BGE Integrated Decarbonization Strategy

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Executive Summary

About this study

The transition to a deeply decarbonized economy is underway in Maryland, building upon over a decade of climate change mitigation efforts led by the State, utilities, and other key stakeholders. The Maryland Department of Environment (MDE) began to chart this path, supported by E3's analysis, by considering scenarios that meet the statewide Greenhouse Gas Reduction Act (GGRA) goals of 40% reductions in greenhouse gas (GHG) emissions below 2006 levels by 2030.[1] MDE then built on this work by engaging with E3 to develop more ambitious illustrative decarbonization pathways for the buildings sector, which confirmed that building electrification is critical to reducing emissions to net zero by 2045, and that pursuing a mix of technologies, including hybrid systems, helps to decrease costs.[2]

Expanding upon these recent statewide analyses, in late 2021, E3 began working with Baltimore Gas and Electric (BGE) to assess decarbonization options within BGE's service territory, focusing on impacts for BGE's gas and electric customers. With the subsequent introduction and April 2022 passage of the Climate Solutions Now Act of 2022 (CSNA), this latest E3 analysis represents the first decarbonization study developed since CSNA's enactment and shows the value of coordinated electric and gas infrastructure planning in meeting Maryland's new goals of 60% reductions by 2031 and net zero GHG emissions by 2045.

Reducing emissions from both Maryland's building and industrial sectors will be critical to achieve the State's climate targets. Direct fuel use in Maryland's building and industrial sectors accounts for 11% and 6% of State emissions respectively. As the largest utility in Maryland, serving approximately half of the state's residential, commercial, and industrial gas customers, BGE is a key partner in decarbonizing these sectors.

BGE currently delivers electricity to 1.3 million customers and natural gas to nearly 700,000 customers through its networks of electric and gas infrastructure. The decarbonization strategies that Maryland and BGE's customers pursue will materially impact the relative emphasis of the company's investment in its electric and gas infrastructure. Those changes will in turn affect BGE customers' costs to safely and reliably power and heat their homes and businesses, as well as their costs associated with transportation and mobility.

E3 developed an economy-wide Pathways model for BGE's service territory to evaluate plausible options that achieve the state's climate goals. E3's modeling approach includes an economy-wide treatment of energy demands across BGE's service territory, an assessment of impacts on both electric and fuel energy supply transformations that occur upstream of BGE's system, impacts on BGE's gas and electric infrastructure, and an assessment of implications of decarbonization for customer affordability.

E3 worked with BGE to develop three alternative decarbonization scenarios that vary the use of the Company's gas and electric infrastructure and the mix of technology solutions that customers adopt

[1] https://mde.maryland.gov/programs/air/ClimateChange/Documents/2030%20GGRA%20Plan/Appendices/Appendix%20F%20-%20Docuementation%20of%20Maryland%20PATHWAYS%20Scenario%20Modeling.pdf

[2] https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/MWG/Decarbonizing%20Buildings%20in%20Maryland.pdf

across sectors. The scenarios are summarized in Figure ES-1. Throughout this report, the Hybrid and Diverse scenarios are referred to as Integrated Energy System Scenarios, meaning that they rely on a combination of electric and gas infrastructure to achieve decarbonization. In contrast, the Limited Gas scenario shifts a larger share of energy demands to BGE's electric system.

Figure ES-1. Decarbonization scenario assumptions by sector

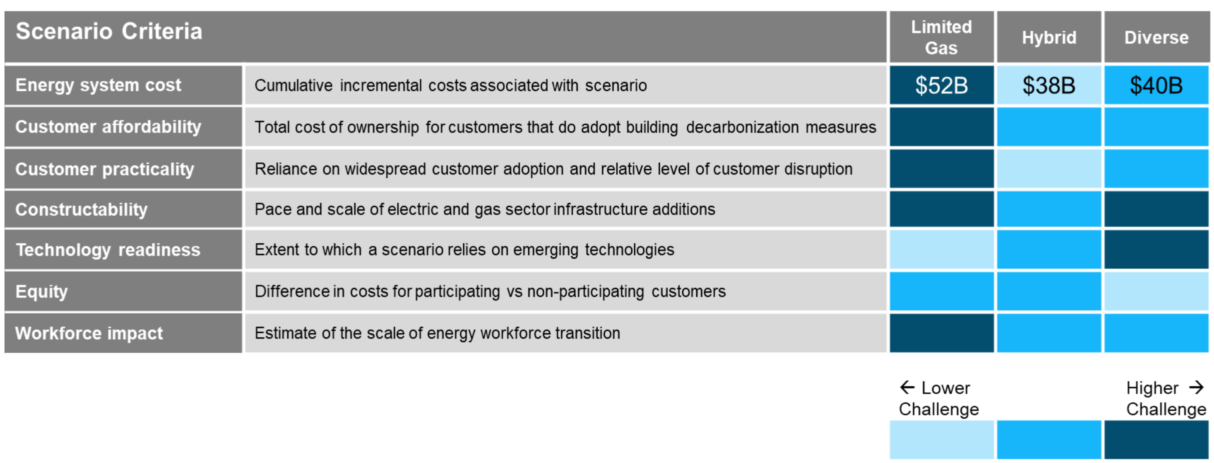
		Integrated Energy System Scenarios	
	1. Limited Gas	**2. Hybrid**	**3. Diverse**
Scenario narrative	High-electrification and shift away from delivered gas and other fuels	Leverages an increasingly clean electric system, high electrification, and the gas network	
Buildings	Efficiency and electrification	Efficiency, electrification, gas-electric hybrids, and a targeted role for alternative fuels	Efficiency, electrification, gas-electric hybrids, gas heat pumps, network geothermal, and alternative fuels
Industry	Efficiency and electrification	Efficiency, electrification, and alternative fuels	Efficiency, electrification and alternative fuels
Transportation	LDV electrification and alternative fuels for MDV & HDV		
Electricity	Zero-carbon electricity by 2045		
Other Sectors	66% reduction by 2045		

Key Findings

There are multiple viable paths to decarbonization, and any future that meets net zero will require significant transformations and investments across the economy and a role for electrification in buildings and transportation.

1. **Pathways that rely on an Integrated Energy System carry a lower overall cost and level of challenge relative to those that rely more exclusively on electrification or renewable gases.** Electrification is the core engine of decarbonization across all scenarios considered in this report because of its high level of commercialization, scalability, and complementarity to an increasingly decarbonized electricity system. However, scenario findings identify ongoing value for gas infrastructure that deliver an increasing blend of renewable gases[3] as a complement to electrification. Gas infrastructure serves as an existing, low-cost source of capacity that reduces the amount of electric generation, transmission and distribution capacity that will need to be added over the coming decades. Investments in gas infrastructure, including the STRIDE Program, help to modernize the system, reduce methane emissions and improve safety and reliability. Those investments could be balanced against future opportunities to pursue targeted electrification that enable gas infrastructure savings where such initiatives produce system and ratepayer cost savings. An integrated approach that leverages the advantages of both electric and gas infrastructure can help to reduce both total energy system and consumer costs, while also reducing challenges associated with large-scale electric infrastructure additions and customer retrofits, while still achieving decarbonization across all sectors.

Figure ES-2. Assessment of the level of challenge across evaluation criteria for decarbonization scenarios. "Level of challenge" denotes the extent to which the scenario is substantially different from current practices, policies, or technologies.

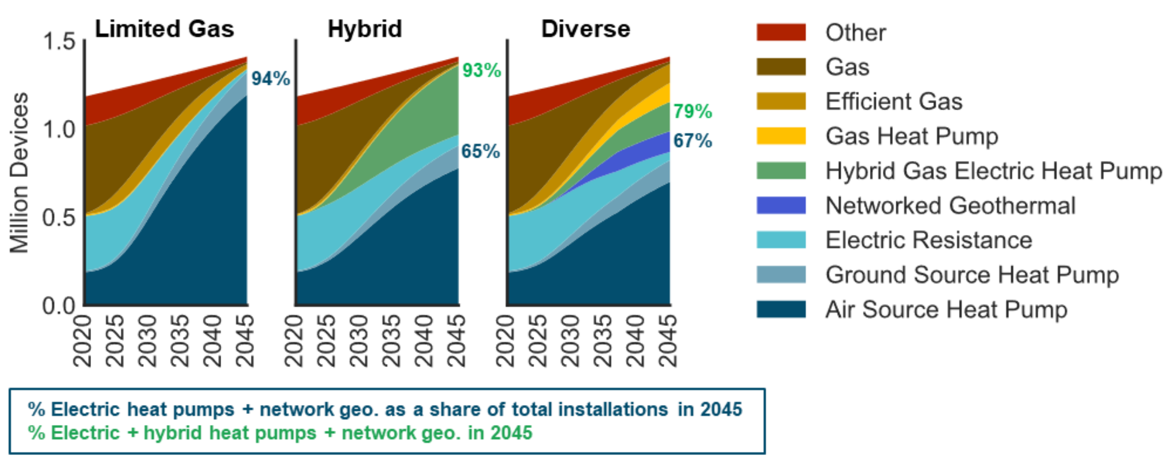


[3] Renewable gases considered in this study encompass renewable natural gas from biogenic sources produced via anaerobic digestion and gasification, hydrogen produced via electrolysis powered by renewable energy, and synthetic natural gas produced using hydrogen and a climate neutral source of CO2.

2. **All scenarios that achieve net-zero require significant investments in electric generation and delivery infrastructure, but those costs can be mitigated via an integrated approach**. Clean electric generation capacity will need to be sited, permitted, built and interconnected into the grid. BGE's electric delivery system will need to increase in capacity and modernize to accommodate new electrification loads while at the same time the energy it delivers via both gas and electricity will need to become cleaner. Relying on a dual energy approach reduces the overall scale of infrastructure additions required to achieve net-zero goals. As a result, pathways that rely on an integrated energy system are lower cost than all-electric or all-renewable gas based pathways [4] and have a lower level of challenge in terms of the constructability of new infrastructure, while providing more flexibility to navigate rapidly-changing technological and market developments to continue to allow the most appropriate choices for all customers throughout the energy transition. Those advantages are tempered by higher reliance on renewable fuels, which have a comparably lower level of technology readiness compared to all-electric measures.

3. **Consumers are central to the transformations required to achieve net-zero** and achieving the scale of adoption envisioned here will require developing solutions that are affordable and work for all customers, equitably. All-electric solutions can lead to higher retrofit costs for existing buildings, particularly older buildings, relative to alternatives. Decarbonization pathways that include a diverse set of heating technologies enable strategic application of all-electric solutions where they are most appropriate, while allowing for alternative strategies in cases where all-electric solutions are more challenging. Lower income customers are expected to face higher energy burdens, particularly in the Limited Gas scenario, so identifying strategies to mitigate those impacts will be critical to achieving a just transition to net-zero. Relative to Limited Gas, the Hybrid and Diverse scenarios offer potential pathways through which the energy burden of decarbonization can be managed.

Figure ES-3. Stock transition for residential space heating devices in BGE's territory



[4] This study does not directly consider an all renewable gas based pathway. Such a pathway was considered in the MD Buildings Report and was found to carry a high degree of challenge across several different considerations.

4. **As Maryland's largest utility, BGE will have an important role in supporting customer adoption of decarbonization options by introducing and scaling new products, programs, and services required to achieve net zero** through, for example, research and demonstration programs, incentives, and new types of infrastructure investments. Examples where BGE could have a role in facilitating and scaling decarbonization technologies include, but are not limited to, strategic electrification, networked geothermal, and green hydrogen production and delivery. BGE's role could also include working to ensure that all its customers are able to participate in and share the benefits of the decarbonization transition by, for example, ensuring equitable electric vehicle charging infrastructure in disadvantaged communities, supporting efficient heating technologies adoption for low-income customers, and finding additional ways to protect low-income customers from bearing undue burdens through the energy transition.
5. **Regulatory and policy support will be necessary to manage the challenges associated with decarbonization.** Regulatory and policy interventions are needed in several areas including, but not limited to, enabling BGE and its customers to support the state's decarbonization ambitions in order to manage the cost impacts of implementing decarbonization, supporting customer adoption of electrification technologies, and implementing non-pipe alternatives projects.

Key Recommendations

Based on the key findings of this study, E3 recommends the following strategies to BGE, its regulators, policymakers and other key stakeholders in Maryland:

1. **Increase funding for and scope energy efficiency programs and align measures to support decarbonization.** All scenarios include levels of energy efficiency savings that go beyond even Maryland's current ambitious targets and include both traditional efficiency measures and electrification. For that to happen, additional funding is likely needed and measures like weatherization of buildings will need to be emphasized even further.

2. **Develop incentives and other programs to support building decarbonization in new construction and in retrofits**. Customer incentives will be needed to support the adoption of building decarbonization technologies, including bringing down the up-front customer costs of retrofits and equitably supporting low-income customers with cleaner technologies choices.

3. **Support development of electric vehicle charging infrastructure and vehicle adoption**. Transportation electrification is a common feature of all the scenarios evaluated. For transportation electrification to scale to levels consistent with decarbonization goals, sufficient at-home, workplace, and public charging infrastructure is required, along with investments in electric grid infrastructure, management, and technology solutions to support such widespread transportation electrification.

In addition to those initiatives, E3 recommends that BGE, its regulators and policymakers in Maryland pursue the following types of research and development, demonstration, or pilot activities to support GHG reductions within BGE's gas delivery service:

1. **Pilot and develop hybrid electrification operations and control strategies.** E3 recommends that BGE pilot alternative hybrid heat pump operations to optimize the use of its combined electric and gas infrastructure. Supportive rate design structures, as well as the collection of real-world customer adoption and system performance data are needed to validate the potential benefits of hybrid electrification strategies in Maryland.

2. **Pilot and develop a networked geothermal pilot program.** Networked geothermal systems, which are renewably powered heating and cooling systems, hold the potential to provide commercial and home heating in a manner that substantially reduces electric system impacts, offers a possible transition path for BGE's gas workers, and could diversify BGE's business and operations to better support Maryland's energy transition. Networked geothermal systems are currently being piloted in Massachusetts and New York. Detailed engineering studies of networked geothermal potential in Maryland, followed by demonstrations, and supportive rate design structures, are needed to develop real-world cost data and experience with these systems in Maryland.

3. **Develop statutory support and a regulatory process to identify opportunities for non-pipeline alternatives to avoid or reduce conventional gas infrastructure investments. Define the utility incentives and cost-recovery mechanisms for non-pipeline alternatives to ensure the projects result in customer cost savings**. All-electric solutions like networked geothermal or air-source heat pumps are most likely to be cost effective in instances where gas infrastructure can be avoided and where the electric system has sufficient capacity. Developing a process to assess the technical feasibility, customer acceptance, and net-benefits or costs of non-pipeline programs would therefore help to identify where all-electric vs integrated gas-electric approaches are most warranted. Any non-pipeline alternative initiatives will need to be balanced against the safety, reliability and methane emissions reduction benefits of ongoing gas infrastructure replacement programs, including the Strategic Infrastructure Development and Enhancement (STRIDE) program.

4. **Support the emergence of renewable natural gas (RNG) supply sources and associated regulatory support and rate development**. RNG resources are leveraged in all scenarios though, given the modeled pace of electric sector decarbonization and electrification, these resources are not blended into the gas delivered by BGE until after 2030. In practice, BGE should consider procuring initial quantities of RNG before then to gain familiarity with the technology and support the development of regulatory standards through which these resources can be procured and developed.

5. **Pilot blends of hydrogen and dedicated hydrogen infrastructure.** The Hybrid and Diverse cases envision blends of hydrogen to reduce the GHG intensity of BGE's gas supply. Other studies[5]

[5] See for example: https://www.socalgas.com/sites/default/files/2021-10/Roles_Clean_Fuels_Full_Report.pdf and https://gasforclimate2050.eu/wp-content/uploads/2022/04/EHB-A-European-hydrogen-infrastructure-vision-covering-28-countries.pdf

have explored a role for dedicated hydrogen to decarbonize clusters of industrial activity. Similar to RNG, the use of hydrogen does not need scale until after 2030, so the remainder of this decade presents an opportunity to explore the technical and operational requirements of both dedicated hydrogen and hydrogen blends.

Introduction

Context and Previous Work

In 2022, the Maryland General Assembly enacted the CSNA, which calls for a 60% reduction in the state's GHG emissions by 2031 relative to 2006 levels and net-zero GHG emissions by 2045. These commitments established Maryland as a leading state in economy-wide climate policy ambition. While Maryland has already made meaningful progress towards a cleaner energy economy via policies like the Renewable Portfolio Standard and programs like EmPOWER Maryland, more action will be needed to realize the state's new targets.

The State of Maryland, supported by analysis by E3 conducted under the direction of the MDE, has done extensive analysis and research to evaluate pathways to decarbonize the state. In early 2021, MDE published the GGRA Plan, which described how the state would meet its previous goal of a 40% reduction in economy-wide emissions by 2030. The GGRA Plan identified strategies such as renewable and decarbonized electricity, energy efficiency and electrification as pivotal components of achieving the state's decarbonization targets. The final GGRA Plan scenario achieved a 48% reduction by 2030, exceeding the prior target but falling short of the new goal of 60% reductions by 2031. Though the focus of this work was the 2030 target, modeling extended through 2050, which allows for a comparison between those scenarios and the new targets under the CSNA. The GGRA Plan scenario achieved a 68% reduction by 2045 and an optimistic sensitivity achieved 81% reductions by 2045, highlighting a gap where new policies and actions will be needed to achieve the new CSNA goal of net zero by 2045.

The State followed its economy-wide work with a targeted sector analysis, the Maryland Building Decarbonization Study (MD Building Study), also supported by E3, which focused on options to reduce GHG emissions in the state's building sector by 86%-100%, going beyond the ambition in the GGRA. The MD Building Study further explored the role of energy efficiency in reducing building sector emissions and compared alternative pathways to decarbonize building heating loads. A key conclusion of the MD Building Study was that hybrid electrification, or electric heat pumps with fuel back-up, lower the total net incremental cost of achieving deep GHG emissions reductions in the building sector than scenarios that relied exclusively on electrification or renewable fuels.

Scope of this Study

As Maryland's largest energy utility, BGE delivers energy to approximately half the population of Maryland, including over 1.3 million electric and nearly 700,000 natural gas customers. BGE does not own electric generation infrastructure, nor does it produce natural gas. Instead, BGE owns networks of electric and gas infrastructure that deliver energy to its customers. In addition, BGE offers customer programs to support its customers in becoming more energy efficient or enabling them to adopt new technologies like electric vehicles. With that, BGE will play a key role in the transformation to a clean energy economy targeted by the State.

BGE originally retained E3 to explore potential strategies to achieving BGE's decarbonization targets for itself and its broader decarbonization goals for customers' own energy and sustainability choices. After initial engagement in 2021, upon introduction of early forms of the CSNA in 2022 and its passage in April 2022, BGE specifically asked E3 to build on its prior efforts in the State by evaluating the implications of decarbonization strategies that achieve the state's newly legislated net-zero targets with an intent to understand how BGE's electric and gas businesses and infrastructure could play a supporting role. Given the significant existing scenario analysis in Maryland, E3 was able to build on the foundation of core assumptions with scenarios specific to BGE's service territory and align with the new statewide emissions goals.

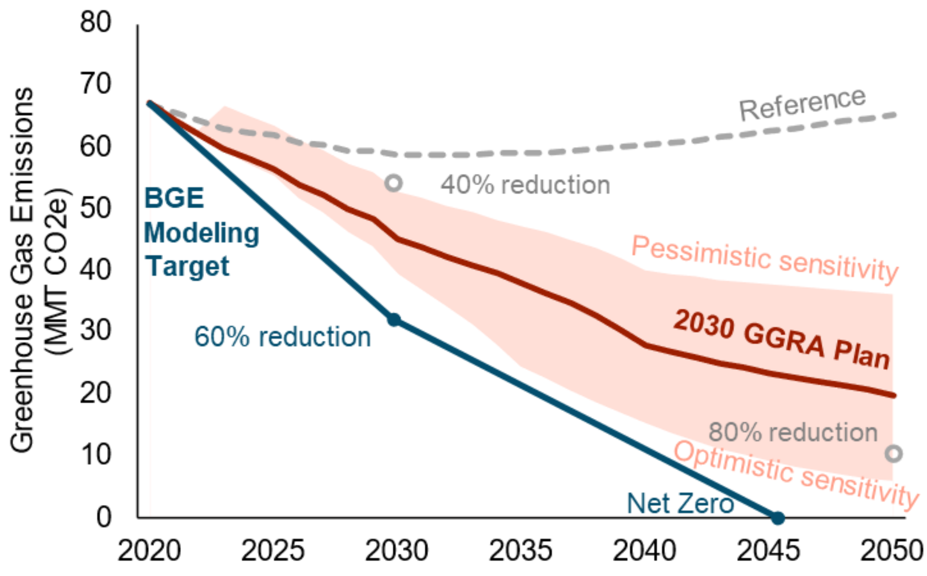
A key hypothesis of this study, based on findings from the MD Building Study, is that integrated approaches to decarbonization that leverage electric and gas infrastructure are more likely to be feasible and cost-effective relative to approaches that rely only on electrification or only on low-carbon fuels. With that hypothesis in mind this study considers several options to achieve decarbonization within BGE's service territory. Each strategy includes high levels of electrification, though the way electrification occurs, particularly in buildings, varies between all-electric, hybrid, and networked geothermal based strategies.

This study builds on past work developed by the State of Maryland in many respects, but differs in four key areas.

1. First, this study is focused on the energy transition specifically within BGE's service territory where E3's prior work has been statewide. This is significant given the difference between the population density and demographics, overall age of building stock and other industrial energy end-uses.
2. Second, this study considers a broader set of building heating decarbonization strategies than past work commissioned by the state, including emerging technologies like gas-powered heat pumps and networked geothermal systems reflective of rapid technology development occurring over the last decade and continuing today.
3. Third, the decarbonization scenarios modeled represent potential portfolios of decarbonization measures, rather than purely bookend solutions. The results are not meant to suggest a preferred portfolio, but rather to describe options that could be applied across a broad range of building types, gas and electric infrastructure needs, and sets of customer preferences.
4. Finally, consistent with the CSNA, this study considers a deeper and more rapid emissions reduction trajectory than past work developed by the state as highlighted in Figure 1.

A more detailed crosswalk of objectives and key assumptions between studies can be found in Appendix A.

Figure 1: GHG ambition in this study relative to past work

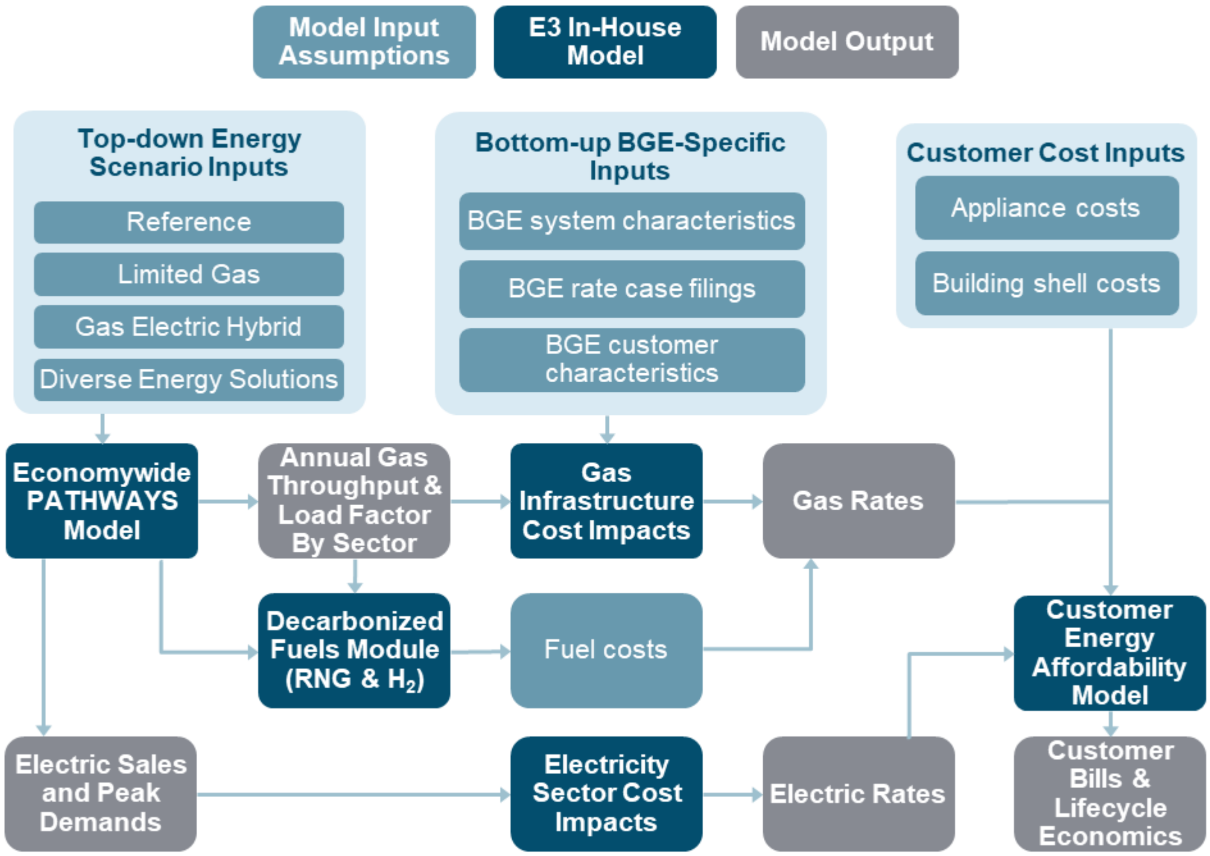


Approach

Modeling Framework

E3's modeling approach includes an economy-wide treatment of energy demands across BGE's service territory, an assessment of impacts on both electric and fuel energy supply transformations, impacts on BGE's load and peak demands for gas and electric infrastructure, and an assessment of implications of decarbonization for customer affordability. These impacts are evaluated in an integrated modeling framework depicted in Figure 2.

Figure 2. E3 modeling framework



Key elements of the modeling framework include:

- **Economy-wide PATHWAYS Model**. This study explores BGE's role in the state's transition to net-zero GHG emissions. Given that, E3 developed a representation of energy and emissions within BGE's service territory in the PATHWAYS model, which includes an economy-wide representation of emissions and energy demands. This PATHWAYS model was also used in support of the state's GGRA Plan and the MD Building Study.
- **Electricity Module (Electric Sector Sales and Peak Demands and Electric Sector Cost Impacts).**
    - **Electricity Supply:** E3's representation of the electric sector is like that of the GGRA Plan, though it includes a refined treatment of the costs of decarbonizing out-of-state generation from the PJM Interconnection. That treatment builds on E3's 2020 study *Least Cost Carbon Reduction Policies in PJM*. This report includes no new modeling of electric supply decarbonization, instead treating BGE as a price-taker within the context of a broader state and regional electric sector transformation.
    - **Electric Delivery:** E3 assessed the likely investment needed to meet changes in BGE's electric delivery infrastructure by considering changes in the seasonal timing and magnitude of peak demands over time. This module includes a treatment of the

incremental costs associated with serving those peak demands and other transmission and distribution infrastructure upgrades associated with electrification.

- **Gas Infrastructure Module.**
  - **Gas Supply**: E3 modeled the cost and potential for decarbonized gas supply through E3's decarbonized fuels module that calculates a supply curve for renewable gases such as renewable natural gas from biogas and gasified biomass, green hydrogen from renewable-powered electrolysis, and synthetic natural gas with a biogenic carbon source.
  - **Gas Delivery:** E3 developed a treatment of BGE's gas revenue requirement, including costs associated with growth, routine reinvestments, and the Strategic Infrastructure Development and Enhancement (STRIDE) program. This module considers changes in gas system costs as utilization changes over time.
- **Customer Energy Affordability Module**. E3 assessed the impacts of decarbonization scenarios for representative residential customers in the Customer Affordability Module. The module calculates electric and gas bills for customers with traditional gas or new heating technologies. In addition, this module includes the upfront costs of building heating technologies, which is used to identify the total cost customers would incur to heat their homes in each scenario.

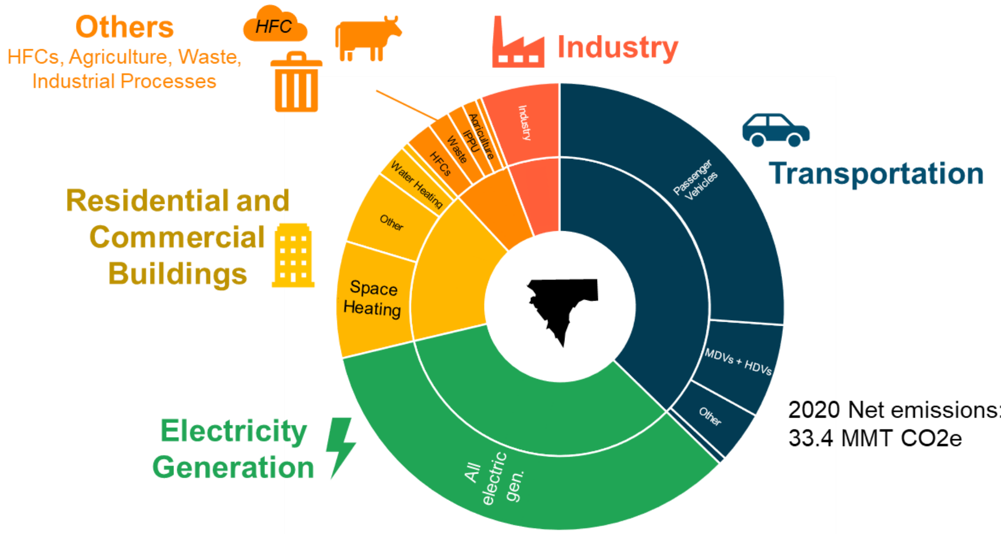
This modeling framework is similar to that used by E3 in past work in Maryland but includes additional detail relating to the current capacity of BGE's infrastructure and energy use requirements of their service territory, as well as a more detailed treatment of electric and gas rates and customer affordability. Similarly, most assumptions underlying this analysis were derived from past work conducted by the state, though this analysis reflects data specific to BGE's electric and gas systems and customers, and more up-to-date information on the costs and performance of emerging technologies, as well as more recent modeling of costs to decarbonize electric supply within PJM, by leveraging the 2020 study noted above that was not available at the time of the GGRA work. This study focuses on long-term technoeconomic scenarios; neither this study nor E3's prior work in Maryland presents a detailed analysis of electric generation capacity or transmission and distribution capacity needs under a net zero future, or detailed analysis of capacity siting challenges, capabilities and timelines. A comparison of differences in modeling assumptions and methodologies relative to past work can be found in Appendix A. A more detailed description of the technical approach and assumptions used for this analysis can be found in Appendix B.

Representation of BGE Geography

BGE's service territories cover many of the state's urbanized regions. As a result, approximately half of the state's population, energy usage and gas customers fall within BGE's service territory, highlighting BGE's critical role in meeting Maryland climate goals. This analysis represents all categories of GHG emissions within BGE's geography, which includes emissions associated with BGE's gas and electric business (both its own emissions and emissions associated with the supply and use of the energy they deliver) as well as all other categories of emissions that may occur within their territory and that are covered by the State's GHG inventory.

Notably, BGE only has direct control, subject to review by the Maryland Public Service Commission, over its electric and gas delivery infrastructure. Economy-wide decarbonization will require a broader set of actions by BGE's electric and gas suppliers, as well as its customers.

Figure 3. BGE GHG emissions scope



Buildings. The built environment within BGE's service territory materially impacts opportunities for electrification. Seventy-nine percent of homes within BGE's service territory currently have central air conditioning. These buildings are likely to represent lower-cost opportunities for electrification because the infrastructure for an air conditioner can, in many cases, be repurposed for a heat pump and these homes are likely to already have a sufficiently sized electrical panel. However, many homes, particularly those within the City of Baltimore, are older (just 36% were built after 1980) and are less likely to have either a central air conditioner or a high efficiency building envelope. Even homes with air conditioning may require some significant retrofits, including redoing ductwork to deliver sufficient heat to maintain occupant comfort. These and other physical characteristics of older buildings increase the complexity of electrification projects, making them harder to electrify from both technical and economic perspectives. In addition, lower-income customers are less likely to live in buildings with central air conditioning, so retrofitting these buildings carries additional challenges given those customers' limited access to credit and the higher likelihood that they are renters who do not have a direct choice in the equipment heating or cooling their homes.

BGE also provides gas to large commercial customers whose buildings tend to be heated via gas-fired boilers. Those boilers cannot be directly replaced by a heat pump system, so large commercial buildings would need to undergo a more extensive retrofit to accommodate a variant refrigerant flow system to be fully electrified. Such retrofits are technically complex, require substantial construction activities, and come at a larger incremental cost over conventional gas systems compared to projects in most residential or small commercial building types.

Transportation. The transportation sector within BGE's territory has similar characteristics to Maryland as a whole. Around 50% of total transportation energy consumption is assumed to occur within BGE's service territory, aligned with its share of the state's population.

Industry. Similar to Maryland as a whole, BGE's territory today has a relatively small amount of industry compared to other regions. Total industrial energy consumption is approximately 10% of energy consumption within BGE's territory. The largest industrial subsector by energy is the chemicals industry, which consumes approximately 30% of total industrial energy. Based on the industrial subsectors and end-uses present within the region, E3 assesses that approximately half of total energy consumption in the industrial sector within BGE's service territory could be electrified from a technical feasibility standpoint, though the economic feasibility of industrial electrification is far more uncertain and will be context-specific.

Electricity. Electricity generation in Maryland is served by in-state power plants and imports from neighbors in PJM, with imports making up nearly half of the electricity supply. As fossil plants within the state retire and demand grows with electrification, the percent of imported electricity could grow if not replaced and supplemented by clean in-state electric generation resources. As a delivery-only utility today, GHG emissions from the electric supply sector are largely outside of BGE's control but have been assumed to decline in line with the ambitions and associated costs from other net zero decarbonization studies for this work. Nonetheless, electric generation does represent a large share of both the emissions that must decarbonize, as well as the needed investments that drive costs to achieve decarbonization goals; generation supply is an important consideration for this study.

Non-Energy and Other GHGs. Remaining GHG emissions include categories such as agriculture, wastewater, and refrigerants, which have been downscaled to BGE territory by population. These emissions are also outside of BGE's control but represent a critical part of the story when modeling net zero emissions as they can be challenging to fully abate. Any net zero GHG future will need to consider these remaining emissions and pursue greater reductions in other sectors to compensate. Negative emissions from natural and working lands (e.g., carbon stored in Maryland's forests and soils) will need to offset any remaining positive emissions to achieve a net zero goal.

Decarbonization Scenarios

This analysis is scenario-based. Decarbonization scenarios reflect user-defined transformations of the energy system and economy-wide emissions. The scenarios are not forecasts, nor do they result in a single optimal or preferred solution. Instead, by examining multiple pathways, this analysis is used to identify and compare key features of different plausible futures and their relative costs, feasibility, and risks.

E3 worked with BGE to define three alternative scenarios that *all achieve* the state's 2031 and 2045 decarbonization targets. A key differentiator of these scenarios is the transition of the building heating sector, where E3 estimates that BGE's gas infrastructure delivers over two thirds of final energy today. Each scenario represents an alternative pathway for decarbonizing that sector, tracing through implications for BGE's infrastructure and resulting impacts on BGE's customers, while still including all sectors that will contribute to the state's GHG goals and have potential competing demands on BGE energy delivery systems. The scenarios include:

- **Limited Gas**. Emphasizes high levels of electrification and a shift away from delivered gas and other fuels in the buildings sector. This scenario also includes a relatively high level of electrification and a limited role for renewable fuels in the industrial sector. The primary technology driver of building thermal decarbonization in this scenario are all-electric air-source heat pumps.
- **Hybrid**. Emphasizes electrification, including high levels of electrification in the buildings sector, but some existing gas customers adopt a hybrid approach to electrification. A combination of electrification and renewable fuels reduces emissions in the industrial sector. The primary drivers of building thermal decarbonization in this scenario are air-source heat pumps, with the gas system and renewable gases used during cold conditions.
- **Diverse**. Emphasizes high levels of electrification but incorporates a mixture of strategies to decarbonize the building heating sector, including both all-electric buildings and hybrid electrification, as well as emerging strategies like gas powered heat pumps and networked geothermal systems. Gas powered heat pumps operate using similar principles to electric heat pumps and hold the potential to use gas to efficiently provide space- and water-heating services. Networked geothermal systems connect ground-source heat pumps for multiple buildings via a network of underground pipes that distribute heating and cooling energy between buildings. Networked geothermal systems could substantially mitigate the electric system impacts of electrification and repurpose BGE's expertise in maintaining and operating underground infrastructure.

In addition to achieving the same economy-wide reductions over time, each scenario also shares a consistent level of climate ambition in buildings to help make the customer gas and electric utility bill impacts comparable across scenarios.[6] This approach allows for a more direct comparison of the alternative strategies to decarbonize the buildings sector and the implications for BGE's systems and customers.

Outside of buildings and industry, the scenarios share many similar features. All scenarios include high levels of electrification in the transportation sector, a transition to zero-GHG electric supply by 2045 and strategies to mitigate emissions in non-energy sectors of the economy. The assumptions for electricity supply and other sectors (agriculture, waste, natural and working lands) were held constant across scenarios to help focus results on differences in the built environment. The key features of each scenario are shown in Table 1.

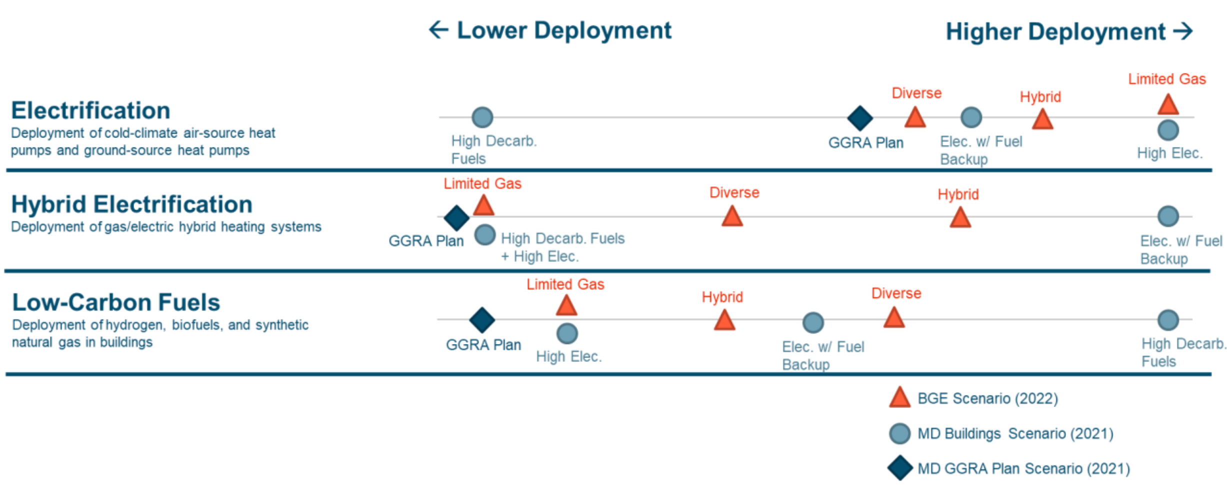
[6] The level of building decarbonization aligns to the MWG Policy Scenario from the Maryland Building Decarbonization work, which equates to an 86% direct reduction of GHGs in buildings relative to 2006 levels.

Table 1. Key scenario features by economic sector

		Integrated Energy System Scenarios	
	1. Limited Gas	**2. Hybrid**	**3. Diverse**
Scenario narrative	High-electrification and shift away from delivered gas and other fuels	Leverages an increasingly clean electric system, high electrification, and the gas network	
Buildings	Efficiency and electrification	Efficiency, electrification, gas-electric hybrids, and a targeted role for alternative fuels	Efficiency, electrification, gas-electric hybrids, gas heat pumps, network geothermal, and alternative fuels
Industry	Efficiency and electrification	Efficiency, electrification, and alternative fuels	Efficiency, electrification and alternative fuels
Transportation	LDV electrification and alternative fuels for MDV & HDV		
Electricity	Zero-carbon electricity by 2045		
Other Sectors	66% reduction by 2045		

Figure 4 compares the relative level of deployment of building decarbonization measures in each of the three BGE scenarios to the 2021 Maryland Building Decarbonization Study scenarios and the Maryland GGRA Plan Scenario. The figure illustrates that the BGE scenarios include high levels of building electrification and lower levels of hybrid electrification and low-carbon fuels compared to past scenarios evaluated for the state. The 2021 MD Buildings Study started with scenarios that explored more pure "bookends" related to high electrification or high decarbonized fuels, and learnings from that analysis and similar analyses in other jurisdictions have shown that those bookends often result in higher costs. The MD Buildings Study included a final scenario (the "MWG Policy Scenario") that combined elements of the High Electrification Scenario with a larger role for hybrid heating solutions.

Figure 4. Deployment of building decarbonization measures in BGE scenarios compared to recent MD scenario analysis



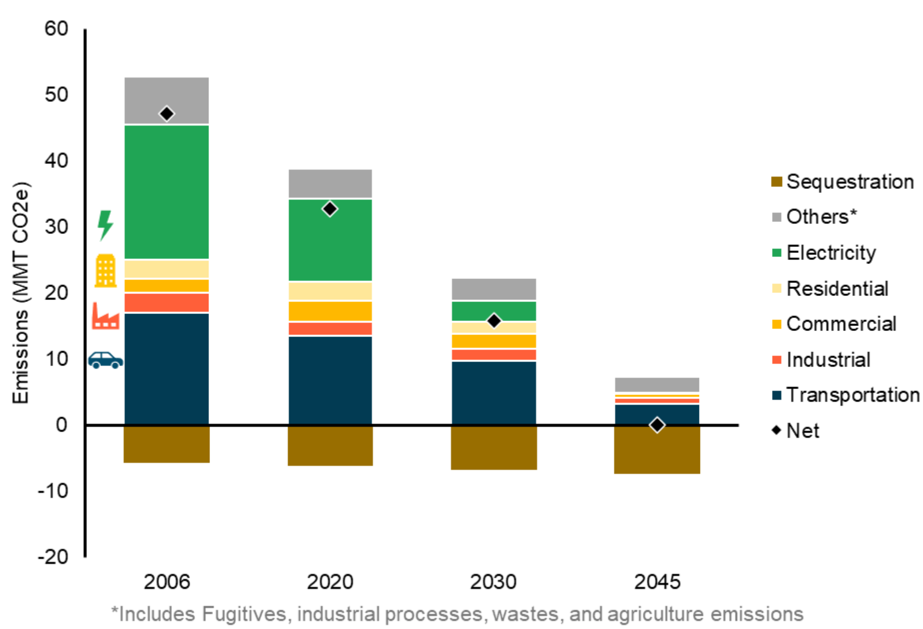
Decarbonization Pathways Key Results

Economy-wide results

GHG Emissions

All three scenarios achieve the state's 2031 60% GHG reduction and 2045 net-zero targets for BGE's geography, including deep reductions in all economic sectors as shown for the Diverse scenario in Figure 5. Achieving the state's decarbonization targets requires substantial reductions in emissions across all economic sectors. In buildings, industry, and transportation, we see a need for transformations in the equipment used (home appliances, vehicles), the type of energy that powers that equipment (renewable electricity, hydrogen, low-carbon fuels), and the infrastructure needed to support those transformations (vehicle charging infrastructure, hydrogen electrolysis). All pathways include a critical role for electric passenger and fleet vehicles, efficiency and electrification in buildings, and low-carbon fuels in sectors that are challenging to decarbonize. All pathways require significant investment in expanding zero carbon electric generation, transmission and distribution to fulfill energy use that is shifting from fossil fuels to electric. The differences in the scenarios incorporate varying levels of investment in clean fuel technologies to help pace those electric sector changes. In the 2030 timeframe, decarbonization of the electric sector is the largest single source of emissions reductions, while by 2045 deep emissions reductions are required in all economic sectors. Results indicate that how the transformation occurs affects the total cost of decarbonization, the costs that customers will pay, and the pace of technology deployment needed for customers. Given the significance of the transformation needed to meet the net zero GHG goal, all pathways require action and investments from all segments of the economy.

Figure 5. GHG emissions by sector in the Diverse Scenario



The range of emissions reductions across scenarios in this study by sector are shown in Table 2. The only sources of variation in sectoral emissions between scenarios are the transportation and industrial sectors. The level of climate ambition is held constant in buildings and electricity to make customer costs more comparable across scenarios, and small variations exist in the level of ambition in transportation and industry aligned with the mitigation actions included in each scenario. All scenarios achieve net-zero GHG emissions by 2045, which includes a reduction of total gross emissions of about 87% in 2045 (relative to 2006) and remaining emissions in that year are offset by negative emissions from natural and working lands. Maryland's natural and working lands (e.g. forests) in BGE territory currently store approximately 5 MMT CO2 per year, and with dedicated support we assume this will grow through 2045.

Table 2. 2045 GHG emissions reductions by sector relative to 2006 in BGE scenarios

All Sectors	Emissions Reduction by 2045
Buildings	86%
Transportation	81-85%
Industry	57-69%
Electricity	100%
Other Sectors	66%

It is important to note that the CSNA does not specify the level of GHG reductions required by sector, only the need to achieve economy-wide emissions reductions. We have modeled deeper reductions in buildings, transportation, and electricity generation where technology solutions are relatively mature. As this analysis will show, technology adoption is particularly significant in buildings and passenger vehicles. If new technologies mature and additional ambition is achievable in other sectors (e.g. trucks and off-road transportation, industry, agriculture, negative emissions technologies), a slower adoption trajectory in buildings and transportation could lessen the challenge for customers, which may lower costs and energy burdens.

Demand-Side Transformations

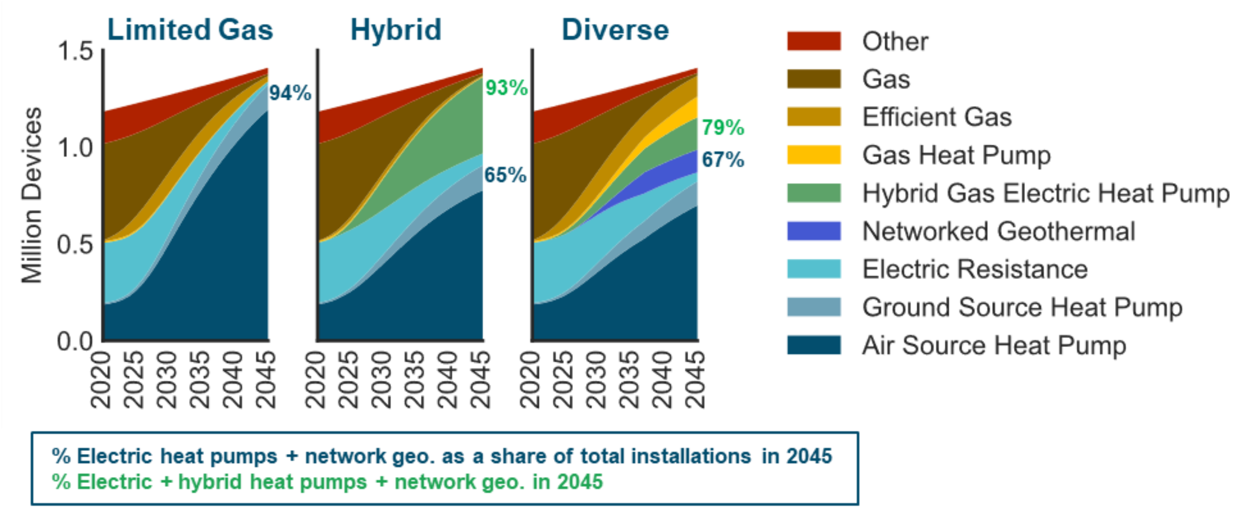
In order to achieve the sectoral emissions reductions targets described in Table 2, each of the three scenarios includes a transformation of how energy is both supplied and consumed.

Buildings Sector

A key source of variation in the scenarios is the transition of the building heating sector. Based on the finding from the MD Building Study that all-electric new construction is lower-cost than alternatives, *all scenarios* assume all-electric new construction from 2027 onwards. With that, the key distinction between the scenarios are alternative strategies to decarbonize ***existing*** buildings.

Figure 6 shows the transition of residential building space-heating equipment for each scenario. The Limited Gas scenario has the largest growth in air-source heat pumps due to a near-complete conversion of natural gas heated buildings such that, by 2050, 94% of homes in BGE's service territory are electrically heated. The Hybrid scenario has a similar total number of electrically heated homes as Limited Gas, but gas furnaces and boilers are retained as back-up to air-source heat pumps in 28% of homes. The Diverse scenario has both the lowest overall level of electrified homes (79% of buildings are electrically heated) and the widest variety of technologies used, including condensing gas furnaces, gas heat pumps, and networked geothermal systems.

Figure 6. Stock transition for residential space heating devices in BGE's territory



Transportation Sector

A common feature of the scenarios are high levels of electrification in the transportation sector, including achieving 80-90% of new sales of zero-emission passenger vehicles by 2035, leading to nearly all zero-emission light-duty vehicles and a large number of zero-emission trucks by 2045. Cars and trucks are long-lived assets, so a rapid ramp-up of the market for these technologies is needed in the 2020s such that nearly all on-road vehicles sold in the 2030s are zero-emissions. By 2045, the vast majority of passenger vehicles in the state are battery electric, with roles for hydrogen fuel cell or biofuel powered vehicles in trucks and off-road vehicles. These necessary advances in all of the scenarios by 2045 may require adoption of policies to support continued and expanded education, programmatic and incentive offerings from BGE and the state now and in the future, along with increased availability, diversity and affordability of new and used electric vehicles.

Figure 7. Stock transitions of light-duty vehicles in BGE's territory

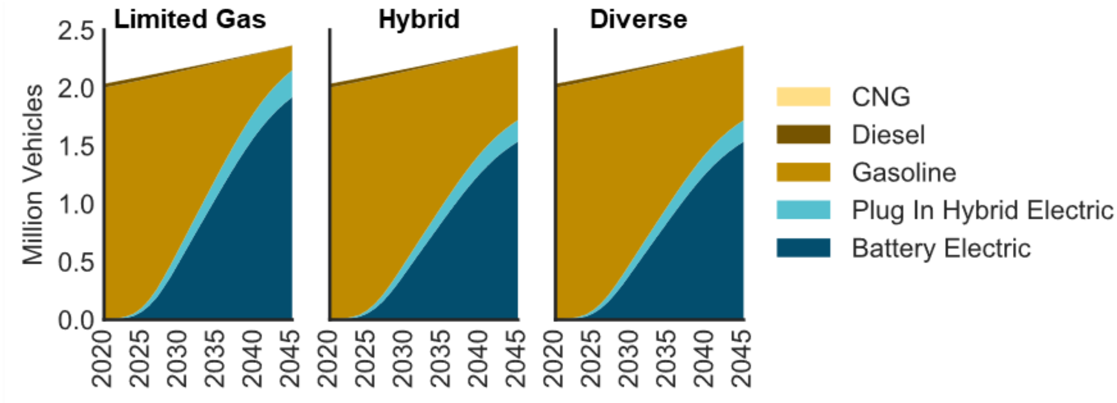
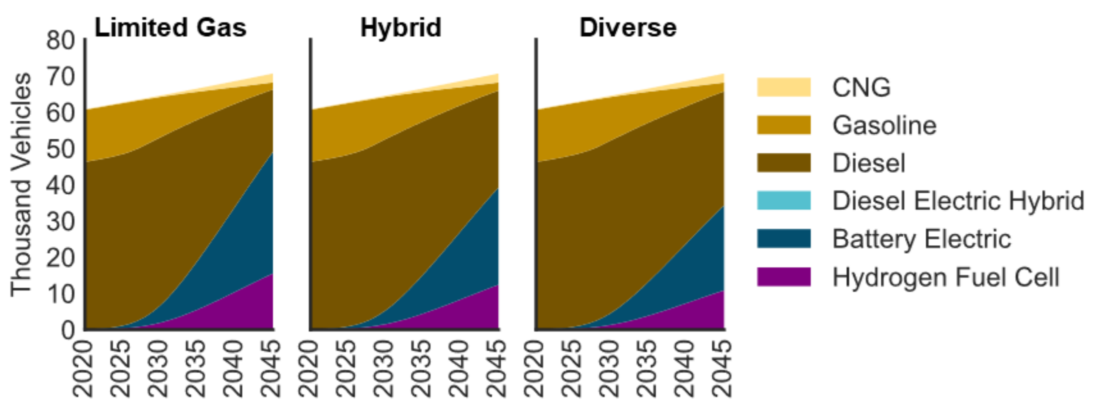


Figure 8. Stock transitions of medium- and heavy-duty trucks in BGE's territory



The levels of light-duty vehicle electrification in this study are most ambitious in the Limited Gas scenario, in line with goals in leading states of 100% zero-emission vehicle (ZEV) sales in light duty vehicles (LDVs) by 2035 and 100% sales in MHDVs by 2045. ZEV adoption is lower in the hybrid and diverse scenario, following from this study's scenario design approach, which was intended to align the emissions reductions achieved in the buildings sector.[7]

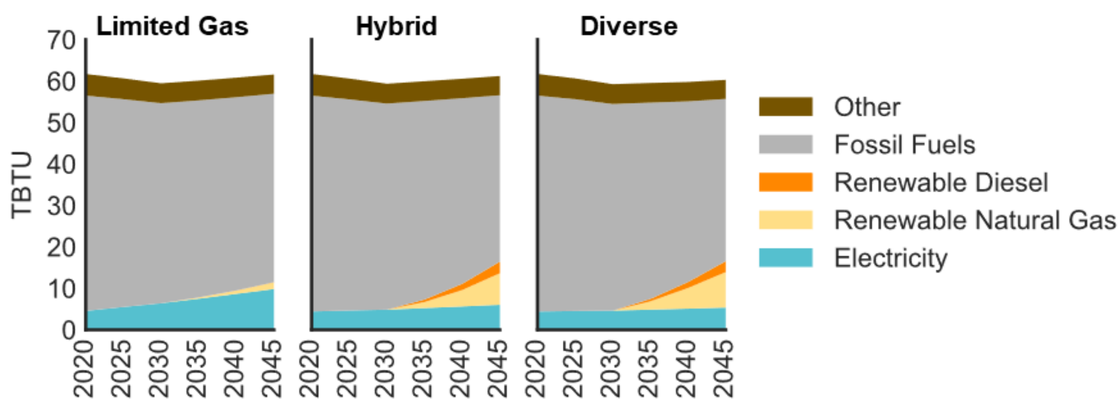
Industrial Sector

Energy usage in the industrial sector is approximately 13% of total energy consumption in BGE's service territory. Consistent with past state modeling efforts, the largest residual emissions allowed in each

[7] The scenarios were primarily defined based on different demand-side transformations in buildings (e.g. all-electric vs hybrid heat pumps, networked geothermal, etc.), which resulted in different levels of remaining gas and liquid fuel demands. As a result, the Hybrid and Diverse scenarios include higher levels of fuel demands, which impacts emissions across all sectors that use those fuels. Given those higher blends, and in order to meet the same economy-wide net-zero target, E3 applied a lower level of transportation electrification in the Hybrid and Diverse scenarios. In practice, higher levels of transportation electrification may be warranted given technology progress and the co-benefits of eliminating combustion of gasoline and diesel fuels.

scenario are in the industrial sector. E3 adopted this approach because, in general, industrial decarbonization options are less technologically mature and less cost effective than transportation and building decarbonization. In addition, many states such as Maryland have concerns about the economic development and jobs implications of imposing strict climate requirements on industry. The Limited Gas scenario emphasizes electrification where feasible, while the Hybrid and Diverse scenarios include a larger role for renewable fuels as replacements for natural gas. All scenarios share ambitious levels of energy efficiency, which is likely to be both more technologically mature and cost-effective than conversions of industrial processes to direct electrification or hydrogen combustion. The level of residual emissions in this sector does not represent an upper bound on decarbonization potential, but instead reflects a moderate and targeted approach to electrification and low-carbon fuels in industry. To the extent that cost effective emissions reductions can be achieved in industry through creative partnerships and commercialization of new technologies, additional decarbonization in this sector would help to relieve the burden of decarbonization required by other sectors.

Figure 9. Final energy demand by fuel in BGE's industrial sectors



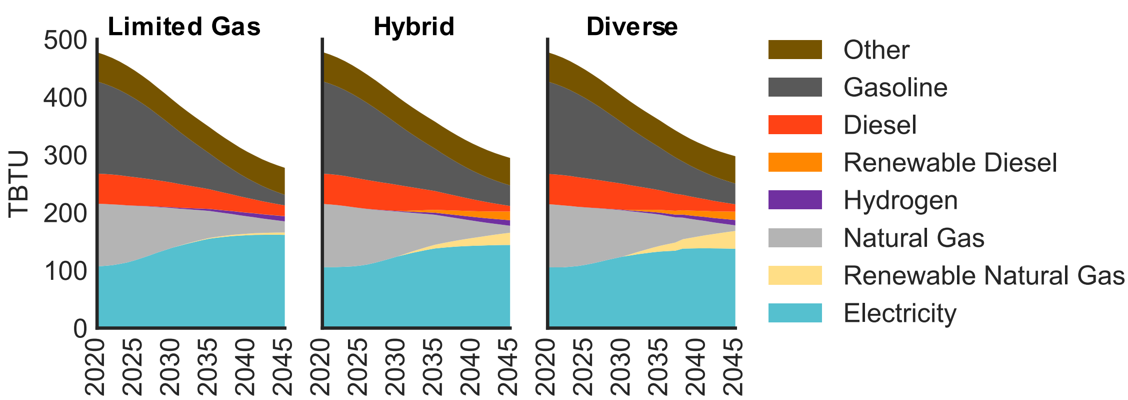
"Other" includes wood and waste.

Final Energy Demands

Final economy-wide energy demands within each scenario fall over time due to the high levels of electrification incorporated by E3 across all scenarios. Electrification reduces final energy demands because technologies like electric motors and electric heat pumps are substantially more efficient than combustion-based technologies they replace. Indeed, taking the transformations across each sector as an economy-wide whole, the pivotal role of electrification in achieving net-zero in Maryland becomes clear. The share of final energy demands that are served by electricity increases from 22% today to 46-58% by 2045. When paired with 100% clean electric supply, electrification is also the largest driver of GHG emissions reductions across all scenarios. The use of other fossil liquid, gaseous and solid fuels falls precipitously in all scenarios (60-73% in 2045 relative to 2020), with remaining demands being served by increasing blends of renewable fuels.

While overall energy use may decrease, notably, across all scenarios, the share of final energy delivered via BGE's electric and natural gas infrastructure increases as it takes on more electric load from what is now energy supplied by GHG-intensive transportation fuels. Today, electricity and natural gas are 45% of the final energy consumed in BGE's service territory, while in 2045 that combined value rises to between 61 and 67%.

Figure 10. Economy-wide final energy demands by scenario



"Other" includes jet kerosene, asphalt and road oil, coal, kerosene, LPG, miscellaneous petroleum, residual fuel oil, waste, wood, biomass, feedstocks, and still gas.

Other Sectors

The focus of this analysis is on the distinct impacts to buildings, industry, transportation, and fuel supply, but to reach a net zero GHG economy, action will be needed in other sectors as well – including, for instance, in agriculture, waste, and natural and working lands. Modeled actions in these sectors are in line with past work in Maryland and are consistent across scenarios. One key interconnection with building decarbonization is the role of refrigerants with a high global warming potential (GWP), which are used in heat pump systems. It will be critical to pursue climate-friendly refrigerant policies in any scenario, but especially in scenarios that rely more on heat pump adoption. Key measures are reflected in Table 3.

Table 3. Key mitigation actions in agriculture, waste, industrial processes, fossil fuel industry and natural and working land sectors

Sector	Subsectors Represented	Key Mitigation Actions Modeled
Agriculture	Methane from animal manure and enteric fermentation, soil management	Methane management, soil carbon programs
Waste	Wastewater treatment, landfills	Methane capture from wastewater and landfill facilities, organic material management in landfills
Industrial Processes	Refrigerants (e.g. Hydrofluorocarbons or HFCs), process emissions	Refrigerant management policies

	from cement, iron and steel, and other facilities	
Fossil Fuel Industry	Coal mining, natural gas industry	Methane emissions reduction from natural gas transmission and distribution
Natural and Working Lands	Forests, urban trees	15% growth in Maryland's natural carbon sink

Impacts to BGE's Gas and Electric Systems

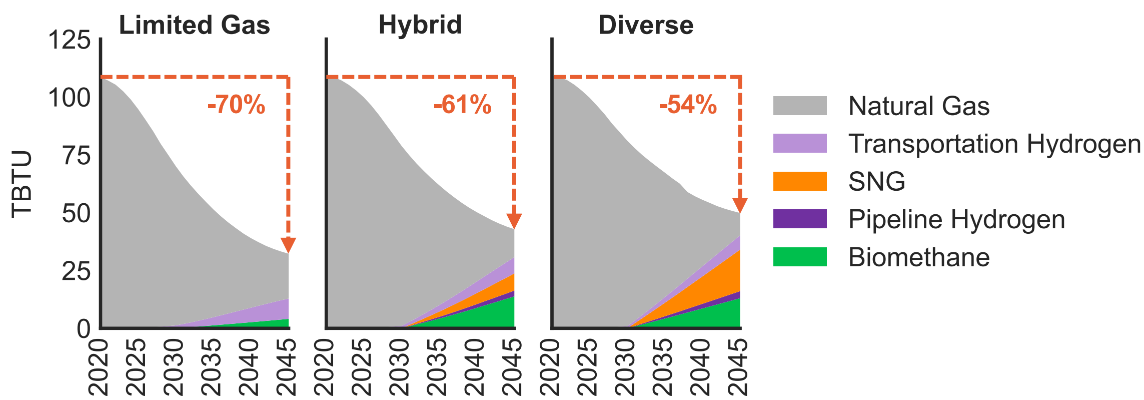
Electrification is a key driver of decarbonization across all three scenarios considered. Between scenarios, differences in electrification, particularly building heating electrification, implicate the pace and scale of electric generation, transmission, and distribution infrastructure additions that will be needed to support the state's decarbonization goals. Conversely, the way building heating loads are electrified impacts the utilization and long-term transition pathways for the State's gas infrastructure. Indeed, the transition of the State's gas and electric systems are, to a significant extent, linked. Less reliance on existing gas infrastructure necessarily requires more investment in the electricity system, and the role of the remaining gas infrastructure will depend on the needs of remaining gas customers. Within that state context, BGE's role is primarily in the maintenance and transformation of the electric transmission and distribution system and gas system within its service territory. BGE does not own or operate electricity generation or upstream gas supply assets, but identifying the necessary transformations of energy supplied through BGE's infrastructure is critical to understanding potential paths to decarbonization and affordability impacts on customers.

Gas System

BGE's gas system has been primarily built to provide heating services to buildings. As a result, approximately 74% of the company's gas revenues are from residential customers and a further 11% from small commercial customers. All the decarbonization scenarios evaluated by E3 in this study envision a transformation in the way buildings are heated in BGE's service territory, including an emphasis on electrification as the core engine of building heating decarbonization. As a result, BGE's gas sales fall in all scenarios, with reductions ranging between 54% and 70% in 2045 relative to 2020, which also includes potential supply of hydrogen for medium- and heavy-duty vehicle fueling (Figure 11). Focusing just on all gas delivered via BGE's pipelines, gas throughput declines 60%-78% in 2045 relative to today. The drastic reduction of natural gas – through a combination of electrification, efficiency, and displacement by cleaner fuels – is a critical factor in how emissions reductions are accomplished in the building and industrial sectors. These reductions reflect the fact that in all scenarios electric heat pumps are the primary source of heating energy for most of the year. The remaining gas delivered by BGE in 2045 is primarily used by the industrial sector, to provide heating to buildings during very cold days via hybrid heat pumps, and potentially for use in a limited number of buildings with high efficiency gas equipment. Taking an economy-wide approach to reaching net-zero GHG emissions can allow a small amount of natural gas to remain in industry and buildings and those remaining emissions can be offset with Maryland's natural carbon sinks.

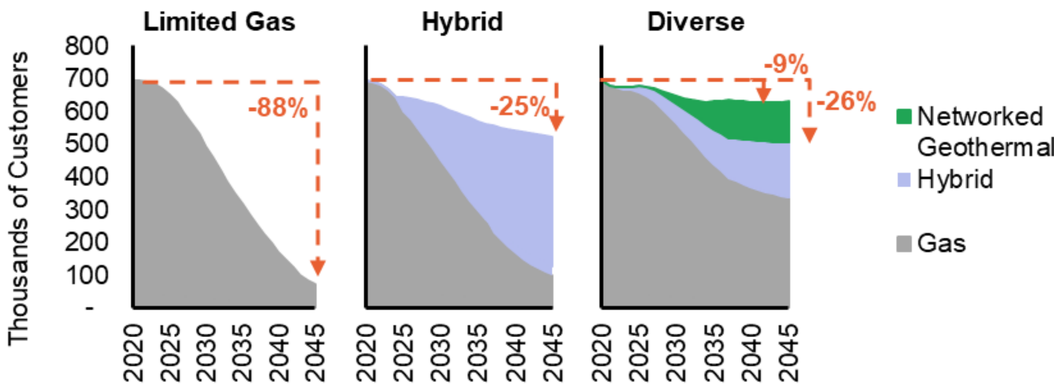
At the same time as BGE's gas throughput falls, the composition of the gas it delivers changes in each scenario. From 2030 onwards, BGE's gas supply shifts from entirely natural gas to a blend that includes increasing quantities of renewable fuels. Because each scenario is designed to achieve the same 86% reduction in building sector emissions, scenarios with lower levels of building electrification and higher gas throughput leverage higher levels of renewable fuels. For example, as shown on Figure 11, the Diverse scenario has the lowest level of electrification and therefore relies to the greatest extent on renewable fuels to meet emission reductions goals. Conversely, the Limited Gas scenario uses a lower amount of renewable fuels because nearly all buildings are fully electrified. Potential availability and an increasing cost curve for renewable fuels (especially green hydrogen, biomethane from gasified feedstocks, and synthetic natural gas (SNG)) are considerations that were used when determining amounts of renewable fuels used in each scenario.

Figure 11. Change in BGE's gas sales and composition of gas supply by scenario



Like gas sales, all scenarios see declining numbers of BGE gas customers as they electrify or convert to geothermal heat sources. The Limited Gas scenario has the largest number of departures, with 90% of BGE's existing customers converting to all-electric service by 2045. The Hybrid and Diverse scenarios see more gradual rates of customer attrition. In both cases, the number of customers with a gas meter falls by approximately one quarter relative to today. In the Hybrid scenario, most of the remaining customers use the gas system primarily as back-up, while in the Diverse scenario approximately 42% of remaining customers have not adopted electrification measures and instead rely on efficient gas appliances. The Diverse scenario is also unique given that it includes the transition of customers from gas to networked geothermal service. Depending on regulatory treatment, discussed below, those networked geothermal customers could be considered part of BGE's gas or electric customer base.

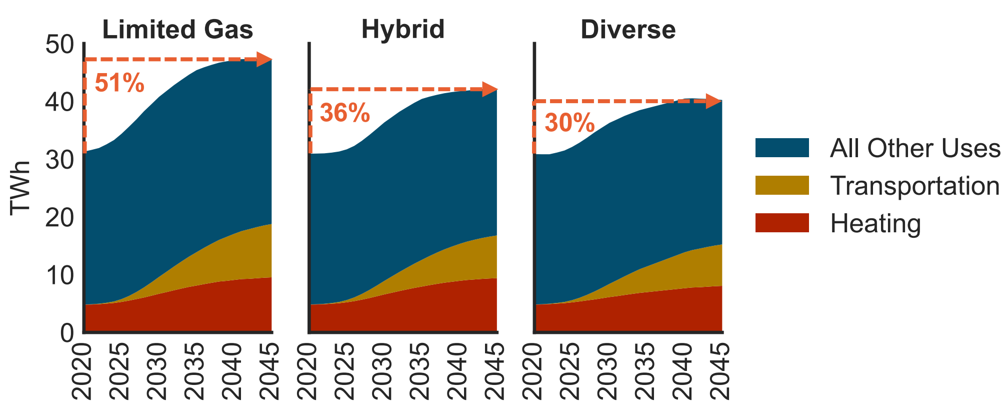
Figure 12. Transition of BGE's residential and commercial gas customers by scenario



Electric System

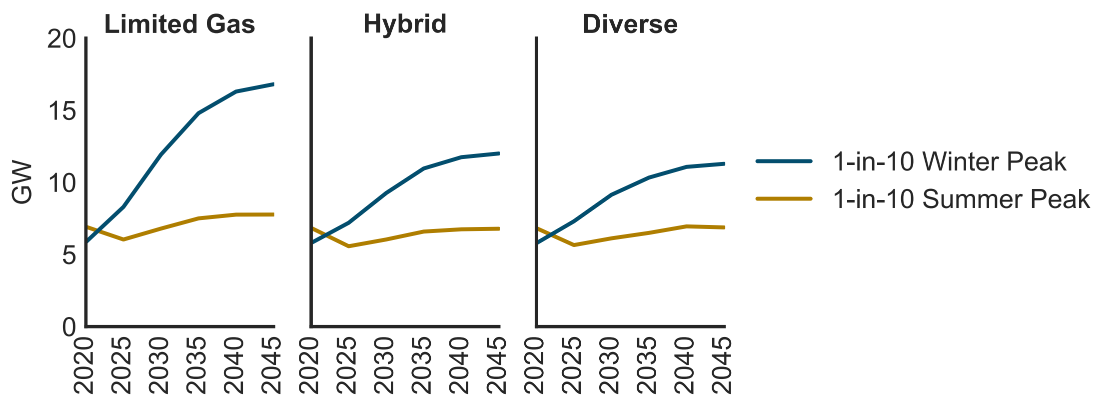
All scenarios include high levels of electrification in the transportation and buildings sectors, leading to increased sales of electricity of between 30% and 51% on BGE's system by 2045. The largest single source of electric sales growth is the transportation sector, where energy demands that are currently served by gasoline and diesel are converted to electricity. The Limited Gas scenario has the largest load growth because it includes the highest overall amount of electrified heating loads and because it includes the highest levels of direct electrification in the transportation and industrial sectors. The Diverse scenario has the lowest overall level of electric load growth because it has the lowest levels of direct electrification and because networked geothermal systems are more energy efficient than the air-source heat pumps leveraged in Limited Gas and Hybrid.

Figure 13. Electric load growth by scenario



An electric system must be designed to operate reliably not only for average annual operations but also for extreme weather events, regardless of frequency. Thus, the system peak is a key system design parameter and overall cost driver of electric capacity and the transmission and distribution system. Today, the primary electric generation technology to provide that reliability service is natural gas-fired generation (e.g. combustion turbines). In the long-run, clean firm resources like long-duration energy storage, natural gas-fired turbines with carbon capture or hydrogen, or advanced nuclear – along with significant demand management technology deployment and control, as well as substantial physical distribution system upgrades – will be needed for systems with 100% decarbonized electricity, any of which come at higher cost and many of which involve siting challenges.

Figure 14. Electric peak demand by scenario, before flexibility



Peak electric demands (inclusive of all categories of electricity demand such as building appliances and electric vehicles) increase more quickly relative to annual sales in all scenarios due to conversions of current fossil space-heating loads to electric heat pumps. As shown in Figure 14 system peak electricity demands increase by 66-150% by 2045 relative to 2020. Space-heating loads primarily occur during the winter, with particularly large peak requirements occurring during multi-day cold-snaps. A challenge for all-electric approaches is that during very cold weather the efficiency of air-source heat pumps, including cold-climate models, falls just as heating loads are at their highest. Those periods can also coincide with low levels of wind and solar production across a large geographic extent, and therefore require significant amounts of firm generation capacity to be served reliably.

BGE currently plans their distribution system to a 1-in-10 year reliability standard. This standard reflects that a reliable electric system must be designed to meet unusually high periods of load, rather than simply planning to typical conditions. Such conservatism will be particularly important as a larger share of final energy demands are moved to the electricity system. In particular, customer power outages during a cold-snap would present significant safety and human health challenges. Given BGE's imperative to maintain a reliable system, the 1-in-10 year levels of peak demands are used to assess the incremental infrastructure required in each scenario.

The Limited Gas scenario has the largest electric system impacts because it primarily relies on air-source heat pumps. The Hybrid scenario substantially reduces those peak demands and associated infrastructure impacts by leaving a role for gas backup in a subset of existing buildings. The gas backup utilizes the existing firm capacity of BGE's gas infrastructure rather than requiring new electric infrastructure. Finally, the Diverse scenario has the lowest peak demand impacts because it has the lowest overall level of electrification. The electrification that does occur in the Diverse scenario includes peak mitigation strategies like hybrid electrification and the use of networked geothermal systems, whose efficiencies are not affected by outdoor air temperature.

The Limited Gas scenario includes both higher overall levels of peak demand impacts during a typical cold snap and higher overall sensitivity of load to extreme conditions. Thus, maintaining reliability requires the addition of more electric infrastructure, including transmission and distribution, than for the Hybrid and Diverse scenarios. Those latter two scenarios require less new electric infrastructure because a substantial share of customers continue to use the existing capacity of BGE's gas system.

Some peak impacts can be mitigated through demand-side load management programs, including treating space heating and electric vehicle charging as flexible loads. Without load management programs, transportation electrification would have a significant impact on peak loads, but the impact can be limited by implementing rate structures and programs that encourage customers to charge vehicles during off-peak hours. For light-duty vehicles, approximately 50% of load is assumed to be shiftable to avoid peak hours. For heating loads, by preheating spaces ahead of the coldest hours of a cold snap, space heating impacts to peak load can be reduced between 2-6%, reflecting a smoothing of demand over the coldest hours of the morning. However, a key challenge from a peak demand perspective are sustained, multi-day day cold-snaps, which load shift strategies are not well suited to address. In addition, customer acceptance of load-flexibility and other demand management approaches warrants further investigation. Still, load flexibility reduces infrastructure investments are across all scenarios, with the largest benefit in the Limited Gas scenario.

Scenario Comparison and Discussion

This study examines three alternative and distinct decarbonization scenarios that all achieve the same climate goal of net zero GHG emissions by 2045. The purpose of this approach is not to pick a preferred pathway for BGE or the state of Maryland, but rather to identify key commonalities and trends to better inform the eventual development of a portfolio of decarbonization solutions; while not the purpose of this study, E3 does, however, offer recommendations for the State's and BGE's consideration. As illustrated in Figure 15, each scenario faces challenges when considered across different evaluation criteria. For example, scenarios that rely to a greater extent on air source heat pumps may have a lower level of risk with respect to technology readiness, but carry high infrastructure requirements and costs due to the peak design dynamics previously discussed. Conversely, the Hybrid and Diverse scenarios could reduce economy-wide cost but rely to a greater extent on technologies with lower levels of commercialization. **However, on balance, the findings of this work support the hypothesis that decarbonization strategies that leverage the advantages of both electrification measures and gas infrastructure carry a lower overall level of challenge relative to an all-electric approach**.

Figure 15. Assessment of the level of challenge across evaluation criteria for decarbonization scenarios. "Level of challenge" denotes the extent to which the scenario is substantially different from current practices, policies, or technologies.

Scenario Criteria		Limited Gas	Hybrid	Diverse
Energy system cost	Cumulative incremental costs associated with scenario	$52B	$38B	$40B
Customer affordability	Total cost of ownership for customers that do adopt building decarbonization measures			
Customer practicality	Reliance on widespread customer adoption and relative level of customer disruption			
Constructability	Pace and scale of electric and gas sector infrastructure additions			
Technology readiness	Extent to which a scenario relies on emerging technologies			
Equity	Difference in costs for participating vs non-participating customers			
Workforce impact	Estimate of the scale of energy workforce transition			

← Lower Challenge — Higher → Challenge

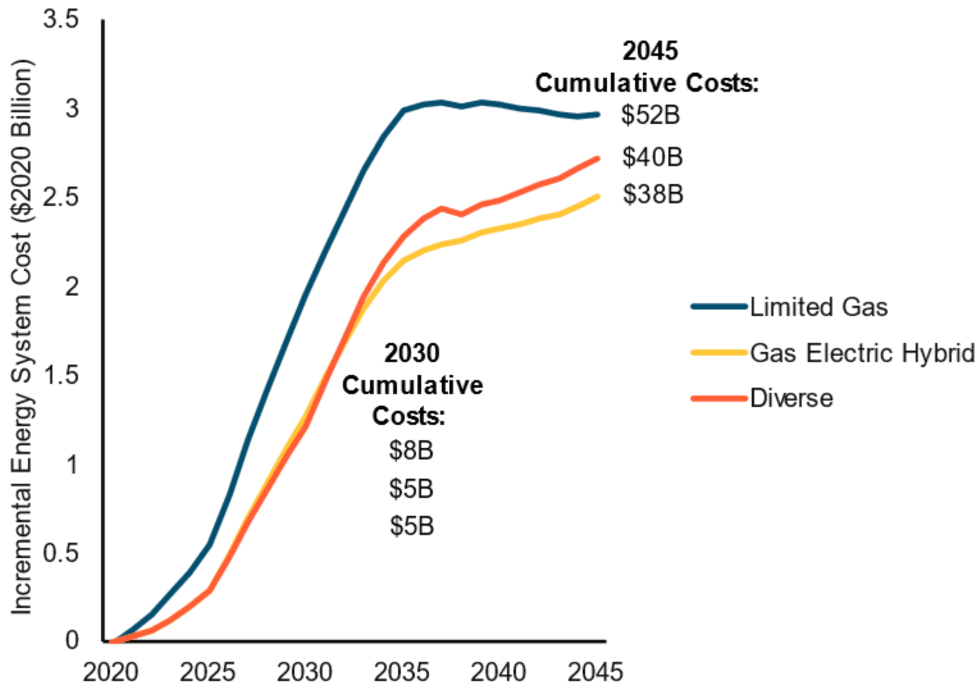
The subsequent sections of this chapter describe E3's evaluation of each scenario with respect to the scenario criteria listed in Figure 15.

Energy System Cost

Decarbonization scenarios require incremental investments in energy supply and demand transformations relative to a Reference Scenario.[8] For those transformations to occur, investments must begin to scale immediately such that, over the period from 2022 through 2050, total investments reach $40 and $52 billion in cumulative incremental cost – which consist of electric generating capacity, electric transmission and distribution, customer capital costs, renewable and fossil fuels costs and costs of gas and networked geothermal infrastructure, as shown on Figure 16 and described in the section that follows. The Hybrid and Diverse scenarios define the lower range of that bound, while the Limited Gas scenario sets the upper bound. These costs represent the estimated investment needed across sectors in BGE's geography to achieve net zero GHG emissions by 2045 using these scenarios as compared with a business-as-usual future, and this reflects a significant transformation.

[8] Our Reference Scenario is in line with the business-as-usual assumptions in the 2021 GGRA Plan and include current population, household, and VMT trends, current EMPOWER efficiency targets, state zero-emission vehicle adoption goals, and current renewable portfolio standard (RPS) required by the Clean Energy Jobs Act.

Figure 16. Total incremental energy system cost over time by scenario



Though these scenarios reflect real investments needed across the economy and the cumulative number is sizable, it is informative to put these costs in context, and two helpful reference points are (1) the size of the State's economy and (2) the benefits of meeting climate targets. For the size of the State's economy, Maryland's gross state product (GSP) in 2020 was $411B, and assuming it grows at 2% per year, cumulative GSP over this time horizon would be $13,830B.[9] The benefits of meeting climate targets include improved air quality and decreased incidence of related health conditions and avoided extreme weather events. This analysis did not include a detailed climate benefits analysis, but as a proxy we can estimate the economic impacts using the EPA's social cost of carbon, which is about $50/tonne of CO2e avoided.[10] Estimating the cumulative GHG emissions savings of our scenarios, the cumulative societal cost of carbon is approximately $25B, which does not include the air quality benefits of reduced air pollution, nor higher estimates of the social cost of carbon that appear in the literature[11].

Figure 17 shows the relative cost of each scenario in 2045, broken out by key cost components. The distinctions between scenarios shown on Figure 17 occur as follows:

- **Electric Capacity**. In all scenarios, Maryland's power generation and regional electric supply must get bigger and cleaner, expanding to meet increasing electric demands and concurrently decarbonizing rapidly to meet climate goals. The extent and cost of electric infrastructure additions that are needed varies by scenario. Limited Gas requires more decarbonized electric

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[9] https://fred.stlouisfed.org/series/MDNGSP
[10] Assuming the 3% average value as $54 escalated to $2020 from https://19january2017snapshot.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf
[11] Wagner, Gernot. "A tale of two carbon prices." Gernot Wagner (gwagner.com)

energy and higher levels of firm generation capacity relative to the Hybrid and Diverse scenarios. A key difference between Limited Gas and Hybrid/Diverse is that the latter two scenarios continue to take advantage of the existing BGE gas distribution system to meet heating capacity requirements, which reduces the need for new firm capacity on the electric system. [12]

- **Electric Transmission and Distribution**. As electricity demand grows, additional investment will be needed in transmission and distribution (T&D) infrastructure. New and existing T&D infrastructure must be strengthened in order to reliably deliver the increase in electric supply to customers; this would include new feeders, upgrading existing feeders, and building new or upgrading existing substations using innovative technologies like microgrids, grid and customer scale storage, vehicle to grid, among many other investments. Due to increased dependence on the electric system, BGE will also need to invest in making its electric infrastructure more resilient.
- **Customer Capital Costs**. Each scenario requires a transition of customers' energy-consuming equipment. In all scenarios internal combustion engine vehicles are replaced with electric drive trains in both passenger and freight vehicles, furnaces and boilers are replaced with heat pumps, household appliances are replaced with higher efficiency alternatives, industrial processes are converted to electricity or low-carbon fuels, and a diverse set of energy efficiency measures are deployed. On net, across all end-uses, BGE's customers can expect to pay higher up-front costs for their energy-consuming equipment in scenarios that are consistent with the state's decarbonization goals. Customer Capital Costs are highest in the Limited Gas scenario because that case requires more extensive building retrofits, particularly in harder-to-electrify buildings within BGE's service territory, requiring additional expense.
- **Renewable Fuels**. All scenarios, including Limited Gas, rely on renewable fuels to some extent, and those fuels carry incremental costs over the fossil alternatives they replace. Renewable fuels include a role for green hydrogen and advanced biofuels such as renewable natural gas and renewable diesel. Spending on renewable fuels is largest in the Diverse scenario, where higher costs are driven by the need for costly synthetic natural gas. However, none of the scenarios relies on renewable fuels as a primary driver of emissions reductions, but rather each leverages them strategically to reduce the GHG intensity of remaining fuel demands.
- **Avoided Fossil Fuels Investment.** This cost metric includes spending on liquid and gaseous fossil fuels including gasoline, diesel, jet fuel, natural gas, and their renewable equivalents. The incremental costs of decarbonization are partially offset by avoided direct costs on fossil fuels, which leads to cost savings that show up as negative incremental costs relative to a Reference Scenario. The largest sources of savings are avoided expenditures on liquid fuels like gasoline and diesel in transportation end uses. The fuel costs assumed here represent delivered fossil fuel prices and do not include any price on carbon.
- **Gas + Networked Geothermal Infrastructure**. The Limited Gas scenario sees decreasing gas system utilization, raising the possibility of decommissioning some gas infrastructure to reduce

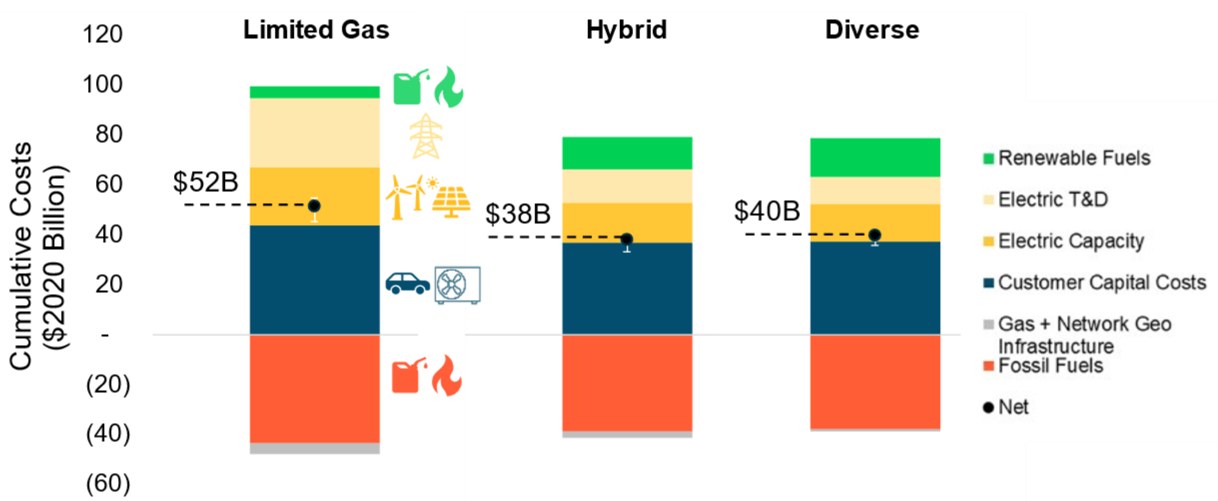
[12] Note that this study did not do new economic or engineering modeling of electric capacity, transmission, and distribution needs. This study leveraged assumptions from recent PJM modeling estimate the costs of new 100% zero-carbon generation and BGE estimates of costs for new transmission and distribution infrastructure.

total energy system costs. However, the scale of those potential savings from decommissioning is small relative to incremental expenditures in other sectors of the economy for several reasons. First, the gas system infrastructure is long-lived, with assets like gas main lines having 60+ year useful lives, so opportunities for avoided reinvestments will only be a fraction of the total value of the system between 2022 and 2050. Furthermore, not all gas infrastructure that is up for replacement can be replaced, and ongoing investments will be needed for reasons ranging from safety and reliability to the feasibility challenges inherent in implementing electrification projects at neighborhood scale. In addition, investments in the gas system, in particular STRIDE, have an additional benefit of reducing methane emissions.

Taking each cost component into account, the Hybrid and Diverse scenarios carry lower overall energy system costs than Limited Gas. The largest drivers of this outcome are the incremental electric system expenditures required to reliably serve building heating loads using an electric only strategy. The Hybrid and Diverse scenarios substantially reduce incremental electric system expenditures by leveraging the existing capacity of BGE's gas infrastructure. In addition, the Hybrid and Diverse scenarios see cost savings due to lower overall requirements for extensive building retrofits, particularly in harder-to-electrify segments of BGE's building stock.

These economy-wide cost findings support the hypothesis that a strategy that uses an integrated energy delivery system, rather than relying on an electric-only approach, reduces total cost of achieving the state's decarbonization ambitions within BGE's service territory.

Figure 17. 2045 Incremental costs by component relative to Reference Scenario[13]



Customer Costs

All scenarios rely on a transformation in how BGE's customers currently use energy, including substantial building retrofits. Given that role, E3 developed an assessment of cost impacts on BGE's customers for

[13] Chart error bars include a range of costs for T&D investments and a lower cost to achieve 100% decarbonized electricity

building investments within each decarbonization scenario. This cost assessment focuses on how customer bills and upfront costs will change given shifts from heating services currently delivered via natural gas to the primary alternative technologies that distinguish the decarbonization scenarios. Key metrics used to assess consumer costs include:

- **Upfront capital cost**, or the cost of retrofitting a building from traditional gas service to an all-electric, hybrid, networked geothermal or gas heat pump-based arrangement.
- **Bill impacts**, inclusive of changes in electric and gas rates due to decarbonization of energy supply, growth or contraction of infrastructure and changes in the utilization of infrastructure.
- **Levelized cost of ownership**, which evaluates the combined bill impact plus upfront capital costs, assuming the latter can be amortized or spread evenly over the lifetime of the appliance. This provides a view as to what the monthly expenditures on household heating could look like.

Across all scenarios, the keystone technologies required to achieve decarbonization in buildings are currently more costly than equipment relying on traditional gas service. Those costs occur primarily because of the higher upfront costs of electrification technologies. For example, a new electric heat pump or network geothermal system will range from $7,000 and $16,000 in incremental cost, compared to conventional gas alternatives. In addition, each scenario sees an increase in the operating costs of decarbonized heating technologies over time, largely driven by costs associated with achieving zero-GHG electric supply.

E3 modeled how adopting different technology packages would impact energy consumption and customer costs for a range of households representative of the BGE's customers under each of the decarbonization scenarios. Figure 18 highlights capital costs and energy bills for a 1960s vintage single-family home. This figure reflects costs for space heating, water heating, clothes drying, cooking, air conditioning, and building shell measures. Reference case electricity and gas usage for this customer are modeled to be 12,000 kWh/year and 620 therms/year.

Figure 18. Upfront and energy bill costs for a residential customer

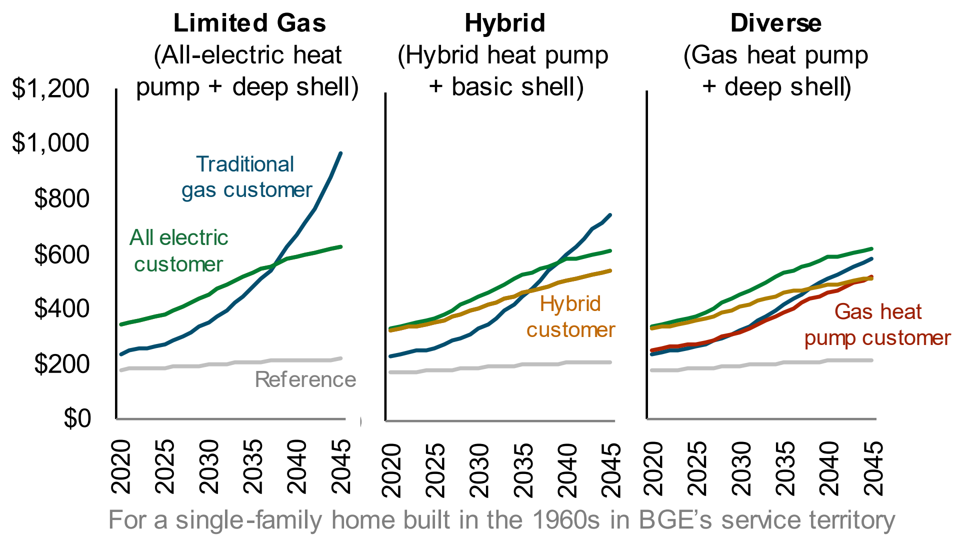
			Monthly household energy bills 2045		
Scenario	**Customer Type**	**Capital Cost**	**Gas**	**Electric**	**Total**
Limited Gas	Traditional gas	$10,562	$640	$270	$910
	All electric	$30,580	$0	$500	$500
Hybrid	Traditional gas	$10.562	$480	$220	$700
	Hybrid	$17,085	$60	$390	$450
Diverse	Traditional gas	$10,562	$320	$210	$530
	Gas heat pump	$27,488	$240	$170	$410

Note that Figure 18 is focused on the capital costs and monthly household bills associated with household appliances and does not include a perspective on vehicle use. The scenarios we model include a transition for electric passenger vehicles to replace traditional gasoline vehicles, which are expected to reach cost parity around 2030 for upfront sticker price in addition to fuel savings due to the high efficiency of electric vehicles.

Notably, as shown in Figure 19, the cost of traditional gas service increases in each scenario such that decarbonization heating technologies become more cost effective in the 2030s. The reasons why this switchover occurs differ by scenario as follows:

- In **Limited Gas**, traditional gas customer costs increase primarily due to the fixed costs of BGE's gas infrastructure being spread over a declining number of customers. Those fixed costs are driven by the infrastructure in use, rather than the number of customers connected to the system. By the mid-2030s, the cost of being a traditional gas customer is greater than that of an all-electric customer, raising the prospect of an unmanaged transition where, absent policy interventions, a small number of customers are burdened with the costs of a gas system built for a much higher level of utilization. This cross-over point could engender a feedback loop through which increasing the numbers of customers departing gas service and the costs of the gas system are no longer recoverable through rates.
- In **Diverse**, costs for a traditional gas customer increase primarily due to impacts of renewable fuels on BGE's gas supply cost. With those higher supply costs, opting for alternative forms of heating becomes a financially favorable prospect for customers in the mid-2030s. Customers who adopt gas heat pumps or hybrid heating systems require less overall gas to heat their homes, so are less impacted by the higher cost of gas supply relative to traditional gas customers. Notably, this scenario does not appear to engender a feedback loop of gas customer departures because of the availability of hybrid, gas heat pump and networked geothermal options.
- The **Hybrid** case reflects a combination of the gas delivery and supply cost dynamics from the Limited Gas and Diverse cases, though to a lesser extent. Average gas delivery rates increase due to declining overall gas usage, however there is still a large customer base which results in a more modest impact on customers' gas bills. Gas supply costs also increase, but those impacts are tempered relative to Diverse due to lower overall reliance on renewable fuels, particularly costly SNG.

Figure 19. Monthly BGE residential customer cost, inclusive of energy bills and amortized equipment costs for building appliances



All scenarios see increasing costs associated with heating buildings in BGE's service territory. These higher costs stem in part from the higher equipment costs discussed above, as well as the impacts from decarbonized energy supply, which put upward pressure on both electric and gas rates. An integrated approach to decarbonizing building heating can reduce those rate impacts by reducing electric system infrastructure requirements and by reducing reliance on costly renewable fuels.

Regardless of the technology, the upfront costs associated with converting buildings from traditional gas service are high and will likely be burdensome, particularly to populations without ready access to financial resources. This implies that support will be needed for customers to adopt decarbonized heating technologies. Such support will be especially critical for low- and moderate-income customers who may not be able to afford the upfront cost of a retrofit or who are renters and do not have the ability to choose the heating technologies installed in their homes. Similar challenges occur with respect to transportation electrification. Notably, the recently passed Inflation Reduction Act offers support for low- and moderate-income customers to electrify, which will help to reduce upfront cost barriers to adoption.

Constructability

In all scenarios, the regional electricity system must decarbonize and expand, while at the same time BGE must appropriately size its electric infrastructure to maintain reliability and increase resilience. This will require additions and replacements of infrastructure at a scale that exceeds recent history, more akin to the post-WWII period of the electric system.[14] Achieving the level of scale envisioned in the scenarios will require overcoming challenges including siting of both renewable and firm capacity, siting of transmission and distribution infrastructure, workforce and supply chains. All else equal, there will be a higher degree

[14] For a discussion of historical rates of electric load growth vs growth in electrification scenarios see: https://www.nrel.gov/docs/fy18osti/71500.pdf

of challenge with respect to electric sector constructability in the Limited Gas case relative to other scenarios.

The Hybrid and Diverse scenarios require less overall electric infrastructure by strategically leveraging the gas system, renewable fuels and networked geothermal, though this integrated gas-electric approach comes with its own constructability challenges. For example, production of hydrogen-based renewable fuels (e.g. green hydrogen and synthetic natural gas) will require large amounts of renewable energy and associated production infrastructure. In addition, networked geothermal requires neighborhood-level conversions of gas distribution systems, which will require both a high level of coordination and significant construction to be accomplished at the scale envisioned here.

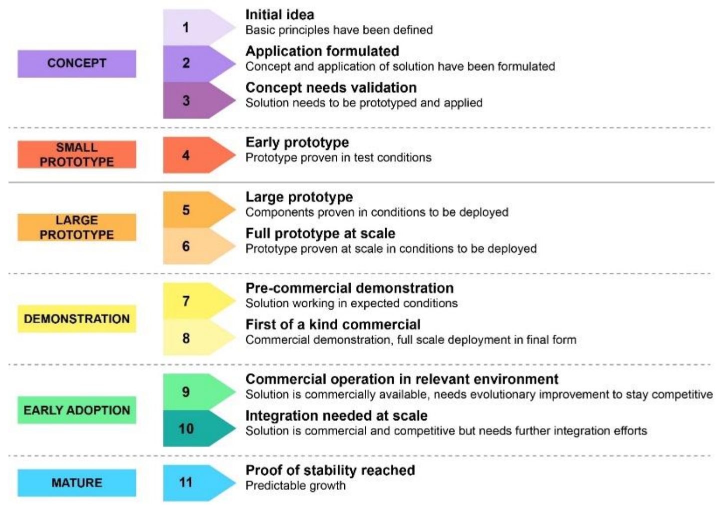
Technology readiness

Electrification is the primary driver of decarbonization across all three scenarios. Electric vehicles and heat pumps are both commercially mature technologies across many use cases, meaning that each scenario has a high degree of near-term technology readiness.

Longer-term, the scenarios diverge in their reliance on emerging technologies that have a lower level of commercialization. For example, the Diverse scenario includes a ramp up of gas-fired heat pumps, networked geothermal and synthetic natural gas technologies after 2030. None of those technologies has achieved widespread commercialization. The risks inherent in relying on these strategies are mitigated to an extent by the overall portfolio approach in the Diverse scenario, which does not rely on any one technology to achieve decarbonization, reflecting the opportunity to incorporate new technologies as they become available. The Hybrid scenario leverages proven, commercially available demand-side technologies, but requires a higher level of renewable fuels relative to Limited Gas; as with the Diverse scenario, a Hybrid path would offer opportunities to shift between approaches as renewable fuels either successfully scale or fail to effectively develop. The Limited Gas case also relies on proven demand-side technologies and requires lower levels of less-commercialized renewable fuels, but provides less ability to pivot between new and/or evolving technologies and pathways. The Limited Gas scenario does require, notably, the emergence of a form of zero-GHG firm generation to ensure that its substantial new winter peak demands, particularly multi-day cold-snaps, can be served reliably. There are several promising technologies that could fill that role, hydrogen or advanced nuclear are two examples, but none of those technologies are commercially mature today.

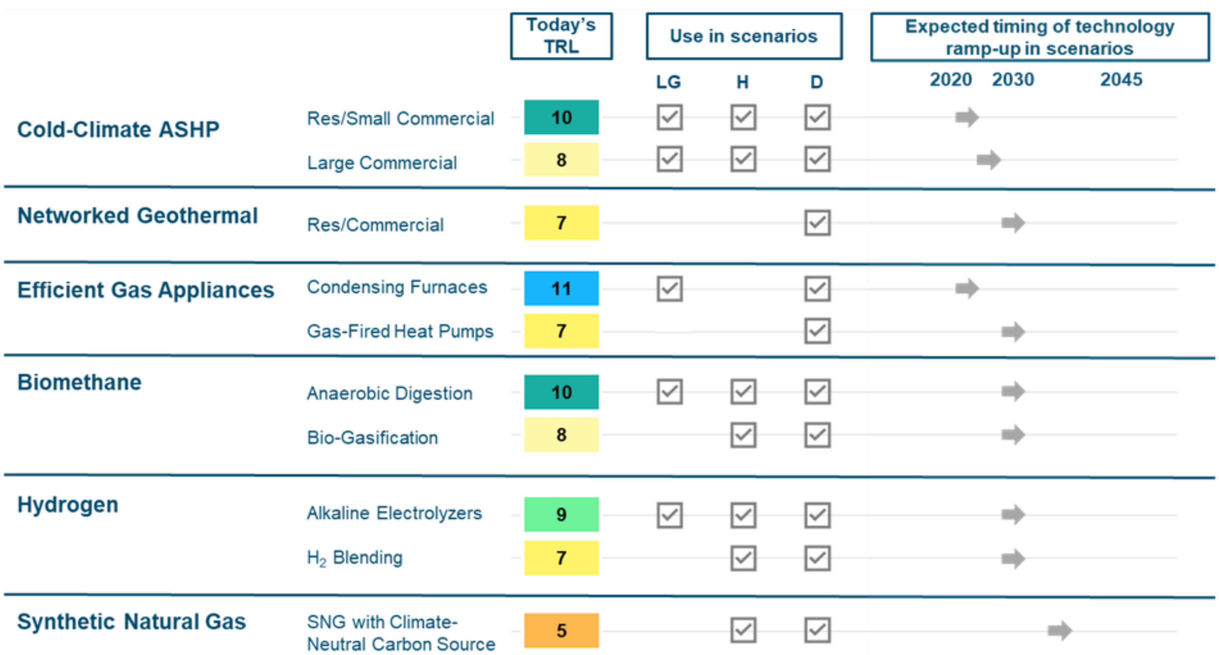
The International Energy Agency (IEA) has established a Technology Readiness Level (TRL) scale for decarbonization measures. A technology with a TRL of 11 is ready to scale, options lower than that may need research, development, and commercialization support. Portfolios of decarbonization options that rely on lower TRL measures carry additional risk. The IEA's TRL scale is shown in Figure 20.

Figure 20. Technology Readiness Scale



E3 and other deep decarbonization researchers generally screen out technologies that are less than a 5 on the TRL scale because of their speculative nature and the short time horizon of mid-century climate goals. A comparison of the technology readiness of building decarbonization measures is shown in Figure 21.

Figure 21. Technology Readiness Levels (TRLs) for building decarbonization measures and their deployment timing in scenarios[15]



[15] TRLs are based on values from an IEA database, modified in some cases by E3 based on our professional judgement, including an assessment of geographic context.

Customer Adoption and Practicality

All scenarios require high levels of consumer adoption of new building heating technologies to achieve levels of scale consistent with Maryland's climate goals. The pace of consumer conversions envisioned is without recent precedent, with such a transition not seen since past conversions from solid fuels or manufactured gas to natural gas for heating[16]. Achieving that scale will require overcoming the higher upfront costs associated with heat pumps and other electric technologies. Customers typically replace their energy consuming equipment or vehicles at end-of-product-life or failure. Those replacements happen infrequently, so early action and rapid market transformation are needed to achieve the scale of adoption considered in the three scenarios.

With respect to customer adoption of building sector retrofits, the number of homes that undergo a conversion is similar across scenarios, though the extensiveness of the actual retrofit projects varies. The Hybrid scenario offers a relatively lower-cost, lower-disruption path to electrify large amounts of heating loads in BGE's service territory, primarily targeting replacement of central-air conditioners with electric heat pumps. The Limited Gas scenario requires more extensive building retrofits to fully replace traditional gas heating systems with electric heat pumps, while at the same time improving the thermal efficiency of buildings. The Diverse scenario falls in-between, with some customers undergoing substantial retrofits and others do not. In addition, the Diverse scenario envisions the installation of networked geothermal systems, which would require a higher level of customer engagement and neighborhood level coordination compared to other technologies. However, the multiple technologies included in the Diverse scenario may allow for more extensive retrofits to be applied in cases where they are lower in cost, with less intensive measures targeted at harder-to-electrify use cases.

Equity

Absent policy interventions, decarbonization scenarios could have deleterious impacts on equity, particularly because in all scenarios the cost of heating homes in BGE's service territory increases. For example, in the Limited Gas case, the costs of being a traditional gas customer increase substantially over time as the fixed costs of the gas system are spread over fewer customers. In the Diverse scenario, traditional gas customers incur higher energy bills as renewable fuels are blended into BGE's gas supply. In both cases, customers can insulate themselves from those cost impacts, provided they can pay the high upfront costs of adopting electrification or gas heat pump technologies. All else equal, customers with higher incomes will be better able to incur those costs, while lower-income customer or renters will not. It will be critically important to support customers in managing the costs of the transition, both for early adopters and those unable to adopt new technologies until later in time.

Table 4 illustrates the energy burden for a median residential customer. Energy burden reflects energy costs as a share of household income. Here, gross household income is modeled as approximately $84,000/year in 2020, the median income for the service area, and is assumed to grow at 0.6%/year[17] in

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[16] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760508/hydrogen-logistics.pdf

[17] Average historical annual income from St. Louis Fed from 2008-2020. Data available online: https://fred.stlouisfed.org/series/MEHOINUSA672N

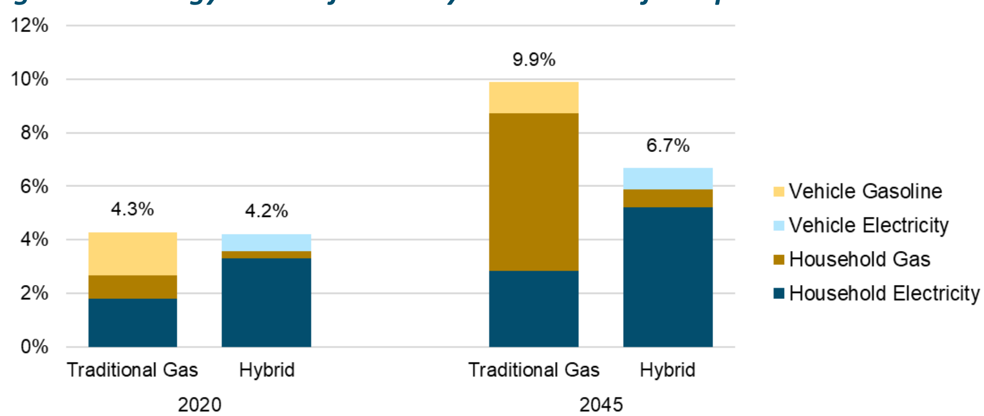
real dollars. This table also includes the energy costs associated with one personal vehicle, assuming that customers who adopt novel building technologies also replace a conventional car with an electric vehicle.

Table 4. Energy burden for a representative residential customer

Scenario	Customer Type	Household Electricity		Household Gas		Vehicle Electricity		Vehicle Gasoline		Total	
		2020	2045	2020	2045	2020	2045	2020	2045	2020	2045
Limited Gas	Traditional Gas	1.8%	3.6%	0.9%	7.8%	0.0%	0.0%	1.6%	1.2%	4.3%	12.6%
	All Electric	3.3%	6.6%	0.0%	0.0%	0.7%	1.0%	0.0%	0.0%	4.0%	7.6%
Hybrid	Traditional Gas	1.8%	2.8%	0.9%	5.9%	0.0%	0.0%	1.6%	1.2%	4.3%	9.9%
	Hybrid	3.3%	5.2%	0.3%	0.7%	0.7%	0.8%	0.0%	0.0%	4.2%	6.7%
Diverse	Traditional Gas	1.8%	2.7%	0.9%	3.9%	0.0%	0.0%	1.6%	1.2%	4.3%	7.8%
	Gas HP	1.4%	2.1%	0.7%	3.0%	0.6%	0.8%	0.0%	0.0%	2.8%	5.9%

Figure 22 illustrates the energy burden under the Hybrid Scenario. By 2045, energy burden is forecast to increase both for customers who retain traditional gas technologies and those who adopt hybrid building technologies and electric vehicles. However, comparing the technology options in 2045, the hybrid customer achieves a significantly lower energy burden than the customer who retains traditional equipment, due primarily to the significant increase in gas rates by 2045.

Figure 22. Energy burden for the Hybrid Scenario for representative residential customer



This evaluation of energy burden indicates that energy costs are likely to be a growing burden for customers. To help reduce energy burden for low-income customers, it will be key to ensure that these customers can afford novel technologies that can reduce their energy costs relative to a reliance on traditional devices. However, even with these technologies, energy burden is forecast to increase. Ultimately, it may be necessary to provide additional financial support to customers and/or to increasingly finance the societal project of decarbonization using government funds, like the programs that will support low-income customer electrification in the Inflation Reduction Act, rather than relying on customer bills.

Workforce Impact

The large amount of infrastructure added to each scenario will require an expanded energy workforce, creating economic opportunity and job creation across scenarios. In particular, the central role of electrification across all decarbonization cases will require skilled labor to decarbonize and expand the state's electricity system and support customer installations and retrofits. Along the same lines, an expanded building performance industry will be needed to achieve the scale and depth of building electrification and energy efficiency retrofits envisioned in all scenarios. Other sectors of the economy, especially those associated with the production and delivery of fuels, are more likely to see workforce declines. For example, in the Limited Gas scenario, the gas workforce may need to be reskilled over time though, importantly, even in that case the transition occurs over a multi-decade period.

Safety, Reliability and Resilience

All scenarios are assumed to comply with existing standards as defined by organizations including the Maryland Public Service Commission, the US Department of Transportation, the PJM Interconnection and others. However, it is important to note that gas and electric infrastructure have markedly different characteristics. Gas infrastructure is largely underground and therefore is less likely to be impacted by factors like inclement weather. However, loss-of-load events for gas are substantially more challenging to recover from. As a result, gas systems are designed with stricter criteria on the frequency of outages that may occur. Because of those considerations, gas customers have historically been much less likely to experience a service interruption than electric customers[18] and, absent large-scale undergrounding of electric distribution, a similar trend is likely to hold into the future. A final consideration with respect to the comparative reliability of electric versus gas is that appliances fueled by both fuels rely on electricity to operate.

Resilience is a concept that does not have a formal definition that has been established in the energy industry. Definitions of resilience range from an ability to quickly recover from or withstand shocks to the system, but can also include a broader set of technical, political, social and other factors. It is clear, however, that a resilient energy system is a critical need of any decarbonized energy system to avoid outages of critical energy systems such as space heating in the winter. In principle, having multiple energy delivery systems, as is the case in the Hybrid or Diverse scenarios, provides a degree of redundancy that a single energy delivery system cannot provide. Retaining a degree of energy infrastructure diversity and redundancy may be particularly valuable as the majority of economy-wide energy usage shifts to the electric system. Absent redundancy, disruptions in electric systems would have a more disruptive impact on Maryland's economy and society, with implications for human comfort, health, safety and mobility. As a result, an all-electric approach, as is the case in the Limited Gas scenario, may require stricter reliability standards than the 1-in-10 year standard considered here and increased investments in resilience than today, which could further increase the cost of such an approach. In addition, an all-electric approach may

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[18] https://www.gti.energy/wp-content/uploads/2018/11/Assessment-of-Natural-Gas-Electric-Distribution-Service-Reliability-TopicalReport-Jul2018.pdf

require more extensive investments in building shell retrofits than was envisioned in this study, to ensure building temperatures remain safe[19] during electric outages that occur in cold temperatures.

Regulatory and Policy Implications

Regulatory and policy support will be necessary to both manage the challenges associated with decarbonization and capture new opportunities. In this section, E3 suggests a set of regulatory and policy changes that we recommend be explored in Maryland.

Rate design

Ensuring cost-reflective pricing for both electric and gas systems will be a critical step to ensuring customer decision-making is aligned with efficient use of BGE's infrastructure. For electric rates, this would imply an emphasis on time-varying prices to ensure customers are incentivized to adopt technologies that manage the peak demand implications of electrification. For gas, net-zero consistent rates might shift to subscription or other fixed-price means of collecting gas infrastructure costs from hybrid customers with much lower volumes than today.

Utility and customer incentives

In addition to earning a rate of return on traditional infrastructure, utilities in Maryland could be offered the opportunity to invest in selected infrastructure investments to support customer adoption of electrification technologies that carry upfront costs. For example, Southern California Edison has recently filed to earn a return on incentives they provide to support behind-the-meter infrastructure like upgraded electrical panels or wiring in their customers' buildings.[20] Incentives funded by rate-payers will need to be designed to be complementary to provisions of federal programs such as those that may result from the Inflation Reduction Act.

Procurement and sale renewable gases.

Renewable gases are used in all scenarios. Maryland should consider policy regulatory modifications to allow for the procurement of these fuels. Such modifications might include approval of voluntary renewable gas offerings, a renewable portfolio standard for gas, inclusion of a social cost of carbon in gas supply planning, or as part of a technology neutral clean heat standard.

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[19] See, for example, https://rmi.org/insight/hours-of-safety-in-cold-weather/
[20] https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M432/K773/432773552.PDF

Accelerated depreciation

The results of this study suggest that gas system utilization is likely to fall in net-zero scenarios. As a result, shorter depreciation periods may be warranted to reflect a lower overall useful life for certain gas infrastructure. Doing so would better align the costs of the system with its usage and more fairly allocate on an intergenerational basis. Both National Grid in Massachusetts and PG&E in California have proposed modifications to gas infrastructure depreciation given the decarbonization initiatives underway in those states.[21]

Redirect incremental gas investment

All decarbonization scenarios envision reductions in the cost of BGE's gas system relative to business-as-usual. Achieving those cost reductions will require regulatory support, including consideration of BGE's obligation to serve its existing gas customers and ability to leverage cost savings from non-pipe alternative projects to support decarbonization initiatives like targeted electrification or networked geothermal. These and related issues have begun to be explored in both California and New York.[22] Initial findings from work in those states indicates that redirecting investments will involve substantial changes to utility planning practices, including more extensive coordination between electric and gas distribution planning.

Electric to gas benefit payments

An integrated energy delivery system provides benefits by leveraging BGE's gas system to reduce the overall size and cost of its electric system. As a result, transfer payments from the company's electric business to its gas business could help to ensure that the costs of BGE's gas system are shared among all ratepayers who benefit from the capacity and other benefits it provides. Such a benefit sharing approach is currently being implemented in Canada, where Hydro Quebec, an electric utility, is currently compensating Energir, a gas utility, for infrastructure it maintains that supports hybrid heating customers.[23]

A summary of the regulatory and policy changes recommended for consideration is provided in Figure 23. The initiatives are sorted into those that are common across scenarios and E3 recommends be pursued and those that need further exploration or that are scenario-specific.

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[21] D.P.U. 20-120; https://www.pge.com/pge_global/common/pdfs/about-pge/company-information/regulation/general-rate-case/PGE-GRC-Application-2023.pdf

[22] https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/natural-gas/long-term-gas-planning-oir/presentation-for-r2001007-track-2-workshop-1_2022-01-07.pdf;

[23] D-2021-172 File R-4169-2021 Phase 1, "Demande Relative Aux Mesures De Soutien À La Décarbonation Du Chauffage DesBâtiments," Regie De L'Energie (September 2021) http://publicsde.regie-energie.qc.ca/projets/597/DocPrj/R-4169-2021-B-0005-Demande-Piece2021_09_16.pdf

Figure 23. Regulatory and policy initiatives

Solution	Limited Gas	Hybrid	Diverse	Example
Recommended				
Rate design Cost reflective pricing on electric and gas (TOU, subscription -based)	✓	✓	✓	Various
Utility and customer incentives e.g., BGE investments to support customer adoption	✓	✓	✓	SCE
Procurement of renewable gasses e.g., Voluntary tariffs or updated gas supply procurement standards	✓	✓	✓	Various
Needs Further Exploration				
Accelerated depreciation Ties the pace of recovery to remaining system utilization	✓			PG&E National Grid
Avoided incremental gas investment Strategically reduce incremental rate base	✓		✓	PG&E
Benefit payments e.g. compensate the gas system for avoided incremental investment		✓	✓	Energir/Hydro Quebec

Key Takeaways and Recommendations

This study examined three distinct decarbonization scenarios for BGE's service territory that are consistent with achieving net-zero GHG emissions in Maryland. None of these scenarios are intended to be viewed as a 'preferred' strategy. Instead, their individual features and outcomes are intended to inform BGE's and the state's decarbonization planning, in particular by identifying actions for the near-term and nascent strategies that warrant further examination.

Key Takeaways

1. **Pathways that rely on an integrated energy system carry a lower overall cost and level of challenge relative that rely more exclusively on electrification or renewable gases.** There are multiple viable paths to decarbonization, but any future that meets net zero will require significant transformations and investments across the economy and a role for electrification in buildings and transportation. Electrification is the core engine of decarbonization across all scenarios considered in this report because of its high level of commercialization, scalability, and complementarity to an increasingly decarbonized electricity system. Key trade-offs include types of electrification technologies that are adopted and the overall level of electrification vs reliance on efficient gas technologies. Scenario findings identify ongoing value for gas infrastructure that deliver an increasing blend of renewable gases[24] as a complement to electrification. Key trade-offs include types of electrification technologies that are adopted and the overall level of

[24] Renewable gases considered in this study encompass renewable natural gas from biogenic sources produced via anaerobic digestion and gasification, hydrogen produced via electrolysis powered by renewable energy, and synthetic natural gas produced using hydrogen and a climate neutral source of CO_2.

electrification vs reliance on efficient gas technologies. Investments in gas infrastructure, including the STRIDE Program, help to modernize the system, reduce methane emissions and improve safety and reliability. Those investments could be balanced against future opportunities to pursue targeted electrification that enable gas infrastructure savings where such initiatives produce system and ratepayer cost savings. An integrated approach that leverages the advantages of both electric and gas infrastructure can help to reduce both total energy system and consumer costs, while also reducing challenges associated with large-scale electric infrastructure additions and customer retrofits.

2. **All scenarios that achieve net-zero require significant investments in electric generation and delivery infrastructure, but those costs can be mitigated via an integrated approach**. Clean electric generation capacity will need to be sited, permitted, built and interconnected into the grid. BGE's electric delivery system will need to increase in capacity and modernize to accommodate new electrification loads while at the same time the energy it delivers via both gas and electricity will need to become cleaner. Relying on a dual energy approach reduces the overall scale of infrastructure additions required to achieve net-zero goals. As a result, pathways that rely on an integrated energy system are lower cost than all-electric or all-renewable gas-based pathways and have a lower level of challenge in terms of the constructability of new infrastructure, while providing more flexibility to navigate rapidly-changing technological and market developments to continue to allow the most appropriate choices for all customers throughout the energy transition. Those advantages are tempered by higher reliance on renewable fuels, which have a comparably lower level of technology readiness compared to all-electric measures.

3. **Consumers are central to the transformations required to achieve net-zero** and achieving the scale of adoption envisioned here will require developing solutions that are affordable and work for customers, equitably. All-electric solutions can lead to higher retrofit costs for existing buildings, particularly older buildings, relative to alternatives. Decarbonization pathways that include a diverse set of heating technologies enable strategic application of all-electric solutions where they are most appropriate, while allowing for alternative strategies in cases where all-electric solutions are more challenging. Lower income customers are expected to face higher energy burdens, particularly in the Limited Gas scenario, so identifying strategies to mitigate those impacts will be critical to achieving a just transition to net-zero. Relative to Limited Gas, the Hybrid and Diverse scenarios offer potential pathways through which the energy burden of decarbonization can be managed. In all cases, customers will need to adopt electric vehicles, supported by a combination of private and public charging infrastructure.

4. **As Maryland's largest utility, BGE will have an important role in supporting customer adoption of decarbonization options by introducing and scaling new products, programs, and services required to achieve net zero** through, for example, pilot programs, incentives and new types of infrastructure investments. Examples where BGE could have a role in facilitating and scaling decarbonization technologies include, but are not limited to, strategic electrification, networked geothermal, and green hydrogen production and delivery. BGE's role could also include working to ensure that all its customers are able to participate in and share the benefits of the decarbonization transition by, for example, ensuring equitable electric vehicle charging infrastructure in disadvantaged communities, supporting efficient heating technologies adoption

for low-income customers, and finding additional ways to protect low-income customers from bearing undue burdens through the energy transition.

5. **Regulatory and policy support will be necessary to manage the challenges associated with decarbonization.** Regulatory and policy interventions are needed in several areas including, but not limited to, enabling BGE and its customers to support the state's decarbonization ambitions in order to manage the cost impacts of implementing decarbonization, supporting customer adoption of electrification technologies, and implementing non-pipe alternatives projects.

Based on the key findings of this study, E3 recommends the following strategies to BGE, its regulators, policymakers and other key stakeholders in Maryland:

1. **Increase funding for energy efficiency programs and align measures to support decarbonization.** All scenarios include levels of energy efficiency savings that go beyond even Maryland's current ambitious targets through traditional efficiency measures and electrification. For that to happen, additional funding is likely to be needed. Achieving higher levels of energy efficiency progress will likely require additional funding beyond that offered today. In addition, the emphasis of energy efficiency programs may need to shift, including an emphasis on building shell retrofits that reduce both customer bill and utility electric system impacts from building thermal decarbonization. Energy efficiency funds could also be used to support the commercialization of emerging technologies gas heat pumps.

2. **Develop programs and incentives to support building and transportation decarbonization**. Customer incentives will be needed to support the adoption of decarbonization technologies. For example, expanding the remit of BGE's current programs to include fuel-switching could be a practical initial strategy to support customers in managing the incremental cost of electrification. Current programs that incentivize high-efficiency cooling could be reoriented to require installation of a heat pump, rather than a stand-alone air conditioner, to be eligible for an incentive. Such an intervention could be a feasible initial step to encourage hybrid electrification of BGE's customers.

3. **Support development of electric vehicle charging infrastructure and vehicle adoption**. Transportation electrification is a common feature of all the scenarios evaluated. For transportation electrification to scale to levels consistent with decarbonization, sufficient at home, workplace and public charging infrastructure will be needed. While much of that infrastructure will be provided via non-utility market actors, there are gaps that BGE could fill like, for example, installations of charging infrastructure in multi-unit dwellings or in disadvantaged communities. In addition, make-ready investments that prepare customer sites for the eventual installation of charging equipment are warranted to ensure customers who want to adopt an electric vehicle can do so in a timely manner. Alongside those infrastructure additions, upfront incentives will be needed until electric vehicles reach upfront cost parity with gasoline and diesel vehicles. In addition, allowing BGE investments in advanced electric vehicle charging management technologies may be warranted to help defray costs that might otherwise be required for certain physical infrastructure upgrades.

In addition to those initiatives, E3 recommends that BGE, its regulators and policymakers in Maryland pursue the following types of research and development or pilot activities to support GHG reductions within BGE's gas delivery service:

1. **Develop and pilot hybrid electrification operations and control strategies.** Like past work for the state, this work confirms that a building electrification strategy that includes hybrid heat pumps has lower overall costs than an electric-only approach. However, the extent to which those benefits are captured will depend on how the hybrid systems are operated. Historically, hybrid systems have been operated via contractor- or user-defined temperature set points at which backup thermal system takes over from the heat pump. However, utilities in both Canada and the United Kingdom have begun to pilot alternative control strategies that leverage differences in gas vs electric pricing, weather conditions and other factors to optimize the operation of hybrid systems. Similar to those initiatives, E3 recommends that BGE pilot alternative hybrid heat pump operations alongside the deployment efforts for these systems described above.

2. **Develop a networked geothermal pilot program.** Networked geothermal systems hold the potential to provide all-electric heat in a manner that substantially reduces electric system impacts, offers a transition path for BGE's gas workers, and represents a potential evolution for BGE's business. However, there are many uncertainties with respect to the technical and economic feasibility of this solution in BGE's service territory, as well as the extent to which customers will be interested in receiving networked geothermal service. Initial pilots, similar to those being conducted by Eversource Energy and National Grid in Massachusetts, would help to resolve these uncertainties.

3. **Develop a process to identify opportunities for non-pipeline alternatives to conventional gas infrastructure investments.** All-electric solutions like networked geothermal or air-source heat pumps are most likely to be cost effective in instances where gas infrastructure can be avoided and where the electric system has sufficient capacity. Developing a process to assess the technical feasibility, customer acceptance and net-benefits or costs of non-pipeline programs would therefore help to identify where all-electric vs integrated gas-electric approaches are most warranted. Any non-pipeline alternative initiatives will need to be balanced against the safety, reliability and methane emissions reduction benefits of ongoing gas infrastructure replacement programs, including the Strategic Infrastructure Development and Enhancement (STRIDE) program.

4. **Support the emergence of renewable natural gas (RNG) supply sources and associated regulatory support and rate development**. RNG resources are leveraged in all scenarios though, given the modeled pace of electric sector decarbonization and electrification, these resources are not blended into the gas delivered by BGE until after 2030. In practice, BGE should consider procuring initial quantities of RNG before then to gain familiarity with the technology and support the development of regulatory standards through which these resources can be procured and developed.

5. **Pilot blends of hydrogen and dedicated hydrogen infrastructure.** The Hybrid and Diverse cases envision blends of hydrogen to reduce the greenhouse gas intensity of BGE's gas supply. Like RNG the use of hydrogen does not need scale until after 2030, so the remainder of this decade will be an opportunity to explore the technical and operational requirements of both dedicated hydrogen and hydrogen blends. Several gas utilities throughout the United States and abroad are pursuing similar initiatives[25], so BGE can both learn from and contribute to broader learnings in this space. Finally, the scenarios modeled here focus on hydrogen blending in the gas system, but other studies have explored a potential for dedicated hydrogen clusters if greater ambition in industry is pursued in Maryland.

[25] https://www.capitaliq.spglobal.com/web/client?auth=inherit#news/article?KeyProductLinkType=2&id=65570349

Appendix A: Comparisons between recent E3 studies in Maryland

Discussion of Recent Decarbonization Analyses in Maryland

E3 has a history of developing decarbonization scenario analysis in Maryland. E3 supported the Maryland Department of the Environment in their development of scenarios for the Greenhouse Gas Reduction Act (GGRA) in 2017, and the update in 2021 The most recent statewide analysis was published in early 2021 after broad stakeholder engagement through the state's Mitigation Working Group under the Maryland Commission on Climate Change (MCCC)[26]. This work explored economy-wide scenarios to achieve a minimum of 40% GHG reductions below 2006 levels by 2030.

Following on the work for GGRA work, E3 provided technical support to the MCCC by modeling different pathways to decarbonize building emissions by 2045 and engaging with the Buildings Sub-Group to the Mitigation Working Group. This analysis informed a Buildings Energy Transition Plan that was published in November 2021 by MDE.

In 2022, E3 was retained by BGE to explore economy-wide scenarios that are consistent with the State's new GHG targets of net zero GHG emissions by 2045 but tailored to their service territory. Our intent was to build on and be aligned with the existing foundation of the work for the State by using the same methodology while aligning with the BGE geography and appropriate data sources. Each of these three studies has a slightly different viewpoint and set of objectives, but still have largely consistent findings. This appendix serves as a comparison and crosswalk of key objectives and assumptions between studies.

All three studies explore deep decarbonization in Maryland, but the key differences are related to overall ambition, geography, and sectoral scope.

> **Ambition**: The GGRA Plan explored the potential to meet GHG Targets set under the 2006 GGRA, which includes 40% reductions by 2030 and 80% by 2050. The most recent GGRA plan exceeds the 2030 target but falls short of 2050. The MD Buildings and BGE studies both target net zero GHG emissions by 2045.
>
> **Geography**: The GGRA and MD Buildings study are exploring statewide GHG emissions, while the BGE study focused on BGE's service territory and energy consumption, which is roughly half of the state.
>
> **Sectoral Scope**: The GGRA and BGE studies looked at economy-wide GHG emissions, including emissions from buildings, industry, electricity generation, transportation, agriculture, waste, and forestry. The MD Buildings work focused primarily on buildings and included upstream emissions from electricity generation.

Table 5 below highlights some of the key similarities and differences between the three studies.

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[26] https://mde.maryland.gov/GGRA

Table 5. Comparison of key design parameters of recent E3 work in Maryland

	2030 GGRA Plan	Maryland Building Decarbonization	BGE Integrated Decarbonization Scenarios
Year Published	2021	2021	2022
Project Sponsor	MDE	MCCC/MDE	BGE
Sectors Covered	Buildings Industry Transportation Electricity Generation Agriculture Waste Forestry	Buildings	Buildings Industry Transportation Electricity Generation Agriculture Waste Forestry
GHG targets	40x30, 80x50	Net zero by 2045	60x31, Net zero by 2045
Geography	Statewide	Statewide	BGE Service Territory
Economy-wide Net GHG Reductions Achieved by 2045 (vs. 2006)	76%	100%	100%
GHG Reductions achieved by sector in 2045			
Buildings	23%	86-100% (depending on scenario)[27]	86%
Transportation	65%	N/A	81-85%
Industry	54%	N/A	57-69%
Electricity Generation	93%	100%	100%
Other Sources	31%	N/A	66%
Natural and Working Land Sinks	+15% in net carbon sinks	N/A	+15% in net carbon sinks

[27] The high electrification scenario, electrification with fuel backup scenario, and high decarbonized methane scenario all achieve 100% decarbonization in buildings. The MWG policy scenario achieves an 86% reduction in direct building emissions and remaining emissions are subject to an alternative compliance payment.

Comparison of Key Assumptions

In the tables below we will compare key assumptions from the three analyses: (1) key building space heating technologies, (2) role of electric vehicles, (3) role of low-carbon fuels, (4) natural gas throughput, and (5) decarbonization of electricity supply.

Table 6. Percent of stocks of key technologies in 2030 and 2045 in residential space heating

Project		GGRA	MD Buildings			BGE		
Scenario	Year	GGRA Plan	High Elec	Elec with Backup	High Decarb. Methane	Limited Gas	Hybrid	Diverse
ASHP	2030	25%	40%	25%	11%	40%	31%	28%
	2045	63%	80%	40%	14%	85%	55%	50%
GSHP	2030	~0%	4%	~0%	0%	4%	4%	4%
	2045	~0%	9%	~0%	0%	9%	9%	9%
Hybrids	2030	0%	0%	20%	0%	0%	13%	5%
	2045	0%	0%	40%	0%	0%	28%	12%
Efficient Gas	2030	2%	4%	4%	24%	8%	2%	10%
	2045	4%	1%	1%	54%	2%	0%	8%
Gas HP	2030	0%	0%	0%	0%	0%	0%	9%
	2045	0%	0%	0%	0%	0%	0%	8%
Networked geothermal	2030	0%	0%	0%	0%	0%	0%	2%
	2045	0%	0%	0%	0%	0%	0%	8%

Table 7. Percent of new sales of key technologies in residential space heating

Project		GGRA	MD Buildings			BGE		
Scenario	Year	GGRA Plan	High Elec	Elec with Backup	High Decarb. Methane	Limited Gas	Hybrid	Diverse
ASHP	2030	50%	90% by 2035 and after	90% by 2035 in new construction	14%	86%	53%	47%

	2045	80%	90%	90% in new construction	14%	89%	58%	55%
GSHP	2030	0.3%	10% by 2035	10% by 2035 in new construction	0%	9%	9%	9%
	2045	0.3%	10%	10% in new construction	0%	10%	10%	10%
Hybrids	2030	0%	0%	100% by 2035 in non-new construction	0%	0%	30%	12%
	2045	0%	0%	100% in non-new construction	0%	0%	30%	12%
Efficient Gas	2030	25% of gas sales	25% of gas sales	25% of gas sales	100% of gas sales	3%	0%	8%
	2045	25% of gas sales	25% of gas sales	25% of gas sales	100% of gas sales	0%	0%	8%
Gas HP	2030	0%	0%	0%	0%	0%	0%	5%
	2045	0%	0%	0%	0%	0%	0%	2%
Network geothermal	2030	0%	0%	0%	0%	0%	0%	9%
	2045	0%	0%	0%	0%	0%	0%	6%

Table 8. Percent of stocks of zero-emission vehicles (ZEVs) in 2030 and 2045 by vehicle class

Project		GGRA	MD Buildings			BGE		
Scenario	Year	GGRA Plan	High Elec	Elec with Backup	High Decarb. Methane	Limited Gas	Hybrid	Diverse
LDA	2030	24%	N/A	N/A	N/A	29%	23%	23%
	2045	75%	N/A	N/A	N/A	95%	76%	76%
LDT	2030	7%	N/A	N/A	N/A	28%	22%	22%

	2045	61%	N/A	N/A	N/A	88%	70%	70%
MDV + HDV	2030	9%	N/A	N/A	N/A	10%	8%	7%
	2045	61%	N/A	N/A	N/A	69%	56%	49%

Table 9. Percent of new sales of ZEVs in 2030 and 2045 in transportation

Project		GGRA	MD Buildings			BGE		
Scenario	Year	GGRA Plan	High Elec	Elec with Backup	High Decarb. Methane	Limited Gas	Hybrid	Diverse
LDA	2030	64%	N/A	N/A	N/A	96%	77%	77%
	2045	88%	N/A	N/A	N/A	100%	80%	80%
LDT	2030	24%	N/A	N/A	N/A	96%	77%	77%
	2045	88%	N/A	N/A	N/A	100%	80%	80%
MDV + HDV	2030	35%	N/A	N/A	N/A	52%	42%	36%
	2045	84%	N/A	N/A	N/A	95%	76%	66%

Table 10. Energy consumed from low-carbon fuels [TBtu] in 2045

Project	GGRA	MD Buildings (buildings sector only)			BGE (economy-wide, BGE geography only)		
Scenario	GGRA Plan	High Elec	Elec with Backup	High Decarb. Methane	Limited Gas	Hybrid	Diverse
Renewable Diesel	0	N/A	N/A	N/A	0.2	15.1	14.5
Renewable Natural Gas	0	9.4	58.0	120.2	4.1	23.7	30.9
Renewable Jet Fuel	0	N/A	N/A	N/A	0	0	0
Hydrogen	0	0.7	4.4	9.0	8.8	7.0	9.2

Table 11. Natural Gas throughput in buildings [% decline vs. 2020] in 2045

Project	GGRA	MD Buildings			BGE		
Scenario	GGRA Plan	High Elec	Elec with Backup	High Decarb. Methane	Limited Gas	Hybrid	Diverse
Gas throughput	37%	93%	59%	16%	87%	74%	65%

Table 12. Electricity generation decarbonization [% zero-carbon electricity generation] in 2045

Project	GGRA	MD Buildings			BGE		
Scenario	GGRA Plan	High Elec	Elec with Backup	High Decarb. Methane	Limited Gas	Hybrid	Diverse
Share of zero-carbon electricity generation	77%[28]	100%			100%		

E3 model updates in 2022

E3 made two categories of model updates in 2022 relative to past work in Maryland: (1) updated representation of local BGE territory, and (2) updated assumptions reflective of better and more recent data.

Representation of BGE Territory

- **Downscale of GHG emissions sources to BGE geography.** E3 developed an economy-wide Pathways model of BGE's service territory by downscaling each category of the Maryland GHG inventory and benchmarking to BGE data sources.
- ***Buildings.*** BGE's service territory has approximately half of the population but more than half of current building emissions for the state. E3 used BGE consumption data to benchmark to energy usage by fuel.
- ***Industry.*** Similar to Maryland as a whole, BGE's territory has a fairly small amount of industry. Total industrial energy consumption is approximately 10% of energy consumption within BGE's territory.

[28] Calculated as % of generation coming from solar, wind, biomass, hydroelectric, and nuclear power. Excludes imported power.

- ***Transportation.*** The transportation sector within BGE's territory has similar characteristics to Maryland as a whole. Around 50% of total transportation energy consumption is assumed to occur within BGE's service territory, aligned with its share of the state's population.
- ***Electricity***. Electricity generation in Maryland is served by in-state power plants and imports from neighbors in PJM. GHG emissions from the electric sector are largely outside of BGE's control but are assumed to decline in line with the ambition from other net zero decarbonization studies.
- ***Non-Energy and Other GHGs***. Remaining GHG emissions include categories such as agriculture, wastewater, and refrigerants, which have been downscaled to BGE territory by population.
- **Alignment with BGE data on energy consumption and building types.** Residential, commercial, and industrial energy consumption for electricity and natural gas was aligned with BGE sales data for 2019. The study aligned starting stock penetration of key space heating device types with the existing space heating stock in BGE's service territory. Throughout the study, E3 considered the age and building characteristics of residential buildings within BGE's service territory. Approximately half of the residential units within BGE's territory were built before 1980, with 20% built before 1950. Around 25% of residential units are in multifamily buildings and a third are rented.
- **Renewable fuels.** In modeling a role for low-carbon fuels, E3 assumed approximately half of Maryland's renewable fuel availability would be available to BGE. For biomethane, synthetic natural gas, and pipeline hydrogen, the fraction was the ratio of BGE's pipeline gas demand (fossil natural + biomethane + synthetic natural gas + pipeline hydrogen) to MD's pipeline gas demand. Similarly for renewable diesel, the fraction was the ratio of BGE's total diesel demand (fossil diesel + renewable diesel) to MD's total diesel demand. Depending on scenario and the modeled year, this fraction was about 55% for biomethane, pipeline hydrogen, and synthetic natural gas, and about 45% for renewable diesel.

Updated model assumptions

- **More diversity in building shell options**. Only one type of deep building shell retrofit was considered in the Maryland Buildings Study, consisting of wall insulation, roof insulation, glazing, air-tightness, and heat recovery. Feedback from stakeholders in that work suggested that the deep shell retrofit modeled was expensive and assuming a binary option of deep shell retrofit or no retrofit at all was too simplistic. In this study for BGE, E3 reflected this feedback and included several options for building shells for both residential and commercial buildings. For both residential and commercial buildings, new construction standards were assumed to reduce those buildings' space heating services demands between 45%-53% (single family to multifamily homes) and 31% for commercial buildings, relative to the average building in BGE's service territory. Existing residential buildings were assumed to have an efficient shell retrofit available, which reduced their service demands by 33% for single family homes and 22% for multifamily homes relative the average residential building. Existing commercial buildings were also assumed to have an efficient shell retrofit available, which reduced their service demands by 37% relative to the average commercial building.
- **Updated commercial building electrification load shapes.** E3 updated the modeling of commercial building electrification load shapes for the BGE study from the GGRA study and the Maryland Buildings Study. The updated shapes are smoother and less "peaky", consistent with commercial heating demand profiles derived from historical gas data available through the Energy Information Administration and provided by BGE.

- **Updated perspective on availability and cost of biofuels.** Biofuels were not included as part of the GGRA Plan, but were considered for application in buildings through blend in pipelines in the Maryland Buildings Study. The Maryland Buildings Study assumed Maryland has access to the population-weighted share of national biomass feedstock in an optimistic scenario of biomass availability. The BGE study limits the biomass availability to east of the Mississippi, reflecting E3's most recent view consistent with E3's work for the Massachusetts Department of Public Utilities Docket 20-80. The BGE study includes additional biomethane sources from landfill gas and wastewater treatment plant based on the American Gas Foundation's "Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment" report. In addition, the BGE study also provided a holistic view of the use of biofuels among various sectors to provide the highest value in carbon abatement, whereas the Maryland Buildings Study only focuses on residential and commercial buildings.

Comparison of Key Findings

Though each of the three studies reviewed in this appendix had different primary objectives, we draw consistent conclusions from them.

Both economy-wide analyses (GGRA and BGE) point to the need for ambitious action across all sectors of the economy to reach deep decarbonization goals, with critical roles for electrification, efficiency, and low-carbon electricity.

The Maryland Buildings Study and BGE study found that there are multiple pathways to decarbonize buildings, but that electrification has an important role to play, especially in new construction. These studies both pointed to cost benefits in leveraging additional building space heating solutions that can lessen impacts on the electric grid, such as hybrid heat pump systems.

The Maryland Buildings Study and BGE Study found increasing electric peak demands in any scenario with building electrification and, depending on the pace and scale of electric technology deployment and level of flexibility loads, a transition to a winter peaking system in the 2020s or early 2030s.

The BGE study explored the potential for emerging technologies such as network geothermal and gas heat pumps to be part of the solution, and found that if they can reach scale they can also be part of a cost-effective building decarbonization solution.

The Maryland Buildings Study and BGE study also found that in order to achieve net zero by 2045, technology deployment and policy ambition will need to go beyond the levels explored in the 2021 GGRA scenario planning exercise.

Appendix B: Model Methodology