity of the construction, management, engineering, and oversight that is necessary for SMR construction and operation. The average annual salary for the construction phase is $135,804, reflecting high salaries for management professionals and the construction labor force. These high salaries have important implications for the magnitude of estimated economic impacts as they will drive large volumes of spending through the multiplier process, yielding significant numbers of jobs and robust growth in state output.

***Construction impact estimates***. The estimated impacts of construction and startup on employment, income, and output are presented in Tables 1-3. All monetary data presented here and elsewhere below are in nominal terms unless otherwise indicated.

Direct employment impacts start in 2024 with a total of 9 person-year direct jobs, jumping to 919 jobs in 2029, then falling to 276 jobs in 2032, at which time TVA's startup and commission workforce will be larger than construction employment. Over the course of the construction phase, 4,867 person-year jobs are supported.

Construction-related nonpayroll spending is zero in 2024, 2025, and 2032, so there are no impacts on the supply chain in these years. However, multiplier income is generated from payroll spending in these same years. (Note from the discussion above that only nonpayroll spending affects the supply chain, while all spending has a multiplier impact.) *Indirect Plus Multiplier* employment estimates start at 18 jobs in 2024, rising to 292 jobs in 2025, and then increase significantly as construction activity (including nonpayroll spending) accelerates. Peak indirect and multiplier employment comes in 2029 with 2,350 jobs. Total indirect and multiplier employment supported by construction across all years is 11,573 person-years.

The total employment impact reported in the last column of **Table 1** accounts for direct jobs as well as indirect and multiplier jobs. Beginning at 27 jobs in 2024, the total employment impact reaches a peak of 3,269 jobs in 2029. Total person-year employment is 16,440 for an average of 1,827 jobs per year

Note that the final row of Table 1 implies that the employment multiplier is 3.4 (16,440/4,867), indicating that each job created in construction produces an additional 2.4 jobs through supply chains and the

[30] Pensions are an important deferred benefit program for workers but spending impacts do not occur until retirement. Health insurance benefits are generally omitted from economic impact modeling because of the difficulty of making linkages to in-state spending.

multiplier process. This large employment multiplier impact is attributable to the relatively high salaries of construction, management, and startup workers noted above, which means a large amount of new purchasing power is injected into the state economy. The average salary for this labor force ($135,804) is more than twice the statewide average wage of $67,800 for all Tennessee workers in 2024.[31] This volume of construction-related payroll income fuels support for large numbers of jobs through the multiplier effect. In other words, a job paying twice the state average can support many more jobs through the multiplier process than one paying the statewide average.

### Table 1: Employment Impacts from Construction

| Employment | | | |
|---|---|---|---|
| Year | Direct | Indirect Plus Multiplier | Total |
| **2024** | 9 | 18 | 27 |
| **2025** | 209 | 292 | 501 |
| **2026** | 707 | 1,511 | 2,218 |
| **2027** | 595 | 1,924 | 2,519 |
| **2028** | 695 | 2,108 | 2,803 |
| **2029** | 919 | 2,350 | 3,269 |
| **2030** | 869 | 2,116 | 2,985 |
| **2031** | 589 | 941 | 1,530 |
| **2032** | 276 | 313 | 588 |
| **Total** | **4,867** | **11,573** | **16,440** |

Income impacts for construction are reported in **Table 2**. In 2024, direct income is just $1.9 million, rising to a peak of $119.7 million in 2030. Total direct income across all years is $661.0 million, or $73.4 million per year.

*Indirect Plus Multiplier* income rises sharply following 2025 to $91.3 million in 2026, largely reflecting construction nonpayroll spending. Total indirect and multiplier income across all years amounts to $702.3 million or $78.0 million per year. The total income impact (including direct, indirect, and multiplier effects) starts at just $3.0 million in 2024, climbs rapidly to $181.9 million in 2026, peaks at $256.2 million in 2029

[31] Appendix A, Table 1, An Economic Report to the Governor of Tennessee, 2024, Boyd Center for Business and Economic Research, the University of Tennessee, https://haslam.utk.edu/publication/economic-report-to-the-governor-2024/

and then falls to $65.0 million in the final year of construction. Total income estimated to accrue to workers in Tennessee is $1.4 billion or $151.5 million per year.

The implied income multiplier is 2.1, using the total income figure across all years ($1.4 billion) divided by total direct income ($661.0 million). In other words, each dollar of income expended on the projected yields just over another dollar of income for a worker in Tennessee.

### Table 2: Income Impacts from Construction

| Income | | | |
|---|---|---|---|
| Year | Direct | Indirect Plus Multiplier | Total |
| **2024** | $1,909,593 | $1,124,136 | $3,033,729 |
| **2025** | $26,716,566 | $17,753,147 | $44,469,714 |
| **2026** | $90,602,149 | $91,284,170 | $181,886,319 |
| **2027** | $79,333,181 | $116,022,267 | $195,355,448 |
| **2028** | $92,516,519 | $127,166,666 | $219,683,184 |
| **2029** | $114,315,752 | $141,885,684 | $256,201,436 |
| **2030** | $119,662,482 | $128,659,418 | $248,321,901 |
| **2031** | $91,184,460 | $58,139,001 | $149,323,461 |
| **2032** | $44,710,174 | $20,246,731 | $64,956,906 |
| **Total** | **$660,950,876** | **$702,281,221** | **$1,363,232,097** |

**Table 3** provides impact estimates of SMR construction on the state's output, i.e., state GDP. Because there is no nonpayroll spending incurred in Tennessee in the first two years and in the last year of construction, there are no *direct* impacts on output in these years. (It is likely that nonpayroll acquisitions will take place outside Tennessee in all years of the project.) Other years show the direct output (i.e., nonpayroll spending) associated with materials and commodities acquisition in Tennessee. The total direct output from nonpayroll acquisitions is $379.2 million or $42.1 million per year of the project. The indirect/multiplier impact on output rises sharply in 2026 when nonpayroll expenditures come into play and income from payrolls grows (see Table 2). Total output from the supply chain and multiplier is $1.2 billion across all nine years or $133.1 million a year. The total impact accounting for direct, indirect, and multiplier effects is nearly $1.6 billion or $175.2 million per year.

The ratio of total output ($1.6 billion) to direct output ($379.2 million) implies an output multiplier of 4.2. This relatively large multiplier reflects the absence of any direct spending impact for three years of the project as well as significant amounts of income supporting multiplier impacts on output.

### Table 3: Output Impacts from Construction

| Output | | | |
|---|---|---|---|
| Year | Direct | Indirect Plus Multiplier | Total |
| **2024** | $0 | $2,894,752 | $2,894,752 |
| **2025** | $0 | $40,499,643 | $40,499,643 |
| **2026** | $39,746,126 | $157,848,824 | $197,594,950 |
| **2027** | $84,260,107 | $163,730,958 | $247,991,065 |
| **2028** | $87,289,904 | $185,278,652 | $272,568,556 |
| **2029** | $87,289,904 | $218,324,110 | $305,614,014 |
| **2030** | $73,665,547 | $219,400,413 | $293,065,960 |
| **2031** | $6,965,312 | $141,819,927 | $148,785,239 |
| **2032** | $0 | $67,776,153 | $67,776,153 |
| **Total** | **$379,216,900** | **$1,197,573,431** | **$1,576,790,332** |

***Economic impacts for a representative year of operations***. The proposed SMR would have a life span of 40 – 60 years. During this time period, there will be ongoing operational spending as well as spending tied to maintenance, refueling, and upgrades. Nonpayroll spending data from TVA include broad categories—e.g., general and administrative, fuel and control blades, dry casks, and waste treatment. Some TVA costs are omitted here, specifically those for outages and a decommissioning fund. The reason is that these categories do not necessarily represent actual expenditures injected into the economy that support typical year activities—the expenditure of these funds would create economic impacts that are not accounted for here. Capital expenditures are estimated by TVA to be $2.1 million a year for costs incurred in Tennessee. The facility would be staffed by 205 workers who earn an average salary of $121,057 per year.

The *representative year* impacts are summarized in **Table 4**. Direct nonpayroll spending amounts to an output contribution of $35.5 million. Indirect and multiplier impacts add $63.0 million to state output. Together, the output effect for a representative year of facility operations totals $98.5 million. The output multiplier is estimated to be 2.8.

Direct payroll income amounts to $24.8 million, and indirect and multiplier income amounts to $32.0 million. Total income for Tennessee workers is $56.9 million. The income multiplier tied to operations is 2.3. Direct employment is 205, and indirect/multiplier employment across the state is 512. Together, the ongoing employment impact is 717 jobs per year. The employment multiplier is 3.5, once again reflecting the substantial income generated from payroll spending that supports greater employment creation across all sectors of the state economy.

**Table 4: Representative Operational Year Impacts**

| | Output | Income | Employment |
|---|---|---|---|
| Direct | $35,496,129 | $24,816,704 | 205 |
| Indirect Plus Multiplier | $62,974,526 | $32,040,650 | 512 |
| Total | $98,470,655 | $56,857,353 | 717 |

***Implications of increased state sourcing of inputs***. The multipliers noted above can be used to reveal the broad implications of additional direct output purchases, employment, and income for both construction and operations. For example, an additional job tied to construction would lead to the creation of 2.4 jobs elsewhere in the state economy based on the figures presented above. An important caveat is that these multipliers are *aggregate*, capturing the mix of spending, salaries, and employment embedded in the source data for the project. Even the simple example here of one additional *construction worker* is problematic since the actual workforce will include construction labor, construction management, and permanent TVA staff engaged in startup. If the mix of spending and/or direct salaries changes, the multiplier effects estimated here may not be precise.

Growing the in-state supply chain could have a material impact on the benefits of both construction and operations. For example, for the representative year analysis, a 50 percent increase in spending on fuels and control blades sourced in Tennessee would increase the overall operational income impact by 4.8 percent and support an additional 40 full-time jobs for Tennesseans. While it is not known whether this is feasible, it does illustrate the potential economic benefits of drawing a specific element of the supply chain closer to the facility. Turning to a second example, if radioactive waste treatment expenditures increase by 30 percent, the total operational income impact would increase by 1.2 percent and support an additional 10 jobs. These hypothetical scenarios demonstrate how changes in estimated operational expenditures or in the states' supporting supply chain affect the economic impacts for Tennessee's economy.

***Potential state and local tax impacts.*** Tax impacts from construction and operations can be estimated using the output estimates from the economic impact model coupled with data on state and local tax collections. The focus here is *taxes* because other revenue sources, like intergovernmental aid from the federal government, are difficult to link to changes in in-state economic activity. Taxes, on the other hand, are generally tied directly to economic activity, particularly the sales tax which is the state's most important revenue source and the second most important tax source for local governments.

TVA pays a gross receipts tax (i.e., PILOT or payment in lieu of tax) to the State of Tennessee that is based on power sales. Revenues accruing to Tennessee are significant, amounting to $410 million in fiscal year

2022/23.[32] Estimated PILOT revenue is not separately accounted for but is implicitly included in the estimates presented here since they account for gross receipts taxes generally.

State and local revenue estimates presented here account for the sales, corporate income, gross receipts, and local property taxes, as well as special excise taxes on cigarettes, alcoholic beverages, and other transactions.[33] Based on the estimates of output presented above, construction would produce $14.7 million a year in state and local taxes for cumulative collections of $132.5 million across all nine years of the project. Operations would yield total state and local taxes of $8.3 million per year.

## Special Considerations

There are many nuances that underlay economic impact modeling. Moreover, many facets of the SMR project are unique, including FOAK costs. The following sections highlight some of the more salient issues that should be considered when evaluating the estimates presented in this report.

***Federal support and national security***. The federal government has keen interest in growing the nation's nuclear sector to support clean energy, energy independence and national security, as well as RDD&D. The recently passed Advance Act[34] shows this commitment:

- Strengthens U.S. energy resiliency by investing in domestic nuclear energy infrastructure, research, and workforce, building upon international collaborations and relationships to advance nuclear technologies, and ensuring national security through energy independence.
- TITLE II Section 102 of the act- $900M in for nuclear prizes- Up to $800M to support Gen III+ Small Modular Reactor (SMR) projects & up to $100M for projects assisting in SMR supporting design, licensing, supplier development, and site preparation of a grid-scale Gen III+ reactor design.
- Improving Nuclear Regulatory Commission efficiency, strengthening of the NRC workforce, and streamlining of processes like NEPA reviews and licensure demonstrate commitment to address key challenges in developing and deploying SMRs and new nuclear technologies, including fusion.

---

[32] Tennessee Advisory Commission on Intergovernmental Relations, "Tennessee Valley Authority Payments in Lieu of Taxes, https://www.tn.gov/tacir/tva-pilots.html For details on how these funds are allocated, see TVA In Lieu of Tax Payments, https://www.ctas.tennessee.edu/eli/tva-lieu-tax-payments#:~:text=TVA%20in%20lieu%20of%20tax%20payments%20are%20payments%20made%20by,is%20determined%20by%20federal%20law.

[33] Data are drawn from the State and Local Finance Data calculator provided by the Urban Institute. The calculator allows users to choose from a variety of tax measures, ranging from specific taxes to highly aggregated measures of revenue. The calculator also provides *tax burden* measures, including taxes per capita and taxes as a share of personal income. The tax measure used here is (R05) Total Taxes. See https://state-local-finance-data.taxpolicycenter.org/pages.cfm

[34] The White House, "Statement from National Climate Advisor Ali Zaidi on Signing of the Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy (ADVANCE) Act into Law," July 9, 2024. https://www.whitehouse.gov/briefing-room/statements-releases/2024/07/09/statement-from-national-climate-advisor-ali-zaidi-on-the-signing-of-the-accelerating-deployment-of-versatile-advanced-nuclear-for-clean-energy-advance-act-into-law/

This and other initiative mean federal financial support as well as support in moving good investments forward.

***Supply chain, production costs and technology***. The RIMS II economic impact multipliers used here for income, employment, and state GDP account for the existing inter-industry structure and supply chain in Tennessee; actual data on business transactions underlays the development and estimation of these (and other) regional multipliers by the U.S. Bureau of Economic Analysis. The economic linkages are necessarily retrospective, i.e., based on what has happened in the past as reflected in historical data on business-to-business transactions and other economic activity. Business supply chains evolve over time so one would expect a growing supply chain in Tennessee if SMR construction takes place, especially if multiple units were to be produced and deployed. Proximity alone would attract firms by reducing transportation costs and improving communications and networking both along the supply chain and with TVA and its contractors.

The multipliers implicitly assume that greater spending can occur with no changes in the unit costs of production. In the short run, costs may rise because of capacity constraints. On the other hand, over time, an increased scale of production can lead to lower per unit costs for many inputs and components. The reason is that increased scale allows the fixed costs of capital (that embodies production technology) to be spread across more and more units of production. These lower costs might occur if multiple SMRs were to be built in Tennessee. The implication is that the economic impact of the first SMR would likely be larger than the impacts of subsequent SMRs. Lower costs would, in practice, manifest themselves first in the costs TVA would incur for additional units. These lower costs would then be reflected in a smaller economic impact.[35]

The technology underlying goods and services production in Tennessee is also assumed to be static when economic impacts are measured. This makes sense in the short run because most businesses have fixed equipment *and* processes to guide production activity. Improvements in technology and production processes can also lead to lower unit costs, regardless of scale. Lower costs arising from technology would also translate into a lower economic impact on the state. At the same time, it could lead to growth in other sectors directly or indirectly tied to the nuclear sector, benefits that are no accounted for here.

A smaller economic impact from lower input costs does not diminish the importance of SMRs as a source of clean, safe baseload electric power for Tennessee. Nor does it diminish the potential economic development benefits that could arise from growing the state's nuclear sector. Alternative power generation from natural gas, for example, would not likely lead to robust technology, R&D, and workforce development spillovers like those discussed below from SMR development.

[35] Increased in-state *sourcing* would lead to higher impacts on Tennessee, potentially offsetting the effects from lower per unit input costs.

***FOAK costs and the learning curve***. The lack of active component production for many inputs means that the first SMRs to be built will confront potentially significant FOAK costs. Prominently, this would include reactor vessels and their essential component parts. On the other hand, turbines, cooling towers, and switchyard equipment are examples of inputs and costs that are standard for power generation facilities, with a well-established and potentially regionally anchored supply chain for component manufacture. Some off-the-shelf components are already approved for use in sensitive applications like power generation and could conceivably be acquired from established vendors. There are numerous other costs that are not new. Many facets of site development are standard costs, including land clearing and basic site preparation. Burying the SMR reactor in the ground would include some costs that would rely on well-known construction procedures and the use of traditional aggregate fill; new costs would be incurred because of the uniqueness of the SMR and the need to insure the reactor against risks like seismic events. While no good estimate is available, a commonly noted figure is that FOAK costs represent about 50 percent of the project's cost.

Elements of out-of-pocket FOAK costs are included in the purchase of unique inputs (including the examples noted above), regulatory costs, testing and readiness activities, and possible project cost escalation. TVA has incurred about $20 million in Nuclear Regulatory Commission fees to date related to the *Early Site Permit* and the *Construction Permit Application*; total projected costs for TVA to obtain the *Early Site Permit* and develop a *Construction Permit Application,* including the Nuclear Regulatory Commission fees, is about $100 million. Additional reactors would be less costly once the regulatory precedent has been established. The cost of activating the reactor and testing it for safety and performance would be unique, even though all generation facilities need testing prior to deployment. Procurement cost estimates are always subject to revision over time. However, this can be especially problematic for the construction of new capital projects that have no market precedent.

SMR construction, maintenance, and operation would require a high-wage and highly skilled workforce, including design experts, project engineers, construction labor, and operational specialists. While reliance would be placed on many traditional trades and occupations (welders, electricians), these workers may require unique training and skills. In general, labor costs will be high due to the relative scarcity of skilled workers and professionals and the need for specialized training.

Several prominent FOAK SMR *risks* include the necessary long-term financial payback period, design/performance risk, and high cost per KW hour, which makes generation less competitive. Related risks include the potential for the emergence of lower-cost alternatives to the GE-Hitachi model and a technology disruption like a breakthrough in battery technology that would allow storage of intermittent wind and solar power. The ultimate risk is that the SMR becomes a stranded asset that requires cost recovery from ratepayers (and possibly the public sector), while GE-Hitachi loses the return on its investment. TVA and GE-Hitachi share these risks to varying degrees.

GE-Hitachi asserts that their BWRX300 reactor has a FOAK cost of $1 billion or less and a $2,250/kW for the $n^{th}$ unit,[36] with the LCOE between $35 to $50/MWh.[37] NuScale states that its SMR has a LCOE of $68/$100 for a FOAK unit and $61/$86 for the $n^{th}$ of a kind (NOAK) reactor, for municipally owned or investor-owned utilities, respectively.[38] The lower costs for municipally owned facilities are due to risk sharing with the public sector. While the estimates are now somewhat dated, the NuScale figures imply cost savings of roughly 10 – 14 percent for $n^{th}$ unit production compared to first unit production.

A 2023 report from the EFI Foundation[39] offers a policy framework on how to tackle risk and uncertainty regarding FOAK costs. This is just an example, but it is illustrative. The report notes that the first-mover disadvantages can be managed through three steps:

1. *Demand Pooling* – a commitment by multiple actors to construct and operate the same SMR design, similar to the creation of an "orderbook" for a specific airplane deployed by numerous airlines.
2. *Knowledge Sharing* – costs decrease, and estimates become more certain through successive builds of SMRs within an orderbook. The building of the first SMR followed by iterative builds allows for knowledge sharing across "engineering, procurement, and construction (EPCs) firms, the project sponsors, the financial community, third party design and engineering entities, trade and training facilities, academia, and regulatory and policymaking entities."
3. *Risk Sharing* – is enabled through tiers, (i) within the project group through the implementation of an integrated project delivery agreement (IPD) amongst the key stakeholders that allows for the sharing of information and limiting costs; and (ii) outside the project group, "overrun risk" should be borne partially by an outside entity that has sufficient capacity to absorb costs, such as a government entity.

One lure of constructing multiple SMRs is the potential for lower costs of input acquisition and the realization of a learning curve that helps make SMRs a more competitive power source.[40] The scope of the savings is unclear and would depend on the number of units to be constructed. In terms of the language immediately above, no one knows exactly what savings would accrue from the *$n^{th}$ unit*. Savings would likely be muted for a very small number of SMRs. The learning curve would arise from experience on the

---

[36] GE Hitachi Nuclear Energy, "Deep decarbonization with nuclear," March 2019. https://thinkatom.net/wp-content/uploads/2020/03/christer-dahlgren-ge-hitachi-bwrx-300-deep-decarbonizing-with-nuclear-1.pdf

[37] These figures do not reflect more recent, higher cost estimates noted above. See Advanced Reactors Information Systems, "Status Report – BWRX-300 (GE Hitachi and Hitachi GE Nuclear Energy)," International Atomic Energy Agency, September 30, 2019. https://aris.iaea.org/PDF/BWRX-300_2020.pdf

[38] NuScale Power, "Nuscale Levelized Cost of Energy," 2022. https://www.nuscalepower.com/-/media/nuscale/pdf/fact-sheets/lcoe-fact-sheet.pdf

[39] Ernest J. Moniz, "A Cost Stabilization Facility for Kickstarting the Commercialization of Small Modular Reactors," EFI Foundation, October 2023. https://efifoundation.org/wp-content/uploads/sites/3/2023/10/20231011-CSF-FINAL-1.pdf

[40] Lower costs can arise from economies of scale as well as improved processes.

part of an owner and its workforce as well as suppliers that improves productivity. For example, the construction of one new home by a work crew would likely take more time and, therefore, cost more than the per-house construction of many homes with the same blueprint. The same principle would apply to SMR construction, especially if the design was common. Welding the first reactor vessel would take more hours of labor than welding the 20th reactor. Management of a complex engineering project can also be expected to yield cost savings through the learning curve. TVA is addressing the procurement and acquisition question behind the scenes and knows something about how costs may fall with the production of multiple units.

Potentially high FOAK out-of-pocket and risk costs represent significant barriers to entry for SMRs, like the barriers that generally exist for the introduction of other new products and technologies. While they have a bearing on estimated economic impacts, the real issues are cost and risk sharing that may be required to allow construction and deployment to move forward.

***Clusters and agglomeration economies*.** Clusters and agglomerations are often characterized to include businesses and sectors that formally trade with one another—think *supply chain*. Location can be important, if not essential, to supply chain cluster development by making inputs less costly by virtue of proximity. With proximity comes a host of benefits, including lower transportation costs and easier, often direct communication with business partners. The key is that the proximate or co-location of businesses imparts lower costs.

Importantly, the role of clusters can go beyond the supply chain to capture spillover effects that are not tied directly to business-to-business transactions. These spillovers entail lower business costs and lead to what economists refer to as *agglomeration economies*. As economic development guru Michael Porter notes, it "allows each member to benefit *as if* it had greater scale or *as if* it had joined with others without sacrificing its flexibility."[41] In other words, a business may find a region to be a more attractive location by virtue of lower costs, even if it has no business dealings with other firms in the same regional economy.

For example, businesses that do not trade with one another may rely on similarly skilled workers, creating a broader labor pool within a region. This enhanced labor pool may lower employer and employee search costs, offering businesses improved productivity and workers higher salaries through better matching and skills alignment. For the state's nuclear sector, this could include jobs ranging from nuclear engineers to security guards and communications specialists. Companies may find that training resources are lower cost when other companies require the same or similar training. Common bidding systems and contracting experience with federal agencies and prime contractors can be shared while also creating a pool of uniquely skilled workers. Information exchange and the synergies of research are enhanced by the nearby location of workers in other firms as well as educational institutions like the University of Tennessee, where scholars are working on similar projects. It is generally agreed that knowledge-based industries have

[41] Michael E. Porter, "Clusters and the New Economics of Competition," *Harvard Business Review* November-December 1998. https://hbr.org/1998/11/clusters-and-the-new-economics-of-competition Emphasis in the original.

the potential to benefit the most from agglomeration.[42] Knowledge-based industries, in turn, enhance the economy and its performance, including the cultivation of high-skill and high-wage jobs.

Direct cluster linkages *between* firms as well as spillovers *across* firms are both of particular interest for the nuclear sector anchored in the Oak Ridge region that spills across Tennessee and other states. Depending on the firm, it may include lower transportation costs, lower search costs for employers and workers, information sharing, and knowledge spillovers, as noted above. Information sharing may take place through informal networks and formal business associations (e.g., ETEC); these same communications may identify supply chain gaps more quickly than standard market forces. For business-to-business transactions, proximity translates to lower transportation costs, whether for the movement of goods or simply for face-to-face meetings. Peer effects and the pursuit of largely common goals—nuclear deployment—can enhance morale and productivity. Anyone who has done business in the Oak Ridge community is aware of this unique and ubiquitous driving spirit.

An agglomeration cluster already exists in the East Tennessee region that is especially robust and generally known to many professionals and others in the community and has been documented by ETEC. One way to summarize the group of industry sectors is with the North American Industrial Classification System taxonomy.[43] There are multiple businesses with nuclear-related activities that can be placed into these NAICS categories:

- 21 Mining, Quarrying, and Oil and Gas Extraction
    - Beneficiation of mineral ores (uranium, radium, vanadium)
- 23 Construction
    - Power and communication lines and related structures
- 32-33 Selected Manufacturing Sectors
    - Chemical manufacturing, pharmaceutical and medicine manufacturing, metal products and metal working machinery, control instruments, battery manufacturing, uranium enrichment, nuclear medicine
- 51 Information Computer infrastructure providers, data processing, web hosting, related services
- 54 Professional, Scientific, and Technical Services
    - Geographical surveying and mapping, testing laboratories and services, computer systems design, research and development
- 56 Administrative and Support and Waste Management and Remediation Services
    - Security guards; hazardous waste collection, treatment, and disposal; remediation services

---

[42] Kathleen Bolter and Jim Robey, “Agglomeration Economies: A Literature Review,” W.E. Upjohn Institute for Employment Research, 2020. https://research.upjohn.org/cgi/viewcontent.cgi?article=1256&context=reports s
[43] The complete NAICS accounting system is supported by the U.S. Census Bureau, https://www.census.gov/naics/

Importantly, inducing cluster growth by targeting specific components of the cluster can yield spillover benefits and enhance agglomeration economies. This means that attracting more SMR-related activity will have significant impacts on growing the overall nuclear cluster and a host of related economic activities in Tennessee.

A recent report takes this broad perspective to its discussion of the regional nuclear cluster in five southeastern states, Georgia, North Carolina, South Carolina, Tennessee, and Virginia. Novel considerations include going behind the scenes to examine businesses in the nuclear supply chain, university-related research and support activities, and federal government entities that have ties to the five-state region's nuclear sector. This information is highly complementary to the discussion here on agglomeration effects, highlighting the rich breadth of related businesses, sectors, and support services, as well as revealing economic benefits.[44]

***Workforce and workforce development***. Workforce availability and quality will be essential to the SMR project. As with other components of the impact modeling, an underlying assumption is that sufficient labor will be available to meet in-state construction and supply chain needs--this is implicit in the historical data that supports the development and estimation of the multipliers. Sustaining and growing business support sectors will require a well-trained workforce, or business and job opportunities will go elsewhere.

While the workforce is key to SMRs, it is also a key element of industry clusters and agglomeration effects, as indicated above. ETEC has documented 18,596 jobs tied to the nuclear sector.[45] Stakeholders and partners from industry, government, and educational institutions have ongoing discussions of potential gaps in the nuclear workforce through ETEC's Nuclear Working Group.[46] Examples of nuclear sectors considered include the front-end fuel cycle (e.g., processing and preparing uranium for use in nuclear reactors), the back-end fuel cycle (e.g., waste management, storing used fuel, and nuclear commissioning), nuclear security and nonproliferation, nuclear power plants (e.g., nuclear supply chains, reactor component manufacturing, advanced fission reactor technology), medical isotopes and nuclear medicine (e.g., nuclear imaging), and fusion energy (e.g., fusion technology research and design). Note that these industries are generally included in the NAICS categorization presented immediately above.

The types of jobs and educational requirements vary within and across these sectors. A partial list of example occupations includes nuclear technicians, engineers, physicians, biologists, radiochemists, physicists, operators, project managers, and skilled craft workers (e.g., nuclear welders, electricians). While a significant share of jobs require advanced degrees, many others are in various trades and specialty occupations. Many of these occupations will require advanced technical training and on-the-job experience to adequately prepare workers. Note also that many of the jobs and occupations discussed

---

[44] Joseph Von Nessen and Lukas Brun, "The Economic Impact of the Nuclear Industry in the Southeast United States, A Regional and State-Level Analysis," E4 Carolinas, February 2024.

[45] This figure from ETEC accounts for only direct employment. A broader measure of employment using a different methodology that accounts for indirect and supply impacts is over 40,000, see footnote 1.

[46] For more information, see: https://www.eteconline.org/nuclear-industry-hub/

here pay very high wages and salaries. Expanding partnerships and nuclear educational programs to fulfill these workforce needs will not only attract new nuclear companies and grow Tennessee's nuclear sector, but also translate into lasting investments in people. This is one of the most important investments that the state can make in its future.

While there is an established nuclear employment base in the region, many workers will be aging out and few new workers are entering the related labor force. The addition of SMR activity at the Clinch River Nuclear site, along with the ongoing needs of the broader nuclear sector, means there will be many new job opportunities, especially in critical supply chains. Fulfilling nuclear workforce needs will mean a renewed commitment to educational and training programs, beginning at the high school level (if not earlier), and include certificates and/or degrees from Tennessee Colleges of Applied Technology, State Community Colleges, and four-year universities in the state. New steps will be required to address the lack of a robust pipeline of workers. Several current partnerships and educational programs exist, and some institutions have recently received funding to support and grow their nuclear programs. For example, the University of Tennessee, Knoxville and Roane State Community College will receive funding from the state's Nuclear Energy Fund.[47] At the University of Tennessee, the funds will go towards establishing a new minor in nuclear engineering, and separately at Roane State Community College, the funds will be used to support a nuclear measurement lab and a new nuclear technology program, which will begin in Fall 2024. Ongoing coordination and evaluation will be needed to ensure success.

## Conclusion

SMRs have the potential to help meet the state's energy needs while contributing to the nation's economic and energy security. They would also yield numerous additional economic development benefits, especially for those places that host component production, facility construction, and deployment of generating capacity. Deployment of carbon-free energy will especially be attractive to many energy large consumers, especially new industrial customers that require efficient industrial heat.

For many reasons, Tennessee is a prime site to be a first adopter of SMR technology. The state has a longstanding nuclear presence dating back to the Manhattan Project, and it has embraced nuclear power deployment through TVA generating capacity. Expertise, along with considerable industrial capacity to support SMR construction, is already present in Tennessee. Substantial economic development benefits would come from SMR construction and deployment, including job and income creation and the generation of knowledge spillovers that would not likely arise from the introduction of alternative power-generating capacity.

This report has documented the estimated economic impacts on jobs, income, and state output that might accrue to the state should TVA move forward with the construction and operation of a single GE-Hitachi BXWR300 SMR. The estimated economic impact from the nine-year construction phase (2024-2032)

---

[47] See: https://tnecd.com/news/governor-lee-commissioner-mcwhorter-announce-new-funding-for-nuclear-education/

includes a total of 16,440 person-year jobs for an annual average of 1,827 jobs. A representative year of facility operation, beginning in 2032, would include 205 direct jobs held by TVA employees and an additional 512 jobs through the supply chain and the multiplier, producing a total of 717 jobs on an ongoing basis. Overall, the job, income, and output impact of SMR production and deployment would have substantial and long-lasting benefits for Tennessee and its economy. TVA may choose to deploy up to four SMRS, leading to additional economic impacts. If costs and in-state sourcing remain the same as the first unit, each additional unit would have a similar impact on the Tennessee economy.