THE UNIVERSITY OF TENNESSEE KNOXVILLE

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

ENERGY TRANSITION: An Annual Assessment of the Tennessee Energy Sector

Prepared for the Tennessee State Energy Policy Council

Matthew N. Murray, PhD

August 2024

ENERGY TRANSITION

AN ANNUAL ASSESSMENT OF THE TENNESSSEE ENERGY SECTOR: 2024

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in cooperation with the Tennessee State Energy Policy Council

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The Baker School would like to thank Noah Ankar (TVA), David Owenby & Molly Cripps (Tennessee Department of Environment and Conservation), Jonathan Overly (TN Clean Fuels Coalition) and Hancen Sale (Reworld) for comments. The views expressed in this report are those of the Baker School and do not necessarily reflect the views of the State of Tennessee.

Preface

This *Annual Assessment of the Tennessee Energy Sector: 2024* is a continuation of the State Energy Policy Council's (SEPC's) ongoing efforts to inform policymakers and stakeholders on issues of importance to the state, with an eye on identifying challenges and opportunities to support a more safe, stable, resilient, secure, equitable, and affordable energy sector. The goal is to ensure that the state's ever-changing energy sector can help maximize the state's economic development potential and the wellbeing of Tennesseans both today and tomorrow.

In addition to *Annual Assessments*, SEPC's program of work includes special reports, testimony to legislative committees, executive briefings for key stakeholders and state officials, and responses to inquiries from policymakers and legislators. By providing objective analysis and information, SEPC seeks to enable more informed, data-driven policymaking.

Legislation passed in the 2024 session of the Tennessee General Assembly restructured the membership of the SEPC, moving the number of members from 15 to 22. The revised membership categories are included in the Appendix to this report. All new members of the SEPC will be appointed by the Governor (8), the Speaker of the House (7), and the Speaker of the Senate (7). Notable additions to the membership roster include representatives from the U.S. Department of Energy/Oak Ridge Reservation, the nuclear manufacturer sector, and the radiological control/safety sector. These additions will help SEPC address the growing importance of advanced nuclear to the state.

TN State Energy Policy Council

Council Membership, 2023-24

Member's Name	Representing
Dr. Joe Hoagland, Chair	Tennessee Valley Authority
Molly Cripps	Governor's designee
Dr. H.M. Hashemian	Energy resource extraction or energy production industries
Dale Barnett	Commercial, industrial, or agricultural energy consumer
Jasbir Singh Dhaliwal	Institution of higher education
A. L. Qualls	Energy research and design industry
Brian Solsbee	Local distribution utility
Matt Stennett	Industries that provide natural gas to consumers
John Kenny	Energy efficiency and conservation as it relates to the built environment
Jerry Kettles	Tennessee Public Utility Commission
Roy West	State Treasurer's designee
Hannah Rubin	Graduate student with expertise in energy issues
Vacant	Transportation-related industry
Vacant	Residential energy user
Vacant	Environmental group

Tennessee Nuclear Energy Advisory Council (TNEAC)

In 2023, Tennessee Governor Bill Lee established the Tennessee Nuclear Energy Advisory Council (TNEAC) through Executive Order 101. It sought to build upon the state's expertise in advanced nuclear by continuing to invest in nuclear innovation and advancements. With the goal of Tennessee being the national leader in nuclear energy, TNEAC was to make recommendations for the continued development of nuclear energy within the state.

TNEAC was tasked with recommending legislation, policies, and budgetary changes to address regulatory, workforce, education, and other barriers that might impede further expansion of the nuclear sector in the state. TNEAC was also charged with the identification of funding opportunities for the State, local governments, and the private sector. Recommendations were to include storage and waste practices to continue to protect and preserve Tennessee's environment.

These tasks were designed to support the expansion of the nuclear industry in the state, create jobs for Tennesseans, generate economic growth, increase energy independence, and enhance national security.

TNEAC has 22 members including representatives from State and local government, industry and economic development advocacy groups, utilities, the private sector, and education. The council submitted a Preliminary Report to Gov. Lee, Lt. Gov. McNally and Speaker Sexton in December 2023 and will be responsible for delivering recommendations in a Final Report due in October 2024. The enabling Executive Order is set to expire in November 2024.

For the Preliminary Report, the council recommended the State of Tennessee should focus on two broad strategies to secure the benefits of nuclear energy:

Broad Strategy #1: Advance New Nuclear & the Clinch River Nuclear SMR project

The State should partner with the Tennessee Valley Authority (TVA) and other states in the TVA service area to advance new nuclear generally and, specifically, to advance the Clinch River Nuclear Small Modular Reactor (CRN SMR) project and next-generation SMR configurations.

Broad Strategy #2: Build the Nuclear Workforce & Supply Chain Ecosystem

The State should position itself as the obvious choice for companies that will comprise the new nuclear supply chain, regardless of where new nuclear power is ultimately deployed. A workforce trained to work in the nuclear sector can underpin growth in related nuclear industries, such as fusion energy and radiopharmaceuticals.

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The Preliminary Report outlined these strategies, including identification of key strength, weakness, opportunity and threat (SWOT) indicators as well as working recommendations that the Council would offer for continuing evaluation and development upon consultation and agreement of the Governor and the General Assembly. It established a framework for the council's work through 2024, leading up to submission of a Final Report by Oct. 31, 2024.

Tennessee Governor Bill Lee and the Tennessee General Assembly approved $50 million to establish the TN Nuclear Fund in the 2023-2024 budget and provided an additional $10 million for the Fund in the 2024-2025 budget. The funds are administered by the Tennessee Department of Economic & Community Development (ECD) to provide grants and assistance to new and growing nuclear businesses in the state and support development and growth of nuclear workforce and education programs. The first recipient from the Fund was Type One Energy, Inc., a fusion energy company that intends to locate a stellarator fusion prototype machine at TVA's former Bull Run Fossil Plant in Clinton. The company also announced in February it will invest $223.5 million to establish its headquarters and expand operations in Tennessee, creating a total of 330 new jobs. The TN Nuclear Fund will also be supporting education and workforce development by enabling the University of Tennessee to establish a new minor in nuclear engineering and providing funds to Roane State Community College to equip a hands-on laboratory for a new nuclear technology program launching in Fall 2024. The TN Nuclear Energy Advisory Council is available to assist ECD with review and recommendations as that agency administers the TN Nuclear Fund.

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EXECUTIVE SUMMARY

This report fulfills the State Energy Policy Council's (SEPC's) legislated mandate for an *Annual Assessment of the Tennessee Energy Sector*. The focus of this year's report is the global *energy transition*—the shift from an economy built on fossil fuels to one that relies substantially on renewable energy in the pursuit of decarbonization. The SEPC brings its ongoing policy focus to the energy transition, framed by the need for a safe, stable, resilient, secure, equitable, and affordable energy sector that can support statewide economic development. There are many possible energy futures. Tennessee can define its own future by making important policy choices today that will affect its economic development trajectory over the course of the transition.

A primary domestic policy goal contributing to the energy transition is to realize carbon neutrality by 2050. Many steps are being taken by the public and private sectors to achieve this goal. Other forces like rapidly changing technology (batteries, small modular reactors) are contributing to the energy transition. Together the transition will upend energy markets across the world and in Tennessee. Some of the disruptions will need to be mitigated (job losses) and others seized upon for new opportunities, like electric vehicle, battery, and energy efficient appliance production.

Decarbonization will lead to increased electrification of the economy, with greater and greater reliance placed on renewable energy sources including wind and solar. The role of fossil fuels will wane, but these energy sources will remain important for centralized power generation to meet baseload power demand as well as support other applications like transportation. The Tennessee Valley Authority (TVA) will play a key role since it provides more than 90 percent of the state's electricity. TVA has already realized large reductions in carbon emissions and plans for an additional 70 percent reduction in carbon intensity by 2035 and net-zero carbon emissions by 2050. But TVA cannot do it alone. The transportation sector accounts for 39 percent of carbon dioxide emissions in the Tennessee Valley, illustrating the need for a more inclusive approach that engages all energy consumers. The Tennessee Volunteer Emission Reduction Strategy (TVERS), developed by the Tennessee Department of Environment and Conservation, is taking a statewide approach that relies on information and voluntary action to reduce emissions.

Electrification brings the spotlight to the electric grid and the need for essential upgrades to ensure its safety, stability, and resiliency. Many components of the grid, including transmission lines and transformers, are decades old. This aging capital stock was designed to support uni-directional power supplies from centralized generation facilities and not the injection of electricity from many highly dispersed sources—*distributed generation*. Renewable energy sources create many engineering challenges for the grid and its operators, including balancing intermittent supplies from wind and solar with user demand. The grid is also subject to a range of threats, from bad actors to extreme weather events. Addressing grid-related problems is a task for the federal government, energy suppliers, and energy distributors, leaving little room for state policy. Options for the state include promoting energy efficiency, which reduces pressure on the grid, and ensuring viable security and emergency services for energy assets in the state. Tennessee State government can also pursue self-insurance through the provision of microgrids and energy storage systems behind-the-meter to protect against the eventuality of grid failure. Households and businesses could adopt similar systems to self-insure.

The role of renewable energy sources continues to grow, accounting for over 21 percent of national utility-scale electricity generation in 2023. TVA had 8,668 MW of renewable capacity in the same year and plans on adding 10,000 MW of new capacity by 2035. Energy storage systems are an important complement to renewable energy because of the intermittency of wind and solar. Neither of these renewables is capable of meeting baseload demands today, a gap that will be filled in part by natural gas as reliance on coal continues to fade. Storage system capacity continues to improve, and utility-scale systems are now being deployed around the world. Renewables and storage systems enhance energy security and resiliency through energy diversification. The state has related economic development opportunities running from R&D to the production of manufactured goods that support the energy sector of the future, like wind turbines, composite materials, electrical components, and energy efficient products.

As energy markets and related sectors transition, efforts need to be made to address education and training programs that can meet the needs of employers and the workforce. Some workers will be displaced from the energy transition, e.g., those involved in the traditional oil, gas, and coal sectors, while new jobs will be created in renewable energy production and other activities. In addition to the skills challenge is the regional impact of the transition, with some regions seeing growth and others seeing slower growth or contraction. If Tennessee does not move aggressively to meet the challenge, economic development opportunities will escape to other regions of the country.

The *Annual Assessment* also addresses three topics of special interest to Tennessee that are linked closely to the energy transition. First is advanced nuclear, which is important because of the strong, longstanding roots the nuclear sector has in the state, the potential for the deployment of a new small modular reactor (SMR) on the Clinch River, and the global push for more nuclear power. Nuclear power is already a unique anchor in TVA's energy generation portfolio. Additional nuclear power adds another source of resiliency and security to the portfolio and creates notable economic development opportunities. Second are rare earth elements (REEs) and critical materials (CMs) that underlay the energy system (from generation to distribution), a wide range of consumer and business products (like cellphones), and national security tools (including weapons systems). Many of these resources are now supplied predominantly or exclusively by China. Coal ash from power generation contains both REEs and CMs. If cost-effective technologies could be developed, exploitation of these ash reserves could help meet national and state energy security needs while supporting jobs and industry. Third is renewable natural gas (RNG) that is sourced from organic waste including landfills. Organic waste streams generate methane that may escape into the environment. This same methane can be processed and purified to be identical to natural gas. Successful generation of RNG would provide energy diversity to the state and help fill the gap from increasingly constrained natural gas supplies. The industry remains in its infancy and feasibility studies will be needed to determine the economic viability of RNG for Tennessee.

INTRODUCTION

The *Annual Assessment of the Tennessee Energy Sector: 2024* has been developed by the Baker School of Public Policy and Public Affairs in cooperation with the Tennessee State Energy Policy Council (SEPC). It explores the *Energy Transition* and the future of energy for Tennessee. Energy transition is the movement away from fossil fuels toward renewable energy with the key goal of engineering net-zero greenhouse gas emissions by 2050.[1] The transition has sweeping implications for the state, creating disruptions for all energy-related markets and widespread opportunities for workers, businesses, and communities across Tennessee.

Consistent with its mission, the SEPC will monitor the energy transition as well as other energy trends, evaluate policy options, share insights, and offer its recommendations on how the state might best adapt and respond. The membership of the SEPC—which includes representatives from the private sector, energy sector, State government agencies, and the general assembly—is uniquely positioned to play this important role for the State.[2] On an ongoing basis, SEPC provides testimony, special briefings, and responses to inquiries from policymakers[3] as well as special reports.[4] All of this is to help guide the State toward more effective energy policy. The global energy transition needs to be a primary consideration in the development and implementation of State energy policy.

The energy transition is accompanied by rapidly changing energy markets, technology, and consumer tastes. The pace of change and its inherent uncertainty are fundamental challenges to the development of State policy. While the end goals of a cleaner and safer environment, along with a more secure energy

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[1] The White House, "The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050," November 2021, https://www.whitehouse.gov/wp-content/uploads/2021/10/us-long-term-strategy.pdf

[2] Minnesota's new *Energy Transitions Office* is uniquely tasked with overseeing transition initiatives, including identification of opportunities and mitigation of negative impacts like worker displacement from coal-fired power plants. The Energy Transitions Office is housed in the state's Department of Employment and Economic Development, https://mn.gov/deed/programs-services/energy-transition/

[3] Previous *Annual Assessments* include *Energy Sector Disruptors in Tennessee: Framing the Options*, December 2021, https://comptroller.tn.gov/content/dam/cot/energy-policy-council/documents/reports/sepc-reports/reports-of-2021/SEPC_Annual_Energy_Assessment_2021_(Final).pdf
and *An Annual Assessment of the State Energy Sector in Tennessee*, November 2020, https://comptroller.tn.gov/content/dam/cot/energy-policy-council/documents/reports/sepc-reports/reports-of-2020/SEPC_2020_Assessment_Final.pdf Public testimony is available at https://comptroller.tn.gov/content/dam/cot/energy-policy-council/documents/reports/sepc-reports/reports-of-2023/SEPC_Electrical_Grid_Discussion_(Final).pdf and https://comptroller.tn.gov/content/dam/cot/energy-policy-council/documents/reports/sepc-reports/reports-of-2023/SEPC_house_testimony_Feb27_2023_FINAL.pdf

[4] "Energy Security Planning," March 2022, https://comptroller.tn.gov/content/dam/cot/energy-policy-council/documents/reports/sepc-reports/reports-of-2022/SEPC_Natural_Gas_Report_final_22.pdf

sector, are reasonably clear today, exactly how we get there is not so clear. State policy must nonetheless seek to be proactive and agile in this uncertain and rapidly changing environment to address both the costs and benefits of the transition. Tennessee cannot afford to simply react—*it needs to lead*.

The discussion that follows digs deeper into the energy transition and what it means for the future of energy in Tennessee. The transition is already well underway, including many public policy and decentralized steps aimed at decarbonizing the energy sector. Along with decarbonization comes electrification. These two forces are changing how energy is produced and how it is used. This has important consequences for economic development—where power is sourced; how power is produced, distributed, and stored; the types of goods and services that use energy; and how goods are produced for investment and consumption. It will affect the safety, resiliency, security, and affordability of energy for all Tennesseans.

Decarbonization is addressed in considerable detail because of its essential role in the energy transition. Discussed is the federal role in promoting decarbonization as well as the necessary commitment to mitigate its adverse consequences. Efforts to decarbonize the Tennessee Valley Authority (TVA) service delivery area and Tennessee are also discussed. Importantly, these latter efforts are largely built on the voluntary actions of individuals and businesses rather than government mandates.

Three other elements of the energy transition are addressed in turn, including renewable energy sources and energy storage, grid modernization and security, and workforce development. Renewable energy is a key building block of the transition. Renewables provide energy security and resiliency and, in many applications, can help save costs and improve energy affordability. They are also essential because they have a much lower climate impact than fossil fuels. Energy storage works hand in hand with renewables. It supports security, resiliency, and emergency services, offering insurance in the face of the loss of power. Storage is also critically important due to the intermittency of wind and solar power—meeting baseload power demands with clean energy is one of the more daunting challenges of the energy transition. Grid modernization and enhanced grid security will be essential to electrification. The grid and energy security are largely taken for granted today because of the historical integrity of the energy system. Few recognize the age of the grid and other risks to the distribution network. New threats include distributed energy, the Internet, increasingly volatile weather, bad actors, and artificial intelligence. Workforce development will be needed to address the energy transition as some industries and occupations wane and others prosper. This includes displaced workers in fossil fuels sectors as well as workers preparing for new jobs supporting the energy system of the future. Places with effective education and training programs that can meet worker and business needs will thrive.

This *Annual Assessment* closes with a focus on rare earth elements (REEs), renewable natural gas (RNG), and the potential for a rebirth of nuclear power, topics that few Tennesseans are likely to be well versed in. Everyone uses REEs—they are in batteries, magnets, appliances, smartphones, and so on. They are also embedded in largely unseen energy generation/distribution systems and national security resources like jet aircraft. Supplies of REEs continue to be dominated by China. There may be economic development opportunities in Tennessee for the extraction of REEs from existing coal waste streams (coal ash) that could also mean enhancement of national security through domestic sourcing. RNG comes from organic waste, including landfills and agriculture. Adding more RNG to the state's energy portfolio would enhance energy security and resiliency and promote competition across alternative energy supplies. It could also potentially address localized economic development challenges, especially in rural areas of the state. Interest in nuclear power has grown as the need for more clean energy to support the energy transition becomes clearer. Tennessee has a long history tied to the nuclear energy sector, as well as many assets and investments, from a trained nuclear workforce to active nuclear power plants. There is the potential to build on these strengths and amplify the role played by nuclear power as an energy source and economic development opportunity. Small modular reactors (SMRs) are at the center of the resurgence in the nuclear sector, both in the U.S. and abroad.

This report just touches the surface of many complex topics, highlighting key points and State policy implications, and offering extensive resources for a deeper dive into subject matter of interest. Promoting dialogue on the energy transition and possible energy futures today will allow Tennessee to define its path forward in a rapidly changing energy and policy marketplace.

ENERGY TRANSITION AND ENERGY FUTURES

Sweeping changes are taking place across global energy systems, from the sources of power generation to the way energy is deployed and used by final consumers. These changes can be seen across Tennessee, in the workplace, in the home, and elsewhere. *Energy transition* is the phrase that is often used to describe what is occurring. It entails upending the historical fossil-fuel driven energy system to one that more carefully balances energy needs against environmental concerns through the deployment of renewable energy to promote decarbonization. Energy transition is expected to take decades as more and more clean and renewable energy is brought into the energy portfolio while reduced reliance is placed on fossil fuels. Energy *futures* indicates that there are many possible outcomes depending on the decentralized and public choices that are made over the course of the energy transition.

This basic description of energy transition does not fully characterize the many ways in which society will be affected by decades of ongoing energy system change. As an example, few could have imagined the changes that would transpire over the course of a few decades following the introduction of the cellular phone as a wireless communications device. Cell phones soon became powerful microcomputers and innocuously led to the demise of the wristwatch. The technology of sending signals through the air helped transform social networking through applications like TikTok, Facebook, and LinkedIn, re-shaping communications and patterns of social engagement. Expanding personal and business applications enhanced the capacity for remote work and created new security threats that had to be addressed to protect information sharing and abuse. Early dissatisfaction with mobile phone battery capacity helped drive innovations that have dramatically extended battery use for a wide range of applications, not just smartphones. Smartphones now have remarkable computing capacity because of ongoing innovation. The introduction of the automobile is another example of how a singular technology broadly upended markets and society.

Energy transition entails much more than the introduction of a new product like the cell phone or the automobile, even though each ushered in sweeping technological and social change. It is inherently multifaceted with many moving parts. The component parts of change—like growing reliance on renewable energy sources—cannot be viewed in isolation from other issues like baseload energy needs, grid capacity, workforce adjustment, and energy security. Every facet of the system needs to work in harmony to support the energy system of the future. Finding a harmonious path forward will be a challenge. Tennessee must find its own place in this transition.

Decarbonization Means Electrification. The pursuit of decarbonization to reduce greenhouse gas emissions will lead to an increased role for electric power generation, storage, distribution, and use. Seeds were planted years ago when electricity markets were restructured in pursuit of the benefits of competition, turning electricity into a basic *commodity*. This facilitated a decoupling from centralized energy sources to distributed and renewable energy sources. Many businesses have pursued the use of renewable energy sources to meet the interests of both stockholders and consumers; households have utilized renewable energy to reduce costs, provide own-source energy resiliency, and simply *get off the grid*. The formal policy goal of decarbonization that now prevails across the globe will speed up the process of energy transition.

Electrification is a useful way to highlight the path of the energy transition. Examples include the deeper penetration of electric vehicles into the transportation sector, the growing use of electric arc furnaces in industry, and the development of highly-efficient electrical appliances like new heat pumps for residential and commercial use.[5] The growth of applications built around the Internet all rely on electricity, from energy-intensive Bitcoin mining to home security cameras; traditional data centers and applications of artificial intelligence (AI) are expected to continue to expand and place higher and higher demand on the electric grid.[6] Energy-consuming batteries are becoming ubiquitous within the home and workplace, as well as everywhere in between. Utility-scale battery storage systems are being deployed around the globe, including the Tennessee Valley.[7]

It is remarkable that despite ongoing electrification of the national economy, electricity generation and use have slowed. Electricity consumption per capita has slowed in Tennessee while overall electricity generation has held steady dating back to 2010.[8] Looking forward, national electric power generation is expected to grow 23.3 percent between 2024 and 2050, for an average annual increase of 0.7 percent.[9] Slower population growth will help dampen growth in electricity demand. The U.S. is expected to see cumulative population growth of only 7.2 percent between 2024 and 2050, yielding a compound annual growth rate of just 0.26 percent.[10] For perspective, U.S. population growth was just under 1.0 percent in the early 2000s and has been trending down since then. Because of net in-migration, Tennessee is

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[5] For an introduction, see Becky Waldram, "Electric Arc Furnaces: The Technology Poised to Make British Steelmaking More Sustainable," *The Conversation*, December 2023, https://theconversation.com/electric-arc-furnaces-the-technology-poised-to-make-british-steelmaking-more-sustainable-214756 and "Everything You Need to Know About the Wild World of Heat Pumps," *MIT Technology Review*, February 2023, https://www.technologyreview.com/2023/02/14/1068582/everything-you-need-to-know-about-heat-pumps/ Also see Xiaobing Liu, et al., "Grid Costs and Total Emissions Reductions Through Mass Deployment of Heat Pumps for Building Heating and Cooling Electrification in the United States," Oak Ridge National Laboratory, Energy Science and Technology Directorate, November 2023, https://info.ornl.gov/sites/publications/Files/Pub196793.pdf
[6] Lauren Leffer, "The AI Book Could Use a Shocking Amount of Electricity," *Scientific American*, October 2023, https://www.scientificamerican.com/article/the-ai-boom-could-use-a-shocking-amount-of-electricity/ Data centers generally are expected to consume as much energy in 2026 as the entire country of Japan. International Energy Agency, *Electricity 2024*, https://iea.blob.core.windows.net/assets/18f3ed24-4b26-4c83-a3d2-8a1be51c8cc8/Electricity2024-Analysisandforecastto2026.pdf
[7] Tennessee Valley Authority, "Energy Storage," https://www.tva.com/energy/technology-innovation/energy-storage
[8] Southern States Energy Board, *Southern Regional Energy Profiles 2022*, pages 68-69, https://www.sseb.org/wp-content/uploads/2023/02/REP_final_web.pdf
[9] U.S. Energy Information Administration, *Annual Energy Outlook 2023*, Reference Case Projection Table 8 https://www.eia.gov/outlooks/aeo/tables_ref.php
[10] U.S. Bureau of the Census, 2023 National Population Projections Tables: Main Series, Table 1, https://www.census.gov/data/tables/2023/demo/popproj/2023-summary-tables.html

projected to see stronger population growth of 17.4 percent between 2024 and 2050, for a compound growth rate of 0.6 percent.[11]

Systemic Change. Energy transition will affect virtually every element of the global and state energy systems, from energy sources to final uses. Upstream from generation are the businesses, workers, and regions that source traditional fossil fuels. The new energy-sourcing chain includes utility-scale solar and wind power and widespread utility-scale battery storage systems as well. These systems need to be designed, built, installed, and maintained. Downstream from generation is the movement of power to final users. This will require improvements to the grid to accommodate distributed energy resources like rooftop solar as well as hardening of the grid to ensure energy security. As technology develops further, more and more power will be generated and stored by households and businesses. This threatens the role of traditional centralized power generation and its regulatory apparatus and bears the risk of stranded energy assets that cannot realize full cost recovery through the traditional regulatory apparatus. The growing dependency on electricity requires greater and greater attention to security and resiliency to protect society and the economy from supply interruptions.

Applications that rely on electricity are already transforming end-use markets for individual and business consumers and rippling through supply chains and support services. For example, new electric vehicles (EVs) require charging systems while internal combustion automobiles are fueled at traditional gasoline service stations. As EV market penetration increases, the role of traditional gasoline and services stations will decline and ultimately evolve to fill new market needs. Pressures on the supply chain include growing demand for inputs like copper, aluminum, and REEs (e.g., neodymium, dysprosium), and critical materials (e.g., lithium, cobalt) that support electrification. Growing demand for these raw materials and essential resources in turn raises national security issues. Supply chain challenges also include the need for newly-skilled workers while addressing the needs of newly-displaced workers.

While energy transition means more renewables, the transition itself will require the maintenance of a broader portfolio of energy sources because there is too little renewable power, insufficient storage (particularly utility-scale storage), and a grid that is capacity constrained. For the foreseeable future, the national and state economies will need baseload power capacity. Natural gas will fill a large part of the gap as reliance on coal continues to decline. While in conflict with decarbonization, natural gas does have a lower environmental footprint than coal. Nuclear is another baseload energy source that has the

[11] Boyd Center for Business and Economic Research, March 2024, https://tnsdc.utk.edu/estimates-and-projections/boyd-center-population-projections/

potential to meet additional baseload needs. Through TVA, nuclear capacity may grow through the deployment of new SMRs. There are renewed discussions in policy and technology circles around the world about expanding the use of large-scale nuclear reactors, something that would have been dismissed just five years ago.[12]

Regional impacts will be an important element of the energy transition, with adverse impacts arising in some places and new growth opportunities emerging in other places. An example is reduced reliance on coal, which negatively affects coal-producing and coal-using regions, and increased reliance on solar power, which benefits places with abundant, exploitable solar capacity. The transition from internal combustion fueled light-duty vehicles to EVs will also have regional impacts on the automobile sector. Fortunately, the EV transition is well underway with production and supply chains both adapting and expanding in Tennessee, in turn supporting the automotive sector of the future. *Place-based* policies can be used to promote regional energy transition benefits as well as mitigate impacts like those on fossil fuel communities. These may be especially important in rural communities and other places that experience broad-based negative impacts from the energy transition.

The energy transition also will have equity impacts on people, households, and particular population subgroups. Not everyone will be able to afford new energy efficient appliances, home improvements, or vehicles. While extensive new job opportunities will arise, there is no assurance that these will be shared by disadvantaged population groups across urban and rural Tennessee. Ensuring that all segments of the population benefit from the energy transition is referred to as *energy justice*.[13] Targeting specific segments of the population that are in need calls for *people-based* policy.

The capacity of state and local governments to raise revenue will be affected by the pattern of rising and declining economic activity tied to the energy transition. In Tennessee, this would include traditional state revenue sources like the sales, corporate income, and gasoline taxes, along with local government sales and property taxes. For example, the closure of a coal-fired power plant could negatively affect both state and local tax revenues; replacement of the same facility with gas turbine generation could in principle neutralize these negative impacts. Business sectors linked to the energy transition, like energy

[12] Some suggest that a nuclear renaissance is just around the corner, despite similar visions of a renaissance that never materialized. Recent technologies are discussed by Alan Toth, "Nuclear Power Renaissance: Reinventing Energy Systems Via Molten Salt Technology, *Berkeley Engineering*, November 2023, https://engineering.berkeley.edu/news/2023/11/nuclear-power-renaissance/

[13] National Renewable Energy Laboratory, "Energy Justice," https://www.nrel.gov/about/energy-justice.html Because some target population groups may be concentrated in particular regions, place-based policies may still be appropriate.

efficient appliance manufacturing and solar installation, will be buoyed while sectors anchored to the old fossil-fuel economy will struggle.

It is possible that the overall net effects on state and local revenue collections in Tennessee will be muted. However, there are instances with specific implications for state and local governments. For example, Tennessee policy responded to the potential erosion of gasoline tax revenue from EVs in 2023 with the passage of the *Transportation Modernization Act* which increased the registration fee for EVs and created a new registration fee for hybrid and plug-in hybrid vehicles. The fee as of 2024 is $200 for EVs each year and will increase to $274 by 2027 and thereafter be adjusted annually for inflation. The fee for hybrid vehicles is $100 annually, and it will increase according to inflation in 2028.[14] These fees correspond roughly to the amount of gasoline tax revenue that would be derived from the typical automobile propelled by an internal combustion engine; the State decided not to subsidize the use of EVs.

Electricity generators (and distributors) often confront a unique and complex tax structure because of their regulatory/ownership status. In Tennessee, TVA pays a gross receipt tax in lieu of general State and local taxation. The rate is "five percent of gross power sales proceeds to the state."[15] A portion of this revenue is shared with Tennessee cities and counties that have no ability to directly tax TVA. Because the base of the tax is gross sales, the acquisition of out-of-state electricity (e.g., wind) will not adversely affect revenue that accrues to Tennessee. Revenue consequences from a shift from coal to natural gas power generation would depend on the resulting volume of power sales.

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[14] Tennessee Department of Revenue, "Transportation Modernization Act of 2023 Changes Electric and Hybrid Vehicle Registration Fees," June 2023, https://www.tn.gov/content/dam/tn/revenue/documents/notices/titlereg/tr23-14.pdf

[15] University of Tennessee Institute for Public Service, Municipal Technical Advisory Service, "Gross Receipts: TVA," https://www.mtas.tennessee.edu/reference/gross-receipts-tva Note that residential consumers do not pay sales tax on purchases of electricity and natural gas; industrial consumers pay a reduced tax rate of 1.5 percent on electricity and natural gas purchases. Federation of Tax Administrators, 2017 Services Taxation Survey," https://www.statetaxissues.org/services/2017/

PURSUIT OF DECARBONIZATION

The pursuit of decarbonization is based on the goal of limiting global warming and other adverse consequences associated with rising levels of carbon in the environment. The use of fossil fuels is a primary source of carbon release. The underlying source of the problem is that markets do not accurately price the climate-changing greenhouse gases that come from the use of fossil fuels. While the price consumers pay for fossil fuels includes the cost of resource extraction, processing, shipment, retailing, and so on, it does not include the costs of damage to the environment from the wellhead to the final disposition and safe closure of wells. As a result, the price of fossil fuels that consumers face is too low and too much consumption takes place. This is a classic case of a negative externality that is not mitigated by unfettered private markets.[16]

The energy transition is influenced significantly by government policies that reflect this failure of the market. Rather than imposing higher taxes on fossil fuels, subsidies are being provided to facilitate the transition through use of clean energy.[17] However, fossil fuels will not go away any time soon. The International Energy Agency has forecast the peak of global fossil fuels use to occur by 2030.[18] Legacy applications of fossil fuels—including the internal combustion engine and centralized power generation—will continue indefinitely due to sunk costs and inertia and the need for energy diversity and resiliency.

National Pursuit of Carbon Reduction. The U.S. and countries around the world are deploying carbon reduction strategies with the common goal of realizing substantial reductions in carbon emissions by 2050.[19] While government policy is an essential driver of decarbonization, so are the decentralized actions of consumers, businesses, investors, and energy suppliers. Homeowners may install a rooftop solar system for energy cost savings and to reduce greenhouse gas emissions that adversely affect climate and public health. Investors may choose so-called green investments because they are rewarded

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[16] See, for example, The Union of Concerned Scientists, "The Hidden Costs of Fossil Fuels," August 2016, https://www.ucsusa.org/resources/hidden-costs-fossil-fuels

[17] Designing these subsidies is extremely difficult in practice. See Richard G. Newell, et al., "U.S. Federal Government Subsidies for Clean Energy: Design Choices and Implications," *Energy Economics* 80, May 2019, https://www.sciencedirect.com/science/article/abs/pii/S0140988319300751

[18] https://www.theguardian.com/environment/2023/sep/12/beginning-of-the-end-of-fossil-fuel-era-approaching-says-iea

[19] The International Energy Administration frames carbon reduction in terms of net zero emissions by 2050. "Net Zero by 2050: A Roadmap for the Global Energy Sector," October 2021. https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

in the marketplace. Industrial users may use co-generation systems that save costs while yielding environmental benefits. And energy suppliers may provide green energy because that is what customers want.

In 2021 President Biden released Executive Orders 14008 and 14057 explicitly calling for an electricity sector free of carbon no later than 2035.[20] Projections from the U.S. Energy Information Agency show carbon dioxide emissions roughly matching current emission levels by 2050 under a high economic growth and high carbon reduction technology cost scenario and down substantially under a low economic growth and low cost of technology scenario. This range of possible outcomes exemplifies the uncertainty that characterizes the transition. Many sources of fossil fuel use and carbon release remain in the energy portfolio under both scenarios. Solar generating capacity will see dramatic growth by 2050.[21] This will shift electric power generation away from traditional power plants to places with exploitable solar capacity.

Tennessee can be expected to generally follow the range of these national emission projections. Historical data for the state show carbon dioxide emissions for coal, petroleum products, and natural gas trending down dating back to 2010.[22] Policy, market forces, and technology will continue to drive these emissions down. The Southern States Energy Board actively monitors carbon management strategies of its member states, including Tennessee, as well as other states around the country.[23] This helps interested states identify best practices.

Mitigating the Consequences of Change. While federal policy is helping to move the energy transition forward, there are also numerous programs intended to mitigate associated adjustment costs. These mitigation strategies are especially important since policy is helping drive the transition and its

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[20] The White House, "Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability," https://www.whitehouse.gov/briefing-room/presidential-actions/2021/12/08/executive-order-on-catalyzing-clean-energy-industries-and-jobs-through-federal-sustainability/ and "Executive Order on Tackling the Climate Crisis at Home and Abroad," https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/ For a more general discussion of energy transition policy and its foundation, see "Accelerating and Smoothing Clean Energy Transition," chapter 7 in *Economic Report of the President*, April 2022, https://www.whitehouse.gov/wp-content/uploads/2022/04/ERP-2022.pdf

[21] https://www.eia.gov/outlooks/aeo/pdf/AEO2023_Narrative.pdf

[22] Page 68 https://www.sseb.org/wp-content/uploads/2023/02/REP_final_web.pdf

[23] See "Fossil Energy and Carbon Management Legislative Digest," December 2023. https://www.sseb.org/wp-content/uploads/2024/01/FECM23_web.pdf Also see "Southeast Regional Carbon Sequestration Partnership: A Southern States Energy Board Carbon Management Plan," March 2019, https://www.sseb.org/wp-content/uploads/2019/05/SECARB-March-6-2019.pdf

disruptions. They are important for Tennessee since they often come with federal funding that can help promote economic development. For example, the Inflation Reduction Act (IRA) of 2022 includes the Energy Community Tax Credit Bonus to "advance the Administration's commitments to support and revitalize the economies of coal and power plant communities."[24] Successful programs include the development of alternative energy sources and downtown community revitalization.

Energy communities are regions with brownfield sites; metropolitan areas reliant on coal, oil, or natural gas; and census tracts that previously had coal mines. In Tennessee, numerous eastern counties qualify because they used to have active coal mines or coal power, or they are directly adjacent to tracts that did. And several census tracts between the Cumberland Plateau and Kentucky also qualify for the tax credit because of fossil fuel employment and unemployment rates. This same region, west of Knoxville and east of Nashville, qualifies for the 48C tax credit for designated energy communities under the new $10 billion in allocation provided by the IRA.[25] The priority areas for 48C are electric grid component manufacturing, electric heat pump manufacturing, EV manufacturing, nuclear reactor and nuclear fuel manufacturing, solar energy, sustainable aviation fuel equipment manufacturing, and wind energy component production.

Carbon Reduction in Tennessee and the Tennessee Valley. About 95 percent of the electricity consumed in Tennessee is supplied by generating units owned by TVA.[26] Because of population and energy demand growth, pressures from climate change impacts on the electricity grid, and a federally-led push to decarbonize electricity to federal facilities by 2030, TVA is at the forefront of the energy transition.[27] TVA's own plan, released in 2022, calls for an 80 percent reduction in carbon intensity by 2035 and net-zero carbon emissions by 2050 consistent with White House goals.[28]

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[24] US Department of Energy, Interagency Working Group on Coal & Power Plant Communities & Economic Revitalization, 2024, "Energy Communities," https://energycommunities.gov/

[25] U.S. Department of Energy, "Qualifying Advanced Energy Project Credit (48c) Program," https://www.energy.gov/infrastructure/qualifying-advanced-energy-project-credit-48c-program

[26] U.S. Energy Information Administration, Independent Statistics and Analysis, https://www.eia.gov/state/seds/data.php

[27] U.S. Department of Energy, "DOE Partners with Tennessee Valley Authority to Power Oak Ridge Facilities with 100% Carbon Pollution-Free Electricity," https://www.energy.gov/articles/doe-partners-tennessee-valley-authority-power-oak-ridge-facilities-100-carbon-pollution

[28] Tennessee Valley Authority, *2022 TVA Federal Sustainability Plan*, https://tva-azr-eastus-cdn-ep-tvawcm-prd.azureedge.net/cdn-tvawcma/docs/default-source/about-tva/guidelines-reports/annual-sustainability-plans/2022-annual-sustainability-planeba027d3-df4b-4c00-bb09-15832d391f0a.pdf?sfvrsn=ca45b8f9_3

TVA's *2021 Carbon Report* describes the current state of carbon emissions for the valley.[29] Tennessee consumes more energy than it produces, making it a net importer of energy; the state imports about one-fourth of its electricity supply.[30] The primary consumer of energy is the manufacturing sector, followed by the transportation sector; the transportation sector leads all others in emissions. TVA has achieved a 63 percent reduction in carbon emissions since 2005, counting both power production and power purchased. A plan is in place that includes improving nuclear and hydropower performance, additional solar and flexible gas sources, more requirements for coal-fired power plants, grid modernization, partner flexibility, and the Green Invest Program.[31]

Currently, the overall transportation sector is responsible for 39 percent of CO_2 emissions, or 44.2 million metric tons of carbon dioxide equivalent (MMT CO_2e). Electricity generation is responsible for 22 percent (24.1 MMT CO_2e), industry is responsible for 20 percent (22.9 MMT CO_2e), agriculture is responsible for 8 percent (9.2 MMT CO_2e), and the remaining sectors – commercial and residential buildings, waste and materials management, and wastewater – make up the remaining 11 percent (11.7 MMT CO_2e).[32] Electricity emissions from generating units can be split into categories by end-use case: residential (responsible for 43 percent of the total CO_2e emissions produced), commercial (36 percent), and industrial (21 percent).

Tennessee weather is becoming more variable due to climate change, which increases the frequency of severe weather, such as extreme heat and cold waves, large storm events, and cycles of drought and flooding. Heating and cooling the residential sector in response to the weather accounts for about a quarter of the state's energy use.[33] However, there can be a large discrepancy among residents who are impacted by climate disasters; the most vulnerable and disadvantaged communities are often the least resilient. This means that mitigating climate change not only has direct benefits due to decreased climate

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[29] Tennessee Valley Authority, "2021 Carbon Report," https://www.tva.com/environment/environmental-stewardship/sustainability/carbon-report

[30] Tennessee has limited fossil fuel reserves (natural gas, petroleum, and coal) and moderate capacity for exploitation of wind and solar power. State Energy Policy Council, *An Assessment of the Energy Sector in Tennessee*, November 2020, https://comptroller.tn.gov/content/dam/cot/energy-policy-council/documents/reports/sepc-reports/reports-of-2020/SEPC_2020_Assessment_Final.pdf

[31] Tennessee Valley Authority, "Green Invest," https://www.tva.com/energy/valley-renewable-energy/green-switch/green-invest

[32] Tennessee Department of Environment and Conservation, "Tennessee Volunteer Emission Reduction Strategy Priority Climate Action Plan," https://www.tn.gov/environment/policy/tvers/about.html#:~:text=Priority%20Climate%20Action%20Plan%20(PCAP,developed%20a%20PCAP%20Summary%20Report.

[33] US Energy Information Administration, "Residential Energy Consumption Survey (RECS)," https://www.eia.gov/consumption/residential/

risk but often also has co-benefits for the most economically-disadvantaged and historically-marginalized populations, such as improved air quality, decreased healthcare spending, and more resilient communities.

The recently released *Valley Pathways Study* evaluates available opportunities to reduce carbon emissions while creating a sustainable economy.[34] The goal is a net-zero carbon Tennessee Valley economy by 2050, achieved largely through voluntary and independent actions of individuals, businesses, and state and local governments. An important facet of the process underlying *Pathways* was the engagement of 24 participants representing different stakeholder groups that sought and found consensus on the study's methods and findings. *Pathways* applies to the entire Tennessee Valley, not just Tennessee. The Tennessee Department of Environment and Conservation (TDEC) is developing the *Tennessee Volunteer Emission Reduction Strategy* (TVERS) to reduce greenhouse gas emissions, funded by the federal Inflation Reduction Act.[35] Like *Pathways*, the state will rely heavily on information and volunteer actions as opposed to mandates to reduce emissions. TDEC and the TVA/Baker School team working on the *Pathways* study have been in communication to discuss their respective plans and share information.

Pathways reports that much recent progress – 2019 emissions were 30 percent lower than 2005 emissions – is due to a reduction in the emissions associated with electricity generation as noted above. TVA is the supplier of the vast majority of electricity consumed in the state, and it is their investments in renewables, energy storage, carbon capture, nuclear energy, retiring coal plants, demand response tools, and energy efficiency updates that have directly led to this 50 percent reduction in electricity generation emissions.

Three strategies are recommended in the Pathways report to decarbonize: reduce energy demand, electrify energy demand, and use cleaner fuels. The steepest reductions in emissions will be driven by the electrification of current energy demands, especially light-duty vehicles. Investments in energy

[34] For an overview, see Tennessee Valley Authority and Baker School of Public Policy and Public Affairs, "Valley Pathways Study," https://baker.utk.edu/research-centers/cetep/valley-pathways-study/ and for the complete report see "The Valley Pathways Study: Building a Competitive, Clean Economy," February 2024, https://tva.webdamdb.com/directdownload.php?ti=212118973&tok=cJ42HzUe/fr9M5iaokIBPQRR&token=$2y$10$rd88OiCQPGMOxqDu3Seliu7hRvHkCffrNON81qlgK0d.AxICy8vxm&preview=1

[35] Tennessee Department of Environment and Conservation, "Tennessee Volunteer Emission Reduction Strategy (TVERS)," https://www.tn.gov/environment/policy/tvers.html.

efficiency and housing density (to reduce the average vehicle miles traveled per person) will also help to reduce emissions.

Utilizing cleaner fuels includes investments in nuclear, flexible low-carbon gas, solar, and wind, and the retirement of coal power plants. The Watts Bar Nuclear Plant, which opened in 2016, together with the Sequoyah Plant, continue to provide almost 45 percent of the electricity in Tennessee.[36] Additional investments in nuclear include a possible SMR at the Clinch River Site, which has already been approved for an early site permit by the Nuclear Regulatory Commission.[37] In addition to nuclear energy, renewable energy in Tennessee represents a significant portion of the total generation. In 2022 hydropower supplied 12 percent of Tennessee's total net electricity; the state also has solar power, biomass burning, and wind farm production, although they are all small contributors to the overall electricity total.

Tennessee relies on natural gas for 17.8 percent of its electricity generation. Natural gas is much less carbon intensive than coal, and replacing Tennessee's coal with natural gas will lower emissions. Most of this is sourced from the Gulf of Mexico and Pennsylvania and shipped via pipeline through Kentucky and Mississippi. Similarly, Tennessee imports coal for 22.4 percent of its electricity generation via rail and river from Kentucky and Illinois.[38]

Currently, light-duty cars and trucks produce most of Tennessee's transportation sector emissions, accounting for a combined 53 percent of the total.[39] Since TVA-produced electricity has half the carbon-intensity of gasoline, there are large emission gains possible with electrification. TVA's Electric Vehicle Initiative aims to grow the total number of EVs from 27,264 statewide today to 200,000 by 2028, particularly focusing on policies that incentivize building charging stations.[40] One major stakeholder,

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[36] Nuclear Energy Institute, "State Electricity Generation Fuel Shares," https://www.nei.org/resources/statistics/state-electricity-generation-fuel-shares
[37] U.S. Nuclear Regulatory Commission, "Issued Early Site Permit - Clinch River Nuclear Site," https://www.nrc.gov/reactors/new-reactors/large-lwr/esp/clinch-river.html
[38] Nuclear Energy Institute, "State Electricity Generation Fuel Shares," https://www.nei.org/resources/statistics/state-electricity-generation-fuel-shares
[39] Tennessee Department of Environment and Conservation, "Tennessee Volunteer Emission Reduction Strategy Priority Climate Action Plan, 2024" https://www.tn.gov/content/dam/tn/environment/policy-planning/documents/tvers/opp_tvers_pcap.pdf and Navigant Consulting, "A Public Power Guide to Understanding the U.S. Plug-in Electric Vehicle Market*,"* 2017, https://www.amea.com/wp-content/uploads/2018/08/understanding_the_us_plug-in_electric_vehicle_market_2017_digital_final.pdf
[40] Drive Electric Tennessee, 2022, https://www.driveelectrictn.org/

Drive Electric Tennessee, a statewide EV consortium, published a roadmap for EV adoption in 2019,[41] and the state followed up with a *Needs Assessment* that found that additional EV charging infrastructure will be needed, especially along highway corridors and to connect rural and urban areas.[42] TDEC and TVA have partnered to develop a fast-charging network for EVs along interstates and major highways. The goal is to add 40 new locations in strategic infrastructure gaps and eventually have a charging station every 50 miles.[43] At the same time, Tennessee is experiencing an uptick in EV corporate investment. Three big automakers–Nissan, General Motors, and Volkswagen–already operate EV or battery manufacturing plants in the state, and Ford is planning to open a new complex in 2025.

As part of the TVERS' Priority Climate Action Plan (PCAP),[44] 11 implementation-ready measures are identified for promoting efficiency and reducing emissions in Tennessee in the near term that already have public and stakeholder support. Natural gas is much less carbon intensive than coal, and replacing Tennessee's coal with natural gas will lower emissions. Recommended are incentive programs for energy efficiency measures in commercial and industrial buildings that can yield cumulative greenhouse gas (GHG) emissions savings of 63.3 MMT CO_2e by 2050. This can include upgrading products to certified energy-efficient versions. Similarly, TDEC recommends creating incentive programs for upgrading streetlights and commercial and industrial lighting for a cumulative GHG savings of 25.6 MMT CO_2e. They also suggest that replacing building products with energy-efficient versions could save 60.0 MMT CO_2e of GHG emissions, and weatherization could save an additional 21.9 MMT CO_2e by 2050.

For the transportation sector, TDEC suggests that programs to increase the share of State and local government fleets of light-duty electric vehicles and electric medium and heavy-duty vehicles, as well as

[41] Drive Electric Tennessee, A Roadmap for Electric Vehicles in Tennessee, 2019, https://www.tn.gov/content/dam/tn/environment/energy/documents/Roadmap%20for%20Electric%20Vehicles%20in%20Tennessee_Report.pdf

[42] Tennessee Department of Environment and Conservation, Drive Electric Tennessee, 2024, https://www.tn.gov/environment/program-areas/energy/state-energy-office--seo-/programs-projects/programs-and-projects/sustainable-transportation-and-alternative-fuels/sustainable-transportation-and-alternative-fuels/drive-electric-tennessee.html

[43] Tennessee Department of Environment and Conservation and Tennessee Valley Authority, "Memorandum of Agreement to Define Responsibilities for the Deployment of Public Electric Vehicle Charging Infrastructure in Tennessee," 2021, https://www.tn.gov/content/dam/tn/environment/energy/documents/TVA-TDEC%20MOA%20-%20EV%20Chargers.pdf

[44] Tennessee Department of Environment and Conservation, "Tennessee Volunteer Emission Reduction Strategy," March 2024, https://www.tn.gov/content/dam/tn/environment/policy-planning/documents/tvers/opp_tvers_pcap.pdf

expanding charging infrastructure, could have a cumulative GHG emissions saving of 13.2 MMT CO_2e by 2050. Additional upgrades to electricity distribution can save 1.8 MMT CO_2e by 2050.

A substantial amount of GHG emissions (130.3 MMT CO_2e) can be prevented by reducing deforestation and implementing sustainable land use practices. Diverting waste from landfills can save 15.2 MMT CO_2e by 2050. (See the discussion of renewable natural gas below.) And developing renewable energy generation potentially has the greatest impact, estimated at a cumulative 215.7 MMT CO_2e by 2050. These measures have great potential to provide air quality co-benefits and other indirect benefits, such as housing affordability and reduced noise pollution, especially to low-income and disadvantaged communities throughout the state.

TVA and the citizens of Tennessee share responsibility for ensuring that both the state's energy needs and federal decarbonization goals are met. Meeting the goals of the *Drive Electric Tennessee* EV report, such as widespread EV charging, would dramatically contribute to decarbonization efforts. Additionally, TDEC's recent research shows that new incentives for energy efficiency technologies, research on low-carbon fuels, investment in education, and academic facilities and rural resources are important next steps. Tennessee should consider fact-based policy to decrease costs and convince consumers to decarbonize potentially using tools like tax credits, green mortgages, and other financial assistance.[45]

Individual communities can play a significant role. For example, Chattanooga just established a new microgrid for emergency services in addition to the one they already have for the airport. The Inflation Reduction Act has funding for about 150 new microgrid sites in the southeast, all based on solar and battery storage.[46] Lack of clarity about TVA versus Tennessee Public Utility Commission jurisdiction could be slowing development.[47]

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[45] EV take-up rates are uneven across income groups because of high front-end costs and subsidies that generally apply to new vehicle acquisition. There is evidence that incentives for used vehicles may create wider access while at the same time having a larger impact on emission reduction. See Ashley Nunes, et al., "Re-Thinking Procurement Incentives for Electric Vehicle to Achieve Net-Zero Emissions," *Nature Sustainability*, April 2022, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4588060

[46] U.S. Environmental Protection Agency, "Investment Tax Credit and Production Tax Credit," https://www.epa.gov/green-power-markets/summary-inflation-reduction-act-provisions-related-renewable-energy#ITCPTC

[47] For a discussion of some of the issues confronting potential adopters in Tennessee, see Caroline Cox and Victoria S, "Microgrids: Legal Opportunities and Barriers in Tennessee," Vanderbilt Law School Energy, Environment and Land Use Program, 2022, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4588060

GRID MODERNIZATION

The Northeast Blackout of 2003 was caused by overgrown foliage and a software bug. As innocuous as these individual events were, they rippled and led to widespread power outages across wide swaths of Canada and the U.S.[48] The Northeast Blackout ultimately affected 50 million people and led to $10 billion in forgone gross domestic product (GDP). A joint U.S. and Canada Power System Outage Task Force report dissected the nature of the problem and made 46 specific recommendations to improve future grid security.[49] As important as the recommendations were at the time, more important is the history lesson regarding the vulnerability of the electric grid. The Blackout clearly illustrates the compelling linkage between *energy* security and *economic* security.

Today's electrical grid was developed decades ago to deliver uni-directional power from centralized generation facilities to final consumers. As U.S. DOE notes, 70 percent of the nation's electric transmission lines and major transformers are now over 25 years old, which can contribute to power outages, increased security risks, and heightened risk of network failure from localized emergencies.[50] Modernizing the grid will be expensive, with upfront costs generally paid by the public sector and utilities, costs that ultimately will be borne by taxpayers and ratepayers. It is not practical to reduce all grid-related risks to zero because risk mitigation itself is costly. This requires a balancing act for energy stakeholders that carefully evaluates both benefits and costs of grid investments.

An aging capital stock, growth in renewables and distributed generation, extreme weather events, and security concerns are among the primary threats to the grid today. In October 2023, U.S. DOE announced a plan to promote $8 billion in new investments in the grid, including resiliency targets and new microgrids.[51] These investments are part of the Bipartisan Infrastructure Law's Grid Resilience and Innovations Partnerships (GRIP) Program. In May 2024, the Biden Administration introduced Federal-State Modern Grid Deployment Initiative Principles to help coordinate grid modernization and

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[48] U.S. Department of Energy, "August 2003 Blackout," https://www.energy.gov/oe/august-2003-blackout#:~:text=August%2014%20and%2015%2C%202003,50%20million%20customers%20were%20impacted.
[49] https://www.energy.gov/oe/articles/blackout-2003-final-report-august-14-2003-blackout-united-states-and-canada-causes-and
[50] U.S. Department of Energy, "What Does it Take to Modernize the Grid?" https://www.energy.gov/gdo/articles/what-does-it-take-modernize-us-electric-grid
[51] https://www.energy.gov/articles/biden-harris-administration-announces-35-billion-largest-ever-investment-americas-electric

improvements to the transmission and distribution network.[52] Utilities across the country are also investing billions of dollars to upgrade the grid. Ongoing steps like this are critical to Tennessee's energy security and resiliency because the state itself has limited influence over the electric grid—it is the province of utilities and the federal government.[53]

The Grid and Renewables. The electric transmission system is increasingly subject to pressures from the energy transition's growing reliance on distributed energy resources.[54] The grid was simply not designed to accommodate the entry of piecemeal distributed energy systems across the network. The use of distributed energy, from small-scale residential rooftop solar to dispersed utility power sources from wind and solar creates unique new hurdles. Balancing these energy sources and their disposition across the grid requires sophisticated systems and management techniques—a combination of both technology and highly-skilled workers.

Renewables create a fundamental supply and demand balancing problem largely because of intermittent and uncertain supply from large numbers of providers. Basic approaches to address the supply side of the problem include energy storage systems, additional transmission lines, and diversified renewable energy portfolios that smooth the variability of individual supply sources. Demand-side management techniques can also be employed to shift and encourage energy use to when renewable supplies are abundant.[55] Tools as simple as smart meters can significantly improve energy management systems when they are broadly deployed.

Grid Security. Electrification of the energy system means rising digitization and growing Internet access to control home energy systems, business networks, and connection points on the grid that raises the risk of potentially serious disruptions. Cyber-attacks are an especially prominent concern, now with an

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[52] White House, "Federal-State Modern Grid Deployment Initiative Principles," May 2024, https://www.whitehouse.gov/wp-content/uploads/2024/05/Federal-State-Modern-Grid-Deployment-Initiative-Principles_formatted.pdf

[53] The National Conference of State Legislatures offers a basic overview of the issues and state policy options. "Modernizing the Electric Grid: State Role and Policy Options, September 2021, https://www.ncsl.org/energy/modernizing-the-electric-grid

[54] For an elementary introduction, see U.S. Department of Energy, "Grid-Connected Renewable Energy Systems," https://www.energy.gov/energysaver/grid-connected-renewable-energy-systems

[55] Flexible pricing programs can also be introduced to encourage utilities to find mechanisms to quickly adjust to changing load demand. See Kathryne Cleary and Karen Palmer, "Renewables 101: Integrating Renewable Energy Resources Into the Grid," Resources for the Future, https://www.rff.org/publications/explainers/renewables-101-integrating-renewables/

additional layer of complexity introduced by artificial intelligence (AI).[56] While AI is a threat, it also offers promise in addressing critical electric grid challenges, including planning, permitting, operations and reliability, and resilience.[57] Technology is a threat but also a valuable and essential tool to ensure a resilient and secure grid.

In addition to challenges arising from the energy transition are increasingly common weather events that arise from climate change including high wind, snow, and extreme cold and heat that have been mentioned above. Solar flares and electromagnetic pulses (EMPs) are two other threats. [58] Solar flares can affect transmission lines and damage transformers and other equipment. EMPs are instantaneous, intense energy fields that can overload or disrupt electrical systems and microcircuits and can arise from nuclear detonation or specially designed electromagnetic weapons. Major faults on the distribution system can lead to grid instability or outright failure. A major event could also mean the complete failure of computers, communication systems, vehicles, water and gas distribution systems, emergency response systems, and so on. It is not simply a loss of power, but systemic failure and breakdown of electric and electronic devices of all kinds. In extreme cases, these impacts could be catastrophic for the domestic and global economies and society.[59] These and other threats to the grid need to be addressed by federal agencies, TVA, and local distributors.

One recent extreme weather event was winter storm Elliot in December 2022. The severe cold ended up causing the highest 24-hour demand in TVA history. One solution to unexpected power demand surges is to improve battery storage capabilities and capacity in the state. TVA is investigating the potential for

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[56] For a discussion of cyber threats to the electric grid, see Theodore U. Marston, "The US Electric Power Infrastructure and Its Vulnerabilities," *The Bridge 48*, 2018, 31–39, https://www.nae.edu/19579/19582/21020/1%2083082/183133/The-US-Electric-Power-System-Infrastructure-and-Its-Vulnerabilities and Marc Casanovas and Aloys Nghiem, "Cybersecurity—Is the Power System Lagging Behind?" International Energy Agency, August 2023, https://www.iea.org/commentaries/cybersecurity-is-the-power-system-lagging-behind

[57] U.S. Department of Energy, "AI for Energy: Opportunities for a Modern Grid and Clean Energy Economy," April 2024, https://www.energy.gov/sites/default/files/2024-04/AI%20EO%20Report%20Section%205.2g%28i%29_043024.pdf

[58] U.S. Department of Homeland Security, Science and Technology Directorate, "Electromagnetic Pulse (EMP)/Geomagnetic Disturbance (GMD)," https://www.dhs.gov/science-and-technology/electromagnetic-pulse-empgeomagnetic-disturbance

[59] The 1859 Carrington Event is a common reference point for concerns voiced today about EMPs. For a popular discussion, see David Wallace, "A Solar Storm the Size of the Carrington Event Could Knock Out the Backbone of the Internet," *Astronomy*, May 2024, https://www.astronomy.com/science/a-large-solar-storm-could-knock-out-the-internet-and-power-grid-an-electrical-engineer-explains-how/ For a technical application specific to nuclear weapon events, see Electric Power Research Institute, "High Altitude Electromagnetic Pulse and the Bulk Power System," 2019 Technical Report, https://www.epri.com/research/products/3002014979

new battery storage, carbon capture, improved hydroelectric, and hydrogen as well as low-carbon fuel sources for manufacturing and industrial processes that cannot be easily electrified.[60] TVA invested $123 million in 2023 after winter storm Elliott with another $120 million planned for 2024 to prevent rolling blackouts.

Many federal and state agencies, as well as utilities, distributors, and other stakeholders are actively engaged in efforts to protect the nation's energy assets.[61] For example, the National Renewable Energy Laboratory (NREL) conducts research and works with its federal partners to address energy transition and the growing use of renewable energy sources.[62] Many other federal agencies are actively involved in addressing specific problems and issues.

In Tennessee, primary State responsibility for energy security rests with the Tennessee Department of Environment and Conservation and the Department of Safety and Homeland Security.[63] U.S. DOE helps the state gauge and monitor security threats through its *Energy Sector Risk Profile*.[64] The report includes a range of natural risks (drought, earthquake, flood), mechanical/infrastructure risks (equipment failures), and electric, natural gas and petroleum assets. Cyber threats are not addressed likely because of their infrequency today. Utilities, including TVA, have their own programs to protect electric grid security and related assets.[65]

Threats to electric supply increase the importance of effective emergency response mechanisms. Emergency management generally includes all the traditional public safety resources of the State and its

[60] Tennessee Valley Authority, "2021 Carbon Report," https://www.tva.com/environment/environmental-stewardship/sustainability/carbon-report
[61] For an overview of assets, see U.S. Department of Energy, "Cybersecurity," https://www.energy.gov/ceser/cybersecurity The Department of Homeland Security includes critical energy sectors (e.g. electricity and oil) and infrastructure sectors (e.g. food and agriculture) in their security efforts, https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/critical-infrastructure-sectors/energy-sector
[62] U.S. National Energy Renewable Laboratory, "Strategic Energy Security," https://www.nrel.gov/security-resilience/strategic-energy-security.html
[63] Tennessee Department of Environment and Conservation, "Energy Security Planning, Preparedness, and Response," https://www.tn.gov/environment/program-areas/energy/state-energy-office--seo-/programs-projects/programs-and-projects/energy-security.html and Department of Safety and Homeland Security https://www.tn.gov/safety/homeland-security/cyber_awareness.html Also see National Association of State Energy Officials, "Energy Security Planning," https://www.naseo.org/issues/energy-security/energy-security-planning
[64] U.S. Department of Energy, State of Tennessee Energy Sector Risk Profile, March 2021. https://www.energy.gov/sites/default/files/2021-09/Tennessee%20Energy%20Sector%20Risk%20Profile.pdf
[65] See https://www.tva.com/energy/transmission/protecting-the-grid

local governments.[66] The Tennessee Department of the Military, for example, also has a mission to address energy emergencies.[67] The most important facet of a large-scale adverse energy event is coordination across levels of government and all other emergency service providers, ranging from hospitals to local utilities. Coordination between different levels of government and the private sector is required to effectively engage in risk management and crisis mitigation. This in turn requires resilient communication systems.

It's Not Just the Electric Grid!

Key to an effective energy system is a secure and resilient distribution network that can safely move power to final consumers. While the focus in this section is the electric grid, there are other energy distribution systems that are critical to the economy, including those for coal, petroleum, and natural gas. For example, crude oil must be moved from the wellhead to refining facilities, stored, and then moved via pipeline and truck distribution systems to retail gasoline fueling stations. Casting the net more broadly, energy security and resiliency encompass every facet of the energy system, including the security of raw materials that support energy production/distribution/use (e.g., copper, aluminum, rare earth elements), resource extraction and processing (e.g., off-shore drilling platforms and petroleum refining), the wholesale movement of energy resources (gasoline, natural gas, coal), retail distribution (gasoline filling stations and local natural gas distribution) and storage/use. These other energy resources must be secure and resilient to support the effectiveness of the overall energy portfolio and its ability to meet the needs of the state. All energy sources in the portfolio must work in concert to support the needs of Tennessee.

[66] The National Conference of State Legislatures provide a brief overview of the role of the states in emergency preparedness and recent state policy action. https://www.ncsl.org/energy/energy-emergency-response-restoration-and-recovery
[67] Tennessee Department of the Military, "Tennessee Threats," https://www.tn.gov/content/tn/tema/prepare/tennessee-threats.html/

Private Sector and State Policy. There are numerous actions that can be taken by individuals, businesses, and the State to provide security and resiliency through self-insurance. For example, behind-the-meter are extensive networks and systems that rely on stable and secure electricity, including electrical systems themselves. These resources need to be maintained and secured by residential, commercial, industrial, agricultural, and transportation sector consumers. Examples include home wiring, wireless, and security systems; commercial and agriculture heating, cooling, and computer networks; business industrial processes and communications systems; and vehicle on-board wiring and wireless communications systems. Security protection directly benefits users and provides spillover insurance benefits by helping to protect the overall network as well.

There are other steps that can be taken to provide protection in the face of grid instability or failure. Options include backup power generation capacity, renewables, energy storage systems, and microgrids. Many households and businesses already rely on behind-the-meter backup generators, alternative energy sources (natural gas, solar), and storage systems.[68] Business parks, data centers, and other essential services can rely on microgrids with power sourced behind-the-meter to provide resiliency. The City of Chattanooga has partnered with EBP to create a microgrid using diesel generating capacity and a 500 kilowatt battery o support emergency police and fire services.[69]

Tennessee State policy channels are narrow because of the fundamental role played by the federal government, TVA, and local utilities. The State has some control over electricity use through its own building stock and energy efficiency programs that influence final consumers; by reducing load demand, less pressure is placed on the grid helping to restrain grid congestion and defer capital upgrades. As distributed generation and reliance on energy storage systems grows, State and local regulatory burdens need to be evaluated to ensure that they are not a barrier to deployment. The State also has the capacity to choose control over behind-the-meter critical infrastructure like emergency energy storage, power generating systems, and microgrids. These systems allow for enhanced resiliency. The State could

[68] The residential and nonresidential sectors in the U.S. had 960 MW of storage capacity behind-the-meter in 2020, representing 32 percent of total installed capacity (3,000 MW). Jeffrey J. Cook, et al., "Check the Storage Stack: Comparing Behind-the-Meter Energy Storage Policy Stacks in the United States," National Renewable Energy Laboratory, August 2020, https://www.nrel.gov/docs/fy22osti/83045.pdf For background on behind-the-meter systems see National Renewable Energy Laboratory, "Behind-the-Meter Battery Energy Storage," https://www.nrel.gov/docs/fy21osti/79393.pdf and "Behind-the-Meter Storage Analysis," https://www.nrel.gov/transportation/behind-the-meter-storage-analysis.html

[69] "City of Chattanooga and EPB Partner to Enhance Energy Resilience for Emergency Resources," EPB Press Release, May 2023, https://epb.com/newsroom/press-releases/city-of-chattanooga-and-epb-partner-to-enhance-energy-resilience/

provide guidelines and incentives for local government deployment of similar systems. The human element of grid security is also important, so ongoing efforts need to be made to ensure that the related workforce is well-trained and understands current and emerging energy-related threats.

RENEWABLE ENERGY AND STORAGE

Renewable energy and energy storage systems have a complementary and central place in the energy transition. In 2023, renewables accounted for 21.4 percent of national utility-scale electricity generation, surpassing both coal and nuclear power. Wind held the largest share, 10.2 percentage points, followed by hydropower (5.7 percentage points), solar (3.9 percentage points), and biomass (1.1 percentage points). All other renewable energy sources together contributed less than 1.0 percent point.[70] Solar and wind power are expected to see especially robust growth by 2025, with ongoing gains likely to continue unabated through 2050 and beyond.[71] Complementary storage systems can speed up the process of decarbonization by storing intermittent wind and solar power, as well as other energy sources. When balanced with baseload energy supply, renewable energy alone helps support system-wide security and resiliency through energy portfolio diversity.

Subsidies for renewables are premised on their lower environmental footprint, existing subsidies for fossil fuels,[72] and the pursuit of scale economies through broader deployment and production. Despite common assertions, renewable energy sources still produce emissions, though generally these arise from production and final disposition of generating capital rather than operations.[73] Renewables remain especially attractive because of their lower *lifecycle* emission costs. Lifecycle emission costs for different energy sources (calculated as grams of carbon dioxide equivalent per kilowatt hour or gCO_2eq/kWh) place coal (820) as the most costly to the environment, followed by natural gas (490). Utility-scale solar has much lower lifetime emissions (48), followed by hydropower (24) and on-shore wind (11).[74]

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[70] See https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

[71] U.S. Energy Information Agency, "Solar and Wind to Lead Growth of U.S. Power Generation for the Next Two Years," January 2024, https://www.eia.gov/todayinenergy/detail.php?id=61242

[72] Subsidies include tax preferences (depletion allowance) and the failure to account for external costs like air pollution, traffic congestion, and vehicular accidents. International Monetary Fund, "Climate Change: Fossil Fuel Subsidies," https://www.imf.org/en/Topics/climate-change/energy-subsidies

[73] See, for example, https://www.eia.gov/energyexplained/solar/solar-energy-and-the-environment.php

[74] Median values are reported in parentheses. Note that nuclear power has lifetime emissions of 12 gCO_2eq/kwh. Bruckner et al., "2014: Annex III: Technology Specific Cost and Performance Parameters," in *Climate Change 2014: Mitigation of Climate Change*, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press. See Table A.III.2.

TVA has continued to add renewable capacity to its portfolio with more on the horizon, including 10,000 MW by 2035.[75] As of September 2023, TVA had 8,668 MW of total renewable capacity, with 30.0 percent from solar, 14.3 percent from wind, 50.2 percent from hydroelectric, and the remaining 0.1 percent from biomass. Out-of-Valley renewables represented 17.9 percent of *operating* renewables in 2023.[76]

Aside from hydroelectricity and wind in the eastern portion of the state, Tennessee has limited potential for large utility-scale renewable energy deployment.[77] However, there are opportunities for smaller scale deployment of roof-top solar, biogas/renewable natural gas, and geothermal. This lack of large-scale capacity will compel reliance on imported renewable energy from other states to meet in-state consumer demand. Efforts should be made to identify and reduce barriers to the use of these renewable resources, including local zoning, homeowner association, and other regulations that may hamper adoption and deployment.

Agrivoltaics, which is the co-location of solar power generation with agricultural production, has the unique potential to produce power while at the same time protecting agricultural space from diversion.[78] For some crops, livestock, native species, and bees, photovoltaic solar arrays can produce ecosystem benefits through shade provision and a cooler local environment without crowding out agricultural activity. A small number of these facilities are now present in Tennessee and elsewhere across the country.[79] Agrivoltaics represent a potentially significant economic development opportunity for rural communities. Not only do they support agriculture, but they yield a diversified energy source that supports energy system resiliency like other renewables.

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[75] Tennessee Valley Authority, "Delivering Sustainable Solutions: Fiscal Year 2022," page 11. https://tva-azr-eastus-cdn-ep-tvawcm-prd.azureedge.net/cdn-tvawcma/docs/default-source/environment/tva-sustainability-report-fy-2022.pdf?sfvrsn=319a22fd_1

[76] Tennessee Valley Authority Security and Exchange Commission Form 10-k filing, 2023, page 17. https://d18rn0p25nwr6d.cloudfront.net/CIK-0001376986/b1d84fa0-fedc-4285-a4c7-cddd3b623ec0.pdf

[77] Department of Energy, Office of Energy Efficiency and Renewable Energy, "Renewable Energy Resources Assessment Information for the United States," March 2022. https://www.energy.gov/sites/default/files/2022-03/Renewable%20Energy%20Resource%20Assessment%20Information%20for%20the%20United%20States.pdf

[78] Background on agrivoltaics is available from the National Renewable Energy Lab, https://www.nrel.gov/solar/market-research-analysis/agrivoltaics.html For a Tennessee perspective on land conversion required to support solar generation and an introduction to agrivoltaics, see Karen DeLong et al., "Evaluating Potential Land use of Utility-Scale Photovoltaics (Solar Panels) on Farmland in Tennessee," University of Tennessee Institute of Agriculture, 2023, https://ageconsearch.umn.edu/record/337419?ln=en&v=pdf

[79] See the open-source site https://openei.org/wiki/InSPIRE/Agrivoltaics_Map

Energy storage systems provide a just-in-time energy source that disconnects energy generation from direct use. [80] Storage systems come in vastly different and often novel forms, from small lithium batteries in a watch to large utility-scale systems.[81] The evolution of technology has led to more reliable and durable storage systems of longer duration. Storage systems coupled with renewable energy sources also enable applications in areas that are not otherwise served by the grid. Examples include parks and recreation areas.

Storage systems, especially large-scale systems, offer a range of important benefits to support the energy transition.[82] For both individual users and utilities there are arbitrage opportunities, using energy sources during periods of low demand and low prices to charge storage systems for subsequent use. For example, an EV owner may face lower electricity rates at night that enables lower-cost charging. For utilities, large storage systems similarly can be charged when low-cost capacity is available. TVA's Racoon Mountain pumped storage facility uses excess hydropower to pump water to a lake, and this water is discharged through turbines when power is needed.[83] In places like California, renewables frequently generate more power than is needed, but there is insufficient storage capacity to capture all the unused power. Storage systems also provide resiliency through their backup power that can be tapped in emergencies. Utility-scale storage systems can improve electric grid resiliency and stability by helping to balance supply and demand. In doing so, they can help defer costly upgrades to the network.

Utility-scale storage systems have at least 1 MW of net generation capacity. (TVAs Raccoon Mountain has a capacity of 1,616 MW.) The U.S. Department of Energy has a keen interest in fostering the development and commercialization of new technologies and introduced its Energy Storage Grand Challenge in 2000.[84] Most utility-scale storage systems in the U.S. continue to rely on lithium batteries. At

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[80] For additional background see section two, *Energy Sector Disruptors in Tennessee: Framing Options*, prepared for the Tennessee State Energy Policy Council, December 2021, https://comptroller.tn.gov/content/dam/cot/energy-policy-council/documents/reports/sepc-reports/reports-of-2021/SEPC_Annual_Energy_Assessment_2021_(Final).pdf

[81] Novel new battery storage systems continue to be developed. "Two Massive Gravity Batteries are Nearing Completion in the U.S. and China," April 24, 2023, https://interestingengineering.com/innovation/two-massive-gravity-batteries-are-nearing-completion-in-the-us-and-china and Amos Zeeberg, "Storing Renewable Energy, One Balloon at a Time," New York Times, March 18, 2024, https://www.nytimes.com/2024/03/18/science/renewable-energy-storage-climate.html-

[82] U.S. Energy Information Agency, "Electricity Explained: Energy Storage for Electricity Generation," https://www.eia.gov/energyexplained/electricity/energy-storage-for-electricity-generation.php

[83] Tennessee Valley Authority, "Raccoon Mountain," https://www.tva.com/energy/our-power-system/hydroelectric/raccoon-mountain

[84] Department of Energy, "Energy Storage Grand Challenge," July 2020, https://www.energy.gov/sites/prod/files/2020/07/f76/ESGC%20Draft%20Roadmap_2.pdf.

the close of 2022, the nameplate capacity of U.S. utility-scale battery storage was 8,842 MW.[85]

As with other facets of the energy transition, renewables and storage systems offer potential economic development opportunities linked to R&D, final and intermediate products, and supply chains, including wind turbines, magnets, solar panels, composite materials, electrical components, and so on. Expected growth in renewables and storage systems, coupled with the state's large and vibrant manufacturing sector, make opportunities like this especially favorable for consideration in Tennessee.

WORKFORCE AND EMPLOYMENT

The disruptions of the energy transition include both job losses and new job opportunities. Examples are abundant, including the demise of coal-fired power plants and the emergence of utility-scale solar and wind farms; another example is the ascendance of EVs at the expense of gasoline powered light-duty vehicles.[86] Some occupations and business sectors associated with the energy transition are expected to see exceptionally strong growth between 2022 and 2032, including wind turbine service technicians (45 percent) and solar voltaic installers (22 percent).[87]

The following quote aptly summarizes the workforce challenge for Tennessee:

> *Similar to the country's broader infrastructure workforce, green workers tend to specialize in the skilled trades. Even though these positions pay competitive wages, tend to not require a four-year college degree, and have massive hiring needs, many prospective workers don't know such jobs exist or don't have flexible ways to get needed on-the-job training for them. That is especially the case for younger people, women, and people of color who lack supportive services such as child care and transportation, and face other long-standing barriers in the workplace. Meanwhile, employers—including utilities, contractors, and other public and private entities—compete against each other for a limited pool of talent.*[88]

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[85] U.S. Energy Information Agency, "Electricity Explained: Energy Storage for Electricity Generation."

[86] The EV market share, including hybrids, electric and plug-in vehicles, has been trending up since 2018, despite a setback in the first quarter of 2024. U.S. Energy Information Agency, "U.S. Share of Electric and Hybrid Vehicles Sales Decreased in the First Quarter of 2024," https://www.eia.gov/todayinenergy/detail.php?id=62063#:~:text=Hybrid%20vehicles%2C%20plug%2Din%20hybrid,to%20estimates%20from%20Wards%20Intelligence.

[87] U.S. Bureau of Labor Statistics, "Fastest Growing Occupations," https://www.bls.gov/ooh/fastest-growing.htm and Joseph W. Kane, "The Incredible Shrinking Workforce—And What to Do About It," Brookings Commentary, May 2023, https://www.brookings.edu/articles/the-incredible-shrinking-infrastructure-workforce-and-what-to-do-about-it/

[88] Joseph W. Kane, et al., "Unlocking New Federal Funding to Drive Green Workforce Development," Brookings Research, October 2023, https://www.brookings.edu/articles/unlocking-new-federal-infrastructure-funding-to-drive-green-workforce-development/

A foundational need throughout the energy transition will be education and workforce training that starts early in school and extends through adulthood as individuals prepare for the future and react to ongoing changes in energy-related (and other) labor markets. Many will transition into and out of work and training over the course of their careers, as is already the case. Workers will need to learn more about new opportunities as well as skills, jobs, and occupations that are ill-fated for the future. Information sharing will be critical.

Individuals learn workforce skills through formal education and training as well as on-the-job experience, all shaped by the broader influences of society. The public sector is generally tasked with providing *general* education that can be applied across occupations, including reading, writing, and mathematics. The growing role of STEM fields—science, technology, engineering, and mathematics—shows how public education has tried to adapt to changing workforce needs. These fields will be an essential component of the education foundation for workers responding to the energy transition since many jobs will require advanced skills and the ability to adapt to changing job complexities. Highly *specialized* training that is largely used by specific employers or within narrow occupational categories is generally the responsibility of businesses since they stand to gain the most from the worker skillset. In practice, most education and training provides a mix of general and specific skills. In this more common case, the burden of education and training provision will fall on all three partners—workers, the public sector, and private business.[89] It will take responsive education and training programs, good information, and the active engagement of all three partners to enable an effective response to the energy transition.

Employers today commonly note that they cannot find adequate numbers of skilled workers, a problem that is spread across many business sectors and occupations, not just those tied to energy transition.[90] Part of this is the tight national labor market, as reflected by exceptionally low unemployment rates. But part of it is a growing skills gap.[91] The practical consequences of a skills gap include forgone worker opportunity and diminished business competitiveness. These problems are often hidden beneath the

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[89] This is a discussion of classic human capital theory in labor economics. More generally, human capital includes health since health status can affect learning and labor market performance. For an introduction, see “Human Capital,” https://en.wikipedia.org/wiki/Human_capital or any textbook in labor economics.

[90] Joe McKenrick, “We Can’t Find Enough Skilled Workers: Can Automation Fill the Gaps?” Forbes, September 2023, https://www.forbes.com/sites/joemckendrick/2023/09/27/we-cant-find-enough-skilled-workers-can-automation-fill-the-gaps/?sh=20776537699a and U.S. Chamber of Commerce, “Understanding America’s Labor Shortage: The Most Impacted Industries,” https://www.uschamber.com/workforce/understanding-americas-labor-shortage-the-most-impacted-industries

[91] For an in-depth discussion of the skills gap, see U.S Congressional Research Service, “Skills Gaps: A Review of Underlying Concepts and Evidence,” March 2022, https://crsreports.congress.gov/product/pdf/R/R47059

surface, slowly manifesting themselves in the form of reduced economic growth. For the energy transition, the lack of skilled workers also means a delay in the utilization of clean energy sources and the realization of the benefits of a cleaner, safer environment.

Compounding skills inadequacy is the equally vexing problem of a spatial mismatch arising from energy transition—the jobs that are in decline are not always in the same place as the new jobs that are being created. It has been estimated that as many as 1.7 million jobs may be lost in the fossil fuel sector because of the energy transition, concentrated in specific regions of the country, while new, green jobs will be created largely in other regions.[92] Many of those who are displaced do not have the education and training to enable them to gain entry into rapidly growing occupations.[93] There is also evidence that regions with solar and wind potential may experience stronger growth than other areas.[94] These distributional changes will take place both across and within states and require somewhat different policy responses to meet the differential needs of workers, including both people-based and place-based policies.

Creating Opportunity Through Training. The energy transition will affect wide swaths of the economy but will be driven by sectors directly tied to energy markets. Within these same sectors, there will be many affected occupations that do not appear to be linked to energy markets, including managers, accountants, human resource specialists, architects and drafters, protective service workers, and so on.

The global energy sector is estimated to employ 67 million workers, with green jobs driving recent growth. China alone accounts for 30 percent of these jobs. Thirty-six percent of energy jobs are in high-

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[92] Junghyun Lim et al., "Location is a Major Barrier for Transferring U.S. Fossil Fuel Employment to Green Jobs," *Nature Communications,* September 2023, https://www.nature.com/articles/s41467-023-41133-9 Additional evidence indicates that the disruptions will have disproportionate impacts on regions with a large fossil fuel *imprint*, as captured by both energy production and use. See Kailin Graham and Christopher R. Knittel, "Assessing the Distribution of Employment Vulnerability to the Energy Transition Using Employment Carbon Footprints," *Proceedings of the National Academy of Science*, February 2024, https://www.pnas.org/doi/10.1073/pnas.2314773121
[93] Jacob Greenspon and Daniel Raimi, "Matching Geographies and Job Skills in the Energy Transition," Resources for the Future working Paper 22-25, October 2022, https://media.rff.org/documents/WP_22-25_PnkcURf.pdf
[94] Findings based on U.S. labor markets between 2005 and 2019. H. Ron Chan and Christy Zhou, Charged Up: Impacts of Green Energy Transition on Local Labor Markets," *Social Science Research Network*, March 2024, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4534479

skill occupations compared to an economy-wide figure of 27 percent; the new jobs provide a compensation premium over other jobs in the economy.[95]

Tennessee's energy sector accounted for 202,637 jobs in 2021, or 2.6 percent of the nation's energy jobs and 6.5 percent of all Tennessee nonfarm jobs.[96] These jobs are in electric power generation; fuels; transmission, distribution, and storage; energy efficiency; and motor vehicles. It is noteworthy that solar electric generation ranked second with 4,870 jobs, trailing traditional hydroelectric generation (5,131 jobs) and dominating all other technologies; wind electric generation had 546 jobs in 2021. Another report identified 393,756 jobs in the state's *advanced energy* sector in 2021, with jobs growing 9.9 percent compared to 2016, much faster than overall state job growth.[97] The number of jobs and expected job growth rates illustrate the significant scope of the energy sector and the opportunities and challenges arising from the energy transition.

The federal government is actively promoting workforce development to meet worker and employer needs to facilitate energy transition. Substantial support is provided through the Infrastructure Investment and Jobs Act (also known as the Bipartisan Infrastructure Law, the Inflation Reduction Act, and other recent initiatives. The Infrastructure Investment and Jobs Act and Inflation Reduction Act have $75 billion to support green workforce development. U.S. DOE's Office of Energy Jobs and Office of Energy Efficiency and Renewable Energy are also trying to facilitate workforce development, including focal areas on energy efficiency (e.g., buildings), renewable power (e.g., solar and water), and sustainable transportation (e.g., hydrogen and fuel cells).[98]

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[95] International Energy Agency, "World Energy Employment 2023," https://iea.blob.core.windows.net/assets/ba1eab3e-8e4c-490c-9983-80601fa9d736/World_Energy_Employment_2023.pdf

[96] U.S. Department of Energy, "U.S. Energy and Employment Report by State 2022," June 2022, https://www.energy.gov/sites/default/files/2022-06/USEER%202022%20State%20Report_0.pdf and University of Tennessee Boyd Center, *An Economic Report to the Governor 2024*, appendix table 1, https://haslam.utk.edu/publication/economic-report-to-the-governor-2024/

[97] Matthew N. Murray and Jilleah G. Welch, "Tennessee Advanced Energy Economic Report," Tennessee Advanced Energy Business Council, August 2021, https://www.tnadvancedenergy.com/advanced-energy-economic-impact-report/

[98] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "Clean Energy Job Creation and Growth, https://www.energy.gov/eere/clean-energy-job-creation-and-growth

TDEC submitted the PCAP to EPA in March 2024. PCAP includes the TVERS discussed above.[99] TVERS will also identify workforce opportunities for low-income communities, including weatherization, energy infrastructure, energy-related manufacturing (e.g., appliances), solar installation, and waste management. The State's Climate Change Action Plan (CCAP) will be provided to EPA in 2025 and include workforce planning analysis.[100] This analysis will seek to coordinate education and training opportunities around growing and declining sectors tied to climate pollution reduction.

Tennessee is one of 10 southeastern states that will share $927 million in funding over 2022-2026 to support EV charging infrastructure. This builds on a vibrant regional EV production system that has strong anchors in Tennessee, soon to include large-scale battery manufacturing at BlueOval City. Keen to seize on emerging opportunities, policymakers now have an inventory of EV-related workforce development initiatives across the southeast. [101] An inventory of state training programs highlights the need for ongoing coordination and partnerships between educators, trainers, and businesses, although some new programs have been or will be created.

An important lesson is that not all new job opportunities will require highly specialized training, instead building on the core skills, trades, and occupations that have applicability across business sectors. For example, a welder could be essential in an EV parts facility but also deploy the same skills in unrelated businesses like construction. The same would likely be true of many other trades and occupations. Education and training programs need to prepare workers for employment but also for specialized skill upgrading within specific job areas.

SMALL MODULAR REACTORS

The discussion around decarbonization has led to the widespread adoption of renewable energy production and also the realization that nuclear power is needed to fully achieve it. The idea of using smaller reactors as lower-cost and more distributed power sources has gained considerable attention

[99] Tennessee Department of Environment and Conservation, "Tennessee Volunteer Emission Reduction Strategy," March 2024, https://www.tn.gov/content/dam/tn/environment/policy-planning/documents/tvers/opp_tvers_pcap.pdf

[100] Tennessee Department of Environment and Conservation, "Climate Pollution Reduction Grants—Planning Grants Tennessee Workplan," https://www.tn.gov/content/dam/tn/environment/policy-planning/documents/tvers/opp_tvers_tdec-workplan.pdf

[101] National Association of State Energy Officers, "Building an EV Workforce: A Review of Southeast Transportation Electrification Workforce Development Training Programs," https://naseo.org/data/sites/1/documents/publications/Building%20an%20EV%20Workforce_v3.pdf

over the past decade. However, the introduction of nuclear power into an area and to new organizations is challenging. The introduction of new fuel and reactor technologies adds to that difficulty. The emerging nuclear market offers the possibility of all power ranges, a variety of fuel forms, and different business models. As of today, only one reactor option is commercially available in the U.S.: the Westinghouse AP-1000, used to produce electricity. The current state of the emerging nuclear market can be described as follows:

- Microreactors producing ~5 MWe could potentially be available within 5-8 years and could be used to provide localized power for smaller needs.
- Commercial Light water SMRs could be available at ~100-300 MWe levels, perhaps within 7-10 years.
- Advanced reactors that do not use water could become available over the next 10-15 years. Decisions on the deployment of advanced reactor concepts may be delayed until there is more certainty in their availability and costs after successful early demonstrations.
- Delays in the availability of High Assay Low Enriched Uranium (HALEU) and delays in advanced reactor development could lead to decisions to expand nuclear power with the Westinghouse AP-1000 reactor because it is commercially available and the most recently built.

There are numerous opportunities for Tennessee to engage and benefit from nuclear expansion regardless of which reactors are constructed or where they are constructed. These include nuclear design, fabrication of specialized components, equipment and systems, and facilities related to the commercial fuel supply chain.

Emerging Reactor Technology. The current state of the art in the U.S. is the large LWR that uses commercially available 5 percent enriched uranium fuel. Smaller versions of this same technology, with design improvements, are under development and, if successful, may soon be demonstrated in east Tennessee. These smaller LWRs use the same fuel as the existing fleet and will share the existing fuel infrastructure. The next step in complexity is to increase the enrichment of existing uranium fuel to allow for smaller reactor cores or cores that can operate longer. Thus, High Assay Low Enriched Uranium (HALEU) fuel is expected to be the next evolution in reactor technology. Most advanced reactor concepts rely on HALEU fuel and will have to wait for the production of HALEU to be scaled up and for regulatory measures to be implemented for its use. Several companies are interested in expanding enrichment capability in our region.

TRi-structural ISOtropic (TRISO) particle fuels are common advanced reactor fuels with a number of similar forms currently under development. The coated particles are designed to contain fission products produced during operation. The particle itself is thus the confinement barrier for radioactivity and, under most conditions, very little will escape the fuel. Crediting the particles for confinement, in theory, reduces the safety burden on the rest of the reactor system and reactor building. The argument is that the reactor will be cheaper and safer.

Currently, LWR fuel and TRISO fuels are proposed for use only within a once-through fuel cycle. Used fuel can be reprocessed to recover the available fissile material for reuse. Some reactors are designed to reuse fuels to get more energy from the same amount of fuel and to reduce the amount of high-level waste that will eventually require permanent disposal. These reactors usually use liquid metal (LM) coolants. Costs for LM reactors have historically been high, and availability (the percentage of time it operates) has generally been lower than that needed for market competitiveness. Several planned demonstrations are currently proposed to mature and demonstrate the technology.

Roles, Challenges and Opportunities. The nuclear industry is expected to evolve and grow. However, the course of development is difficult to predict. It will depend on the ability to mature a technology and to have the right market pull in place to match that technology. Two key changes are expected in the next few years: 1) the U.S. nuclear sector will invest in fuel enrichment and production; and 2) advanced reactors will be demonstrated. Tennessee has attracted interest in both areas.

The recent U.S. restrictions on the use of Russian uranium have led several companies to consider new fuel enrichment and fuel processing capabilities. Some of these are developmental while others are based on demonstrated technology. East Tennessee is considered an attractive location for new enrichment facilities. The research and development base for enrichment technology already has a foothold in east Tennessee and that can be expanded to additional companies and new technologies. Fuel fabrication factories targeted for east Tennessee using HALEU fuel are currently under development. With uranium enrichment and processing, and fuel fabrication co-located in east Tennessee, Tennessee will be a central hub of the new nuclear fuel economy. One advanced reactor company, Kairos Power, continues to show excellent progress and is highlighting Tennessee by proposing two reactor demonstrations in the Oak Ridge area. A local reactor demonstration in combination with local fuel production capability would be a complete success for the state. Efforts to support the elements already here and efforts to bring in others are of paramount importance today.

Not many new reactors will be built in Tennessee. However, all new reactor builds can rely on a nuclear industry centered in Tennessee. Having qualified nuclear design and construction expertise will be essential. Nuclear technical expertise is not difficult to find in Tennessee, but it may be difficult to maintain. Many experienced personnel working in the industry are approaching retirement. A vital issue today is the ability to educate and train the next generation of nuclear workers under the mentorship of the current workforce. Educational programs to target all necessary technical levels either exist or are under development. These programs will need support well in advance of the need for workers, but critically, new advanced nuclear technology companies need to be in place to accept new workers as they become available. Otherwise, they will be lost to other industries or other regions.

Tennessee is in a favorable position to benefit from nuclear expansion. At least four SMRs are currently under consideration for east Tennessee. The key to Tennessee's extended success is to be prepared to provide the precursor nuclear capabilities needed. If we have those, Tennessee can be integral to every reactor built in the U.S. and perhaps most of those built elsewhere. To pull all the elements together, the focus needs to include 1) ensuring design and construction capability, 2) attracting fuel enrichment and production facilities, 3) expanding our role in nuclear supply chains, and 4) supporting education and workforce development.

Technology Overview. Four "more near-term" LWR small modular reactors (SMRs) are characterized in Table 1, Summary Design Information for LWR SMRs*. These LWR SMR designs use current generation LWR technology, materials, and fuel (LEU) and are in various stages of development.

A recent report provides a convenient comparison of three advanced reactor concepts (including an LWR) against a reference baseline large LWR. The advanced reactors considered are 1) the NuScale VOYGRTM, 2) X-Energy Xe-100TM, 3) and the TerraPower NatriumTM. (The NuScale project is no longer active at this time.)

The NuScale's VOYGR power plant is a modular concept that provides scalability from ~77 MWe to ~924 MWe within a single facility using NuScale's Power ModuleTM. The plant can be configured for four-, six-, or 12-modules. The reactor building is designed and constructed from the outset to house multiple modules to allow the "scaling up" of installed capacity over time. NuScale has received a design certification from Nuclear Regulatory Commission (NRC) for its ~50 MWe module and has applied to the NRC for approval of the ~77 MWe module.

The Xe-100 is a helium-cooled TRISO fueled pebble bed reactor rated at ~80 MWe. In comparison, the NuScale reactor uses similar fuel as the current fleet of LWRs. Xe-100 deployment therefore requires additional elements of fuel development and qualification. The Xe-100 can be a single standalone reactor or used in a multi-reactor configuration. Typically, up to four co-located reactors have been discussed. X-Energy is in a partnership with DOW industries to provide power (heat and electricity) for oil refining in Texas.

The Natrium reactor is a fast spectrum liquid-metal cooled reactor. It is based on many decades of experience and is likely targeted ultimately for the fuel recycle market. The first demonstration reactor is rated at ~350 MWe, but an eventual commercial plant would likely be closer to 1000 MWe.

The reactors discussed in the Argonne National Laboratory (ANL) study referenced above are all solid fuel reactors. The Xe-100 differs in that operators can continuously load and remove pebble fuel during operation. This has the benefits of not needing excess fuel in the core during operation and allowing extended operating cycles. The VOYGR and Natrium reactors, like LWRs, have fixed cores with excess reactivity at the beginning of an operating cycle and must be shut down periodically to remove used fuel and add new fuel. The amount of time any reactor can operate before it must be shut down for refueling and/or other maintenance is design dependent.

Two other concepts of note include the pebble bed salt-cooled concept under development by Kairos Power and various molten salt-fueled concepts. The pebble bed salt-cooled reactor uses fuel similar to Xe-100, TRISO-based pebbles, and is also continuously fueled. Salt-fueled reactors (as opposed to salt-cooled reactors) have liquid fuel that circulates through the reactor primary system and is also continuously fueled. A major advantage of salt-cooled, salt-fueled, and liquid metal-cooled (LM) reactors is that they operate at low pressures (~ 1 to 2 Bar), even at elevated temperatures, allowing components to have thinner walls and in theory cost less.

The LWRs described in Table 1 are smaller than traditional LWRs. Only the NuScale concept is modular in the sense that multiple reactors operate within a common building. The others are standalone concepts. Small reactors may require less capital investment, take less time to construct, and fit more easily on available sites and within modern grid portfolios. The BWRX-300 is being considered for near-term deployment at the Darlington site in Canada and the Clinch River Site in Tennessee.

*Table 1. Summary Design Information for LWR SMRs**

LWR SMR Designs				
Design Feature	**BWRX-300** GE-Hitachi	**AP300™** Westinghouse	**Power Module™** NuScale	**SMR-160™** Holtec
Application	Flexible-Electricity, Hydrogen Production, Desalination, District Heating, Black Start Capability	Flexible-Electricity, Hydrogen Production, Desalination, Black Start Capability	Flexible-Electricity, Hydrogen Production, Desalination, District Heating, Black Start Capability	Flexible-Electricity, Hydrogen Production, Desalination, District Heating, Black Start Capability
Fuel	LEU	LEU	LEU	LEU
Outlet Temperature	287 C	~300 C	314 C	316 C
Power Output Base Model (MWe) Plant Scalability Output (MWe)	300	300	77 308 (77x4) 462 (77x6) 924 (77x12)	160
NRC Status	Preapplication engagement, Construction Permit Application Expected	Regulatory engagement plan submitted May 2023, Design Certification anticipated by 2027	NRC issued final rule to certify NuScale Design for 50 MWe unit in Feb 2023. Approval for 77 MWe unit submitted to NRC January 2023	Pre-application engagement activities
Deployment Expected (Projected as of July 2023)	Darlington (Canada) Site: 2028 Clinch River Site: 2032	Not publicly available	Carbon-Free Power Project (USA) 2029**	Not publicly available

* Source: Nuclear Innovation Alliance's "Advanced Nuclear Reactor Technology – A Primer," July 2023

** Post July 2023 Note: Effective November 8, 2023, NuScale and UAMPS of Idaho mutually ended the CFPP. NuScale continues to engage with other companies in potentially deploying its SMR, both domestically and internationally.

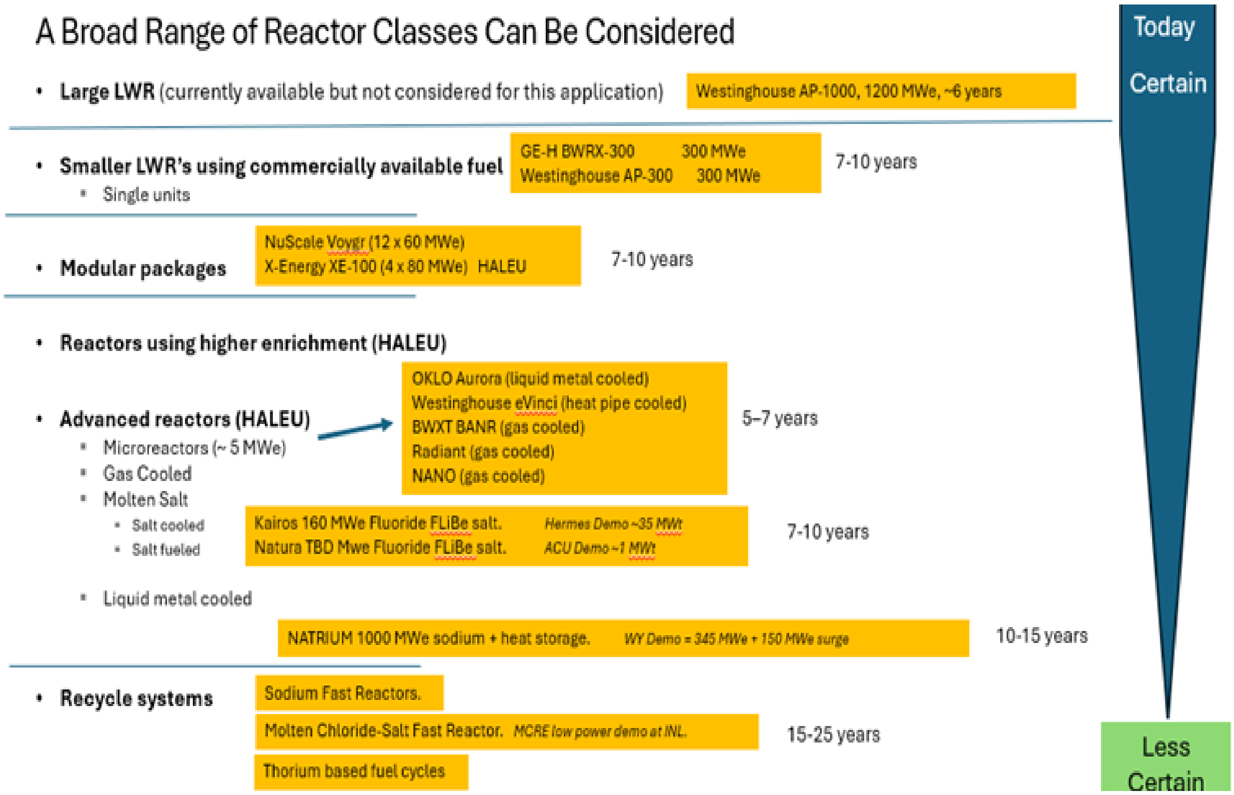
Cost Considerations: Nuclear Construction and Operation. Nuclear construction costs are dependent on the technology chosen. However, actual data is limited to only earlier U.S. LWRs, the recently built AP-1000s, and LWRs built in other countries. There is insufficient data to reliably predict costs for the next reactor builds. For advanced reactors, different materials, fuels, systems, and fabrication methods are needed. Generally, the more "new" features, the higher the development and First-of-a-Kind (FOAK) construction costs. Cost uncertainty and project risk for FOAK advanced reactor projects are also increased.

There are cost savings to be had from building similar (as similar as possible) reactors a number of times. The early builds are usually the highest cost. Nth-of-a-Kind costs refer to the stabilized costs of later units once processes are in place and experience has been gained. Nth-of-a-kind cost models did not apply to the first generation of reactor builds in the U.S. because different organizations were building different reactor designs at different sites. Advanced reactor design is focusing more on producing factory-made reactor components and systems in manufacturing environments to better control consistency, quality, and reduce costs.

Various reactor technologies are shown in Figure 1. The current state of the art in the U.S. is the large LWR that uses commercially available 5 percent enriched uranium fuel. Smaller versions of this same technology, with design improvements, are under development. These smaller LWRs would share the existing fuel infrastructure and regulations. A smaller reactor could eventually be cheaper per unit of electricity produced, but it will take several builds to know if this is true.

The next step in complexity is to increase the enrichment of existing uranium fuel to allow for smaller reactor cores or cores that can operate longer. Thus, HALEU fuel is expected to be the next evolution in reactor technology. Most advanced reactor concepts rely on HALEU fuel and will have to wait for the production of HALEU to be scaled up and for regulatory measures to be implemented for its use.

Figure 1: Classes of Reactor Technology



Currently, LWR fuel and TRISO fuels are proposed for use only within a once-through fuel cycle. Used fuel can be reprocessed to recover the available fissile material for reuse. However, the overall economics of reprocessing are not currently favorable given the availability and cost of natural uranium. Some reactors are designed to reuse fuels to get more energy from the same amount of fuel and can potentially reduce the amount of high-level wastes that eventually will require permanent disposal. These reactors usually use liquid metal coolants. Costs for LM reactors have been high, and availability has generally been lower than that needed for market competitiveness. Several planned demonstrations are currently proposed to mature the technology. The fuel recycling concept requires reprocessing facilities and historically those costs have also been high. However, there is currently increased interest and discussion around the subject.

A 2022 study by the Massachusetts Institute of Technology (MIT) estimated the costs for the next AP-1000 based on the experience with the Vogtle Units 3 and 4 as well as that in China where four AP-1000s are operating.[102] The estimated capital costs ($/kWe) are as follows:

• Historic PWR Pre-TMI (Three Mile Island)	$4,700 per kWe
• Historic PWR Post-TMI	$9,512 per kWe
• Vogtle Units 3 and 4 – 2021 estimate	$7,956 per kWe
• Next AP-1000 "Should Cost"	$4,300 per kWe
• 10th unit AP-1000 "Should Cost"	$2,900 per kWe

More recent estimates for the two completed U.S. Westinghouse AP-1000 units range from $12B-$14B cost per unit, with a variety of reasons for the costs and schedule overruns. Significant reduction in construction schedule and costs are reported for the second completed unit. It is not unreasonable to think that the next round of AP-1000 builds could significantly improve upon that second build and perhaps cost $6B-$8B.

One-third scale LWRs based on LWR technologies may eventually cost less per unit of electricity produced; however, there is currently no basis for that assumption. Direct scaling suggests costs of $2B-$3B per unit might be expected. FOAK units will likely cost more. Targeted costs of $1B for 300 MWe units have been suggested, but again, there is currently no basis for that estimate.

Modular reactor concepts build out a site for multiple reactors and install and operate plants over time. This approach still has a considerable capital cost related to site construction, but it allows revenue from the first reactors to pay for the later reactors. In principle, this concept reduces the debt burden developed in the construction phase of a standalone reactor, during which no revenue is generated. However, the full site engineering costs are paid prior to the first reactor installation and the site operates at reduced power (and revenue) until it is completed. A FOAK modular LWR concept demonstration was recently suspended due to rising cost projections. However, there is still a need for and an interest in the modular concept.

[102] Koroush Shirvan, "Overnight Capital Cost of the Next AP1000," Center for Advanced Nuclear Energy Systems. Massachusetts Institute of Technology, March 2022, https://web.mit.edu/kshirvan/www/research/ANP193%20TR%20CANES.pdf

The Nuclear Energy Institute (NEI) evaluates the competitiveness of microreactors for remote markets.[103] In so doing, NEI developed a “reference” microreactor working with proprietary data from several microreactor developers. The parameters for the reference microreactor evaluated are presented in Table 2:.

Table 2: NEI Reference Microreactor Parameters

	Reference Value	Range of Values
Reactor Size (MWe)	5	1 – 10
Number of Co-Located Reactors	2	1 – 4
Plant Life (Years)	40	10 – 60
Core Life (Years)	10	5 - 20
Capacity Factor	95%	45 % - 95%

The Reference Value in Table 2: shows the single value used for each parameter. The Range of Values represents the range of values used to conduct sensitivity analyses.

Table , NEI Reference Microreactor Costs, shows estimated costs for the major cost elements that correspond to the parameters for both the “Reference Value” and “Range of Values.” Major cost elements include:

- Capital Costs
- Fixed Operations and Maintenance (O&M) Costs
- Fuel Costs
- Decommissioning Costs
- Refueling Costs

[103] Nuclear Energy Institute, “Cost Competitiveness of Micro-Reactors for Remote Markets,” April 15, 2019, https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/Report-Cost-Competitiveness-of-Micro-Reactors-for-Remote-Markets.pdf

Table 3: NEI Reference Microreactor Costs

	Reference Value	Range of Values
Overnight Capital Cost ($/kWe)	$15,000	$10,000 to $20,000
Fixed O&M Cost ($k/kWe)	$350	$250 to $450
Fuel Cost ($/kWe) – includes used fuel management	$10	$6 to $14
Decommissioning Costs (kWe)	$5	$3 to $7
Costs per Refueling – includes transport and installation, excluding fuel – included above	$20 million	$13 million to $27 million

From Table , capital costs dominate the overall cost, while fuel and decommission costs are considerably lower. Other key findings from the NEI study include:

- Microreactors are expected to be cost competitive for remote and/or special applications and defense applications where costs are higher than the general energy market.
- A 10 MWe microreactor is estimated to cost ~$150M, including site preparation. This assumes the designs are complete and licensed.

While the projected capital costs for microreactors are higher per unit of power compared to larger nuclear power plants, it is anticipated that microreactors will offer the following cost offsetting factors to make them more cost competitive:

- Simplified/standardized designs
- Factory fabrication
- Lower financing costs
- Shortened construction time
- Lower power levels translates to lower radioactive source terms, resulting in simplification of safety and control systems, reduced numbers of operations personnel, and reduced emergency planning zones (EPZs)

Tennessee could host large or small LWRs, advanced modular concepts for specific customer needs (i.e., data centers), or micro-reactors. Partnerships among State, federal, and private organizations are essential for successful nuclear demonstrations and specifically FOAK reactor projects. Partnerships typically include public-private partnerships to pay for design and construction, and power purchasing agreements that pay a guaranteed price for energy produced. Reactor operating costs are the responsibility of the owner and are either offset by revenue (for power reactors) or funded through government and/or commercial sponsorship (university research reactors, for example). The key to successful nuclear development will be the strength of the partnerships formed.

The Future. The nuclear industry is expected to remain strong and to grow. However, bringing new technology to the market requires commitment, time, and investment. Two key initiatives are expected in the next few years: 1) the U.S. nuclear sector will invest in fuel enrichment and production; and 2) advanced reactors will be demonstrated. Tennessee has attracted interest in both areas.

The recent U.S. restrictions on the use of uranium have led several companies to consider fuel enrichment and fuel processing capabilities. Some of these are developmental, and others are based on demonstrated technology. The research and development base for this technology can be in east Tennessee, and these new fuel facilities can be in Tennessee. In fact, fuel factories using HALEU fuel are currently being designed. If uranium enrichment and processing, and fuel fabrication are co-located in Tennessee, Tennessee will become an international hub of nuclear activity.

One company, Kairos Power, is showing excellent progress and is highlighting east Tennessee by proposing two reactor demonstrations in the Oak Ridge area. The combination of new fuel handling and production capability and its use in a local demonstration reactor would be an unmitigated success for Tennessee. Efforts to support those nuclear initiatives already here and to bring in others are of paramount importance today. Tennessee is looking forward to a successful LWR being constructed at the CRN site. We should work to follow that with an advanced reactor build.

If all emerging opportunities hit, finding qualified labor will be a limitation. There are many experienced personnel already working within the nuclear sector in east Tennessee. Success will depend on the ability to bring in a new generation of nuclear workers and to train them under the current generation of workers. Educational programs to target all necessary technical levels either exist or are under development. These programs will need support and new nuclear companies will need to be in place as these workers become available.

It seems that Tennessee is in an excellent position to benefit from nuclear expansion. Our focus needs to include 1) nuclear design and construction capability, 2) fuel enrichment and fabrication facilities, 3) expansion into emerging nuclear supply chains, and 4) education and workforce development.

The keys to success for Tennessee are to be involved in strong partnerships and to be prepared with precursor nuclear technologies. If we have those, Tennessee can be integral to every reactor built in the U.S. and many of those built beyond.

RARE EARTH ELEMENTS[104]

Rare earth elements (REEs) are a set of metals identified in the periodic table of elements, many of which are essential to the production of high-demand products, including magnets. While deemed "rare," many are common and widespread but dispersed at low concentrations. This means that large volumes of source material may be required, along with potentially complex and environmentally unsafe extraction and separation technologies to yield small quantities of processed material. Another set of resources, critical materials (CMs), are often categorized to include REEs as well as other elements, including cobalt, copper, lithium, and nickel. The U.S. Department of Energy defines a CM as a resource that is both essential and subject to supply risk.[105] For many applications there is simply no current substitute for REEs and CMs. There is very limited sourcing of these materials in the U.S. today.

Tennessee has an opportunity to contribute to the sourcing of a select number of REEs and lithium from coal waste streams generated as a biproduct of electric power generation. This translates into an economic development opportunity for the state while at the same time meeting national and state resource security needs, including those anchored in the energy sector.

Applications and Sourcing. The importance of REEs and CMs arises from their widespread application as an input in important market segments, rapidly growing demand, and limited exploitation of domestic supplies. For example, dysprosium and neodymium are two examples of REEs, both of which are used extensively in magnet production, and are in turn embedded in motors, electronics, machinery, and

[104] The material presented here draws upon work supported by the Department of Energy under Award number DE-FE0032045.

[105] https://www.energy.gov/cmm/what-are-critical-materials-and-critical-minerals#:~:text=Critical%20materials%20for%20energy%20(%E2%80%9Cthe,silicon%2C%20silicon%20carbide%20and%20terbium

other products. Other applications for REEs and CMs include LED lighting, lasers, solid state electronics, wind turbines, cell phones, aircraft engines, and computer hard drives.

EVs are an illustration of a final product that requires an extensive array of these elements and materials for various components of the vehicle, not just traditional lithium batteries. Tennessee has a robust EV assembly and supply chain sector that is highly dependent on these processed metals embedded in intermediate inputs to production. This sector continues to expand its assembly capacity and input supply chain, including visible new market entrants like Ford's BlueOval City, which will focus on magnet production and electric truck assembly. Estimates indicate that nearly 500 pounds of rare earth elements and lithium are embedded in an electric car.[106] Resource extraction and processing in Tennessee would further enrich this supply chain for EVs as well as other products. Moreover, it may help meet the nation's need for increased domestic content of inputs that are used for infrastructure projects under the Bipartisan Infrastructure Act and investments under the Inflation Reduction Act.[107]

The global energy transition to electrification and decarbonization means that the demand for REEs and CMs is escalating rapidly. For example, U.S. DOE views both nickel and lithium as critical materials today, but not currently subject to significant supply risk. However, between 2025 and 2035, both elements will move to the *high supply risk* category. Dysprosium, cobalt, graphite, and neodymium are among the elements that have already been deemed to be critical and subject to high supply risk.[108]

Economic development, energy security, and national security challenges arise from the limited domestic sourcing of many of these much-needed resources. China continues to dominate the market as a source of many of the raw materials that contain REEs and CMs, with estimates at 90 percent of global supply.[109] While China engages extensively in extraction, separation, and processing to produce the rare earth oxides that are ultimately used in production, it also outsources considerable volumes of raw materials for processing elsewhere, for example, Myanmar and Thailand. China, in turn, either sells

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106 https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary

107 https://www.whitehouse.gov/build/guidebook/#:~:text=The%20Bipartisan%20Infrastructure%20Law%20makes,%2C%20energy%2C%20and%20the%20environment and https://rsmus.com/insights/tax-alerts/2023/new-treasury-guidance-on-ira-domestic-content-rules.html#:~:text=Generally%2C%20to%20satisfy%20the%20domestic,manufactured%20in%20the%20United%20States.

108 Ibid.

109 https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary

processed materials to other countries or embeds them as inputs to intermediate and final products that are sold elsewhere. China's hold on these markets is unprecedented.[110]

The U.S. has limited production of REE and CM source reserves.[111] Moreover, much of this material is still shipped overseas—including to China—for processing and refining. Because of concerns over domestic sourcing, many steps are being taken by the federal government and the private sector to expand capacity. Notably, in Tennessee, a new lithium processing plant is being built in McMinn County by Piedmont Lithium, *Tennessee Lithium*.[112] The facility will source raw materials from Ghana to produce lithium hydroxide that can then potentially fuel the region's manufacturing sector that includes EVs, vehicle components (e.g., batteries), and other products. Piedmont Lithium hopes to produce 30,000 metric tons of lithium hydroxide, more than doubling current domestic production of 20,000 metric tons. It is striking that there is so little domestic production given domestic reserves that represent 3.8 percent of global reserves.[113]

United Rare Earth Elements has recently broken ground on a new $30 million facility in Caryville, Tennessee, that would first recycle magnets, then expand to refining and processing rare earths, and ultimately engage in research and development.[114] While it is not clear whether this firm would have the capacity to exploit in-state metals, it is a sign that Tennessee is a player in this global arena for precious resources.

Coal Ash Beneficiation. As the nation struggles to address these resource supply challenges, circumstances are favorable for Tennessee to engage in sourcing much-needed mineral resources through beneficiation of coal combustion residuals, more commonly referred to as *coal ash*.

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110 For background on China's role in these markets, see Yuzhou She, Ruthann Moomy and Roderick G. Eggert, "China's Public Policies Toward Rare Earths, 1975-2018," *Mineral Economics* 2020, 127-151.

111 Mountain Pass is a large vertically-integrated facility that extracts and processes rare earths. https://mpmaterials.com/what-we-do/

112 See https://piedmontlithium.com/projects/tennessee-lithium/#:~:text=Selecting%20Tennessee,%2C%20road%2C%20and%20river%20transportation. Also see https://www.powermag.com/plant-bowen-will-showcase-largest-coal-ash-beneficial-use-project-in-the-u-s/#:~:text=Fly%20ash%20%E2%80%9Charvested%E2%80%%20from%20Plant,Southeast%2C%E2%80%9D%20Eco%20Material%20said

113 The U.S. has extensive lithium reserves but very limited production. The Federal government is aggressively pursuing capacity expansions. https://www.energy.gov/articles/doe-invests-millions-americas-massive-lithium-production-potential DOE has chosen 12 projects to support domestic commercial-scale lithium production. https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-lithium.pdf

114 https://www.unitedre.com/ and https://www.1450wlaf.com/2023/12/21/141833/

Coal ash is a waste biproduct of electric power generation and is stored in various configurations of both wet ponds and landfills. Current beneficial uses of coal ash include cement, concrete, gypsum board, and brick production, as well as aggregate fill.[115] Ten of the eleven coal plants in the Alabama, Georgia, and Tennessee region sold ash for beneficiation in 2021 (see the discussion of Figure 2 below, where this information is embedded). For concrete and related products, coal ash adds strength and durability. Georgia Power operates a new facility that processes (wet) pond and (dry) landfill ash for use in making Portland cement. The goal is to produce 600,000 tons of ash per year.[116] This new source of demand for ash has created a formal market and put upward pressure on its price.

A substantial volume of coal ash—as much as 10 percent of the U.S. volume—is now being stored in temporary or permanent storage sites across Tennessee, Alabama, and Georgia. Some sites are closed, while others are in the process of being closed. Closure would place some constraints on future beneficiation because of cost and regulatory burdens as well as public attitudes associated with storage facility re-opening.

A potentially important form of coal ash beneficiation is the extraction of embedded REEs and lithium that are present by virtue of the source material, coal.[117] Research is currently underway within the region to (1) characterize the volume of embedded REEs and lithium in stored ash and (2) identify environmentally-friendly extraction and separation processes.[118] From the perspective of resource exploitation, each ash storage facility is a *mine* that can be tapped for its embedded minerals. Until coal use for electric power generation ends, ash will continue to be deposited in the storage sites. As a result, potential REE mining capacity will continue to expand.

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[115] See, for example, https://ecomaterial.com/products-and-technologies/fly-ash/

[116] "Georgia Power to Begin Third Coal Ash Re-Use Project," https://www.power-eng.com/coal/material-handling/georgia-power-to-begin-third-coal-ash-re-use-project/#gref

[117] A recent report from the U.S. Department of Energy, "Recovery of Rare Earth Elements and Critical Materials from Coal and Coal Byproducts," May 2022, provides considerable background. https://www.energy.gov/sites/default/files/2022-05/Report%20to%20Congress%20on%20Recovery%20of%20Rare%20Earth%20Elements%20and%20Critical%20Minerals%20from%20Coal%20and%20Coal%20By-Products.pdf

[118] U.S. Department of Energy has funded a large multi-state grant program to examine potential resource extraction from various coal products, including coal itself, coal waste streams and ash. One of the grants is being administered by IACMI and the Baker School of Public Policy and Public Affairs at the University of Tennessee. Its focus is the Alabama, Georgia Tennessee region with emphasis on coal ash and REEs. See https://usea.org/sites/default/files/event-/Bromhal%20-%20CORE-CM%20workshop%20intro%20slides_draft.pdf

Creating REE Markets in Tennessee. Figure 2 illustrates the location of ash storage facilities across Tennessee, Alabama, and Georgia and whether they are open, closed or slated for closure, as well as other information.[119] There are 58 sites in total, with 16 in Alabama, 24 in Georgia, and 18 in Tennessee. Of these, 26 are open, 13 are closed, and the remaining 19 have shown an intent to close. Cement plants are also shown in the figure, many of which currently make use of dried ash for concrete production.

There is considerable heterogeneity across the storage sites because of the nature of the ash (e.g., wet versus dry) as well as the source coal that affects the scope of embedded rare materials.[120] This means that the resource characterization process must in principle consider each individual site to determine the potential for exploitation. This characterization process is underway.

One of the map layers in Figure 2 shows the open ash sites; the interactive map referenced above reveals concentration testing data for 14 REEs and lithium for five electric power plants in Alabama and four plants in Georgia. While individual storage sites at the plants were tested, the average REE concentration data are shown for a given plant. More sites will be evaluated in the future to help guide the process of determining the technical and economic feasibility of extraction.

A suggestive measure of capacity builds on crude and transparent assumptions. If TVA and the Southern Company together hold 400 million tons of impounded ash and extraction can capture 50 percent of embedded REEs, that translates to about 100,000 tons of REEs based on known concentration figures. At current mining rates, the U.S. produces about 10,000 tons of REEs per year. So, mining coal ash does not solve the nation's rare earth elements problem, but it makes a significant dent. Ash resources available elsewhere in the U.S. could also contribute in a significant way to meeting the nation's need for REEs.[121]

There are several additional uncertainties about the potential for and consequences of ash processing. One is storage site heterogeneity, which may influence the nature of effective extraction and separation technologies; a single technology cannot necessarily be applied to all the different configurations of sites. Another issue is how the extraction of REE source material from ash affects the ability to extract multiple minerals from the same source—will the extraction of one element affect the ability to extract others? Finally, there is a question of whether mineral extraction from ash will adversely affect other

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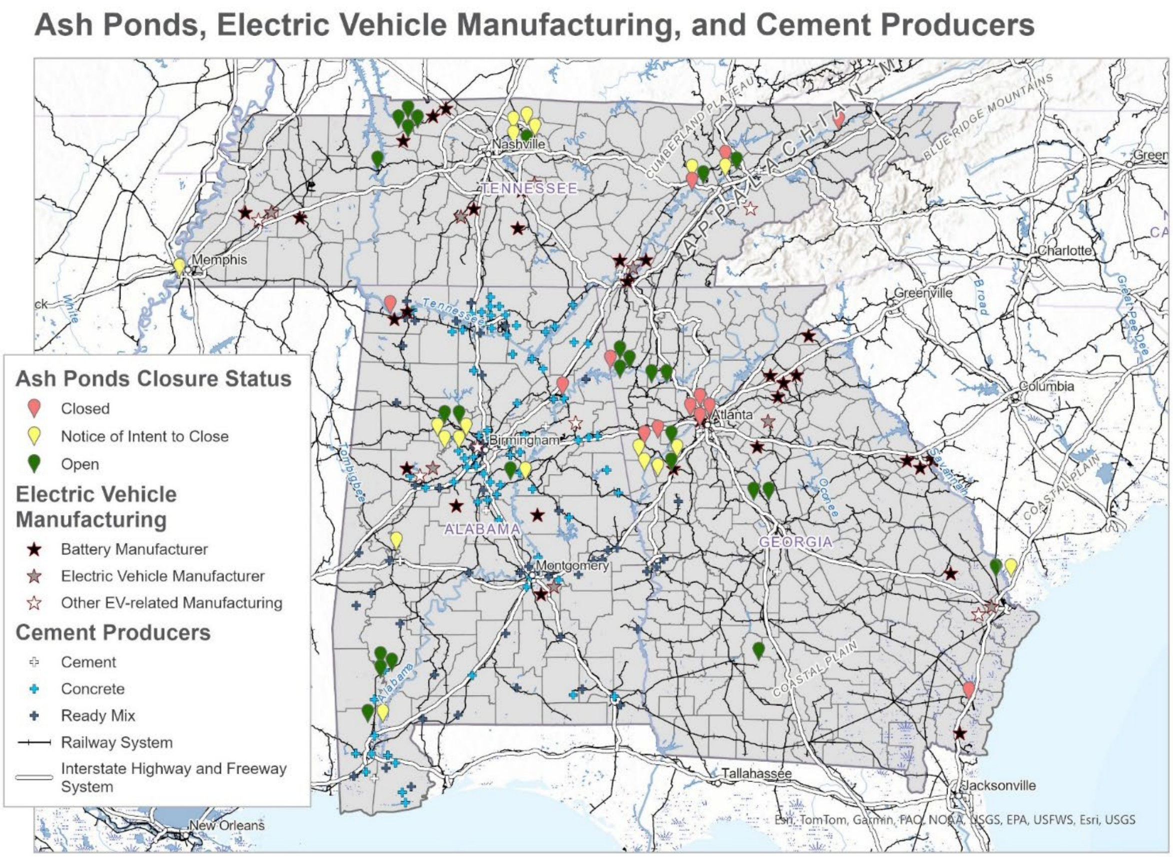
[119] An interaction version of the map with additional layers is available at https://baker.utk.edu/energy-and-environment-reports/southern-appalachia-rare-earth-element-ecosystem/
[120] For a brief coal primer, see https://www.eia.gov/energyexplained/coal/
[121] The U.S Environmental Protection Agency reports 130 tons per year for 2014. https://www.epa.gov/coalash/coal-ash-basics

applications like concrete production. If this is the case, the applications become mutually exclusive, and competition will take place over the respective applications. On the other hand, if extraction allows ash to be *jointly* used for both applications, the benefits and economic value of use becomes additive for the full value of each application.[122] Because of the small volume of embedded REEs relative to the total volume of coal ash, there is hope that both applications can take place without compromising alternative uses.

Figure 2: Ash Ponds in Alabama, Georgia, and Tennessee



Interactive map: https://baker.utk.edu/energy-and-environment-reports/southern-appalachia-rare-earth-element-ecosystem/

[122] An analogy is petroleum where the overall value is the sum of the value of the individual products (e.g. gasoline, kerosene, and jet fuel).

Opportunities for *cost-effective* extraction of REEs from coal ash remain uncertain because key technologies remain in development and resource characterization is incomplete. But there is clearly promise. These uncertainties must be resolved to determine if supply markets can, in fact, emerge in Tennessee. Uncertainty, coupled with potentially high-front end costs of technology development and deployment, may require public sector intervention. This intervention would be justified as a means of promoting energy and national security, as well as economic development.

Exploiting Ash Sites. Tapping ash sites for minerals could take at least one of two forms. The first would require the movement of ash to another site for extraction, a hub and spoke model. This would be attractive if extraction technologies could realize scale economies through large scale processing. However, the hub and spoke model has drawbacks--moving ash would entail large volumes of material, new regulatory challenges for processing sites, and potential public opposition to both ash movement and new processing sites. Moreover, the residual ash would still require storage. [123]

In situ extraction is an attractive alternative since environmental-related permitting is already present at storage sites (though some issues may still arise from alternative use), and the sites are well positioned with respect to supporting infrastructure, including proximate rail lines and major highways. In principle, this infrastructure could support mobile extraction technologies that could move from site to site. Ash could potentially be stored at the same site, avoiding its movement and the development of new storage sites. Extracted minerals could be processed in the region, or alternatively shipped to other sites for processing. The relatively high value-to-weight for some minerals may make shipment out of the region more attractive.

The Future. Security and economic development opportunities will hinge on the nature of emerging technologies and the value of REEs embedded in ash sites. These uncertainties must be resolved to enable fledgling markets to emerge in Tennessee. Potential economic development opportunities include upstream R&D and technology development and deployment for resource extraction and processing. New resource supplies would support downstream supply chains for intermediate and final products, including a range of automotive inputs and batteries where Tennessee already has a national production advantage.

[123] The processing of ash does not have a significant impact on post-extraction ash volumes—REE extraction does not eliminate the need for ash storage. Applications for concrete, on the other hand, do reduce the amount of residual waste that needs to be stored.

RENEWABLE NATURAL GAS

Renewable natural gas (RNG) is purified biogas derived from organic waste material that can be used in lieu of traditional natural gas.[124] The most common source of RNG in the U.S. is landfills. Other biogas sources include agricultural waste, forestry biproducts, and wastewater. Organic waste produces methane, which is the primary component of natural gas. Landfills alone account for 14.4 percent of human-related methane.[125] Because methane easily escapes to the atmosphere, it is commonly referred to as fugitive methane.

With limited processing, RNG can be used as a substitute for natural gas in applications including power generation. With additional processing, it can be used directly or injected into the natural gas distribution system for a range of traditional applications like heating and transportation. Capturing naturally occurring methane is considered *carbon negative* and can be used to offset other carbon emissions by utilities, businesses, and government bodies. This creates a market value for its use in addition to its value as a fuel. Any source of naturally occurring methane can be used for this purpose, and many different landfill, wastewater, and agriculture-based solutions have been implemented effectively.

Benefits and Economic Development Opportunities. RNG offers many benefits as an element of the energy portfolio. First, it supports the energy transition goal of reducing greenhouse gas emissions. Atmospheric methane has an extraordinarily negative impact on climate, with a greenhouse effect 28 times larger than CO_2 over a 100-year horizon. This scope of environmental damage has motivated both federal, state and global action, including establishing formal targets and strategies for mitigation.[126] The *Valley Pathways Study*, referenced above, reports that non-energy methane sources account for 16 percent of the greenhouse gases emitted in the Tennessee Valley and represent a major challenge to the

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[124] For an introduction see U.S. Environmental Protection Agency, Alternative Fuels Data Center, "Renewable Natural Gas Production," https://afdc.energy.gov/fuels/natural-gas-renewable For a perspective from industry advocates see American Biogas Council, "Harness the Benefits of Biogas," https://americanbiogascouncil.org/resources/why-biogas/ A more thorough and comprehensive assessment is U.S. Environmental Protection Agency, "An Overview of Renewable Natural Gas from Biogas," January 2024 https://www.epa.gov/system/files/documents/2024-01/lmop_rng_document.pdf

[125] U.S. Environmental Protection Agency, "Basic Information About Landfill Gas," https://www.epa.gov/lmop/basic-information-about-landfill-gas

[126] U.S. Environmental Protection Agency, "Overview of Greenhouse Gases," https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane "The nonbinding Global Methane Pledge seeks to reduce methane emissions by 30 percent or more by 2030. International Energy Agency, "The Global Methane Pledge," https://www.iea.org/reports/global-methane-tracker-2022/the-global-methane-pledge

goal of a carbon-neutral region by 2050.[127] Beneficiation of renewable organic waste stocks yields dual environmental benefits through the isolation of RNG as well as potentially more efficient waste management practices. RNG produces lower emissions than diesel fuel, offering another important environmental benefit for some applications. In 2023, 79 percent of the greenhouse gas equivalents (GGEs) used in transportation came from RNG.[128] In general, the use of RNG is an important complement to EVs as a means of reducing transportation-related greenhouse gas emissions.

A second benefit of RNG is resiliency through the diversification of natural gas supplies that enables direct uses at or near source points. This includes landfills as well as other biogas sources like farms where traditional natural gas supplies may not be available. Third and related, it is storable at localized source locations and can provide energy security if other energy supplies become restricted or unavailable. Fourth, it provides a small but potentially important in-state energy source that could dampen the need for energy imports from outside the state.

There are also possible economic development opportunities associated with processing and utilizing RNG. This would include landfills that today simply flare methane and smaller landfills that currently do not capture or otherwise use the gas. Other opportunities may be of special interest in farm communities and areas with limited economic development potential.

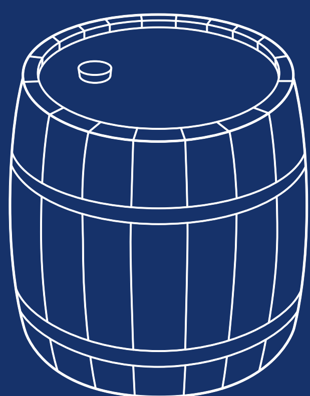
The U.S. had 230 RNG projects in 2021 tied solely to transportation (for direct vehicular use or pipeline distribution), with a production capacity of 574 million diesel-gallon equivalents.[129] Over 72 percent of this total came from landfills, and nearly 20 percent came from livestock/agriculture. According to industry analysts, there were 10,600 jobs tied to the operation of RNG facilities, including direct effects (facility operation itself) and supply chain and multiplier effects, with 27,900 more jobs engaged in

[127] Fossil fuel extraction and use also produces large volumes of methane, estimated at 40 percent of the global total. International Energy Agency, "Global Methane Tracker 2022: Overview," https://www.iea.org/reports/global-methane-tracker-2022/overview

[128] The Coalition for Renewable Natural Gas, "Decarbonize the Road Ahead," https://static1.squarespace.com/static/53a09c47e4b050b5ad5bf4f5/t/662914d096ef060a7fbdf885/1713968337235/TTP+RNG+Decarbonize+2024.pdf There are more than 135,000 natural gas vehicles in use today; class 8 trucks, refuse vehicles and fleet buses are major users of RNG. The Transportation Project, "Vehicles for Every Route," https://transportproject.org/vehicles/

[129] U.S. Department of Energy, "Fact of the Week," https://www.energy.gov/eere/vehicles/articles/fotw-1242-june-13-2022-production-capacity-renewable-natural-gas-projects#:~:text=Vehicle%20Technologies%20Office-,FOTW%20%231242%2C%20June%2013%2C%202022%3A%20Production%20Capacity%20of,Diesel%2DGallon%20Equivalents%20in%202021&text=In%202021%2C%20there%20were%20230,diesel%2Dgallon%20equivalents%20for%20transportation.

facility construction.[130] These modest figures show that market development of RNG is still limited, reflecting dispersed RNG sources, the costs of gathering and processing RNG, and the costs of accessing natural gas pipelines for distribution. These issues affect both national and in-state opportunities for further exploitation of RNG. Further technological advances may be required to support significant market development.



A partnership between *3 Rivers Energy Partners* and *TC Energy* shows how a Tennessee icon promotes sustainability by exploiting its organic waste products. The project will rely on spent distillers grains from corn, otherwise known as stillage, from the Jack Daniels distillery in Lynchburg, Tennessee to produce 900,000 to 1,100,000 MMBTUs of RNG annually. The RNG will be used by Jack Daniels to support its operations. In addition, liquid digestate fertilizer derived from by-products can be used by area farmers. The project would enable treatment of as many as 43,000 acres of farmland reducing the need to acquire commercial fertilizer. Over 400 Tennessee farms could benefit from the project. There are likely other opportunities like this across Tennessee.

Source: https://3riversenergy.com/2022/11/project-with-jack-daniels/

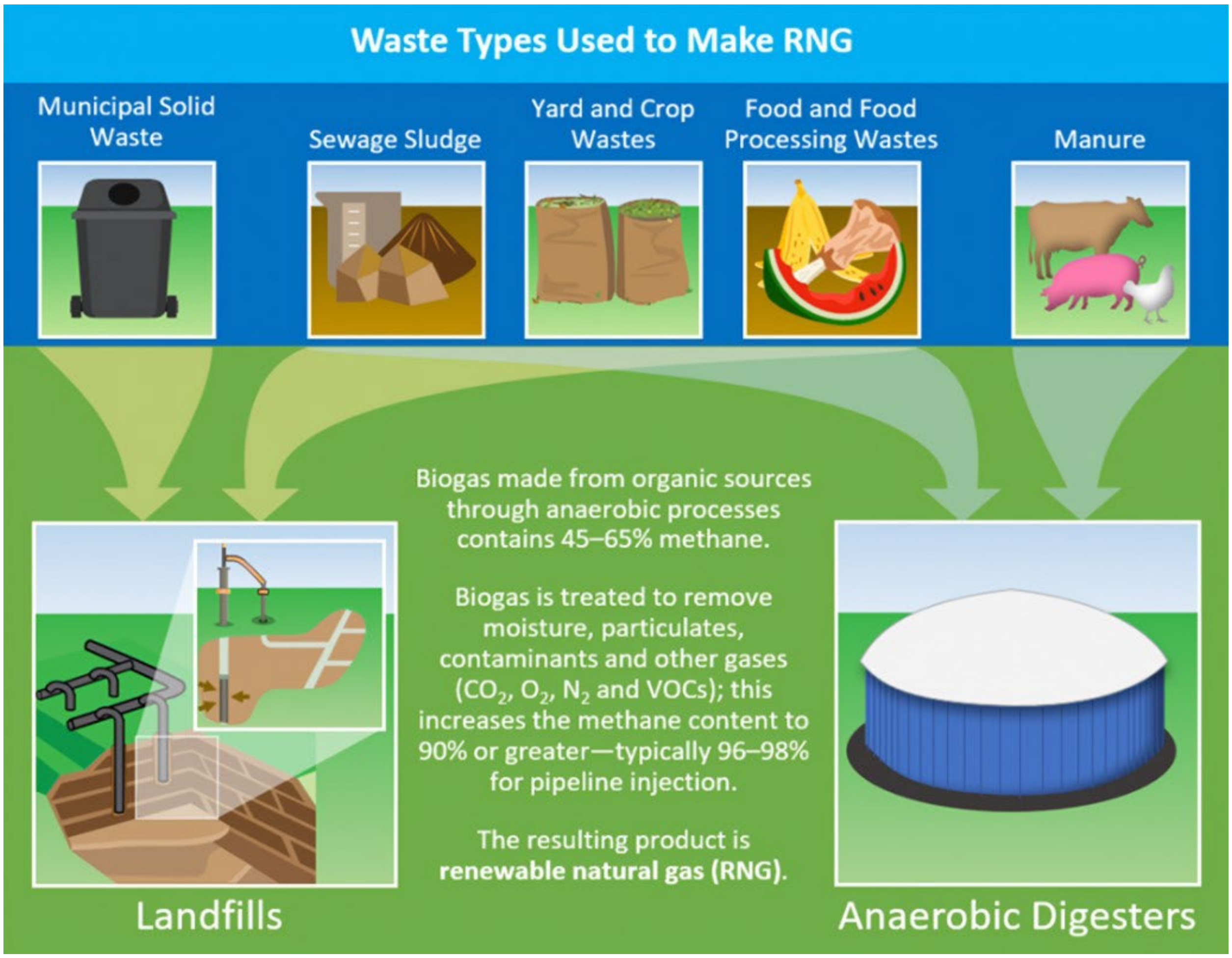
Sourcing RNG. Figure 3 provides a succinct summary of how RNG is sourced, processed, and treated for end-use applications. Renewable organic waste stocks are the foundation. An anaerobic digestion process is then required to produce biogas from the waste. This happens naturally in landfills while standalone systems can be used in other cases (including for food diversions from landfills). The biogas is treated and purified to yield RNG.

Unlike landfills, many biogas feedstocks are decentralized and often of small scale, e.g., farm sources such as manure. On-site collection and shipment are both costly. Costly digester systems are required to support biogas production. For example, an on-farm system is estimated to cost between $400,000 and $5,000,000, with the typical unit costing $1.2 million. In this specific application, costs of RNG expressed

[130] The Coalition for Renewable Natural Gas, "Economic Analysis of the U.S. Renewable Natural Gas Industry," December 2022, https://guidehouse.com/-/media/www/site/insights/energy/2022/guidehouse-esirng-coalition-final-report122022.pdf

in kilowatt hours will typically exceed standard utility rates.[131] RNG can potentially be used on site depending on need and the capacity for application.

Figure 3: From Organic Waste to RNG



Source: U.S. Environmental Protection Agency, "An Overview of Renewable Natural Gas from Biogas," January 2024 https://www.epa.gov/system/files/documents/2024-01/lmop_rng_document.pdf

Other challenges include the movement of processed RNG to end users, regardless of source. One mechanism is to inject RNG into existing natural gas pipelines, but these pipelines may not be close to RNG sources, especially in rural communities; some pipelines may not be able to physically accept additional RNG capacity. Most importantly, introducing RNG into the pipeline transmission system

[131] See, for example, "Anaerobic Digestion Cost – Plus Gate Fees and Other Rules of Thumb," https://anaerobic-digestion.com/anaerobic-digestion-cost-gate-fees/

requires specialized and costly injection facilities. Alternatives include localized use and pressurized storage. Virtual pipeline distribution—transportation via roadways or rail—is possible, but these options are expensive and may not be economically feasible.

Landfills. Landfills may capture methane for on-site use, distribution, or flaring. There are currently 13 landfill and 14 wastewater systems producing RNG within Tennessee today while nationwide there are 2,300 operating projects.[132] Tennessee ranks 24th out of the 50 states for its biogas production potential, though it is not clear how much of this capacity could be exploited economically. An estimated 16.44 billion cubic feet of renewable methane from biogas could be produced annually from a total of 201 potential additional systems within the state. This amount of natural gas could heat over 350,000 residential homes every year and offset the CO_2 emissions equivalent to over 200,000 gasoline-powered vehicles.[133]

Food waste constitutes a significant source of landfill deposits. Food waste decays at a rapid rate and accounts for 58 percent of fugitive methane coming from landfills.[134] Part of the problem is that methane capture systems are not in place or not put in place quickly enough to capture the fugitive emissions from food waste (and potentially other sources as well). New EPA enforcement priorities seek to limit the release of methane from the country's landfills.[135]

The permitted landfills shown in Figure 4 tend to be located in close proximity to metropolitan areas that are the primary source of waste. This means they are also reasonably close to transportation infrastructure and natural gas pipelines that are common in metropolitan areas. These factors contribute to the attractiveness of landfills as an RNG source.

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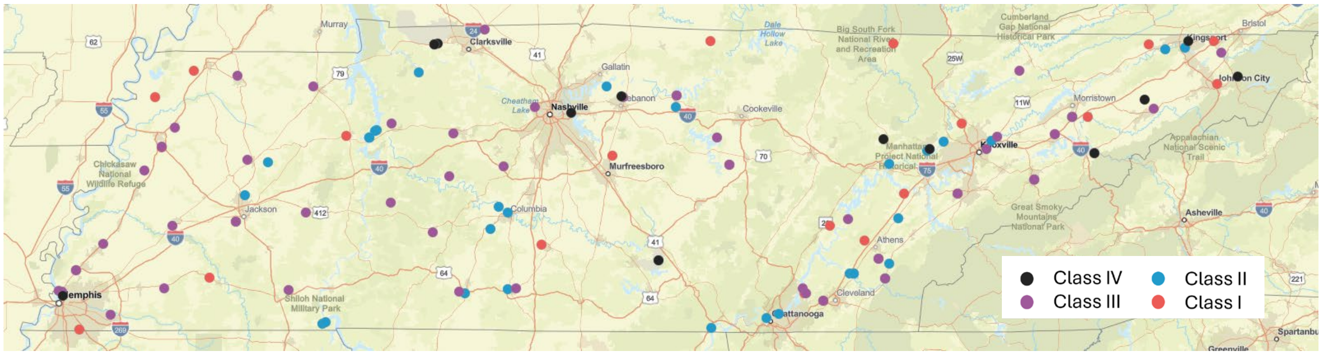
[132] American Biogas Council, "Harnessing the Benefits if Biogas," https://americanbiogascouncil.org/resources/why-biogas/

[133] Based on data from Middle Tennessee Natural Gas (average residential customer natural gas usage was 46,426 cubic feet per year in 2023) and the U.S. Environmental Protection Agency "Greenhouse Gas Equivalencies Calculator," https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results

[134] U.S. Environmental Protection Agency, "Quantifying Methane Emissions from Landfilled Food Waste," https://www.epa.gov/land-research/quantifying-methane-emissions-landfilled-food-waste#:~:text=Due%20to%20its%20quick%20decay,are%20from%20landfilled%20food%20waste Also see Landfill Methane Outreach Program," https://www.epa.gov/lmop/frequent-questions-about-landfill-gas#:~:text=LMOP-,What%20is%20LMOP%3F,avoid%20methane%20emissions%20from%20landfills.

[135] U.S. Environmental Protection Agency, "FY 2024-2027 National Enforcement and Compliance Initiatives," August 2023, https://www.epa.gov/system/files/documents/2023-08/fy2024-27necis.pdf

Figure 4: Major Landfills in Tennessee



Source: https://www.tn.gov/environment/program-areas/solid-waste/maps.html

RNG and Tennessee Agriculture. Agriculture accounts for 37 percent of human-related methane gas emissions offering a potentially important source of RNG.[136] However, there are no active livestock anaerobic digester projects in Tennessee today.[137] While farm-scale covered lagoon systems are possible for dairy and hog operations, dairies in Tennessee do not have the herd sizes or clusters of operations needed for developing substantial concrete and steel digester projects (see the Anaerobic Digestor in Figure 3 above). Manure from cattle must be freshly collected to optimize the biochemical methane potential (BMP) value when being fed into above-ground tanks, and the grit must be separated and removed through very costly procedures on the front end when manure is scraped and collected daily (and not flushed into a lagoon). Hog manure must be collected at intervals of two weeks or less for optimal gas production, when feeding digesters daily. This is not currently feasible for hog operations with pit manure collection systems as they are not set up to do this until the end of a production cycle, which is typically several months or longer.

Unlike ruminants (i.e., animals that chew their cud), chickens and other poultry do not produce methane in their digestive tracts and their excrement does not generate methane unless subsequently placed under anaerobic conditions. Poultry manure is very high in uric acid and the global warming potential for resulting nitrous oxides is 273 times that of CO_2 on a 100-year timescale.[138]

[136] U.S. Environmental Protection Agency, "Agriculture and Aquaculture: Food for Thought," October 2020, https://www.epa.gov/snep/agriculture-and-aquaculture-food-thought
[137] U.S. Environmental Protection Agency, "Livestock Anaerobic Digester Database," https://www.epa.gov/agstar/livestock-anaerobic-digester-database
[138] U.S. Environmental Protection Agency, "Understanding Global Warming Potentials," https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

Estimates indicate that 100,000,000 broilers (meat chickens) are needed to produce enough spent litter (used up bedding material with manure, excrement) to generate 1000 dekatherms (Dths) per day. From a logistical standpoint, to minimize feedstock transportation costs, a poultry-litter-to-RNG project built to this scale in Tennessee would need to receive additional poultry litter from a neighboring state, or from other feedstock sources (to co-digest). While Tennessee produces large numbers of broilers, it is not in the top ten of producing states.[139] Leading poultry producing states (such as Georgia, Alabama, Arkansas, North Carolina, and Mississippi) raise 4-7 times the number of chickens and have more attractive concentrations of poultry for those pursuing litter-to-RNG projects. Environmental pressures to remove nutrient overloading concerns (nitrogen and phosphorus, primarily) from watersheds have greatly increased the support for these projects to occur, to redirect poultry litter and meat processing plant dissolved air floatation (DAF) sludge (via dissolved air floatation separation of fats, oils, and greases) from the various waste streams.

Resistance from local communities presents challenges in seeking approvals and zoning to build projects like this in logistically strategic locations in Tennessee, and around the country. Concerns include recycled wastewater discharge, nuisance odors, potential for use of human waste (biosolids), CO_2 capture, and ammonia stripping from wastewater to make commercial (stable, non-flammable) ammonium sulfate fertilizer.

As noted above an engineering and economic challenge for agricultural (and others) is accessing a gas injection point into the natural gas distribution system. Interconnect service is not always possible at a desired project site due to limitations of local pipelines and services, transmission capacity, thermodynamics, and cost. This is a significant hurdle in some rural communities (and other places as well). An interconnect into a main interstate transmission line can cost 2-3 times that provided by a local gas utility company, adding several million dollars to project development. Because of the costs of a virtual pipeline, uses on the farm may be the most attractive option for agriculture-based RNG.

Incentives and Market Development. Historically, RNG was much more expensive than the cost of conventional natural gas and so it was only feasible to use in unique applications.[140] Prices remain high

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[139] U.S. Department of Agriculture, National Agricultural Statistics Service, https://www.nass.usda.gov/Charts_and_Maps/Poultry/brlmap.php

[140] Research from 2016 shows that the cost of pipeline quality RNG ranged from $7 (large scale) to $25 (small scale) per million Btu, much higher than traditional natural gas prices. U.S. Environmental Protection Agency, "Evaluating the Air Quality, Climate and Economic Impacts of Biogas Management Technologies," September 2016, https://nepis.epa.gov/Exe/ZyPDF.cgi/P100QCXZ.PDF?Dockey=P100QCXZ.PDF

today reflecting high sourcing costs. Efforts to promote greenhouse gas reductions through federal incentives for production and use have increased the attractiveness of RNG by lowering its effective price. Even at high market prices, RNG acquisitions can be used by a business or government entity to meet environmental goals. For example, a business in Tennessee could receive credit for using renewable energy when it purchases RNG from a marketer in another state, even if the RNG is used elsewhere. Renewable energy credits (RECs) and renewable thermal credits (RTC), respectively, can be used to verify compliance and use of a renewable energy source.[141] These and other subsidies for RNG will not last indefinitely so technology gains in biogas generation and processing, along with more efficient gathering systems from often dispersed locations will be required. Existing incentives have done little to accelerate market growth to date.

Pipeline quality RNG can be compressed and used as a gaseous or liquid transportation fuel, including for heavy-duty vehicles. Renewable Identification Numbers (RINs) that uniquely denote physical gallons of renewable fuel along with the federal Alternative Fuels Tax Credit (50 cents/gallon through December 31, 2024) incentivize RNG use in the transportation sector. [142] A Clean Fuels Production Credit is also available for low emissions transportation fuel including RNG.

A federal Production Tax Credit is available to help defray the cost of qualifying biomass and landfill gas projects. Since tax credits can only be used when a tax liability is present, a monetization program is in place to provide direct payments to investors.[143] The Biomass Crop Assistance Program (BCAP) provides funding support for biogas feedstock development.[144] These are examples of a complicated and changing portfolio of federal programs.

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[141] This is referred to as the *book and claim* method. For a brief overview of the business case for such applications, see KPMG, "Decarbonizing with Renewable Natural Gas," https://kpmg.com/kpmg-us/content/dam/kpmg/pdf/2023/decarbonizing-renewable-natural-gas.pdf

[142] U.S. Department of Energy, Alternative Fuels Data Center, "Renewable Identification Numbers," https://afdc.energy.gov/laws/RIN.html#:~:text=A%20RIN%20is%20a%2038,guidelines%20on%20a%20quarterly%20basis

[143] For background, see The White House, "Delivering the U.S. Methane Emissions Reduction Action Plan, November 2022," https://www.whitehouse.gov/wp-content/uploads/2022/11/US-Methane-Emissions-Reduction-Action-Plan-Update.pdf For production tax credit information see U.S. Environmental Protection Agency, "Summary of Inflation Reduction Act Provisions Related to Renewable Energy," https://www.epa.gov/green-power-markets/summary-inflation-reduction-act-provisions-related-renewable-energy#ITCPTC and "Renewable Electricity Production Tax Credit Information," https://www.epa.gov/lmop/renewable-electricity-production-tax-credit-information

[144] U.S. Department of Agriculture, "Biomass Crop Assistance Program," https://sandbox.fsa.usda.gov/programs-and-services/energy-programs/BCAP/index

Coupled with a range of federal incentive programs, the RNG can typically be sold closer to competitive market prices as private developers/investors profit off RIN, REC, and RTC sales. This makes it much more attractive to local distribution companies (LDCs) to add to their supply portfolio without penalizing their customers with higher rates. Distribution constraints for transportation applications limit adoption and use. Efforts are being made in Tennessee to address this challenge by coupling RNG with CNG and EV charging stations.[145] Despite these opportunities, limited capacity and high supply costs have constrained the amount of RNG brought to the market.

The Future. RNG has the potential to incrementally add energy to the state and national energy portfolios, facilitating the energy transition and realization of climate goals, while adding a new source of energy resiliency. Importantly for Tennessee, there are potentially valuable economic development opportunities from the exploitation of RNG and reduced reliance on imported energy to fuel the state economy. As natural gas from the existing pipeline distribution system becomes increasingly constrained, RNG could help fill some of the gap. Opportunities are available across the state where organic feedstocks that produce biogas are present. This includes landfills that are generally located near population centers, industries that yield organic waste by-products, and some farms and farm communities. At the same time, the discussion above has indicated the challenges to market development that may continue to constrain growth opportunities in Tennessee and elsewhere.

There are several steps to consider in further evaluating the economic viability of RNG for Tennessee. First, RNG could in principle be used to supply highly-efficient fuel for rural industrial parks, though the economic viability is not clear. Regional partnerships involving multiple counties (landfills, farms, industrial development boards) may allow for cost sharing and scaled up applications that increase returns on such projects, improving overall project favorability. Second, localized uses near RNG feedstock sources like the Jack Daniels example above should be considered since these applications avoid the need to gather and move supplies to another location. Third, more information is needed on the cost of accessing interstate and intrastate pipelines that distribute natural gas. The capital investment required to access the network for injection of pipeline quality RNG may represent a major impediment to market development. Finally, comprehensive market and feasibility studies could offer more systematic guidance on opportunities and barriers to RNG growth in Tennessee. An example is a

[145] The East Tennessee Clean Fuels Coalition has developed a roadmap to guide funding to support multi-source alternative fuel service stations. See "A Prologue + Funding Strategies for Tennessee: A DCFC & RNG Station Funding Guide," June 2024.

recent report funded by the Michigan Public Service Commission that provided options and recommendations for further exploitation of RNG in Michigan.[146]

CONCLUSION

The global energy transition is well underway, easing out fossil fuels and easing in renewable energy sources that have a lower carbon footprint. Some in Tennessee may want this process to speed up while others would like it to slow down. One thing is certain—the energy transition will continue unabated for the foreseeable future. The challenge is to find a middle ground that can meet the needs of Tennesseans today while laying the groundwork for an energy sector that can support the wellbeing of Tennesseans tomorrow.

This report began with the phrase *energy futures* to amplify the importance of how decisions made today can affect future prosperity. There is no single energy future for Tennessee. While market forces and federal policy create constraints for state policymakers, there are still opportunities to make choices. The analysis here is intended to help frame the energy transition and reveal opportunities for state action. It does not provide answers. But it does provide ideas and alternatives that can help shape the public policy debate and policy decision-making.

[146] ICF Resources, LLC, "Michigan Renewable Natural Gas Study," September 2023, https://www.michigan.gov/mpsc/-/media/Project/Websites/mpsc/workgroups/RenewableNaturalGas/MI-RNG-Study-Final-Report-9-23-22.pdf

APPENDIX

State Energy Policy Council Representative Seat Classifications, Effective July 1, 2024

Seat Classification	Term	Appointed By:
Energy Resource/Production Industries	1 Year	Governor
TDEC Representative	1 Year	Governor
TNECD Representative	1 Year	Governor
Public College/University	1 Year	Governor
TN Public Utilities Commission	1 Year	Governor
TVA Representative	1 Year	Governor
US DOE / Oak Ridge Reservation (NV)	1 Year	Governor
Residential Energy User	1 Year	Governor
Natural Gas Distributor/Pipeline	2 Years	House Speaker
Radiological Control / Nuclear Safety	2 Years	House Speaker
Crude Oil Processing / Pipeline	2 Years	House Speaker
Nuclear Manufacturing Industry	2 Years	House Speaker
Innovative Energy Production	2 Years	House Speaker
Member of the State House of Reps.	2 Years	House Speaker
Farmers / Agricultural Enterprises	2 Years	House Speaker
Electric Cooperative Representative	3 Years	Senate Speaker
ORNL Representative	3 Years	Senate Speaker
Municipal Electric Provider	3 Years	Senate Speaker
City of Oak Ridge Official	3 Years	Senate Speaker
Local Government (Various Counties)	3 Years	Senate Speaker
Member of State Senate	3 Years	Senate Speaker
Small Business Owners Representative	3 Years	Senate Speaker

TNEAC Appointed Members:

Commissioner David Salyers - Tennessee Department of Environment and Conservation
Braden Stover - Tennessee Department of Economic and Community Development
Director Patrick Sheehan - Tennessee Emergency Management Agency
Dr. Loong Yong, Ph.D., Spectra Tech - Congressional Delegation Designee
Adam DeMella, ADG Strategies - Congressional Delegation Designee
Don Moul - Tennessee Valley Authority Representative
Jeff Smith - Oak Ridge National Laboratory Representative
Dr. Wes Hines, Ph.D., University of Tennessee - Higher Education Representative
Tracy Boatner, East Tennessee Economic Council - Workforce Development Representative
Mayor Terry Frank, Anderson County - Local Government Representative
Chris Jones, Middle Tennessee Electric - Utilities Representative
Jennifer Stone, Thompson Engineering, Inc. - Energy Production Representative
Dr. Hash Hashemian, Ph.D., Analysis and Measurement Services - Nuclear Industry Representative
Michelle Amante-Harstine - Member At-Large
Blake Harris - Member At-Large
Steve Jones - Member At-Large
Maria Korsnick - Member At-Large
Dr. Padma Raghavan, Ph.D. - Member At-Large
Ken Rueter - Member At-Large
Lang Wiseman - Member At-Large
Chairman Ken Yager, Tennessee Senate – Lieutenant Governor Appointee
Chairman Clark Boyd, Tennessee House of Representatives – Speaker of the House Appointee