ENERGY SECTOR DISRUPTORS IN TENNESSEE: FRAMING OPTIONS

An Annual Assessment of the State's Energy Sector Prepared for the Tennessee State Energy Policy Council*

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*This research was produced by the Howard H. Baker Jr. Center for Public Policy at the University of Tennessee, Knoxville for the State Energy Policy Council. All views reflect those of the authors.

State Energy Policy Council

About the State Energy Policy Council

The State Energy Policy Council was created in 2017 by Public Chapter 458 to serve as the central energy policy planning body of the state and communicate and cooperate with federal, state, regional, and local bodies and agencies for the purposes of affecting a coordinated energy policy. Reports and other information are available at https://comptroller.tn.gov/boards/sepc.html.

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EXECUTIVE SUMMARY

This annual assessment of Tennessee's energy sector for 2021 focuses on a small set of disruptors which have the potential to transform the energy sector: energy storage systems, the electric grid, energy efficiency and small modular reactors.

Energy Storage Systems

Analysis provides an overview of energy storage systems and potential policy options to expand their deployment in Tennessee. Energy storage systems are benefiting from technological improvements that enhance their effectiveness in a variety of settings. A major breakthrough could have significant disruptive impacts on the energy sector as we know it.

Greater use of energy storage systems offers many benefits, including a reduced environmental footprint (especially when paired with renewable energy sources), improved grid system resiliency, and lower capital and maintenance costs for utility-scale generation capacity. New storage systems will also create applications that may not otherwise be cost effective. And there are economic development benefits like job creation tied to the design, manufacture and deployment of both small-scale and large-scale storage systems.

Because of TVA's role in power generation, transmission and distribution, policy options in Tennessee are largely confined to behind-the-meter applications of storage systems and the pursuit of economic development opportunities. The state could use tax and other incentives to encourage deployment by residential and business consumers, as well as directly procure storage systems for use by state entities. These efforts would require coordination with TVA and local power distributors.

The state could also promote storage system design and manufacture in the state in order to create jobs and expand the tax base. Research activities could be fostered across private industry, state universities and entities like Oak Ridge National Laboratory; manufacturers could be recruited just as the automobile industry has been recruited over the past 40 years.

Finally, there is a need for a regulatory policy scan to ensure that the state and local regulatory apparatus does not discriminate against the deployment of energy storage systems. This is especially important in light of the rapid pace of technological change that is now taking place.

The Electric Grid

The electric grid in Tennessee is preparing to manage several unprecedented transitions. Power generation supplying the electric grid has traditionally been the primary source of carbon dioxide emissions in the state. Efforts to reduce carbon dioxide emissions from the electricity sector to mitigate climate change has resulted in a shift from a reliance on coal for electricity generation to cleaner burning natural gas and renewable energy. The generation and transmission of electricity on the grid in Tennessee has also traditionally been managed by one wholesale utility, the Tennessee Valley Authority (TVA). Rapid innovation and adoption of distributed energy resources is also transitioning Tennessee's grid from a centralized hub-and-spoke network with generation occurring at a few large power plants to a more decentralized model where customers take a more participatory role in generation and management of electricity. While these transitions will necessitate new investment in technology and infrastructure by TVA and the 81 local power companies in the state, the uncertainty created by these potentially countervailing transitions makes it hard to plan such investments. In the midst of all this change and uncertainty, there is also increasing recognition that current efforts to ensure the resiliency of the electric grid may be insufficient especially in light of growing demand.

These transitions have prompted several ongoing policy debates by public utility commissions in other state on topics ranging from how the investments necessitated by these transitions should be paid for, how should states incentivize efforts to enhance grid resiliency, and when/how should states facilitate the adoption of rooftop photo-voltaic (PV) systems. TVA's role as a federal agency responsible for generation and transmission of electricity through the majority of the state limits the role Tennessee has to play in these debates. However, there are five ways the state can play a role to ensure business and residents in the state benefit.

The first is addressing inequities created by grid transitions. As a relatively poor and rural state (based, e.g., on per capita income), Tennessee could act to ensure that these transitions benefit all businesses and residents. As the TVA was initially designed to electrify a distressed part of the country, Tennessee could work to ensure that current energy transitions benefit distressed parts of the state. The second is job placement and training that leverages the state's current economy and workforce to take advantage of the new employment and manufacturing opportunities created by these grid transitions. The third is transmission planning and siting. New transmission investments are likely to be a critical aspect of several of the grid transitions but the siting and land acquisition process has been lengthy. The fourth is further enhancing relationships with TVA and emergency management officials in the state to improve preparedness for long-duration, widespread power outages. The fifth is revisiting regulations surrounding local power companies. The grid transitions will likely result in some of Tennessee's 81 local power companies taking on new roles leading to potential blind spots in local utility regulation.

Energy Efficiency

This section addresses trends and potential disruptors in the energy efficiency sector. Improvements in energy efficiency nationwide over the past four decades have saved the U.S. economy at least one trillion dollars and have helped to decouple economic growth from the growth in energy demand. Decoupling has in turn produced significant environmental benefits. Improvement in energy efficiency is a story with many characters. Relentless technological change lies at the heart of the story, with year-by-year incremental improvements in appliance and lighting efficiencies being particularly prominent. Energy efficiency technologies can be anticipated to continue to make progress, as research and development investments continue to yield improvements in everything from insulation to refrigeration. Advancements in energy management systems will continue to optimize energy-consuming systems in buildings and other contexts. New institutional players will seek to aggregate energy consumers to increase market influences and share energy efficiency investment costs. The prospects are bright for a massive influx of new funding for energy efficiency programs from both the health care and climate change sectors. While no one piece of the energy efficiency puzzle could be anticipated to disrupt this sector, the combination of pieces can be anticipated to greatly increase the scale, scope and effectiveness of advancements in energy efficiency over the coming decades.

The state of Tennessee has benefited and will continue to benefit economically from improvements in energy efficiency. Energy efficiency programs create jobs both in the manufacturing of energy efficient products and in the installation of those measures in homes and businesses. Residential weatherization programs are known to improve human health and reduce health care costs, while also reducing energy burdens felt by income-eligible urban and rural households. The state is also well positioned to build economic development efforts in the energy efficiency sector. Oak Ridge National Laboratory is one of the nation's leaders in energy efficiency technology research and development, and the University of Tennessee system and TVA are also influential in the energy efficiency sphere. The state also hosts entrepreneurial activity in this sector.

The energy efficiency sector is driven in large part by programs run by federal, state and local governments and utilities. Federal policy is a major driver for TVA and the state. Utility programs are typically driven by mandates given to investor-owned utilities by state public utility commissions. This particular option is less available to the state of Tennessee because the TVA, a quasi-federal agency, generates and transmits most of the state's electric power, which is then distributed by municipally owned utilities and cooperatives. Nevertheless, the state and its municipal governments have a wide range of energy efficiency policy tools available, including how they operate their buildings and fleets.

There are numerous other policy topics that could be considered to complement economic development policies and programs centered on energy efficiency. Regulatory regimes related to the financing of energy efficiency investments by the health sector could be evaluated. Regulatory reform may also be warranted to remove barriers to energy service sellers and aggregators. Investments could focus on improving the human capital available in the state to work at all levels of the energy efficiency sector, from researchers to product designers to technology installers. There are exciting new energy efficiency opportunities in the residential and commercial building sector which may require innovative approaches to zoning and building codes. Advances in energy management systems, though, could pose serious privacy and security concerns that could be require state- level regulatory responses. Investments in income-eligible residential energy efficiency programs in urban and rural areas can address issues of energy and health equity.

Small Modular Reactors

As decarbonization goals increase, the possibility of using nuclear energy as a dispatchable source of clean energy to reduce environmental impacts while spurring economic growth shows promise. While traditional nuclear reactors have fallen out of favor due to safety concerns, large up-front investment costs, and cost overruns, a potential market disruptor has appeared: small modular nuclear reactors (SMRs).

SMRs have unique potential to function as a carbon-free form of cost-effective baseload energy generation that can be utilized in Tennessee and across the globe. Through economic benefits such as modularity, flexible output designs, improved energy security, and passive safety features, SMRs continue to improve upon large reactor technology.

Tennessee is in a unique position to support and develop SMR technology. Due to the Department of Energy's presence and investments in east Tennessee, the unique position of the Clinch River site, an existing nuclear industry supply chain, and UTK's current nuclear engineering program, Tennessee has many resources available to develop SMR technology. There is also the potential for building parts and assembling SMR components. Doing so can benefit the state, as estimated benefits of SMRs could include jobs, increased tax revenue, and increased economic output.

This introductory survey yields preliminary recommendations on taking advantage of the many opportunities offered by SMRs.

- Pursuing SMRs as an R&D and economic development opportunity.
- Cultivating ancillary industries to help foster growth of the SMR industry.
- Resolving supply chain and training gaps that can meet the needs of SMR development as well as the broader nuclear industry.
- Developing advanced education programs to nurture a professional workforce into SMR-related fields.
- Considering the formulation and use of federal and state incentive programs to foster SMR development and deployment.

INTRODUCTION

The University of Tennessee's Howard H. Baker Jr. Center for Public Policy, in cooperation with the Tennessee State Energy Policy Council (SEPC), is mandated by the General Assembly to produce *an annual assessment of the energy sector in Tennessee*. The intent of the annual assessment is to inform policymakers and the public and guide the EPC as it develops an ongoing energy plan for the state.

This assessment for 2021 focuses on a small set of *disruptors* which have the potential to transform the energy sector: energy storage systems, small modular reactors, the electric grid and energy efficiency. These disruptors were chosen because of their potential to produce significant impacts on Tennessee's energy sector, the environment and economy. As such, each disruptor is a candidate for the development of targeted public policies by the state of Tennessee. These policies might pursue goals like improved system resiliency and a diminished environmental impact. They could also focus on the economy and economic development, mitigating the consequences of disruptor-induced change (e.g., job losses in affected industries) or taking advantage of opportunities created by the disruptors (e.g., the recruitment of new industry to the state).

The global energy sector is subject to ongoing transformation through technological innovation, self interest and decentralized markets, and public policy initiatives coming from all levels of government. Disruption and ongoing change has become the norm and a dramatically new energy landscape will emerge in the decades ahead. In some instances, this change is slow and evolutionary, while in other instances the pace of change is rapid and revolutionary. When change is slow, adaptation is relatively easy and policy responses are straightforward. However, when change is rapid, adaptation can become highly disruptive and policy responses may be introduced too slowly to be effective. For example, the first electric vehicle (EV) was developed well over 100 years ago. For many decades there was very little penetration of EVs into the market for light vehicles and thus very little outright disruption. However, improvements in battery technology, growing consumer interest in clean vehicles and supportive public policies have together sped up the pace of displacement of the internal combustion engine. Significant and rapid disruption is now taking place as new EV investments unfold and automobile producers change their platforms to accommodate EV production.

Some of the new energy technologies seem more like alchemy or magic than science—for example, the ability to charge small appliances like smart phones wirelessly. While most of the electricity that is consumed today continues to be sourced from large-scale generation facilities, including new solar arrays and wind farms, distributed generation is placing this old system at risk of dramatic disruption. Renewable energy sources, paired with high-efficiency storage systems behind the meter, could displace a significant share of centralized power generation. Research is now underway that seeks to harvest power from ambient sources. If this research is successful, new systems could disrupt virtually every facet of current energy markets.[1] The only certainty today is that the world of energy will look very different in 20 years. Understanding patterns of change in the state's energy sector is important so that problems can be mitigated and opportunities can be seized upon.

Creative Destruction: Winners and Losers

The importance of an energy sector disruptor is that it displaces some current or existing activity, creating stress but also offering opportunities for those who can take advantage of them. Economist Joseph Schumpeter developed his notion of displacement and disruption—*creative destruction*—which he defined as the "process of industrial mutation that continuously revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one."[2] The general presumption of economists is that if the market economy works well, this process of creative destruction will yield net benefits to society. Yes, there will be winners and losers, but society as a whole will be better off. This same principle applies generally to the transitions taking place across the energy sector.

The two important processes underlying creative destruction are *destroying* and *creating*. What this means for the energy sector is that disruptors will generally produce both winners and losers. Electric vehicles offer a powerful example in a Tennessee context. As EVs increasingly penetrate the transportation market they become the winners. The demand for electrical components and batteries increases, supply chains are refined or newly established and new production lines are developed for vehicle assembly. These trends have the potential to alter the spatial pattern of production across regions of the global economy, the nation and the state. New economic activity leads to new job opportunities and commonly new worker skill requirements as well. The environment is better off as the use of fossil fuels declines.

The losing sector in this example is the traditional automobile industry. Manufacturers of internal combustion engines and their parts see falling demand and shrinking job opportunities. Production facilities are shuttered and old assembly lines are closed. Unemployed workers must now pursue other jobs that may very well require different education, training and skills. Spatial mismatches are likely for displaced workers—there is no assurance that new economic activity will sprout where old economic activity is declining. The demand for gasoline declines which negatively impacts the petroleum sector and traditional fueling stations. [3]

In Tennessee, EV parts manufacture and assembly, along with battery production, are on the rise as the traditional transportation equipment sector experiences growing stress. Tennessee is in the fortunate position of seeing the old industry offer an anchor for the development of its replacement, which is not always the case as industries experience structural change. Decades ago, garment production represented

1. Cusick, D. October 2013. Ambient Energy Could Replace Batteries. *Scientific American*. https://www.scienti i-camerican.com/article/ambient-energy-could-replace-batteries/
2. Creative Destruction. *Wikipedia*. https://en.wikipedia.org/wiki/Creative_destruction
3. Gas tax revenue can be protected via combinations of higher rates on fuel and levies on electric vehicles.

a significant share of the state's nondurable goods manufacturing base. Today, this industry has largely vanished and moved offshore. (Consumers are the winners while garment producers and workers are the losers.) The EV sector, on the other hand, has prospered. The state, working with partners including TVA, local utility companies, Oak Ridge National Laboratory and others have facilitated the EV transition through the creation of Drive Electric Tennessee.[3] The aggressive industrial recruitment and retention efforts of the state and local communities across Tennessee have been instrumental in fostering EV parts production and assembly. Together these policy actions will likely have long-term beneficial impacts on the state economy and its tax base as EVs become more prominent, offering lessons for policies that address other facets of energy sector transition.

Disruptors and State Energy Policy

Energy policy can be used to support transition and disruption when there are clear benefits to the state. Policy might also be used to address the negative consequences of energy sector change as well. In general, energy policy must be guided by well-established and agreed-upon criteria to ensure effectiveness.

The SEPC has established criteria to guide its policy development[4] and each of these needs to be considered when evaluating policy options focused on energy sector disruptors:

- Economic development
- Efficiency and conservation
- Environmental impacts
- Equity
- External effects
- Resource use
- Resiliency

Consider these criteria in the context of energy storage systems, one of the topics of this report. Fostering the production of batteries for EVs has clear economic development implications for the state, including job gains and the creation of a supply chain. EV battery production in Tennessee may yield spillover benefits for the design and production of batteries used in other applications. These benefits may help offset any losses in the state's traditional transportation equipment sector which is built on the internal combustion engine. When storage systems are linked to the power grid, system-wide efficiency can be enhanced by better balancing alternative power sources and the use of centralized power generation. Negative environmental impacts can be mitigated if renewables are used to charge energy storage systems versus traditional fossil fuels. The Federal Energy Regulatory Commission has sought to level the playing field for the distribution of energy derived from renewables across the grid, representing an external effect that makes renewables and energy storage systems more attractive. When used in conjunction with renewable energy sources, including wind, solar and biomass, the use of own-source state resources is enhanced; to

3. See: https://driveelectrictn.org/
4. See: See https://comptroller.tn.gov/content/dam/cot/energy-policy-council/documents/SEPC%20White%20Paper%2001.15.2020%20Final.pdf

the extent these resources reside in rural places, equity and rural wellbeing is improved. Energy storage systems also offer the promise of improved energy sector resiliency.

The fact that there are multiple benefits associated with energy storage systems is insufficient to warrant state policy action; the same argument applies to the other disruptors discussed in this report. There are several reasons. First, much of the energy landscape in Tennessee is controlled by TVA and federal agencies, leaving little room for state policy action. Second, markets may work sufficiently well to stave off the need for policy. Third, policy should be built on a careful needs assessment that digs deeply into benefits and costs, addresses alternative policy targets and considers different policy instruments. In practice, the benefits of policy may simply fall short of the costs.

The disruptors presented in the body of this report are for potential policy development. High level overviews are provided for each disruptor, highlighting potential implications for Tennessee. Broad policy issues and options are discussed but no specific recommendations are offered.

ENERGY STORAGE SYSTEMS

Introduction[1]

As the global economy moves through the ongoing path of transition to a new energy sector, there are dramatic changes taking place with energy storage systems (ESS) of various forms. Many of these changes apply to electrical storage systems like batteries that are now used in electric vehicles (EVs). Given the anticipated replacement of internal combustion engines by electric engines, the market potential for new generation batteries is enormous. At the same time, significant progress is being made in the development and deployment of non-electric storage systems including pumped hydropower and mechanical systems that rely on gravitational forces.

New and evolving ESS offer a host of benefits, including the potential for environmental gains, reduced costs of system-wide power generation, improved power system resiliency and improved functionality of end-use electric products. There are also potentially important economic development benefits for regions that can attract designers and producers of ESS, as well as the ESS supply chain.

This chapter of the 2021 annual assessment of the state's energy sector provides a high-level overview of ESS with an eye on policy implications for the state of Tennessee. The chapter begins with a description of ESS and their use and then quickly turns to preliminary policy considerations.

State policy in Tennessee regarding ESS is muted because of the role played by TVA and federal agencies. Tennessee has no direct role in affecting the use of ESS by TVA or local distributors across the state. As noted below, TVA does in fact make use of large-scale ESS and plans are to increase this capacity further. The state could, on the other hand, pursue initiatives to deploy ESS behind the meter for use by households, businesses and commercial enterprises, including state government itself. Any large steps in this direction would require coordination with TVA and local distributors because of implications for generation system and the grid.

Other possible steps for ESS policy include the evaluation of economic development opportunities and an evaluation of the state and local regulatory environment that may affect the deployment of storage systems, especially behind the meter. The state is already a vibrant location for EV battery production and this may serve as a foundation for further growth and diversification, yielding more businesses and jobs for the state economy. The regulatory environment is not likely structured to accommodate evolving systems for energy storage. If this is the case, it creates an uneven playing field for different forms of energy dispatchment.

Energy Storage Technologies

ESS can be as simple as a rubber band or a crudely dammed river that supports ongoing use of a waterwheel. They can also be highly sophisticated electrical devices that can store energy for long periods of time. Everyone is familiar with lead batteries that have been in widespread use for well over 100 years.

1. This chapter of the annual energy assessment was prepared by Matthew N. Murray, PhD.

Modern ESS of various forms have evolved substantially over this window of time. Consumers are now very familiar with lithium-ion batteries as they are used extensively in smart phones, EVs and other common consumer items. Tesla has been an industry leader, also building on lithium-ion systems to support their Megapack that is used as a large-scale storage system.[2] Most people and policymakers are much less familiar with novel forms of energy storage, including pumped hydropower and other technologies which have tremendous potential for the future. The widespread adoption of ESS to meet general consumer electricity demand has inched forward due to the slow pace of technology development and a range of market and regulatory barriers.

This once-evolutionary environment is now changing rapidly. A technological breakthrough could have revolutionary and highly-disruptive implications for energy markets, especially for the current system of centralized generation and distribution. For example, if consumers could pair efficient and resilient ESS with renewable energy sources like solar or wind, behind-the-meter generation and storage could lead to large reductions in electricity demand from traditional sources on the grid. Another example, and one that would be less disruptive to the current structure of energy markets, would be the ability to link large utility-scale ESS to renewable energy sources. This could reduce the pressure on traditional base-load power sources like coal and natural gas that have significant impacts on the environment.

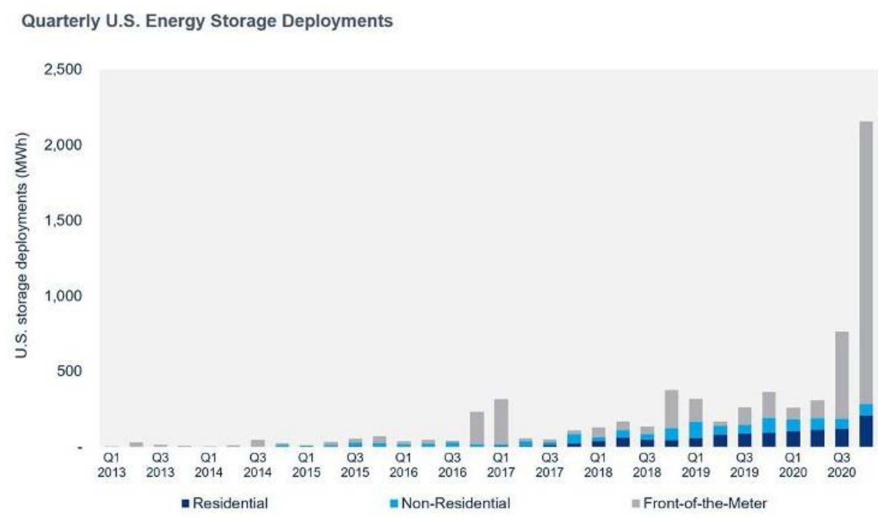
There are several accepted technologies that enable energy storage, sharing in common the ability to store energy for use when there is effective demand for electricity. ESS can help meet demand when other sources are not available and when market prices are relatively high. They can be especially effective when paired with renewables by enhancing the value of renewable resources via market expansion. And they can help balance load demand on the network, making network resources more efficient and potentially helping to defer maintenance on other components of the system.[3]

ESS technologies generally fall into one of the following categories:[4]

- Batteries, including lithium-ion, lead-acid, nickel-based and flow batteries.
- Pumped hydropower where water is pumped to a reservoir and then used to run a turbine when generation is needed; this source accounts for the vast majority of global energy storage in place today.
- Thermal, which uses heat and cold as energy sources.
- Compressed air, which utilizes underground storage in caverns and is then heated in a natural gas chamber to drive a generator.

2. Tesla. January 2019. Introducing Megapack: Utility-Scale Energy Storage. https://www.tesla.com/blog/introducing-megapack-utility-scale-energy-storage
3. For introductory background, see Energy Storage Energy Storage | Department of Energy, For more detailed information on ESS, as well as selected policy implications, see Charging Ahead: An Energy Storage Guide for State Policy Makers, April 2017. Available at IREC_Charging-Ahead_Energy-Storage-Guide_FINALApril2017.pdf (irecusa.org)
4. A concise summary is U.S. Grid Storage Energy Storage http://css.umich.edu/sites/default/files/US%20Grid%20Energy%20Storage_CSS15-17_e2020.pdf

Figure 1: Quarterly U.S. Energy Storage Deployments



Source: Wood Mackenzie Power & Renewables/Energy Storage Association Energy Storage Monitor 2020 Year in Review

- Flywheels and mechanical storage systems that rely on kinetic or gravitational energy.
- Hydrogen created using electrolysis from excess electricity.

Energy storage in the U.S. is dominated by front-of-the-meter systems as shown in Figure 1.[5] The fourth quarter of 2020 showed exceptionally strong growth in deployment, driven largely by large-scale systems put in place by the state of California. In 2020, overall new storage deployments grew by 1,654 MW of rated power and 3,487 MWh of energy storage capacity, an increase of 179 percent over the previous year. Projections indicate that storage capacity will grow 500 percent over 2020 levels by 2025, with 75-85 percent of the growth accounted for by front-of-the meter systems.[6] Total storage in the U.S. stood at 23.2 GW of capacity and 1,100 GW of generation capacity in 2020.[7]

Industry advocates have been instrumental in supporting reduced regulatory burdens and open market access to foster ESS growth. The Energy Storage Association is a prominent industry advocate for the deployment of ESS and has provided recommendations on supporting state-level policies.[8] Their policy objectives include:

- Develop comprehensive cost-benefit studies that quantify the value of energy storage in the specific state context.

5. Detailed information on individual storage systems is available from the U.S. Energy Information Agency for generators with more than 1 MWh of nameplate capacity. https://www.eia.gov/electricity/data/eia860/
6. Colthorpe, A. March 2021. In 2020 the US went beyond a gigawatt of advanced energy storage installations for first time ever. *Energy Storage News.* https://www.energy-storage.news/news/in-2020-the-us-went-beyond-a-gigawatt-of-advanced-energy-storage-installati#:~:text=The%20US'%20installations%20of%20advanced,was%20close%20to%203.5GWh
7. Center for Sustainable Systems. 2020. U.S. Grid Energy Storage Factsheet. University of Michigan. http://css.umich.edu/sites/default/files/US%20Grid%20Energy%20Storage_CSS15-17_e2020.pdf
8. See States - Energy Storage Association

- Spur deployment targets to complement state policy objectives and that are aligned with scenarios modeled in cost-benefit studies.
- Create incentive programs that drive deployment of behind-the-meter storage and drive down state specific soft costs.
- Establish regulatory guidance on storage for utility planning processes, including distribution, integrated resource plans and transmission planning.
- Advance business model innovation for storage through regulatory reforms that allow multiple use applications.

These policies are intended to generate revenue streams for ESS, open the doors of competition and ensure technology-neutral access to markets. State policy has tended to center on largely similar objectives as noted below.

The Interstate Renewable Energy Council (IREC) is another leading industry advocate for ESS and has developed a useful energy storage guide for the states.[9] The report discusses the technology side of ESS as well as policies that might be used by the states to foster research and encourage deployment. The guide is a useful source of ideas on potential state policy in Tennessee.

Economic Footprint

Measuring the size of the ESS sector in terms of standard metrics like the number of employers, employment and payroll is complicated by several factors, including the diversity of battery technologies and small-scale individual industry sectors. This means that information on storage systems, especially for individual states, is typically embodied in broader industry groups that make isolation of ESS-specific data impossible. Traditional storage battery data, for example, are in North American Industrial Classification System (NAICS) sector 335911 (storage battery manufacturing). National data for 2020 indicate 280 business establishments, September employment of 26,444 and an average weekly wage of $1,502 (or an implied annual salary of $78,104). The related industry group NAICS 335912 captures the primary storage battery manufacturing sector. In 2020, there were 131 business establishments, September employment of 12,536 and an average weekly wage of $1,346 (an implied annual salary $69,992).

In Tennessee, each of these sectors are embedded in the broader electrical equipment, appliances and component manufacturing sector (NAICS 335). There were 18,020 jobs in this sector in Tennessee in 2019, a decline of 40.2 percent from 1998. The U.S. Energy and Employment Report 2020 indicates 829 jobs in the energy storage sector in Tennessee.[10]

Tennessee currently is home to lithium battery production which is linked to the transportation equipment sector and the rise of EVs. Notable investments have been made by Microvast (Clarksville)

9. Stanfield, S., Auck, S., & Petta, J. April 2017. Charging Ahead: An Energy Storage Guide for Policymakers. Interstate Renewable Energy Council. https://energystorage.org/policies-issues/states/
10. National Association of State Energy Officials. 2020. U.S. Energy & Employment Report 2020. https://static1.squarespace.com/static/5a98cf80ec4eb7c5cd928c61/t/5ee78423c6fcc20e01b83896/1592230956175/USEER+2020+0615.pdf

and GM and LG Chem (Spring Hill). The Tennessee Department of Economic and Community Development reported the Microvast location would add $220 million in new investment to the state and create 287 jobs. GM and LG Chem announced a $2.3 billion investment for the state in April, 2021. This is part of GM's pivot to amped up EV production. The facility is slated to open in 2023 and will create 1,300 jobs.[11] Like the Microvast investment, additional jobs will be created along the supply chain and through the ripple effects of the multiplier.

Policy Scan[12]

States have taken differential policy stances toward ESS, with some showing an active and aggressive push for further deployment and others largely sitting on the sidelines. A recent report from the National Conference of State Legislatures (NCSL) provides timely background.[13] In 2019 and 2020, over 260 legislative initiatives on ESS were monitored by NCSL, a sharp increase from 88 in 2017 and 2018. State policy initiatives are dominated by energy storage targets, though other issues, including state procurement policy (i.e., the direct acquisition and deployment of ESS) and policies that pair ESS with renewables are addressed. One path to monitoring the status of state initiatives is a database developed by Pacific Northwest National Laboratory PNNL).[14] Their energy storage policy database offers a clickable source of information on state-by state initiatives, including relevant web links.

A small number of states have addressed distribution interconnection and utility planning, with the latter intended to yield a level playing field for ESS. In Tennessee, this is a role for TVA, systems operators and federal agencies. Several states have established megawatt targets for ESS deployment and incentive programs to encourage adoption. And a handful of states have completed or initiated cost-benefit studies to determine the scope of net benefits for ESS adopters and markets.[15]

A recent paper summarizes the status of state energy storage initiatives using a taxonomy of policy developed by PNNL.[16] The policy areas include:

- Procurement targets.
- Regulatory adaptation.
- Demonstration projects.
- Financial incentives.

11. Wayland, M. April 2021. GM and LG to spend $2.3 billion on second EV battery plant in U.S. *CNBC*. https://www.cnbc.com/2021/04/16/gm-and-lg-to-spend-2point3-billion-on-second-ev-battery-plant-in-us.html
12. The federal government, through the Federal Energy Regulatory Commission (FERC), promulgated Order No. 841 in 2018, requiring grid operators to remove entry barriers for ESS. FERC Order No. 2222, issued in 2020, included energy storage as a form of distributed energy resource; the rule allows behind-the-meter distributed energy resources to engage with wholesale markets. See Order-841.pdf (ferc.gov) and E-1_0.pdf (ferc.gov)
13. Shields, L. November 2020. The Growing Role of Energy Storage in Clean Energy Policy. National Conference of State Legislatures. https://www.ncsl.org/Portals/1/Documents/legisbriefs/2020/NovemberLBs/Energy-Storage_39.pdf
14. Pacific Northwest National Laboratory. March 2020. Energy Storage Policy Database. U.S. Department of Energy. https://energystorage.pnnl.gov/regulatoryactivities.asp
15. Energy Storage Association. States in the Spotlight. https://energystorage.org/policies-issues/states/states-in-the-spotlight/
16. Twitchell, J. 2019. A Review of State-Level Policies on Electric Storage Systems. *Current Sustainable/Renewable Energy Reports*. pp. 35-41. https://link.springer.com/content/pdf/10.1007/s40518-019-00128-1.pdf

- Consumer protection.

Procurement targets address state purchasing and the desire to facilitate energy market transformation inclusive of new ESS technologies. Regulatory adaption refers to inclusion of ESS in statewide energy and integrated resource planning, a task that TVA is charged with; other state/local regulatory issues that might affect ESS deployment are not addressed. Demonstration projects are efforts to conduct cost-benefit studies to identify best practice adoption. Financial incentives are generally for behind-the-meter applications of ESS. An example is Maryland, which has a pilot program using income tax credits for households ($5,000) and commercial and industrial customers ($75,000) for behind-the-meter adoption of ESS. Consumer protection is intended to protect owners of ESS from differential tariffs (Nevada) and ensure that customers can install ESS behind the meter.

Preliminary Energy Storage System Policy Considerations for Tennessee

Policies focused on promotion of ESS may be justified by several goals that have been established by the State Energy Policy Council (SEPC), including energy resiliency, economic development, resource use and environmental impacts.[17] However, any decision to move forward with the development and deployment of such policy must be predicated on further analysis to more precisely document the need for government intervention. Policy coordination should be championed to ensure the most effective impact and encompass both state and local government policy in Tennessee. Policy coordination should also include TVA and local distributors.

TVA limits the policy options available to the state because of its broad control over generation, transmission and distribution across most of the state. This means that the state has no direct control over the deployment of ESS which feed the TVA network. It also means that private sector parties cannot directly connect ESS to the transmission/distribution network. The public sector, private citizens and the business community may indirectly influence ESS adoption by TVA through the formulation of its Integrated Resource Plan which accommodates public input.[18]

The preliminary policy options considered below represent prime opportunities for further evaluation of opportunities to exploit the many benefits of ESS.

Behind-the-Meter (BTM) Applications. While ESS cannot tap the network absent TVA's support, they can reside behind the meter for private use by households, businesses and government entities. These could be single-user applications for a specific home or business or multi-user applications (including support for local micro grids that could be funded by a number of different mechanisms). ESS could be especially attractive for users who face differential electric prices over time, enabling the use of stored energy when

17. Tennessee State Energy Policy Council. January 2020. Tennessee State Energy Policy Council White Paper: Mandate, Vision, and Steps Forward. https://comptroller.tn.gov/content/dam/cot/energy-policy-council/documents/SEPC%20White%20Paper%2001.15.2020%20Final.pdf

18. Tennessee Valley Authority. 2019. Integrated Resource Plan. https://tva-azr-eastus-cdn-ep-tvawcm-prd.azureedge.net/cdn-tvawcma/docs/default-source/default-document-library/site-content/environment/environmental-stewardship/irp/2019-documents/tva_executivesummary_final_20190628-spreads.pdf?sfvrsn=939819db_4

prices from the grid are relatively high, as well as users who have the opportunity to exploit the use of renewables to charge the storage system. Localized ESS may emerge as a practical back-up system to insure against service interruptions from the distributor system. At some point, utility-scale storage systems may also offer insurance against the loss of power from other sources.

There are numerous candidate policies that could be used to further the adoption of behind-the-meter ESS. For example, the state could establish a deployment goal for megawatts of ESS capacity and then directly procure storage capacity for government enterprise use to meet the target goal. As noted above, several states already have procurement and deployment goals. Another example would be to pair ESS with renewable energy sources like solar where grid connections are especially costly, like isolated state parks or standalone electric vehicle charging stations.

The state could also provide incentives to encourage private sector adoption and use of ESS. One instrument would be the state's tax system. Under the current tax structure, sales tax would apply to the cost of ESS acquisition; an exemption could be carved out to protect ESS from taxation and encourage their use by both businesses and households.[19] Incentives could also be built into the corporate tax system and potentially the system governing the taxation of limited liability corporations. Another instrument would be financial incentives such as low-cost loans or grants. Financial incentives could potentially be extended to local governments to encourage their acquisition of ESS.

ESS and Economic Development. The state, along with local governments across Tennessee, are actively engaged in the recruitment of new industry and typically focus on targeted industry groups. The automotive sector and tier 1 suppliers are currently targeted industries. As noted above, there has also been some success in recruiting battery manufacturers to the state using standard tools like tax incentives and job training. The state's large and vibrant automotive sector and its ongoing transition to EVs makes Tennessee an attractive location for battery production.

The growing lithium battery industry in the state that complements EV production is an important asset. Diversification into other types of ESS that support different applications could yield significant economic development benefits for the state as demand for batteries continues to climb. Further benefits could be nurtured in the supply chain that lays behind battery production.

There are several other niche areas where policy might be focused to yield economic development benefits. For example, the state could seek to forge partnerships between private industry, colleges and universities, and entities like Oak Ridge National Laboratory to encourage R&D and pilot ESS programs. This would help deepen the footprint of the ESS sector

19. In general, sales tax applies to the purchase of tangible goods unless there is a specific exemption. For businesses, the purchase of tangible goods is exempt from sales tax if the good is embodied in a final product that is subject to sales tax. Industry acquisition of batteries for EVs, for example, is exempt from the sales tax because the vehicle itself is subject to tax. Purchases of ESS for own use by households and businesses would generally be subject to sales tax unless enumerated for exemption by the general assembly.

in the state beyond simply production. Another example, especially as ESS creep further into household and business use, would be technical assistance to potential adopters[20] and training programs for installers and maintenance workers. This would help lower the soft costs associated with technology deployment and maintenance.

Regulations and Technology Neutrality. In principle, the state and local regulatory structure, including local zoning ordinances, should not be an impediment to the deployment of ESS. New technology platforms will emerge in the future, requiring ongoing monitoring of the regulatory structure in the state to ensure technology-neutral regulatory policy. The New York Energy Research and Development Authority has developed a guidebook for local governments to help design model rules, zoning regulations and permitting processes for ESS.[21] Tennessee could consider a similar approach that would benefit potential adopters, industry advocates and those involved in regulatory design and enforcement at the state and local levels.

20. The Department of Energy and the Electric Power Research Institute have developed the DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA, touted as "a how-to guide for utility and rural cooperative engineers, planners, and decision makers to plan and implement energy storage projects." Available at https://www.sandia.gov/ess-ssl//publications/SAND2013-5131.pdf

21. Available at battery-storage-guidebook.pdf

THE ELECTRIC GRID

Introduction[1]

A significant transformation of the electric grid is currently underway. This transformation is driven by the rapid innovation, integration with the Internet and adoption of new energy technologies providing utilities, businesses, and homeowners in Tennessee with an increasing number of options for generating, using and managing energy. The grid is transitioning from a static system with centralized electricity generation and management to one that is dynamic and more reliant on renewable energy where consumers play a role in managing generation and consumption to help balance the grid. While this transition is only beginning in Tennessee, it is already well underway in other parts of the U.S. The purpose of this chapter is to briefly describe the major drivers of the grid transition, discuss policies being considered in other states to manage this transition, and highlight key areas where the state of Tennessee can play a role in shaping the transition of the grid.

What is the Electric Grid? An electric grid is an interconnected network for electricity delivery from producers (i.e., generators) to consumers. The U.S. electric grid, comprising everything from bulk power generation to household electricity users, is made up of three components that must work together to maintain a constant balance between supply and demand:

1. Physical infrastructure that generates and moves electricity (see Figure 1).
    - *Power plants*: electric generators that convert mechanical power into three-phase electric power.
    - *Electrical substations*: transform voltage from high to low or the reverse. Transmission substations connect two or more transmission lines. Distribution substations transfer power form the transmission system to the distribution system. Collector substations are similar to distribution substations but power flow is in the opposite direction. Collector substations are required for distributed generation projects such as wind farms and photo-voltaic (PV) power stations.
    - *Transmission network:* high-voltage power lines that connect power plants to substations.
    - *Distribution network:* medium- and low-voltage power lines that connect substations to customers. Primary or medium-voltage lines connect substations to distribution transformers located near customers. Distribution transformers lower the voltage again to a level used by lighting and household appliances. Secondary or low-voltage distribution lines connect the distribution transformer to one or more customers.
2. Critical software and hardware assets that manage the physical infrastructure.
    - *Energy management systems*:

1. This chapter of the annual energy assessment was prepared by Charles Sims, PhD and Tim Roberson, PhD.

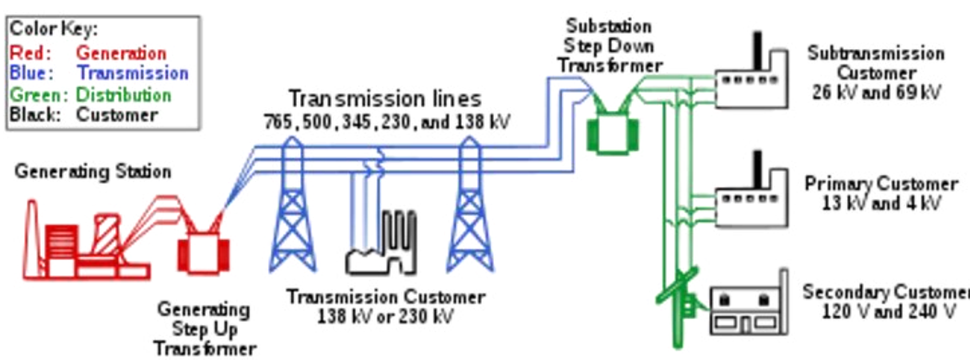
A suite of tools used to monitor, control, and optimize the performance of generation and transmission systems.

- *Networking equipment*: used to digitally connect physical assets on the grid.
- *Data storage and processing:* Hardware platforms running virtual machines or virtual storage.

3. Responsible entities that make decisions and rules about how the grid operates and evolves.

- *North American Electric Reliability Corporation (NERC)*: a nonprofit corporation that promotes the reliability and adequacy of bulk power transmission in the electric utility systems of North America. NERC was established by the Federal Energy Regulatory Commission (FERC), which is tasked with regulating interstate electricity trade.
- *Balancing authorities*: ensure that electricity supply meets demand within a local or regional network.
- *Interchange Authorities*: manage exports/imports of electricity between balancing authorities.
- *Transmission system operators (TSOs)*: not-for-profit companies typically owned by the utilities in their service areas that coordinate, control, and monitor the operation of the electric transmission system. TSOs are obliged to provide nondiscriminatory transmission access to electricity generators and customers. TSOs that operate in a single state are known as independent system operators (ISOs) while TSOs that cover larger areas that cross state borders are known as Regional Transmission Organizations (RTOs).
- *Generation and transmission owners/operators*: ownership and operation of generation and transmission assets varies by state. From roughly 1920 to 1980, electric utilities operated as regulated monopolies. Under this structure, utilities controlled every aspect of the grid from generation to distribution. Following the energy crisis of the 1970s, Congress

Figure 1. Key physical components of an electric grid.



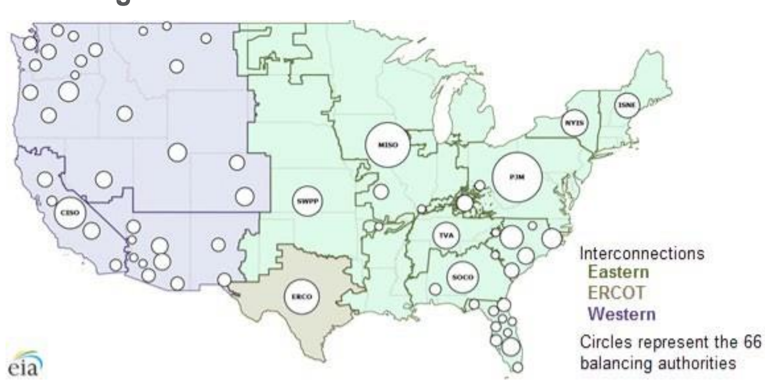
Source: https://upload.wikimedia.org/wikipedia/commons/4/41/Electricity_grid_simple-_North_America.svg changed this structure to allow wholesale competition in electricity generation, while transmission operators (ISOs and RTOs) maintained a monopoly over the management of the transmission system. Today, the U.S. has a mix of market structures. Seventeen states operate under this restructured electricity market enabling customers to buy electricity in a competitive market. In these areas, many private companies generate electricity. The remaining states, including Tennessee, continue to operate under the old model where a single utility is responsible for both generation and transmission. Tennessee is unique in that this single utility is a federal entity rather than a private, regulated company.

- *Load servicing entities (LSEs) or local power companies (LPCs):* municipally owned utilities or electric cooperatives that supply electricity to customers through the distribution network.

The U.S. electricity grid is served and overseen by several overlapping organizations with differing goals and responsibilities. The grid is divided into three interconnections: east, west, and Texas (see Figure 2). Electricity flows through transmission lines within each interconnection, but rarely between different interconnections. Tennessee and TVA are within the eastern interconnection, which serves states from Oklahoma and the Dakotas to the east coast.

Each interconnection is further divided into regional reliability organizations. These organizations oversee bulk power generation and high-voltage electricity transmission systems. This includes large power plants and long-distance transmission lines, but does not include local electric facilities such as small distribution lines and meters which serve end-use electricity customers. Regional reliability organizations ensure that there are enough generation resources to meet consumer electricity demand, and that the electric grid is resilient enough to withstand unexpected occurrences which may impact electricity supply, such as natural disasters or extreme weather events. As part of their oversight role, regional reliability organizations

Figure 2. U.S. electric grid Interconnections and balancing authorities.



Source: Energy Information Administration often provide training on regulatory compliance, conduct long-term planning on electric grid reliability, and ensure regulatory compliance. Tennessee's regional reliability organization is the Southeastern Electric Reliability Corporation (SERC), which also oversees the electric grid in 16 other southeastern states. SERC and the seven other regional reliability organizations are overseen by NERC.

Daily management of the electric grid is the role of balancing authorities. Balancing authorities ensure that electricity supply meets demand within a local or regional network (see Figure 2). This includes scheduling and dispatching generators to meet expected demand and avoid blackouts. The terms regional transmission organization (RTO) or Independent System Operator (ISO) are often used in place of the term balancing authority. RTOs and ISOs are very similar--both serve as balancing authorities for large regions, often consisting of multiple states. Both manage access to and operation of high-voltage transmission systems within a region, and both are regulated by FERC. Examples of RTOs include the California Independent System Operator (CAISO) and the Pennsylvania-New Jersey-Maryland Interconnection (PJM).

RTOs/ISOs often perform multiple functions, serving as transmission system operators (TSOs), Interchange Authorities, and market operators, which manage the economics of local electricity markets. Depending on the organization and varying local regulations, market operators either minimize the long-run cost of generation, or manage an electricity auction market in which suppliers submit competitive bids to meet consumer demand. Many regions of the country, including Tennessee, are not part of an RTO/ISO and are instead balanced by local utilities. The balancing authority in Tennessee is TVA, which operates in parts of five other bordering states. The TVA is also the transmission system operator and interchange authority for the entire state of Tennessee.

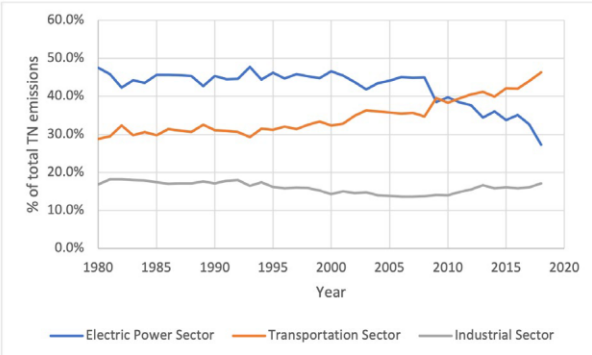
Managing Multiple Grid Transitions

It is often stated, as with the beginning of this chapter, that the electric grid is going through a transition. In reality, it is going through several simultaneous transitions that at times seem to be pulling it in multiple directions. The eventual outcome of these simultaneous transitions is uncertain. We cannot know exactly what the grid of the future will look like. However, it is certain to trigger fundamental changes in market structure, utility business models, and the Tennessee economy. Many of these transitions are already beginning in Tennessee and several others are on the horizon. Below we highlight four transitions currently influencing the grid in Tennessee.

Grid Decarbonization. Historically, the combustion of fossil fuels to generate electricity has been the largest single source of CO2 emissions in Tennessee. In 2000, 47 percent of total Co2 emissions in Tennessee were due to electricity generation.[2] However, Tennessee's

2. U.S. Energy Information Agency. March 2021. Energy-Related CO2 Emission Data Tables: 2018. https://www.eia.gov/environment/emissions/state/

Figure 3. Tennessee Carbon Dioxide Emission from Fossil Fuel Consumption: 1980-2018.

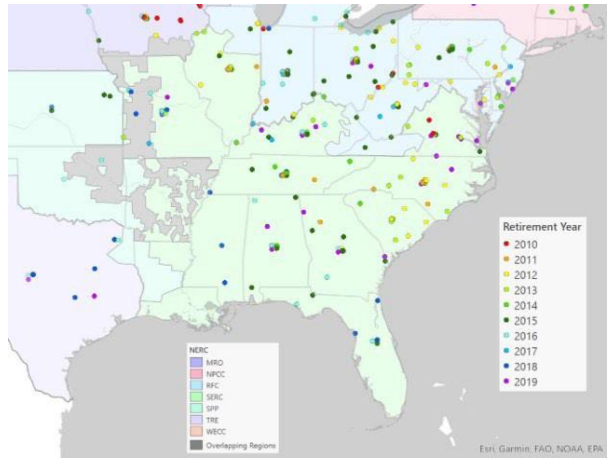


Source: Energy Information Administration (https://www.eia.gov/environment/emissions/state/)

electric grid is becoming less carbon intensive – a trend known as gird decarbonization (see Figure 3). In 2018, 27 percent of Tennessee's total CO_2 emissions were due to electricity generation.[3] TVAhas cut its carbon output by 63 percent since 2005, nearly twice the industry average for all U.S. utilities. According to TVA President Jeff Lyash, by 2035, TVA anticipates cutting its carbon emissions from the burning of fossil fuels by 80% below a 2005 baseline.

Grid decarbonization is being driven by two trends. First is the lower cost of natural gas which has made it more economically viable to phase out TVA's aging coal plants. TVA has shut down 34 of the 59 coal-fired units it once operated. Figure 4 shows the location of coal-fired generators that retired between 2010-2019. The color of the circle indicates the year the generator retired. The loss in coal-fired generation has been offset with investments in natural gas generation which is less carbon-intensive

Figure 4. Coal-fired generator retirements, 2010-2019.



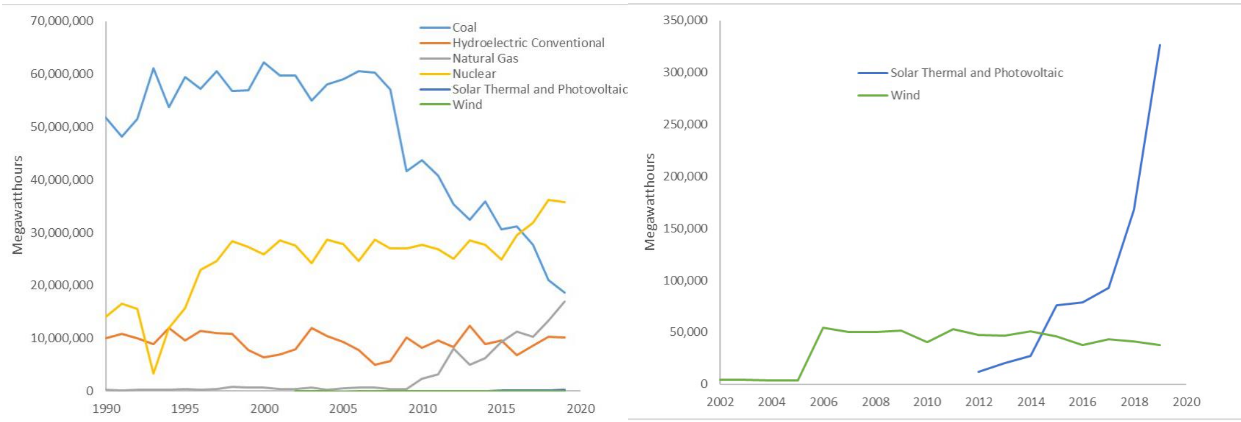
Source: Authors' mapping of EIA Form 860 Data for 2019. A small amount of jitter is added so that multiple generators at the same plant are all visible.

than coal. The result is a shift from TVA's historically coal-dominant generation portfolio to one where coal and natural gas generate roughly the same amount of electricity (see Figure 5). The wave of retirements over the last decade is just the beginning. TVA is preparing to shutter its Bull Run Fossil plant by 2023 at which point it will have been in operation for 56 years. TVA is also planning to ultimately shut down its remaining coal-fired plants (Cumberland, Gallatin, Kingston, and Shawnee) by 2035. These planned retirements are consistent with the rest of the U.S.

The second factor is the declining cost of generating electricity from renewable sources such as solar and wind. As shown in Figure 6, the *levelized cost* of energy (LCOE) for solar PV and wind has fallen by 89 percent and 70 percent respectively since 2009. The LCOE is a measure of the average net present cost of generation from a plant

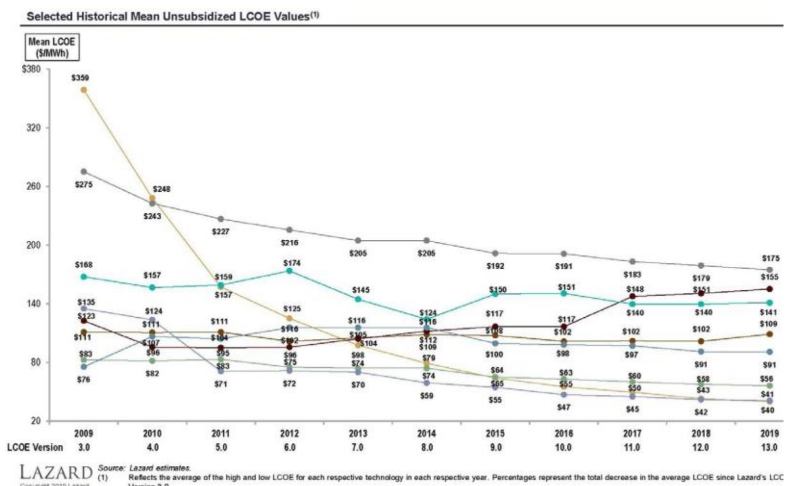
3. U.S. Energy Information Agency. March 2021. Energy-Related CO_2 Emission Data Tables: 2018. https://www.eia.gov/environment/emissions/state/

Figure 5. Energy source for electric power industry in Tennessee, 1990-2019



Source: Energy Information Administration https://www.eia.gov/electricity/data/state/

Figure 6. Levelized cost of energy comparison: Historical utility-scale generation comparison



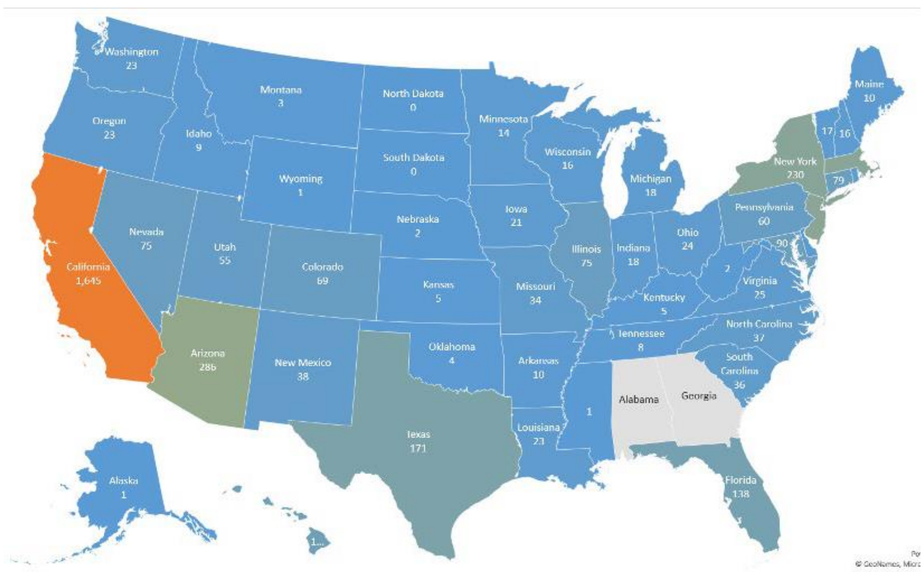
Lazard's Levelized Cost of Energy Analysis – Version 13.0. November 2019. Source: https://www.lazard.com/media/451086/lazards-levelized-cost-of-energy-version-130-vf.pdf

over its lifetime and is used to consistently compare different methods of electricity generation. By comparison, the fracking boom in the U.S. that reduced natural gas prices to historic levels reduced the LCOE for gas combined cycle plants by32 percent during this time. These cost declines make renewable generation less costly than coal generation in many parts of the U.S. In Tennessee, these decreasing costs have manifested as a 25-fold increase in utility-scale solar generation since 2012. In 2018 alone, utility-scale solar generation nearly doubled. The amount of electricity generated from wind and solar in Tennessee remains modest relative to hydroelectric generation. However, TVA plans to add 7,000-10,000 megawatts of utility-scale solar capacity by 2040. TVA also plans to add 1,542 megawatts of wind energy to its portfolio by buying wind energy from nine wind farms throughout the Midwest.

Widespread adoption of distributed energy resources. The declining cost of renewable energy is also driving a greater acceptance of distributed energy resources (DER). DERs are physical assets on the distribution grid, typically close to load, and usually behind the meter, which can be used individually or in aggregate to generate, store or manage power for the grid, individual customers, or both. This transition has the potential to revolutionize how utilities provide power for customers. The electric grid has evolved as a hub-and-spoke system where electricity was generated at a small number of large electricity plants and transported to customers through the transmission and distribution system. Under this model, TVA has been the sole entity responsible for electricity generation and local power companies were responsible for distributing this electricity over short distances to residential, commercial, and industrial customers. The lower cost of renewable energy, combined with federal and state incentives, has led to increasing adoption of small-scale generation technologies such as rooftop PV and combined heat and power (CHP) systems. Widespread adoption of these distributed generation technologies will require the grid to be redesigned to accommodate power flows between customers with utilities facilitating its distribution and transmission and providing backup power during times when distributed assets are unable to generate sufficiently. Other DERs such as storage batteries and smart meters can be used to modulate the more drastic swings in electricity demand that arise with distributed generation. Thus, a fundamental question facing the electricity industry is whether technological advances in renewable generation and storage will manifest at the utility-scale or will be deployed behind the meter.

Distributed solar generation (DSG) is

Figure 7. Thousand megawatt hours of distributed solar generation.



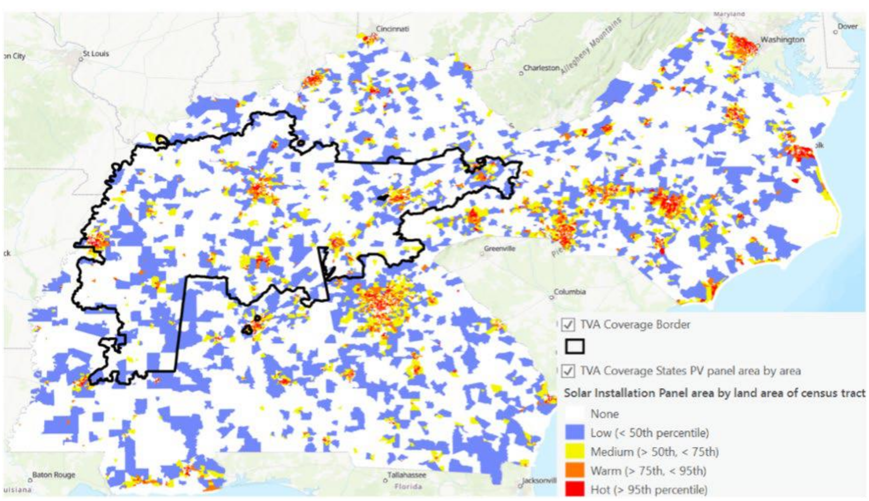
Source: Energy Information Administration, Electric Power Monthly, Table 1.17.A.

an increasingly prevalent type of DER that spans rooftop PV to community solar systems. Across the U.S., electricity generatedfrom DSGincreased 20% during 2020.[4] Figure 7 shows the amount of DSG generation (in Thousand Megawatthours) in each state in the U.S. as of March 2021. The majority of adoption to date has been in states with plentiful solar resources (California, Arizona) or states that have incentivized DSG to achieve carbon emission reduction goals (New York, Massachusetts). DSG generation in Tennessee is low (8,000 MWh) but expected to increase as technological improvements generate additional cost reductions and customers become more aware of these technologies.

DSG provides both opportunities and challenges for electric utilities in Tennessee. DSG can allow utilities to defer generation and transmission investments, avoid energy costs, achieve environmental compliance, sell valuable renewable energy credits (RECs), and lower transmission and distribution system energy losses.

Challenges are rooted in the inability to control when generation is produced and include intermittent generation, inability to dispatch, and frequency regulation. Generation from DSG fluctuates unpredictably making it difficult to balance electricity supply and demand necessary for grid integrity. These concerns have not yet manifest in Tennessee due to the low amount of DSG generation (see Figure 7). However, DSG generation is expected to grow giving TVA and local power companies an opportunity to plan for this coming influx of non-dispatchable electricity. Another challenge is DSG is not spread evenly across space and occurs without consideration of the existing transmission and distribution network. Figure 8 shows the location of rooftop PV installations across the southeast including the TVA service area. DSG hot spots (greater than or equal to the 95th percentile)

Figure 8. Installed solar panel area per land area



Source: Authors' mapping of DeepSolar dataset

4. EIA, Electric Power Monthly, Table 1.17.A. https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_1_17_a

are in major cities (Memphis, Nashville, Knoxville, Chattanooga) with lower levels of adoption scattered through the state. This spatial pattern of adoption is similar in other parts of the southeastern U.S.

Several strategies have been proposed to help capitalize on opportunities and overcome challenges such as electricity storage, demand side management, more flexible power plants, real time pricing, and transmission and distribution network extensions. To identify preferred strategies, utilities are seeking ways to incorporate forecasts of the derived net load (i.e., total load minus DSG) into resource planning activities. Incorporating derived net load requires forecasts of technical, economic, and customer adoption potential of DSG. Due to the intermittency of DSG and the difficulty in predicting the diffusion of DSG, the derived net load forecast will differ from the traditional load forecast but in unpredictable ways.

One strategy employed by TVA to increase distributed generation while maintaining some coordinated energy management is to allow local power companies (LPCs) to be more directly involved in energy generation. In 2020, TVA announced that LPCs could reduce the amount of energy they buy from TVA by generating up to 5 percent of their average energy needs provided they enter into 20-year Long- Term Partnership Agreements with TVA. LPCs can then put the locally-generated energy on their distribution system for customers' use. As of June 2020, 91% of the LPCs in the TVA service area have entered into a 20-year Long-TermPartnership Agreement.

More uncertain demand for centralized electricity. Another transition, partially driven by the first two, is from a period of relatively predictable growth in electricity demand to one where electricity demand is more unpredictable. Historically, electricity demand in Tennessee has predictably increased at about 2% annually. This predictable increase in electricity demand made it relatively easy to plan the grid expansion investments needed to meet this demand. The electric grid evolves through large capital investments in things like generating units and transmission lines that require large upfront costs in exchange for many years of electricity revenues. In general, when electricity demand is rising, the additional revenues created by these grid expansion investments is rising. In recent years, electricity demand in Tennessee began to flatten and to decline. The decline is largely due to an increase in energy efficiency such as increased adoption of less energy intensive lighting and appliances. However, load demand is now rising because of popularity and industry growth, along with digital currency mining and EV adaptation. This increase in energy efficiency has been large enough to counter increases in electricity demand due to a growing state economy and population.

However, there is considerable uncertainty about whether this trend will continue. Technology-driven investment in automation and artificial intelligence as well as lower battery prices could drive electrification in Tennessee's manufacturing and transportation sectors raising electricity use. Gains from energy efficiency improvements will also begin to dissipate as low-hanging fruit (e.g., low-income weatherization) becomes harder to find.

However, it is unclear how much of this increase in electricity demand will manifest as larger demand for the centralized power TVA provides. Growing consumer awareness of and preference for energy choice, coupled with rapid advances in energy technologies may drive high penetration of distributed generation, energy storage, and energy management leading to further declines in TVA demand forecasts.

These countervailing trends make the demand for TVA's centralized generation services uncertain which makes determining when and how to adjust Tennessee's grid difficult. If TVA makes investments in generation and transmission to meet demand that never materializes, wholesale electricity rates in Tennessee will likely increase to cover the cost of these capital investments. Higher electricity rates will then increase customer incentives to adopt distributed generation and other DER which would exacerbate declines in electricity demand and necessitate additional increases in electricity rates. On the other hand, supply-side planning that under-estimates electricity demand will lead to scarcity which will likely manifest as higher electricity rates as well.

The importance of this uncertainty is reflected in TVA's focus on flexibility in its 2019 IRP[5]:

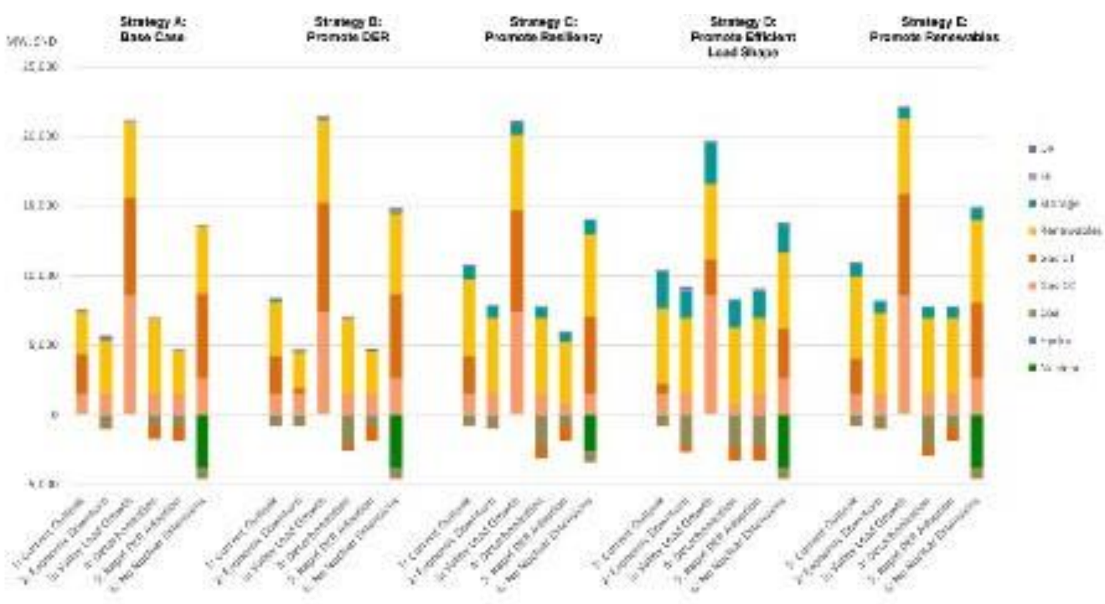
> *TVA evaluated a wide range of possible futures and how flexible the power system needs to be to ensure reliable power at the lowest system cost. […] The IRP is focused on flexibility because TVA needs a diverse power-generation system that is well positioned to meet future demand; has the capacity to incorporate renewable energy sources and DER along with more traditional resources; and has the capability to respond in a variety of circumstances well into the future.*

The 2019 IRP considered two scenarios to reflect this long-term demand uncertainty. The first was a Valley Load Growth scenario which represents economic growth driven by migration into the Valley and a technology-driven boost to productivity, underscored by increased electrification of industry and transportation. The second is a Rapid DER Adoption scenario which is driven by growing customer awareness and preference for energy choice, coupled with rapid advances in technologies, resulting in high penetration of distributed generation, storage and energy management. The differences in TVA's energy portfolio under these two scenarios indicate the impact of this uncertainty in Tennessee (see Figure 9). If Tennessee's future is similar to the Valley Load Growth scenario, TVA will need 244 percent more natural gas and 80 percent more renewables relative to its current outlook.[6] If Tennessee's future is characterized by rapid DER adoption, TVA will retire more coal and natural gas combustion turbine capacity relative to its current outlook.

Increasing grid resiliency. Grid resiliency refers to the ability of the grid to respond to unexpected, short-term power outages. Resilience includes lessening the likelihood that these outages will occur, limiting the scope and

5. TVA. 2019. Integrated Resource Plan. https://www.tva.com/environment/environmental-stewardship/integrated-resource-plan
6. Author calculations from 2019 TVA IRP Strategy A: Base Case. https://www.tva.com/environment/environmental-stewardship/integrated-resource-plan

Figure 9. Incremental capacity by 2038 under 5 TVA resource planning strategies paired with 6 future scenarios



Source: 2019 TVA Integrated Resource Plan https://www.tva.com/environment/environmental-stewardship/integrated-resource-plan

impact of outages when they do occur, restoring power rapidly afterwards, and learning from these experiences to better deal with events in the future.

Several recent events highlight the importance of increasing grid resiliency. The ransomware attack on the Colonial pipeline resulted in gasoline shortages along U.S. east coast. The 2021 winter storm in Texas knocked generators offline causing billions of dollars in damage and more than 100 deaths. In April 2021, the Biden Administration announced a coordinated effort between DOE, the electricity industry, and the Cybersecurity and Infrastructure Security Agency (CISA) to enhance the cybersecurity of electric utilities' industrial control systems (ICS) and secure the energy sector supply chain.

There are several strategies currently being taken to enhance grid resilience. One strategy to increase resiliency is through changes in the portfolio of centralized generation assets. TVA has begun to consider generation and transmission planning strategies that explicitly promote resiliency. According to TVA's 2019 IRP, changes in the generation portfolio needed to increase resiliency can be inferred by comparing strategy A (Base Case) and strategy C (Promote Resiliency) in Figure 9. In general, a more resilient portfolio of generation assets would require more investment in utility-scale storage, demand response (DR), and renewables. These additional investments will also trigger more coal-fired generator retirements relative to the Base Case strategy.

Another strategy is to enhance cybersecurity. Electric utilities use computer networks to operate vital infrastructure, so they are naturally a target for computer hackers. A cyberattack on an electric utility could cause disruption to the electricity service for millions of households. The energy sector accounted for 35 percent of self-reported cyber incidents from 2013-2015, although most attacks are never made public, and data on attacks is therefore difficult to find.[7] Also as of 2015, 75 percent of energy companies reported an increase in successful cyber-attacks with estimates of the annualized cost of cybercrime for an average energy company exceeding $27 million.[8]

Much cybersecurity of electric utilities is similar to security best practices used in other businesses such as use strong passwords, two-factor authentication (2FA), a firewall, etc. Less sophisticated hacking attempts, such as "phishing emails," in which hackers send emails to employees, often impersonating a coworker or supervisor, in the hope that the employee clicks on a link to a compromised site can be difficult to prevent entirely, as the attacks are cheap, and even a success rate of 1 in 100 can compromise a system. A recent State of Electric Utilities (SEU) survey revealed that 57% of utilities nationwide are increasing spending on digital operations and security, while 55% of respondents said their organization uses a systematic approach for promptly patching vulnerabilities.[9]

As a large electric utility with 29 hydroelectric dams, seven nuclear reactors, and an electricity provider to the Oak Ridge nuclear arsenal, TVA is a high-value target for potential cyber-attacks. TVA maintains a cybersecurity unit in Chattanooga with 60 employees, and over 2 dozen IT specialists. This unit constantly monitors for cybersecurity threats to the electric grid. Although currently housed in the TVA's Chattanooga office, the cybersecurity unit is planning to move to a $300 million secure rural facility in Meigs County by 2023.[10] TVA, like all federal agencies, must also comply with the Federal Information Security Modernization Act of 2014. As a wholesale electricity supplier, TVA must also comply with North American Electric Reliability Corporation Critical Infrastructure Protection (NERC-CIP) standards which covers physical and digital security controls and recovering from a cyber breach.[11]

Grid decarbonization efforts may enhance or undermine grid resiliency efforts. The intermittency of renewable generation

7. Office of Electricity Delivery & Energy Reliability. March 2018. Multi-year Program Plan for Energy Sector Cybersecurity. U.S. Department of Energy. https://www.energy.gov/sites/prod/files/2018/05/f51/DOE%20Multiyear%20Plan%20for%20Energy%20Sector%20Cybersecurity%20_0.pdf
8. Office of Electricity Delivery & Energy Reliability. March 2018. Multi-year Program Plan for Energy Sector Cybersecurity. U.S. Department of Energy. https://www.energy.gov/sites/prod/files/2018/05/f51/DOE%20Multiyear%20Plan%20for%20Energy%20Sector%20Cybersecurity%20_0.pdf
9. Walton, R. April 2021. State of the Electric Utility 2021: Utilities' cybersecurity approach shows cause for concern, experts say . *Utility Dive*. https://www.utilitydive.com/news/state-of-the-electric-utility-2021-utilities-cybersecurity-approach-shows/596664/
10. Flessner, D. August 2018. TVA to build $300 million power control center in Meigs County. *Chattanooga Times Free Press*. https://www.timesfreepress.com/news/local/story/2018/aug/28/tvbuild-300-millipower-control-center-replace/477989/?bcsubid=50a56e05-02ae-4f1a-bdf9-7f4770593fe6&pbdialog=reg-wall-login-created-tfp
11. Currens, E. November 2018. What You Need to Know about NERC CIP Cybersecurity Standards. *Trust Wave*. https://www.trustwave.com/en-us/resources/blogs/trustwave-blog/what-you-need-to-know-about-nerc-cip-cyber-security-standards/

introduces the potential for short-term disruptions to supply though these disruptions can be forecasted based on historic weather data. Further, increased integration of renewable generation on the grid also represents a diversification of generation technologies that will lessen reliance on a single fuel source or supply chain thereby enhancing grid resiliency.

Increased adoption of DER may also increase or decrease grid resiliency. Distributed generation can cause unexpected changes in electricity demand and supply which can be moderated to some extent by other DER such as smart meters and programmable thermostats and appliances. DERs may also represent new access points for cyberattacks since these assets will be virtually connected to grid. However, distributed generation can also enhance grid resiliency by making the power supply less reliant on a small number of large generators. Distributed generation plus storage means that local communities may have access to some power even when the bulk energy system that serves that community is temporarily off-line. DER and microgrids can contribute to grid resiliency by aiding "black start" processes, which turn power on after it has gone down. Many electrical generators require an external battery to start, just like a car engine does. To combat widespread electrical failure where generators are unexpectedly put offline, utilities create black start plans, in which small generators start larger ones to steadily bring generation online. Communities with microgrids could become a valuable resource to begin start-up processes on their own and provide the capacity required to start up larger generators.

The Elephant in the Room: Storage. It is impossible to know how each of these transitions will play out to shape the electric grid of the future. However, the emergence and widespread adoption of cost-effective electricity storage technologies—the focus of another chapter of this annual assessment—will greatly influence how these trends play out. Given the current pace of technology improvement, TVA will increasingly view utility-scale storage as a more cost-effective way to balance demand and supply compared to transmission and generation upgrades. Greater adoption of utility-scale storage will likely lower the cost of integrating renewable generation onto the grid. Traditional solar is often a difficult sell for some businesses due to load requirements. However, cost-effective distributed storage technologies will improve the economic feasibility of distributed generation pushing more homeowners and business to invest in rooftop solar and CHP systems thereby hastening the transition to distributed generation and lowering electricity demand from traditional utilities. Conversely, improvements in battery storage will lead to increased adoption of EVs increasing electricity demand. Cost-effective storage will also be a critical tool for improving the resiliency of the electric grid. The harm created by unexpected disruptions to the power supply will be greatly muted when widespread adoption of storage allows for rapidly dispatchable energy reserves. Further improvement in ESSs will be required.

Policy in States at the Leading Edge of Grid Transitions

Several of the transitions highlighted here are just beginning in Tennessee. However, they are well underway in other states like California, Texas, Arizona, and New York. Policy initiatives in these states provide a glimpse of the types of actions Tennessee may take to mitigate the impact of these grid transitions. This section, highlights a few of the policy discussions ongoing in other states related to the electric grid.

Paying for energy transitions. Addressing all of the trends and challenges identified in this report will require TVA and LPCs to make investments in physical infrastructure, employee training, and software systems. New transmission lines will be needed to connect new renewable facilities, which cannot always be sited next to existing transmission networks. Local distribution networks will need to be enhanced to deal with the reversed flow of electricity generated by DSG. Meanwhile, investments in existing generation and transmission assets must still be paid off. The question TVA, and by default Tennessee, is currently facing is how to best finance these multiple energy transitions without placing an undue burden on electricity ratepayers. Some states, notably California and Texas, are already attempting to answer this question. In California, retail electric rates have increased faster than the rate of inflation since 2013, reflecting increasing investment costs related to, in part, transmission investments.

Raising volumetric electric rates (dollars/kw) is a typical strategy to recover the cost of these infrastructure investments. However, raising volumetric rates is highly regressive, meaning that poor electricity consumers would a pay a disproportionally large share of their income to cover the TVA's fixed costs compared to wealthy consumers. Poorer households tend to spend a larger share of their monthly income on electricity than wealthy households, so recovering costs by raising volumetric rates will consume a larger portion of poorer households' monthly income.

One potential solution to the regressive nature of volumetric rates is to institute "volumetric block-pricing," under which consumers initially pay a low rate for electricity, but then pay higher rates as their monthly consumption moves above pre-determined thresholds. This is the same principle by which marginal income tax brackets work; taxpayers pay an increasing percentage of their income in federal taxes as their annual income rises. Instituting block pricing would also serve the same purpose as marginal tax brackets. Block pricing would require that high volume electricity users, who also tend to have higher incomes, pay higher rates, shifting the burden of financing grid upgrades from poorer to wealthier households. However, this kind of rate structure may increase the rate at which wealthy consumers install DSG, since top marginal electric rates under block pricing might be quite high. Paying for energy transitions in this way may cause wealthy consumers to purchase DSG to offset rising volumetric electric rates, forcing the TVA to again raise rates on their remaining, relatively poorer, consumers to recover their fixed capital costs.

Rather than increasing volumetric rates to cover new investment costs, TVA may choose to charge fixed fees for grid access. TVA recently implemented such a fee, which was justified to regulators as a way to recover fixed costs. Fees like this should already be familiar to Tennessee consumers, who typically pay a fixed fee and a volumetric charge on their monthly electricity bills, with the fixed fees helping local utilities cover their own overhead costs. Raising fixed fees rather than raising volumetric rates allows electric rates to be set at the marginal cost of electricity production, resulting in efficient production and consumption of electricity. Fixed fees also do not incentivize consumers to adopt distributed generation like volumetric rates, alleviating the worry of driving wealthier consumers off the electric grid and shifting the burden of covering the TVA's fixed costs toward poorer consumers. However, fixed fees will still place a relatively large burden on poorer households, since the same fee will consume a larger share of a poorer household's income. Some have proposed that fixed fees be indexed to income so that higher income consumers pay higher fees. While this would make fixed fees less regressive in theory, it would require that utilities keep accurate records of household income, likely in the form of tax receipts. This is therefore unlikely to be implemented.

In California, it has been proposed that the cost of financing new public electric grid investments be shifted into the state's general fund, meaning that electricity infrastructure be funded through state tax revenue rather than recovered by raising electric rates. Since TVA is a federal agency, this solution is not currently an option in Tennessee. As such, the state of Tennessee cannot shift the costs of these energy transitions from ratepayers into general tax revenue. Unlike most other states, there is little the state of Tennessee can do with respect to electric rates due to the presence of TVA.

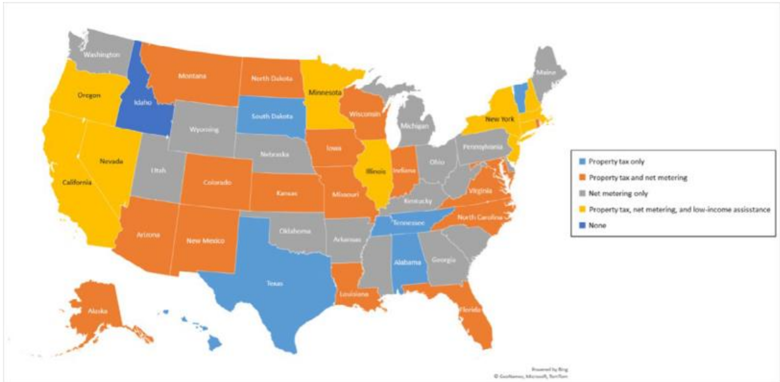
Creating incentives to enhance resiliency. Grid resiliency can be viewed as a weak-link public good. Grid resiliency can only be achieved if each grid actor (transmission service providers, transmission owners, transmission operators, generation owners, generation operators, and load servicing entities) does their part to secure the physical infrastructure and critical assets that they own and operate. However, actions to enhance resiliency such as generator weatherization and upgraded security protocols are costly and actors that choose to defer these resiliency investments will benefit from the resiliency investments made by other actors. The public good nature of grid resiliency suggests that voluntary actions will be insufficient to combat the growing threats to the electric grid.

NERC-CIP standards for wholesale electricity suppliers represent one approach to move past voluntary actions with respect to cybersecurity. A similar unified set of standards for local power companies (distribution utilities and electric cooperatives) may also be needed. However, it is likely that many of these local power companies lack the funding or resources necessary for implementing effective cybersecurity controls. Local governments face similar challenges. In order to address these challenges, the Comptroller's Division of Local Government Audit created COT Cyber Aware to help local government officials protect their computer systems and educate their staff about potential cybersecurity threats.[12]

Several states are also considering policies that would enhance resiliency by incentivizing certain generation technologies that can store fuel onsite. For example, Texas is considering

12. See: Local Government Cybersecurity. https://www.tn.gov/cybersecurity/local-government-cybersecurity.html

Figure 10. Distributed solar generation incentives



Source: DeepSolar dataset and National Renewable Energy Laboratory SEEDS-2 dataset

legislation that would impose "reliability costs" on renewable energy.[13] In 2019, Ohio enacted a bill that granted reliability subsidies for coal-fired generation and nuclear reactors.[14] Recent Baker Center research finds that this strategy will be expensive, requiring a fuel subsidy equal to roughly half the cost of delivered fuel on average.[15] Regardless, this policy option is largely unavailable in Tennessee since TVA determines the mix of generation technologies in the state.

Encouraging DSG. DSG is subsidized at the federal, state, and local level. Federal subsidies include purchase rebates and tax credits designed to lower the purchase and installation cost of DSG. The federal tax credit for residential solar is expected to end in 2024. State and local programs come in three forms: property tax rebates, net metering programs, and low-income assistance programs (see Figure 10). Property tax rebates are designed to prevent DSG from increasing property taxes. Net metering allows DSG owners to use excess electricity generated by DSG at any time instead of when it is generated. Low-income assistance programs provide loans and other financing options to make it easier for middle- and low-income households to adopt DSG. Only property tax rebates are available to businesses and homeowners in Tennessee. In Tennessee, property taxes can only increase by up to 12.5 percent of the installed costs associated with the DSG system.[16]

State and local authorities are also responsible for zoning and building codes that can influence the cost of adopting DSG. Sixty-four percent of solar PV system costs are due to soft

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13. Trabish, H. May 2021. 'A terrible idea': Texas legislators fight over renewables' role in power crisis, aiming to avert a repeat. *Utility Dive*. https://www.utilitydive.com/news/a-terrible-idea-fight-over-renewables-role-in-texas-february-power-cri/599842/?utm_source=Sailthru&utm_medium=email&utm_campaign=Issue:%202021-05-17%20Utility%20Dive%20Newsletter%20%5Bissue:34268%5D&utm_term=Utility%20Dive
14. This bill was recently repealed: https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/040121-repealing-subsidies-to-2176-mw-of-ohio-nuclear-power-leaves-uncertainty.
15. Davis, R., Holladay, J.S., & Sims, C. May 2021. Coal-Fired Power Plant Retirements in the US. https://www.nber.org/books-and-chapters/environmental-and-energy-policy-and-economy-volume-3/coal-fired-power-plant-retirements-us
16. Tenn. Code Ann. § 67-5-601

costs, such as installation, permitting and inspection.[17] Variations in local permitting and regulatory procedures can result in significant differences in the cost of installing rooftop solar–$3,200 to $4,700 for a typical 5-kilowatt residential solar installation. To reduce soft costs, some states are streamlining and expediting the permitting, inspection and interconnection processes.[18]

Preliminary considerations for Tennessee

The presence of TVA limits what Tennessee policymakers can do to shape the grid transitions highlighted in this chapter. However, there are several related issues on the periphery of the electric grid where the state can play a vital role.

Addressing inequities created by grid transitions. The impending grid transitions raise several equity concerns. The technologies at the grid edge—such as rooftop solar, behind-the-meter storage, and electric vehicles with smart chargers—are accessible primarily to high-income customers. Tennessee can play a role in ensuring that low-incomeand rural residents also benefit from the improvements in DER technologies including rooftop solar. Ten states currently have a program designed to increase adoption of rooftop solar among low-income households. A recent report from Lawrence Berkeley National Laboratory discusses a variety of financing options which may incentivize low- and middle-income consumers to adopt DSG. It finds that incentives targeted at low income communities, solar leasing options, and creative financing programs have expanded adoption of solar in low income communities.

Job placement and training in renewable energy, DER, and grid security. Transitioning the grid to become less carbon-intensive, more decentralized, and more resilient will mean some job losses in Tennessee. However, increases in renewables, DER, and security are examples of new sources of employment opportunities that could offset job losses. In 2021, wind turbine technicians and solar installers were the first and third fastest growing occupations in the U.S. respectively. Through the state's universities and community colleges, the state plays a vital role in providing job placement and retraining for displaced workers in the electricity industry. The state can also help attract jobs manufacturing grid components critical to these transitions such as solar panels, batteries, and bulk energy system control technologies. Domestic manufacturing of these critical grid components has recently become a national priority due to concerns about securing energy supply chains. Due to the automotive industry and expertise at Oak Ridge National Laboratory, Tennessee is already growing an EV battery manufacturing industry and this industry could expand further to include other applications.

Transmission planning and siting. The impending transitions will require new investments in transmission. Renewable generation cannot always be sited near

17. Office of Energy Efficiency & Renewable Energy. Soft Costs. U.S. Department of Energy. https://www.energy.gov/eere/solar/soft-costs
18. Cleveland, M. July 2017. Tackling Solar Energy's 'Soft Costs'. National Conference of State Legislatures. https://www.ncsl.org/research/energy/tackling-solar-energy-s-soft-costs.aspx

existing transmission networks and widespread adoption of distributed generation will require new transmission lines to reflect changes in supply and demand. The process of planning, development, permitting, financing, and construction of transmission lines is lengthy and there is an urgency to reform regional transmission planning and siting processes. Much of the policy around transmission lines is under the purview of the Federal Energy Regulatory Commission (FERC). However, Tennessee can work with TVA to enable meaningful participation in regional transmission planning and siting activities and this could have economic development implications, including for rural areas of the state.

Grid resilience exercises. A recent National Academies report suggested operators of electricity systems work with state and local emergency management offices to conduct more regional emergency preparedness exercises that simulate accidental failures, physical and cyber-attacks, and other sources of large-scale loss of power and other critical infrastructure sectors (for example, communication, water, and natural gas).[19] While such exercises may not reduce the probability of outages, they can reduce the economic damages and hardships crated by outages. The state could serve as a facilitator between TVA and local emergency management offices to initiate these exercises. While utilities often conduct such exercises to prevent outages or facilitate re-powering procedures, widespread power outages are not typically within the domain of many state and local emergency management offices. These exercises will also serve as an opportunity to for local utilities to assess readiness of backup power systems and develop strategies to increase investments in resilience enhancing technologies.

Local power company regulation. There are 81 LPCs in Tennessee. These local power companies, both municipal utilities and regional cooperatives, purchase power from TVA and distribute it to consumers within their designated service areas. Unlike TVA, the state of Tennessee has some regulatory authority over these LPCs. Because several of the grid transitions will require LPCs to take on new roles and responsibilities, these regulations will need to be revisited. For example, TVA has recently reached an agreement with LPCs to allow them to serve 5 percent of their demand. Since all LPCs were previously obligated to serve all of their electricity needs from TVA, LPCs will be developing new rules and regulations surrounding the acquisition, management, security, and financing of the distributed generation assets.

The Outlook

The electric grid in Tennessee is subject to little direct impact by state government policy given the role of TVA and federal and regional agencies. However, grid transition is of great importance to the state and its economy. There are focused initiatives that could yield benefits to the state, including worker training for emerging job opportunities. Grid transition will need to be monitored closely so that Tennessee reaps the benefits of a more robust system and can take advantage of unique opportunities over the path of transition.

19. National Academies of Sciences, Engineering, and Medicine. 2017. *Enhancing the Resilience of the Nation's Electricity System.* https://www.nap.edu/catalog/24836/enhancing-the-resilience-of-the-nations-electricity-system

ENERGY EFFICIENCY

Introduction[1]

The topic of this section of the annual assessment of the energy sector is *trends and disruptors in energy efficiency affecting Tennessee*. Continued improvements in energy efficiency will save Tennessee household and business energy consumers money, reduce emissions from the consumption of energy, and contribute to reducing peak electricity demands. Targeted programs for low-income households can promote equity in Tennessee. Energy efficient homes and buildings have higher market values than less energy efficient ones. Weatherizing homes and other structures can improve the health of Tennesseans.[2] Energy efficient cities can reduce strains upon electricity grids, increase the technical and economic feasibility of micro-grids, and reduce demands upon distributed and renewable energy resources.

Discussions about energy efficiency typically start with a focus on technology. In the residential sector, these technologies include heating and cooling systems, insulation, substances to air seal homes, water heating systems, lighting, refrigerators, dishwashers, and clothes washers and dryers. Commercial buildings have these types of technologies plus a plethora of others depending on whether they are hospitals, arenas, schools, restaurants, dry cleaners, car dealerships, etc. Given that health care is one of the top employers in Tennessee, advances in energy efficient hospital equipment could reap large benefits in cost and emissions savings for the state. Industrial plants rely on technologies to process, shape and treat virgin materials, manufacture products, and package those products. As an automotive manufacturing hub, Tennessee will have to adapt to the needs of electric car manufacturing. The growth of semiconductor manufacturing in the state is a promising trend on this front, together with research on advanced charging technologies taking place at ORNL.[3,4] While electric vehicles will increase the state's electrical load, they offer superior energy efficiency by converting over 77% of consumed energy into vehicle movement; compare this to 12-30% for gasoline engines, which waste much of their energy in the form of heat and other losses.[5] The transportation sector consumes most of the nation's liquid fuels, upon which the agricultural sector also relies. The information

1. This chapter of the annual energy assessment was prepared by Bruce E. Tonn, PhD and Michaela Marincic, Three[3] Inc.
2. Tonn, B., Rose, E., Hawkins, B., & Marincic, M. 2021. Health and Financial Benefits of Weatherizing Low-Income Homes in the Southeastern United States. *Building & Environment, 197*. https://www.sciencedirect.com/science/article/abs/pii/S0360132321002535
3. Tennessee Department of Labor and Workforce Development. Tennessee's Economy: 2018 Reference Guide. https://www.tn.gov/content/dam/tn/workforce/documents/majorpublications/reports/TennesseeEconomyGrowth2018.pdf. Accessed June 7, 2021
4. Oak Ridge National Laboratory. May 2021. Hands-Free: Wireless Charging System Advances Electrical Vehicle Convenience. https://www.ornl.gov/news/hands-free-wireless-charging-system-advances-electric-vehicle-convenience. Accessed June 7, 2021.
5. U.S. Department of Energy. All-Electric Vehicles. https://www.fueleconomy.gov/feg/evtech.shtml. Accessed June 7, 2021.

technology sector should now be treated independently as demands for electricity to support cryptocurrency mining, blockchains, the training of artificial intelligence systems, and streaming services are skyrocketing.

Discussions about energy efficiency also now address financing issues and improving the effectiveness of programs to increase energy efficiency. The discussions take into account energy burdens faced by tens of millions of U.S. households; the Southeast has some of the highest rates of energy burden in the nation.[6,7] Discussions also embrace smart thermostats, grid interactive technologies, the Internet of Things (IoT), big data, building codes, and zoning ordinances. Lastly, energy efficiency is an important topic in climate resilience. While no one technological change or trend that falls within this broad expanse of energy efficiency may be capable of causing disruptive transformation across the energy efficiency sector, it is quite plausible that a synthesis of changes and trends can lead to disruptive transformation. Individual technologies, like LED lights, can be significant disruptors within their own sector.

The next section presents a brief overview of the history of energy efficiency and how improvements in energy efficiency have delinked increases in energy consumption from national economic growth. Section 3 presents a high-level overview of trends in technology and ancillary issues that could impact energy efficiency over the next decade or two. Section 4 addresses the potential economic impacts of these trends upon the state of Tennessee. Section 5 concludes with a preliminary discussion of policy issues that the state might consider.

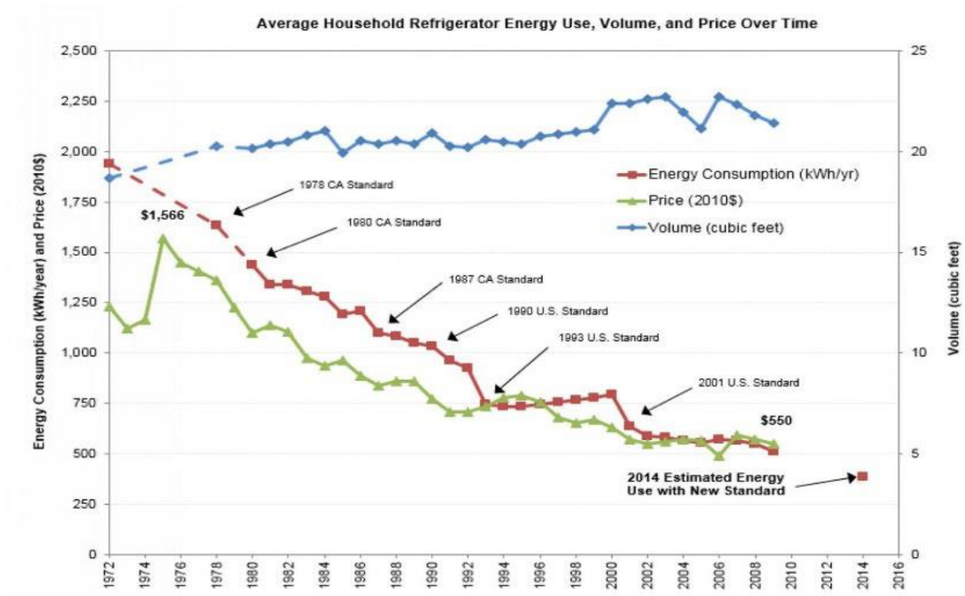
Energy Efficiency – An overview of progress

Steady progress has been made in improving the energy efficiency of our key technologies over time. For example, Figure 1 documents several decades of improvements in refrigerator energy efficiency; efficiency increased by approximately 75% while the average size of refrigerators slightly increased. Similarly, since 1990, new clothes washers use 70% less energy, new dishwashers 40% less, and new air conditioners 50% less.[8] Figure 2 plots the stunning improvements in energy efficiency that LED lights have brought to the lighting sector and are forecast to be achieved in the near-term. In combination, improvements in energy efficiency have helped to decouple economic growth from growth in primary energy consumption (Figure 3). This has created capital planning issues for public utilities across the country, including TVA.

While increases in energy efficiency are not the only cause for gross domestic

6. U.S. Energy Information Administration. September 2018. One in Three U.S. Households Faces a Challenge in Meeting Energy Needs. *Today in Energy*. https://www.eia.gov/todayinenergy/detail.php?id=37072. Accessed March 20, 2019.
7. Drehobl, A., Ross, L., & Ayala, R. September 2020. How High are Household Energy Burdens? American Council for an Energy Efficient Economy. https://www.aceee.org/sites/default/files/pdfs/u2006.pdf. Published September 2020. Accessed June 7, 2021.
8. U.S. Department of Energy. January 2016. Saving Energy and Money with Appliance and Equipment Standards in the United States. https://energy.gov/sites/prod/ les/2017/01/f34/Appliance%20and%20Equipment%20Standards%20Fact%20Sheet-011917_0.pdf.

Figure 1. Changes in refrigerator energy efficiency over time



Source: *https://energyindemand.files.wordpress.com/2015/02/imrs.jpg*

product (GDP) outpacing both electricity and primary energy consumption, they are a major contributor; other causes include the transition from an industrial to a service economy, electrification, and the increase in renewable resources.[9,10] The U.S. Energy Information Association (EIA) predicts that commercial floor space will grow at a faster pace than energy consumption due almost entirely to improvements in energy efficiency and building controls; due to climate change, energy demands for heating will decrease but be replaced by energy demands for cooling.[11]

In addition to economic benefits, advances in energy efficiency have increased national security by reducing the country's reliance on energy imports. In 2019, U.S. energy exports exceeded imports for the first time in 67 years following a steep, 14-year decline in gross imports.[12] Changes in energy extraction, production and exportation policies partially drove this change, but EIA predicts that the U.S. will remain a net energy exporter through at least 2050 due in large part to continued advances in energy efficiency.[13]

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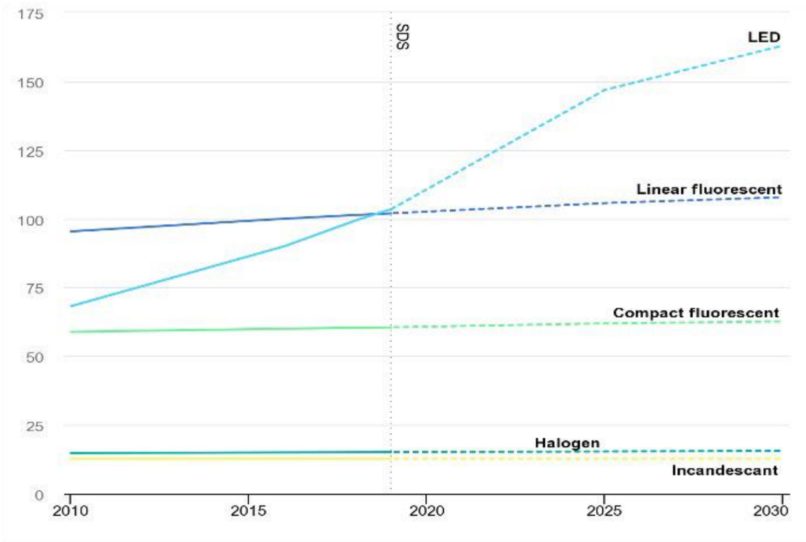
9. Sharma, N., Smeets, B., & Tryggestad, C. April 2019. The decoupling of GDP and energy growth: A CEO guide. *McKinsey Quarterly*. McKinsey. https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-decoupling-of-gdp-and-energy-growth-a-ceo-guide.
10. US Energy Information Administration. November 2017. Link between growth in economic activity and electricity use is changing around the world. *Today in Energy*. https://www.eia.gov/todayinenergy/detail.php?id=33812
11. US Energy Information Administration. April 2021. EIA expects commercial energy use to grow more slowly than floorspace. *Today in Energy*. https://www.eia.gov/todayinenergy/detail.php?id=47736.
12. US Energy Information Administration. February 2020. U.S. total energy exports exceed imports in 2019 for the first time in 67 years. *Today in Energy*. https://www.eia.gov/todayinenergy/detail.php?id=43395.
13. Yen, Terri. January 2020. EIA: U.S. to remain net exporter through 2050 through technology-enabled growth. *World Oil*. https://www.worldoil.com/news/2020/1/29/eia-us-to-remain-net-exporter-through-2050-through-technology-enabled-growth.

Figure 2. Changes in lighting energy efficiency over time



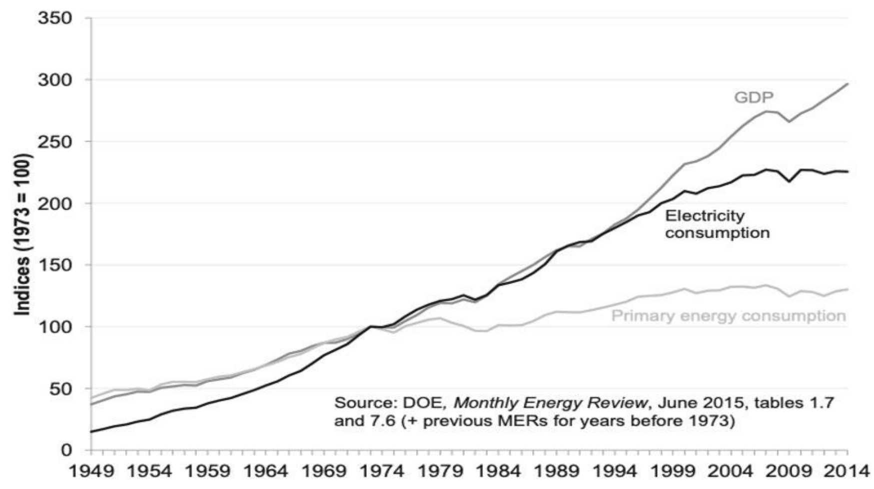
SDS stands for Sustainable Development Scenario. The x-axis is lm/W.
Source: *https://www.iea.org/reports/lighting*

Though counterintuitive at first glance, many electric utilities have increasingly offered incentives, rebates, and other programs to help their customers improve energy efficiency and reduce energy consumption in both the residential and business sectors. TVA's EnergyRight initiative offers multiple energy efficiency services for customers, ranging from industrial and commercial clients to everyday homeowners; one of its newest offerings, Home Uplift, helps low-income Tennesseans weatherize their homes. While lower consumption leads to lower revenues, the cost is outweighed by the benefits of lower generation and distribution costs, improved grid reliability, and increased flexibility for incorporating renewable energy sources.[14] Utilities are particularly concerned with reducing peak demand, or the maximum amount of energy consumption the grid experiences in a given day, month or year. While utilities have more than sufficient generation capabilities for the average level of energy demand, the system becomes strained during extreme heat and extreme cold events as cooling and heating costs soar.[15] Accordingly, investments in generation and transmission are driven by what is needed to meet peak demand, and reducing peak demand through energy efficiency investments can prevent the need to build new generation facilities and even retire existing facilities, dramatically cutting operational and capital expenditures.

Policies and programs that promote energy efficiency happen at all levels of government and throughout the private and non-profit sectors. National appliance codes and standards are the

14. Relf, G., Cooper, E., Gold, R., Goyal, A. & Waters, C. February 2020. 2020 Utility Energy Efficiency Scorecard. ACEEE. https://www.aceee.org/sites/default/files/pdfs/u2004%20rev_0.pdf.
15. US Energy Information Administration. (Feb. 2021) "Hourly electricity consumption varies throughout the day and across seasons." *Today in Energy*. [https://www.eia.gov/todayinenergy/detail.php?id=42915.](https://www.eia.gov/todayinenergy/detail.php?id=42915)

Figure 3. Changes in energy consumption versus GDP over time



Source: Hirsh, R. F. and J. G. Koomey. Electricity Consumption and Economic Growth: A New Relationship with Significant Consequences? The Electricity Journal, Volume 28, Issue 9, 2015, Pages 72-84, ISSN 1040-6190, https://doi.org/10.1016/j.tej.2015.10.002.

purview of the federal government. The federal government also funds national energy efficiency deployment programs, such as the State Energy Program and the Weatherization Assistance Program, and a broad range of energy efficiency research and development initiatives. Beyond the U.S. Department of Energy programs, other agencies such as the U.S. Department of Housing and Urban Development, the U.S. Department of Agriculture, and the U.S. Department of Defense fund programs that improve the energy efficiency of HUD supported housing, rural housing, and military bases, respectively.

The bulk of state energy efficiency programs are typically administered by states' Investor-Owned Utilities (IOUs). Per direction from state public utility commissions (PUCs), the utilities offer a wide range of energy efficiency programs that touch all sectors of the economy. A typical program might offer rebates to residential customers with respect to the purchase of new, energy-efficient technologies. State-level programs can also be funded by taxing the transmission of electricity (i.e., through systems benefit charges). The forty-plus energy efficiency programs offered by the New York State Energy Research and Development Authority (NYSERDA) are funded by systems benefit charges. The state of Tennessee is unusual in that its electric power is generated and transmitted by a quasi-federal agency, the TVA, and delivered by municipally-owned utilities and cooperatives. Thus, policies that target independently owned utilities (IOUs) and programs that are funded by systems benefit charges are not within the state's sphere of influence; however, the states and municipal governments have other policy instruments at their disposal. Both can influence energy efficiency through building codes and standards, the operation of their buildings and fleets, and purchasing policies. Policies with respect to energy efficiency financing are generally the purview of states (e.g., laws to allow property assessed clean energy (PACE) programs that provide property owners with the option to pay back energy efficiency investments through their property taxes[16]). Policies related to land use are more dependent upon local decision making. States and municipalities can work together to improve the energy efficiency of schools, hospitals and other government buildings.

Energy Efficiency Trends & Potential Disruptors

Energy efficiency trends and disruptors come in all shapes and sizes. Some are related to changes in energy consuming technologies. Others are related to big data and much larger pools of funding potentially available to finance energy efficiency investments. This section touches upon the many and diverse currents within our society and our technological base that could impact energy efficiency gains over the next decade or two. The focus is on the building sector generally and the residential sector more specifically, as these areas are generally more policy relevant to state legislatures than industrial energy efficiency and transportation issues.

Energy Consuming Equipment and Building Envelopes. As briefly documented in the previous section, over the past several decades we have witnessed steady incremental improvements in energy-consuming equipment and the energy efficiency of building envelopes. These improvements are very likely to continue as technologies such as these come widely to market.

- *Energy Efficient Building Skins:* Instead of blowing insulation into wall cavities, a firm in the Netherlands has developed an innovative approach to installing pre-fabricated, highly-insulated facades on the outsides of homes, multifamily buildings and commercial buildings.[17] Figure 4 shows a piece of pre-fabricated façade being lowered into place that will be attached to an affordable multifamily building in the United Kingdom. This new technology is especially suited to improve the energy efficiency of hard-to-weatherize multifamily buildings. Tennessee contractors could be encouraged to learn this

Figure 4. Pre-fabricated insulating facade

Source: https://renovation-hub.eu/case-studies/hem-district/

16. Office of Energy Efficiency and Renewable Energy. "Property Assessed Clean Energy Programs." Department of Energy. https://www.energy.gov/eere/slsc/property-assessed-clean-energy-programs.
17. Shapiro, I. 2018. Energiesprong: A Dutch Approach to Deep Energy Retrofits and Its Applicability to the New York Market. NYSERDA Report 18-10, New York State Energy Research and Development Authority, New York, March; Egerter, Amy, and Martha Campbell. 2020. Prefabricated Zero Energy Retrofit Technologies: A Market Assessment. Oakland, CA. DOE/GO-102020-5262. https://www.nrel.gov/docs/fy20osti/76142.pdf

new method, and weatherization agencies could increase their multifamily production, which is very low to non-existent for apartment buildings in the state currently.

- *High Efficiency Insulation:* Advances in building insulation can be expected to continue. Insulation with ultra-high R values[18] will continue to expand market share as will insulation manufactured from healthier materials.[19] Advances will be made on dynamic insulation, which is insulation where cool outside air flowing through the envelop will pick up heat from insulation fibers.[20] Insulation using phase change materials are still in the early days of commercialization but also hold much promise.[21]

- *Windows*: Oak Ridge National Laboratory (ORNL) and its partners are developing "a highly transparent, multilayer window film that can be applied onto single-pane windows to improve thermal insulation, soundproofing, and condensation resistance."[22] This technology is expected to be used in instances where replacing single pane windows is cost prohibitive. Stanford University has developed windows that can lighten or darken within a minute as solar incidence changes (Figure 5).[23] Smart windows and other window technology promise to greatly reduce cooling needs in buildings.

- *More efficient HVAC Systems:* Improvements are continuing to be made on furnace technologies[24] and air source heat pumps.[25] Mini-split technologies are also beginning to penetrate the

Figure 5. Smart window technology

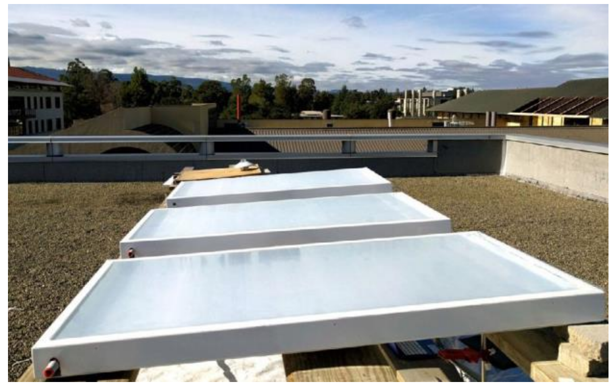
Source: *https://news.stanford.edu/2017/08/10/smart-windows-darken-lighten-fast/*

18. Peraudeau, N. July 2019. E=0 Hem' Social-housing (Energiesprong). Renovation Hub. https://renovation-hub.eu/case-studies/hem-district/
19. US Department of Energy. March 2020. Grid-interactive Efficient Building Technical Report Series. https://www.energy.gov/node/942331?page=1
20. Dynamic Insulation. November 2020. https://en.wikipedia.org/wiki/Dynamic_insulation
21. Katahdin Cedar Log Homes. August 2013. Green Tip: Thermal Mass Insulation Through Phase Change Materials. https://www.katahdincedarloghomes.com/blog/green-tip-thermal-mass-insulation-through-phase-change-materials/
22. Sharma, J. and Schiff, E. May 2016. Multilayer Insulating Film. Advanced Research Projects Agency. Department of Energy. https://arpa-e.energy.gov/technologies/projects/multilayer-insulating-film
23. Shwartz, M. August 2017. Stanford engineers create smart windows that go from clear to dark in under a minute. *Stanford News*. https://news.stanford.edu/2017/08/10/smart-windows-darken-lighten-fast/.
24. Energy Star. 2021. ENERGY STAR Most Efficient 2021 — Furnaces. https://www.energystar.gov/products/most_efficient/furnaces
25. Energy Star. 2021. ENERGY STAR Most Efficient 2021— Central Air Conditioners and Air Source Heat Pumps. https://www.energystar.gov/products/most_efficient/central_air_conditioners_and_air_source_heat_pumps

marketplace.[26] Gas Absorption Heat Pumps represent a new class of heating and cooling technologies that could significantly penetrate the residential market.[27] Stone Mountain Technologies, which is headquartered in Johnson, Tennessee, is one of this market's leaders.[28] Stanford University has developed a rooftop technology that reflects sun light and can also cool water for air conditioning without using electricity (Figure 6).[29] All of these technologies can be developed to be 'smart' (i.e., controllable by smart phones and have embedded intelligence to efficiently manage heating and cooling loads).[30] This highlights the importance of big data and IoT to the future of energy efficiency.

- *More efficient Appliances and Lighting*: Energy-consuming appliances and lighting will continue to become more energy efficient. For example, ORNL and General Electric are partnering on research on magnetocaloric refrigeration, where temperatures are controlled by changing magnetic fields.[31] ORNL is also conducting R&D on thermoelectric clothes dryers.[32] LED technology will continue to revolutionize the lighting marketplace, as prices continue to drop and as new types of LED products continue be developed, including tunable LED's.[33] Demand for tunable LEDs are expected to increase as businesses, hospitals, and others wish to capitalize on the health benefits of tuning LEDs to match natural circadian rhythms.[34]

Figure 6. Rooftop sunlight reflection and air conditioning system



Source: https://news.stanford.edu/2017/10/05/future-energy-efficiency/

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26. Fujitsu. What is a Mini-Split? *Fujitsu General*. https://www.fujitsugeneral.com/us/residential/what-is-a-mini-split.html
27. Department of Energy. Absorption Heat Pumps. *Energy Saver*. https://www.energy.gov/energysaver/heat-pump-systems/absorption-heat-pumps
28. Stone Mountain Technologies. https://stonemountaintechnologies.com/
29. Adams, A. October 2017. Future of energy: Efficiency. *Stanford News*. https://news.stanford.edu/2017/10/05/future-energy-efficiency/
30. November 2020. Five Reasons why you Need to Buy a Smart Furnace for your Smart Home. *Supanet*. https://www.supanet.com/five-reasons-why-you-need-to-buy-a-smart-furnace-for-your-smart-home-a23694.html
31. Electric Chocie. Future of Energy Savings: Upcoming Improvements in Technology to Reduce Energy Costs and Consumption. https://www.electricchoice.com/blog/future-of-energy-savings/
32. Department of Energy. May 2019. Thermoelectric Clothes Dryer. https://www.energy.gov/eere/buildings/downloads/thermoelectric-clothes-dryer-0
33. Department of Energy. Understanding LED Color-Tunable Products. https://www.energy.gov/eere/ssl/understanding-led-color-tunable-products
34. Human Centric Lighting. July 2020. What is Circadian Lighting and How Does it Work? https://bioslighting.com/human-centric-lighting/what-is-circadian-lighting-and-how-does-it-work/

Energy Management Systems, Modeling and Big Data. Building energy management systems will continue to improve the joint control of key energy systems, including HVAC and lighting.[35] Deploying more extensive arrays of sensors and fusing the resultant data in new ways will help these systems improve their attunement to human behaviors and proactive adjustments to outdoor and indoor conditions. More buildings and specific energy end-using technologies in those buildings will become grid-interactive.[36] Intelligent systems will be able to construct plans for the operation of energy end-use systems that achieve multiple objectives, such as minimizing energy costs while also maximizing the health of occupants. Additional achievements in realized energy efficiency can be anticipated that do not impinge upon energy services enjoyed by customers.

Advances in modeling and big data could pay substantial dividends to the energy efficiency sector. (Limited access to broadband in rural communities will limit the diffusion of these dividends to rural residents and businesses.) With respect to the former, the U.S. Department of Energy (DOE) has invested resources to create its EnergyPlusTM whole-building energy modeling system.[37] This open-source code allows modelers to simulate building energy consumption under a wide range of environmental conditions and with the installation of many of the emerging technologies discussed herein. ORNL has expanded upon this software base to model every building in Chattanooga, Tennessee, in partnership with Chattanooga's Electric Power Board (EPB).[38] ORNL plans on extending this model to encompass every building in the U.S. This modeling capability allows utilities to hyper-target the recipients of their energy efficiency programs. The capability also allows utilities to consider many configurations of their energy efficiency programs and maybe even to tailor their programs in real-time to meet the needs of specific customers. One can argue that these capabilities will substantially increase the cost-effectiveness of energy efficiency programs, which then may also lead to increased funding.

Combinations of big data and modeling systems could better support innovations in energy efficiency financing. For example, aggregators (see Section 3.4) will have much better information at hand to support more financially-sound aggregation plans. Utilities and third parties could come to own all energy consuming equipment in homes and businesses and charge customers energy technology usage fees, instead of sending them utility bills.[39] Such fees could be determined on a customer-by-customer

35. Iota Communications. December 2020. A Guide to Building Energy Management Systems (BEMS). https://www.iotacommunications.com/blog/building-energy-management-system/
36. Department of Energy. 2020. Grid-Interactive Efficient Buildings. https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings
37. Department of Energy. August 2014. EnergyPlus. https://www.energy.gov/eere/buildings/downloads/energy-plus-0
38. Oak Ridge National Lab. November 2019. Modeling every building in America starts with Chattanooga. https://www.ornl.gov/news/modeling-every-building-america-starts-chattanooga
39. American Council for an Energy Efficient Economy. February 2019. Emerging Opportunities: Energy as a Service. https://www.aceee.org/topic-brief/eo-energy-as-service

basis and refined over time based on improvements of AI's abilities to manage the energy systems.

Codes and Standards. It can be anticipated that energy-related codes and standards will continue to spur improvements in energy efficiency. It is estimated that the U.S. energy efficiency standards program has saved the national economy $2 trillion in energy costs since the program was initiated in 1987.[40] It can be expected that the appliance standards program will be renewed and refreshed under the Biden Administration.

It can be argued that the International Energy Conservation Code (IECC)[41] has also been renewed and refreshed as the 2021 code contains provisions to increase energy efficiency by up to 14% more than the 2018 code.[42] The next version of the IECC codes to be released in 2024 is expected to lay out an optional pathway for jurisdictions to achieve net-zero energy buildings immediately or by 2030, though it will be only one of multiple options included in a "menu" that will also include minimum requirements that fall below net-zero energy.[43] The process for developing the 2024 IECC will also mark a notable departure in that it will be developed through the same process used to develop American National Standards Institute (ANSI) standards for industries throughout the globe. Previous IECC versions were developed through a process that involved public comment periods and public hearings and culminated in local jurisdictions around the world voting on which amendments to adopt. The ANSI process will eliminate public comment and voting and instead create a less transparent process run by committee.[44,45,46,47] The International Code Council (ICC) notes that future versions of the IECC will "be part of a portfolio of greenhouse gas reduction solutions that could address electric vehicles, electrification and decarbonization, integration of renewable energy and energy storage, existing buildings performance standards and more."[48] Bringing together the IECC, International Residential Code (IRC), and

40. National Resources Defense Council. February 2019. The $2 Trillion Success Story: Energy Efficiency Standards. https://www.nrdc.org/sites/default/files/energy-efficiency-standards-success-story-fs.pdf
41. International Code Council. January 2016. International Energy Conservation Code. https://codes.iccsafe.org/content/IECC2015
42. Pearson, C. April 2021. Local Governments To Be Disenfranchised After Voting for Green Codes. *Building Green, 30.4.* https://www.buildinggreen.com/newsbrief/local-governments-be-disenfranchised-after-voting-green-codes
43. Neal, M. March 2021. International Code Council releases new framework to address energy efficiency needs across the entire building industry. International Code Council. https://www.iccsafe.org/about/periodicals-and-newsroom/international-code-council-releases-new-framework-to-address-energy-efficiency-needs-across-the-entire-building-industry/
44. Port, D. March 2021. The 2021 IECC, The Last Energy Code? Northeast Energy Efficiency Partnership. https://neep.org/blog/2021-iecc-last-energy-code
45. Pearson, C. April 2021. Local Governments To Be Disenfranchised After Voting for Green Codes. *Building Green, 30.4.* https://www.buildinggreen.com/newsbrief/local-governments-be-disenfranchised-after-voting-green-codes
46. Boyce, A. March 2021. ICC Eliminates Governmental Voting in Model Energy Code. Institute for Market Transformation. https://www.imt.org/icc-eliminates-governmental-voting-in-model-energy-code/
47. Urbanek, L. March 2021. Changes to Energy Code Process Strip Power from Local Voters. National Resources Defense Council. https://www.nrdc.org/experts/lauren-urbanek/changes-energy-code-process-strip-power-local-voters
48. Neal, M. March 2021. International Code Council releases new framework to address energy efficiency needs across the entire building industry. International Code Council. https://www.iccsafe.org/about/periodicals-and-newsroom/international-code-council-releases-new-framework-to-address-energy-efficiency-needs-across-the-entire-building-industry/

International Green Construction Code (IgCC) under one umbrella with other climate resilience strategies, ICC claims it seeks to provide a more comprehensive and coordinated set of strategies for addressing climate change.[49]

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is also continuously working to improve its Standard 90.1 energy standard for buildings.[50] Additionally, the International WELL Building Institute (IWBI), which manages the WELL Health-Safety certification for commercial buildings, released a new research agenda in January 2021. The Global Research Agenda on Health, Well-Being and the Built Environment identified 12 priority research topics that will drive IWBI's efforts to bring together funders, community partners and researchers to advance our understanding of how buildings can promote both human health and climate adaptation. Impact topics include climate change, air quality, equity and inclusivity in both rural and urban areas, performance, and technology, among others.[51] The research could lead to new building strategies, standards and certifications, as well as expand our understanding of and ability to measure the health and climate benefits of energy-efficient buildings.

Architects are being urged to design net-zero buildings that can be constructed with less and/or recycled materials that are sourced near where buildings are to be constructed.[52] The U.S. Green Building Council's Leader in Energy and Environmental Design (LEED) certification has continued to adopt newer and more stringent versions, including the most recent v4.1. However, the next step will be LEED Positive, a shift in focus from simply reducing energy and water consumption to creating buildings that are actively regenerative and restorative.[53][54] This new vision includes smaller, more specific credentials for performance in water and energy, for example, that will act as steppingstones for existing buildings not yet capable of fully reaching LEED. For new construction and more advanced existing buildings, LEED Positive will mean being carbon positive and producing rather than consuming energy. Rather than simply minimizing their negative impact, these buildings will contribute to healthier and greener spaces by taking a more holistic view of how construction impacts the environment. LEED will begin to account for social equity and human health impacts in its certifications,

49. International Code Council. 2021. Leading the Way to Energy Efficiency. https://www.iccsafe.org/wp-content/uploads/ICC_Leading_Way_to_Energy_Efficiency.pdf
50. ANSI/ASHRAE/IES Standard 90.1-2019 – Energy Standard for Buildings Except Low-Rise Residential Buildings. American Society of Heating, Refrigerating and Air-Conditioning Engineers. https://www.ashrae.org/technical-resources/bookstore/standard-90-1
51. Loder, A. Gray, A.W., Timm, S. April 2021. IWBI Global Research Agenda: Uniting Human Health and Climate Change. International WELL Building Institute. https://resources.wellcertified.com/articles/iwbi-global-research-agenda-uniting-human-health-and-climate-change/
52. Pramod, G. 10 Emerging trends in sustainable architecture in 2020. *Re-thinking the Future*. https://www.re-thinkingthefuture.com/fresh-perspectives/a1742-10-emerging-trends-in-sustainable-architecture-in-2020/
53. US Green Building Council. LEED Positive. A long-term regenerative and restorative design vision for LEED. https://www.usgbc.org/programs/leed-positive
54. Melton, P. November 2019. The Future of LEED Will Be Positive. *Building Green*. https://www.buildinggreen.com/newsbrief/future-leed-will-be-positive

as well as all sources of carbon in the construction process, such as materials and transportation, rather than just water and energy consumption.[55]

Energy Demand Aggregators. The job of *aggregators* is straightforward: gather a group of energy customers together to form a partnership to contract for energy services. In theory, this partnership will increase the market power of energy customers and allow for the negotiation of more favorable rates. A common aggregation approach is called Community Choice Aggregation (CCA).[56] Under this model, communities can choose to work together to put out a bid to purchase all energy for their residents in bulk. This allows communities the freedom to purchase energy that is cheaper and cleaner than what is currently available through their utility company, while the utility continues to oversee energy delivery and billing.[57] Communities can choose to incorporate demand management and energy efficiency as part of their energy portfolio, reducing overall energy consumption and costs for residents and local businesses. Seven states currently offer local governments the opportunity to participate in CCA: Ohio, Illinois, Massachusetts, New Jersey, New York, California and Rhode Island.[58]

Sophisticated IT systems and smart technologies are paving the way for a new, more adaptable business model for distributed energy resource (DER) providers. Able to collect large quantities of real-time data, these systems coordinate multiple sources of energy such as combined heat and power (CHP), biogas, wind and solar to best meet the needs of both consumers and the grid. These systems take advantage of battery storage and smart electric car charging to absorb periods of excess energy generation and store it until demand rises again. All of these nodes in the energy system are collectively referred to as DERs to distinguish them from conventional power plants. Aggregators help their customers save money on energy bills and maximize the performance of DERs by operating and coordinating them through a central IT control system.[59] Aggregators also help DERs compete on a more level playing field with more centralized, wholesale energy; for example, this could make it easier for homeowners to sell the energy produced by their rooftop solar.[60]

Potentially Disruptive Funding. It has taken decades to evolve the model now dominant in the utility sector that investments in energy efficiency can be beneficial for customers and the utility's

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55. Schaffner, C. July 2020. The Future Of LEED. *The Green Engineer*. https://www.greenengineer.com/mixed-greens/2020/7/24/the-future-of-leed
56. Becker, S. June 2019. Is your town or city joining a community choice aggregation (CCA) program? Here's what you need to know. Solstice. https://solstice.us/solstice-blog/community-choice-aggregation/
57. New York State Energy Research and Development Authority. Community Choice Aggregation. https://www.nyserda.ny.gov/All-Programs/Programs/Clean-Energy-Communities/How-It-Works/Toolkits/Community-Choice-Aggregation
58. Environmental Protection Agency. Community Choice Aggregation. https://www.epa.gov/greenpower/community-choice-aggregation
59. International Renewable Energy Agency. 2019. Aggregators: Innovation Landscape Brief. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovation_Aggregators_2019.PDF.
60. Cano, C. September 2020. FERC Order No. 2222: A New Day for Distributed Energy Resources. Federal Energy Regulatory Commission. https://www.ferc.gov/media/ferc-order-no-2222-fact-sheet

bottom line. Energy efficiency programs are now seen as cost-effective sources of energy supplies and are included in integrated resource decision making.[61] Of course, the main goal of the energy efficiency programs is to save energy.

Over the years, it has been noted that energy efficiency programs often yield non-energy benefits (NEBs).[62] Most straightforwardly, energy efficiency programs can lead to reductions in air and water pollutants and emissions of greenhouse gases. Thus, energy efficiency programs can contribute to climate change mitigation. Reductions in air pollutants can benefit public health and ecosystem health. NEBs attributable to low-income residential energy efficiency programs include improved home conditions, health of occupants, and household finances.[63] Installation of insulation, air sealing, and new heating and cooling systems can reduce instances of thermal stress during extreme temperature conditions.[64] In this way, residential energy efficiency programs can also be viewed as having climate adaptation and resilience benefits. Together energy efficiency programs also give rise to economic development opportunities, ranging from the design and production of energy-efficiency products to job creation in specific trades like rooftop solar installation.

The health, climate mitigation, climate adaptation, and resilience benefits of energy efficiency programs may end up attracting prodigious amounts of new funding for energy efficiency in the next decade or two and the state will want to capture its share. Consider first health-related NEBs. It is expected that the health care sector will soon represent a full 25% of the GDP of the U.S. national economy. The pressures to reduce health care costs are expected to amplify tremendously in response. Emerging research is showing that weatherization programs can improve housing, which then can improve health and decrease health care costs. The health care community is beginning to embed social determinants of health (SDOH) factors into its formal diagnostic codes,[65] which lays the groundwork for physicians to diagnose the causes of an illness as bad housing and high energy burdens, for example, and to allow the prescription of weatherization as a reimbursable treatment. Routine prescription of weatherization could bring hundreds of millions if not more new funds into the energy efficiency sector.

61. For example, see TVA's most recent Integrated Resource Plan: https://tva-azr-eastus-cdn-ep-tvawcm-prd.azureedge.net/cdn-tvawcma/docs/default-source/default-document-library/site-content/environment/environmental-stewardship/irp/2019-documents/tva-2019-integrated-resource-plan-volume-i-final-resource-plan.pdf?sfvrsn=44251e0a_4

62. Skumatz, L. March 2014. Non-energy Impacts/non-energy Impacts and Their Role and Values in Cost Effectiveness Tests. Skumatz Economic Research Associates. http://energyefficiencyforall.org/sites/default/files/2014_%20NEBs%20report%20for%20M aryland.pdf. Accessed March 20, 2019.

63. Tonn B., Rose E., Hawkins B., Conlon B. September 2019. Health and Household-related Benefits Attributable to the Weatherization Assistance Program. *ORNL/TM-2014/345.* Oak Ridge National Laboratory. https://weatherization.ornl.gov/wp-content/uploads/pdf/WAPRetroEvalFinalReports/ORNL_TM-2014_345.pdf. Accessed March 20, 2019.

64. Ahrentzen, S., Erickson J., & Fonseca E. August 2015. Thermal and Health Outcomes of Energy Efficiency Retrofits of Homes of Older Adults. *Indoor Air 2016, 26(4)*:582-593. doi:10.1111/ina.12239.

65. These are known as z-codes which are part of the latest ICD-10 diagnostic codes. https://www.icd10data.com/ICD10CM/Codes/Z00-Z99

Renewed efforts to reduce GHG emissions could also result in new funds for energy efficiency programs. Draft versions of the Biden Administration's infrastructure plan include funding to weatherize two million low-income homes, whereas the current federal budget supports less than forty thousand weatherization jobs per year. Programs to improve the resilience of the economy to climate change challenges could have spillover benefits with respect to energy efficiency. For example, efforts to reduce urban heat island effects by planting trees to shade buildings will also reduce energy demands.

As the U.S. moves towards electrification, utilities will find energy efficiency programs to be more cost effective with respect to reducing peak electricity demands. As the climate continues to warm, the pressure to reduce summer evening peaks driven by air cooling loads will only escalate the need for energy efficiency programs to reduce peak demands. Improvements in energy efficiency will also support utility efforts to expand the use of micro-grids and renewable energy resources. Thus, it is anticipated that utility funding for energy efficiency programs could increase substantially, as well.

Miscellaneous Trends and Potential Disruptors. This section takes the opportunity to explore a few additional topics that are within the broad scope of energy efficiency adopted by this part of the annual assessment of the state's energy sector. One topic is increasing demands for electricity from information technology. For example, an enormous amount of computer power, and therefore electricity, is needed to 'mine' crypto-currency and track its ownership and transactions through blockchains. One site that tracks Bitcoin mining energy consumption compares it to the level of power consumption of the country of Chile.[66] Computing power is also needed to train the aforementioned AI systems. Demand for streaming services is also considerably increasing demands for electricity, as are the needs to power data centers and server farms. Improvements have been achieved in the energy efficiency of computers and information systems but utilities and others may find these applications to fall within their energy efficiency portfolios sooner than later.[67]

Cutting in the opposite direction are improvements in textiles and fabrics.[68] The potential for the new fabrics in the energy efficiency context is to reduce the build-up and capture of body heat in warm-to-hot environments. Designers claim that well-designed fabrics could make the surrounding environment feel as many as 40F cooler, thereby reducing the needs for energy for cooling.

Many are also envisioning new passive building designs that could provide high levels of comfort and energy services without the need for new and expensive

66. Bitcoin Energy Consumption Index. *Digiconimist*. https://digiconomist.net/bitcoin-energy-consumption/
67. "Against a backdrop of exponential growth in connected devices, and rapid industrialization, our current energy supply will be limited in its ability to support future demand" (31). Betchel, M., Buscaino, R., Erb, L., Golem, A., Hickin, R. April 2021. Technology Futures: Projecting the Possible, Navigating What's Next. World Economic Forum. http://www3.weforum.org/docs/WEF_Technology_Futures_GTGS_2021.pdf
68. Abate, T. September 2016. Stanford engineers develop a plastic clothing material that cools the skin. *Stanford News*. https://news.stanford.edu/2016/09/01/plastic-clothing-material-cools-skin/

technologies.[69] Advances in green and cool roofs can easily be added to these passive home designs. Lawrence Berkeley National Laboratory's research on fluorescent pigments for cool roofs is particularly interesting.[70] Abandoned urban properties are being re-imagined and re-used as vertical farms. One can anticipate that commercial spaces depopulated during the COVID-19 pandemic could be radically re-imagined to include office space, residential space, retail space, and even distributed manufacturing space all within one building envelope. New design concepts can reduce imbedded energy and can also reduce direct energy consumption if the designs are imbued with a culture of energy efficiency.

Summary and Outlook. The picture of the energy efficiency sector painted above is extraordinarily rich. This sector has many facets that interlink in numerous and complicated fashions and continue to evolve. It appears that few if any facets by themselves can be imagined to significantly disrupt the energy efficiency sector over the next couple of decades. On the other hand, in combination, one may anticipate that the energy efficiency sector will be a significant disruptor putting downward pressure on the demand for energy. Core energy end-use technologies will be vastly improved individually and collectively, and how they are used will be made much more efficient. The potential exists for a disruptive amount of new energy efficiency financing. Innovative new designs for textiles and buildings could further transform the energy consumption landscape. Expansions in access to broadband will be needed to ensure that households and business in rural Tennessee have full access to the benefits of energy efficiency gains.

Economic impact

The economic footprint associated with an expanded view of the energy efficiency sector is itself quite broad. Every dollar saved on energy bills can be reinvested elsewhere by households, businesses, municipalities, universities, schools, hospitals, and non-profit organizations. Energy efficiency is important to keep Tennessee's industrial plants internationally competitive. Increased expenditures in the community will increase jobs, and sales taxes. Residential and commercial buildings that are more energy efficient have higher market values than less energy efficient buildings, which benefits building owners and local property tax bases. Installing energy retrofit measures is labor intensive; local low-weatherization programs are a source of jobs for their communities.

Energy efficiency can be an economic development opportunity for the Tennessee. The types of new technologies and information systems described above need further design and development. New manufacturing facilities need to be established. The locations of the new manufacturing plants will then attract firms that provide key supply chain inputs. With sound and directed investments, it is imaginable that key elements of the energy efficiency sector

69. Passive House Alliance. Passive House Principles. https://www.phius.org/what-is-passive-building/passive-house-principles
70. Chao, J. October 2018. Ancient Pigment Can Boost Energy Efficiency. *Berkeley Lab News Center*. https://newscenter.lbl.gov/2018/10/09/ancient-pigment-can-boost-energy-efficiency/

could grow and expand into major economic hubs, like the automobile industry across Tennessee, the television and movie industry in Georgia, and the FedEx hub in Memphis. The University of Tennessee system, ORNL, and the TVA are well placed to provide a foundation for such an economic development initiative.

Investments in improving the energy efficiency of low-income homes and affordable multifamily buildings can improve the health of occupants. (This can be especially important to rural Tennessee where incomes are relatively low and there are significant public health problems to address.) In turn, individuals will miss fewer days of work and school, and require less medical care. Potential savings to TennCare and other medical insurance companies could be substantial. In the extreme, installation of energy efficiency measures could save lives by reducing incidences of deadly thermal stress during extreme temperature events.

Preliminary Energy Efficiency Policy Considerations for Tennessee

This section addresses several energy efficiency-related topics that could be considered by policymakers in the Tennessee. The topics include increasing financing for energy efficiency, promoting regional economic development around core energy efficiency sectors, improving the human capital needed to support economic development efforts, re-assessing zoning and building codes to allow innovation, protecting privacy, and fostering equity in both rural and urban areas. It is assumed that direct investments by the state to support the research and development of emerging energy efficiency technologies is not needed. However, there may be opportunities to support specific R&D opportunities in the state's institutions of higher education. The ideas presented below were based, in part, upon a review of a recent ACEEE report on state energy efficiency,[71] and review of other selected state energy plans.[72] For the most part, the ideas below are tailored to the trends and disruptors described above and Tennessee's unique energy regulatory context.

Financing Energy Efficiency. Current funding for energy efficiency programs comes from the federal government, state programs, and utility companies. Many states also reprogram a portion of their Low-Income Home Energy Assistance Program (LIHEAP) funding into weatherization programs. A topic for consideration by policymakers is how to increase this pool of funding for energy efficiency programs. As noted above, some energy efficiency programs can yield monetizable health benefits, though at this point in time the health care sector does not invest in energy efficiency measures that could improve the health of patients.[73] TVA has initiated a first-step project with TennCare to explore

71. Berg, W. Vaidyanathan, S., Jennings, B., Cooper, E., Perry, C., DiMascio, M., Singletary, J. December 2020. The 2020 State Energy Efficiency Scorecard. ACEEE. https://www.aceee.org/sites/default/files/pdfs/u2011.pdf
72. For example, https://energyplan.ny.gov
73. The Systems for Action (S4A) program of the Robert Wood Johnson Foundation refers to a situation where one party invests in an activity that improves health, but another party receives the economic benefits as the wrong pocket problem.

the cost savings that TVA's Home Uplift program may be providing to TennCare. There may be some regulatory issues that the state could consider that could allow cooperative arrangements between the energy efficiency and health care sectors to flourish.

Other sources of funding include property insurers and rental property owners. The former may become motivated to invest in energy efficiency to improve the climate resilience of buildings or at least consider reductions in insurance rates for more resilient and energy efficient buildings. The latter may be more inclined to invest in energy efficiency if progress was made at solving the mixed incentive problem. Currently, residential rental property owners may not care about the energy efficiency of their buildings if all energy costs can simply be passed along to their renters, though the renters themselves would prefer to live in more energy efficient buildings that have much lower energy costs. Of course, the renters have no incentive to invest in buildings that they do not own. This mixed incentive conundrum is particularly problematic for low-income renters.

Economic Development. As mentioned in Section 4 above, the energy efficiency sector could represent a significant economic development opportunity for Tennessee. New technologies are being developed in the state's university research laboratories. The state has other successful regional economic development initiatives that could serve as excellent models, such as the recruitment of the automobile industry. The goal would be to help align economic development incentives, investments in human capital, and regulatory provisions around a strong regional planning initiative to produce agglomeration benefits to encourage the location of new energy efficiency businesses and supporting supply chains in Tennessee.

Human Capital. In addition to direct investments in economic development, investments could also be considered under the rubric of human capital. In this area, what typically comes to mind initially are investments in training for entry level and skilled jobs in the energy efficiency sector (e.g., installing energy efficiency building envelope measures and more efficient heating and cooling systems, building code inspectors). Indeed, these workers are already in short supply in the state. It is understood that new technical training programs to supply workers to new energy efficiency sector jobs is important as well. The jobs challenge is not just limited to these types of jobs, however. New researchers, engineers, product designers, and others with higher levels of education are also needed. As found in the solar sector, improvements in human capital are also needed throughout the state's financial institutions and law firms so they can better understand the energy efficiency sector and serve businesses operating in the sector. One could also argue that realtors could be better informed about the economic value that energy efficiency can add to properties that they help sell.

Zoning and Building Codes. Codes and standards were addressed previous sections. The state can certainly consider adopting more recent, optimal reach building codes. Additionally, the state can consider revisiting the regulatory environment around zoning and building codes to better foster innovation and experimentation. For example, there might need to be revisions to both building codes and zoning ordinances to allow the installation of energy efficient building skins, green facades, green roofs, and smart windows and the construction of passive homes, as highlighted in the previous section. Energy efficient reuse of commercial office space, widespread market penetration of 3D printing, and the development of vertical farms may also benefit from a more flexible regulatory environment.

Big Data, Privacy and Security. As discussed in the previous section, advances in modeling energy use in buildings and big data applications could revolutionize energy efficiency design and implementation programs. However, unprecedented access to data about household energy-use behaviors can raise privacy concerns. Disaggregated energy use data can provide insights into when people are in their homes, and what they use their energy for. Decisions about allowing utilities to manage their electric appliances and HVAC systems could provide insights into household incomes and finances. Some customers may judge that the insights derivable from big data applications may violate their privacy. Of course, sharing these data with various third parties can be particularly problematic, especially if customers are not paid for the unapproved use of their data. The state may wish to review law and regulations related to privacy in order to balance the concerns of customers with the benefits derivable to the energy sector from big data applications.

Another important issue concerns security. At an earlier stage of this section's development (May, 2021), parts of Tennessee were suffering from a gasoline shortage due to a ransomware attack on the Colonial Pipeline facility.

It should be anticipated that hackers will also target any system that has an exposure to the Internet. In this space, vulnerable appliances could include heating and cooling systems, and their connectivity with the grid. It may prove valuable for the state to help ensure that cybersecurity challenges are sufficiently addressed by all parties that provide technology and energy services to customers in the state.

Energy Service Sellers and Aggregators. A major trend in the energy efficiency sector is the emergence of energy service aggregators (e.g., CCAs), as discussed in Section 3.4. The aggregators can help empower energy end-user customers in their interactions with energy providers. Aggregators could potentially be quite impactful in helping empower lower-income customers. Aggregators could also be a source of funding for new energy efficiency investments, in the same way that energy service companies invest in energy savings for very large customers in order to share energy cost savings. State laws and regulations could be reviewed to ascertain their ability to allow the emergence of aggregators in a sound manner.

Equity. Many issues discussed herein have equity considerations. The split incentive issue is particularly important to renters, who are disproportionatelylow-income. Economic development investments should focus on producing job opportunities in economically distressed communities, both urban and rural. Households of color will still need assistance in reducing energy burdens through energy efficiency programs, as will elders living on fixed incomes. These latterhouseholdsmayalsoneedadditional assistance in confronting data privacy issues and participating in energy service aggregation agreements. Low-income households and households with elders, disabled individuals, and individuals with life-saving electrical equipment need due consideration with respect to time-of-use pricing, grid interactive technologies, and other programs and policies enabled by the confluence of smart grids, smart homes, and smart thermostats. Conversely, additional value could be placed on expanding broadband services to rural communities for these households to take advantage of an energy-centric revolution in the information technologies sector. Rural residents of the state confront somewhat unique circumstances, with relatively low incomes, poor health status and an aged housing stock. The emphasis that the new Biden Administration is placing on environmental justice and racial equity as related to programs administered by the U.S. DOE and the Environmental Protection Agency suggest a positive disruption of historical inequities.

Lead by Example. One goal is for Tennessee should be to nudge energy efficiency market transformation. This can be accomplished through its procurement practices, for example. The state can also participate in pilot demonstration projects of new, emerging energy efficient technologies, as it is doing with respect to gas absorption heat pumps. The state can be a willing living laboratory. Results of its cutting-edge activities should then be widely disseminated throughout the state.

Additionally, the state can actively convene stakeholders to address key issues discussed herein. Cyber-security is one such issue as are privacy and equity issues. Stakeholders could also be convened to address complicated multi-party energy efficiency financing, creation of CCAs, workforce development, big data sharing, and building and zoning codes.

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SMALL MODULAR REACTORS: MEETING BASELOAD DEMANDS AND FILLING MARKET NICHES

Introduction[1]

The nation's electricity sector has seen a significant shift in focus with an emphasis on reducing reliance on fossil fuels. Aggressive and deep decarbonization goals have been announced by the federal government, states, power providers, and consumer groups. Coal-powered generation is already being phased out within the Tennessee Valley Authority (TVA) region, but reliance on natural gas has been increasing to compensate for this lost capacity due to low prices. While renewable energy resources are being deployed, they are anticipated to be a small percentage of Tennessee's generation portfolio due to their service intermittency. The four light water nuclear reactors (LWRs) currently producing carbon-free electricity could produce electricity beyond mid-century, but they will eventually reach their operational limits. New nuclear capacity in Tennessee may be needed as coal generation is phased out, especially if reliance on natural gas generation is also reduced before 2050 to meet decarbonization goals. Importantly, after 2050, almost all large nuclear reactors in the southeastern U.S. will begin to age out and substantial amounts of carbon-free generation will be lost. If environmental goals are to be realized, this carbon-free baseload capacity must be replaced and nuclear represents a prime candidate for consideration.

The economics of the existing fleet of commercial LWRs was based on the notion of *economies of scale*: large generating facilities can produce at lower marginal and average cost than their small-scale counterparts. Plants with thermal generation capacity of approximately 3000 megawatts (MW) were constructed to put approximately 1000 MW of electricity on the grid. The large size of the plant and the required high-pressure operation of LWRs results in large and expensive plant components, which are built offsite in specialized facilities (often offshore) and shipped to the site for assembly. The heyday of reactor construction ended in the 1970's and limited construction occurs today. As such, the U.S. nuclear industry supply chain has atrophied considerably and recent attempts to build large plants have experienced delays and cost overruns directly associated with the supply chain. In Tennessee, many machine shops that once made nuclear components currently are making automobile parts; specific indicators of nuclear-qualified shop capacity, such as the number of nuclear certifications held, are decreasing.

Small modular reactors (SMRs) offer an alternative to the large-scale nuclear facilities in place today. These smaller generators may emerge as a market disruptor and important energy source of the future. Not only do SMRs avoid the dangerous emissions that come from the use of fossil fuels, but their modular design also offers unique niche applications to electricity generation, potential cost savings, and potential

1. This chapter of the annual energy assessment was prepared by Alec Apostoaei, Matthew N. Murray, PhD, and Lou Qualls, PhD. This chapter draws on "Exploring the Viability of Investmentin Small Modular Nuclear Reactors (SMRs): Mitigating Climate Change through Advancements in Energy Generation," an undergraduate thesis prepared by Alec Apostoaei.

reductions in production delays that have plagued deployment of large nuclear reactors. Properly employed, SMRs could enhance the security and resiliency of the nation's generation capacity, potentially in tandem with ESSs. For Tennessee, the emergence of SMRs offers economic development opportunities as well, building on an existing supply chain, the presence and public acceptance of an existing nuclear industry, the Department of Energy's (DOE) large footprint and nuclear-related assets in east Tennessee, and the Clinch River site's availability for SMR demonstration projects. Ancillary industries in manufacturing, like the electrical components and automotive sectors with their skilled workforce represents assets that may also be able to support an expanded nuclear supply chain.

Traditional Nuclear Power and the Current State of Electricity Generation

While closures of coal-fired plants have been occurring over the last decade, new investment in low-greenhouse gas (GHG) baseload generation in the U.S has failed to close the gap. From 2019-2020, natural gas power generation increased by 9% while nuclear power generation decreased by 4%.[2] This trend is likely to continue if the increase in dry natural gas supply that has pushed natural gas prices to historic lows persists. Natural gas prices in June 2020 reached a low of $1.63 per million British thermal units (MMBtu), the lowest monthly inflation-adjusted price since 1989. Natural gas prices in the U.S. have remained low due to an increase in dry natural gas production, a decline in the export of liquefied natural gas, and warmer than average winters.2 The growth in natural gas power generation this past year is not an exception, and low ongoing natural gas prices would encourage more natural gas consumption in the electric power sector, especially as coal plants are shut down.[3] While natural gas generators have historically been used for peak loads, the trend of sustained low natural gas prices and the inherent operational flexibility of gas systems have enabled them to be used for baseload power, which is increasing reliance on fossil fuels. According to scholars, "nuclear power is the only baseload electricity source that could effectively replace fossil-burning plants and help in reduction of [the] global warming threat" and is already reducing GHGs by "2.5 billion tons per year" (Vujić et al., 2012).

Further examination of current trends shows that "U.S. nuclear power generating capacity is projected to decline from 99.3 gigawatts (GW) to 79.1 GW over the period of 2017-50", a decrease of 20.3%. As of 2018, six large nuclear plants were projected to be closed by 2025, and, other than Watts Bar Unit 2 in the Tennessee Valley region, there have been no new additions to the U.S. nuclear fleet since 1996.[4] This trend of large nuclear reactor closures is due to aging plants and cost competitiveness of other forms of generation while the lack of new construction is largely due to the high upfront capital costs and risks, negative public perception, and, again, lower costs from other forms of energy generation. An additional concern is

2. Energy Information Agency (EIA), August 12 2020. Available at: www.eia.gov/todayinenergy/detail.php?id=44716
3. EIA, July 13 2020. Available at: www.eia.gov/todayinenergy/detail.php?id=44337
4. EIA, "Nuclear Power Outlook: Issues in Focus from the Annual Energy Outlook in 2018," 2018.

the uncertainty surrounding license renewal. When nuclear plants begin operation, they receive licenses from the Nuclear Regulatory Committee (NRC) to operate for 40 years. After this term expires, plants can apply for renewal for an additional 20 years.[5] As of now, there is no precedent for a second renewal, and therefore, most nuclear plants are expected to retire between 2030 – 2050 as their licenses expire.

Nuclear Energy: Risks and Opportunities

One of the largest concerns about nuclear energy involves potential impacts from adverse events including damages, health impacts, and even deaths. There have been approximately 30 reported adverse events globally since the introduction of the first nuclear reactor on the grid in 1951.[6] Out of these reported events, only two, the Chernobyl nuclear disaster in former Ukrainian SSR and the Fukushima Daiichi nuclear disaster in Japan have had significant loss of life and regional impact.

Comparatively, the actual or projected deaths from nuclear power are significantly fewer than deaths attributed to fossil fuels, though this may not be consistent with public perceptions. The annual death rate per terawatt hour (TWh) produced from accidents and air pollution are: 24.6 deaths for coal, 18.4 deaths for oil, 2.8 deaths for natural gas, and 0.07 deaths for nuclear energy (Markandya et al., 2007). That equates to one death every 14 years due to nuclear energy generation, and 641 deaths for fossil fuels over that same time span.

In addition to feeding critical baseload energy demand, nuclear power offers positive direct environmental impacts that have been recognized for many years. While studies project that both the nuclear power industry and the coal industry will, for now, remain as mainstays in the energy production industry in the U.S. (Vujić et al., 2012) nuclear energy offers nearly zero pollution effects (excluding nuclear waste), and can therefore sustainably meet future energy needs. In fact, nuclear power is unique in its position to positively affect climate change concerns because it is a carbon-free energy source that "is already contributing to world energy supplies on a large scale, has potential to be expanded if the challenges of safety, nonproliferation, waste management, and economic competitiveness are addressed, and is technologically fully mature" (Hezir, 2011).

Continued investment in nuclear technology is important strategically to the U.S. The DOE has, as its high-level objectives, to (1) sustain the existing fleet of operating reactors, (2) promote the development and deployment of advanced reactors, and (3) continue to maintain U.S. leadership in the global nuclear energy market. This strategy is important to Tennessee for several reasons. The presence of nuclear power generation in the state signals the public's acceptance of this source of electricity. The DOE's presence in the state, especially in east Tennessee, offers a job creation engine, a research facility, and related private sector assets that can yield benefits to the state. Additionally, a number

5. Nuclear Energy Institute, "Second License Renewal." Available at: www.nei.org/advocacy/preserve-nuclear-plants/second-license-renewal
6. International Atomic Energy Agency (IAEA), "Nuclear Accident Knowledge Taxonomy," 2016.

of important associated Tennessee industries are related to the nuclear power sector that create jobs for state residents while additionally expanding the state and local tax base. Prominent industries include nuclear qualified component suppliers, the medical isotope industry, and neutron science research performed at ORNL with their paired national assets, the High Flux Isotope Reactor and the Spallation Neutron Source. As Tennessee looks to the future of the nuclear industry, it is important to anticipate and position for changes that will lead to new opportunities.

SMRs: Technology

To improve the economics of reactors, industry is focusing on SMR systems that use different fuels and coolants. SMRs are an advanced type of nuclear reactor, often built in modular arrangements of less than 600MW, and then shipped to the site for use (Hezir, 2011). SMRs are further classified according to the technology used. Some concepts are smaller versions of the larger LWRs that make up the existing fleet. Other advanced reactors use different coolants to increase operating temperature while decreasing operating pressure and to improve inherent safety characteristics.

Some of the general categories of small, advanced reactors are listed in Table 1.

SMRs are expected to overcome a number of major issues associated with large

Table 1: Brief overview of reactor types considered for small or modular deployment.

	Coolant	Fuel / Fuel cycle	Potential market	Comment
Small Light Water Reactor	water	Uranium / once through or reprocessed	Electricity at lower conversion efficiency	Mature technology with existing licensing framework
Gas Reactors	helium	TRISO / once through	Industrial heat / electricity	High temperature fuel / safe response
Liquid metal Fast Reactors	Liquid sodium or lead	Uranium / Plutonium	Electricity / fuel breeding	Can close the U/Pu fuel cycle, reducing waste and long-term supply concerns
Fluoride High Temperature Reactors	Fluoride salts	TRISO / once through	Industrial heat / electricity	High temperature and low-pressure operation
Molten Salt Reactor	Liquid fuel in halide salts	Thorium Uranium fuel cycle or Uranium Plutonium fuel cycle	Industrial heat / electricity	Can close the U/Pu or Th/U fuel cycle reducing waste and long-term supply concerns
Special purpose reactors			Medical radioisotope production	

nuclear plants including improvements in up-front capital cost, efficiency, safety characteristics, and time to implementation.

Benefits from Deployment of SMRs

Experts (e.g., Iyer et al., 2014) offer the following economic rationales for investment in SMRs:

- Modularity, which allows for a cost-effective, staggered construction cycle marked by reducing up-front investment costs, incorporating positive cash flows during the construction period, reducing labor-related costs, controlling construction time more efficiently than traditional reactors and providing a buffer for uncertainty in future electricity prices thereby reducing risk and financial burden.
- Flexible output designs that allow SMRs to vary generation to respond to variations in demand and renewable outputs.
- Improved energy security due to nuclear power not being affected by changes in commodity markets like oil and gas.
- Increased access to a wider range of markets, including remote locations, due to their "small size and inherent safety features."
- Passive safety features reducing/ eliminating the risk of fuel damage and radiation release.
- Smaller fuel inventory reducing "maximum possible release during an adverse event."
- Standardized off-site construction of modules creating cost savings compared to site-specific deployment of large nuclear reactors.
- The possibility of an 'early mover advantage' for the U.S. and Tennessee which could become world industry leaders in SMRs just as Denmark did with wind energy, creating employment opportunities and increasing their position in the global market.

Compared to large nuclear reactors, SMRs can "better match demand growth at lower up-front capital costs, provide flexibility to integrate with renewables and repower retired fossil plant sites, and can generate resilient baseload power." Therefore, SMRs can potentially improve upon large nuclear reactors through their modularity, lower capital investment, higher efficiency, and inherent safety characteristics. According to an analysis conducted by the Organization for Economic Co-operation and Development (OECD), "SMRs could be competitive with many non-nuclear technologies in the cases when [nuclear power plants] with large reactors are unable to compete."

Resilience and Safety. Resilience is a combination of sufficient resources to meet demand and the ability to withstand disturbances while additionally encompassing high-impact external events, such as weather events or security threats. Here too, SMRs have the potential for improvement over some existing technologies.

Some modern fuels that are under development have a significantly higher allowable temperature and are less likely to fail, even under extreme events. Some coolants (helium), allow for higher temperature, and others (liquid metals and molten salts) allow for higher temperatures at significantly lower operating pressures (perhaps only a few atmospheres). Higher operating temperatures allow for increased conversion efficiencies, requiring less heat to make the same amount of electricity and requiring less waste heat to be released to the environment. Smaller, more efficient plants can be located near rivers with less flow, greatly increasing the number of possible siting locations. This is in sharp contrast to existing large-scale facilities like Watts Bar Unit 2 which sits prominently along the heavy-flow Tennessee River.

Most SMRs are passively safe concepts that essentially eliminate the risk of catastrophic accidents that have occurred with older designs. Passively safe concepts may allow for a reduction in the size of the exclusion area that surrounds the reactor site to the point where it could be possible to locate SMRs on existing coal plant sites after coal generation has been terminated. This approach opens dozens of existing generation sites within Tennessee (and hundreds across the country) to the possibility of hosting small nuclear plants as brownfield sites with ready access to coolant water. It also lends itself to applications around the world.

Supply Chain Effects and Economic Development. Another aspect of the emerging SMR market is the concept of increasing the percentage of fabrication and assembly work performed in a modern factory environment. This can yield regional economic development benefits through capital investment and new hiring. In addition, there may be important efficiency benefits in fabrication processes since controlled environments offer efficiency gains that have outpaced gains in general construction. The new economics of nuclear power will involve producing more of the components in the factory, transporting the largest possible sections to the construction site, and performing the minimum amount of field assembly. Advanced manufacturing methods, such as additive manufacturing and as-built inspection to produce “born-qualified” components, will also be increasingly used to produce more consistent and cheaper parts for a plant. ORNL’s pioneering efforts in this area have made east Tennessee a central hub of advanced manufacturing capability and advanced reactor companies have already begun locating manufacturing capability in the area.

As noted above, there already are elements of a nuclear industry supply chain in Tennessee, though it has lost momentum as deployment of nuclear capacity has declined. There is also a large manufacturing sector in the state which could readily expand its focus to meeting the needs of SMR parts manufacturing. Worker training and qualification would likely be required to facilitate a transition to SMR parts manufacture and facility assembly.

Because of limited anticipation for increased power demand within the Tennessee Valley, the currently low price of natural gas, and the emphasis on adding renewable power, TVA is not expected to expand its nuclear-based electricity generation with construction of a large LWR in the near future.

However, several U.S. companies are developing reactor concepts that could come into the market offering different sizing, location, and operating choices. Near-term opportunities in nuclear installation (another economic development opportunity for businesses in the state) may relate to the need to build and operate first-of-a-kind or precommercial reactor prototypes as a means of introducing the technology to the market while sharing the costs among public and private stakeholders and reducing the overall deployment risk. However, increased electrification of the transportation sector will likely increase the future electricity demand profile and may accelerate the need for commercial reactor deployment.

Environmental Impacts: SMRs and Emission Abatement. Iyer et al. (2014) discuss the viability of SMRs in mitigating the effects of climate change through reduced carbon emissions. Utilizing the Global Change Assessment Model (GCAM), a dynamic-recursive model, the authors input prices under different assumptions of SMR costs and availability of large reactors to determine GHG emissions. Under this model, it was shown that net present value of abatement costs can be reduced up to approximately 27% using higher technology SMRs if there is no market competition from large nuclear reactors (Iyer et al., 2014). The decrease in abatement costs is reduced with assumptions of using SMRs with comparable LWR technology or with the assumption of large nuclear reactors as a market competitor. Given the current decrease of traditional nuclear power production, this market competition may be unlikely, meaning the introduction of SMRs might be expected to lower abatement costs up to the 27% value. The authors emphasize that "even pessimistic assumptions about SMR tech[nology] and costs can lead to a reduction in mitigation costs" and that regardless of assumptions, "the costs of achieving a 2 °C [global temperature increase] are lower with SMRs than without" (Iyer et al., 2014).

Challenges to SMR Investment

Despite the many strengths associated with SMRs, new investments have proceeded cautiously. SMRs are challenged by both investor perception of risk (due to uncertain capital costs) and the same negative public perceptions of traditional nuclear power (Iyer et al., 2014). However, lower capital costs, improved safety characteristics, and incumbent regulations on nuclear power are expected to help mitigate these concerns. Issues including waste disposal, terrorism, proliferation of nuclear weapons, and adverse events, are not entirely answered by new SMR technology alone.

In addition to the challenges already faced by nuclear power generation, SMRs present several new challenges (Iyer et al., 2014):

- Lock-in effects cause both utility companies and regulatory frameworks to have bias toward incumbent technologies.
- Restrictions due to current nuclear licensing in the U.S. may impede adoption of some desirable SMR features, such as not allowing control of multiple reactors from the same operating room.
- Differences in international

regulatory processes may affect the global diffusion of SMR technology.

- Lack of information for new technologies creates uncertainties which could adversely affect SMRs, including adding to the existing struggle nuclear power has with public perception.
- An inability to reach economies of scale due to the small number of SMRs being deployed.

SMRs will not reach economies of scale in the same way older larger designs did. However, some experts believe that modularization, reduced potential for project time/cost overrun, design simplification, and fractioning of total investments into multiple smaller payments may mitigate this cost or help counteract it - summarized by the term "Economies of the Multiple" (Boarin et al., 2015). A representative number of SMR orders required to offset the costs to build new factories and begin turning a profit is estimated by vendors to be on the order of 100. However, actual and detailed economic analyses to support that claim are not yet available.

Opportunities: Economic Development

The state of Tennessee has limited influence on the deployment of SMRs since power generation across the state is controlled by TVA. But their expanded use in Tennessee and elsewhere could yield benefits in terms of improved system resiliency and reduced environmental impacts from diminished reliance on fossil fuels. In addition, a potentially significant economic development opportunity exists for the state and local communities in terms of R&D, nuclear parts manufacturing, SMR production, and SMR installation/maintenance.

The current regional and national outlook suggests that nuclear power generation will remain at current levels or potentially contract as existing plants age out. By contrast, nuclear power is expected to increase in other parts of the world. If Tennessee is going to increase its nuclear business activity, it will need to look to new opportunities, such as development and manufacture of advanced reactor components, systems, and plants, and, perhaps, nuclear medicine. SMRs are a promising technology to facilitate these opportunities.

Several private companies have expressed interest in leveraging Tennessee's location and nuclear-trained workforce as part of their business development strategy. Perhaps the most impactful and sustained business opportunity for the state would be the development and construction of manufacturing capability for a SMR and the construction and demonstration of multiple SMR concepts. This could potentially include Tennessee's participation in private-public partnerships that help to bring new manufacturing facilities into the state and locate the first demonstration reactor nearby.

Ancillary industries, such as nuclear medicine, medical, and industrial isotope supply, and nuclear instrumentation are business activities that can be expanded in Tennessee as the SMR nuclear industry expands.

Existing Investment Assets to Support Economic Development. DOE annually invests billions of dollars into nuclear work in east Tennessee. This work ranges across many areas including materials and component production for weapons, basic energy science, and environmental management, among others. In addition to the number of federal staff and contractors directly supported, a large number of private companies are supported through these programs and others. Relevant capital investment currently committed by DOE in east Tennessee includes the following:

At Y-12:

- Uranium Processing Facility.
- Lithium chemistry facility.
- Mercury containment facility.
- Command and control facility.

At ORNL:

- Exoscale supercomputing.
- Spallation Neutron Source Second target station.
- Radioisotope Processing Facilities.
- Fuel Fabrication System Development.

Investment by DOE creates capital investment by private companies such as:

- Nuclear enrichment facility at Centrus.
- Coqui Pharma, acquired 200 acres for radioisotope production.
- Kairos Power, through a private-public partnership with the Department of Energy, has announced plans to build and test a 50MW(t) demonstration reactor, called HERMES, at the east Tennessee Technology Park in Oak Ridge Tennessee.

The investments made in east Tennessee, the capability derived from it, and the workforce that surrounds it makes Tennessee an attractive place to establish an incubation center for the next generation of reactors. The Kairos Power HERMES Reactor build is proposed to be the first to bring elements related to fuel enrichment, fuel fabrication, advanced manufacturing, and advanced reactor regulation into a single project. It will establish new and unique capability not only in this region but for the nation. The demonstration reactor will validate remaining design assumptions and performance predictions that will lead into the final design of a commercial reactor prototype, which could also be built and operated in the area. Kairos is currently working in partnership with TVA on their HERMES reactor design.

An SMR Demonstration Project: TVA and Clinch River. Tennessee has the opportunity to serve as a global laboratory to showcase SMR development and deployment at TVA's unique Clinch River site. The site has existing approval to potentially operate reactors as long as the total combined generating capacity of the reactors does not exceed the site limit of 800 MWe.[7] Reactors could be commercial, commercial prototypes, or demonstration reactors. This opens up exciting opportunities to engage multiple reactor developers and could potentially lead to a series of demonstrations that share common infrastructure. Reactors

7. Direct communication, May 2021, TVA Design Engineer Alex Young

at this site would operate under a Nuclear Regulatory Commission license and could potentially supply power to ORNL and/or Y-12 sites as part of a public-private partnership among reactor developers, an operating utility, and a government customer. Comparably, Wyoming has recently announced efforts to advance an SMR demonstration project as well.[8]

The Natrium Experiment

On June 2, 2021, Wyoming Gov. Mark Gordon, PacifiCorp (electric power company), and TerraPower (nuclear company founded by Bill Gates) announced efforts to advance a SMR reactor at a retiring coal plant in Wyoming.

It will be fully functioning with the intention to validate the TerraPower reactor technology named 'Natrium'. This project features a 345 MW sodium-cooled fast reactor with a molten salt-based energy storage system that can boost output to 500MW of power when needed. The DOE awarded TerraPower $80 million in initial funding to demonstrate this technology.

The site looks to provide jobs, ensure former coal generation sites continue to produce reliable power, and provide a cost-effective path towards decarbonization.

Expansion of large nuclear power plants to the central and western portions of the state is not anticipated due to seismic conditions. However, smaller reactors could potentially be seismically isolated to further expand siting options. Expansion of ancillary nuclear industries to other regions of the state may also be a promising opportunity. As an example, production and use of medical isotopes in SMRs near metropolitan areas and established international distribution hubs can be considered.

Educational Institutions. The University of Tennessee, Knoxville has a leading nuclear engineering department, recently ranked 7th in the nation. However, strong national competition exists in nuclear education, typically built around infrastructure that have benefited from strong historical investments. Dozens of universities have excellent programs and many of them own and operate research reactors that attract the best students and faculty and encourage industry engagement. An anchor SMR asset would be of tremendous value to the University of Tennessee nuclear engineering program. Leveraging the relationship between the university and ORNL through state-supported research initiatives can help both institutions be successful.

The UTK nuclear engineering program once offered remote education opportunities, however the program has been discontinued due to limited participation. The state also lacks a strong nuclear medicine curriculum. Expansion of remote educational opportunities and expansion beyond power sectors could potentially include an emphasis on medical isotope production and use and the expansion of computational methods related to medical imaging.

Economic Impacts. The nuclear sector already has a strong presence in Tennessee. Nurturing this sector with

8. TerraPower, 2021. Available at: https://www.terrapower.com/natrium-demo-wyoming-coal-plant/

SMR production would add significant additional benefits. In 2016, the East Tennessee Economic Council and the Nuclear Energy Institute sponsored a report by SIS International Research describing the economic impact of the nuclear industry in Tennessee based on industry surveys. This work concluded that the nuclear industry alone employed approximately 9,000 people and generated over $3.2 billion in revenue in the state. However, confidence in the future direction of nuclear energy was mixed. Businesses reported that recruiting difficulties associated with their work were more related to finding people with the right experience as opposed to finding people with the right education. They also expressed concerns about replacing an aging workforce. Hiring personnel with a graduate level education and hiring craft support, such as nuclear qualified welders, were mentioned as being challenging.

Several studies have been conducted to predict the potential economic development impacts due to SMR production and deployment, though none of the estimates directly apply to Tennessee. According to a 2010 study, a prototypical 100 MWe SMR with installation and manufacturing costs of $500 million would create a total of 7,000 jobs, generate $1.3 billion in sales, $404 million in payroll earnings, and $35 million in indirect business taxes.

Additionally, the proposed 12 x 60 MWe NuScale SMRs under development in Idaho for the Utah Associated Municipal Power Systems (UAMPS) consortium would entail total construction costs of $2.5 billion. During construction, 3,356 jobs would be created, with an estimated increase in labor income in the region of $644.18 million. Production would yield over $2 billion in increased output in the region. State and local tax revenues are estimated to increase by nearly $36.9 million.

After construction, plant operations will add a total of 667 jobs in the region each year over the estimated 40–to–60-year lifetime of the facility. Labor income in the region will increase by nearly $48 million and increased economic output in the region will be $81.15 million. State and local tax revenues will increase by $2.97 million annually.

Preliminary Policy Recommendations

Consistent with other chapters in this year's annual assessment of the energy sector in Tennessee, only preliminary recommendations are offered here for consideration. Each of the possible opportunities presented below requires further scrutiny and a more careful needs assessment to determine how best to proceed with any plan of action.

- Pursue the nuclear industry, especially SMRs, as an industrial recruitment target and economic development opportunity for the state. Focus on key sectors directly involved with the development, manufacture, and installation/maintenance of nuclear technologies used to support power generation, in partnership with DOE, TVA, private industry and institutions of higher education across the state. Leverage these assets to focus on R&D and exporting opportunities.
- Cultivate the location and growth of ancillary industries to help foster agglomeration economies

around the nuclear sector, i.e., the proximate location of firms and workers engaged in similar activities that can promote efficiency gains and cost savings in nuclear-related production activities. Businesses in similar sectors require similar supply chains and workers with similar skills. Even if firms do not trade with one another, the proximate location of firms and workers improves the flow of ideas, promotes scale economies, and improves the skills matching between workers and their employers.

- Identify supply chain gaps and occupational and training gaps that can be filled to support SMR R&D, parts manufacture and SMR assembly in the state. Consider making use of the new Governor's Investment in Vocational Education (GIVE) Program Structure to promote vocational learning in technical schools for nuclear-related trades in the manufacturing sector.

- Promote development of educational programs and nuclear-related demonstration/ pilot projects at the University of Tennessee, Knoxville and other institutions of higher education in the state to promote in-state R&D and the cultivation of a pipeline of well-educated professionals in nuclear-related trades.

- Consider federal and state incentive programs. Federal incentives could be modelled around those already in place for the U.S. solar and wind industries. Federal programs include credit incentives, R&D grants, and tax incentives, with the latter comprising 90% of the $51 billion investment. The state could also consider corporate income tax credits and sales tax exemptions on qualified expenditures. To reach the same level of generation as renewables (8%), estimations show that only $10 billion would be required for SMRs, due to much higher capacity factors of these plants. This level of investment is predicted to drop SMR cost by 22%, thereby improving a business case for SMRs. Tax credits could enhance the economic competitiveness of SMRs through lowered costs and potentially allow this generation source to meet emerging market needs.

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