Maryland Building Decarbonization Study

Early Results Presentation with

Buildings Ad-hoc Group

July 13th, 2021

Energy+Environmental Economics

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Today's Presentation

- E3 is tasked by MDE and MCCC to conduct an analysis looking at **potential pathways to decarbonize Maryland's building stock by mid-century**
- **In May**, E3 held a workshop with the Buildings Ad-hoc group to solicit feedback on **the three scenarios for a deep-dive analysis**
- **Since the workshop**, E3 has been working with MDE, US Climate Alliance and TNC on **finalizing scenario design and input assumptions**, and has completed a **preliminary analysis** of the three scenarios
- **Today's presentation** focuses on **EARLY and PRELMINARY results** from E3's analysis on the three scenarios
- **Questions for today's discussion:**
  - What feedback and suggestion does this group have for E3 based on these early results?
  - Does this group feel comfortable with E3 presenting these results to the MWG on 7/20 with minor updates based on feedback from today?
  - If so, what messages does this group want to bring to MWG based on findings from today's presentation?

Content of E3's Presentation

- Part I. Overview and key findings – Charles Li
- Part II. Energy consumption – John de Villier
- Part III. Electric system peak impact – Michaela Levine
- Part IV. System cost and rate impact – Charles Li
- (Given time) Part V. Consumer economics – Jared Landsman
- Conclusion

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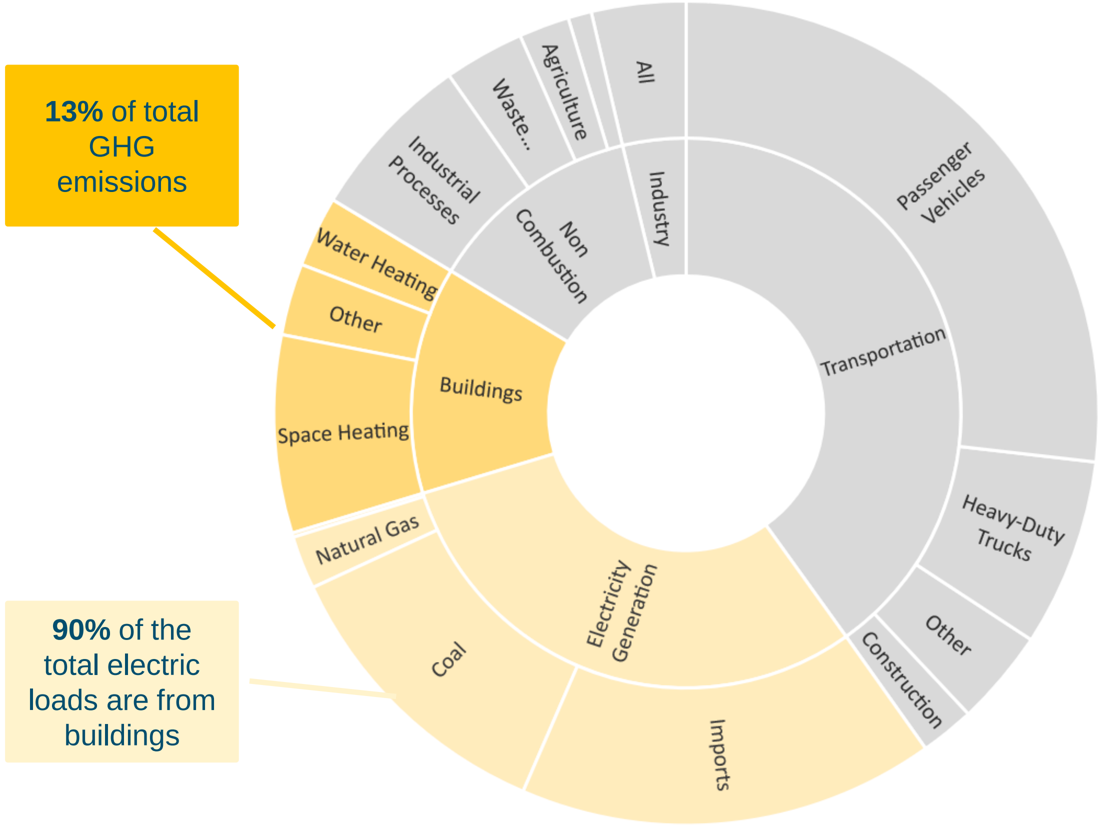
Overview and key findings

Project objective: a Maryland-specific pathway to achieve deep decarbonization of building end-uses by mid-century

- **Based on the most recent Maryland GHG Inventory for 2017, building direct-use emissions account for 13% of economywide GHG emissions in Maryland**
  - 80% of direct building emissions are from space heating and water heating
- **90% of the statewide electric load are from buildings, which contribute to upstream emissions in electricity generation**
  - Currently, electricity generation accounts for 30% of total GHG emissions, but will decrease as clean and renewable energy becomes a larger share
- **Key questions of this project:**
  - What are the potential pathways to achieve deep decarbonization of Maryland's building stock by mid-century?
  - What are the costs and benefits of each pathway from a total system cost perspective, as well as impacts on consumers?

MD 2017 Gross GHG Emissions by Sector and Subsector



This study investigates opportunities for building decarbonization through 3 scenarios

+ E3 and MDE held a 4-hour workshop with the Buildings Ad-hoc Group, where we received feedback and input from stakeholders on scenario design that informed the selection of the following scenarios

Reference	High Electrification	Electrification with Gas Back Up	High Decarbonized Methane
+ Same as the Reference scenario in the GGRA analysis reflecting current policies + Buildings keep using existing devices with no electrification and little efficiency improvement + Building energy demand grows at 0.6%/yr, same as EIA's projected annual growth rate of Maryland households	+ Almost all buildings switch to ASHPs and GSHPs. Heating is supplied by electricity throughout the entire year + High efficiency through building retrofits	+ Existing buildings keep using fuels for heating and are supplied with a heat pump combined with existing furnace/boiler that serves as back up in the coldest hours of the year + All-electric for new construction	+ Buildings keep using fuels for heating while fossil fuels are gradually replaced by low-carbon renewable fuels. Some features: • RNG supplied by biomethane and synthetic natural gas • 7% hydrogen blend • High efficiency through building retrofits

3 steps to analyze the impacts of building decarbonization scenarios

3 selected scenarios

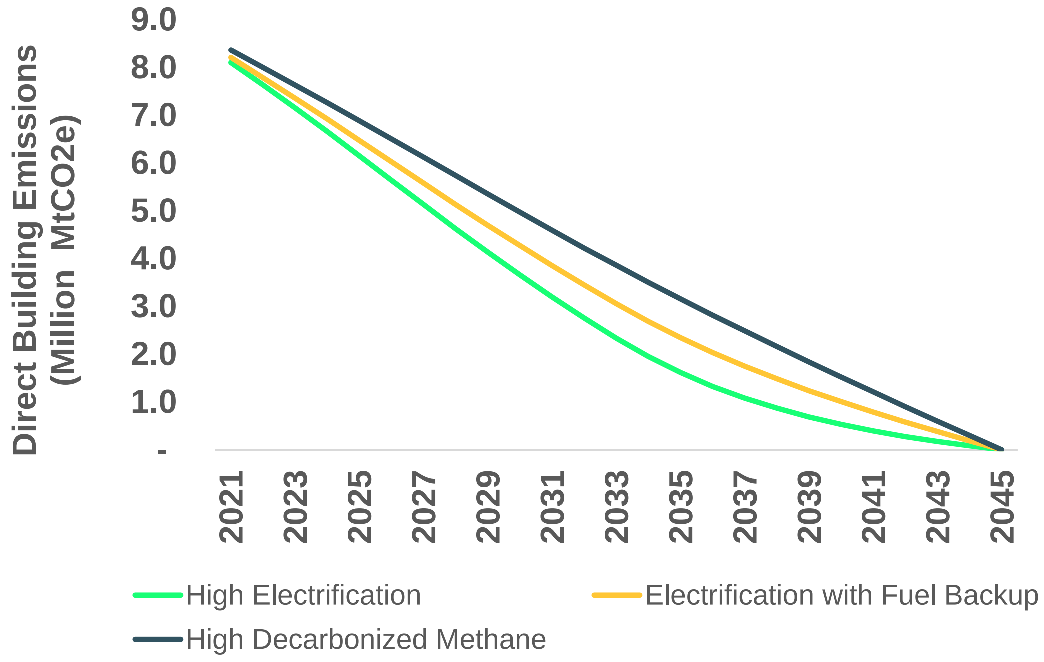
- **Scenario Specification** — Development of decarbonization scenarios, heating equipment costs and renewable fuel supply curve
- **Assess Energy System Impacts and Cost Implications** — Analysis of incremental equipment costs, electric system costs and fuel costs.
- **Electric and Gas Rate Impacts** — Development of electric and gas revenue requirement models to estimate rate impacts

Overview of technical and economic implications

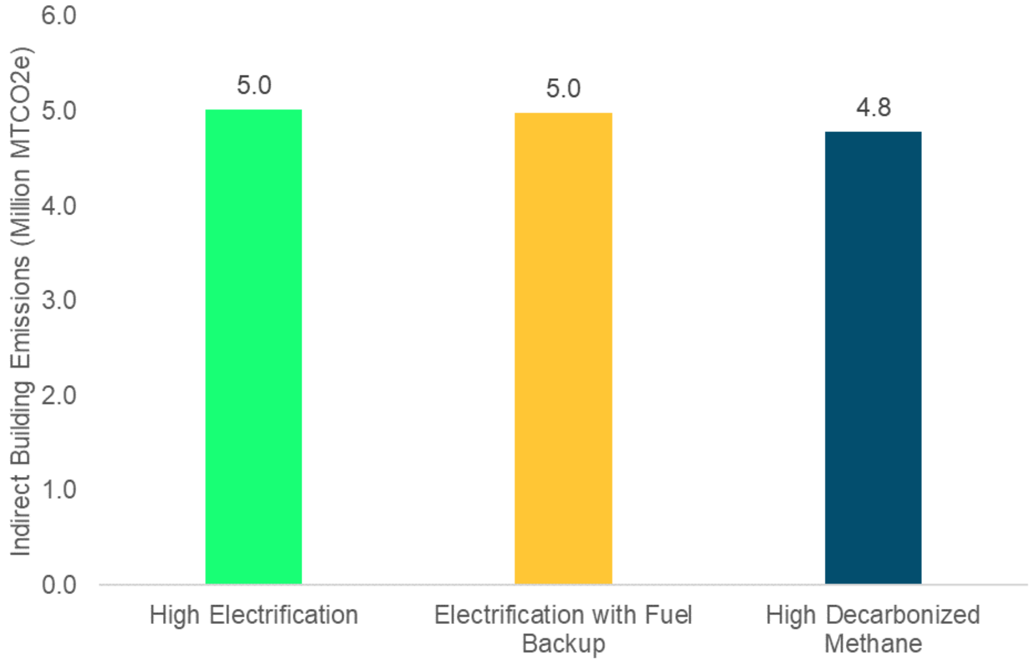
All scenarios achieve zero direct building emissions by 2045

+ **All scenarios achieve zero direct building emissions by 2045 through electrification, efficiency improvement and use of low-carbon fuels**
  - This is consistent with the MCCC-recommended economy-wide target of carbon neutrality by 2045
+ **Indirect emissions from upstream electricity generation still remain by 2045**
  - Using GGRA assumptions that by 2045 all in-state generations are carbon-free but there are still GHG emissions associated with PJM imports

Direct building GHG emissions trajectory (MMtCO2e per year)



Indirect building GHG emissions from upstream electricity generation in 2045 (MMt CO2e per year)



Summary of key findings

Reducing direct building emissions to zero is feasible in all scenarios, but requires technology commercialization and accelerated implementation.

High Decarbonized Methane requires large quantities of zero-carbon fuels, resulting in high incremental fuel costs with significant cost uncertainty

Level of fuel commodity cost increase is highly uncertain and dependent on the availability of and competition for biomass, as well as learning rates of hydrogen and Synthetic Natural Gas (SNG).

High Electrification causes a Summer to Winter peak-shift and significant increase in peak electricity demand, resulting in high incremental electricity system costs

Switch to heat pumps from electric resistance heating, which is currently used in about 25% of Maryland households, has a much smaller impact on reducing peak demand than total load.

Electrification with Fuel Backup has 80% less electricity system cost increase compared to the High Electrification scenario and shows lowest overall resource costs compared to the other scenarios.

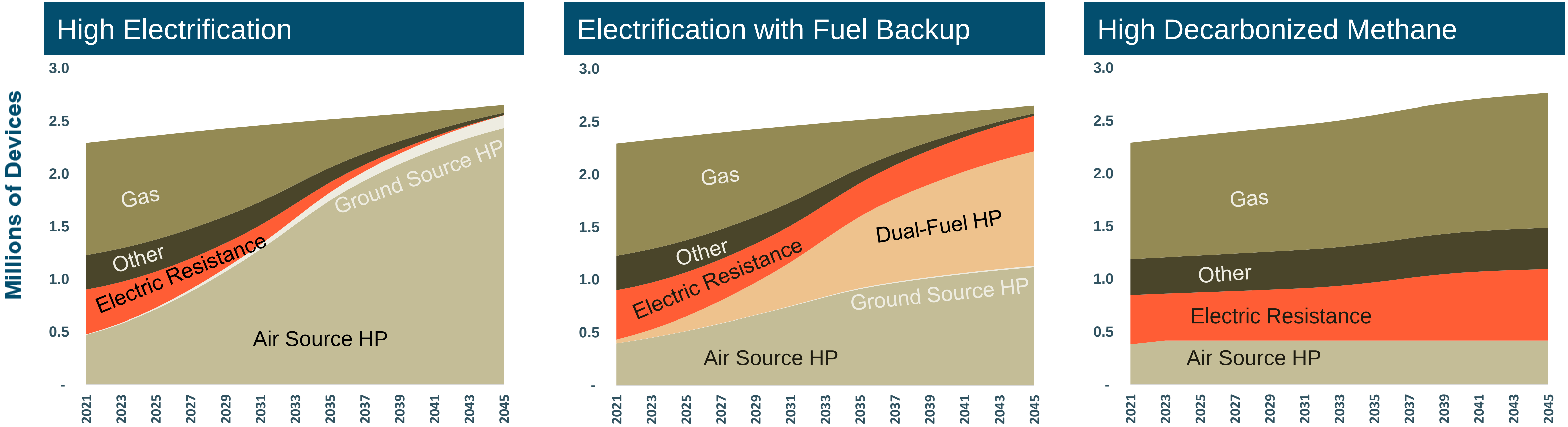
At the same time, this scenario is more resilient to variance in fuel costs and equipment costs and therefore shows benefits in risk mitigation compared to the other two scenarios.

Costs of fuels increase in all scenarios as a result of zero-carbon fuels and higher delivery costs (due to lower consumption levels); emphasis on mitigating the energy burden with customers 'staying behind' is important.

Energy consumption

Space heating end-uses are mostly electrified by 2045 in the two electrification scenarios

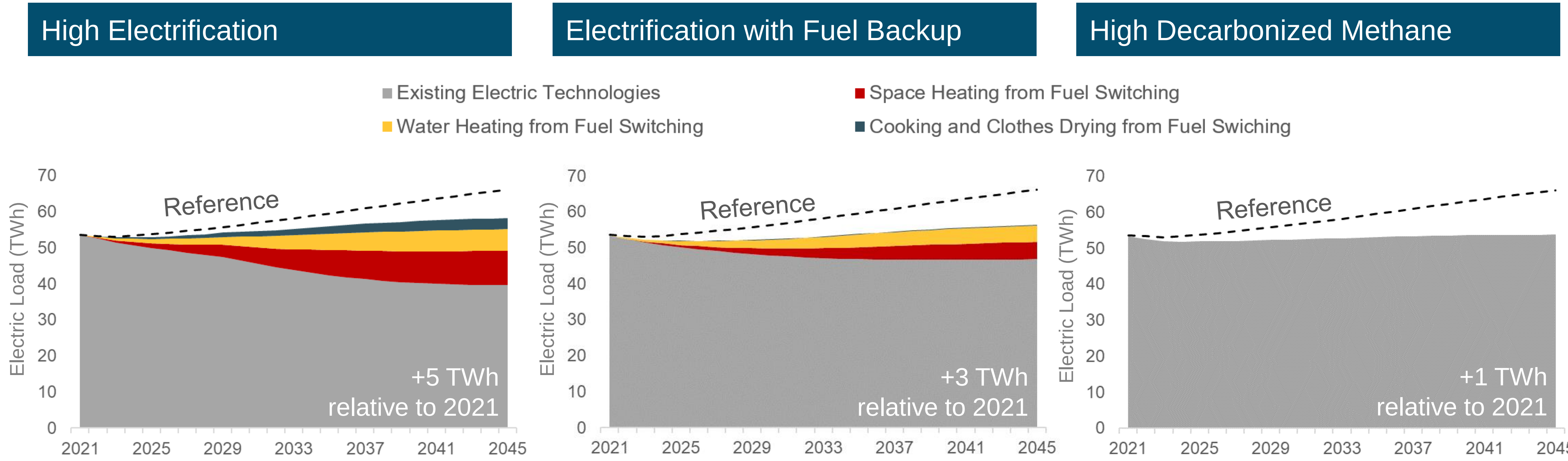
+ **Heat pumps become the major space heating equipment in the High Electrification scenario**
+ **Dual-fuel heat pumps are added to most retrofit buildings in the Electrification with Fuel Backup scenario, pairing with existing fuel-based systems**
+ **Electric resistance currently accounts for about 20% of space heating devices**
  - Phase-out of the current EMPOWER program flattens Air Source HP adoption after 2023 with no further incentives for existing electric resistance customer to switch to HPs in High Decarbonized Methane and Electrification with Fuel Backup scenarios



* "Other" space heating devices mainly include fuel oil and LPG-based furnaces and boilers

Electricity demand in all scenarios are lower than Reference due to energy efficiency gains

+ **Electricity demand increases in all scenarios due to growth in households**
  - **High Electrification** scenario has the highest load growth among the three scenarios due to new space heating, water heating and other loads as a result of fuel switching
+ **Compared to Reference, all scenarios have lower electricity demand due to energy efficiency gains**
  - **High Electrification** scenario also has the largest reduction in existing loads due to higher levels of efficiency from building shell improvement and efficient electric device adoption

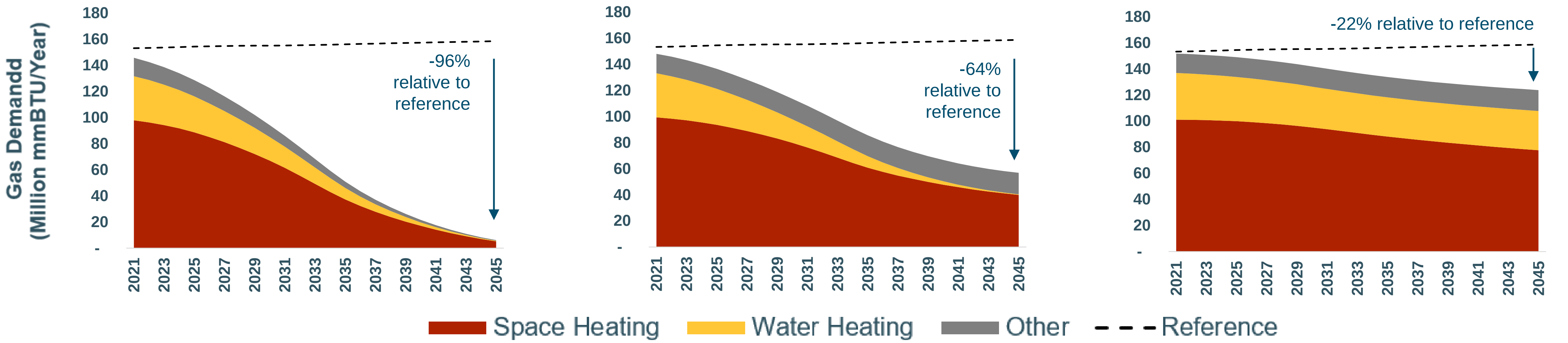


Early Results and Preliminary

Natural gas demand declines in all scenarios due to energy efficiency gains and fuel switching offsetting growth

+ **Natural gas use in buildings is expected to decline in all scenarios due to energy efficiency gains offsetting growth in households, and this decline is accelerated in scenarios with significant building electrification**
  - **High Electrification** reduces gas demand by 96% by 2045 due to aggressive electrification of all building end-uses
  - **Electrification with Fuel Backup scenario** has lower reduction in gas demand by 2045 at 62%, as most customers adopt dual-fuel heat pumps that use gas with gas as a backup heating source during coldest hours of the year
  - **High Decarbonized Methane** scenario results in a 19% reduction in gas demand by 2045 due to efficient gas appliance adoption and building shell improvements

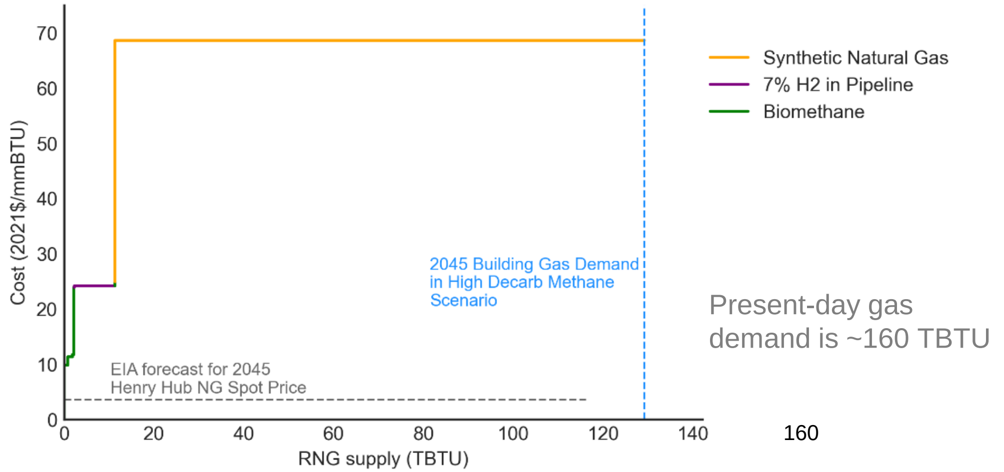
High Electrification | Electrification with Fuel Backup | High Decarbonized Methane



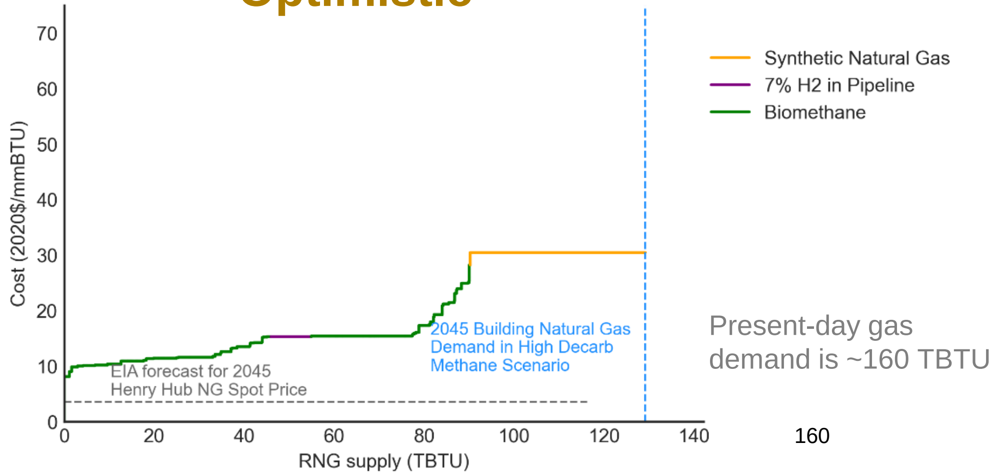
The E3 Biofuels Module models two bookends for RNG Supply

- **RNG Supply Curve assumptions are developed using E3 biofuels optimization module, which determines the most cost-effective way to convert biomass into biofuel across all sectors.**
- **Conservative and Optimistic scenarios modeled here represent two bookends for the supply of RNG towards 2045**
  - **Conservative** scenario has heavy reliance on Synthetic Natural Gas (SNG); it assumes
    - MD only gets access in-state feedstocks
    - ALL cellulosic feedstocks would be more cost-effectively used to produce liquid fuels - such as renewable diesel or jet fuel (due to higher prices and carbon intensities for these fuels)
  - **Optimistic** scenario has moderate reliance on SNG; it assumes
    - MD gets access to its population weighted-share of national feedstocks
    - NO competition for renewable liquid fuels, meaning all biomass feedstocks would be available for RNG production

Conservative



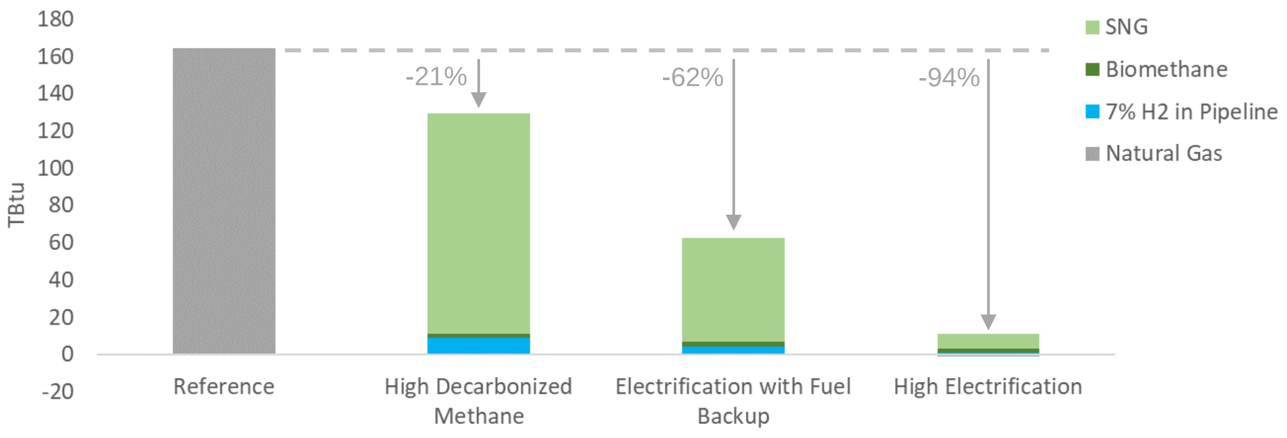
Optimistic



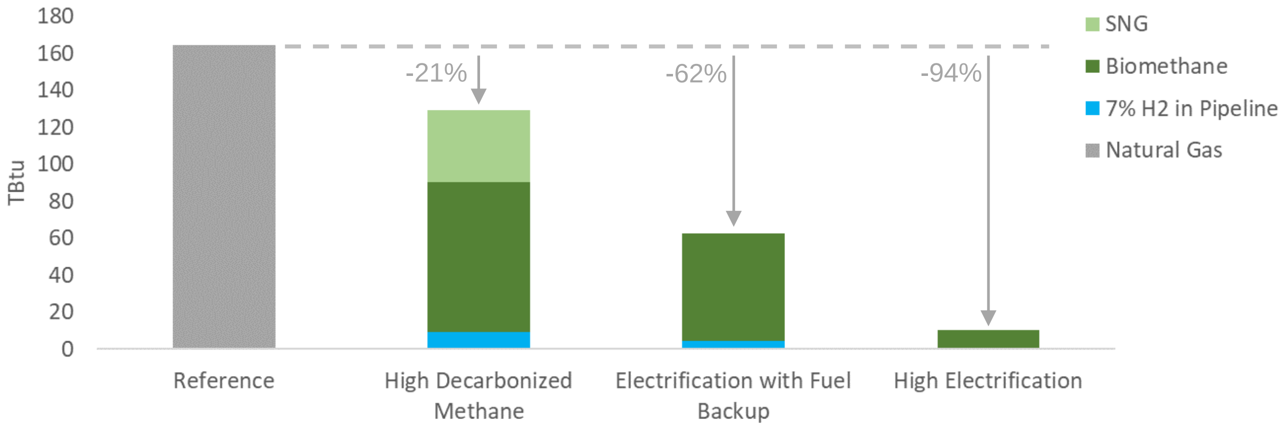
Sources & assumptions: Biomass supply assumptions are developed from the 2016 Billion Ton Report (DOE, 2016), with supplemental landfill gas assumptions from the Renewable Sources of Natural Gas report (American Gas Foundation, 2019). The conservative scenario assumes SNG is produced with CO_2 from Direct Air Capture (DAC), the optimistic scenario assumes SNG is produced using waste bio-CO2 from biofuels. The 7% hydrogen blend is as a percentage of energy content. More background on cost assumptions are included in the Appendix.

Gas composition transitions to RNG

Gas commodity blend in 2045 (Conservative)



Gas commodity blend in 2045 (Optimistic)



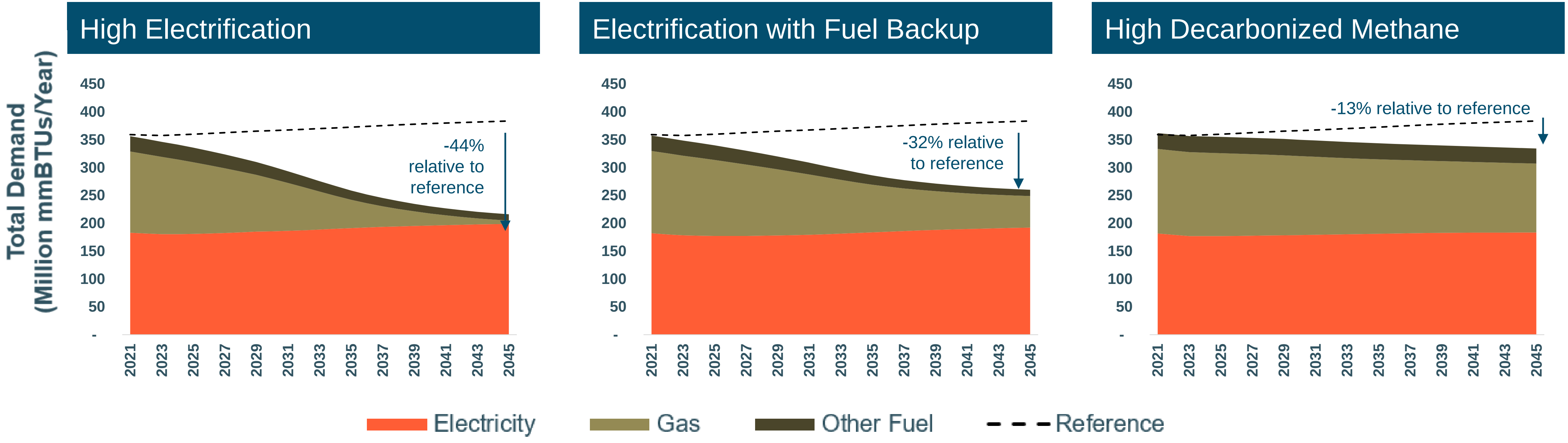
+ **By 2045, all building scenarios have 100% blend of RNG in the remaining gas demand**
  - This helps all scenarios reach zero direct building emissions target by 2045
  - Hydrogen blend in pipeline is assumed in all scenarios where it makes economic sense, up to 7% in energy content (20% in volume) which is the maximum current natural gas pipelines can take without significant modification
+ **In a conservative RNG scenario where biomass supply is limited, SNG is the main source of low-carbon gas in all scenarios**

  In an optimistic RNG scenario where biomass supply is relatively abundant, biomethane becomes the main source of low-carbon gas
  - The High Electrification and Electrification with Fuel Backup scenarios do not need SNG due to their low gas demand

All scenarios reduce total energy demand

+ Overall energy demand decreases through 2045 in all scenarios

- Deep electrification almost eliminates gas demand by 2045 under the High Electrification Scenario
- Gas demand decreases ~62% in the fuel backup scenario due to adoption of dual-fuel heat pumps, while overall energy demand falls 32%
- Efficiency gains from building shell improvements and efficient appliance adoption reduce overall demand by 13% in the High Decarbonized Methane Scenario



* Year 2021 will not perfectly match reference because electrification/efficiency adoption begins in model year 2017

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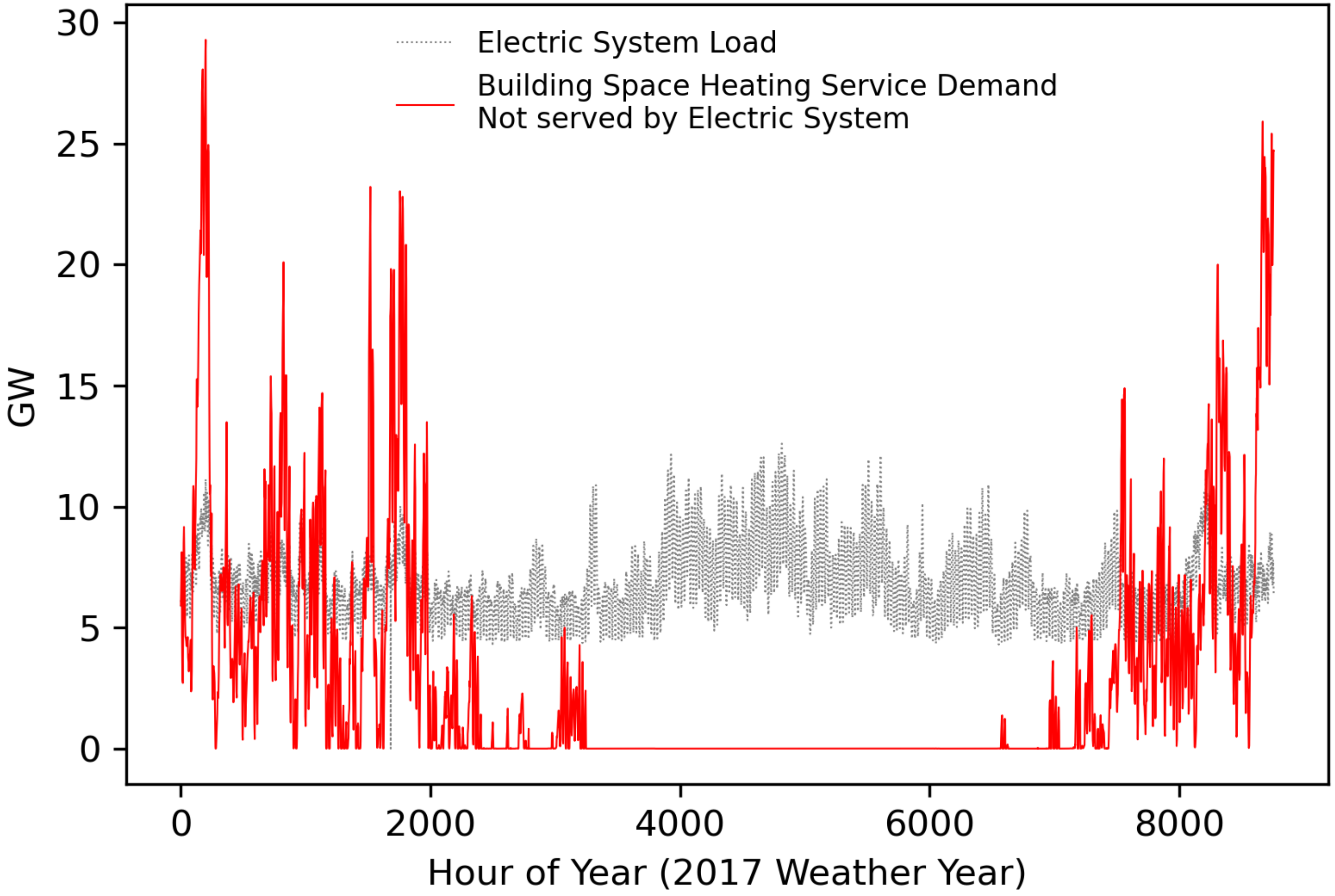
Electric system peak impacts

Maryland's current electric system peaks in summer



Electric system summer peak in 2017 was approximate 12.6 GW and the winter peak was approximately 11.1 GW.

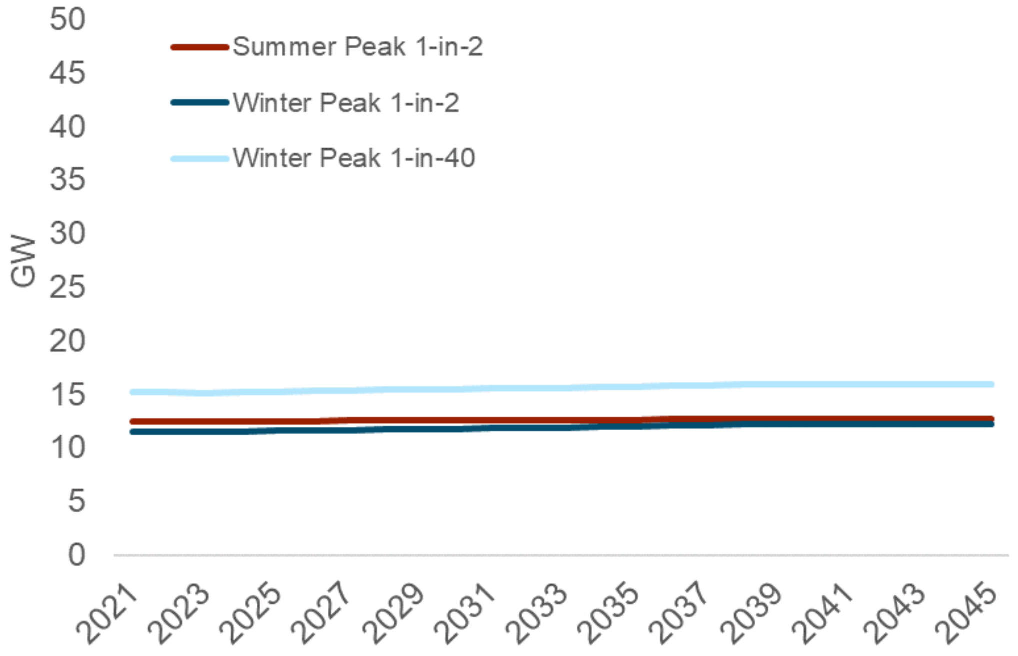
- **Currently, Maryland's electricity system experiences peak load in summer months**
  - Load peaks at around 13 GW, mainly as a result of residential and commercial air conditioning
- **Maryland's *building heat load,* however, currently mainly supplied by gas, shows a large peak in winter as a result of the state's cold winter climate**
  - Building heat loads represent *service demand* of both space and water heating, i.e. total heating load if all supplied by electric resistance
  - Moving the thermal load from gas to electric will result in a significant increase in electric peak in winter

Sources & assumptions: Building thermal load is based on PATHWAYS total space and water heating service. Shape of the thermal load is calculated using E3's RESHAPE model. Note that the chart shows imputed system load for November and December as a result of data gaps.

Maryland is expected to have little peak load growth in the High Decarbonized Methane scenario

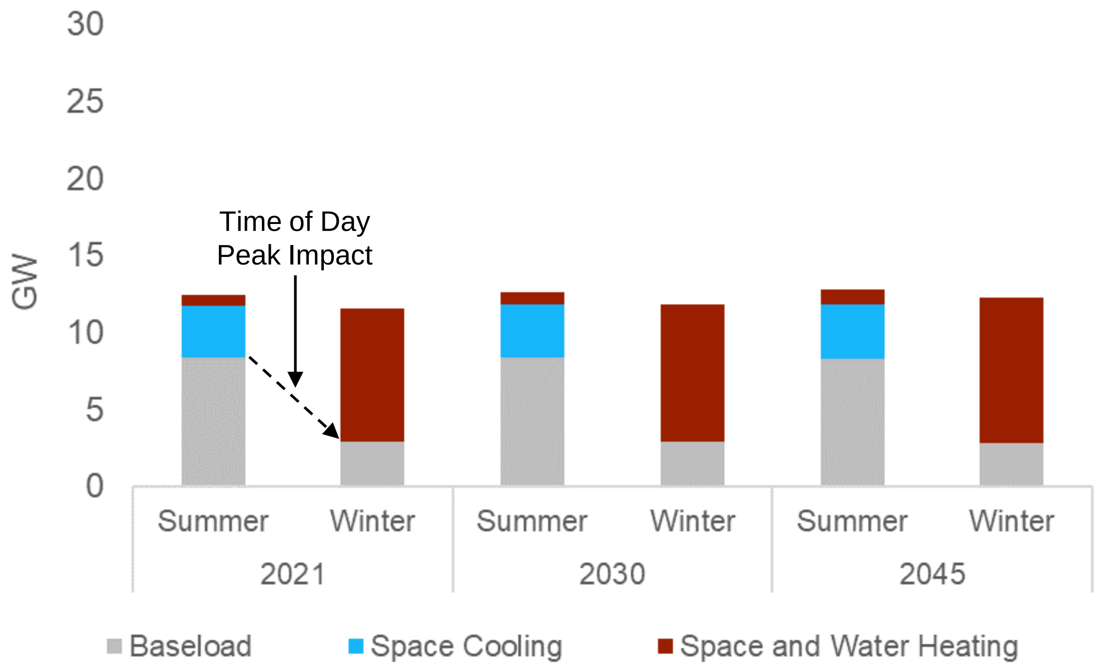
+ **In the High Decarbonized Methane scenario, the small peak load growth is due to growth of households and economy.**

Peak Load Projection 2021-2050
High Decarbonized Methane



*In 2045, the 1-in-10 and 1-in-40 summer peak is 0.6 and 0.7 GW higher than the 1-in-2 peak, respectively.

Contribution to 1-in-2 System Peak by Sector
High Decarbonized Methane

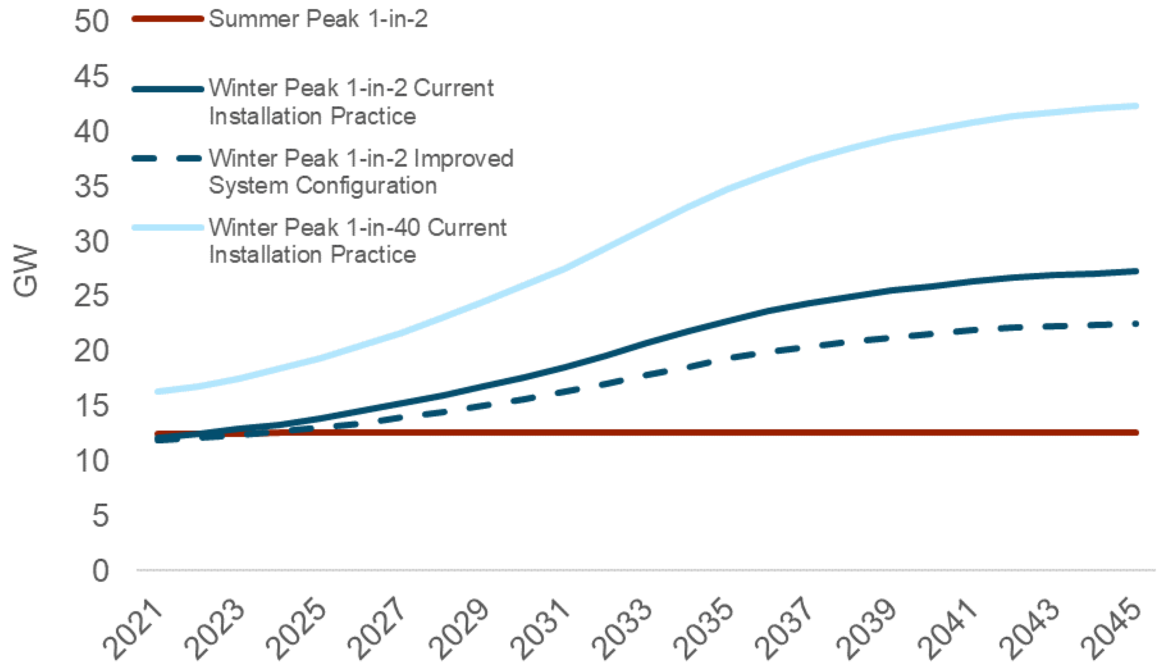


Sources & assumptions: Coincident peak load is based on a modeled hourly load for MD. The projected hourly load is calculated using incremental load in 2050 modeled from PATHWAYS and end-use shapes from RESHAPE based on 2017 weather added to the 2017 historical load.

Winter peak load is expected to grow by 15 GW by 2045 in the High Electrification scenario

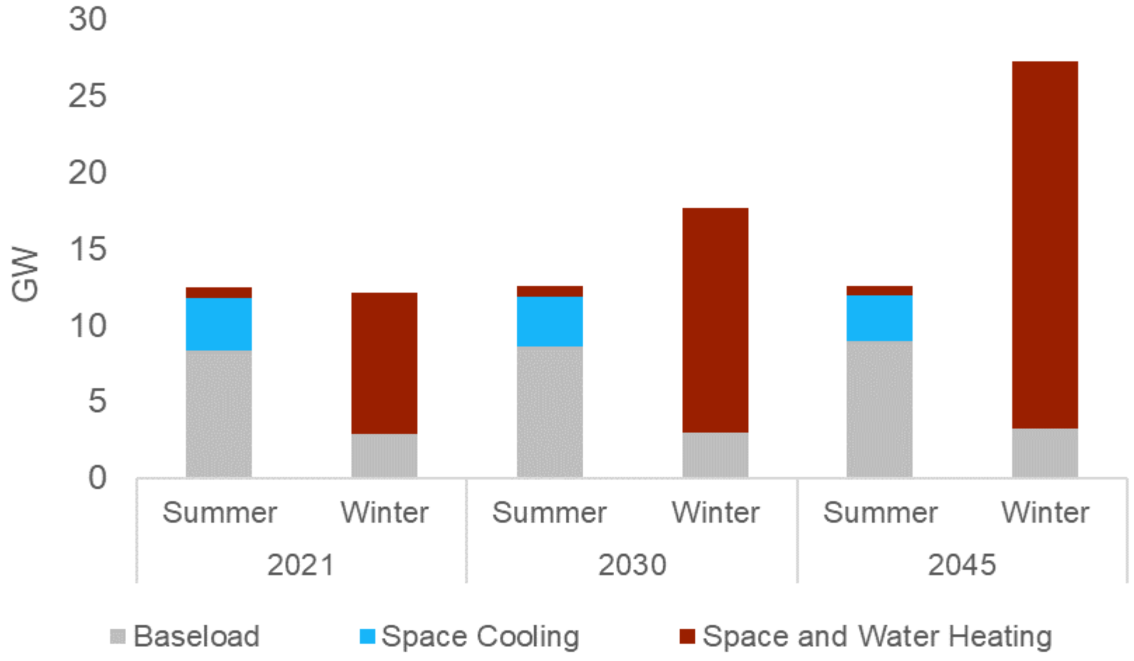
+ **In the High Electrification scenario, Maryland's electricity system is expected to become winter peaking in the near future, and will more than double the current system peak by 2045**
  - Switching to heat pumps from electric resistance heating, which is currently used in about 25% of Maryland households, has a much smaller impact on peak heating load than on annual total heating loads

Peak Load Projection 2021-2045
High Electrification



*In 2045, the 1-in-10 and 1-in-40 summer peak is 0.5 GW higher than the 1-in-2 peak

Contribution to 1-in-2 System Peak by Sector
High Electrification – Current Installation Practice

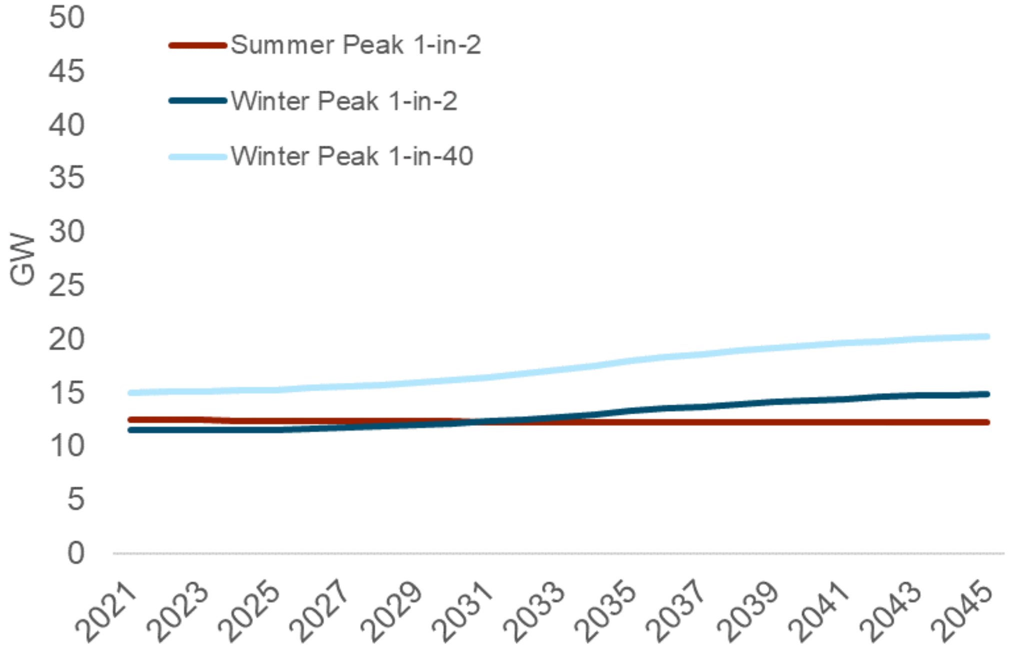


Sources & assumptions: Coincident peak load is based on a modeled hourly load for MD. The projected hourly load is calculated using incremental load in 2050 modeled from PATHWAYS and end-use shapes from RESHAPE based on 2017 weather added to the 2017 historical load.

Electrification with Fuel Backup scenario has much smaller winter peak load growth

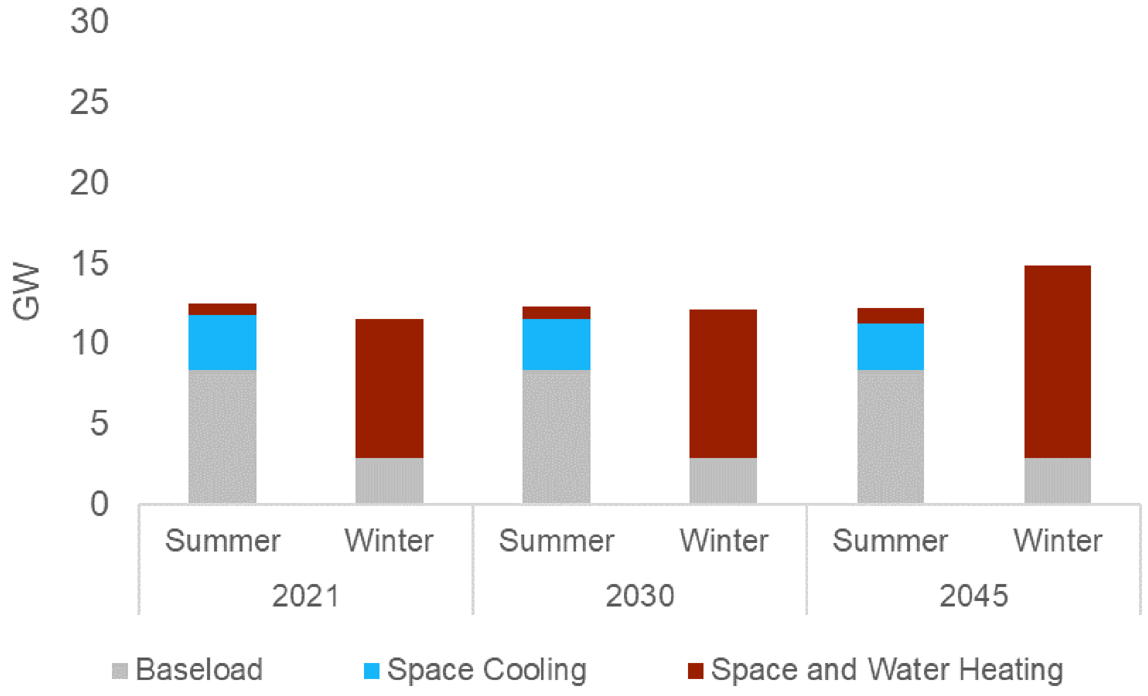
- Compared to the High Electrification scenario, Maryland's electricity system becomes winter peaking about a decade later
- Peak load will be 2 GW higher by 2045 than the current system peak

Peak Load Projection 2021-2045
Electrification with Fuel Backup



*In 2045, the 1-in-10 and 1-in-40 summer peak is 0.5 GW higher than the 1-in-2 peak

Contribution to 1-in-2 System Peak by Sector
Electrification with Fuel Backup



Sources & assumptions: Coincident peak load is based on a modeled hourly load for MD. The projected hourly load is calculated using incremental load in 2050 modeled from PATHWAYS and end-use shapes from RESHAPE based on 2017 weather added to the 2017 historical load.

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System Cost Impact

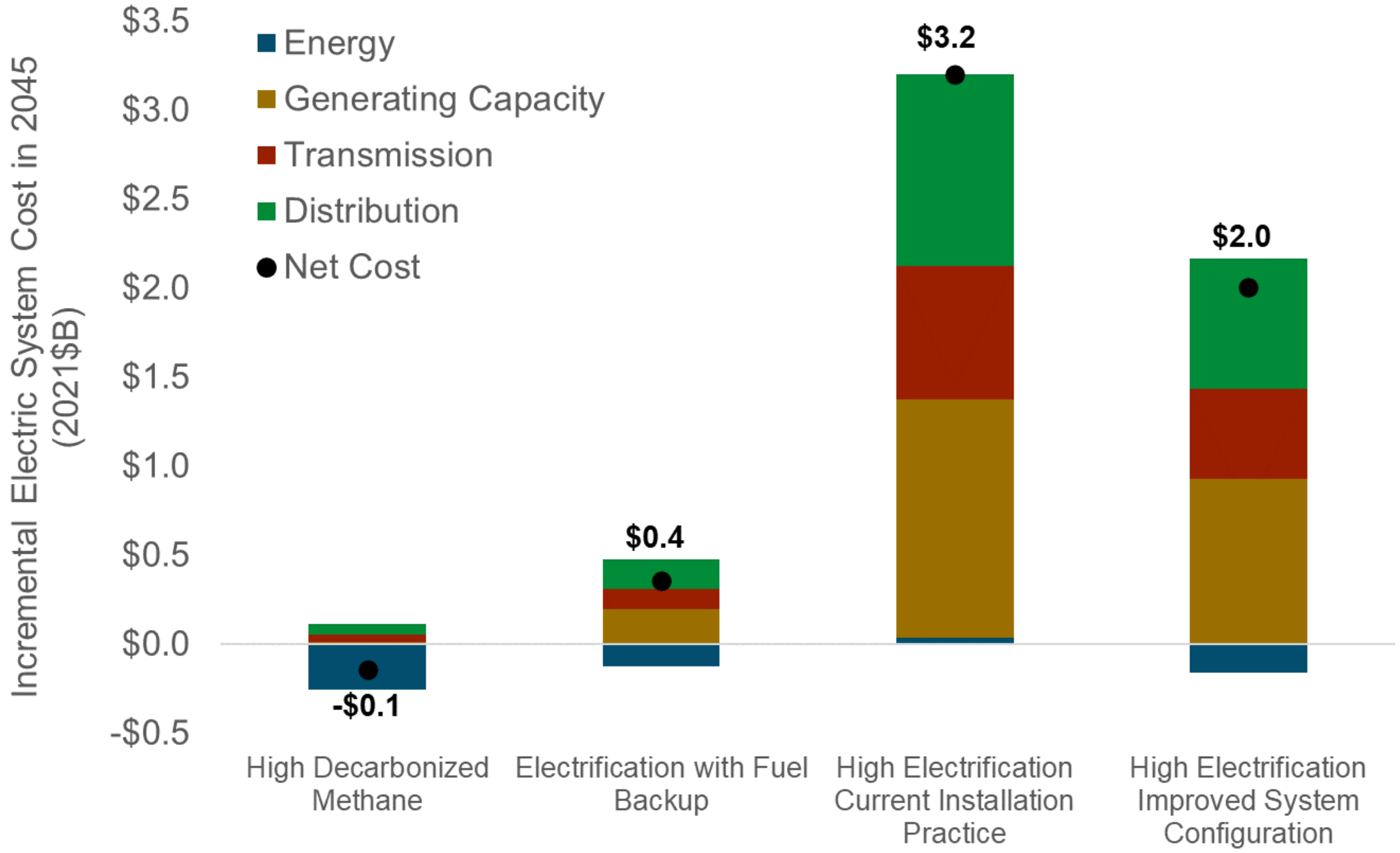
Approach for system cost impact analysis

- The following four cost components are considered in the system cost impact analysis
- System costs of the three main scenarios are calculated as incremental to Reference

Electric System	Gas System	Equipment	Other Fuels
❑ Investment in additional transmission and distribution infrastructure ❑ Investment in additional generating capacity to meet the peak electric demand ❑ Generation cost to meet the additional electricity demand	❑ Capital expenditure for reinvestment in the gas system ❑ Operating costs to maintain the gas system ❑ Gas commodity costs for RNG to replace natural gas	❑ Investment in efficient or electric appliances relative to a reference appliance ❑ Investment in building shell improvement	❑ Fuel commodity costs for bio-based liquid fuels to replace fossil fuels, mainly bio-diesel replacing fossil-based heating oil

Meeting electric loads in the High Electrification scenario requires around $2-3 billion of annual incremental system costs

Annual Incremental Electric System Costs relative to Reference in 2045 (2021$ Billions per year)

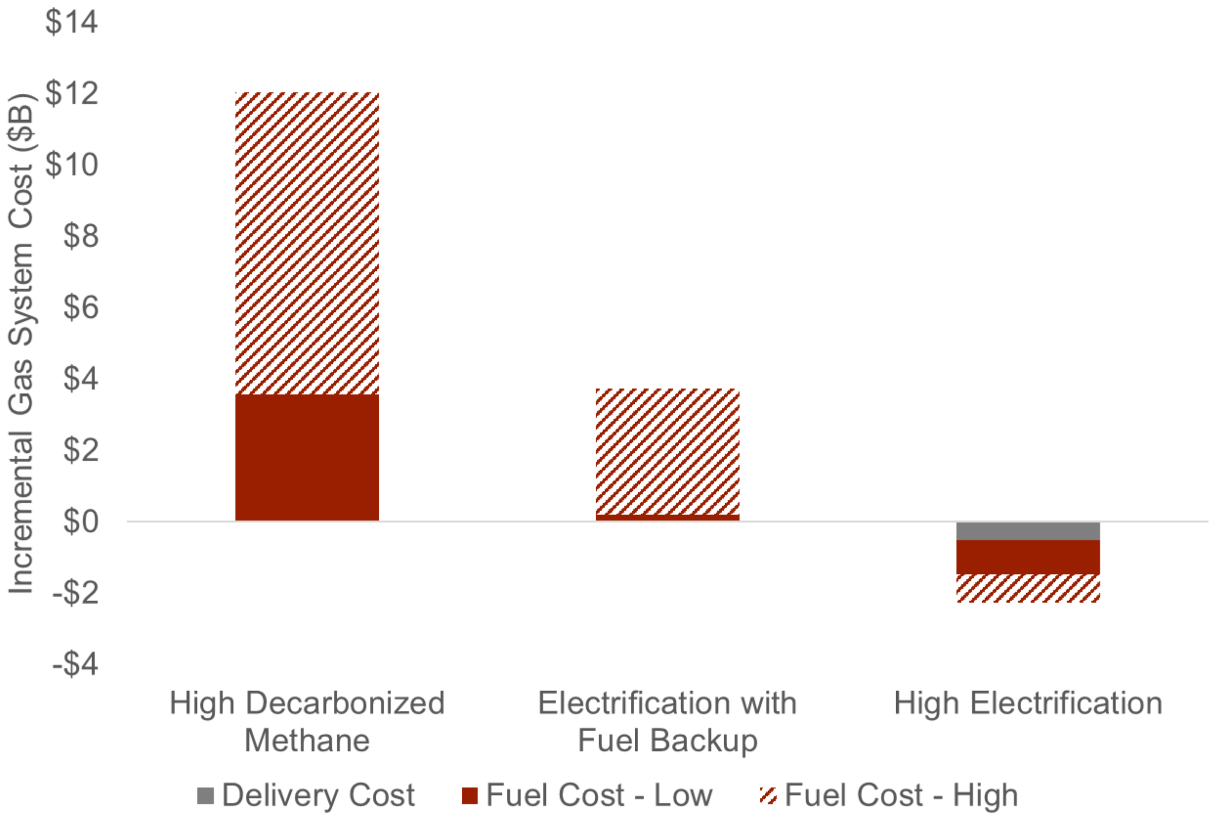


- **High levels of electrification significantly increase electricity system costs, mainly for meeting peak capacity needs.**
  - Improving system installation practices would result in less increase in electric system costs, only ~60% of that in the High Electrification scenario
- **Pairing ASHPs with fuel systems can save more than 80% of the incremental costs, mainly by avoiding T&D infrastructure and generating capacities**
  - System costs in the Electrification with Fuel Back Up scenario are $0.4 billion in 2045 compared to $3.2 billion for the High Electrification scenario

Sources & assumptions: Details of the electric sector cost assumptions are documented in the Appendix

Gas system cost in all scenarios show wide ranges because of the large uncertainty associated with RNG commodity costs

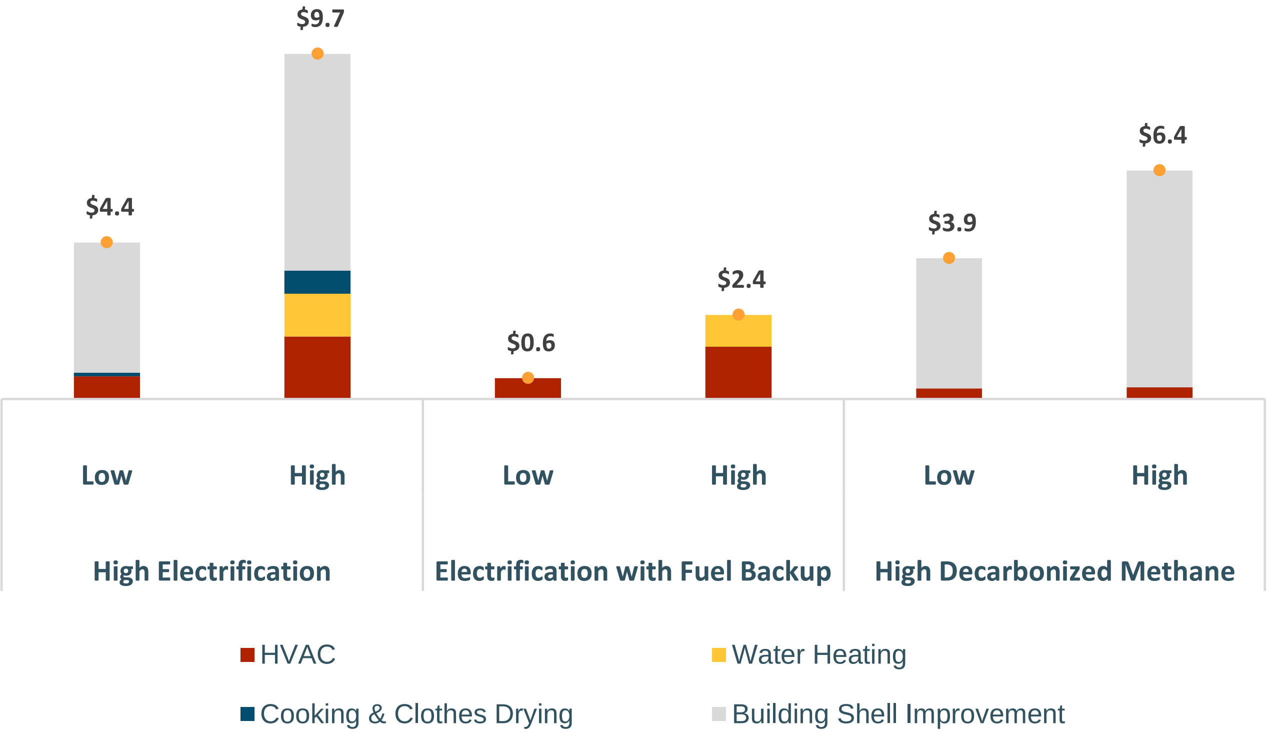
Annual Incremental Gas System Costs relative to Reference in 2045 ($2021 Billions per year)



- **High Decarbonized Methane** scenario has the biggest range of incremental system costs due to its high gas demand
  - Meeting all gas demand with RNG in the High Decarb Methane scenario can increase the annual gas system cost by up to $12B
- Reduced throughput in the **Electrification with Fuel Backup** scenario results in much lower system costs and less wide cost ranges
  - The blend of RNG results in higher gas commodity costs and overall gas system costs relative to Reference even though throughput is less
- **High Electrification** scenario has lower gas system costs relative to Reference due to both lower gas demand and lower infrastructure costs
  - We assume that reduced peak gas throughput in this scenario would require less capital reinvestment and O&M to maintain the gas system

The two book-end scenarios have relatively high incremental equipment costs due to building shell improvement

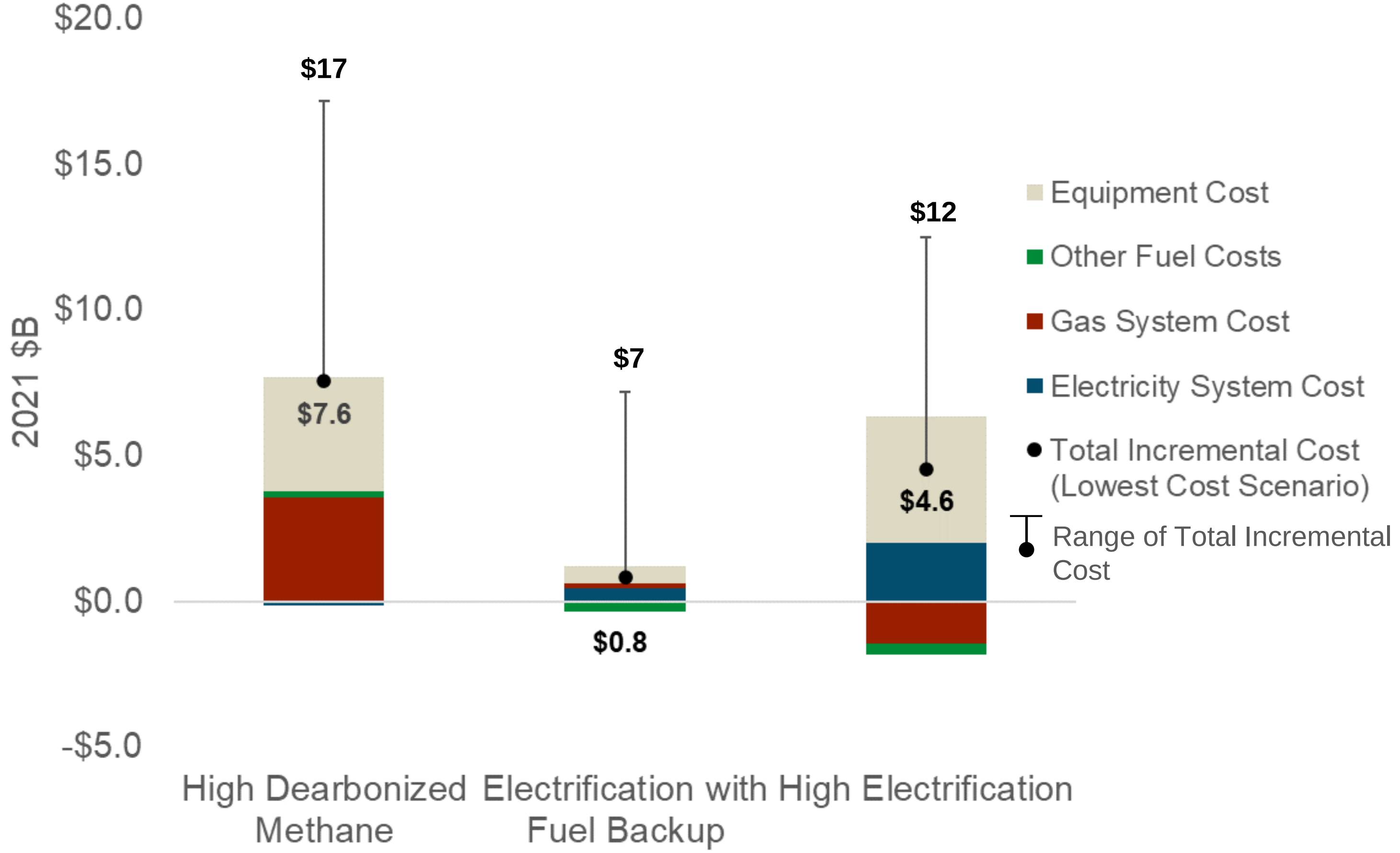
Levelized Total Incremental Equipment Costs in 2045 ($2021 Billions per year)



+ **High and low equipment cost profiles creates uncertainty around future costs in the two book-end scenarios**
  - Building shell upgrades account for the majority of equipment costs
  - Current costs are based on deep shell retrofits that include energy efficiency and heat recovery, and are highly uncertain and location-specific
+ **Electrification with Fuel Backup is the lowest-cost scenario because it does not include building shell improvement**

Electrification with Fuel Backup scenario is expected to be the relatively low-cost and low-risk path among the three scenarios

Incremental Total Resource Costs for Buildings (2045) ($2021 Billions per year)



Total cost range reflects assumptions regarding fuel costs, equipment cost, and heat pump installation practices

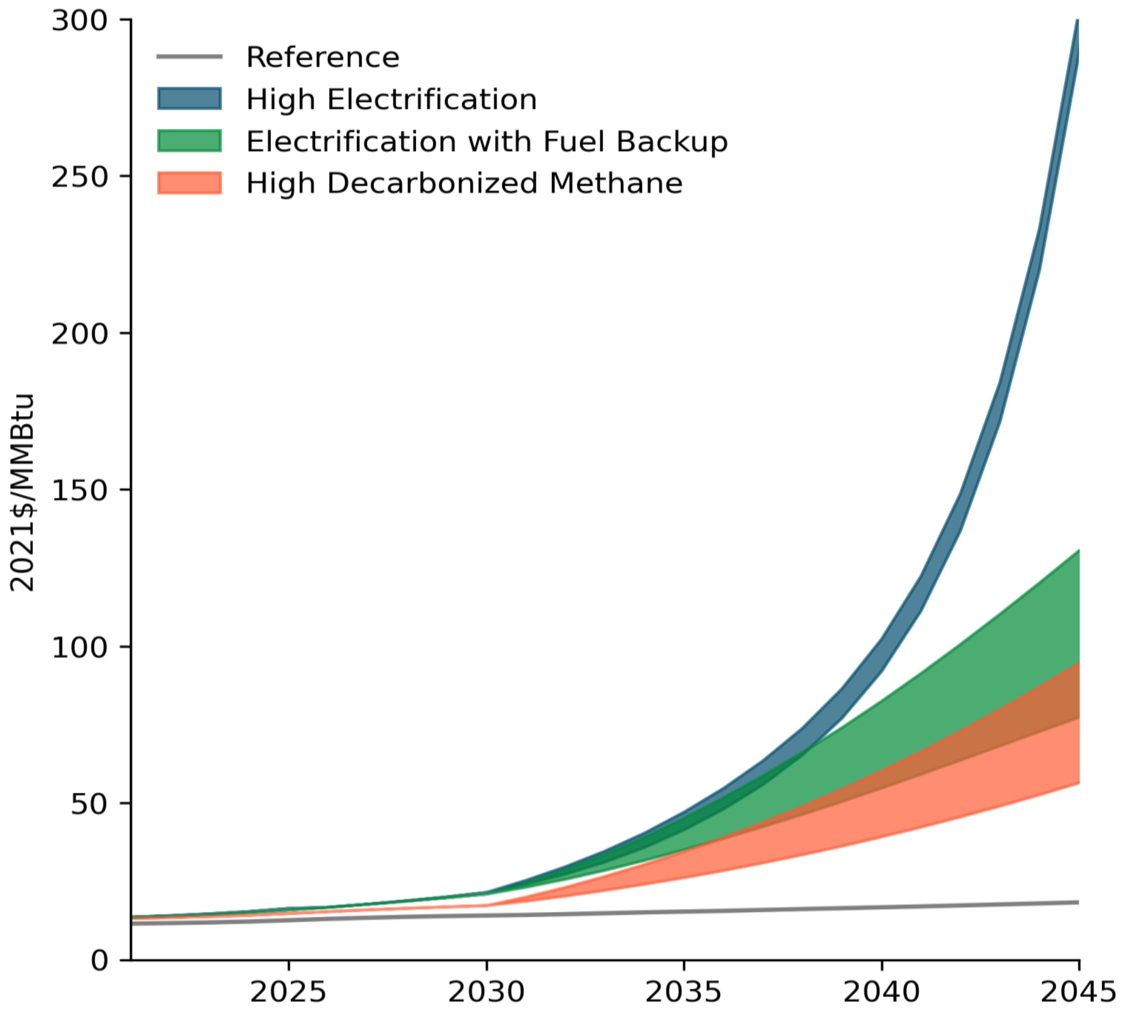
Sources & assumptions: These charts show incremental resource costs of the scenarios compared to the reference scenario.

+ **Building sector costs show large variation across scenarios depending on:**
  - Gas fuel costs (optimistic/conservative supply curve)
  - Equipment costs (mainly building shell upgrade costs)
  - Installation practice for electric heating systems
+ **A hybrid scenario could potentially "hedge" for this uncertainty given its lower overall costs and narrow cost ranges**

Gas and Electric Rate Impact

Gas rates increase significantly across all scenarios

Residential gas rates (2021$/MMBtu)



- **High Electrification scenario** experiences a rapid rate increase driven by declining throughput despite lower total delivery and commodity costs
- Rate increases in the **High Decarbonized Methane scenario** are driven primarily by the commodity cost for zero carbon fuel
- **Electrification with Fuel Backup scenario** has higher gas rates than the High Decarbonized Methane scenario, due to its lower throughput and the resulting higher per MMBtu delivery cost

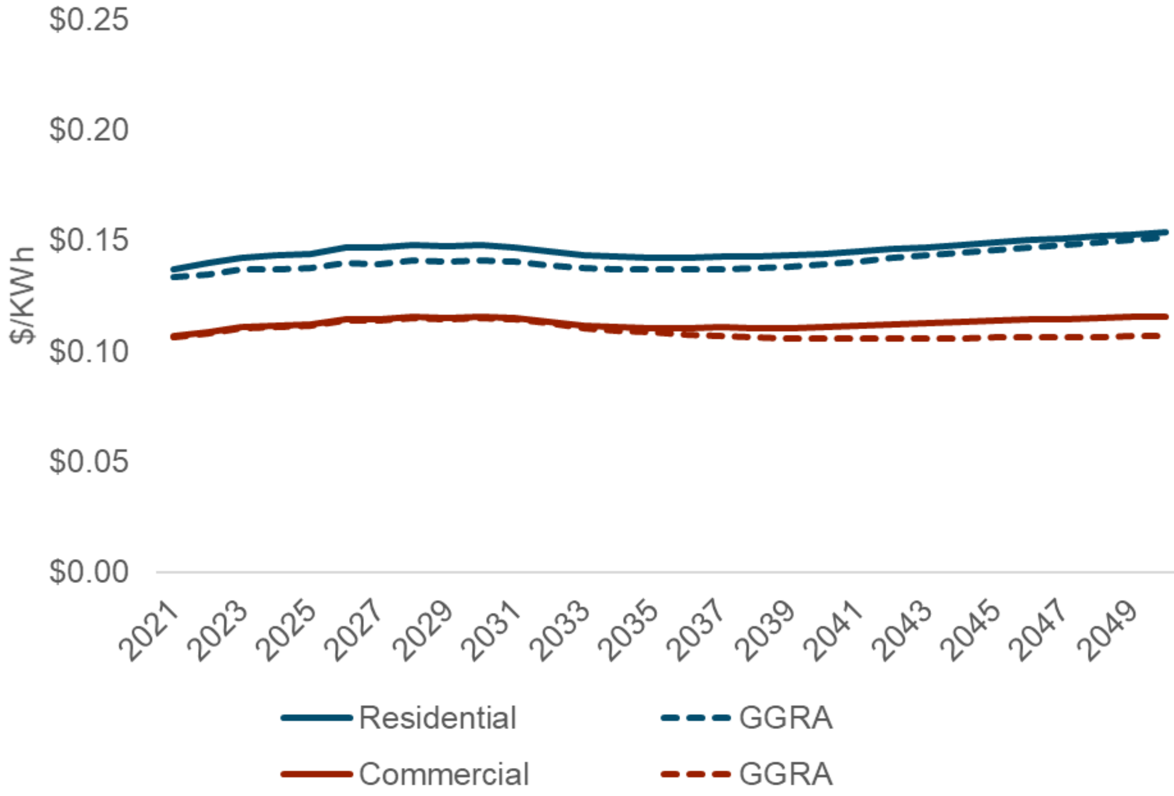
*Range shown in figure reflects the commodity cost forecast uncertainty

High Electrification scenario shows a more rapid electric rate increase compared to Electrification with Gas Back Up

+ **The Electrification + Gas Back-up scenario is projected to have a lower rate increase because it has a smaller load factor and manages to avoid the expensive peak capacity investment.**

Electric rates in the High Electrification Scenario (2021$/kWh)

Electric rates in the Electrification + Gas Back-up Scenario (2021$/kWh)



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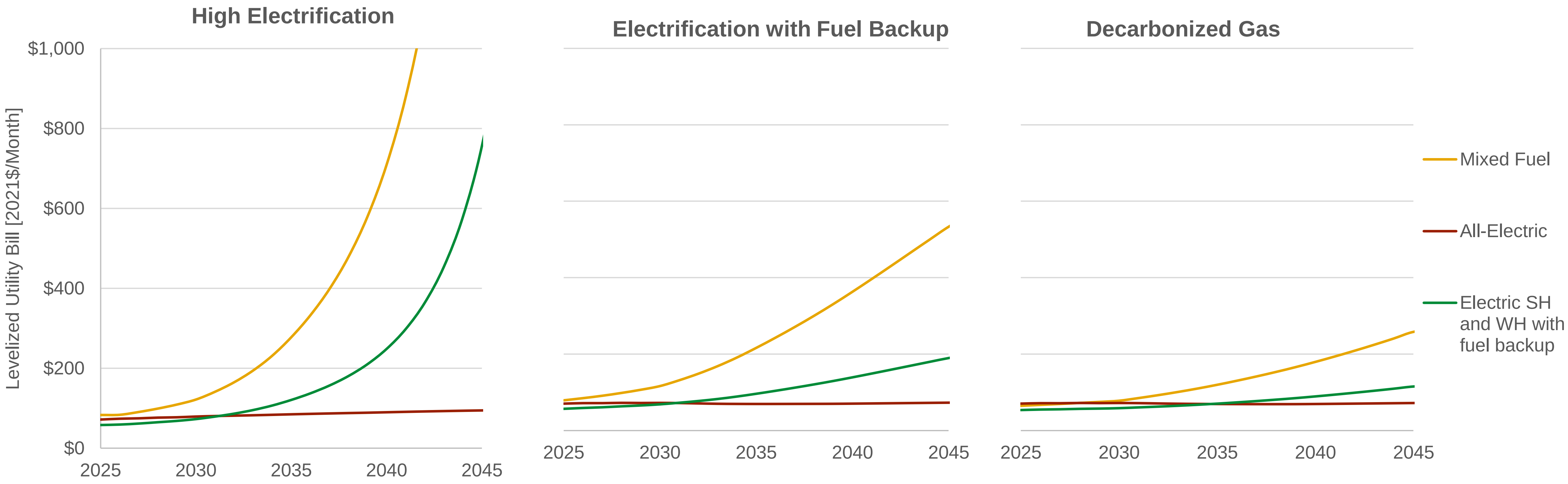
Consumer Economics

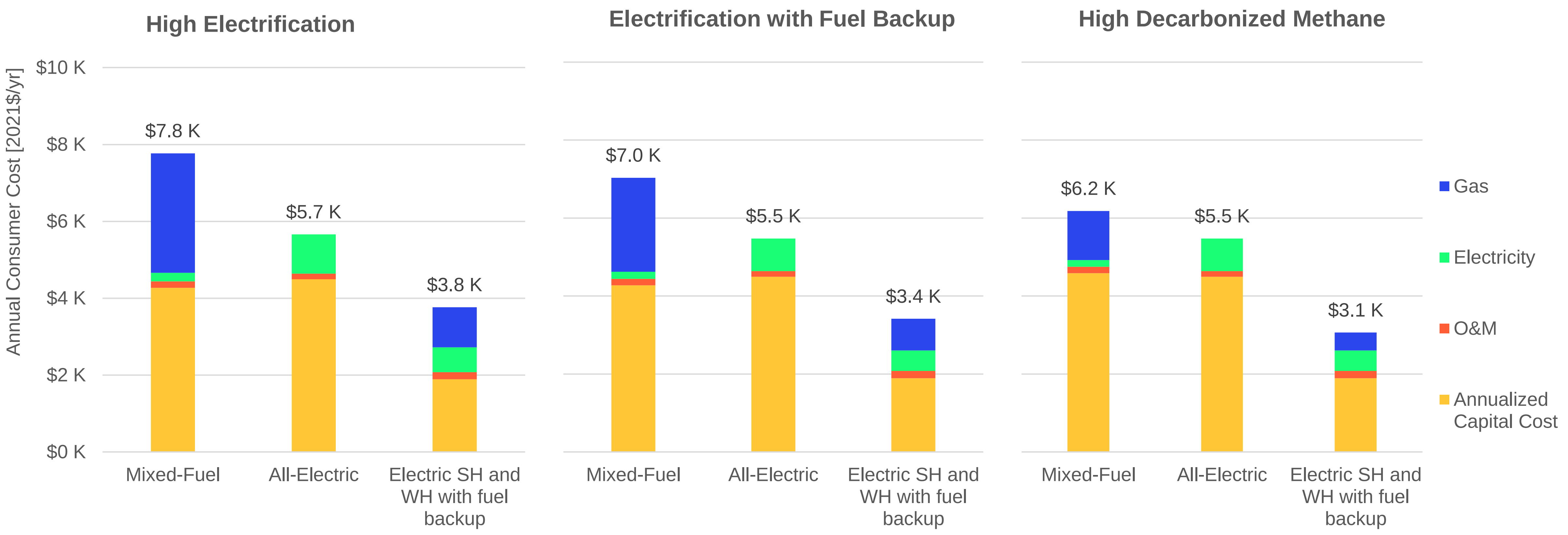
Illustrative customer bill impacts – residential single-family

- **Across all scenarios, customers remaining on the gas system may experience a large increase in utility bills due to the blend of expensive RNG to decarbonize gas use**
- **CAVEAT: These are not predictions of customer bills, but a representation of the potential dynamics under the current ratemaking model. These results indicate the potential equity and affordability challenges that will require systemic changes to the current dynamics.**



Electrifying heating with fuel backup is expected to be the least expensive option when both capital and operating costs are considered

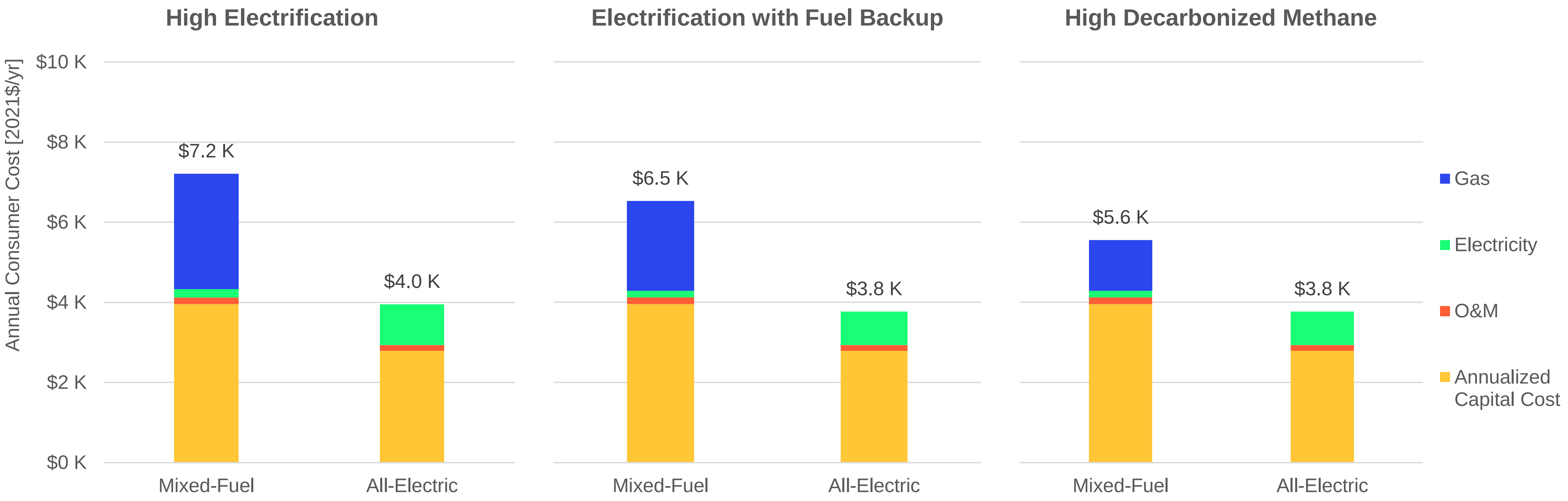
- “Hybrid” customers can save money by utilizing their existing fuel-based heating equipment to provide backup heating during coldest hours of a year, and by not having to upgrade building shells



* Gas costs, electricity costs, and equipment costs are based on 2035 rates

All-electric design is expected to be the less expensive option

+ **All-electric new construction is cheaper than mixed-fuel new construction for single-family residential homes across all decarbonization scenarios due to both lower capital (with avoided gas connection) and operating costs**



* Gas costs, electricity costs, and equipment costs are based on 2035 rates

Conclusions

Conclusions

- **All scenarios** demonstrate technologically feasible pathways to achieve zero direct building emissions by 2045.
  - Achieving this level of building decarbonization would require extensive technology deployment and commercialization efforts.
- **The High Decarbonized Methane pathway** requires high demand for zero-carbon fuels, resulting in high incremental fuel costs with significant cost uncertainty
- **The High Electrification pathway** results in a shift from a summer peak to a winter peak, mainly as a result of space heating loads in winter.
- **The Electrification with Fuel Backup pathway** shows lowest overall costs while also reducing reliance on technologies that have not yet been widely commercialized or that are uncertain in their scalability.
- **Each scenario** presents its own equity and affordability challenges
  - The average costs of the gas service are likely to increase in an electrification scenario as customers leave the system and infrastructure costs are spread over a smaller customer base.
  - Emphasis on mitigating the energy burden with customers ‘staying behind’ is important.
- **Other factors** including but not limited to health impact, job impact and methane leakage, which are beyond the scope of this study, need further investigation to provide a more complete evaluation of impact of the different pathways

Appendix

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Scenario parameters

Sector	Parameter	Reference (2020 Reference Scenario from the GGRA work)	High Electrification	Electrification with Fuel Backup	High Decarbonized Methane
Buildings (residential + commercial)	Appliance efficiency	Current EMPOWER program • 50% of new sales of electric appliances are assumed to be efficient through 2023	Increased EE targets from utilities (consistent with GGRA Optimistic Sensitivity) • 100% new sales of electric appliances are assumed to be efficient through 2030 • 25% new sales of natural gas appliances by 2030	Renewed EMPOWER through 2030 (consistent with 2030 GGRA Plan) • 50% new sales of electric appliances are assumed to be efficient through 2030 • 25% new sales of natural gas appliances by 2030	Increased EE targets from gas utilities • 100% new sales of efficient natural gas appliances by 2030 • Electric appliance sales
	Building shell efficiency	Improved building shell sales in all residential new construction by 2030	Improved building shell sales in all new construction retrofit buildings by 2030 (An improved building shell reduces heating demand of a residential home by 29% and that of a commercial building by 34% relative to a typical existing building)	Reference	Improved building shell sales in all new construction and retrofit buildings by 2030
	Building electrification (heat pump sales share)	Linear adoption trend from historical sales of heat pumps (20% of space heater sales are heat pumps by 2045)	50% sales of electric heat pumps by 2025 (consistent with GGRA Optimistic Sensitivity), 100% sales by 2035 • 90% ccASHP • 10% GSHP (targeting medium/large rural homes currently on non-NG heating and campuses) • Electric resistance back-up	• 100% sales by 2035 of regular ASHP with gas furnace backup for non-new construction natural replacements • All-electric new construction with 90% ccASHP and 10% GSHP	• Reference for electric HPs • Gas in new construction
	Behavioral conservation and other non-stock sectors	Consistent with 2020 Reference	Consistent with 2030 GGRA Plan		
Decarbonized fuels	Fuel blend in 2050	100% natural gas and fuel oil	100% RNG (used mainly for remaining gas customers): • 93% RNG from biomass and Synthetic Natural Gas • 7% RNG with blended hydrogen blend	100% RNG (used mainly for gas backup): • 93% RNG from biomass and Synthetic Natural Gas • 7% RNG with blended hydrogen	100% RNG and renewable diesel: • 93% RNG from biomass and Synthetic Natural Gas • 7% RNG with blended hydrogen
Electricity	Electricity sector emission intensity	Consistent with 2020 Reference	Consistent with 2030 GGRA Plan (additional load will be met by a mix of renewable build and PJM imports; additional capacity need will be provided by a mix of renewables and storage with their corresponding ELCC values with the rest covered by new CTs build; this study will not identify the specific location of the new resource build, which could be in MD or other PJM states. For details, see the input assumptions deck)		