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TENNESSEE
VALLEY
AUTHORITY

# The Valley Pathways Study

## Building a Competitive, Clean Economy

**Preliminary Findings**

February 2024

A report commissioned by The University of Tennessee Baker School of Public Policy & Public Affairs (The Baker School) and the Tennessee Valley Authority (TVA) to identify strategies for the Tennessee Valley to achieve Net Zero greenhouse gas (GHG) emissions by 2050.

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**City of Florence Electricity**
Seth Thompson

*Dr. Charles Sims*

*Jeff Lyash*

To the people of the Tennessee Valley region:

When striving for a clean, sustainable future for our Valley region, we need effective guidance on the best pathways to take towards reducing carbon emissions and building a strong economy.

The Valley Pathways Study brings diverse minds together from a broad range of economic sectors to understand where we are now and explore the actions we can put in place to achieve our shared environmental and economic goals.

During the past year, the University of Tennessee Baker School and TVA gathered insights from representatives in these sectors to establish a baseline of emissions, demonstrate progress to date, and explore options and actionable steps on the Valley's pathway toward a cleaner, sustainable future.

Through open, candid discussions, we forged close partnerships and strengthened our commitment to making lasting and beneficial changes in the way we approach environmental challenges and provide support for the region's economic growth.

The study data is clear. To drive meaningful carbon reductions the whole Valley economy must work together to reach Net Zero. Every business, home, vehicle, farm, factory, and school impacts the quality of our air, lands, and waters, and every sector plays a role in evolving current practices to higher and cleaner standards.

Achieving Net Zero will not happen overnight. It will take long-term efforts to further identify opportunities to work together, leverage innovation, and achieve energy efficiencies. These preliminary findings help identify critical actions as we pursue those efforts.

This study has never been more important. The actions we take now will shape the environmental landscape and prosperity of the Valley for decades to come.

Sincerely,

Dr. Charles Sims,

*Associate Professor and Director*
*Center for Energy, Transportation, & Environmental Policy*
*Baker School of Public Policy and Public Affairs*
*University of Tennessee Knoxville*

Jeff Lyash,

*President and CEO*
*Tennessee Valley Authority*

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1 Source: National Renewable Energy Lab, https://resstock.nrel.gov/factsheets/TN

# Executive Summary

The University of Tennessee Baker School of Public Policy and Public Affairs (The Baker School) and the Tennessee Valley Authority (TVA) partnered with on a study to develop a roadmap to achieve a Net Zero greenhouse gas (GHG) emission economy in the Tennessee Valley by 2050. To bring a comprehensive perspective to the Valley Pathways Study, a Stakeholder Working Group comprised of representatives from across the Valley – including various economic sectors, geographic regions, local communities, and conservation groups – oversaw the work and provided guidance, case studies, and reference material. Throughout the project, the topics of equity and environmental justice were brought to the forefront – discussing how the pathways to Net Zero can minimize costs as well as drive economic and public health benefits for low- and moderate-income communities across the Valley.

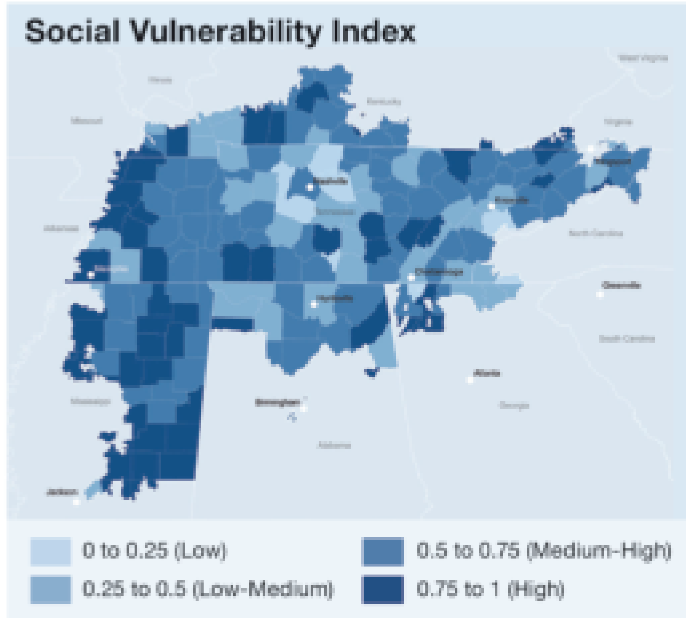



**Figure 1 Social Vulnerability Index across the Valley**

## Getting to Net Zero

Climate change poses major challenges for future generations, as increased frequency of severe weather events and other climate-related disasters can result in economic cost and reduction in quality of life in the Valley. Winter Storm Elliott[1] in December 2022 highlighted how extreme weather events can impact the electric grid. In the Valley, climate change will likely drive an increase in the frequency of storms, as well as extreme heat and cold waves and cycles of drought and flooding. Such events have a more profound effect in vulnerable and disadvantaged communities (DACs). Disadvantaged communities are often more impacted by extreme events. A Social Vulnerability Index can be used to identify communities that are most likely to need additional support before, during, and after a hazardous event (Figure 1).[i] These communities may not have access to financial and organizational resources to recover quickly post-disaster. While the Valley itself cannot stem global climate change, it can lead the way by striving to improve resilience and by investing in new clean technologies that will propel the region toward a Net Zero future. In so doing, it can help to protect its residents and offer opportunities for economic growth across the Valley.

There is no single established definition of Net Zero greenhouse gas (GHG) emissions. Most definitions of "Net Zero" prescribe a minimum reduction in gross emissions (notably, not absolute zero gross emissions – often 80% or 90% reduction, not 100%) and set a target for carbon sequestration to offset any remaining (or residual) emissions. This study

1 Winter Storm Elliott impacted U.S. states from Colorado to the eastern seaboard and south to Florida. The TVA service territory experienced high winds, heavy rain, and cold temperatures on December 22 and 23, 2022, increasing energy demand beyond what had been forecast, and resulting in the highest 24-hour electricity demand supplied in TVA history.

explored and evaluated pathways by which the Valley could transition to Net Zero by 2050, focusing on the Valley's businesses, industries, and residents. The project team started with a detailed evaluation of the sources of GHG emissions in the Valley – from the heaters and air conditioners in homes, to the engines in cars and trucks, to the equipment running on farms and in factories. This "baseline" links activities – driving to work, cooling an office in the summer, manufacturing goods and products – to demands for energy (both fossil and clean), and, ultimately, to greenhouse gas emissions. The project team then forecasted how those activities might change in the future, developing (a) a "business as usual" reference case in which population and economic growth drive an increase in emissions, and (b) four "pathways" to Net Zero, each of which highlight different potential changes to the underlying technologies serving all those demands while both driving economic growth and dramatically reducing GHG emissions.

This study was not intended to predict the future; instead, it explored potential approaches that could lead to Net Zero. This preliminary findings report is intended for everyone in the Valley to understand what pathways are available and how their individual actions, as well as those of their businesses and community organizations, can contribute to a common goal. This report also offers a first step toward coordinating continued work, including identifying key performance indicators and tracking performance metrics.

## Modeling Results and Key Findings

As of 2019, Valley emissions had already fallen by 30% since 2005 (when emissions were about 260 million metric tonnes $CO_2$ equivalent – $MMTCO_2e$). Much of this reduction is attributable to a ~50% reduction in emissions from electricity generation during that time. TVA's efforts to achieve this reduction include continued expansion of renewable energy; development of emerging technologies such as long-duration energy storage and carbon capture; advancement of new nuclear technologies; new demand response tools and programs to mitigate peak loads; and expanded energy efficiency programs. These initiatives, alongside the retirement of older, less-efficient coal-fired plants, have allowed TVA to remain a national leader in carbon reduction.

Today, emissions from the on-site combustion of fuels and direct leakage of methane and other GHGs from the "demand-side" represent two-thirds of emissions sources in the Valley. These emissions come from everyday activities, including but not limited to gas-fired furnaces to heat homes, gasoline and diesel in cars and trucks, methane emissions from cattle digestion, and the fuels used to fire the Valley's manufacturing sector. In particular, passenger vehicles are the single largest source of emissions in the Valley, producing about a quarter of the Valley's overall emissions. While TVA will continue to drive reductions from electricity generation, including a detailed evaluation in its ongoing 2024 Integrated Resource Plan (IRP),[2] this study is focused on how to reduce emissions from the rest of the Valley's economy.

The project team modeled initial pathways to Net Zero focused on three critical strategies, often referred to as "pillars of decarbonization":

1. **Reduce Energy Demand** through energy efficiency and other strategies
2. **Electrify Energy Demand** by replacing fossil fuels with electric alternatives
3. **Use Cleaner Fuels** by replacing traditional fossil fuel combustion with cleaner or renewable sources, such as renewable natural gas (RNG) or biomass

2 Because the IRP will go into detail on supply-side emissions, this study limits its evaluation of the electricity sector to a high level. For the purposes of this study, electricity emissions were estimated as a range, representing anywhere from zero carbon electricity supply up to an "upper bound" in which all new load from electrification is served by new fossil natural gas capacity – see the electricity "potential range" indicator arrows in Figure 3. The IRP will incorporate key findings from this study as it evaluates how to deliver low-carbon electricity reliably and affordably.

The pathways modeled for this study (more on this below) each reflect one of these three pillars, plus one additional pathway modeling a combination of all three (shown in Figure 2).

These pathways as modeled showed the following initial results:

- The steepest reductions are driven by the widespread electrification of current energy demands, especially passenger vehicles (e.g., via a transition to electric vehicles – EVs).
- Investments in energy efficiency and increased density of housing and development (which reduces total annual miles driven) results in quantifiable reductions in emissions and significantly reduces total energy demand, alleviating some pressure on the electric grid.
- Low-carbon fuels offer the potential to deeply decarbonize certain sectors of the economy, especially heavy-duty trucking and high-temperature manufacturing processes where electrification is less technically feasible.
- A combination of all three levers – full electrification of light-duty fleets, decreased energy demands from community reinvestment, and deployment of low-carbon fuels for hard-to-electrify sectors – results in the deepest potential reductions, reflecting synergies across the first three pathways and reinforcing that the strategies can and should be deployed as complementary approaches rather than competing scenarios.

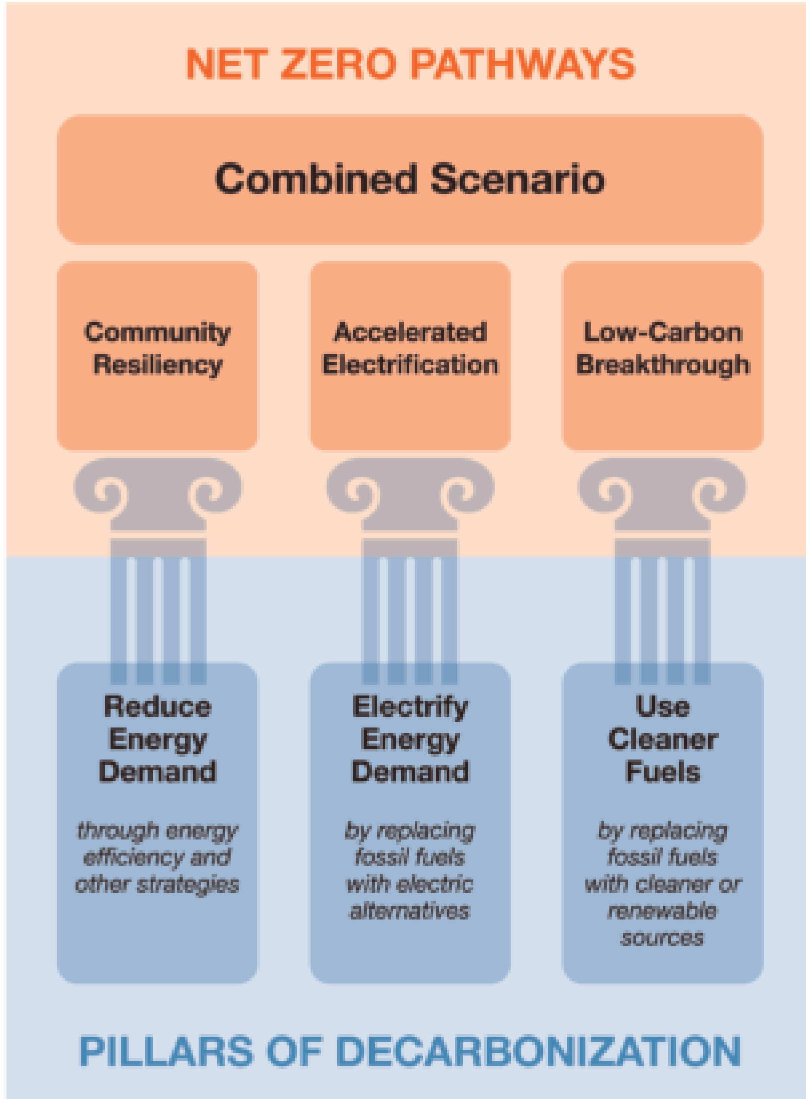



Figure 2 Connecting the pillars of decarbonization to the Net Zero pathways

Net Zero goals in other jurisdictions typically define a target for minimum gross reduction in GHG emissions, which can be as much as 90% lower than a 1990 or 2005 baseline. Those targets then seek to "net out" the remaining emissions through negative emissions, such as forest sequestration or artificial carbon sequestration and storage. Together with further GHG reductions from the electricity sector (options for which TVA's 2024 IRP team is currently evaluating) the changes to energy demand modeled in the scenarios described above enable gross reductions in GHG emissions of at least 70% from 2005 levels. Scenarios with greater electrification enable gross reductions of approximately 80%, although this requires greater simultaneous decarbonization of the grid in order to supply greater electrified demands with clean energy. Non-energy related emissions, especially methane from waste decomposition (both human and livestock), represent a sizable source with limited reduction opportunities. Although there is ongoing research at the University of Tennessee Institute of Agriculture in this area to understand the net carbon flows through pastureland, these emissions are persistent as fundamental biological processes. With high residual emissions from the non-energy sector, 80% may be the greatest gross reduction the Valley-wide economy can target. A summary of potential pathway scenarios vs. 2005 and 2019 levels is provided in Figure 3.

Today, forests in the Valley cover about 40,000 square miles (about half of the Valley's total land area) and sequester about 17 MMT$CO_2$e per year – less than a third of the residual 50-80 million tonnes of GHG emissions left over by a 70%-80% reduction from 2005. Opportunities to maintain or increase forest acreage throughout the Valley – especially through encouraging dense development that accommodates population growth while minimizing land clearing – can increase this number, but not enough to fully

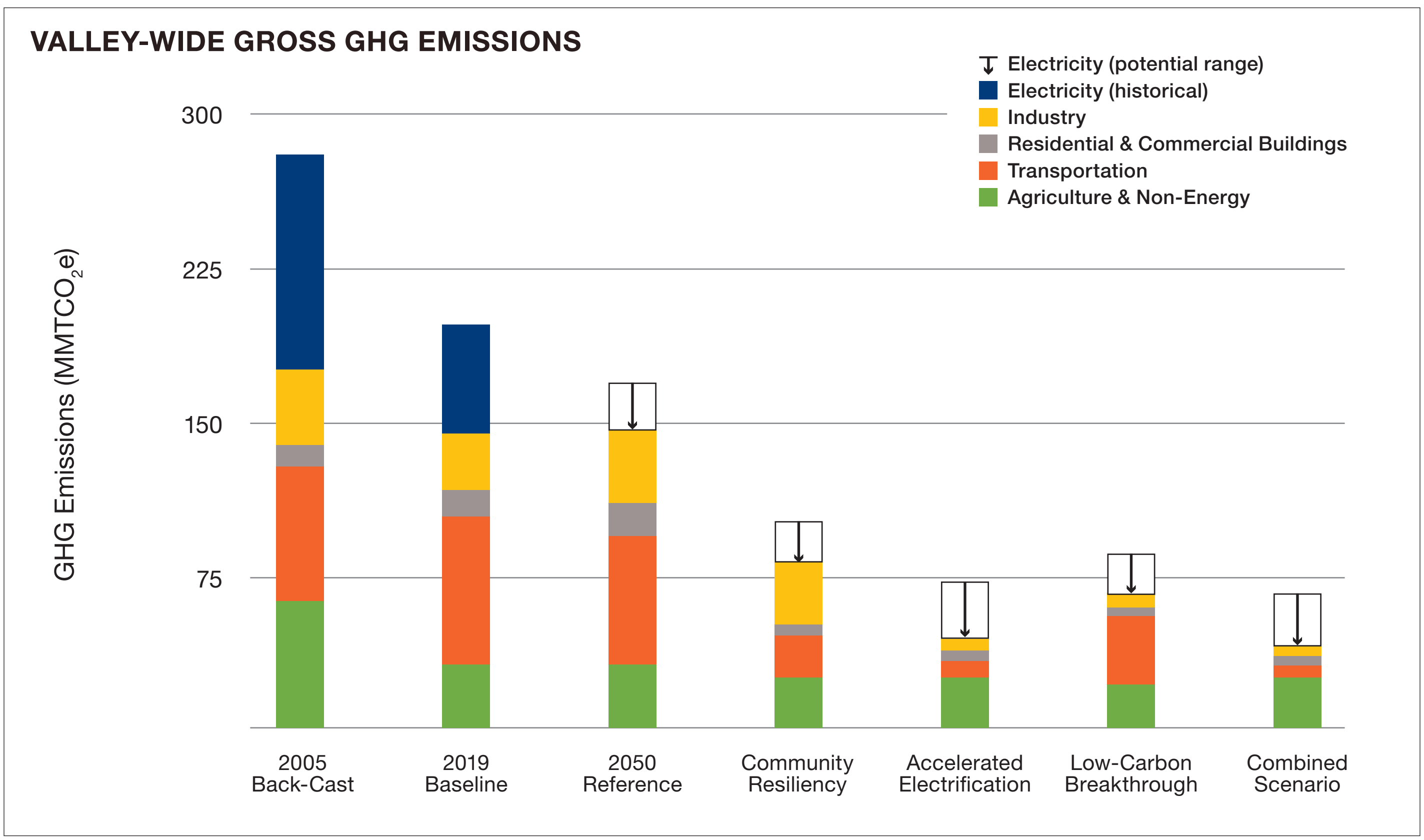



Figure 3 Gross GHG Emissions for 2005 back-cast, 2019 baseline, business-as-usual reference scenario, and four pathways. More information can be found in the Modeling Results section.

net out the Valley's emissions (although restoration and improved forest management techniques can maximize the sequestration potential of existing forests). New technologies and innovations such as direct air capture will be necessary to fully net out the Valley's GHG emissions and reach Net Zero.

No single action or lever alone can enable a Net Zero future, but this study highlights that several foundational actions can unlock deep decarbonization potential. However, several barriers stand in the way of these strategies – actions to address those barriers represent key near-term "no regrets" actions and opportunities:

- Widespread electric vehicle charging is needed to fully unlock the potential reductions associated with passenger vehicle electrification.
- New incentives, whether federal, state, or local, can help to make energy efficiency technologies cost effective for every household.
- Research and pilots are needed to prove out the availability, cost, and sustainability of low-carbon fuels at commercial scales.
- While many of the cities in the Valley have taken early leadership to drive forward local climate action planning, more rural towns and regions may lack the resources to adapt to growing population and service demands today, let alone plan for future needs and infrastructure – initiatives must be put in place to address these areas.
- Finally, investments in education and academic facilities across the region will be needed to make this vision a reality – from the pipeline of a well-trained workforce to install millions of heat pumps and EV chargers to the research grants that will be needed to test and develop innovative climate solutions.

Ultimately, a diversified portfolio of initiatives including electrification of demand, development of low-carbon fuels, greening of the grid, investment in nature-based solutions (potentially including the purchase of high-quality carbon offsets), and new innovative technologies will be necessary to bring the Valley to Net Zero by mid-century.

## The Path Forward

To achieve a consumer-driven Net Zero economy, residents and businesses across the Valley will need to take voluntary actions. To take these actions, individuals – including business owners making decisions for their businesses as well as residents making choices for their personal lives – will need to understand the benefits of changing their purchasing habits and making decisions to upgrade their buildings and systems. They will need to understand how making these choices will improve their quality of life and will need to be aware of the resources available to help them make those changes (especially in the case of lower-income communities, where funds may not be as readily available and older housing stock may make efficiency upgrades more difficult and expensive). In addition, these individual actions will need to be supported by systemic changes and structures, including new policies and initiatives driven by legislation and incentives.

## 2019: 200 MILLION METRIC TONNES OF $CO_2e$

The pathways modeling conducted in this study highlights several critical actions and transitions that will be core building blocks for a Net Zero economy.

**Electric Vehicles**

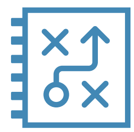
Electrifying light-duty vehicles is the single largest GHG reduction opportunity in the Valley.

**Efficient Homes**

High-efficiency heat pumps can abate GHGs, reduce utility bills, and relieve stress on the grid.

**Low-Carbon Fuels**

Research and investments into low-carbon fuels can unlock deep reductions for aviation, trucks, and industry.



**2050-Ready Communities**

Integrated planning can drive sustainable growth and enable low-carbon transportation.

**Education & Innovation**

Supporting every facet of a Net Zero economy, from workforce training to R&D for carbon capture.

The transition to Net Zero is ultimately driven by millions of individual decisions by residents, businesses, communities, and other key groups of stakeholders in the Valley – where to live, what car to drive, what new equipment to invest in, etc. Many of the technologies modeled by the study represent higher initial costs than existing technologies that run on fossil fuels; however, they typically offer long-term operating cost savings as well as public health benefits from improved air quality. New state, regional, and federal policies and programs can help to close up-front cost gaps and make adopting these technologies a “no regrets” option for decision makers across the Valley.

On the consumer side, tax credits, green mortgages,[3] and other financial assistance products stemming from the Inflation Reduction Act can help make new “Net Zero” aligned purchases make sense for households and businesses. Other programs – such as the U.S. Department of Transportation (DOT)’s National Electric Vehicle Infrastructure (NEVI) program, the USDA’s Rural Energy for America Program (REAP), the U.S. Department of Energy (DOE)’s Regional Clean Hydrogen Demand Programs, and DOE’s Grid Modernization efforts – will work to build out much-needed infrastructure for EV charging; distributed renewable energy; and hydrogen or low-carbon fuel production, transport, and storage. Finally, the U.S. Environmental Protection Agency (EPA)’s new Climate Pollution Reduction Grant (CPRG) program is primed to provide resources to local and regional governments to assist with local planning – especially forward infrastructure planning – that will be needed to lay the groundwork for a Net Zero economy. Local planning will also be key to developing necessary infrastructure and deploying decarbonization strategies.

3 A financial loan that provides added funds that can be applied to finance energy-saving enhancements that are included as part of your home mortgage or refinancing. Source: [https://www.energy.gov/energysaver/energy-efficient-mortgages](https://www.energy.gov/energysaver/energy-efficient-mortgages)

In addition to GHG emissions, the Valley Pathways Study considers the economic and social benefits and impacts to the region, including how to advance environmental justice efforts in the Valley. Transitioning to Net Zero offers the potential to reduce economic struggles for Valley residents, especially low- and moderate-income households who spend a disproportionate part of their monthly income on energy costs. This reduction in burden can be achieved by reducing total energy costs for consumers by, for example, improving building weatherization; deploying highly efficient appliances, equipment, and technologies; or making low-cost distributed energy and community solar available to low-income residents.

The transition can also drive economic growth in the Valley, especially through opportunities to leverage the Valley's industrial infrastructure to manufacture products that will underpin the national clean energy economy (such as electric vehicles and batteries). Energy efficiency can also make businesses more competitive while reducing emissions. As businesses and industries reduce their energy bills through efficiency, they improve their bottom line, become more competitive, and can re-invest the money saved into their businesses and employees. The Valley's industrial sector already produces and exports products and goods across the nation, including steel, cars and automotive equipment, and cattle. Producing these goods involves processes that are among the most difficult to decarbonize and which thus present critical challenges to reaching reductions beyond 70% of 2005 emissions.

One strategy to help accurately account for the emissions associated with this production is to consider the handling of "embodied emissions," which allows emissions associated with an item's production to be allocated to its "end user." Many jurisdictions with Net Zero targets are beginning to consider how to incorporate the embodied emissions associated with the goods and products they purchase from other regions into their targets.[4] To support this type of accounting, a framework may be developed to help allocate emissions that occur in the Valley to the economies throughout the nation that demand those products. Conversely, products produced elsewhere and subsequently consumed in the Valley would add to the region's embodied emissions – however, given the high manufacturing concentration in the Valley, one could speculate that this would still result in a net reduction of emissions for the Valley. This type of accounting and reconciliation will be particularly important for industries that support and enable decarbonization, not just in the Valley, but across the country.

The Valley Pathways Study's data gathering, analysis, modeling, and reporting in this preliminary report is only the first step on the pathway to Net Zero emissions. Getting to Net Zero emissions will require a multi-faceted, "all-of-the above" approach that will reach beyond the study's sponsors and will need to involve organizations from across the whole Valley. In the coming months, stakeholders from across the Valley – beyond the Working Group that supported this study throughout 2023 – will review and provide feedback on the findings and results of the study. Feedback and advice from this peer review will be used to help craft and guide actions across the Valley. The report will be made available for public review in Q1 2024 and a public webinar will be conducted to introduce it to the broader Valley community. Feedback will be collected during that webinar, but it will not be the public's only chance to weigh in – the feedback collection process will continue.

## Next Steps

Reaching Net Zero by 2050 will involve a concerted and coordinated effort by stakeholders across the Valley economy. In the short term, next steps will involve disseminating the Valley Pathways Study through multiple channels to increase awareness of the work and results. Outreach activities will also be needed to reach and engage other groups beyond the Stakeholder Working Group to continue the efforts toward a Net Zero economy going forward. This outreach will help to broaden buy-in to the study and develop the kind of local con-

4 In corporate GHG accounting frameworks, this is well-established as part of "Scope 3" emissions.

sideration, planning, and action that is ultimately needed to guide and support millions of decisions by individual residents and businesses in the Valley.

Looking further out, institutional mechanisms will be crucial to support coordinated project evaluation, planning, capacity building, and investment across sectors. In particular, it may be beneficial to revisit the study in late summer 2024 following the finalization of TVA's Integrated Resource Plan (IRP). Engaging with other existing and ongoing planning efforts – such as the Drive Electric Tennessee Roadmap and the state and community-led planning funded by the U.S. EPA's Climate Pollution Reduction Grant (CPRG) program – will also be critical next steps on the road to Net Zero. Considering the diversity of actors across the Valley, it may be worthwhile to consider a group or body to steer and coordinate actions across these workstreams and sectors, guided by the findings of the Valley Pathways Study.

# Project Goals, Objectives, and Limitations

The Tennessee Valley Authority (TVA) partnered with the University of Tennessee Baker School of Public Policy and Public Affairs (The Baker School) on a study to develop a roadmap to achieve a Net Zero GHG emission economy in the Tennessee Valley by 2050. The Tennessee Valley (referred to throughout this report as "the Valley") is the power service area administered by TVA and 153 local power companies (LPCs). The Valley spans Tennessee as well as parts of Kentucky, North Carolina, Virginia, Mississippi, Alabama, and Georgia. The region is vast and includes a wealth of diverse communities. This report seeks to be as holistic as possible in understanding how decarbonization will impact all facets of Valley life.

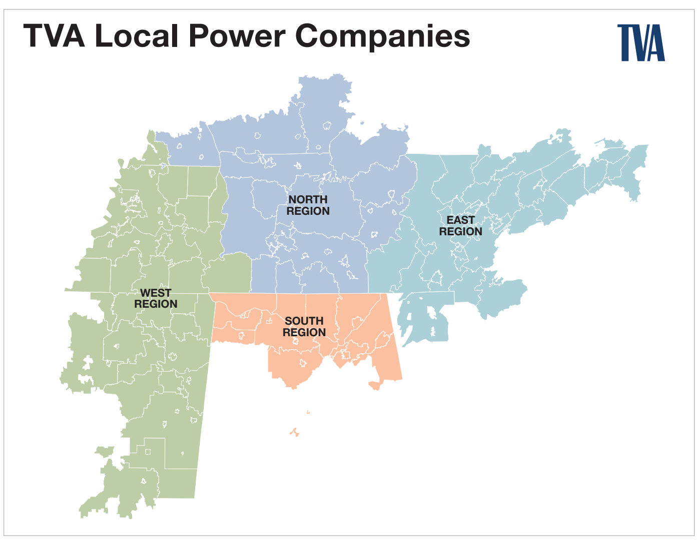



**Figure 4 Map of TVA power service area and local power companies by TVA region (North, South, East, and West).**
**Source:** https://www.tva.com/energy/public-power-partnerships/local-power-companies

TVA's service territory, the Valley, is a unique region that spans seven states with a population of 10 million people. The Valley's electric power is provided by TVA, the largest public utility in the country. Building on the foundation of TVA's reliable, resilient, low-cost, and increasingly clean electricity future and the Baker School's public policy efforts around decarbonization, this study looks beyond just electricity service to evaluate the whole Valley's regional economy.

(Note that case studies included in this report as of Q1 2024 are limited to Tennessee, which comprises the majority of the Valley region – however, the findings of the report are applicable to the entire region, including the parts of Mississippi, Alabama, Georgia, North Carolina, Virginia, and Kentucky serviced by TVA. Future iterations of the report may seek to include case studies from those 6 states as they are available.)

This study will be valuable to:

- Guide policymaking;
- Complement the TVA 2024 Integrated Resource Plan (IRP);
- Inform local planning and zoning;
- Recommend EV charging infrastructure strategy;
- Support efforts to maintain forested areas;
- Complement industrial and corporate sustainability ambitions; and
- Spur further stakeholder engagement or additional studies.

These preliminary findings will be updated with results from the IRP in 2024; uniting demand and supply side analysis will enable further study to evaluate the costs and benefits of pathways to Net Zero.

Throughout the study, partnerships with stakeholders from across the Valley region have provided a holistic view of the entire economy to ensure support for the economic competitiveness of the region. Engaging stakeholders was critical to ensuring that this was truly a Valley-wide study that incorporated the perspectives and inputs of as many communities and sectors as possible, and the study seeks to explore how different actions will produce different consequences for those communities and sectors. TVA and the project team have used insights, perspectives, and ambitions from every sector of the Valley's economy to build out potential pathways to Net Zero. The study's aim is not to try to predict the future, but to create and compare scenarios of what that future could look like – and what would need to happen to achieve that future. This process involves pushing the boundaries of what we envision being possible and exploring the upper limits of strategies to achieve Net Zero.

## Why Net Zero?

Climate change poses an major challenges for future generations, as increased frequency of severe weather events and other climate-related disasters will come at a steep economic cost and reduction in quality of life in the Valley. Sixty-one percent of large Southeast cities are already experiencing worsening heat waves, more than any other region in the country. Under a higher emission scenario, nights above 80 degrees Fahrenheit and daytime temperatures above 100 are expected to become commonplace. Cooling degree days (a measure of the need for air conditioning) are projected to double under a high emission scenario.[ii]

Models also predict changes in precipitation, with wetter springs and drier summers. Changes in water volume and temperature have the potential to impact hydroelectric power plants and agriculture and could lead to drought, further resulting in impacts to the quality of life of residents of the Valley and its natural

### WHAT IS THE VALLEY PATHWAYS STUDY?

- A Valley-wide, economy-wide analysis to explore potential pathways to Net Zero greenhouse gas emissions in the Valley by 2050.
- A study that highlights the economic opportunities for the Valley to pursue while accelerating decarbonization in the Valley and supporting the nation's clean energy economy.
- An opportunity to build partnerships across sectors of the economy and geographies in the Valley through a holistic approach to decarbonization.
- An evaluation of possible futures for the Valley and how similarities and differences in those futures can be interpreted as guideposts or turning points on the road to Net Zero.
- An evaluation of potential impacts or outcomes of the clean energy transition and how to ensure the best outcomes for Valley residents under that transition.

systems. A predicted increase in intensity of rainfall is expected to lead to more flooding and impacts to water quality.

Historically, in the Valley, severe weather has been the principal contributor to power outages, and the predicted increase in severe weather resulting from climate change is likely to have a negative impact on energy infrastructure and increase frequency of outages. The number of days with heavy precipitation in the Valley has already increased at most weather stations, especially since the 1980s.6 Climate change is already resulting in costly infrastructure upgrades; for example, in 2010, some TVA infrastructure was submerged under five feet of water when 15 inches of rain fell in two days. Relocating this infrastructure to higher ground cost about $9 million.[iii]

This study focuses on mitigating emissions in the Valley; however, as discussed above, adaptation will be equally important for the future. Mitigation focuses on reducing emissions to prevent worsening of climatic events, while adaptation is focused on developing resilience to the climatic changes that are already being experienced. This study seeks to explore different pathways to a future in which emissions are reduced to a level that will mitigate future climatic disasters and will therefore focus on mitigation; however, the study also acknowledges that adaptation will be key in the near future as the Valley begins the energy transition.

The Valley's quest for Net Zero emissions by 2050 is a part of a broader global effort to decrease emissions and protect against more severe climatic events in the future. Investments in clean energy and carbon sequestration can reduce the extent and impacts of climate change related threats.[iv]

There is no single established definition of Net Zero. Most definitions of "Net Zero" prescribe a minimum reduction of gross emissions – typically around 80% compared to a 1990 or 2005 baseline – and set a target for carbon sequestration to offset any remaining (or residual) emissions. Achieving these emission reduction targets will be necessary to maintain the current standard of living[v] and will offer new opportunities for the Valley to further develop communities and local economies. Rural areas stand to benefit by exploring new potential markets in renewable natural gas and credits related to carbon sinks. Urban and suburban populations, particularly in disadvantaged communities, could see benefits stemming from reductions in air pollution from power generation facilities and factories in their neighborhoods. Additionally, new markets in EVs and batteries offer new manufacturing opportunities in the Valley and new high-paying jobs. Finally, Valley efforts toward Net Zero can play an important role in supporting businesses' own individual carbon and environmental goals and targets – companies who have set targets or made commitments in that area may factor in Valley efforts when making decisions about moving to the region, positioning the Valley to attract, retain, and grow competitive green businesses and industries.

The Valley Pathways Study will be valuable to many different groups and can be used to guide and support policymaking, local planning and zoning laws, land conservation and protections, and private sector goal setting around carbon targets and other initiatives. This study provides the Valley with an opportunity to understand potential pathways to reach Net Zero emissions by 2050, including some costs, benefits, opportunities, and trade-offs of different strategies driving the journey to Net Zero forward. While not every actor must embrace the same set of strategies, every community, every sector, and every industry will need to change and adapt in some ways to enable the Valley to reach Net Zero.

## Goals of the Valley Pathways Study

This study's findings should serve as a reference guide for anyone in the Valley to consider their emissions and to incorporate these findings into their own climate action plans.

The goal of the Valley Pathways Study is to explore potential pathways to Net Zero GHG emissions for the Valley by 2050. Highlighting key areas of commonality among the different proposed pathways will help to generate consensus on the Valley's next steps, while highlighting their differences will illustrate various options and potential turning points on the journey to Net Zero. The study aims to support the development of actionable strategies and plans to accelerate the transition to a competitive, clean-energy economy throughout the Valley and to maintain the Valley's competitive advantage over other regions of the country.

The key questions that the study seeks to answer are:

- What are the **outcomes and feasibility** of implementing various scenarios to achieve the Valley's climate goals?
- What **strategies** could be implemented in the Valley to help achieve these goals?
- How could implementation of these scenarios impact **costs, policy, public health, and other qualitative factors for Valley residents and businesses,** especially those in disadvantaged communities?
- What are the potential barriers to achieving Valley carbon reductions and what are some **solutions to overcome those barriers?**

### Oak Ridge National Lab (ORNL) Assessment of Project Technical Limitations

The Low Emissions Analysis Platform (LEAP) used for this study is a widely used software tool that is regularly employed by researchers, governments, and practitioners for projecting the future evolution of energy systems, including economy-wide decarbonization scenarios. LEAP supports various modeling methodologies.
For demand forecasting, within an accounting framework, it uses a description of the energy system to generate a consistent view of energy demand as exogenously assumed by the modelers. On the supply-side, it answers "what-ifs" under alternative scenarios input by the user/modeler. Relevant to decarbonization modeling, LEAP is able to account for both energy and non-energy related greenhouse gas emissions. LEAP is an attractive software not only to modelers ("scenario producers"), but also to planners and stakeholders ("scenario consumers") because of its low initial data requirements, its user-friendly design, and the fact that it supports results visualization and communication to stakeholders.

LEAP is one of many available economy-wide energy systems models, the proliferation of which has accelerated in recent years worldwide. These models vary in, for example, their sectoral coverage of the economy (e.g., energy, electricity, transportation, buildings, etc.) and the complexities of their modeling techniques (e.g., optimization, simulation, agent-based, etc.). LEAP is quite flexible and adaptable in its geographic and sectoral coverage. While LEAP is usually used at a national scale, it has also been applied at a more granular scale such as cities or regions, or at broader scale for multi-country analysis. This broad regional coverage is similar to other models such as MESSAGE, GCAM, and TIMES. Other models, or their derivatives, can be made more specific, such as GCAM-USA (50 US States) and NEMS and MARKAL-USA (9 US census divisions). LEAP encompasses all energy sectors. This is also possible in models like MESSAGE, NEMS, GCAM, TIMES, and PRIMES (for the EU). Some versions of these models also include links to land, water, and

*(ORNL) Assessment of Project Technical Limitations (cont.)*

climate systems (so-called integrated assessment models). Other types of models are, by design, less broad in sectoral or geographic coverage but much more granular in their spatial and technological representation – for example, models like PLEXOS and WASP, which are often employed within utility and power companies for electricity systems planning.

As a simple model, LEAP uses built-in calculations for "non-controversial" accounting calculations and spreadsheet-like expressions to create multi-variable models. These can be input to the model quite easily and are transparent to modelers and non-modelers alike. However, this accounting framework is incapable of endogenously representing economics and policies in terms of supply-demand equilibria, technology adoption decisions, and price-induced feedback on service levels. Other energy models are better positioned to represent these real-world dynamics, as they employ optimization and simulation algorithms that rely on rich, detailed descriptions of the various components of the energy systems and how they depend on each other. For example, linear mixed-integer programming models are used to minimize energy system cost, maximize consumer surplus, or some other objective function. Such models include the MARKA L-TIMES family (including TIAM), MESSAGE family, OSeMOSYS, and TEMOA. Meanwhile, recursive-dynamic simulation models, like GCAM, make use of discrete choice (multi-nomial logit) configurations. EPRI's US-REGEN model is a hybrid that includes both optimization and simulation. Another model that employs optimization routines is PLEXOS, though it is specific to the electric sector and is not an economy-wide energy systems model like the others mentioned here.

Owing to their large computational demands and more extensive levels of training needed, all of these models usually involve a tradeoff between computational tractability and accounting for data availability, vs. technical/engineering and economic details. As a simpler accounting-type model, LEAP avoids some of these trade-offs; and while it may lack the ability to endogenously represent economics and policies, it has the advantage of being flexible to adapt and run and of being easier to explain the results to non-modelers.

## Acronyms

**GCAM** – Global Change Analysis Model

**LEAP** – Low Emissions Analysis Platform

**MARKAL** - Market Allocation Model (since 1980)

**MESSAGE** – Model for Energy Supply Strategy Alternatives and their General Environmental

**NEMO** – Next Energy Modeling system

**NEMS** - National Energy Modelling System

**OSeMOSYS** – Open Source Modeling System

**PLEXOS** – A power market simulation software

**PRIMES** – Price-Induced Market Equilibrium System

**TIAM** – Times Integrated Assessment Model

**TIMES** – The Integrated MARKALEFOM System) (since 2000)

# Overall Approach

To answer the study's key questions, the project team began by analyzing current GHG emissions (the Valley's "baseline") and building up an inventory of key facilities, equipment, and activities comprising the Valley's economy. Then four pathways (shown in Figure 5) were created, each exploring different approaches the Valley could take to achieve Net Zero emissions by 2050. These "pathway scenarios" do not intend to predict the future. Rather, they are specific visions of what might be possible under certain sets of assumptions and conditions. No single pathway is the most likely, the best, the optimal outcome, or the "right answer" to get to Net Zero. Instead, looking across these scenarios helps to identify critical commonalities or differences, quantify the relative impact of different strategies, and understand how different solution sets might trade off success, cost, or some other variable compared to alternative solutions.

### PATHWAYS VS. SCENARIOS

The specific terms "pathway" and "scenario" are often used seemingly interchangeably in this and other reports. For the purposes of this study, "pathway" is used to denote a scenario that pushes the economy toward Net Zero, in contrast to other scenarios that do not represent pathways to Net Zero, such as the Reference Scenario. In short, all pathways are scenarios, but not all scenarios are pathways.

# Scenarios

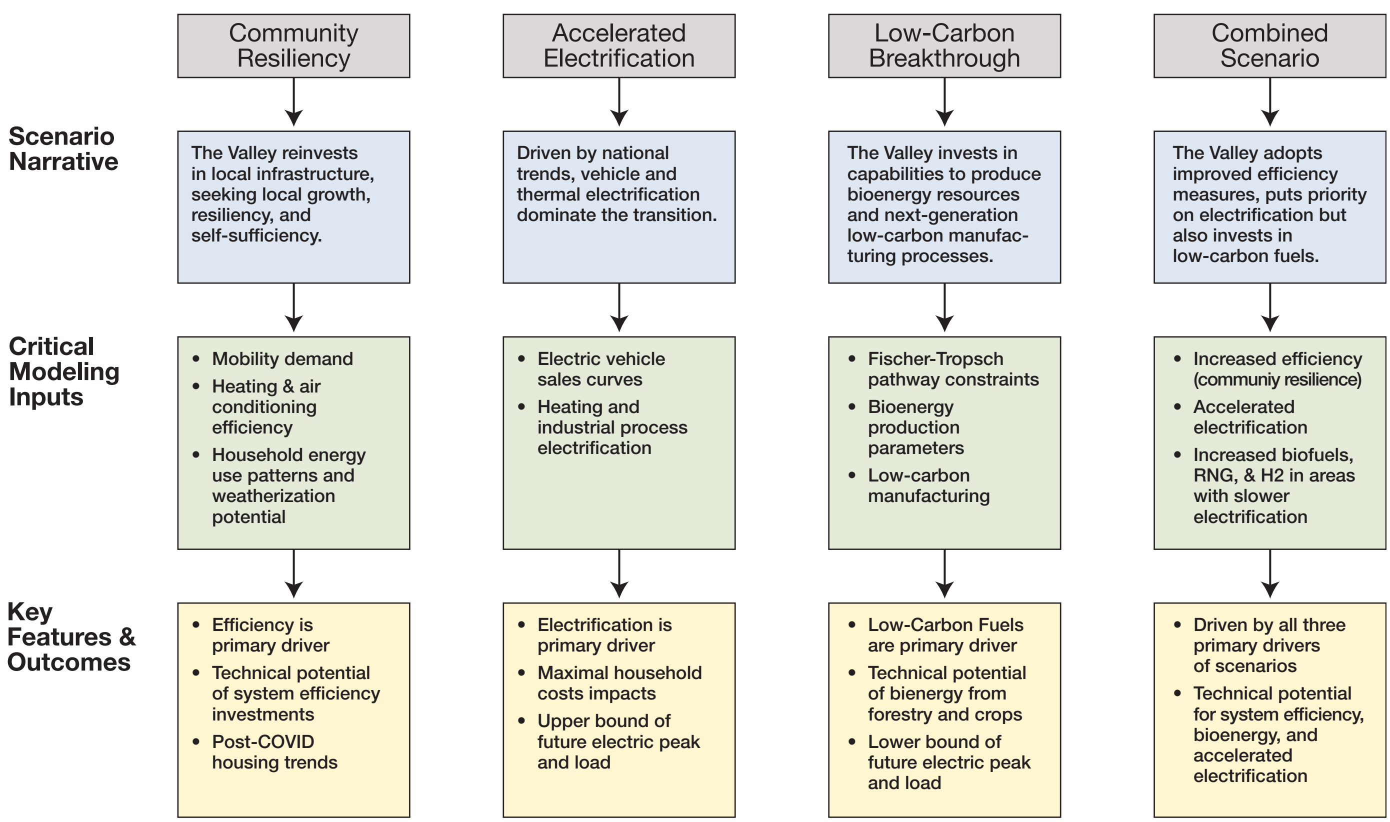



Figure 5 Four Net Zero Pathway Scenarios

The team modeled four different scenarios that would potentially lead to a "Net Zero economy." These scenarios incorporate detailed evaluation of the regional energy system including electricity, natural gas, and other energy sources to account for changing energy needs and costs. The scenarios also consider forecasted future changes to population, technology, and infrastructure. Comparing and contrasting pathways allows the determination of foundational actions that will unlock the deepest reductions in emissions for the Valley, as well as fundamental forks in the road.

Finally, as the project team modeled and analyzed these scenarios, four guiding principles highlighting the study's vision and benefits guided the development of this report:

## VALLEY-WIDE OWNERSHIP

The Valley Pathways Study is not just for its sponsors – it is for the whole Valley. Stakeholders across the economy have been engaged every step of the way, from data collection to modeling to production of the final report.

## TRANSPARENT, DURABLE OUTPUTS

The Valley Pathways Study relied on publicly available, frequently-updated data sets to develop the Valley's baseline, with detailed methodology and assumptions in the Appendix of this report. The baseline was the foundation against which viable pathways were measured. Key Performance Indicators (KPIs) have been compiled to enable transparency, future progress tracking, and long-term accountability.

## VALLEY-WIDE CONSENSUS

The Valley Pathways Study's robust stakeholder engagement plan has ensured that groups from all across the Valley and in every sector are heard. While there are varying viewpoints on specific topics or priorities, and it will take time and further efforts to reach consensus on the path forward, stakeholders from a range of sectors and perspectives can find an upside and see the value of the study's outcomes.

## FLEXIBLE OPTIONS FOR A CHANGING FUTURE

Rather than producing a rigid or static roadmap for the future, the Valley Pathways Study seeks out commonalities across viable pathways, as well as forks in the road. This report highlights not just the key next steps to get started on the journey to Net Zero, but also how to improve quality of life and quality of place, to adapt to new and rapidly-changing technologies, challenges, or conditions.

## Coordination with TVA's IRP

For those familiar with TVA's operations, a study that looks at the future energy needs of the Valley region may sound familiar – TVA regularly updates its Integrated Resource Plan (IRP) to meet electricity demand in the region from a supply-side perspective. That is, the IRP team projects what those needs will be, then develops a plan to meet them. This may sound similar to what the Valley Pathways Study is doing; however, while the two studies are evaluating similar concepts, they do so in critically different ways, and with different focuses as summarized in Figure 6.

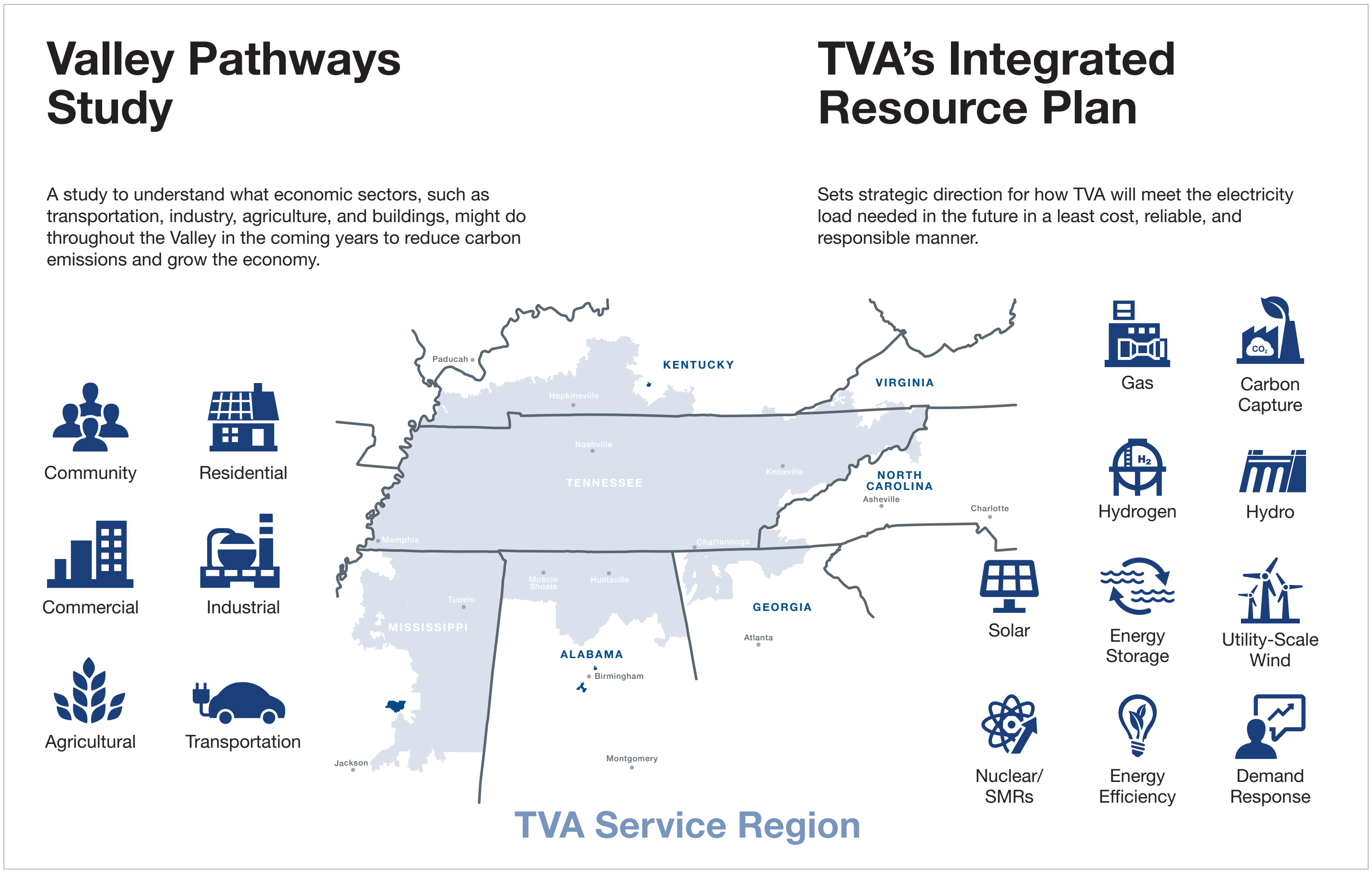



Figure 6 Valley Pathways Study vs. Integrated Resource Plan

## Stakeholder and Public Engagement and Input

Because no single group or sector can accomplish this work alone, and success will require a collaborative and inclusive approach, the distribution of information and incorporation of public comments and feedback lie at the heart of the Valley Pathways Study. The study engaged a diverse group of stakeholders that participated in working group meetings throughout 2023 to disseminate educational materials, gather feedback on study methodology, offer critiques and suggestions, and discuss the overall range and focus of this report.

Decarbonization touches every household, business, and community in the Valley, and it was therefore critical that stakeholder participation in the study's working group meetings begin early in the process and represent the broad character of the Valley. Stakeholders across the economy were engaged every step of the way, from data collection to modeling to production and review of the final report. Inputs to the study were gathered from stakeholders' feedback during several in-person and virtual meetings, and the public was invited to provide comment through the Valley Pathways Study's website and via webinars held at key milestones during the project.

Stakeholders provided input on the direction of the study and modeling assumptions during six stakeholder meetings held throughout the course of the project (see timeline in Figure 7) – high-level goals for each of these meetings are listed below:

1. **May 3, 2023 in Knoxville:** Reviewed study goals and objectives, set expectations, previewed the baseline analysis, and defined an approach to engaging public input.
2. **June 6, 2023 via virtual meeting:** Reviewed baseline and the Business-as-Usual scenario and defined pathway priorities and approaches for structuring scenarios.
3. **July 18, 2023 in Chattanooga:** Reviewed three initial pathways and set criteria for evaluating and prioritizing pathways.
4. **August 23, 2023 via virtual meeting:** Reviewed refined pathways, including the creation of a new scenario that combined the original three, and reviewed the report outline.
5. **September 19-20, 2023 in Nashville:** Reviewed the draft Preliminary Findings Report, determined Key Performance Indicators (KPIs) and the path forward.
6. **November 30, 2023 in Knoxville:** Focused on next steps and collaboration throughout the Valley to advance the goals of the study.

In addition, two public webinars were hosted: one on the Baseline and one presenting the Preliminary Findings Report. The first public webinar, introducing the study and its goals, was held on July 11, 2023 via Webex and attracted 85 attendees. The second webinar, presenting the Preliminary Findings Report to the public, will be hosted when the report is published, in the first quarter of 2024. The general public was also invited to submit comments through the Valley Pathways Study website.[5]

Public comments were aggregated and reviewed throughout the study and incorporated and/or responded to as appropriate.

5 Valley Pathways Study website: https://www.tva.com/environment/valley-pathways-study

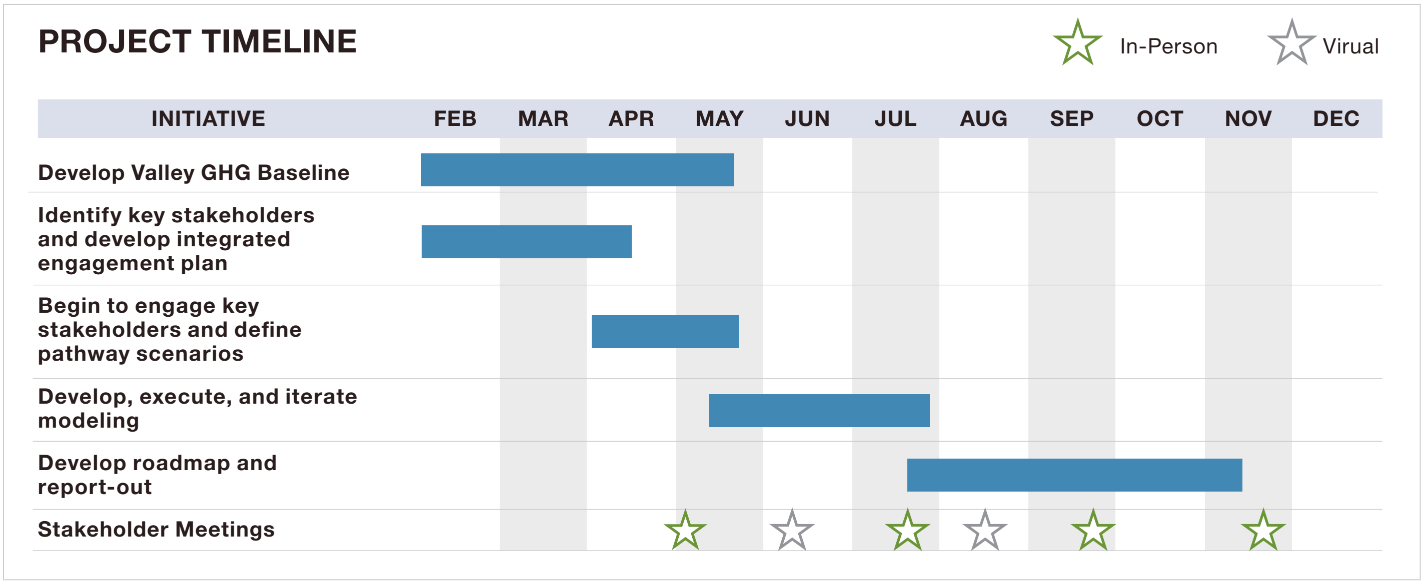



Figure 7 Project Timeline

### TECHNOLOGY LEAPS BY 2050

Over the past 25 years, some technologies that no one could have predicted or imagined in their lifetime have become ubiquitous. For example, cell phones were not common 25 years ago, and smart phones were unheard of. They are now in everyone's hands, with connectivity available nearly everywhere throughout the country. Similarly, regular use of the public Internet was in its infancy 25 years ago and is now ubiquitous and indispensable for work, entertainment, commerce, communication, and more. The next ~25 years between now and 2050 will likely see leaps of technology deployment that may seem far-fetched now, just as smartphones would have in the late 1990s, but that will change the ease of implementing some of these sector-specific emission reduction strategies, making the pathways to Net Zero more easily achievable.

# Progress Made to Date in the Valley

Reducing GHG emissions is not new to the Valley. The Valley has already made great strides toward Net Zero goals while supporting quality of life and economic development across the region.

Emissions throughout this report are reported in carbon dioxide equivalent ($CO_2e$) which is the accepted standard for reporting emissions.[6] Between 2005 and 2019, Valley-wide emissions fell by 78 million metric tonnes of carbon dioxide equivalent ($MMCTCO_2e$), nearly a 30% reduction. The vast majority of those reductions – about 60 $MMTCO_2e$ – come from energy efficiency and fuel switching that reduced emissions from TVA's systemwide operations. However, reductions in the electricity sector alone are unable to bring the entire Valley to Net Zero emissions by 2050. This challenge will be even more pronounced as electrification increases, reducing fossil fuel demand and associated GHG emissions, but also simultaneously increasing strain on the electric grid (due to, for example, expanded EV charging networks). While TVA's IRP will be examining that challenge in detail, the Valley Pathways Study is focused more on the various pathways to decarbonize the economy – the opportunities and

6 $CO_2e$ includes all gases such as methane and nitrous oxides and uses their associated emissions factors to convert them to their warming potential equivalent in carbon dioxide ($CO_2$)—for example, 1 kg of nitrous oxide has the same warming potential as 298 kg of carbon dioxide, so 1 kg of nitrous oxide would be reported in this section as 298 kg $CO_2e$.

challenges facing local communities and businesses, and the perspectives of different sectors and stakeholders from across the Valley.

**Efficiency programs** are offered throughout the Valley by Local Power Companies (LPCs). Energy program offerings are varied, with wide-ranging outcomes and comfort improvements for residents. Across the Valley, 142 of 153 LPCs participate in at least one TVA energy efficiency program.[vi]

In May 2021, **TVA's Board announced an aspiration of reaching Net Zero emissions by 2050.**[vii] Today, TVA's electricity mix is more than 50% carbon-free, primarily due to hydropower and nuclear energy. The Valley's grid is cleaner than that of the U.S. as a whole, which still burns fossil fuels for 60% of its power according to the Energy Information Administration (EIA).[viii]

TVA is taking the steps today to build the energy system of the future. This means adding 10,000 megawatts (MW) of solar capacity by 2035. New operating solar and commitments for new solar account for roughly 3,000 MW of solar capacity. These additions will meet the needs of the TVA system as well as customer needs for renewable energy through the Green Invest program. They will also help reduce overall Valley carbon in a way that drives jobs and investments in the region. Generation Flexibility - the ability for LPCs to generate up to 5% of their average demand from distributed resources - could add up to to 2,000 MW of additional solar through local power company projects at the community level.

## PROGRESS IN ACTION: BETTER BUILDINGS PARTNER CITY OF CHATTANOOGA

The U.S. Department of Energy (DOE) recognized Better Buildings Challenge partner City of Chattanooga, TN, for energy efficiency leadership across more than 200 of its municipal facilities. Chattanooga has achieved 36% energy intensity savings across two million square feet of building space from a 2013 baseline. A key case study in the city's portfolio, the city implemented efficiency and clean energy upgrades to its Moccasin Bend Environmental Campus. To improve the wastewater treatment facility's efficiency and performance, the City of Chattanooga installed a 10-acre solar array, upgraded the facility's equalization blower, retrofitted the building with LED lighting, improved water systems, and installed variable frequency drive controls. The approach resulted in savings of 27% on energy and 24% on water annually, saving $1.4 million per year.

*Photo credit: James Cool, Cool New Media*

For more details, visit: [DOE Recognizes Better Buildings Partner City of Chattanooga, TN for Energy Efficiency Achievements | Department of Energy]

Progress toward Net Zero emissions is also happening at the local scale. For example, as part of its green city initiative, Chattanooga won the U.S. Department of Energy's Better Buildings Challenge in 2022 by decreasing energy intensity across municipal buildings by 36%, particularly through efficiency upgrades at the city's wastewater processing facility. Reduction in energy consumption and bills have not impeded city operations, but rather have enabled the city to save money on operating costs. The wastewater treatment plant was a major energy user and made huge improvements in energy consumption while maintaining performance.

Large industrial and institutional customers are already pushing the economy toward Net Zero emissions, bolstered by consumer demand and corporate sustainability commitments. At the newly constructed industrial park in Shelbyville, Tennessee, TVA facilitated a 35 MW utility-scale project, developed by homegrown solar company Silicon Ranch, roughly 50 miles southeast of Nashville. The Shelbyville site will offset 70% of Vanderbilt University's carbon emissions from electricity consumption. This project was facilitated by an innovative TVA program (Green Invest) that is helping customers install solar in the Valley. Vanderbilt I Solar Farm is the result of a landmark agreement as the first project contracted under TVA's nationally recognized Green Invest program, which matches demand for green power from diverse commercial, industrial, and institutional customers with new utility-scale solar projects in the Tennessee Valley.

The Valley's transition to a Net Zero economy is already driving significant economic growth in the region and will likely continue to do so. Electric vehicle battery manufacturing is taking off in the Valley, with a large Volkswagen plant in Chattanooga having fully pivoted toward EVs. The city is emerging as a central hub for battery manufacturing, with potential partnerships in the works with large automobile manufacturers. When a new EV factory, such as Ford's large BlueOval City outside Memphis, is interested in purchasing clean energy, TVA and Local Power Companies offer a suite of options to meet customers' renewable and clean energy needs.

# Environmental Justice and Community Impact Considerations

Supporting economic development via any pathway will be key to addressing socio-economic inequalities and addressing the fact that the Valley is lagging many national socio-economic indicators. There is a significant urban-rural divide in technology, broadband, job access, and incomes, with rural areas lagging urban areas. A pathway to Net Zero emissions will only be achievable if all socio-economic levels are able to participate and if benefits are shared equitably across socio-economic classes.

Federal Executive Order 14008 states that "Agencies shall make achieving environmental justice part of their missions by developing programs, policies, and activities to address the disproportionately high and adverse human health, environmental, climate-related, and other cumulative impacts on disadvantaged communities, as well as the accompanying economic challenges of such impact."[ix] "Environmental justice" means the just treatment and meaningful involvement of all people, regardless of income, race, color, national origin, Tribal affiliation, or disability, in agency decision-making and other Federal activities that affect human health and the environment so that people: (i) are fully protected from disproportionate and adverse human health and environmental effects (including risks) and hazards, including those related to climate change, the cumulative impacts of environmental and other burdens, and the legacy of racism or other structural or systemic barriers; and (ii) have equitable access to a healthy, sustainable, and resilient environment in which to live, play, work, learn, grow, worship, and engage in cultural and subsistence practices."[x]

The implementation of pathways scenarios will need to consider the potential environmental justice impact on communities to ensure no community suffers disproportionate harm as a result of this transition as well as to ensure that the benefits of a clean energy economy are delivered to disadvantaged communities.

Communities are considered disadvantaged if they are located in a census tract that meets the thresholds for at least one of the Climate and Economic Justice Screening Tool (CEJST) categories of burden.[7] As a result of this burden, members of a disadvantaged community (DAC) may face challenges in accessing opportunities and resources that are readily available to others. Around 1,300 census tracts, or about half of census tracts in the Valley region, have been identified and mapped as DACs in the CEJST. Disadvantaged communities can be mapped by looking at the overall cumulative burden across thirty-six "Justice 40" indicators.[xi]

Across the Valley, 22% of households are housing burdened (spend more than 30% of household income on housing, Figure 8). In addition to housing, energy affordability varies throughout the Valley. Energy burden is the percentage of gross household income spent on energy costs. Compared to the rest of the nation, the East South Central region (Kentucky, Tennessee, Mississippi, Alabama) has the highest percentages of households experiencing high energy burden (Figure 9).[xii] Energy burden is not even across the Valley, with some communities more impacted by the cost of energy than others (Figure 10).[xiii]

7 As defined in the Climate and Economic Justice Screening Tool (CEJST) documentation, https://static-data-screeningtool.geoplatform.gov/data-versions/1.0/data/score/downloadable/1.0-cejst-technical-support-document.pdf.

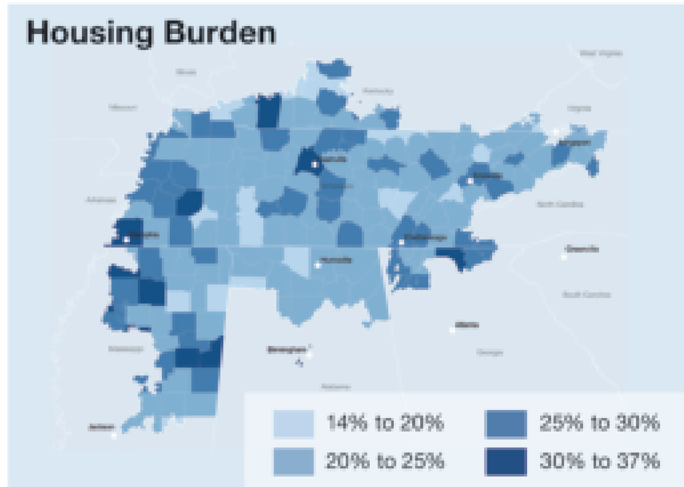



Figure 8 Housing burden across the Valley

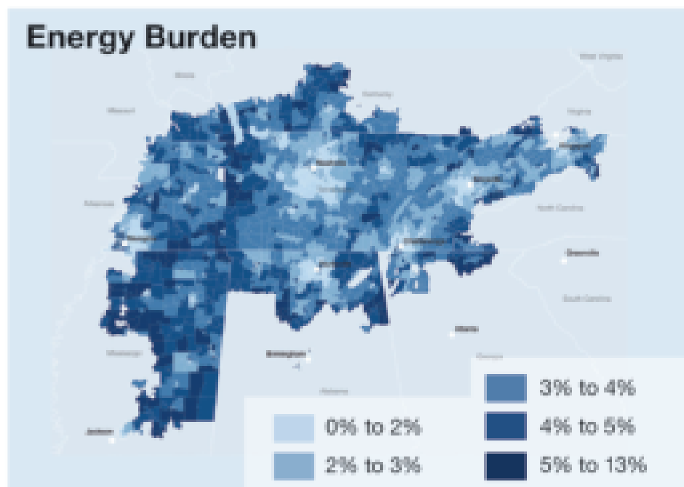



Figure 9 Energy burden across the Valley

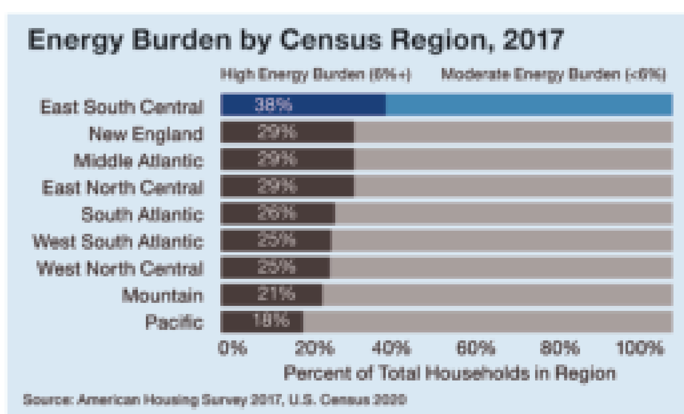



Figure 10 Energy burden by region

**PROGRESS IN ACTION: TVA CONNECTED COMMUNITIES' FOCUS ON ENERGY BURDEN**

The Connected Communities initiative helps Valley communities become more connected by linking them to resources, funding opportunities, and tailored support. By supplementing capacity and bridging communications on both the TVA and community sides, the initiative can help communities more effectively access resources and plan for a more equitable, technology-driven future.

The initiative supports communities in their efforts to reduce energy burden in several ways. One of them is the Community Information Hub (CIH), a community engagement, insights, and reporting platform that tracks fifteen metrics across communities in the Valley on an interactive and easy-to-use map. The CIH can serve as an excellent resource for identifying target communities that need support in addressing energy burden and energy insecurity.

Connected Communities also supports six communities through in-depth partnerships and by linking those communities with targeted resources and tools. This approach complements and deepens the impacts of other initiatives addressing energy burden. These include efficiency improvements and education, such as efficiency and weatherization programs for underserved homes, schools, and communities to decrease energy use (e.g., EnergyRight portfolio, including Home Uplift and School Uplift) as well as home energy financing programs, energy conservation, and bill management education.

The initiative also funds pilot projects, some of which directly focus on reducing energy burden, by offering economic development opportunities or reducing household energy consumption.

## Rural Communities

For nearly a century since its original creation, TVA has supported growth and economic development of rural communities throughout the Valley through the installation and development of critical infrastructure. As rural communities in the Valley thrive and grow, significant infrastructure upgrades – including sewage, roads, and electricity distribution – will be needed to support that growth. Aligning those needed infrastructure upgrades with key features of a Net Zero economy – such as considering EV charging needs – can help to ensure that rural communities are not left behind in the clean energy transition.

In addition to infrastructure challenges, rural residents may face several geographic, financial, informational, and access barriers that make it difficult to invest in home energy upgrades. Research in other regions has shown that, nationally, energy burden is 33% higher in rural areas vs. other areas and that participation in residential energy efficiency financing and rebate programs can be significantly lower in those rural areas.[xiv] In the Valley, the energy burden rate is around 3.25% on average, but is higher in rural areas (3.94%) vs. urban areas (2.94%).[xv] The age and condition of the housing stock can also be a cause of high energy burden in rural areas. Some rural areas have older housing stock and a greater percentage of mobile homes, which are often less energy efficient than newer homes.[xvi]

Rural areas' physical distance from resources (e.g., human, financial) is often further exacerbated by a lack of economies of scale in small communities, making it harder for rural residents to access financing, incentives, and professional services to implement energy efficiency projects. There is often a lack of qualified contractors willing to serve rural areas as well as unavailability of a local, skilled workforce. With lower incomes, residents of rural areas are often unable to afford efficiency upgrades to their homes or access financing for such upgrades.[xvii]

Traditional marketing campaigns that rely entirely on online marketing have more limited success in rural areas, where internet connectivity and connected device ownership is lower, thus reducing awareness of such programs. Small rural communities often rely on word-of-mouth. Thus, skepticism of assistance programs and challenges in finding a trusted messenger can limit the success of traditional online marketing campaigns for efficiency improvements in rural areas.[xviii]

The rural access gap can be addressed through specific strategies such as (a) designing programs, initiatives, and campaigns that take this divide into account; (b) aggregating demand to achieve economies of scale; (c) creating community partnerships; and (d) supporting workforce development and local labor.

## Urban Communities

Poverty and vulnerability are present in urban neighborhoods as well as rural areas. Some urban neighborhoods in the region are among the poorest in the nation. Many of the larger cities in the Valley are leading the way toward decarbonization through the development of community-scaled GHG inventories and climate action planning. However, the incorporation of equity and environmental justice into such climate action plans is complicated, requiring the development of nuanced strategies and, ideally, bringing DACs into the analysis and planning as a two-way dialogue. The EPA has awarded $1 million Climate Pollution Reduction Grants to each of the cities of Knoxville, Nashville, Memphis, and Bowling Green, as well as another $3 million to each to six of the Valley states.. These grants will help governments throughout the region to develop priority climate action plans with a heavy focus on driving forward environmental justice priorities. In particular, these planning resources are meant to drive deep stakeholder engagement needed to identify critical local issues and to prioritize how to address issues such as air pollution exposure, public transit, and urban infrastructure constraints that are all intertwined with deep decarbonization technologies.

### PROGRESS IN ACTION: CLEARPATH COMMUNITY PILOTS

The cities of Chattanooga, Memphis, Nashville, and Knoxville all participated in a TVA-supported pilot to develop GHG inventories and evaluate emission reduction levers using the ClearPath software package developed by Local Governments for Sustainability (originally named the International Council for Local Environmental Initiatives, or ICLEI). These projects, leveraging data aggregated by the Valley Pathways Study in the Valley's GHG baseline, highlight how local action can coordinate with and drive forward regional decarbonization goals. They also represent a simple, repeatable process for communities of all sizes and shapes to develop initial GHG inventories and climate action plans.

# Scenarios, Modeling, and High-Level Approaches to Reduce Emissions

## Analytical Approach

The Valley Pathways Study project team explored pathways using the Low Emissions Analysis Platform (LEAP), an economy-wide energy and emissions model, to create the Valley's reference, baseline, and pathways scenarios. The LEAP modeling platform was developed by the Stockholm Environment Institute and has been successfully applied across 200 different regions to date, with improvements constantly being made to the platform. LEAP's interface provides a transparent accounting framework rather than a black box model, with a framework that is customizable and able to capture key features of the Valley. More details on the LEAP model are in the Appendix.

The modeling team followed a multi-step approach to develop its methodology, each step of which will be discussed in further detail in the following sections.

**Step 1 – Baseline Development:** A GHG baseline was developed for the Valley, which provides a baseline metric for comparing the present day to a reference scenario and proposed pathways. This baseline follows protocols established for public-sector jurisdictions. These are somewhat different from GHG footprint protocols established for private sector companies and non-profit organizations. The Valley's inventory considers all emissions sources within the geographic extent of the Valley.[8] The baseline is separated into distinct sectors and activities, such as the combustion of fuel to heat buildings in the winter ("Buildings"), the generation of electricity to meet demand throughout the economy ("Electricity"), or the combustion of fuel to power on- or off-road vehicles ("Transportation"). Importantly, unlike corporate inventories, the flow of goods and products into and out of the geographic extent of the Valley is not considered. Future iterations of the inventory could include such "embodied" emissions, especially in order to understand how emissions from manufacturing and agriculture in the Valley support the national economy and could be considered in other jurisdictions' inventories.[xix]

**Step 2 – Reference Case:** Next, a reference, or "Business-as-Usual" scenario was modeled, which assumed that current laws, regulations, and socio-economic trends (population growth, vehicle miles traveled, sector-specific growth, etc.) continue through 2050 without any major surprises or changes. Rather than being predictive, the purpose of the reference case is mainly to act as a point of comparison for the modeled scenarios that would allow for a better discussion of the costs and benefits of certain pathways compared with proceeding ahead without any major changes.

**Step 3 – Pathways Modeling:** Finally, four pathways were created, each exploring different approaches the Valley could take to achieve Net Zero emissions by 2050. The goal of each pathway was to explore a potential strategy that the Valley could pursue to achieve Net Zero emissions by 2050 (rather than to recommend any specific scenario as the best one). Similar to the reference case, these pathways were not modeled to be predictive, but rather to provide the basis for a conversation of what actions need to be taken now and in the future to achieve a Net Zero economy. The scenarios aim to answer what the costs and benefits of different approaches look like and how these costs and benefits should be distributed to encourage economic growth, environmental justice, and overall prosperity in the region.

8 Corporate emissions protocols typically separate emissions out into Scope 1 (on-site fuel combustion), Scope 2 (induced electricity generation), and Scope 3 (induced and indirect emissions associated with buying and selling goods and services – i.e., the upstream and downstream value chain). These sources within the Valley can be aligned to corporate emissions scopes, with the caveat that any Scope 3 emissions reflecting goods purchased from or sold to entities outside of the geography of the Valley are excluded.

After all scenarios were modeled, the project team had a rich source of comparable outcomes that allowed for discussions on costs, benefits, societal concerns, behaviors, and environmental justice that will be key considerations for the Valley's future.

## Baseline

To calculate the existing GHG emissions in the Valley, the modeling team prioritized historical data that were available from the federal government and granular to the county level. When county-level federal data were not available, or did not represent the Valley well, state-level data or other sources were used. Non-geographically-specific data were used for characteristics that are not constrained to the Valley, such as energy intensity of industrial processes, efficiency of heating and cooling equipment, or life expectancy of battery types.

The baseline is the foundation for the future pathways, and the data used were critical to establishing the "activity levels" in the Valley. These "activity levels" are a broad and flexible group of characteristics used to quantify how people live, work, and move around the Valley. For example, for certain industrial processes, the activity levels selected were dollars of goods produced; for personal transportation, passenger-miles traveled (PMT) and vehicle-miles traveled (VMT) were selected. Energy consumption was then calculated by multiplying activity level by energy intensity (i.e., energy per unit, such as kilowatt-hour per square foot of building area, or gallons of gasoline per vehicle-mile traveled) for each of the component parts of the Valley's activity level. Resulting values were validated by benchmarking against key external data sources. For example, total electricity consumption from all demand sectors across the Valley was benchmarked and validated against TVA's own operational records for 2019. Similarly, total gasoline demand associated with vehicles in Tennessee was benchmarked to gasoline sales figures from the U.S. Energy Information Administration's State Energy Database System (SEDS). Greenhouse gas emissions were then calculated by multiplying energy consumption by emissions factors, which were then summed across the entire Valley to create the overall baseline.[9]

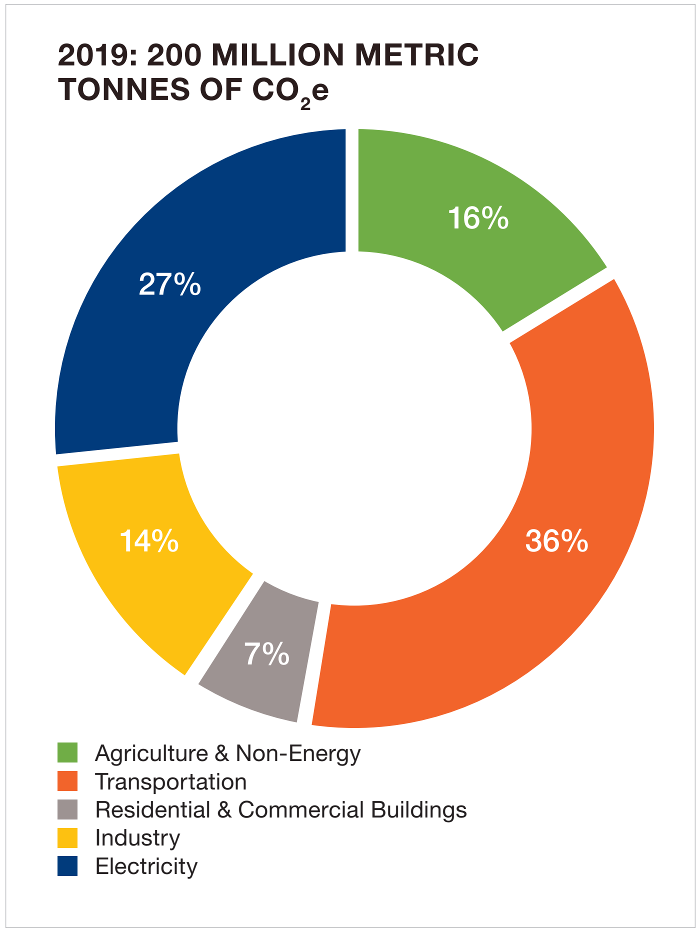



**Figure 11 Baseline Greenhouse Gas (GHG) Inventory for the Valley**

(Note: Activity level and energy intensity are adjustable levers in LEAP and were adjusted to create the different pathways. Adjusting these levers changes characteristics such as the growth and contraction of industries, populations, and land usage [by adjusting activity level], as well as the efficiencies of processes or services [by adjusting intensity]. The details of how these levers were adjusted in LEAP to create the pathways and scenarios is discussed in further detail in the Appendix.)

The modeled baseline results are shown in Figure 11. More than one third of the Valley's baseline GHG emissions are associated with transportation (36%), and a little more than a quarter of GHG emissions

9 Emissions factors taken from EPA Emissions Hub Spreadsheet, version April 2022.

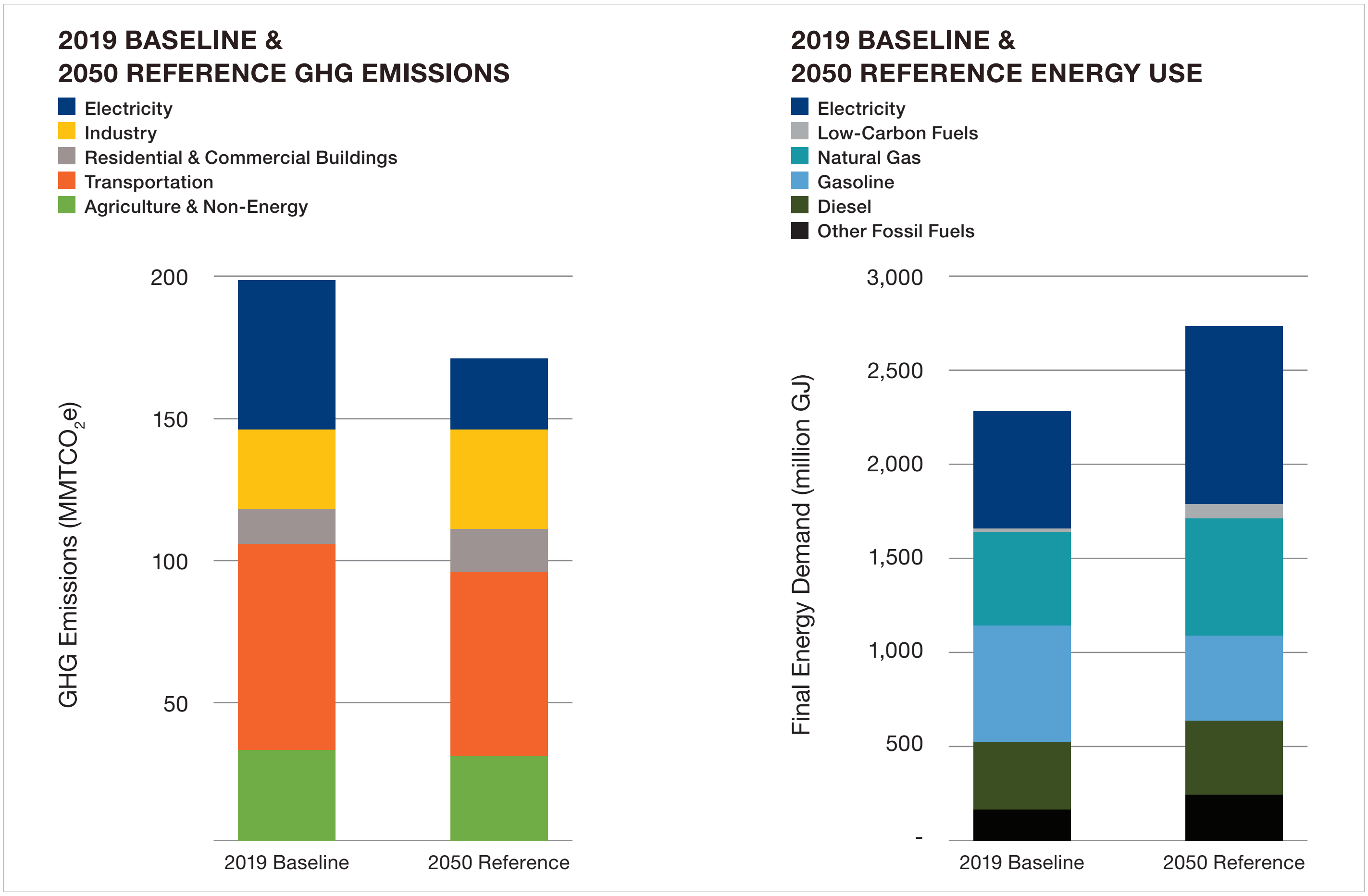



**Figure 12 Baseline and Reference Case GHG emissions and energy use for the Valley**

come from electricity generation (27%). Non-energy GHG emissions, which make up an additional 16% of total emissions, includes sources such as methane emissions from cattle, waste disposal, and storage and wastewater treatment. Transportation emissions in the Valley are a large proportion of the total emissions in part due to the prevalence of personal vehicles and relative lack of public transportation compared to other parts of the country.

## Reference Case

The reference (or "Business-as-Usual") scenario reflects existing plans and policies in the Valley and extends these trends through 2050. The purpose of the reference scenario was not to predict the Valley's emissions and electricity profile, but rather to establish a foundation for comparison of the four pathways scenarios versus what the Valley's future may look like if no substantial changes occur. In the reference scenario, current policies, regulations, growth patterns, and generation consumption behaviors are assumed to remain steady through 2050. Many of the trends and prices used in the reference case were taken from EIA's most recent annual energy output data.[xx] The University of Tennessee's Boyd Center for Business and Economic Research provides population and economic forecasts specific to the TVA territory.

As shown in Figure 12, the reference case assumptions result in a decrease in GHG emissions of about 10% between 2019 and 2050. Transportation marks the largest sectoral growth in emissions which can be attributed to expected population growth and forecast vehicle miles driven. TVA is in the process of creating the next iteration of its IRP, which will investigate how changes to the economy and energy demand such as the ones modeled here will result in new electricity generation needs, including new clean energy sources. The IRP was in process at the time of the publication of this report, so the emissions associated with electricity generation shown in the pathway scenarios are shown as a range. The lower bound of the range represents a scenario where TVA moves to 100% clean electricity generation by 2050. The upper bound, illustrated in the Reference Case below, incorporates key findings from TVA's 2019 IRP as well as announcements made since then, namely:

- 10 GW of solar capacity deployed;
- Retirement of remaining coal capacity; and
- The addition of natural gas generation to meet new load growth due to demand-side electrification.

## Pathways Development

The project team created four pathways toward Net Zero emissions to explore various ways the Valley might achieve that target by 2050. Three scenarios each reflect one of the "Pillars of Decarbonization" that have been described and studied at length in other decarbonization studies throughout the world – electrification, efficiency, and low-carbon fuels. By anchoring each scenario to one of the pillars as shown in Figure 13, the modeling team was able to test the impact and limits of pushing the envelope in certain areas (e.g., efficiency or electrification). Comparing the results of modeling those three scenarios allowed the team to identify common elements representing "no-regrets" actions, while differences and contrasts will help to identify trade-offs and alternative outcomes. A fourth pathway, specifically requested by stakeholders during the modeling process, combines aspects from the original three scenarios to drive gross emissions further down than any of the original three could on their own.

Although sometimes stated slightly different depending on the source and study, the Pillars of Decarbonization are typically represented as:

**1. Reduce Energy Demand** – Investments in energy efficiency and other strategies to reduce energy demand. This pillar was investigated in the "Community Resiliency" scenario.

**2. Electrify Energy Demand** – Wherever feasible throughout the economy, replace fossil fuel combustion with electrified alternatives, such as battery-electric vehicles and heat pumps. This pillar was investigated in the "Accelerated Electrification" scenario.

**3. Use Clean or Renewable Energy Sources** – Switch the source of energy away from fossil fuels and toward clean and/or renewable sources. This pillar was investigated in the "Low-Carbon Breakthrough" scenario.

In addition to the three decarbonization pillars noted above, net zero strategies typically also feature approaches to remove and store carbon through biogenic sequestration and artificial carbon capture. These "negative emissions" must balance out any residual emissions that cannot be abated from the economy in order to mathematically reach "Net Zero" emissions.[10]

### Strategy Components of Net Zero Pathways

Within the pillars identified above, the project team considered a range of different strategies for inclusion in each pathway. Although there are myriad different technologies, processes, and innovations that can be brought to bear on the road to Net Zero, the strategies presented below represent the fundamental building blocks used in this study and informed the assumptions and inputs used to model a Net Zero Valley economy.

10 Evaluation of the Valley's GHG baseline found that the forests within the Valley are a potent sink for carbon dioxide. Rather than develop a specific pathway to test further options to remove carbon, the modeling team elected to use that level of sequestration to determine the maximum amount of GHGs that the economy could still emit in 2050.

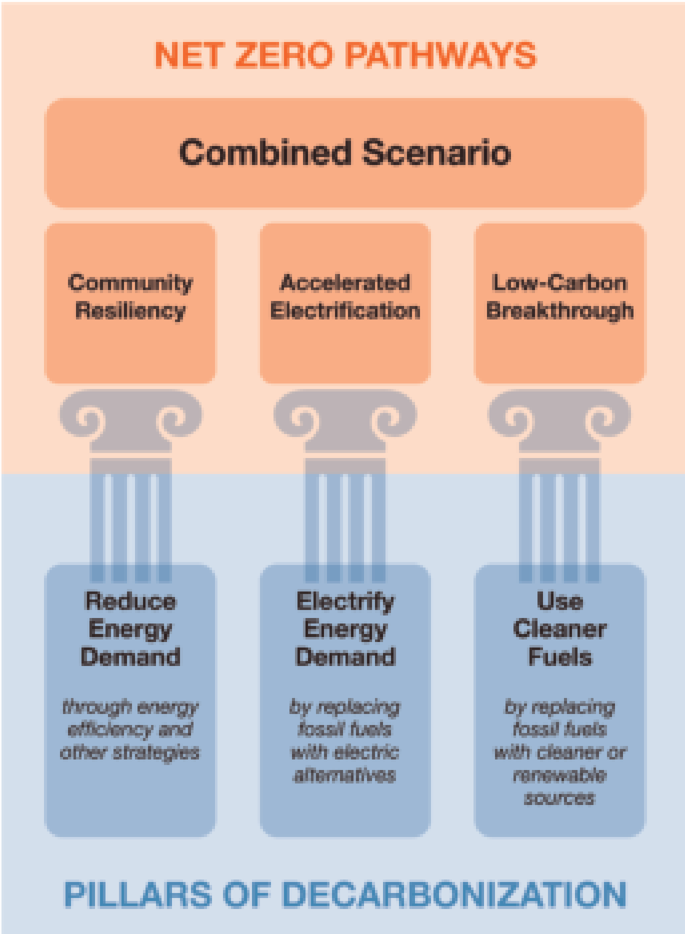



Figure 13 Connecting the pillars of decarbonization to the Net Zero pathways

***1. Reduce Demand***

A reduction in emissions can be achieved while supporting economic activity by utilizing resources more efficiently. Examples of GHG emission reductions achieved through reduced demand are detailed below.

### Building Envelope and Energy Efficiency

Weatherizing buildings – or sealing gaps where air leaks in or out of the building and adding insulation – can reduce how much hot or cool air the building loses during the heating or cooling season, respectively. This not only reduces energy demand and associated GHG emissions, but it also improves comfort and saves on energy bills, allowing residents and businesses to re-invest these funds in the local economy.

The same efficiency principles and resulting decrease in energy demand are achieved by installing appliances and devices that use less energy to do the same task, such as a more efficient refrigerator or air conditioner. Notably, new air-source heat pumps, which provide both heating and cooling, are significantly more effective and efficient than previous generations of the technology and can provide heating up to three times more efficiently than electric resistance or combustion heating technologies.

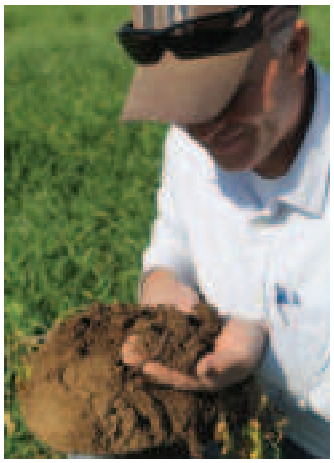
### Zoning, Public Transportation, Urban Planning

Reducing the need for commuting in a single passenger vehicle is another example of reduction in demand. This can be achieved through smart zoning and telecommuting. When cities are designed and built so that residents do not need to travel long distances in single-occupancy vehicles for work and their daily activities, but can instead walk, bike, or take public transportation, then the overall number of miles driven in a car can be reduced. Through smart zoning, emissions associated with vehicle-miles traveled (VMT) can be reduced or eliminated without compromising economic opportunities.

### Agriculture

Using practices that reduce GHG emissions without impacting agricultural output can have a favorable outcome on reducing non-energy emissions. This could include improved manure management, methane capture, and continued research into

the rumen microbiome and implementation of solutions for livestock farmers to increase efficiency and decrease emissions. Although there is much uncertainty over whether these practices will be adopted, stakeholders in the study noted that an analogy for new farming practices could be seen in the adoption of "no-till" farming in the Valley. While relatively uncommon nationally, "no-till" practices – a style of farming that significantly reduces soil erosion – have already been adopted and deployed throughout much of the farmland in the Valley, indicating that change is possible if the right economics and incentives are present.



### *2. Electrify End Uses (Electrification)*

Electrification refers to changing the energy source that a device or system uses from fossil fuels (oil, coal, natural gas) to electricity. This includes many possible transitions, including the following:

- Switching from a gas or diesel vehicle to an EV
- Switching from a natural gas furnace to an electric heat pump
- Switching a natural gas-powered industrial process to a heat pump or electric boiler

The fuel used to produce the electricity these devices demand will determine the emissions associated with electrifying a vehicle, appliance, or process. If the grid were running on only clean energy resources such as nuclear, hydro, and renewables, there would be no emissions associated with operating the electric appliance or vehicle (although there would still be benefits to reducing demand on the electric grid). As current grids do rely on the combustion of fossil fuel to produce electricity, there are currently GHG emissions associated with electrifying end-uses. As of 2020, about half of TVA's electricity generation came from clean energy sources. Heat pumps and EVs are typically more efficient than their fossil fuel counterparts, so they use less energy overall – this means that even with today's grid, electrification of end-uses typically results in a net emissions reduction even after accounting for the emissions associated with increased electricity demand. As the electric power supply moves closer to zero carbon over time, this trend will only improve.

**PROGRESS IN ACTION: CLIMATE ACTION PLANNING IN MEMPHIS AND SHELBY COUNTY**

The Memphis Area Climate Action Plan is a framework for achieving significant reductions in the community's greenhouse gas (GHG) emissions and fostering a more equitable, healthy, and prosperous community. The Plan includes a target to reduce emissions by 15% between 2016 and 2020 (which was accomplished), 51% by 2035, and 71% by 2050. This would be equivalent to a decrease of ~14 $MMtCO_2e$ relative to the 2016 baseline. Implementation of the plan has so far included streetlight retrofits, a green fleet initiative, solar PV arrays, electric buses, methane capture at the wastewater facility, and continued advocacy for grid decarbonization.

Although many electrification options have higher up-front costs than their fossil fuel counterparts,[11] improved efficiency and the associated reduced operating costs (especially due to relatively low electricity rates in the Valley) result in a payback period of just a few years.

During this period of transition toward widespread electrification, hybrid devices that can use both electricity and fossil fuels can ease the transition, especially in areas where EV charging infrastructure is not well-developed or in cooler areas where back-up non-electric heat is necessary. For example, plug-

11 This is a hurdle that is particularly hard to overcome in older homes whose systems were not designed to support electrification of large appliances such as heat pumps. This represents a gap in incentive/rebate structures and can pose additional financial burden on DACs – additional rebates and incentives to help update older homes' electrical systems can help close this gap.

in hybrid cars can switch to a gas engine when the battery is depleted and are a good stop-gap option until EV charging infrastructure is built out. This is especially true in more rural areas where charging stations are currently uncommon. Similarly, a dual-fuel furnace that uses a heat pump but can also burn natural gas can reduce pressure on the electric grid by reducing the peak demand during the coldest days of winter, enabling a smoother transition to full electrification.

### *3. Develop a Low Carbon Energy Supply*

Transitioning the energy supply from higher emission sources such as coal, petroleum, and natural gas to lower-carbon energy sources, including solar, wind, hydro, nuclear, and low-carbon fuels will reduce GHG emissions in the Valley. As discussed elsewhere in this report, this study focused its efforts on strategies to decarbonize energy sources at the point of demand, rather than on decarbonizing the electricity system – that supply-side decarbonization is a key research question for TVA's current IRP, which was in progress at the time of the publication of this report.

### Renewable and Low-Carbon Electricity

Net Zero GHG emission electricity can be produced using renewable energy (solar, wind, biomass) or nuclear (nuclear plants, small modular reactors – SMRs). TVA's IRP is currently evaluating strategies and technology options that can supply the Valley with increasingly clean energy, matching TVA's sustainability ambitions while maintaining a resilient


and low-cost grid. However, reviewing other decarbonization studies from around the world highlights a few critical findings the IRP will likely evaluate and discuss in greater detail.

First, the electrification of end-use demands represents a key challenge to the grid as more generating resources must be brought online and transmission and distribution systems must be augmented to handle higher peak demands. Moreover, growing electricity demand redoubles the challenge of decarbonizing the grid, as operators must provide more and more energy at lower and lower carbon levels. Operating a grid that relies heavily on solar and wind can represent a significant challenge, as the sun does not always shine and the wind does not always blow. Detailed modeling studies have typically found that a diverse array of resources, including short- and long-term storage (e.g., pumped hydro or battery systems), legacy thermal generation with or without carbon capture devices, and advanced low-carbon generating alternatives are likely the most cost-effective and resilient approach to supplying near-carbon-free electricity. Continued research and development and commercialization of innovative technologies – including grid-scale battery storage; clean hydrogen production, storage, and use; and other grid flexibility options – have often been identified as critical needs to enable the Net Zero grid of the future.

### Renewable Natural Gas

Renewable natural gas (RNG), also known as biomethane, can be captured through a number of applications, the most common being landfills, wastewater treatment plants, manure pits on farms, and digesters utilizing farm and food waste. This low-carbon fuel is commercially available today and has many applications in today's energy transition and a role to play in corporate decarbonization strategies. Produced by capturing methane released by decomposing organic wastes, it is currently the cheapest and most scalable form of renewable gas available. The use of RNG can reduce carbon emissions from assets that use natural gas as a fuel source with few or no equipment upgrades, making it a reliable alternative carbon-neutral fuel.

### Hydrogen

Although not in wide use today, hydrogen can be used for many applications:

- Transport: Fuel cells to power passenger and heavy vehicles, materials handling, rail, shipping, and potentially aviation;
- Heat: Circulated in gas networks and combusted to produce heat;
- Industrial processing: Feedstock for a number of chemicals such as ammonia and other higher order liquid fuels;
- Energy storage/electricity generation: Used as a method of longer-term energy storage and electricity generation to overcome the reliability (or energy storage) challenges associated with increasing proportions of variable renewable energy.

Although some of these applications are in early demonstration stages, others are more proven, and hydrogen may play an important role in a future Net Zero economy. Low-carbon-intensity hydrogen can be made using renewable energy (often called "green hydrogen") or from natural gas in association with carbon capture and storage (often called "blue hydrogen").

While the popularity of hydrogen has fluctuated in recent decades, a confluence of factors has prompted renewed interest. Climate change policies in certain jurisdictions and the drop in cost of renewable energy (a material cost input for hydrogen production) have both contributed to this uptick. However, more important is the fact that the hydrogen value chain is now underpinned by mature technologies. De-risking these technologies from a technical perspective has meant that the technology readiness has shifted from research and development (R&D) to market activation.

### Biomass and Biofuels

Using biomass to replace fossil fuel combustion for energy production can be an effective option, particularly for space heating in buildings and as biofuels such as biodiesel.

The most common biofuels are ethanol (alcohol blended with petroleum gasoline for use in vehicles) and biodiesel (diesel that can be produced from waste cooking oil and fats recovered from sewage). Biodiesel is often blended with petroleum diesel for consumption. Other biofuels include renewable diesel, renewable heating oil, renewable jet fuel (sustainable aviation fuel [SAF], alternative jet fuel, or biojet), renewable naphtha, renewable gasoline, and other emerging biofuels that are in various stages of development and commercialization.

Using food crops for energy (corn for ethanol, or soy for biodiesel) produces some challenges. However, coproducts of the ethanol and biodiesel production process remain in the food supply chain through livestock feed. One-third of corn and three-quarters of soybeans are still utilized for livestock feed after the production process for ethanol and biodiesel.[xxi, xxii] Considerations on the best use of the land and vegetation are necessary, as vegetation and trees store carbon that is already in the atmosphere (including carbon dioxide from the combustion of fossil fuels) and can serve as carbon storage on a relatively short timeframe (relative, that is, to long-term geologic carbon storage, which has a timescale of millions of years). Forests also provide important ecological functions, wildlife habitat, and flood protection, and utilization of biomass for energy (heat or electricity generation) must be sustainable to ensure that forest health and carbon storage in forest soils are not unduly impacted.

## From Reductions to Net Zero: Carbon Sequestration and Long-Term Storage

After GHG reductions have been maximized through the key pillars discussed above, reaching net zero typically requires offsetting any residual emissions through carbon sequestration. Maximizing long-term storage of carbon to reduce atmospheric carbon can happen at the source of the emissions using point source carbon storage or can be more broadly distributed across the landscape through nature-based solutions.

### *Point Source Carbon Capture and Sequestration (CCS)*

Carbon capture directly at the powerplant stack can be coupled with long-term sequestration deep underground or in material with a very long life. To maintain reliability, natural gas power plants are likely to remain part of the power generation mix for some time, and capturing carbon produced by those plants can help the Valley to reduce emissions while maintaining immediate power generation and reliability needs. TVA is currently conducting research into ways to capture carbon at two natural gas plants.

### *Direct Air Capture*

Capturing carbon dioxide ($CO_2$) from the air and sequestering it for the long term can bring the Valley closer to Net Zero emissions, once other pillars are in place.

Carbon capture could also be accomplished via direct air capture,[12] a technology currently in demonstration. Direct air capture pulls carbon from the air and transports it via pipelines to large underground storage areas where the carbon can be sequestered for the long term. These projects are not widespread yet but by 2050 could become a tool to bring the Valley to Net Zero.

Natural capture of $CO_2$ from the air (a type of nature-based solution) is another avenue to reducing GHG concentration in the air. This can be done by increasing carbon sequestration in trees through re-forestation or adapting forestry practices. Carbon storage can also be increased through practices that help capture carbon in soils (half of all the carbon in forests is typically found in the soil). These natural approaches also offer additional ecological benefits. Soil rich in organic matter (such as that found in wetlands) holds more nutrients, enhances soil structure, and retains more water, providing additional flood protection.

Any type of carbon storage project can become quite complex and must incorporate considerations of the following:

- Additionality: Would this carbon have been sequestered without deliberate implementation of a specific project?
- Accuracy: Is the baseline accurate? How precisely and frequently is the carbon pool measured?
- Permanence: How long until the forest burns, is logged, or becomes developed?
- Exclusivity of claim: Is anyone else claiming the same trees/soil carbon as a carbon offset?
- Avoiding economic, social, and environmental harm: In light of declining traditional timber production (as exemplified by mill closures) and emerging bioenergy markets, would a carbon sequestration project impact the viability of small-scale family forests and other forestry operations that provide livelihoods to rural communities?

12 Direct air capture technology is sometimes referred to as DAC – however, to avoid confusion with Disadvantaged Communities (which are referred to as DACs in this report), this report will spell out direct air capture fully wherever it is referenced.

# Modeling Results: Scenarios Toward Net Zero in 2050

This section covers the modeled results for the reference case as well as the four pathways that were explored in this study.

The four pathway scenarios are summarized in Figure 14 below.

## Scenarios

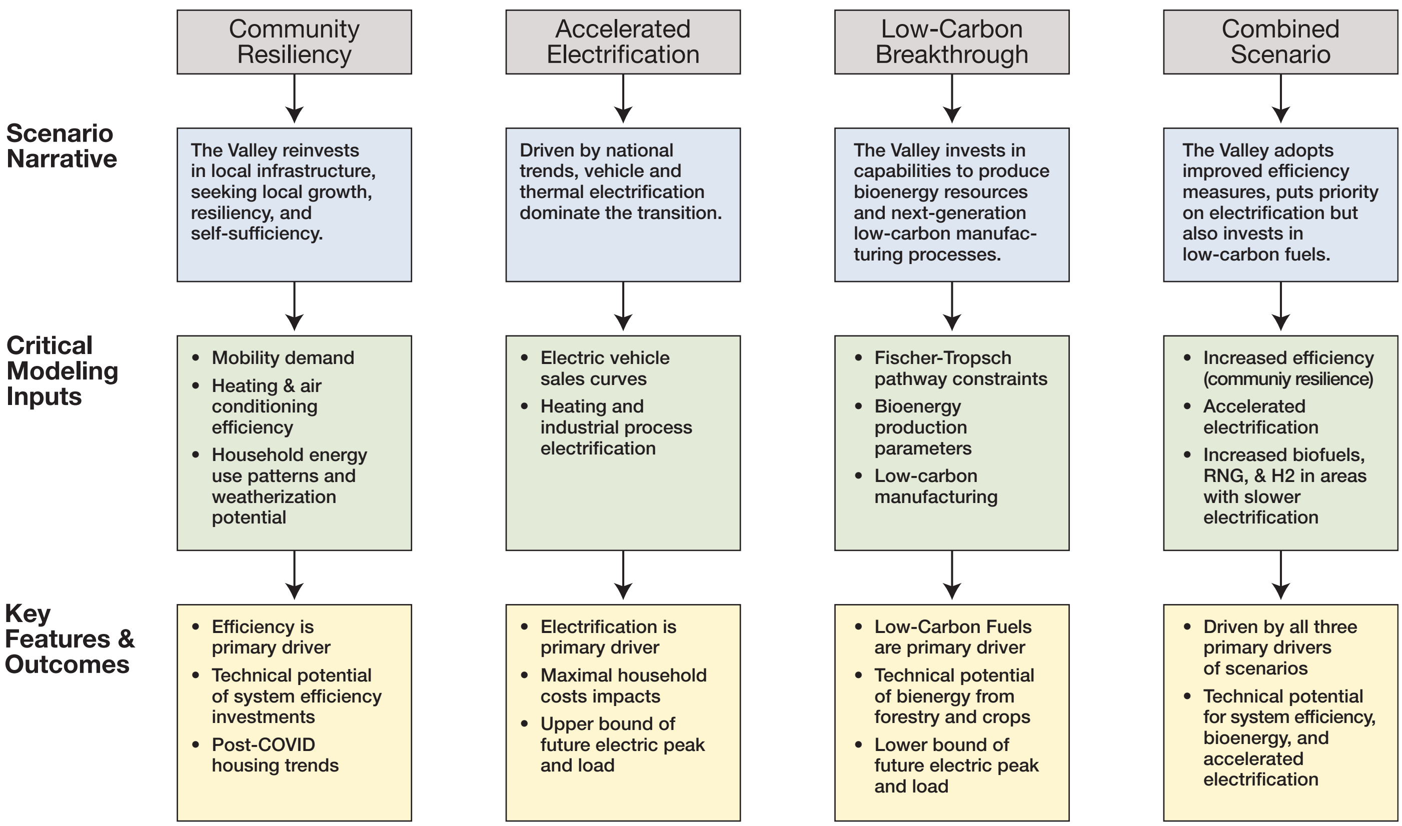



Figure 14 Pathways explored in the study

**The Community Resiliency Scenario** focuses on the "efficiency" pillar and explores a future where more demands – for energy, goods, and services – throughout the economy are met and funded locally. This was modeled as an increase in the density of housing in urban areas, resulting in a reduction in transportation and residential energy use. The scenario also highlights that rural areas could benefit from the development of local biofuels, more local food production, and greater access to protected greenspaces. The scenario evaluates the limit of how much decarbonization can be driven by reductions in energy demand.

**The Accelerated Electrification Scenario** tests the technical potential of electrification of almost everything in the Valley. The modeling team hypothesized that all personal transportation, heating, and other thermal processes except the most intense high-temperature industrial processes would be electrified by 2050. This scenario explores the upper bound of how much electricity demand growth might be expected in a Net Zero economy. Despite the increase in electricity usage, the greater efficiency of EVs and modern heat pumps results in significant total energy use reductions. This reduction is even greater than the Community Resiliency scenario, highlighting that reducing how much energy is "rejected" in combustion processes is a key complement to weatherization and other efficiency measures. With the transition to electrified technologies, however, this scenario pinpoints critical pain-points, such as access to EV charging infrastructure that would need to be addressed.

**The Low-Carbon Breakthrough Scenario** limits the pace and magnitude of electrification while evaluating the potential for low-carbon fuel alternatives to be deployed beyond just the hard-to-electrify sectors (e.g., high-temperature industrial processes and heavy-duty transportation). In this scenario, the overall electricity demand of the Valley is lower than the Accelerated Electrification Scenario, and the Valley still relies on low-carbon gas infrastructure. This scenario evaluates the upper bound of low-carbon fuel resources that might be needed in the Valley and highlights what technology research, development, and commercialization might be needed to sustainably produce those energy resources.

The project team and Stakeholder Working Group recognized that no single pathway would likely be adopted in its entirety by the Valley and that the final path forward would be a combination of aspects from

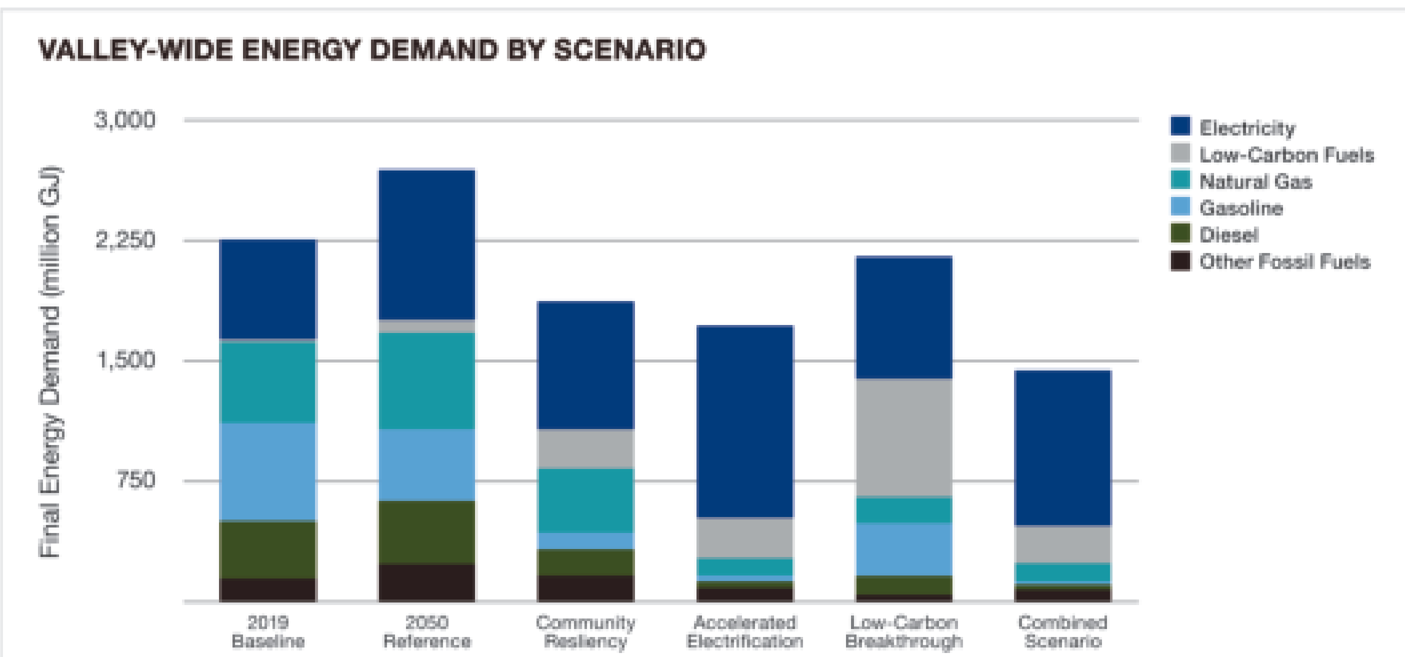



Figure 15 Energy demands across the Valley for the scenarios modeled

the different scenarios. Figure 15 shows how each of these scenarios' energy demand relates back to that of the 2019 baseline and the 2050 reference case, illustrating just how diverse each approach may look. To capture a future where a combination of all aspects of the different scenarios occurs, a fourth scenario was created that combined characteristics of each of the scenarios described above.

The Combined Scenario explores a future where the Valley strives for a combination of the strategies used in the original three scenarios. Efficiencies driven by local production and consumption are incorporated into this scenario. Greater preference is given to electrification while still retaining low-carbon fuel alternatives for especially-hard-to-decarbonize sectors. This scenario takes a "middle road" approach to the other three pathways and is meant to show a future where aspects of all three pathways converge.

Through the entire process of pathway creation, stakeholder feedback was elicited and incorporated. Including stakeholders in the modeling development proved critical to identifying data sources, updating assumptions, and identifying what areas the Valley was most interested in decarbonizing. Further details of the feedback incorporated into the modeling assumptions are included in the Appendix.

Modeling shows that if all activities modeled are implemented, the Valley can reduce GHG emissions toward Net Zero by 2050 (Figure 16). As of 2019, Valley-wide emissions had already fallen by 30% relative to 2005, driven by a 50% reduction in emissions from electricity generation during that time. To further reduce emissions by 2050, the pathways feature deep reductions – about 80% - in emissions from combustion of fuels by distributed energy demands (e.g., cars, homes, factories). The steepest reductions are driven by the widespread electrification of current energy demands, necessitating further work to decarbonize the electricity supply mix for the Valley. TVA's ongoing 2024 Integrated Resource Plan (IRP) will explore strategies that can lead to further emissions reductions. For the purposes of this study, electricity emissions were estimated as a range, representing anywhere from zero carbon electricity supply up to an "upper bound" in which all new load from electrification is served by new fossil gas capacity – see arrows indicating electricity "potential range" in Figure 16 below.

As discussed earlier in this report, the reference case scenario – in which no significant changes are made to current trends in the Valley – shows GHG emissions in 2050 that are roughly 10% lower than those of a 2019 baseline year. Each of the Net Zero

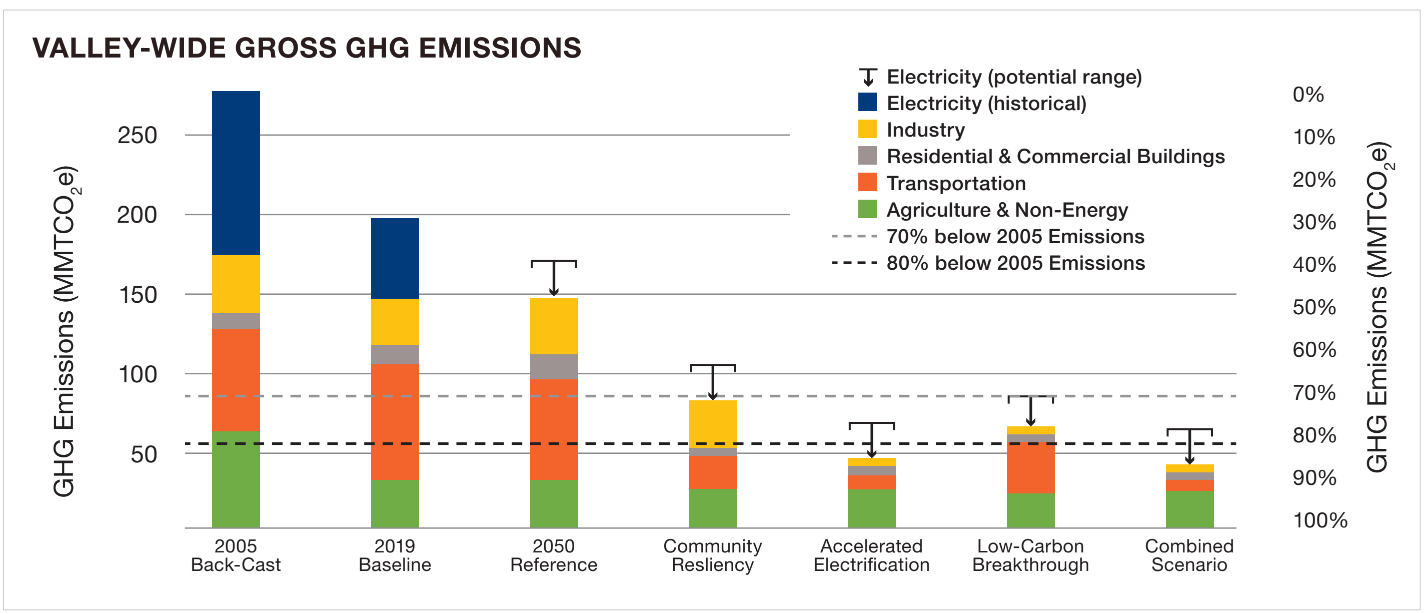



Figure 16 Modeled GHG emissions across scenarios

pathways show significant reductions in emissions by 2050 relative to the reference scenario, with the greatest reduction seen in the Combined Scenario (reflecting the deployment of multiple strategies in combination). Across scenarios, some strategies – such as electrifying the transportation sector – will have a large role in reducing emissions, while others associated with sectors with lower emission levels (e.g., agriculture energy use) will have a lower impact because they are a smaller proportion of the emissions in the Valley.

- The Accelerated Electrification scenario offers the greatest potential to reduce economy-wide emissions in the Valley, but also shows the highest potential electric generation emissions due to the higher electricity demand required for the scenario to occur.
- Buildings emissions decrease uniformly across scenarios, resulting from improvements in home energy efficiency measures and the deployment of high-efficiency all-electric HVAC technologies.
- Similarly, industrial process emissions decrease across all scenarios due to improvements in efficiencies as well as electrification or use of low-carbon fuels, depending on the pathway.
- Non-energy emissions remain relatively constant across scenarios as they are largely driven by emissions related to cattle and their digestive systems producing methane, a potent GHG. The scenarios did not model large changes in the size of cattle herds, although total head of cattle in the Valley has declined since 2005.

In all scenarios, some GHG emissions remain in 2050, indicating the need for carbon capture and sequestration, or "negative emissions," to reach Net Zero carbon emissions in the Valley. This study evaluated the potential for forests in the Valley to contribute to this overall need, however, in all scenarios, the total capacity for forests to sequester carbon falls short of residual emissions. This highlights that further carbon capture technologies will be needed for the Valley to reach Net Zero emissions. However, the technical potential and costs of these technologies are still highly uncertain and, as such, this study did not explicitly model the deployment of specific carbon capture technologies to fill that gap.

## Transportation Sector Emissions

Across the four pathways, the greatest emissions reduction relative to the reference scenario is expected to come from the transportation sector, with up to a 90% decline relative to the 2050 reference scenario as shown in Figure 16. Passenger vehicles represent the largest single source of emissions in the transportation sector and across the Valley's entire economy. The Accelerated Electrification scenario shows a marked decrease in direct emissions due to the modeling input of 100% light-duty vehicle electrification by 2050. This level of electrification results in the greatest total electricity demand of all scenarios, with the potential for significant emissions associated with supplying that load. In contrast, the dramatic reductions in vehicle-miles traveled (VMT) modeled in the Community Resilience scenario results in only a modest increase in electricity consumption, while also achieving significant reductions in gasoline usage. However, the high emissions remaining in the Valley's gasoline fleet showcase some of the limitations in achieving deep decarbonization through efficiency and land-use planning.

Although a smaller total source of emissions than passenger vehicles, trucks and other heavy-duty vehicles represent an important decarbonization target. Many of these duty-cycles will be technologically difficult to electrify. For those cases, hydrogen fuel cells or low-carbon fuels such as RNG or biodiesel represent a viable complement to electrification. The Low-Carbon Breakthrough scenario deploys clean drop-in alternatives to heavy trucking and off-road equipment (e.g., tractors). In addition to heavy trucks, the transportation sector also includes off-road modes, such as trains and airplanes. While trains can be electrified or powered by low-carbon fuels, jet propulsion for commercial aviation in particular is very unlikely to be electrified. While sustainable aviation fuel (SAF) breakthroughs are on the horizon, the modeling does not include a reduction in aviation GHGs. However, there are many investments in this sector and clearer options may well emerge. While highlighting the potential for decarbonizing heavy-duty fleets through drop-in alternatives rather than electrification, the high legacy emissions in the Low Carbon Breakthrough scenario reflect the importance of maximizing emissions reduction from passenger vehicles. Transportation energy demand by fuel type across scenarios is illustrated in Figure 17.

Finally, the Combined Scenario shows the largest drop in transportation emissions, a result of the complete electrification of the light-duty vehicle fleet, deploying low-carbon fuels for heavier vehicles, and dense development limiting overall demand for mobility as population grows. The level of GHG reductions – and the level of remaining emissions by 2050 – highlight the importance of pursuing and maximizing reductions through each of those three levers for the Valley. Ultimately, all three strategies will be needed if the Valley is to reach a Net Zero future.

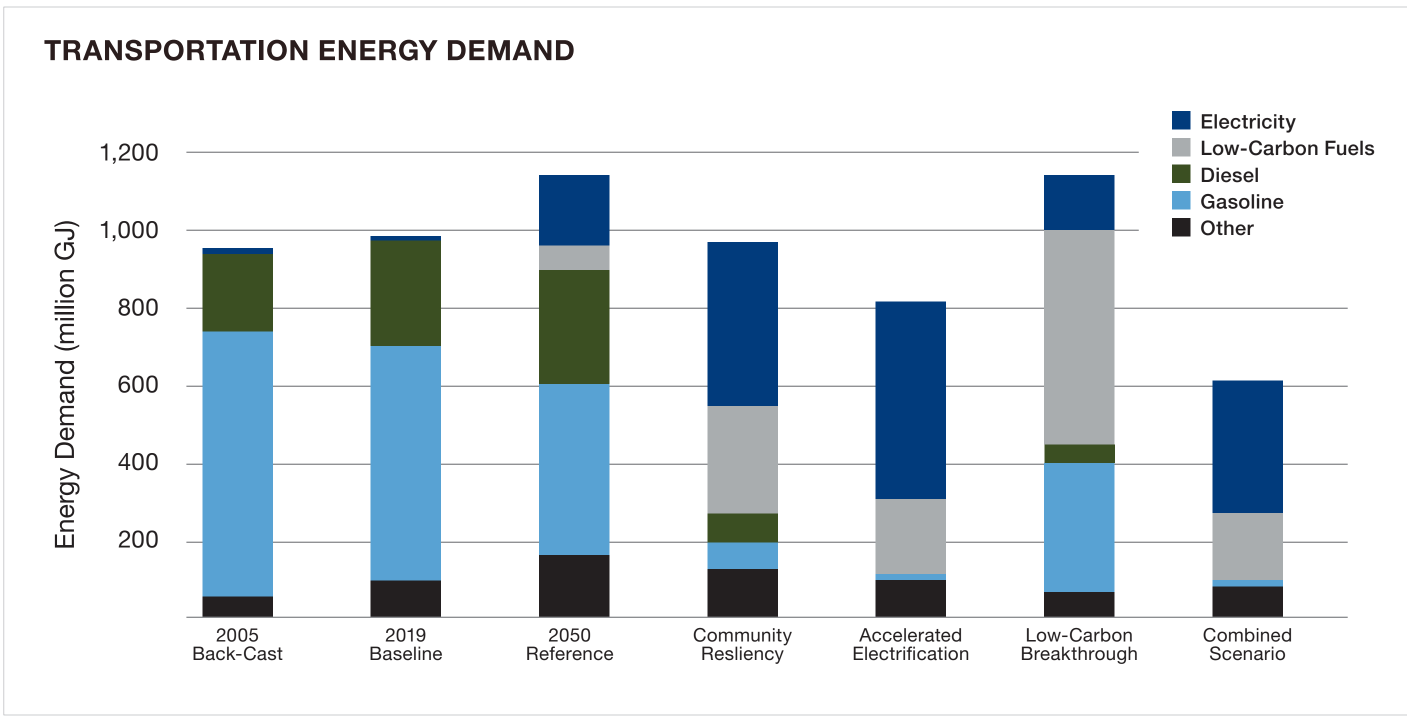



**Figure 17 Transportation sector emissions across scenarios**

## PROGRESS IN ACTION: KNOXVILLE CLIMATE PLANNING

Having published a baseline 2019 community-wide emissions inventory, Knoxville is among several municipalities already pushing forward the modeled reduction measures that comprise the Valley's pathways to Net Zero. Knoxville used ICLEI's ClearPath software to forecast future changes through residential and commercial energy efficiency enhancements, as well as in vehicle-miles traveled (VMT) replacement and reductions. A 20% efficiency retrofit among 5% of existing residential buildings as well as a 37% energy savings in new residential development underway in Knoxville indicates the potential for an annual reduction in natural gas use of more than 20 billion BTUs across the city. Improving the efficiency of insulation, lighting, and other aspects of residential buildings presents a major opportunity for energy and cost savings in Knoxville and could be replicated elsewhere in the Tennessee Valley. Likewise, an identical strategy applied to the commercial sector from 2024-2050 would bring about an annual savings of 32 billion BTU in natural gas use. In applying this effort to commercial buildings, Knoxville will encourage an influx of additional business interest by promoting reduced energy costs, fostering conditions for economic growth.

Knoxville has also successfully modeled a VMT replacement and reduction effort, utilizing a 20% general reduction in VMTs and 15% replacement of current VMTs by electric vehicle (EV) VMTs by the end of the planning period to determine that about 59,535,000 gasoline VMTs could be reduced by 2050 if implementation began 2024. Successes so far include achieving Bronze-level 'Bicycle Friendly Community' designation from League of American Bicyclists, being awarded funding to deploy 18 electric buses and overhead bus chargers, and enacting Complete Streets policy. Incorporating EVs into this reduction effort will increase electricity use by nearly a trillion BTU. However, reducing gasoline dependency through general VMT reduction strategies such as improved bike infrastructure and transit access, as well as EV adoption, will enhance the quality of life for Tennessee Valley inhabitants by minimizing travel expenses and improving the cleanliness of their environment.

While the aggressive scenario laid out in the Valley Pathways Study may feel daunting, Knoxville – as well as Memphis and Nashville – has already taken the initial steps to be well on their way to these goals, lighting the way for communities across the Valley to engage and push forward to a Net Zero future.

## Residential and Commercial Buildings

Partially due to the low-cost, reliable electricity delivered by TVA and LPCs throughout the Valley, a much greater share of the heating, hot water, and other thermal processes in the homes and businesses throughout the Valley already run on electricity rather than direct combustion of fossil fuel. This contrasts with much of the rest of the country, where the critical equipment and infrastructure in basements and factories typically burn fuel oil or natural gas. For residential households, driven by pressure to compete with existing high-efficiency gas furnaces and boilers in other parts of the country, new "cold climate" air source heat pumps represent a stepwise improvement over previous generations of heat pump technology and a dramatic improvement compared to electric resistance heating.

Doubling down through weatherization and other improvements to building envelopes can further reduce demand from residential and commercial buildings. Weatherization has less impact on emissions than electrification, but without weatherization, leaky and poorly insulated buildings will increase electricity peak demand during cold and hot weather peaks and will make it difficult or impossible for a building's HVAC to coast through extreme temperatures or short power outages without disruptions to the occupants and the grid. The resilience provided by good weatherization is therefore an important component of pathways to a climate-ready 2050.

Residential upgrades incorporated in the modeling focused on residential building upgrades in terms of packages as shown in Figure 18.

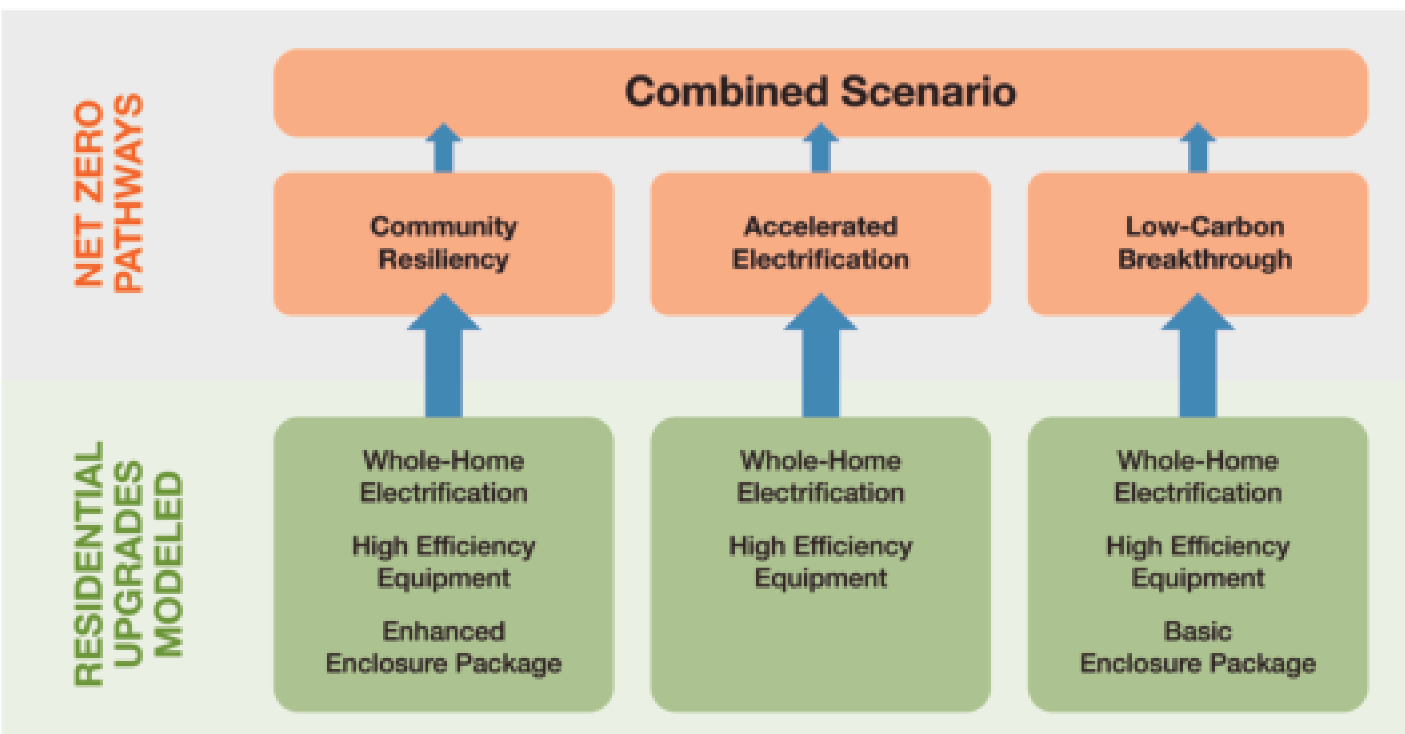



Figure 18 Residential upgrades modeled for each Net Zero pathway

## PROGRESS IN ACTION: DEMONSTRATION OF AN ENERGY PLUS BUILDING IN CHATTANOOGA

This demonstration project was conducted at the Advanced Vehicle Test Facility (AVTF) which consists of a one-mile banked asphalt test track and a 9,400 square foot research building located on 52 acres approximately six miles from the UTC campus in Chattanooga. An aerial photograph of the test track is shown above.

The overarching goal of this project was to demonstrate how to convert a conventional commercial building into an Energy Plus Building. This goal was achieved by:

- Improving the thermal characteristics of the Advanced Vehicle Test Facility (AVTF)
- Installing solar panels
- Replacing an outdated HVAC system with a modern Geothermal HVAC System
- Replacing high energy lighting indoor and outdoor systems with energy efficient bulbs (LEDs).

The project resulted in the reduction of annual energy consumption of approximately 65,000 kWh and produces approximately 22,200 kWh of solar energy per year. This new energy profile represents one of the first energy plus buildings in the Tennessee Valley. Savings in annual utility costs, which include benefits from participating in a past incentive program, have averaged approximately $10,000 since the project was completed in 2014. The energy use itensity (EUI) of the AVTF during this time is averaging about 50% less than the median values of similar properties in the Chattanooga region.

This project won the inaugural Tennessee Department of Environment and Conservation (TDEC) Sustainable Transporation Award in 2015.

Of the many building improvement options, an analysis performed in ResStock in 2017 [xxiii] found 26% savings achievable in Tennessee single family homes with significant utility bill savings (Figure 19). Many of these improvements are included in the packages analyzed in the modeling.

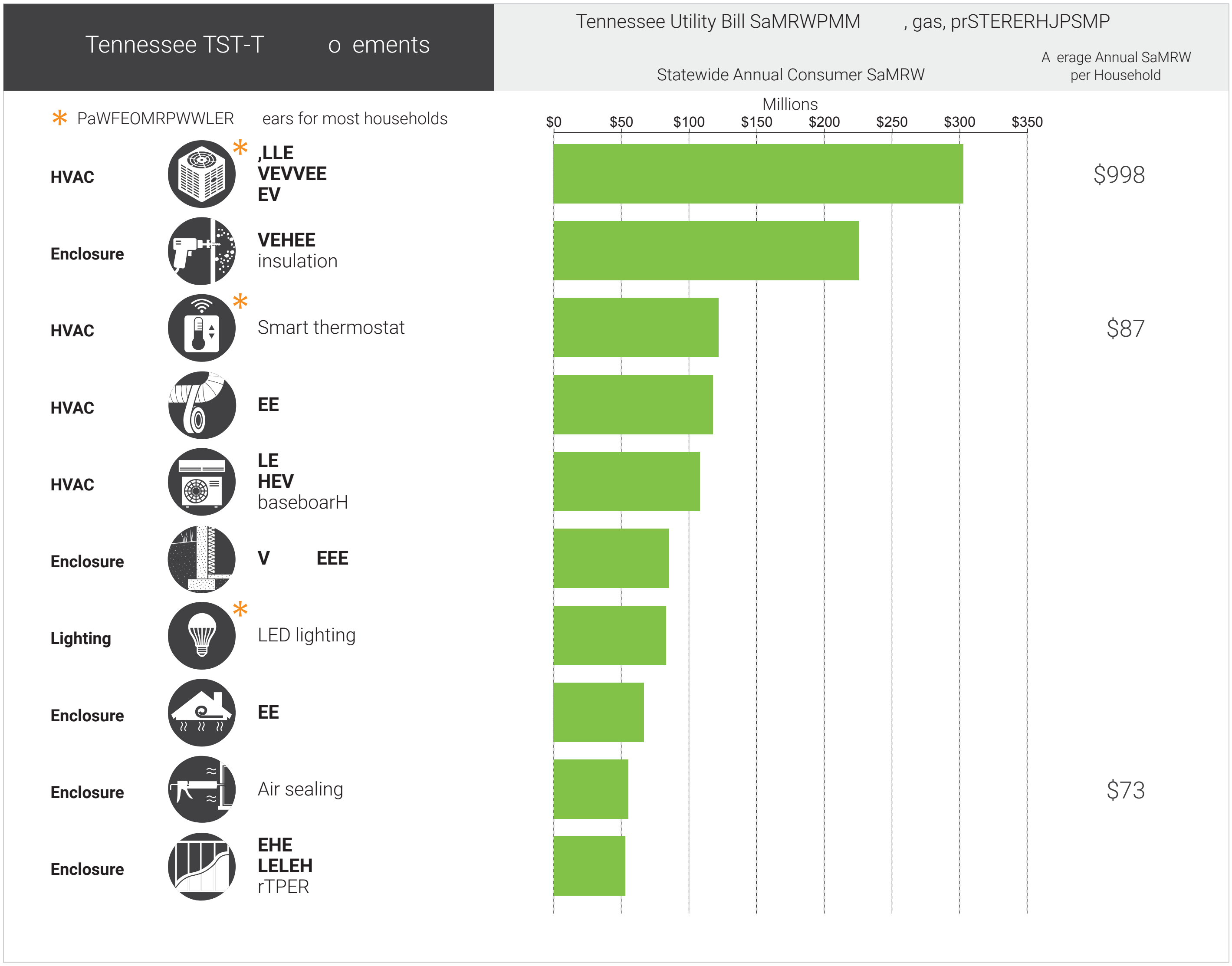



Figure 19 Energy savings options in a residential home (Source: National Renewable Energy Lab, https://resstock.nrel.gov/factsheets/TN)

Commercial building upgrades incorporated in the modeling included the following: [13]

- Exterior Wall Insulation
- Roof Insulation
- Secondary Window System
- Window Film
- Window Replacement
- LED Lighting
- Air-Source Heat Pump Boiler
- Dedicated Outdoor Air System with Mini Split Heat Pumps
- Heat Pump Rooftop Terminal Unit (RTU)

These interventions typically require capital investment, with a slow payback over the course of the typical decades-long lifetimes of HVAC equipment and building components. The adoption of these ultra-efficient devices highlights an opportunity to reduce average household energy consumption from more than 27 MWh per household per year to less than 14. This type of energy reduction typically reduces household costs by $400 to $800 per year, with low-income households typically seeing a greater benefit. However, these upgrades typically come with an initial cost premium, and while that cost premium is repaid through utility bill savings, it can represent a critical barrier, especially for low-income households who lack ready access to capital.

Financial assistance programs, including up-front rebates and long-term financing structures, are often needed to drive such programs forward. New funding opportunities from the federal government, such as financing programs under the EPA's Greenhouse Gas Reduction Fund – developed under the Inflation Reduction Act (IRA) of 2022 – may be critical opportunities to provide capital resources to implement energy efficiency programs throughout the Valley, especially for low-income residents and other vulnerable populations. Importantly, many of the programs authorized under the IRA work to build these improvements into existing home financing structures, such as green mortgages and other types of low-interest loans for technologies that reduce emissions. By incorporating this financial assistance into established markets, these programs seek to drive much broader adoption than individual assistance programs.

**ENERGY EFFICIENCY REDUCES ENERGY BURDEN AND ENABLES INVESTMENTS IN THE LOCAL ECONOMY**

Energy burden is the percentage of a household's income used for energy expenses. Reducing expenses on energy through energy efficiency improvements can not only greatly improve comfort but can also directly reduce residents' expenses on energy and reduce their energy burden. The money that residents and businesses save on their energy bills can be re-invested in the local economy. Investing in efficiency is investing in residents, businesses, and communities of the Valley and can have a positive impact on the local economy. It also creates jobs along the installation and supply chains of weatherization and HVAC trades.

## Industrial Emissions

Industries are already making great progress toward reducing their emissions, partially due to consumer demand and corporate sustainability commitments. Improvements to the efficiency of industrial buildings offer similar opportunities as for commercial buildings. However, many industrial customers have already undertaken efficiency improvement measures,

13 Note that the study findings presented here focus on household averages rather than the full technical potential for the residential sector. This decision was made because (1) the sector is already largely electrified, so GHG reduction opportunities are more limited compared to the co-benefit opportunity, and (2) the scale and pace of adoption remains a very open question. Arithmetically, all pathway scenarios in this study include the model assumption that full technical potential is achieved.

### PROGRESS IN ACTION: TVA INVESTMENTS IN HOUSEHOLD EFFICIENCY

Switching to more efficient heating and cooling technologies can help to reduce peak electricity demand during the coldest and hottest days of the year, respectively. This can result in significant cost savings for the entire electric grid. Striving to realize these cost savings, TVA and the LPCs expect to invest $1.5 billion in energy efficiency and demand response programs to help offset an approximately 30% increase in load growth over the next 10 years. These programs include incentives for "TVA-Preferred" heat pumps that can provide efficient heating and cooling even during periods of intense cold or heat.

In addition, TVA's Home Uplift program provides an average of $10,000 in free home energy upgrades to income-eligible customers. One Home Uplift participant, Eleanor, says:

*"I had sky-high electricity bills because my son and I were using portable space heaters and AC window units. [Since my Home Uplift,] my power bill has decreased, the insulation is making a huge difference in helping the house stay warmer, my air quality is better, and I have more peace of mind now because I don't have to worry about how I'm going to pay a really high power bill."*

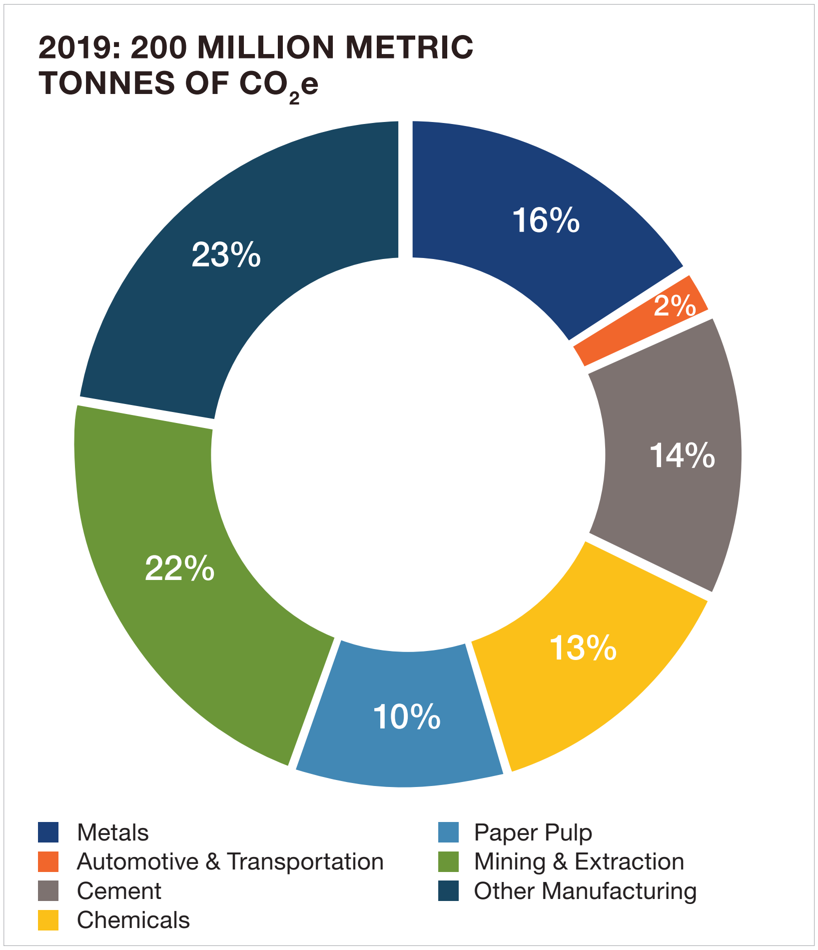



Figure 20 GHG emissions from industrial subsectors

so opportunities to further improve efficiency might be more limited. Opportunities for the greatest reductions in emissions from industrial sources ultimately hinge on the energy used for process heat. Many of these are high-temperature processes that can be electrified, but which may be better suited for hydrogen or low-carbon fuels.

The industrial sector in the Valley includes a diverse array of products and processes, with no single subsector dominating emissions (see Figure 20). Energy uses across the subsectors are similarly diverse. About one third of the energy use is tied directly to process heating, while approximately 10% comes from a combination of Combined Heat and Power (CHP) and Cogeneration processes, building energy use, machine drive, and other non-process activities. The remaining ~55% is large and is not tied to any single end use, but rather is split among multiple diverse end uses.

With such a diversity of processes and products, no single strategy can dramatically reduce emissions – a range of strategies must be adopted and deployed. Some of the easiest gains in efficiency have already been implemented in the Valley, such as utilizing secondary metals rather than primary metals for aluminum, steel, and ferrometal manufacturing. However, the switch to secondary metals still presents opportunities for energy efficiency, and electrification via arc furnaces or for pre-heating materials in medium- and high-temperature processes can reduce emissions. Additionally, low- and medium-temperature heating processes have the potential to fully or mostly electrify in the near-term with current technologies, while hard-to-electrify processes may switch to RNG or hydrogen in the future. In addition, cement production offers opportunities to reduce $CO_2$ emissions from the release of carbon when limestone is heated to high temperatures (biogenic limestone emissions, non-energy related). There are also opportunities to trap $CO_2$ emissions in cement. The future of many manufacturing processes comes down to innovative technology, with novel production processes that are expected to scale up over the next decade and become mainstream by 2050.

The scenarios modeled for the industrial sector test the limits of individual strategies:

- The Community Resiliency scenario emphasizes increased manufacturing output while showing greater investment in efficiency, driving down the energy needed per dollar of output. Although likely the most cost-effective approach to decarbonization, this scenario highlights the limitations of process efficiency.
- The Accelerated Electrification scenario investigates the upper bound of what can be electrified. Industrial non-process and building energy use is electrified fully by 2050, while high-heat processes are only partially electrified due to thermodynamic limitations in current manufacturing processes. Due to efficiency of electrified technologies for low-quality heat, this scenario shows significant reductions in total energy demand. However, failing to address high-temperature processes leaves much of the sector's emissions untouched.
- To that end, in the Low-Carbon Breakthrough scenario, modeled deployment of biodiesel, RNG, and hydrogen for high-temperature processes appears to be the most effective approach for deep decarbonization of manufacturing.
- As seen in other sectors, the Combined Scenario enables the greatest potential for reductions.

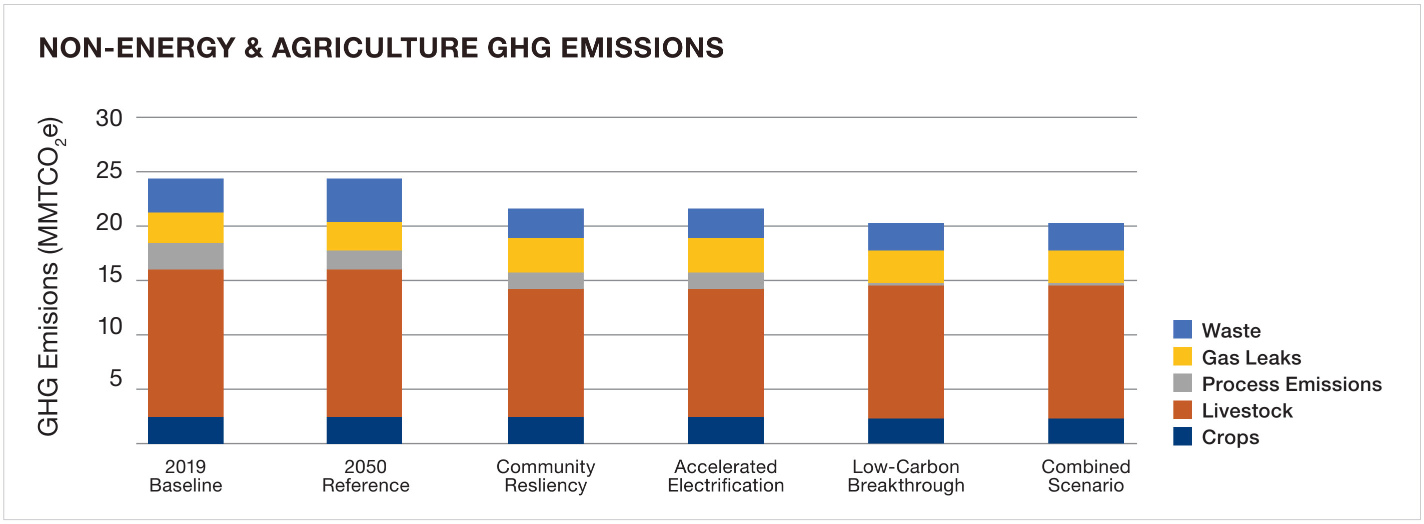



Figure 21 Non-energy, agriculture, and gas leak emissions

## Non-Energy & Agriculture Emissions

In addition to energy-related emissions, the modeling explored the reduction potential for non-energy emissions. As illustrated in Figure 21, non-energy emissions modeled for all scenarios did not show as much decline relative to the 2050 reference case compared to other sectors. The non-energy emissions category primarily focuses on emissions of GHG that do not originate from the combustion of fossil fuel for energy. The agricultural energy sector also includes a very small amount of emissions originating from fuel use in tractors and to heat and cool livestock domiciles (e.g., chicken coops). They also include emissions associated with methane released from waste and agricultural waste as well as emissions associated with cooling system refrigerants and other industrial chemical processes. Non-energy emissions represented approximately 10% of Valley emissions in 2019 and, as seen in Figure 21, are one of the hardest sectors to abate. This is largely due to processes associated with cattle – that is, bovine digestive systems produce methane, which the cows belch throughout the day, making it very difficult to capture and remediate. There are feed additives being researched that can reduce methane emissions from cattle, however, the feasibility of that approach on a commercial scale is unknown at this point.

In contrast to much of the rest of the nation, the Valley already practices no-till farming to a wide extent, which limits emissions from crop cultivation. However, because this practice is already deployed today, the potential additional reductions associated with farming are more limited. There are reduction opportunities associated with the decomposition of organic waste (manure, food waste, etc.), however, much like waste byproducts from domesticated animals, these opportunities may not be able to fully abate emissions.

### PROGRESS IN ACTION: GRASSLANDS PARTNERSHIP

Improved grazing management, fertilization, sowing legumes and improved grass species, irrigation, and conversion from cultivation all tend to lead to increased soil sequestration, indicating that cattle related emissions could go down without reducing stock size. The University of Tennessee Institute of Agriculture's "Grasslands Partnership" is working with numerous organizations to connect with the 290,000 "Fescue Belt" producers (Fescue is a grass species prevalent in pastures in the Southeast and upper Midwest) and incentivize improved grasslands stewardship. Improvements in pasture management have the potential to sequester carbon, as a "nature-based solution" and can contribute to mitigating emissions from cattle.

## PROGRESS IN ACTION: NO-TILL AGRICULTURE – TENNESSEE FARMERS LEADING THE NATION

Tennessee farmers grow over 3 million acres of row crops including soybeans, corn, cotton, and wheat.[cxxxii] A key feature of Tennessee row crop production is no-till and conservation tillage practices which, depending on the crop, is over 80% no-till.[cxxxiii] Tennessee farmers are leaders in these practices considering only 21% of all cultivated cropland acres in the United States are no-till.[cxxxiv]

Although not the original purpose, no-till practice allows farmers to keep more carbon locked beneath the surface of the soil. [cxxxv] Not only does no-till limit greenhouse gas emissions, but it also allows for the potential to sequester $CO_2$ on most, if not all, row crop production acres which utilize no-till and conservation tillage practices.[cxxxvi]

Initially utilized by farmers for the purpose of preventing soil erosion,[cxxxvii] no-till aids in farm profitability by decreasing fuel consumption, lessening labor requirements, and increasing water holding capacity and soil organic matter without negatively impacting production yields.[cxxxviii] No-till is the practice of using proper equipment to plant seeds in which the soil is not tilled. As a result, the soil is left undisturbed in between the harvest of one crop and the planting of another.[cxxxix]

Pictured: No-till soybeans and corn

The non-energy sector also includes several artificially produced and released chemicals, including refrigerants, natural gas leaks, and some industrial processes. Refrigerants today are mostly hydrofluorocarbons (HFCs), which are powerful GHGs that replaced chlorofluorocarbons (CFCs) in the 1990s following the discovery that CFCs were harming the Earth's ozone layer. Following global frameworks, manufacturers are switching to new types of refrigerants that are less harmful, such as hydrofluoroolefins (HFOs) as well as ammonia and carbon dioxide, dramatically reducing the emissions of this subsector. Other sources within these categories are relatively small and certain measures can be deployed to abate them. See the Appendix for further discussion of how these were modeled.

## Land Cover & Carbon Sequestration

Carbon sequestration is the capture of $CO_2$ and methane (two GHGs) from the air and their storage in forms that will last for a long time without releasing the carbon back into the atmosphere. Although much of the Valley's lands are developed or used for agriculture, forests make up half of the Valley's total acreage – representing a critical resource that annually sequesters millions of tons of $CO_2$ from the atmosphere and stores hundreds of millions of tons of carbon in the form of soil litter, tree trunks, and limbs. Developing a parcel of forestland into housing emits some carbon that is stored in the biosphere and removes the future potential of that land to sequester more carbon. In contrast, reforesting an acre of developed land will result in increased future sequestration.

Today, forests in the Valley sequester about 17 MMTCO$_2$e per year, or about 20% of the residual emissions left by a 70% reduction from a 2005 baseline. Opportunities to maintain or increase forest acreage throughout the Valley, especially through encouraging dense development that accommodates population growth while minimizing land clearing, can result in maintaining, or even increasing, annual sequestration levels. As illustrated in Figure 22, the Community Resiliency scenario, in which land used for development is minimized through dense housing and commercial building practices, carbon sequestration from forests can moderately enhance the Valley's sequestration potential. In contrast, the Low-Carbon

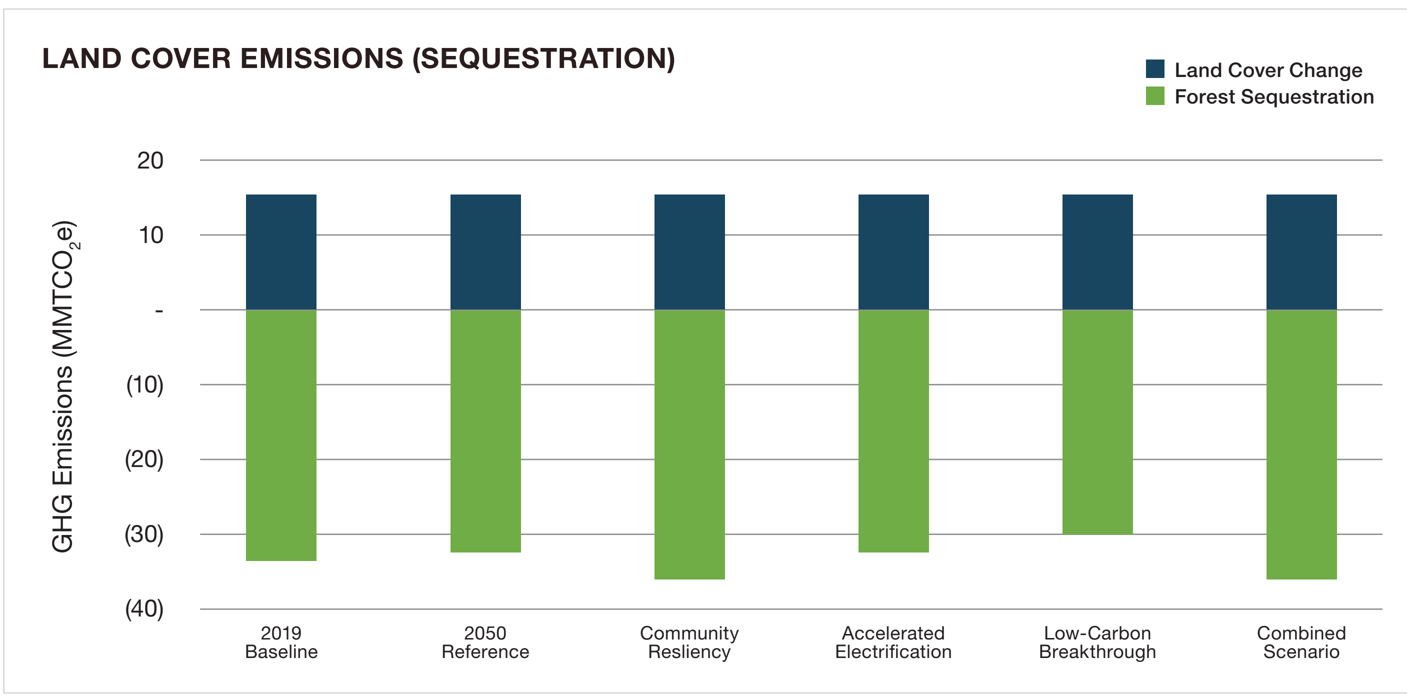



Figure 22 Forest, land, and agriculture (FLAG) emissions

Breakthrough scenario highlights a lower bound for sequestration potential by hypothesizing greater pressures of forestland in order to accommodate sprawling development as well as the potential for an expansion of cropland in the Valley in order to produce bioenergy feedstocks.

Importantly, these bioenergy feedstocks are all part of a broader global market for agricultural and energy commodities, which results in a disconnect between production and consumption of these resources. That is, it is likely that all bioenergy produced in the Valley would not necessarily be consumed in the Valley and that all bioenergy consumed in the Valley would not necessarily be produced in the Valley. Ongoing research at the Oak Ridge National Laboratory to update the U.S. DOE's "Billion Ton Study" is evaluating the United States' bioenergy production capabilities, including how those resources can be produced sustainably. Ultimately, barring dramatic changes to land cover in the Valley, total biogenic sequestration is unlikely to fully offset residual emissions in the Valley.

It is important to note that the modeled results discussed earlier in this report do not account for carbon capture and other non-biogenic negative emissions technologies or strategies. Achieving Net Zero emissions by 2050 will require a combination of emissions reductions across sectors as well as increased negative emissions strategies such as carbon capture and sequestration (CCS), increased carbon sinks such as forests, and potential new technologies like direct air capture. These technologies are still developing and thus the technical potential and cost parameters associated with them are poorly defined. As highlighted in the case study on Direct Air Carbon Capture in this section, research and technological innovation supported by TVA and the University of Tennessee's Spark Center represent a critical lever to better understand and drive forward potential negative emissions.

## Defining Net Zero for the Valley

There is no single established definition of Net Zero. Most definitions of "Net Zero" prescribe a minimum reduction of gross emissions – typically around 80% compared to a 1990 or 2005 baseline – and set a target for carbon sequestration to offset any remaining (or residual) emissions. In the scenarios modeled, overall emissions can be reduced by 70%-80% compared to 2005 (Figure 23), assuming continued improvements in both demand-side emissions evaluated in this study and supply-side emissions that are being evaluated in TVA's 2024 IRP. In all scenarios, innovation and technology development to augment forest sequestration will be needed to fully offset the Valley's residual emissions. Importantly, the Valley's residual emissions in 2050 are tied to how the Valley supports the national economy, exporting goods and products to places that do not have such established manufacturing and agricultural sectors. As the nation transitions to a clean energy economy, emissions will not just represent products shipped to other states, but the very technologies that enable and drive GHG emissions reductions throughout the world.

### PROGRESS IN ACTION: DIRECT AIR CARBON CAPTURE R&D AT THE UT SPARK CENTER

The Valley is a home of both cutting edge technology development and deployment. One example is Holocene Climate Corporation, a direct air capture developer and carbon removal services provider helping corporations and governments deliver on their Net Zero targets where decarbonization cannot fill the gaps.

Holocene is developing a novel, scalable, and affordable approach to direct air capture – removing and sequestering $CO_2$ directly from the atmosphere, versus from point source $CO_2$ emissions – and is being led by direct air capture industry and start-up/venture capital veterans who chose to move to Knoxville to build this company. Holocene has made impressive progress in the ~1 year since its start in Knoxville and knows it will need the help of the entire Valley ecosystem to scale its technology to meet lofty ambitions within and outside the Valley.

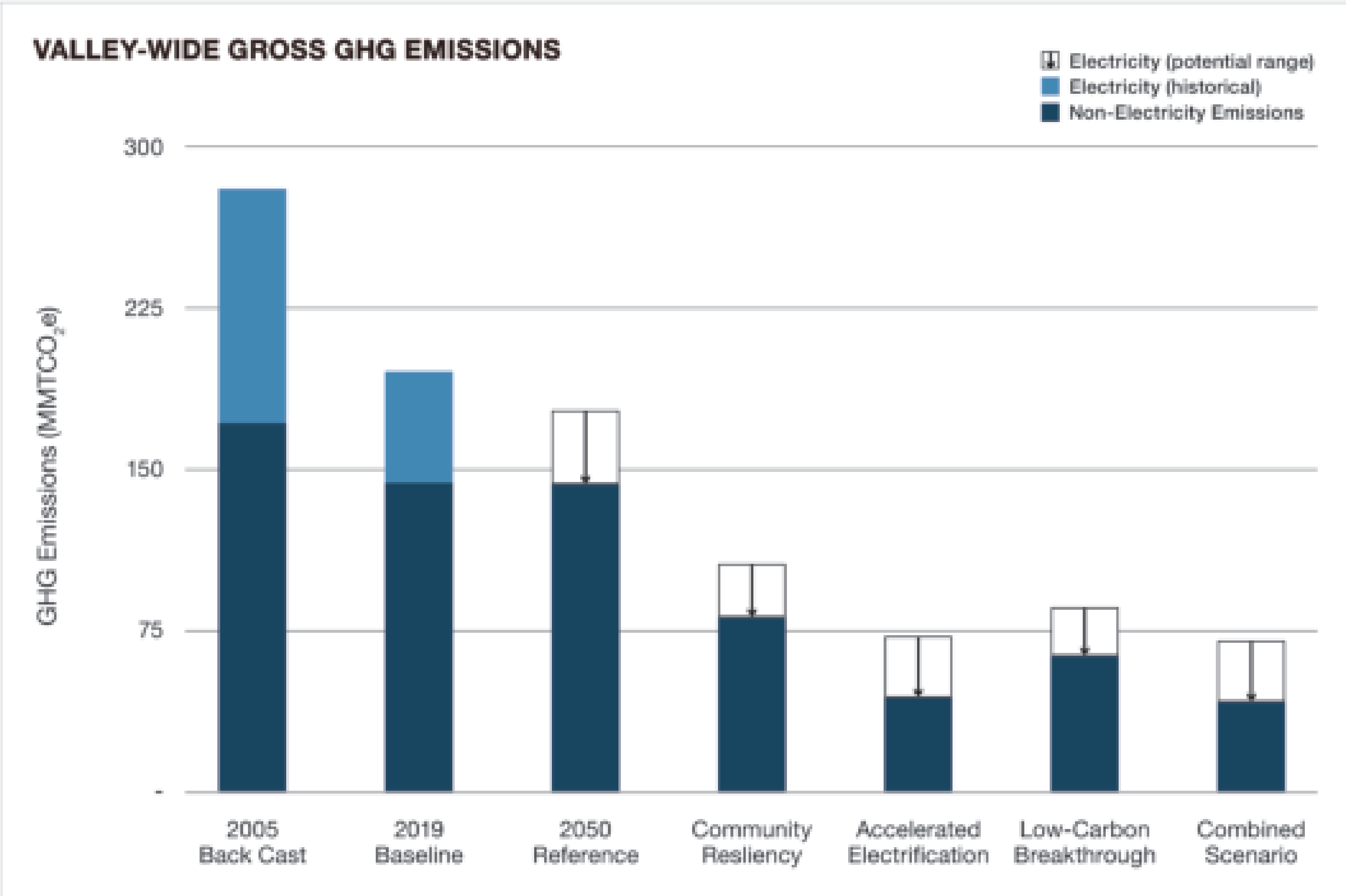



**Figure 23** Gross GHG emissions for the baseline and scenarios, not incorporating carbon sequestration potential

## Implications for Electricity Supply and Grid Infrastructure

TVA, in partnership with the LPCs, is the power provider for the Valley. TVA provides electricity for 153 local power companies (LPCs) serving 10 million people in Tennessee and parts of six surrounding states, as well as directly to 58 large industrial customers and federal installations. Since 2005, a combination of investments in customer efficiency programs and substitution of lower-carbon fuels (e.g., natural gas in place of coal) has halved emissions associated with serving the Valley's electricity demand (Figure 24).

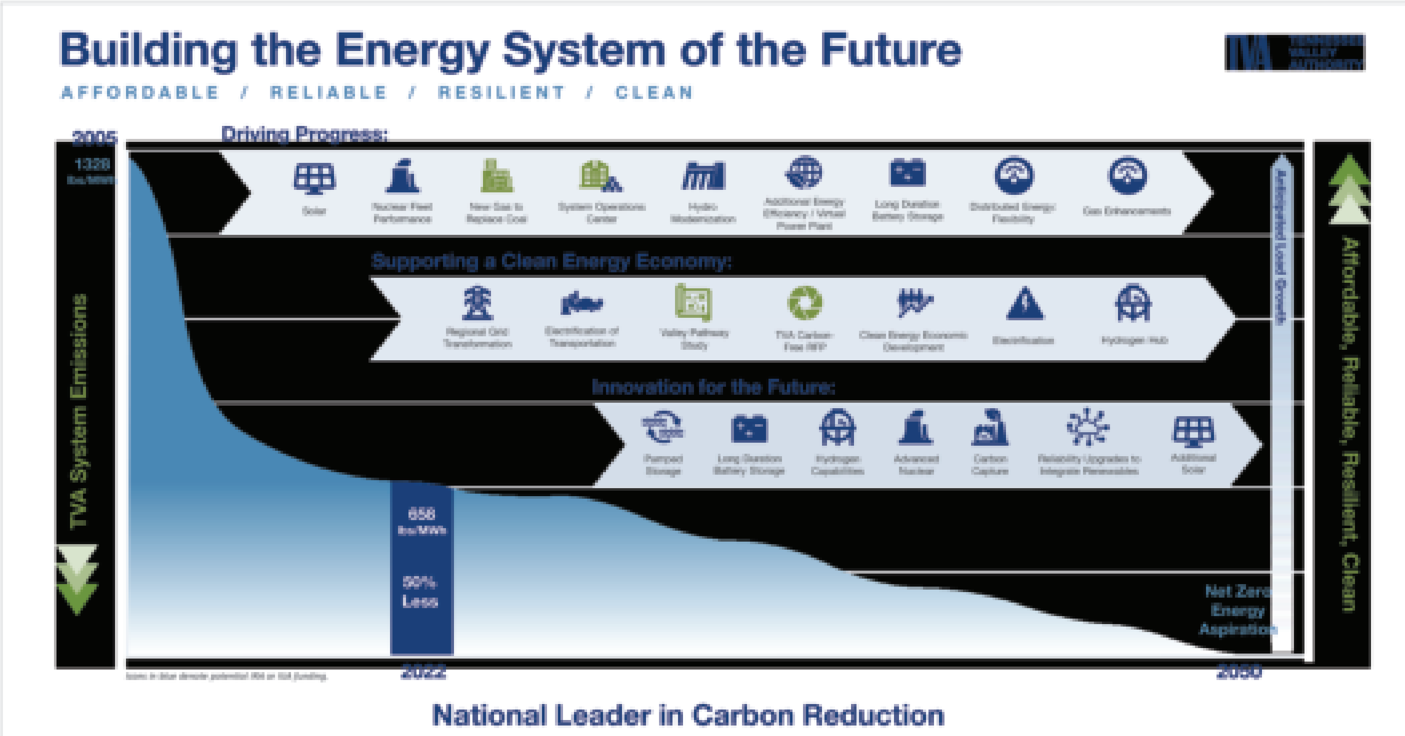



Figure 24 TVA's Decarbonization Journey

Today, TVA generates about 170 terawatt-hours (TWh), nearly 50% of which comes from clean sources such as hydroelectric and nuclear power. Much of the remainder is now gas generation, although coal is still a significant contributor to the grid – and to the sector's GHG emissions. Consistent with the 2019 IRP, TVA expects to retire remaining coal capacity and to add up to 10 GW of solar capacity by 2038. Following up on these and other commitments, TVA's Board of Directors voted on August 24, 2023 to approve $15 billion in investments in new generation and existing system improvements over the next three years.[cxiv] As the Valley adds new demands from electrifying industrial process loads, home heating, and vehicles, TVA will need to supply more and more clean electricity.

Renewable resources, such as solar and wind, can generate zero-carbon electricity but are limited by the availability of those resources – that is, the sun is not always shining and the wind is not always blowing. Complementary resources, including pumped hydro and battery storage to balance intermittent renewable electricity supply with consumer demand, can help to bridge this gap, although battery storage technologies are not yet viable for use at the "grid-scale" from both a technological and a cost perspective. Other new technologies, such as advanced nuclear generators, hydrogen, and even RNG, can also be used to provide "firm" resources to back up renewables on the grid, ensuring resiliency and safety for the Valley's electricity users.

TVA's ongoing 2024 IRP is concurrently evaluating the future of the electricity grid in the Valley, including an

### PROGRESS IN ACTION: CLINCH RIVER NUCLEAR SITE

TVA signed a technology collaboration agreement with GE Hitachi Nuclear Energy (GEH), Ontario Power Generation (OPG), and Orlen Synthos Green Energy (SGE) to support planning and preliminary licensing to help develop a 300 MW light-water small modular reactor (SMR). If approved, TVA's first SMR would be built at its Clinch River Nuclear site near Oak Ridge, Tennessee.[cxl]

| Scenario: | Community Resilience | Accelerated Electrification | Low-Carbon Breakthrough | Combined Scenario |
|---|---|---|---|---|
| Electricity Demand (TWh) | 223 | 334 | 210 | 270 |
| Non-Electricity Emissions (MMTCO$_2$e) | 81 | 44 | 65 | 40 |
| Constraints to Reach 70% Economy-Wide Emissions Reduction from 2005 | | | | |
| Emissions "budget" for Electricity Generation (MMTCO$_2$e) | 3 | 40 | 19 | 44 |
| Implicit Grid Emissions Factor Target (kg CO$_2$ per MWh) | 12 | 119 | 91 | 164 |
| Constraints to Reach 80% Economy-Wide Emissions Reduction from 2005 | | | | |
| Emissions "budget" for Electricity Generation (MMTCO$_2$e) | - | 12 | - | 16 |
| Implicit Grid Emissions Factor Target (kg CO$_2$ per MWh) | - | 35 | - | 60 |

Figure 25 Range of considerations for electricity sector emissions

evaluation of how to adapt to growing demand from electrification as well as how to transition the Valley's electricity generation to Net Zero. While that study is still ongoing, modeling in the Valley Pathways Study highlights a few takeaways for how the electric grid can support a Net Zero economy (summarized in Figure 25):

- Driving forward the demand-side transitions to a clean energy future will result in electricity demands of at least 210 TWh per year (25% more than today) and as much as twice today's total demand, or about 330 TWh per year.
- For the entire Valley to reach a 70% reduction relative to 2005, the grid would need to supply that electricity with an average emissions factor around 100 kg $CO_2$ per MWh, about 50% cleaner than today's grid and about 90% cleaner than the grid was in 2005.
- The Accelerated Electrification and Combined Scenario pathways each enable greater emissions reductions across the Valley but require more significant clean electricity resources to supply those higher electrification totals. In those scenarios, reaching an 80% reduction in emissions across the Valley would require an electricity supply of at least 270 TWh at less than 50 kg $CO_2$ per MWh.

These are challenging – but achievable – benchmarks for the grid to meet, although they also raise further questions about reliability, resilience, affordability, and pace of new asset siting that the IRP will analyze.

## Sensitivity Analysis of Scenarios

The organization of the LEAP model framework allows for extensive testing of sensitivities for each assumption in the model. Sensitivity analysis is important for any type of modeling as it allows for a security check against inputs that may play an oversized role in the model results. This process includes establishing a range of values around a model input and then running the model within that range and seeing how the model results react. For example, if energy efficiency in buildings is expected to improve by 10% by 2050, then the model's sensitivity to that 10% value can be tested by viewing the model results with energy efficiency values ranging from 5% to 15%. If the results vary dramatically, then that signifies that it is especially important to verify that the most accurate data is used for the final model run. As an example, sensitivity analysis around passenger vehicle electrification and use patterns were found to be significant drivers of diverse outcomes for economy-wide energy consumption and GHG emissions. The project team elected to incorporate this finding into the results by specifically evaluating scenarios that tested transportation sector drivers.

## Positive Impact on the Economy

The Valley's pathway to Net Zero offers an opportunity for economic development that could have far-reaching impacts for Valley residents. Although initial capital investments will be required for the energy transition, the Valley currently benefits from electricity rates that are lower than 70% of the country's[14] as well as an abundance of hydroelectric infrastructure. Increased electrification of heating and cooling, transportation, and industrial processes, in tandem with rollout of established renewable technologies and emerging technologies like nuclear small modular reactors (SMRs), has the potential to significantly reduce household and commercial costs as the Valley moves from natural gas to electricity as a primary fuel source. This will be especially important for the Eastern portion of Tennessee, whose pipeline system is already experiencing bottlenecks for the transportation of natural gas to the region, resulting in higher prices.

In addition to affordable electricity prices, the Valley's abundance of agricultural land offers the potential for new revenue streams through increased production of biofuels. This option has the added benefit of decreasing agricultural waste associated with non-

14 TVA Rates, https://www.tva.com/about-tva/tva-rates

### PROGRESS IN ACTION: FORD'S EV MANUFACTURING FACILITY

An all-new $5.6 billion mega campus in Stanton, Tenn., called BlueOval City, will create approximately 6,000 new jobs and reimagine how vehicles and batteries are manufactured. BlueOval City will become a vertically integrated ecosystem for Ford to assemble an expanded lineup of electric F-Series vehicles and will include a BlueOval SK battery plant, key suppliers, and recycling.

The 3,600-acre campus covering nearly 6 square miles will encompass Ford's Tennessee Electric Vehicle Center, which help build out Ford's next generation electric truck, and the BlueOval SK Battery Plant. The battery plant will help produce EV batteries for future Ford and Lincoln vehicles and is a joint venture between Ford and SK On. The campus also includes a supplier park in a vertically integrated system that delivers cost efficiency while minimizing the carbon footprint of the manufacturing process.

The assembly plant will use always-on cloud-connected technologies to drive vast improvements in quality and productivity. The mega campus is designed to add more sustainability solutions, including the potential to use local renewable energy sources such as geothermal, solar and wind power. The assembly plant will use carbon-free electricity from the day it opens. For the first time in 120 years, Ford also is using recovered energy from the site's utility infrastructure and geothermal system to provide carbon-free heat for the assembly plant – saving about 300 million cubic feet of natural gas typically needed each year to heat similarly sized vehicle assembly plants.

Ford plans to start production by 2025.

energy sector emissions. As the previous section showed, the Combined Scenario saw the greatest decrease in emissions in part through the assumption that certain sectors would benefit from low-carbon biofuels. Demand for biofuels would facilitate the creation of new local markets that could significantly benefit rural residents and ensure that they share in the benefits of the transition.

Weatherization and efficiency upgrades to residential and commercial buildings offer another area for household and business cost savings. In addition to TVA's EnergyRight, the Tennessee Housing Development Agency offers numerous weatherization programs that have been expanded with the support of funding from the Bipartisan Infrastructure Law;[15] these measures are targeted at decreasing household energy costs by reducing the amount of heating or cooling that is lost from leaks and other parts of the building that are not adequately sealed. The four Net Zero scenarios modeled in this study anticipate greater emphasis on improving the energy efficiency of new buildings which, in conjunction with state and federal programs targeting weatherization for existing structures, could result in significant cost savings for Valley residents.

Finally, the Valley is positioned right in the heart the "Battery Belt," a region primarily in the Southeast that is seeing significant investments in battery manufacturing capacity.[16] The Valley is not the only region seeking to decarbonize, with EV sales in the United States expected to see exponential growth in the next few years[xxv] and numerous automakers announcing plans to transition to 100% zero-emission vehicle production by the 2030s. This has a two-fold benefit for Valley residents: The first is an influx of manufacturing jobs on the individual level and a higher tax base for state programs. The second is the potential for lower-cost batteries which then translates to lower-cost EVs, lowering the initial capital costs of adoption.

15 Tennessee Housing Development Agency, Weatherization Assistance Program, https://www.tva.com/about-tva/tva-rates

16 Drive Electric Tennessee, Why Chattanooga Should be the Buckle of the Battery Belt, https://www.driveelectrictn.org/opinion-why-chattanooga-should-be-the-buckle-on-the-battery-belt/

## Environmental Justice Considerations

The Valley is a diverse region with a wide variety of communities; as such, any major transition affecting the whole economy needs to consider the equitable distribution of costs and benefits. A primary focus during stakeholder meetings for the Valley Pathways Study was to engage with community leaders and organizations to best understand how decarbonization will be felt at all socioeconomic levels. Disadvantaged and lower-income communities, both urban and rural, were a particular focus during stakeholder meetings, with discussions focused on expanding education efforts for existing programs and further expanding TVA, state, and federal programs to assist with weatherization and energy efficiency measures to help decrease household bills. These communities often face higher exposure to the risks of climate change, face income barriers to home upgrades, have higher rates of health-related vulnerabilities, and are often located near pollution centers, relative to higher-income demographics. Engaging communities on regional and local planning will need to consider environmental justice implications to determine the best way to reduce the equity gap. Distribution of information and funding among these communities will be key to ensure that programs are understood and easily accessible.

The different pathways could have different impacts on environmental justice, but the impacts will be highly dependent on how strategies will be implemented. For example, the Accelerated Electrification scenario is assuming broad EV adoption (including the anticipated reduction in EV purchase prices as they grow in market share, making them cost-competitive with gasoline-powered vehicles). This will only be possible if barriers for home charging infrastructure are removed for renters, multifamily, and low- and middle-income residents. These barriers can include difficulties installing chargers for on-street parking associated with many rental properties. In addition, the cost of installing a charger and upgrading the electric panel, if needed, can be an unaffordable upfront cost for a low- or middle-income resident. In the

Buildings sector, weatherization improvements could lead to increased rental prices if strategies are not implemented to reduce that risk. Scenarios that assume an enhanced weatherization package would necessitate higher investments in upgrading buildings, and therefore greater risk of increasing rent. It will be important to mitigate the effects of these competing pressures through proactive planning; inclusive financing; targeted programming for income-qualified households; and, finally, engagement of low-income communities and DACs, both to understand and to address these barriers to adoption.

# Partnering on the Road to Net Zero Emissions

Every day, people in the Valley make choices to improve their quality of life. The path to a Net Zero economy will need to be built into those choices to enable the rapid adoption of new technologies, perseverance to overcome challenges, and growth into a clean and competitive economy. The path to Net Zero emissions will be built on individual choices by the millions of residents of the Valley over the coming decades, including those who act on behalf of businesses, governments, and institutions.

The modeling results and engagement with stakeholders across the Valley have identified both cross-sector and sector-specific issues that can help to guide residents in the Valley toward decisions that will improve their life, reduce emissions, and overcome barriers. Some of these strategies may be public policy initiatives, while others may simply represent the people and businesses in the Valley embracing new clean technologies when and where they make financial or operational sense.

## Education, Training, and Workforce Development

To achieve a consumer-driven Net Zero economy, residents and businesses across the Valley will need to take voluntary actions. To take these actions, they will need to understand the benefits of changing their purchasing habits and making decisions to upgrade buildings and systems. They will need to understand how making these choices will improve their quality of life and will need to be aware of the resources available to them to help them make that change. As with any economic shift, some sectors of the Valley's workforce will need to transition to new opportunities that ramp up as older practices ramp down. Expanding access to training and education will help to ensure that opportunities in the clean energy economy are available to all residents in the Valley.

To reach every resident and business across the Valley, the approach will need to account for varied levels of education. For example, 14% of Valley residents lack a high school diploma, and in DACs, that percentage rises to 19%.[xxvi] To have the largest impact, state departments of education could develop Science, Technology, Engineering, and Mathematics (STEM) curricula that provide trusted information about renewables, EVs, and other emissions reduction strategies. Several additional approaches could be implemented, such as mobile education trucks deployed in partnership with LPCs.

In addition to building an understanding of the new technologies that will be needed to reach Net Zero, a highly trained workforce will be necessary for the deployment and maintenance of new infrastructure and equipment. Infrastructure projects in particular, will drive job growth across the Valley. For these jobs to go to residents of the Valley, inclusive workforce development strategies to build career ladders into high quality jobs will be needed (including improvements in career and technical education, access to apprenticeships and readiness programs, and coordination with higher education institutions). Partnering with community-based organizations will be critical to ensure that program information reaches intended audiences. In addition, TVA's well-established workforce development programs can also be leveraged to help to keep new jobs in the Valley, rather than having them exported to other regions or countries.

## Equitable Access and Community Outreach

The Valley region is diverse in its socioeconomic makeup, with strong differences between rural and urban areas and among regions (also see introduction section on Environmental Justice and Community Impact Considerations).

Digital education opportunities can increase the offers available and accessibile to the public, but this approach is not sufficient for reaching all residents in the Valley. Access to computers and the Internet varies across the Valley (Figure 26), with urban areas seeing greater access to Internet services than rural areas. Across the Valley, 15% lack internet subscriptions, and in DACs, that percentage rises to 30%. In rural households, 22% lack broadband access.[xxvii] To reach residential customers, a fleet of educational trucks fitted with hands-on exhibits and information could be deployed to bring the subject of energy and emission reduction to community events throughout the region.

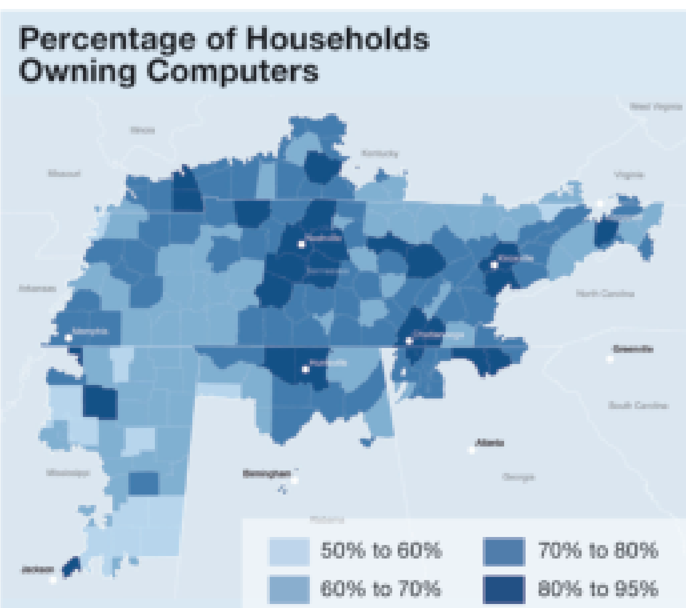



Figure 26 Computer ownership in the Valley

Strategies to reach customers will need to take several forms. For example, LPCs have started educating their industrial customers on the benefits and feasibility of fleet electrification. Strategies will also need to include environmental justice considerations, as low- and middle-income residents face additional challenges. For example, a larger share of less wealthy demographics rent rather than own a home, making EV charging at home more challenging. Renters and low- and middle-income residents may also find prohibitive the costs and logistics of upgrading the breaker box to accommodate the higher load and amperage of EV chargers, heat pumps, heat pump water heaters, and other electrification technologies. Providing incentives for (or free) EV chargers, or additional incentives for making home chargers available to the public, have been implemented with good success in other regions.

Low- and middle-income residents may not have the funds, knowledge, or time to weatherize their homes, especially if health and safety measures (such as repairing roofs) are more immediately necessary. Weatherization programs that prohibit significant rent increase for a set number of years have been used successfully. The rural gap can be addressed through specific strategies such as programs, initiatives, and campaigns that take this divide into account, aggregating demand for economies of scale, creating community partnerships, and supporting workforce development and local labor. This will be important since there is already a divide between higher costs for energy in rural areas (4.4% of total income) compared to those living in urban areas (3.1 to 3.3% of total income).[xxviii] Without proper planning, this divide may only increase as more parts of the economy electrify.

## Local Planning, Engagement, & Infrastructure Development

The Valley's population is growing at a pace far faster than the rest of the nation.[xxix] Keeping up with this population growth requires the development of new infrastructure across the region, especially in rural areas where remote and hybrid work possibilities have resulted in significant growth. From electricity service to sewage, new infrastructure buildouts and upgrades should be planned out with a decarbonized future in mind. This means considering greater electricity capacity than might be required today; pre-wiring new homes and parking areas for EV charging; consideration of where distributed solar might be sited and how it might tie into the grid; and how development patterns as a whole might impact transportation needs, land cover, and other critical drivers of the economy.

Local planning will be key to developing necessary infrastructure and deploying decarbonization strategies, including (but not limited to):

- Renewable power siting;
- Smart zoning;
- Public transportation;
- Adoption of the statewide building code or of a stretch code (a building code that requires more efficient buildings than the statewide code);
- Adopting land use zoning regulations to favor retention of forest for carbon sequestration;
- Siting of EV charging infrastructure to drive customers to local businesses while charging.

Additionally, green infrastructure and other heat island mitigation strategies should be incorporated in urban planning, especially in DACs. This will help reduce the impacts of extreme heat exacerbated by global warming in these neighborhoods. Reducing urban heat islands will also reduce air conditioning needs in these areas, reducing energy demand during the hottest days of the year.

Integrated planning that accounts for all these considerations is needed for communities throughout the Valley. Support is especially needed for rural communities that don't have the resources for comprehensive planning. Consistent guidance in planning is needed to ensure all communities have the information needed to develop plans that support sector-specific Net Zero strategies, enable the deployment of clean energy technologies, and drive forward environmental justice goals. Support in subsequently implementing the plan will also be needed for communities with limited staffing resources.

## Smart Zoning and Transportation Planning

The mode-shift opportunity (i.e., switching from driving a car to walking, taking a bus, etc.) as a result of denser housing has a much greater impact on emissions than reducing the household energy use per square foot. This reflects the simple reality that even with a large population and construction boom, housing that has already been built will continue to dominate total housing stock by 2050. A National Renewable Energy Laboratory (NREL) study estimates a single digit percentage reduction in emissions can be achieved from a bundle of smart growth policies – about 0.8% to 2.5%.

In addition to reducing miles driven, switching from internal combustion to EVs represents the single largest lever to reduce GHG emissions in the Valley. This transition is already in progress. As of Q4 2023, there were about 112,000 EV registrations across the seven states served by TVA. This level of adoption lags the national rate, although as charging infrastructure is deployed and more diverse EV body types come onto the market (e.g., electric pickup trucks), the Valley's rate of adoption will likely accelerate. In addition, supporting critical "first-movers" can help to accelerate adoption. Local Power Companies across the Valley are communicating with their commercial and industrial customers about fleet (light and medium duty) electrification to encourage transition of fleets to EVs.

### PROGRESS IN ACTION: CHARGING INFRASTRUCTURE AT STATE PARKS

Electric vehicle chargers are being installed at state parks throughout Tennessee through a partnership between the Tennessee Department of Environmental Conservation (TDEC) and Rivian, an American electric vehicle and automotive technology company. Over 30 state parks have installed Level 2 chargers, and installations are expected to be completed in 2024.

### ECONOMIC DEVELOPMENT OPPORTUNITIES

Chattanooga, Tennessee is “the buckle” at the center of the “battery belt,” a region of the Southeast where electric battery manufacturing has seen significant growth. The economy is transitioning to electric vehicles nationally and the Valley’s economy can benefit from the transition through manufacturing of electric vehicles and its components.

EV charging infrastructure has the potential to bring business to local economies across the region. If charging infrastructure is placed in a community just off the highway, it can bring people to that downtown and bring additional business to that community. Having these chargers in strategic locations has the potential to support the local economy, but only if the location of the charging infrastructure is carefully planned.

Although 80% of vehicle charging will likely take place at home, widespread residential and fleet adoption will require ubiquitous charging infrastructure, especially public and workplace charging. Currently, over 4,500 public electric vehicle charging stations exist across the seven states served by TVA, and many more will be needed to reach adequate coverage of the region.[xxx] Eight interstate highways crisscross the Valley, offering many opportunities for charging infrastructure. TVA’s Innovation and Research Group is working with partners to add EV chargers every 50 miles along interstates and U.S. highways (the Fast Charge Network), an effort that was informed by an Infrastructure Needs Assessment conducted by the DriveElectricTN initiative. In addition, there are a variety of federal programs funded under the Infrastructure Investment and Jobs Act (IIJA – also known as the Bipartisan Infrastructure Law, or BIL) as well as the Inflation Reduction Act (IRA) that can provide funding for EV charging infrastructure deployment, including the National Electric Vehicle Infrastructure (NEVI) Program, the Charging and Fueling Infrastructure (CFI) Program, and federal tax credits for charging infrastructure.

In Tennessee, the Tennessee Department of Transportation (with support from the Tennessee Department of Environment and Conservation) released the first solicitation of projects under the NEVI-funded Tennessee Electric Vehicle Infrastructure (TEVI) Program, which will build out fast charging stations every 50 miles along Tennessee’s federally-designated Alternative Fuel Corridors for EVs (which includes I-40, I-65, I-24, I-75, I-81, I-26, and the majority of U.S. 64). The Tennessee Department of Environment and Conservation also plans to release incentive programs for Level 2 charging in 2024, to be funded by the state’s Volkswagen Settlement Environmental Mitigation Trust allocation. Additional financial support programs could be developed by a variety of stakeholder types. For example, local utilities and jurisdictions outside the Valley offer incentives for grid-connected chargers, with additional incentives for landlords to make chargers available for public use.

## Land Use Change and Natural Environments

Reduced development pressure will reduce conversion rate of forests and agricultural land into suburban or urban development. This can be achieved through smart zoning and by favoring denser urban developments over unrestrained urban sprawl, as illustrated in Figure 27. Land development results in loss of carbon that was stored in vegetation and the soil (half of carbon stored in forests can be often found in the soil). Limiting land use conversion from natural or agricultural land to developed land will reduce carbon emissions.

Increasing land-based carbon sequestration in wild lands (trees, forest soils, etc.) provides broad and numerous ecological and flood protection benefits and could be considered negative emissions. However, as discussed in the report section From Reductions to Net Zero: Carbon Sequestration and Long-Term Storage, there are uncertainties and concerns around this approach, especially when considering the timeframe of storing this carbon on the scale of decades to centuries as opposed to fossil fuel emissions from carbon stored for millions of years.

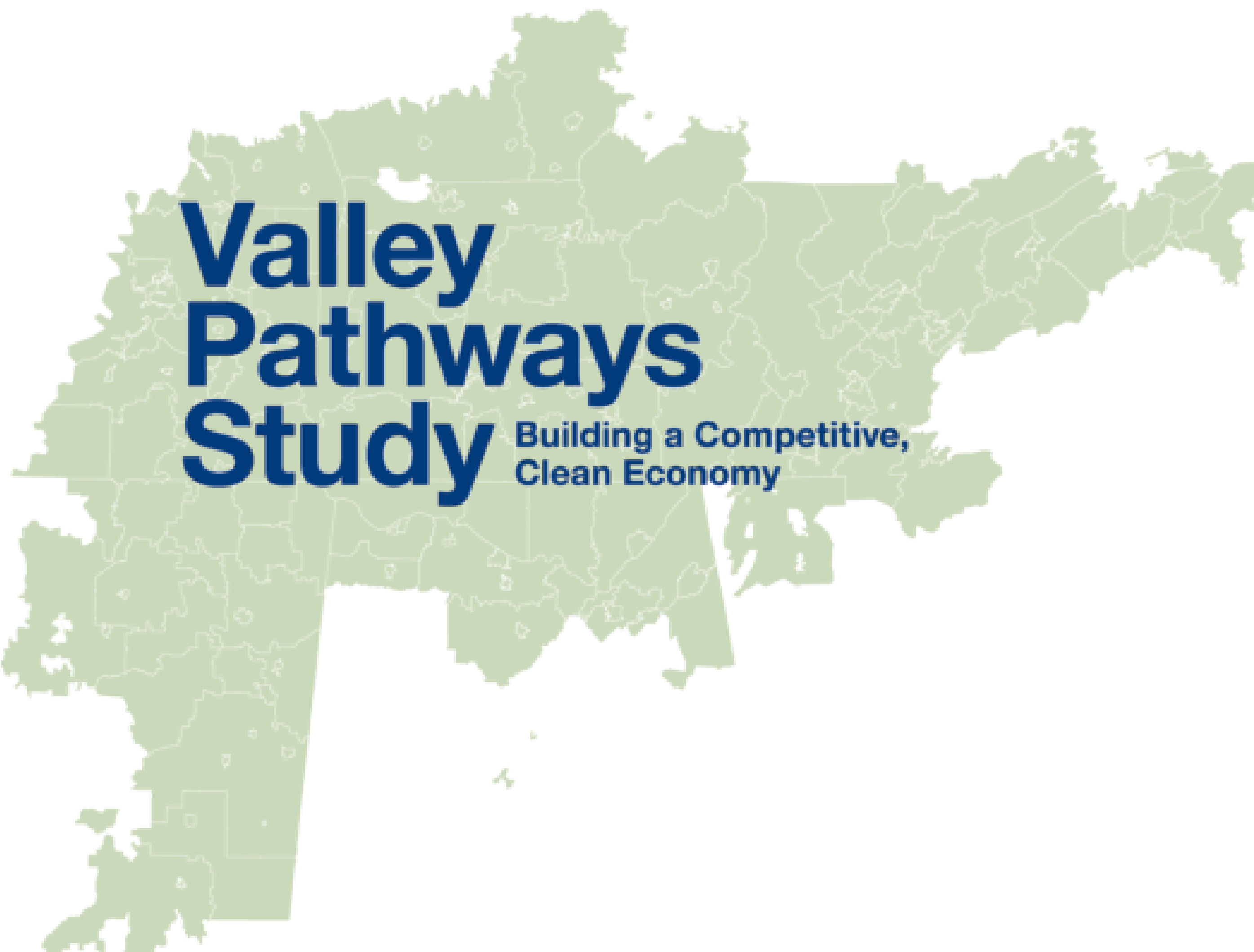

From: "Shaping the Healthy Community – The Nashville Plan", © 2016, Vanderbilt University Press

**Figure 27 Illustration of urban sprawl vs. smart growth.**
**Top: Complete community - balanced, connected, compact. Bottom: Sprawl - fragmented, car-dependent, single uses.**

## Key Next Steps

The Valley Pathways Study's data gathering, analysis, modeling, and reporting in this preliminary report is only the first step on the pathway to Net Zero emissions. To ensure progress toward pathways goals, the information in the Valley Pathways Study needs to be disseminated to policymakers and decision makers around the Valley to ensure a strong economic and environmental outcome. Getting to Net Zero emissions will require a multi-faceted, "all-of-the above" approach that will reach beyond the study's sponsors (TVA and the UT Baker School) and will need to involve organizations from across the whole Valley.

In the coming months, stakeholders from across the Valley – beyond the Stakeholder Working Group that supported this study – will come together to discuss the findings and results of the study. Feedback and advice from this peer review will be used to help craft and guide actions that must take place – not just on UT's campus or in TVA's Operations Centers, but in the city halls and capitol buildings, the homes and driveways, the factories and the farms across the Valley.



## Key Stakeholders and Focus Areas

| Group | Interest or Focus Area |
|---|---|
| **Government** | |
| • **Federal** | |
| • Weatherization Assistance Program | Weatherization and energy justice |
| • Codes and standards | Efficiency improvements, emission standards |
| • Elected officials | Economic development, workforce development |
| • **States** | |
| • Building and energy codes | New construction/ buildings efficiency |
| • Economic development agencies | Economic development, workforce development |
| • State planning divisions | Smart zoning, transportation policies, conservation of resources |
| • State Public Service Board or Utility Commission | Net-metering and DER |
| • Elected officials | Economic development, workforce development, carbon standards |
| • **Regional, Municipal, and City Government** | |
| • Local planning and zoning boards | Smart zoning, conservation of resources |
| • Local planning and zoning boards | New construction/buildings |
| • Economic development agencies<br>• State and local workforce development boards | Economic development, workforce development |
| • Local government operations | Fleet electrification, renewable natural gas production |
| • School districts | Workforce development and access to training |
| • Elected officials | Economic development, workforce development community education and engagement |
| • Solid waste districts | Organics diversion, renewable natural gas |
| **Energy Providers** | |
| • TVA | Electricity supply, storage, and resiliency, decarbonization, energy burden, education campaigns |
| • Local Power Companies | DER, fleet electrification, energy burden, education campaigns |
| • Gas, liquid, and solid fuels providers | Decarbonization and fuel switching |

| Group | Interest or Focus Area |
|---|---|
| **Large industrial producers and commercial businesses** | |
| • Airports and Port Authorities | Decarbonization and fuel switching |
| • EV and battery manufacturers | Economic development, workforce development |
| • Other manufacturers | DER, storage, resiliency, fleet electrification |
| **Research and Education Institutions** | |
| • Universities and Colleges | Decarbonization, fleet electrification, emerging technologies, workforce development, education campaigns, indirect carbon sequestration |
| • Research Labs | Emerging technologies |
| **Not-for-Profit Organizations** | |
| • Resident associations | Weatherization, environmental justice |
| • Faith-based organizations | Environmental justice |
| • ICLEI pilot communities | Sustainability planning |
| • Agricultural Groups | Decarbonization, fleet electrification, renewable natural gas production |
| • Labor unions | Workforce development, environmental justice |
| **Organizations, community and public/private partnerships** | |
| • Drive electric TN | EVs and fleet electrification |
| • Public and private land managers, such as Tennessee Wildlife Federation, the Nature Conservancy | Land use and smart zoning, indirect carbon sequestration |
| • Climate advocacy groups, such as SACE, Sierra Club, SELC, Appalachian Voices | Decarbonization, environmental justice |
| • Equity focused organizations such as United Way | Environmental justice |
| • Federal grant recipients, such as Climate Pollution Reduction Grants representatives: TDEC, Memphis, Nashville, Knoxville | Decarbonization, environmental justice |

# Appendices

Project Team

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## Glossary

**Baker School-** University of Tennessee Baker School of Public Policy and Public Affairs

**BTU-** British Thermal Unit, a measure of heat content of fuels

**CCS-** Carbon Capture and Sequestration

**CEJST-** Climate and Economic Justice Screening Tool

**CFCs-** Chlorofluorocarbons, a chemical used as refrigerant

**CIH-** Community Information Hub

**$CO_2$-** Carbon Dioxide

**DAC-** Disadvantaged community. Communities are considered disadvantaged if they are located in a census tract that meets the thresholds for at least one of the Climate and Economic Justice Screening Tool (CEJST) categories of burden

**DOE-** U.S. Department of Energy

**DOT-** U.S. Department of Transportation

**EPA-** U.S. Environmental Protection Agency

**EV-** Electric vehicle

**GHG-** Greenhouse gas

**HFCs**- hydrofluorocarbons, a chemical used as refrigerant

**HFOs-** hydrofluoroolefins, a chemical used as refrigerant

**HVAC-** Heating, Ventilation and Air Conditioning

**ICLEI-** International Council for Local Environmental Initiatives

**IRA-** Inflation Reduction Act (IRA) of 2022

**IRP-** The TVA Integrated Resource Plan

**$MMTCO_2e$-** Million metric tonne of $CO_2$ equivalent

**KPI-** Key Performance Indicator

**LEAP-** Low Emissions Analysis Platform (LEAP), an economy-wide energy and emissions model used in this study

**LPC-** Local Power Company

**ORNL-** Oak Ridge National Laboratory

**RNG-** Renewable Natural Gas

**SAF-** Sustainable Aviation Fuel

**SMR-** Small modular reactor

**STEM-** Science, Technology, Engineering and Mathematics

**TDEC-** Tennessee Department of Environmental Conservation

**TVA-** The Tennessee Valley Authority (TVA) is a federally owned electric utility corporation in the United States. TVA's service area covers all of Tennessee, portions of Alabama, Mississippi, and Kentucky, and small areas of Georgia, North Carolina and Virginia.

**UT-** University of Tennessee

**Valley-** The Tennessee Valley (referred to throughout this report as "the Valley") is the power service area administered by TVA. The Valley spans Tennessee as well as parts of Kentucky, North Carolina, Virginia, Mississippi, Alabama, and Georgia.

**VMT-** Vehicle-Miles-Traveled

## Key Performance Indicators (KPIs)

The Valley Pathways Study relied on publicly available, frequently-updated datasets to develop the Valley's baseline, which was then used as the foundation against which viable pathways were measured. Key performance indicators were selected to enable future progress tracking and long-term accountability. Measurement, Reporting and Verification is an integral component for KPIs and will be needed to ensure accurate metrics. Data tracking will also need to ensure open access to the KPI data, ideally as a digital asset.

**GHG Emissions by Sector**

- Total $CO_2e$
- Sector-specific $CO_2e$
- Conversion of $CO_2e$ into a more widely understood metric (e.g. removing x gasoline cars form the road)

**Resiliency**

- Number of resiliency microgrids
- Annual hours/days of rolling blackouts and outages

**Energy and Environmental Justice**

- Housing burden
  - Housing burden in DACs
- Number of households with energy burden greater than 6%
  - Number of households with energy burden in DACs
- Energy poverty
  - Number of customers in arrears on their utility bill
  - Number of electric utility disconnections
  - Exposure to air pollution, hazardous waste, and extreme heat in DACs

**Community Plans**

- Number of communities with a comprehensive energy plan
- % of total residents living in a community with an energy plan

**Economic Growth**

- GDP per capita
  - Unemployment
  - Unemployment in DACs
- EV and battery production jobs
- Weatherization jobs
- Renewable energy-related jobs
- Other sustainable jobs
- Sustainability jobs
  - Sustainability jobs in DACs

### Net Zero Emissions Education and Engagement

- Number of community education events
- Number of car dealerships educated on EVs

### Transportation

- Development density for new developments
- VMT by transportation mode
- EV registration
  - EV registration in DACs
- Public transportation ridership
- % of municipal fleets and school bus fleet that are zero-emission
- Percent of the Valley with fast charging stations every 50 miles
- Percent of fast charging stations in DACs vs. non-DAC communities

### Buildings

- Housing units
- Participation in EnergyRight/ efficiency programs
- % of municipalities that adopt the state energy code
- % of municipalities that adopt a stretch energy code
- % of new construction that meets the energy code
- Number of low-income weatherization projects completed
  - Weatherization projects in rural areas (as defined by the census)

### Energy Supply

- Annual energy consumption
- Peak load demand
- Power mix by source and associated emissions
- Investments in grid assets ($)
- % of solar generation from DERs vs utility scale
- RNG production by source: landfill, digesters, on-farm, wastewater
- Number of households with access to DER

### Energy Storage and Grid Modernization

- Dispatchable electricity storage capacity in the Valley (kWh) by type of storage
- Participation in load flexibility program
- Flexible demand available in the region (MW)

### Non-Energy Emissions

- Amount of organics diverted from the landfill

### Indirect Carbon Sequestration

- Carbon sequestration in trees (MT)
  - Acreage of forest
  - Average incremental forest growth
  - Average tree carbon turnover timeframe (years)
- Carbon sequestration in soils (MT)
  - Percent of agricultural land following no-till practices
  - Average soil carbon turnover timeframe (years)

## Other Studies Reviewed for the Pathways Study

The Valley Pathways team also reviewed Decarbonization Roadmaps from other regions as well as Valley- and TVA-focused reports conducted by other organizations:

- The Nature Conservancy's "Power of Place"[56] national study found that the "high electrification scenario" – which incorporates all commercially-available electrification and fuel switching technologies including renewables, nuclear, gas with carbon capture, and hydrogen – to be the optimal pathway for maximizing climate and conservation benefits.
- Similarly, the "TVA Clean Energy Future" report commissioned by GridLab and the Center for Biological Diversity[57] focused on emissions and costs associated with electrification and renewables deployment.
    - Unlike the Pathways Study, the "TVA Clean Energy Future" report centers on TVA's operations (much like TVA's IRP), whereas the Pathways Study focuses on energy demands throughout the Valley-wide economy.
    - The "TVA Clean Energy Future" highlights the economic benefits to the Valley from TVA's power supply transition to clean energy, while maintaining system resilience, and with a strong emphasis on Distributed Energy Resources (DER).

## Modeling Methodology

This appendix describes the modeling approach, sources, and assumptions used to create the 2019 Baseline, the 2005 Back-cast, the 2050 Reference Case, and the 2050 low-emissions pathways. Sources and assumptions are documented by pathway and sector below.

Emissions factors are from the EPA Emissions Hub spreadsheet, version April 2022.[xxxi]

### Baseline GHG Inventory

The modeling team used historical data to calculate GHG emissions in the Valley. Whenever possible, county-level public data from the Federal government was used. This data was critical to establish the "activity level" in the Valley. When county-level Federal data was not available, or was not representative of the Valley as a whole, the modeling team used state-level data and other sources. Often these data were not geographically specific—such as technology characteristics that would not differ region to region—so local sources were less important. These regional or national sources were used for categories such as "energy intensity."

The baseline is the foundation for the future pathways/scenarios. Energy consumption is calculated by multiplying the activity level by energy intensity. The volume of emissions is calculated by multiplying the energy consumption by an emissions factor. The activity level and energy intensity are adjustable levers in LEAP to create different scenarios. Varying the activity level represents growing or contracting industries, populations, land uses. Varying the energy intensity represents changes in the efficiency of a process or product or service.

***Agriculture***

#### Direct Emissions

The United States Department of Agriculture (USDA) 2017 Agriculture Census was used for all calculations determining the electricity and diesel fuel usage for specific agriculture sectors across the Valley.[xxxii]

The average energy-based expenses per-acre for crop farm businesses, the principal commodity, was used to calculate energy consumption per acre of specific crops. Calculations were done by converting dollar-per acre figures into units of energy based on 2014 average #2 diesel and blended commercial electricity cost averages for the United States. The electric rates were an average for the TVA region.[xxxiii, xxxiv] Similarly, the average energy-based expenses per farm for livestock businesses, by principal commodity, was used to calculate electricity and fuel oil demand for livestock farms.[xxxv]

The average energy expenses per unit of production for organic and non-organic farm businesses, by principal commodity, gives the organic and non-organic cost for utilities for one head of dairy cow.[xxxvi] Averaging the organic and non-organic costs for utilities for one head of dairy cow shows that a dairy cow requires 1,000 kWh per year.

Research from the University of Arkansas Division of Agriculture Research and Iowa State University (ISU) was used to calculate broiler and layer/pullet chicken's direct electricity and propane (LP) gas emissions. The figures used come directly from industry studies over the past 10 years. [xxxvii, xxxviii]

The average LP gas usage for a swine raised from ween to full grown in an industrial setting is 2lbs of LP gas per swine annually.[xxxix]

Based on the large population of calves in the Valley, the modeling team used ISU and BEEF magazine data and insights to determine the average weights of cattle/calves and applied this ratio (as a factor of .414) to direct energy emissions. A weighted ratio from all TVA states was then used based on inventory of calves to cattle gathered from USDA NASS statewide Agriculture Overview. This ratio was applied to each county in the Valley to accurately show the inventory of calves to cattle. The weighted ratio of calves to cattle in the Valley is 0.45.[xl, xli]

Data on conservation tillage practices from the USDA showed the adjusted diesel input rate per acre when the conservation practice of "no-till" is used. Stakeholders at the Tennessee Farm Bureau Federation confirmed this practice is used for 80% of crop acres in the Valley.[xlii]

Purdue University research showed that implementing the practice of "no-till" may result in a 57% reduction in $N_20$ emissions from crops. This 57% was adjusted down to 54.4% due to the practice only being applied to 80% of cropland. The same research also showed the average $N_20$ emissions from cattle urine per acre of pasture ranging cattle. Information from the Tennessee Farm Bureau Federation indicated that the average cattle would have roughly 1 acre to graze and therefore we used a 1:1 inventory-to-acre calculation for emissions. For calves we applied a factor of 0.5 given the size ratio of a calf to adult cow.[xliii]

A Penn State research database showed average fuel rates for mowing/raking/baling one acre of hay.[xliv]

### Indirect
### Manure Management-Enteric Fermentation Emissions

Manure and enteric fermentation emissions from EPA livestock data were used for annual methane emissions (enteric fermentation) for cows and the two numbers were averaged to apply across dairy cows and cattle of varying sizes. Other ruminants and pigs were not included in the livestock data from the EPA, so the sum was ratioed based on average weights of varying livestock.[xlv]

The estimated emissions for cows per year were used to calculate the ratio of methane emissions based on enteric fermentation emissions. EPA research estimated that total manure emissions were a factor of 0.461 when compared to total enteric fermentation. This was factored into each livestock's yearly enteric fermentation emissions to generate yearly methane emissions from manure.[xlvi]

Total indirect emissions from the EPA agriculture data were used to show the complete contributions of Methane (CH4) and Nitrous Oxide ($N_2O$) from agricultural practices. These emissions, primarily coming from synthetic fertilizers, enteric fermentation, and manure management, were a large subset of emissions and were included in this analysis.[xlvii]

### Nitrous Oxide ($N_2O$)- Synthetic Fertilizer Emissions

$N_2O$ corn emissions were used to calculate the kg/acre/year fertilizer amount for corn crop.[xlviii] This number was verified using the application rate to emissions of $N_2O$ which showed the correlation of fertilizer rate to $N_2O$ annual emissions based on average nitrogen fertilizer application amounts. The average amount of annual nitrogen application per-acre of corn was 200-240 lbs. For the remainder of crops this process was repeated using the average annual nitrogen fertilizer application rate per-acre of crop. The "Cool Farm Tool" was then used to verify these numbers by simulating basic farm activity inputs to confirm that annual $N_2O$ emissions from crops referenced were correct. The report "Management of Nitrogen Fertilizer to Reduce Nitrous Oxide ($N_20$) Emissions from Field Crops" (Figure 2 of the report) shows that 200 pounds of Nitrogen fertilizer applied per acre results in about 3.0 pounds of Nitrous Oxide emissions.[xlix, l]

Based on the large population of calves in the territory the modeling team used data from BEEF and the Pennsylvania Beef Council to determine average weights of cattle/calves and applied this ratio (as a factor of 0.414) for indirect energy emissions.[li]

## Buildings

### Residential Buildings

The residential buildings analysis estimated energy sales-by-fuel in the Valley and allocated it to building types in NREL's ResStock model.

NREL published several aggregations of their model data. [lii] The modeling team used the "by_state" aggregation for Tennessee and the raw data download by county to aggregate the counties in the Valley. ResStock upgrade package #3 was used for the baseline. ResStock's baseline package #0 used a gas furnace while #3 used the same baseline shell with a minimum efficiency heat pump, SEER 15 and HSPF 9.

For electricity, the modeling team used TVA's 2019 sector sales from EIA form 861 directly.[liii] For natural gas, county-level sales from EIA were summed across the TVA counties. For other fuels, the modeling team used 2019 EIA SEDS data for TN [liv] and scaled it up to the Valley using the ratio of ResStock's total for that fuel in TVA counties compared to the TN by_state aggregation.

The totals for each fuel in the Valley were then allocated to building types using each building type's share of the total in ResStock.

### Commercial Buildings

The commercial buildings analysis estimated energy sales-by-fuel in the Valley and allocated it to building types in NREL's ComStock model. NREL published several aggregations of their model data.[lv] The modeling team used the "by_state" aggregation for Tennessee and the raw data download by county to aggregate to the counties in the Valley.

For electricity, the modeling team used TVA's 2019 sector sales from EIA form 861 directly.[lvi] For natural gas, county-level sales from EIA were summed across the TVA counties. For other fuels, the modeling team used 2019 EIA SEDS data for TN [lvii] and scaled it up to the Valley using the ratio of ComStock's total for that fuel in the TVA counties compared to the TN by_state aggregation. These totals for each fuel in the Valley were then allocated to building types using each building type's share of the total in ComStock.

## Electricity Generation

Summer Net Capability (Capacity) is from the SEC Form 10-K for TVA for fiscal year 2019.[lviii] Pumped storage capacity and generation for all plant types is from eGRID for 2019.[lix]

## Industry

The industrial sector in this analysis included manufacturing activities as well as mining and extraction activities. A set of key manufacturing industries were identified by combining a list of TVA's direct-served customers with the top manufacturing industries by revenue listed by NAICS code.

### Manufacturing Industries Activity Driver

Revenue dollars for each industry was used as the activity level. Revenue data was available from the US Census Bureau County Business Patterns (CBP) which is collected annually and is differentiated at the state and county level. The most recent data available is from 2020 and includes the associated NAICS code for the industry, the number of establishments, the number of employees and the associated revenue dollars associated with the manufacturing activities.[lx] While the 3-digit NAICS codes were the primary categorization, more specific industries with high activity in the valley were pulled from 4-digit or 6-digit NAICS codes. Some NAICS codes were combined to create a single category in LEAP, i.e. Food and Beverage.

A list of the Manufacturing NAICS codes and their categorization can be found in Table 1.

A limitation of using detailed NAICS codes was that county-level values may not be complete. Due to a small number of specific manufacturers at the county level, customer data may be too specific and may result in the inability to identify individual operations for county-level operations. Those values are typically redacted from publicly available data, resulting in skewed revenue values when looking at the county level. Therefore, Tennessee state-level revenue was scaled to the Valley based on population and was compared against the available county-level data; similarly, calculated energy data were compared to total sales reported by TVA to EIA to ensure alignment.

#### *Energy Use*

The energy use for associated manufacturing categories (see LEAP Category in Table 1) was derived using MECS regional data by NAICS code available from the EIA.[lxi] Regional total energy values (in MMBtu) were used to determine an average energy use per revenue dollar for each industry. Energy Information Administration (EIA) data for the manufacturing sector is collected every four years and is differentiated by industry and region throughout the United States. The most recent data comes from 2018.[lxii, lxiii, lxiv] To determine the breakdown of fuel by end use, national-level MECS data were used.[lxv] The national data, which is available by NAICS code (and further separated into subcategory, end use, and fuel type) was used to determine the typical share of energy used for each subcategory, end use, and fuel type by NAICS code. An EUI/$ revenue was determined on the national level as well using US revenue data. The shares were then applied to the total energy at the regional/state level. Energy use with granularity at the subcategory, end use, and fuel type by NAICS code was not available at the regional level but was necessary to incorporate in the baseline to enable the creation of logical pathways within scenarios based on energy trends and technological advancements in this sector. Table 2 offers a list of the Subcategories and End Uses available from the National Level MECS data.

The shares for each manufacturing category by subcategory, end use, and fuel type were then applied to the regional energy use data to get a final energy use for the Valley by category. The final energy use was then divided by the estimated revenue dollars by manufacturing category within the Valley. Bureau of Economic Analysis, BEA, data contains information on gross domestic output in billions of dollars for various industries. The data is collected yearly, with the most recent complete year of data from 2021.[lxvi] The gross regional product (GRP) from the TVA region economic outlook (October 2022) was used as a cross-check of the data and to align it to the baseline year.

#### *LEAP Inputs*

The data is input into LEAP as a share of total revenue for each Manufacturing Category. Within those Categories, a share of the subcategory, end use, and fuel is entered. The final energy intensity is entered at the fuel level as MMBtu/US Dollar of Revenue.

## Mining & Extraction

#### *Mining & Extraction Activity Driver*

In addition to manufacturing, the industrial sector includes mining and extraction activities. State-level revenue for the mining and extraction was derived from the Tennessee Department of Environment and Conservation estimates and statistics from the USGS for

| LEAP smCategory | NAICS Codes | NAICS Categories |
|---|---|---|
| Aluminum | 3313, 331524 | 3313 - Alumina and Aluminum Production and Processing<br>331524 - Aluminum foundries (except die-casting) |
| Automotive | 336110, 336211, 3262, 335910 | 336110 - Automobile and Light Duty Motor Vehicle Manufacturing<br>336211 - Motor Vehicle Body Manufacturing,<br>3262 - Rubber Product Manufacturing<br>335910 - Automobile storage batteries manufacturing |
| Cement | 327310 | 327310 - Cement (e.g., hydraulic, masonry, Portland, pozzolana) manufacturing |
| Chemical | 324, 325 | 324 - Petroleum and Coal Products Manufacturing<br>325 - Chemical Manufacturing |
| Food & Beverage | 311, 312 | 311 - Food Manufacturing<br>312 - Beverage and Tobacco Product Manufacturing |
| Metals | 331 (excl. 3313 & 331524) | 331 - Primary Metal Manufacturing (excluding aluminum) |
| Other Manufacturing | 313, 314, 315, 316, 321, 323, 326 (excl. 3262), 327 (excl. 327310), 332, 333, 334 (excl. 3344), 335 (excl. 335910), 337, 339 | 313 - Textile Mills<br>314 - Textile product mills<br>315 - Apparel manufacturing<br>316 - Leather and allied product manufacturing<br>321 - Wood product manufacturing<br>323 - Printing and related support activities<br>326 - Plastics and rubber products (excl. rubber)<br>327 - Nonmetallic mineral product manufacturing (excl. cement)<br>332 - Fabricated metal product manufacturing<br>333 - Machinery manufacturing<br>334 - Computer and electronic product manufacturing<br>335 - Electrical equipment, appliance, and component manufacturing (excl. automobile battery manufacturing)<br>337 - Furniture and related product manufacturing<br>339 - Miscellaneous manufacturing |
| Paper & Pulp | 332 | 332 - Paper manufacturing |
| Semiconductor | 3344 | 3344 - Semiconductor and other electronic component manufacturing |

Table 1: Manufacturing NAICS codes and their categorization in LEAP

the Mineral Industry of Tennessee.[lxvii, lxviii] Additionally, production of certain commodities was pulled from EIA production data for Tennessee and from DOE Fossil and Energy Management, as well as from the Tennessee Geological Survey to ensure alignment.[lxix, lxx, lxxi]

***Mining Energy Use***

To calculate the energy used in the mining and extraction industries in Tennessee, data from the National Mineral Information Center (USGS) for Tennessee for total tons or Btu output of a mining or extraction commodities was combined with data from the DOE 2007 Bandwidth Study, which provides national Mining and Extraction average energy use by fuel by commodity for the entire US.[lxxii, lxxiii] State-level mining energy use ata were also derived from EIA SEDS data from the industrial sector in 2020 for the state of TN and an energy use per ton (or btu) of extracted commodity was determined.[lxxiv] State-level revenue values were scaled down to the Valley county-level based on population to obtain Valley-wide estimates of revenue and energy use. The GRP from the TVA Region Economic Outlook (October 2022) was used to cross-check values and align data to the baseline year. A total energy use by fuel for mining and extraction was used.

***LEAP Inputs***

For mining and extraction, the total energy for the sector was entered into LEAP as MMBtu by fuel type.

***Land Cover and Forestry***

Land cover and land cover change data is from USGS Earth Resources Observation and Science (EROS) Center.[lxxv]

## Non-energy

***Natural Gas leakage***

The modeling team assumed 1.42% of consumption was leaked based on EPA's methane method, an analysis of 1992 data published in 1997.[lxxvi] EPA uses this value for GHG inventories and has not revised it despite many newer studies that show a different range of leakage rates, most of which are higher than this. Higher leakage than 1992 is expected because of the use of hydrofracking.

**MECS Energy Data Categorization**

| Sub-category | End Uses |
|---|---|
| Direct Uses - Total Non-process | • *Conventional Electricity Generator*<br>• *Facility HVAC (g)*<br>• *Facility Lighting*<br>• *Onsite Transportation*<br>• *Other Facility Support*<br>• *Other Non-process Use* |
| Direct Uses - Total Process | • *Electro-Chemical Processes*<br>• *Machine Drive*<br>• *Other Process Use*<br>• *Process Cooling and Refrigeration*<br>• *Process Heating* |
| End Use Not Reported | • *End Use Not Reported* |
| Indirect Uses-Boiler Fuel | • *CHP and/or Co-generation Process*<br>• *Conventional Boiler Use* |

Table 2: Subcategories and End Uses available from the National Level MECS data

***Refrigerants***

Emissions factors of F-gases used for refrigeration (in Domestic, Commercial, Industrial and Transportation), cooling (in Residential & Commercial AC and Heat pump units, Light-duty Vehicle AC) and chemical agents (in foams, aerosols and solvents) were derived from the CARB/USCA model, which offers emissions intensities across 14 end-use sectors, and the methodology followed to calculate this can be found in the Massachusetts Decarbonization Roadmap for the non-energy sector.[lxxvii, lxxviii] Here it is assumed that these emissions are standard across all states, and the factors are then scaled using state-specific scaling factors or "drivers". For refrigeration, commercial AC and chemicals the scaling factor is population. For residential cooling it is the number of households.

For motor vehicle AC it is the number of light-duty vehicles.

State population and household data were taken from the 2019 US Census data by state and by county. Regional EIA data was used to determine the percent of homes by cooling end-use.[lxxix] Some states fall in the East South Central Region and others are in the South Atlantic Region.

Total light-duty (LDV) vehicle values were taken from the motor vehicle registration from the DOT, by vehicle and state. Auto and Truck were summed to determine number of LDV by state.

The average number of LDVs and Households per capita were calculated. These values were applied to the county level population to estimate the number of Households and LDVs in by county. The F-gas emissions were then calculated from the emissions factors multiplied by the driver.

## Transportation

### *Light-Duty Vehicles*

### *Activity Level*

First, using the BTS State Highway Travel table, person miles (million miles) data for each state was calculated for the year 2020 by dividing person miles data from year 2017 by highway vehicle miles traveled (millions) from year 2017 to yield persons per vehicle rate. The rate was then multiplied by the highway VMT (millions) for year 2020 to provide the most up-to-date person miles (millions) for each state.[lxxx]

Next, VMT and people miles traveled (millions) was calculated by converting state level highway VMT data and person miles from the BTS State Highway Travel table into county level aggregates using county specific population from the County Transportation Profiles (2020).[lxxxi]

After establishing both state and county level data for VMT the FHWA's MV-1, MV-9, tables and AFDC's vehicle database were used to find the VMT in different light-duty vehicle categories.[lxxxii, lxxxiii, lxxxiv] The total vehicle count by type for each state was estimated by combining MV-1, MV-9, and AFDC's EV vehicle registration table. By combining all three tables, a more robust breakdown of vehicle type in each state was compiled. Specifically, MV-1 provided a summary of vehicle types including both light-duty and heavy-duty vehicles in four categories: "Automobiles," "Buses," "Trucks," and "Motorcycles." MV-9 provided specific information about truck vehicle registration types by categorizing trucks into "Truck Tractors," "Farm Trucks," "Pickups," "Vans," "Sport Utilities," and "Others." AFDC provide EV registrations for each state. Farm Trucks were not included in the transportation analysis because on farm diesel use is part of the agriculture analysis.

Truck labels in table MV-9 in the "truck tractor" category were assumed to include all combination trucks for each state. These additional details were necessary to distinguish light-duty trucks which primarily run on gasoline and typically serve a different purpose than heavy-duty trucks which run primarily on diesel fuel. The summation of MV1, MV9, and the AFDC dataset was then used to proportion VMT to each vehicle type for each state. Vehicles assumed to be light-duty passenger vehicle included automobiles, SUVs, pickups, vans, EVs, and motorcycles. Total VMT data by county was then multiplied by the proportion of each vehicle type for each state to estimate VMT data by vehicle type.

## Fuel

To find the level of both gasoline and diesel consumption for each state the EIA data was filtered to state level total gasoline (MSN code: MGACP) and diesel (MSN code: DFACP) consumption (thousand barrels) for the transportation section in year 2019.[lxxxv] Total estimates were converted from thousands of barrels to thousands of gallons by multiplying each estimate by the number of gallons per barrel (42) to get total estimated gallons of gasoline and diesel for each state. Gallon estimates were then multiplied by the VMT county level data to get a total estimate of both gasoline and diesel consumption by county.[lxxxvi]

Calculating fuel use by specific light-duty vehicle types was calculated using the same method as estimating light-duty vehicle type VMT data (described above) but using "highway gasoline use" (in thousands of miles) variable instead of the "highway VMT" by county.[lxxxvii, lxxxviii]

***Heavy-Duty Vehicles Activity Level***

***Trucks***

Total miles traveled for freight estimates for heavy-duty trucks were calculated by determining the total number of tons-miles (in thousands of miles) traveled from each origin and destination state using the BTS's Freight Analysis Framework survey base year 2017. Each state's estimates include ton-miles as well as eight travel distance bands with ranges from 0 to over 2,000 miles in travel distances to add granularity cargo movement data. To find total ton-miles in base year 2017, the survey data for each state was summed together for each origin and destination state and then combined to provide the total estimated ton-miles that moved to and from each state.[lxxxix] The total tons-miles for each state where then multiplied by the proportion of businesses by county for each state using the BTS's county transportation profiles 2020 table to find total ton-miles per county for each state.[xc]

***Public transit***

Total estimates for county level demand of public transit ridership were calculated by multiplying the number of residents per county by the percent of resident workers who commute by transit per county from the BTS County Transportation Profile year 2020. Then passenger miles per county were calculated by multiplying the number of public transit riders per county by the total statewide transit ridership VMT from 2020 and then dividing by the total number of public transit riders for each state to yield passenger miles per county.

***School buses***

Total trip miles estimate for county level school bus transit were calculated by first averaging the total trip miles from each state using the NHST 2017 survey to yield an average trip length of bus routes in miles per state.[xci] Separately, number of school buses per county were calculated by multiplying the total number of yellow school buses per state found in the School Bus Fleet Magazine by the percentage of students per county from the National Center for Education Statistics to provide a proportionate number of buses to students per county.[xcii, xciii] The number of buses per county were then multiplied by the average trip miles per state to calculate the total average of trip miles for a single trip per county. Total average trip miles for a single trip were then doubled to account for two total trips per day for each county (most buses have two trips per day) yielding a total daily average mileage traveled per county. The total daily average miles traveled per county were then multiplied by the number of school days in operation (approximately 180 days) to account for the number of times a school bus is driven during the year and to yield total trip miles driven for the entire school year.

## Fuel

***Trucks***

Heavy-duty truck fuel data was calculated by using the average fuel consumed per vehicle (gallons) from the Combination Truck Fuel Consumption and Travel (2019) data and multiplying the total number of truck tractors for each state from table MV-9 from the FTA's Highway Statistics 2019 database to yield total fuel consumption for truck tractors for each state.[xciv, xcv, xcvi] The statewide fuel totals were then multiplied by the percentage of business establishments for each county from the county transportation profiles 2020 to estimate the total fuel consumption (thousands of gallons per county).

***Public transit***

First, estimates for statewide fuel consumptions were calculated by summarizing gasoline, diesel, and compressed natural gas (CNG) use in 2021 for each public transportation agency within each state using the Fuel and Energy spreadsheet from the DOT.[xcvii] Public transit fuel consumption was then calculated by dividing statewide total fuel estimates for public transit by statewide total estimated public transit ridership from the BTS county transportation profile estimates to yield fuel consumption per passenger mile for each fuel type. Each passenger miles category by fuel type was then added together to give a total statewide fuel use per passenger mile. The total fuel use per passenger mile for each state was then multiplied by the total passenger miles for each state on a county level basis to get the total estimated fuel use in gallons per county.

***School buses***

School bus fuel consumption was calculated by using the total calculated daily average trip miles per county data and dividing it by the estimated fuel economy for school buses calculated in AFLEET for both gasoline and diesel bus types to yield gasoline and diesel use per day per county.[xcviii] Daily gasoline and diesel consumption were then multiplied by the number of school days in operation (approximately 180 days) to account for the number of times a school bus is driven during the year and yield total gasoline and diesel fuel consumption for the entire school year.[xcix, c]

***Air Transit***

Demand for freight transport by air was sourced from the Bureau of Transportation Statistics (BTS) that reports the annual tons of freight and mail each airport handles. The data was then joined to another Bureau of Transportation Statistics dataset to report the annual tons of freight and mail by county. Air passenger transportation was sourced using the same method. From here, the average trip length reported by BTS for both freight and passenger trips was used to get ton-miles and passenger-miles.[ci, cii, ciii]

Fuel consumption for air transit was derived from the US State Energy Data System dataset from the Energy Information Administration (EIA). This dataset reports the total jet fuel consumption in thousands of barrels by state. Given trips for air transit vary widely in how much fuel they consume, the sum of freight tons, mail tons, and number of passengers was used to estimate fuel demand by airport. William B. Hartsfield Atlanta International in Fulton County, Georgia, for example, handled a combined 14.7 million freight tons, mail tons, and passengers in 2021. This is approximately 95% of the state's total freight tons, mail tons, and passengers, and so it is estimated to have consumed 95% of the state's jet fuel reported by the EIA.[civ]

***Rail***

Demand for public transport by rail was sourced from the National Household Transportation Survey (NHTS) developed by the Federal Highway Association and Oak Ridge National Laboratory. The NHTS is the authoritative source on the travel behavior of the American public, including daily non-commercial travel by all modes, including characteristics of the people traveling, their household, and their vehicles. The data is reported by trip origins and destinations by metropolitan statistical areas (MSA). All trips that fall outside of a MSA are grouped together by non-MSA, limiting the ability to translate the data into county level. Data is reported by the number of trips taken in eight bins of travel distance. Only trips originating in Valley were considered as part of this analysis.[cv]

Fuel consumption for rail transportation was sourced from sales of distillate fuel by state reported by the EIA. Statewide sales of distillate fuel numbers 1, 2, and 4 for railroad end uses were considered for tallying fuel demand.[cvi] The number of rail miles in each county was used as a proxy for county-level demand of freight needs and subsequent fuel demand.[cvii] Total ton-miles and passenger miles were calculated by multiplying the county level fuel consumption by fuel efficiency figures from the Association of American Railroads and the Alternative Fuels Data Center for each mode of transit.[cviii, cix]

***Water***

The Bureau of Transportation Statistics Freight Analysis Framework (FAF) provided data on freight demand through waterways in the Valley.[cx] The FAF provides a comprehensive picture of freight movement and apportions the total ton-miles of freight moved through each state. Passenger trips by ferry were sourced from the Bureau of Transportation Statistics at the statewide level, tabulated by the location of the trip's terminal port.[cxi] Further, BTS provides a dataset on total freight tonnage by principal port, which can be used to apportion demand by county.[cxii] Fuel data was unavailable for water-based freight movement, so an emissions factor per ton-mile from the Congressional Budget Office was applied to each state's total.[cxiii]

***Passenger Transportation***

Total passenger miles, vehicle count, annual miles per capita, and population from TVA's 170 counties were used as a baseline to determine the allocation of each category by vehicle type. Using passenger mile trips (PMT) estimates by transportation mode from the FHA National Household Survey provided current estimates of percentage of people traveling by modes of transportation.[cxiv] This is a national survey but given the mix of urban and rural areas in the Valley we assumed regional mode choice was similar to the national average.

These estimates were then multiplied by the total PMT in the Valley to assign total number of passenger miles by vehicle type. Average vehicle occupancy in 2017 was from Oak Ridge National Laboratory's Transportation Energy Data.[cxv] The average vehicle occupancy by vehicle type were used to convert the demand for passenger travel to vehicle miles by mode.

***Determining the number of vehicle type and fuels***

State level vehicle count and fuel type data from Alternative Fuels Data Center (AFDC) was used to provide vehicle percentages based on fuel types for light-duty vehicles in the Valley.[cxvi] Vehicle count data was collected for Tennessee. Fuel type percentages were then calculated using provided count numbers and allocated to each vehicle type. Note, only Tennessee values were collected due to its geographical reach and population density within the Valley. Tennessee values were then assumed for all other TVA states. The fuel type percentages provided a basis for determining the allocation of PMT by fuel type in the TVA region. To align AFDC estimated fuel types with FHA PMT data, fuel types were split into two categories "normal" and "long" vehicles.[cxvii] Normal vehicles consist of cars, SUVs and motorcycles while "long" consists of vans and light-duty pickup trucks. Public transit vehicle fuel types estimates were collected using the FHA National Transit Summaries and Trends report.[cxviii] Vehicle and fuel shares were used to provide demand estimates in the LEAP model.

***Freight***

Fuel efficiencies for each vehicle type including passenger and freight vehicles were collected to provide a basis for emission estimates. The Alternative fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool by Argonne National Laboratory provided miles per gallon (MPG) or Miles per Gallon equivalents (MPGe) estimates for each vehicle type.[cxix] Each vehicle type MPG or MPGe were collected by fuel type. MPGs/MPGes were then converted to their respective Energy Use Intensity (EUI) units for each vehicle and fuel type. EUI units provide the basis for the emission estimates within the LEAP model.

***2005 Back-cast***

Although 2019 was the focus as the baseline year, a recent historic "actual" from which to project possible futures, there was interest to see what emissions were in the past and document the reductions in recent years. The modeling team made an effort to locate older data from the same sources used for the 2019 baseline and to use alternative data when that was not possible. Not every data point was back-cast, the emphasis was on activities and intensities that were known to have changed, for example electricity generation switching from coal to gas, the adoption of no-till farming, the population growth, and the evolving size and efficiency of light duty vehicles.

## Buildings

***Residential***

To calculate emissions from residential buildings in 2000 we compared the Valley total housing units for 2000 and 2019 and applied this ratio to the 2019 Baseline consumption per building type and fuel.

***Commercial***

Commercial building data is not as available as the household and population data from Census. Assuming the number and area of retail, offices, schools, and hospitals are correlated with the local population, commercial energy use was scaled with the same ratio as residential.

***Industrial***

Industrial energy use was backcast using EIA SEDS data by state for each of the states in Valley. For TN the total energy use was used. For the remaining 6 states, the ratios from 2019 were utilized, which were calculated as a % of total Gross Domestic Product for the state attributed to each county for manufacturing.

***Transportation***

Road and off-road vehicle energy use were back-casted using 2005:2019 ratios for activity level (passenger miles traveled) and energy intensity, recognizing that significant fuel economy improvements were made over that time.[cxx]

***Agriculture***

2002 inventory values from the USDA Agriculture Census were applied as an activity level per crop/livestock. All the efficient conditions in the 2019 Baseline were removed from the emissions calculations (primarily cover cropping and no-till). This was done because many of the techniques used in 2019 (2017 Census) were not yet adopted in 2005 (2002 Census).

***Land Cover and Forestry***

The 2000 to 2020 change in forest in Tennessee was used as a basis for the 2005 backcast. The net forest growth from Global Forest Watch[cxxi] was removed from the 2019 baseline to create the 2005 estimate.

## Reference Case

The Reference Case serves as a comparison case for the other pathways rather than a prediction of what will actually happen. It was developed assuming all existing laws and regulations remain in place with no future modifications. The Reference Case uses local forecasts where available. Where appropriate, it also extends current trends. Below are some key inputs for the Reference Case.

***Macroeconomic Drivers***

The Reference Case uses the Boyd Center's estimates for population and household growth.

***Buildings***

The Reference Case assumes that Residential buildings stay largely the same. ResStock upgrade package #3 was used for the baseline and Reference case. ResStock's baseline package #0 uses a gas furnace while #3 uses the same baseline shell with a minimum efficiency heat pump, SEER 15 and HSPF 9. Residential energy does rise with the rising population.

Commercial buildings see naturally occurring improvements in energy efficiency (driven by current policy, economics, and trends). LED lighting is becoming very common and by 2050, we assume 100% of commercial lighting is LED. We assume 15% adoption of ComStock measures Air-Source Heat Pump Boiler, DOAS with Mini Split Heat Pumps, Exterior Wall Insulation, Heat Pump RTU, Roof Insulation, and Secondary Window System. We assume 5% adoption of Window Film and no Window Replacement.

***Electricity Generation***

Electricity Supply is not a focus of the Valley Pathways Study (VPS). TVA's IRP process began concurrently with the VPS and is expected to model the supply side with much greater detail than VPS could. The VPS model did include a simplistic electricity generation model to balance the projected demand.

Electricity generation was based on public information about TVA's plants and plan. All hydro and nuclear plants continue operation, all coal plants shut down by 2035, and solar grows to 10 GW by 2035.

***Industry***

The Reference Case uses the following assumptions (Table 3) based on the Boyd Center's Manufacturing Production.

| Industry | Assumption |
|---|---|
| Aluminum | Al demand increases by 40% by 2050<br>Recycling approaches 100% by 2050 |
| Automotive | 2025 increase of 8% in jobs for EV & associated manufacturing |
| Cement | Growth Aligned with TVA Economic Forecast |
| Chemical | 2025 increase of 8% in jobs for EV & associated manufacturing |
| Food & Beverage | Growth Aligned with TVA Economic Forecast |
| Metal | 3% Increase in 2025 |
| Paper/Pulp | Growth Aligned with TVA Economic Forecast |
| Semiconductor | Growth Aligned with TVA Economic Forecast |
| Transport Equipment Manufacturing | Growth Aligned with TVA Economic Forecast |
| Other Manufacturing | Growth Aligned with TVA Economic Forecast |
| Mining & Extraction | Projected Decrease of 50% by 2050 |

Table 3: Reference case industrial assumptions.

In the reference case, efficiency gains from EIA from the last 20 years were annualized and projected forward.[cxxii]

### *Land Cover and Forestry*

The 2000 to 2020 change in forest in TN was used as a basis for the future pathways. The net forest growth from Global Forest Watch[cxxiii] was annualized and applied as a growth rate through 2050. No changes in forest management or land conservation were modeled through those are ways that sequestration could be increased.

## Non-energy

### *Refrigerants*

The Reference Case incorporates provisions from the American Innovation and Manufacturing (AIM) act and recent ratification of the Kigali Amendment to the Montreal Protocol for HFC phase out and assumes 100% phaseout to low-GWP refrigerants by the end of an assumed 15-year equipment life.

### *Solid Waste & Agricultural Waste*

The Reference Case assumes a continuation of current activities and levels of waste. Continuing a trend from the recent past, the number of cattle in the region was assumed to fall 10% by 2050.

### *Wastewater*

The Reference Case assumes that two-thirds of the population will be receiving water from a wastewater treatment facility while the remaining third will use a leach field, which is consistent with the 2019 baseline. Emission rates are based on typical treatment facilities & leach fields.

### *Transportation*

Vehicle Miles Traveled (VMT) is projected to increase by 59% by 2050, based on the national forecast for population and VMT in the Annual Energy Outlook and the projected 22% population growth in the Valley. Mode share is assumed to remain the same as in 2019.

The energy and GHG impact of that growth is partially offset by vehicle efficiency and electrification. The medium case for EPRI's Light-Duty Vehicle Electrification Forecast for TVA was used which assumes that 40% of LDVs are EVs by 2050. We assumed a lower EV share in pickups and SUVs (80%), and among disadvantaged communities (50%). Both gaps shrink over time, with pickups and SUVs reaching parity by 2050, and disadvantaged communities reaching 90% of the electrification rate of non-disadvantaged communities.

LDV average fleet efficiency includes effects of new CAFE standards. We assumed the Valley's vehicle fleet reflects the 33% improvement from CAFE, seven years after new cars are subject to it in 2026, and a further 12% ten years later. Pickups and SUVs see a lower improvement, 20% from the 2026 target and 30% from the 2035 one.

## 2050 Pathways

The four 2050 pathways demonstrate different ways to try to reach net zero emissions. Community Resiliency focuses on efficiency and demand reduction. Accelerated Electrification focuses on electrifying any fuel use possible. Low-Carbon/Biofuel Breakthrough assumes that the investments in bio-based drop-in replacement for fossil fuels pays off. The Combined scenario takes elements from each of the other scenarios to take advantage of the strengths of each to go further. These pathways are not predictions or projections, they examine what needs to happen to reach net zero emissions, what different ways could that goal be reached.

**Tool: SEI's LEAP**

- The Low Emissions Analysis Platform (LEAP) is an economy-wide energy and emissions model.
- LEAP's interface provides a transparent accounting framework rather than a black box model.
- The framework is also extremely customizable, enabling key features for this project:
    - Ability to drill down from high-level demand at the scale of the whole Valley to specific equipment in a single subregion (the regional capability was not used.)
    - Flexibility customize data structure to match other frameworks
    - Scenario inheritance framework allows the iteration of scenarios and sensitivity analysis.
    - Versatile results graphs and tables available for dozens of output metrics for any input level and region.

LEAP was developed by Stockholm Environment Institute (SEI) and has been applied in nearly 200 countries over decades of evolution. LEAP software itself is not a model. Similar to a spreadsheet, it stands ready to calculate whatever a user imports and enters. It only requires arithmetic for most results and excels at keeping track of a lot of inputs and allowing the creation of scenarios that vary by one or more inputs while keeping the other inputs consistent with other scenarios. This LEAP scenario inheritance means that pathways inherit assumptions from the Reference case unless explicitly defined differently. The assumptions and sources listed below focus on those different assumptions in the net zero pathways. For data points not mentioned below, the pathways use the same assumptions and sources as the Reference Case above.

***Community Resiliency Pathway/Localization***

The Community Resiliency Pathway assumes a future in which the Valley reinvests in local infrastructure, seeking concentrated growth, resiliency, and community self-sufficiency. More needs (energy and other) are met locally, and this scenario could also be thought of as a localization pathway. As a result, the Community Resiliency Pathway assumes that there is decreased demand for mobility, that there are more attached housing types, and that heating, cooling, and envelope efficiency nearly reach to their technical potential. The decarbonization pillar this scenario leans on is efficiency.

***Buildings***

The Community Resiliency pathway assumes that Residential buildings maximize their efficiency and electrify, applying ResStock upgrade package #10. This package uses an enhanced shell with a 30% reduction in air leakage, R-49 to R-60 attic insulation (for climate zone 3A and 4A respectively) when existing insulation was less than R-30 or R-38. For walls without insulation, R-13 is added via drill and fill. What separates this from the "basic" shell in the Low Carbon Breakthrough scenario is sealing the crawlspace vent, R-10 foundation insulation, and R-30 in finished attics and cathedral ceilings. A heat pump water heater is added and a high efficiency heat pump, SEER 24 and HSPF 14.

Commercial buildings see aggressive improvements in energy efficiency in this scenario. 100% of commercial lighting is assumed to be LED by 2050, as in the Reference Case. We assume 50% adoption of ComStock measures Air-Source Heat Pump Boiler and Heat Pump RTU, 20% DOAS with Mini Split Heat Pumps, 100% Exterior Wall Insulation, 100% Roof Insulation, 60% Secondary Window System, 15% Window Film and Window Replacement.

***Industry***

The Community Resiliency Pathway assumes the same as the Reference Case for industrial development (Table 4).

In addition to growth in the industrial sector, efficiency is a strong factor in community resilience. It is assumed in this scenario that the currently available technical potential efficiency according to sector-specific bandwidth studies conducted by DOE.[cxxiv]

## Non-Energy

***Refrigerants***

Like the Reference Case, the Community Resiliency Pathway assumes that the AIM Act and Kigali Amendment will lead to HFC phaseout but replaces the low-GWP refrigerants from reference scenario with a 50/50 split of low-GWP and Natural refrigerants. It also assumes improvements in leak tight installations and improved end-of-life reclamation practices.

***Solid Waste***

The community resiliency pathway assumes that composting increases, transitioning from outdoor aerobic to anaerobic digestion with methane capture. For waste that is landfilled, this pathway assumes improved capture of methane in active landfills and reduced flaring, meaning that more gas is captured for power generation or possibly pipeline injection.

***Wastewater***

The increased population density in this scenario leads to an assumption that a greater population will

| Industry | Assumption |
|---|---|
| **Aluminum** | **Al demand increase by 40% by 2050 Recycling approaches 100% by 2050** |
| **Automotive** | **2025 increase of 8% in jobs for EV & associated manufacturing** |
| **Cement** | **Growth aligned with TVA Economic Forecast** |
| **Chemical** | **2025 increase of 8% in jobs for EV & associated manufacturing** |
| **Food & Beverage** | **Growth aligned with TVA Economic Forecast** |
| **Metal** | **3% increase in 2025** |
| **Paper/Pulp** | **Growth aligned with TVA Economic Forecast** |
| **Semiconductor** | **Growth aligned with TVA Economic Forecast** |
| **Transport Equipment Manufacturing** | **Growth aligned with TVA Economic Forecast** |
| **Other Manufacturing** | **Growth aligned with TVA Economic Forecast** |
| **Mining & Extraction** | **Projected decrease of 50% by 2050** |

**Table 4: Community resiliency pathway industrial assumptions.**

be served by wastewater treatment facilities rather than leach fields. Aerobic treatment facilities convert to anaerobic digestion systems with onsite power generation.

There is also a slight reduction in leach field emissions because of newer systems installed with new construction and replacements as existing systems fail.

***Transportation***

The Community Resiliency Pathway uses the high forecast from EPRI's Light-Duty Vehicle (LDV) Electrification Forecast for TVA, which anticipates 82% of LDVs are EVs by 2050. This pathway also assumes a 20% lower demand for personal miles traveled and 40% reduction in single-occupancy vehicle mode share due to denser and transportation-oriented development. This pathway assumes development of the recommended passenger train service from the Tennessee Advisory Commission on Intergovernmental Relations report, *Back on Track?*[cxxv]

***Accelerated Electrification Pathway, "Electrify Everything"***

The Electrification Pathway assumes that vehicle and thermal electrification dominate the transition, based on larger national trends. Any industrial processes that can electrify also do so. The Electrification Pathway represents a higher bound of electric demand for the Valley.

The Electrification Pathway assumes a high electric vehicle adoption rate, a higher coefficient of performance for heat pumps, and significant industrial process electrification. Everything except the most intense, highest temperature applications switch to heat pumps and electric motors. The decarbonization pillar for this pathway is electrification.

***Buildings***

The Electrification pathway assumes the highest technically achievable electrification of end uses.

This scenario applies ResStock upgrade package #8. This package uses the baseline shell and adds a heat pump water heater and a high efficiency heat pump, SEER 24 and HSPF 14.

Commercial buildings use many of the same assumptions as the Reference case, except 100% adoption of Air-Source Heat Pump Boiler and Heat Pump RTU.

***Industry***

Assumptions related to industrial uses are characterized by a strong shift to electricity (Table 5).

In the electrification scenario energy efficiency savings are assumed to reach the maximum of currently available technologies across the different sector processes according to the DOE Bandwidth studies.[cxxvi]

| Industry | Assumption |
|---|---|
| Aluminum | Process Electrification: 90% by 2050 |
| Automotive | 90% Electric by 2050 |
| Cement | 75% Electric by 2050 |
| Chemical | 90% Electrification by 2050 |
| Food & Beverage | 90% Electrification by 2050 |
| Metal | 90% process by 2050<br>Biogas as a remainder |
| Paper/Pulp | 100% Electrification of process [1] |
| Semiconductor | 90% Electrification by 2050<br>10% biofuels |
| Transport Equipment Manufacturing | 100% Electrification by 2050 |
| Other Manufacturing | 90% Electrification<br>10% biofuels |
| Mining & Extraction | 90% Electrification<br>10% biofuels |

Table 5: Accelerated electrification pathway industrial assumptions

## Non-Energy

***Refrigerants***

Like the Reference Case, the Electrification Pathway assumes that the AIM Act and Kigali Amendment will lead to HFC phaseout but replaces the low-GWP refrigerants from reference scenario with a 50/50 split of low-GWP and Natural refrigerants. It also assumes improvements in leak tight installations and improved end-of-life reclamation practices.

***Wastewater***

Aerobic treatment facilities convert to anaerobic digestion with onsite power generation.

There is also a slight reduction in leach field emissions because of newer systems installed with new construction and replacements as existing systems fail.

### *Transportation*

Passenger travel Demand remains the same as the Reference Case. The Electrification Pathway assumes 100% adoption of EVs for LDVs in 2050, scaling up EPRI's high forecast for TVA. The Pathway also assumes a 20% reduction in single-occupancy mode share and development of the recommended passenger train service from the Tennessee Advisory Commission on Intergovernmental Relations report, *Back on Track.*[cxxvii]

### *Low Carbon [Biofuel] Breakthrough Pathway*

The Low Carbon [Biofuel] Breakthrough Pathway assumes that the Valley invests in bioenergy production and next-generation low-carbon manufacturing processes. This represents a lower bound of electric demand among net zero scenarios.

This Low Carbon Breakthrough pathway assumes that bioenergy production nears technical potential and that low-carbon manufacturing breakthroughs occur. This decarbonization pillar pathways maximizes is low-carbon fuels and processes.

### *Buildings*

The Low Carbon Breakthrough pathway assumes that Residential buildings improve their efficiency and electrify, applying ResStock upgrade package #9. ResStock doesn't include biofuel measures. This package uses a basic shell upgrade with a 30% reduction in air leakage, R-49 to R-60 attic insulation (for climate zone 3A and 4A respectively) when existing insulation was less than R-30 or R-38. For walls without insulation, R-13 is added via drill and fill. A heat pump water heater is added and a high efficiency heat pump, SEER 24 and HSPF 14.

Commercial buildings improve their energy efficiency. 100% of commercial lighting is LED by 2050, as in the Reference Case. We assume 50% adoption of Exterior Wall Insulation and Roof Insulation, 50% Secondary Window System, and 10% Window Film.

### *Industry*

The Low Carbon Breakthrough pathway assumes considerable success in decarbonization research including breakthroughs in low-carbon polysilicon, cement, and aluminum; production of steel without coal for any mills not already using scrap as input; and biofuels use in Pulp and Paper. A full table of the industrial assumptions is in Table 6.

Energy efficiency in this scenario is assumed to reach only half of the currently available efficiency savings potential from the DOE Bandwidth study.[cxxviii]

## Non-Energy

### *Refrigerants*

The initial reduction of emissions for the Low Carbon Breakthrough pathway is assumed to follow the 50/50 split between Low-GWP refrigerants and Nat-

<table>
<tr><th>Industry</th><th>Assumption</th></tr>
<tr><td>Aluminum</td><td>Process 30% Electric<br>70% Hydrogen & Biofuels<br>100% RNG for Indirect use<br>100% Process using inert anodes</td></tr>
<tr><td>Automotive</td><td>Process 30% Electric<br>70% Hydrogen & Biofuels<br>100% RNG for Indirect use</td></tr>
<tr><td>Cement</td><td>75% Biogenic Limestone Biochar replaces Coal by 2040</td></tr>
<tr><td>Chemical</td><td rowspan="7">Process 30% Electric,<br>70% Biofuel 100% RNG for Indirect use</td></tr>
<tr><td>Food & Beverage</td></tr>
<tr><td>Metal</td></tr>
<tr><td>Paper/Pulp</td></tr>
<tr><td>Semiconductor</td></tr>
<tr><td>Transport Equipment Manufacturing</td></tr>
<tr><td>Other Manufacturing</td></tr>
<tr><td>Mining & Extraction</td><td>All non-electric uses switch to Biofuels</td></tr>
</table>

Table 6: Low carbon breakthrough pathway industrial assumptions.

ural Refrigerants until 2025 and then phase in Natural Refrigerants to replace typical refrigerants in 95% of applications.

***Wastewater***

Aerobic treatment facilities convert to anaerobic digestion with onsite power generation. There is also a slight reduction in leach field emissions because of newer systems installed with new construction and replacements as existing systems fail.

***Transportation***

The Low Carbon Breakthrough pathway takes the medium forecast from EPRI Light-Duty Vehicle Electrification Forecast that 40% of LDVs are EVs by 2050 combined with a 20% reduction in single-occupancy vehicle use. An additional 33% of LDVs are hydrogen or biofuel powered. Like the Reference Case, a 59% VMT growth by 2050 (including a 22% population growth) is also assumed.

This pathway assumes development of the recommended passenger train service from the Tennessee Advisory Commission on Intergovernmental Relations report, *Back on Track*.[cxxix]

***RNG***

Renewable Natural Gas potential and cost was from an ICF study for the American Gas Foundation.[cxxx] The study provides low and high resource potentials, both of which recognize that there will be competition for feedstocks and not all of the available feedstock will be captured. Results are provided by Census Region and State within the Valley: 50.2 TBtu/yr by 2040 in the low scenario and 142 TBtu/yr in the high scenario.

***Combined Pathway***

The Combined Pathway assumes the best elements of each of the other pathways, in prioritized order: the higher efficiency of the community resiliency pathway first, the high penetration of fuel switching from the accelerated electrification pathway, and the biofuel breakthroughs of the Low Carbon [Biofuel] Breakthrough Pathway. Accelerated electrification is given priority over biofuels where possible, though increased Biofuels, Renewable Natural Gas, and hydrogen are used in areas where drop-in fuels and bio-energy technologies can mature faster than the rate of electrification. This pathway makes no original assumptions.

***Buildings***

The Combined Pathway for Residential and Commercial buildings is the same as the Community Resiliency Pathway.

***Industry***

For industry, electrification does not overtake gas systems. Gas systems in the hard-to-electrify sectors, which include industries with high process heat demand are assumed to increase efficiency through technological breakthroughs. These are then split with about 50% assuming adoption of RNG, hydrogen or other green fuels, and the other 50% continuing toward electric systems in the combined scenario. Additional industries with medium and low process heat are easier to electrify and continue increasing electrification through 2050. In this scenario, it is assumed that currently available technologies are adopted and that additional energy efficiency savings are realized from technologies that are currently in the R&D phase. In the DOE Bandwidth studies,[cxxxi] the maximum technical potential is not achieved across 100% of industries but rather 75% of the potential maximum savings outlined is realized in this scenario for each manufacturing industry.

## Non-Energy

***Refrigerants***

The initial reduction of emissions for the Combined Pathway is assumed to follow the 50/50 split between Low-GWP refrigerants and Natural Refrigerants until 2025 and then phase in Natural Refrigerants to replace typical refrigerants in 95% of applications.

### *Wastewater*

The increased population density assumed under the Combined Pathway leads to an assumption that a greater population will be served by wastewater treatment facilities rather than leach fields. Aerobic treatment facilities convert to anaerobic digestion with onsite power generation.

There is also a slight reduction in leach field emissions because of newer systems installed with new construction and replacements as existing systems fail.

### *Transportation*

This pathway takes lower transportation demand and single-occupancy vehicle mode share from Community Resiliency Pathway, the high electrification from the Accelerated Electrification scenario, and fills in biofuels where electrification isn't possible.

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