RI Investigation into the Future of the Regulated Gas Distribution Business

Technical Analysis Draft Results

February 13, 2024

DRAFT / PRELIMINARY

Energy+Environmental Economics

Content

- **Introduction to Technical Analysis**
- **Summary and Key Findings**
- **Decarbonization Pathways - Technical Results, impact on:**
  - Emissions
  - Technology Adoption
  - Fuels
  - Gas System
  - Electric System
- **Decarbonization Pathways – Assessment and Implications**
  - Scenario assessment by evaluation criteria

Introduction to Technical Analysis

Energy+Environmental Economics

E3 modeled six scenarios for the Technical Analysis that present distinct pathways to achieving RI's Act on Climate

Variation in scenarios is primarily captured in the type of heating sector (residential, commercial & industrial) transformation achieved, keeping the level of action across other sectors similar across scenarios.

Scenario	Scenario focus	Research question
High Electrification	Emissions targets reached primarily through electrification.	What is the impact of pursuing a full-electrification decarbonization pathway that transitions Rhode Island away from gas infrastructure?
Hybrid Electrification + Delivered Fuels Backup	Emissions targets reached through combination of electrification and delivered fuels used as backup.	What is the impact of hybrid electrification (using backup heat in winter periods) on the energy system? What is the net benefit of avoiding gas infrastructure/decommissioning?
Hybrid Electrification + Gas Backup	Emissions targets reached through combination of electrification and gas used as backup.	What is the impact of hybrid electrification (using backup heat in winter periods) on the energy system? How can existing gas infrastructure be leveraged to reduce electric sector build outs?
Staged Electrification	Staged transition starting with a ramp up of hybrid heat pump conversion in the near-term (both gas and delivered fuels).	How can Rhode Island leverage existing infrastructure and mitigate customer impacts in the near-term, while allowing for a managed transition and achieving long-term electrification?
Alternative Heat Infrastructure	Decarbonization driven by a mix of networked geothermal where possible, all-electric heating, and hybrid heating.	How can highly-efficient heating systems (e.g., network geothermal) support decarbonization in Rhode Island? What is their net impact? Can they provide an alternative to gas investments?
Continued Use of Gas	Decarbonization achieved using a mix of electrification and supply of low-carbon gas.	How can existing gas infrastructure support decarbonization? What is the effect of and potential limit to low-carbon fuels such as biomethane and hydrogen?

The scenarios vary the level of electrification and low-carbon fuels while keeping other factors constant

Parameters refer to the 2050 "end-state" of Net-Zero.

	Efficiency & Weatherization	Building/ Industry Electrification	Zero Emissions Vehicles*	Clean Electricity	Low-Carbon Fuels**	Ag, Waste & Natural Sinks*	Negative Emissions Technologies*
High Electrification	Very High	Very High	Very High	Very High	Low	Medium	Low
Hybrid Electrification + Delivered Fuels Backup	Very High	High	Very High	Very High	Medium	Medium	Low
Hybrid Electrification + Gas Backup	Very High	High	Very High	Very High	Medium	Medium	Low
Staged Electrification	Very High	Very High	Very High	Very High	Low	Medium	Low
Alternative Heat Infrastructure	Very High	High	Very High	Very High	Medium	Medium	Low
Continued Use of Gas	Very High	Medium	Very High	Very High	High	Medium	Low

* The transition of the Transportation and Ag & Waste sectors will be applied similarly in all scenarios to allow better comparisons. In addition, the scenarios will apply similar levels of Negative Emissions Technologies.

** "High" levels of low-carbon fuels indicates high consumption of techno-economically available low carbon fuels. All scenarios will have a significant reduction in fossil fuel throughput resulting in a significantly reduced need for low-carbon fuels by 2050.

The Technical Analysis includes several sensitivities to reflect the uncertainty inherent to scenario modeling

Managed vs. unmanaged transition

- Explores the impact of targeted electrification and gas decommissioning on gas system investments, rates, and societal cost.
- Modeled as a sensitivity onto gas sector costs (avoidance of leak-prone pipe replacement).
- Results in insights regarding potential level of cost savings on the gas system that can be achieved per scenario if electrification takes place through a managed approach.
- Modeled for all scenarios.

Level of efficiency

- Explores the impact of higher levels of cold climate heat pumps performance, reflecting a worldview with accelerated technology improvements.
- Modeled as a sensitivity onto building sector energy demands and capacity needs.
- Results in insights regarding the potential electric sector impacts resulting from the adoption of higher efficiency technology.
- Modeled for the High Electrification scenario only.

Pace of ACCII/ACT

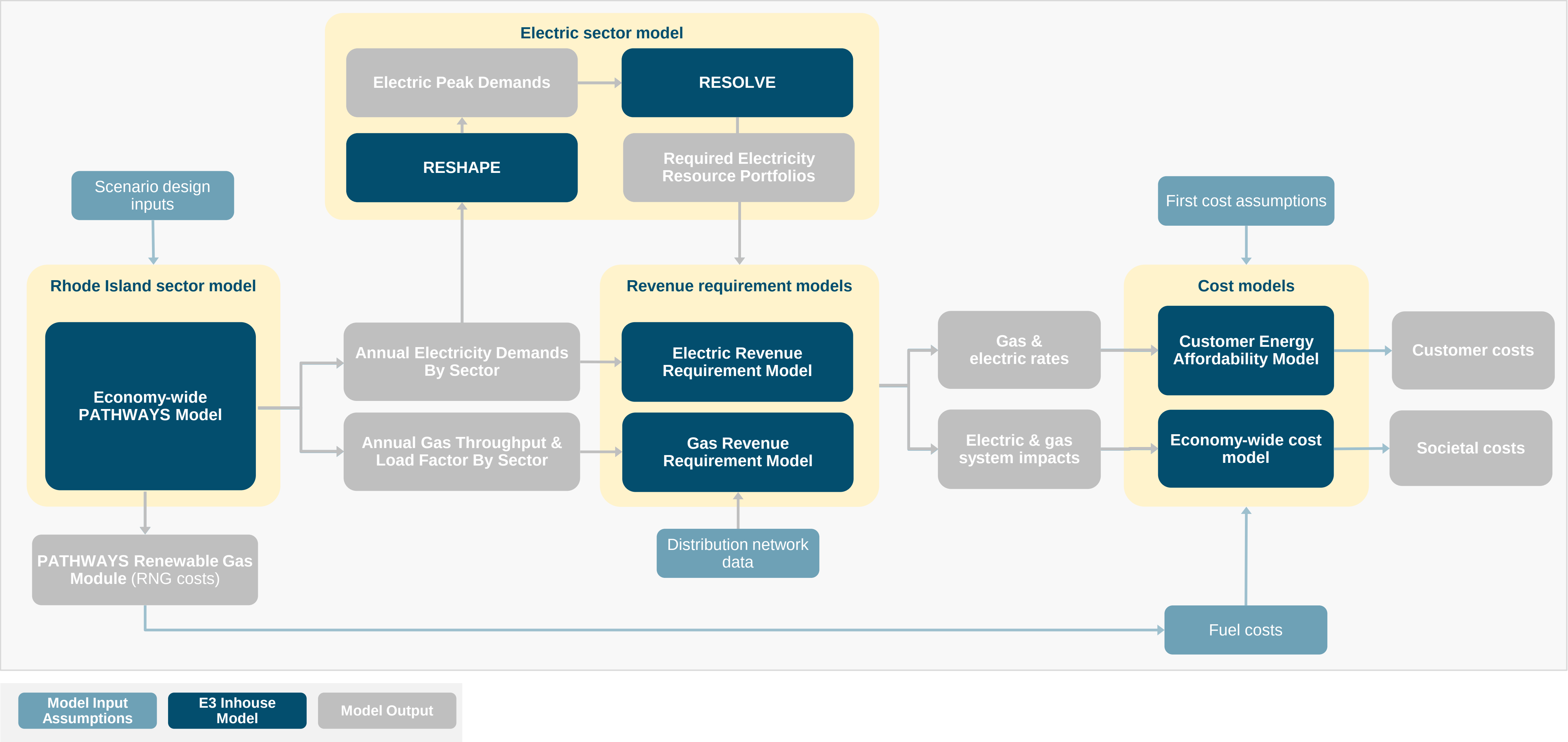
- Explores the impact of lower levels of transportation electrification, e.g., slower pace than Advanced Clean Cars II.
- Modeled as a sensitivity onto transportation sector technology adoption levels.
- Results in insights regarding the potential impacts to other sectors resulting from the slower adoption of electric vehicles.
- Modeled for the High Electrification scenario only.

Impact of GWP and biofuel emissions

- Explores the impact of different GHG accounting frameworks, including higher Global Warming Potentials, upstream fuel emissions and zero emissions benefit from biofuels.
- Modeled as a sensitivity onto fuel emissions factors.
- Results in insights regarding the potential risks associated with higher reliance on biofuels
- Modeled for all scenarios.

In addition, the Technical Analysis includes low/high sensitivities applied to the assessment of economy-wide costs for: heat pumps, networked geothermal systems, renewable gases, and the costs of RECs.

E3's modeling framework analyzes impact of scenarios on RI, RI's gas & electric system, and RI residents



The Technical Analysis addresses key questions raised in the Docket; some questions require follow up

Questions raised in the Docket	Addressed through Technical Analysis		Follow up
1. What infrastructure and non-infrastructure options exist for reducing emissions from the gas system?	✓	Decarbonization Pathways Technical Results - Technology adoption levels, impact on gas/electric system	
2. What scenarios for (all) sector-level emissions will allow the state to meet the emissions reduction mandates of the Act?	✓	Decarbonization Pathways Technical Results - Emissions	
3. What outputs of the Technical Analysis will inform the Policy Development phase?	✓	Decarbonization Pathways Assessment & Implications	
4. What assumptions and inputs are critical to the outputs of the Technical Analysis?	✓	Decarbonization Pathways Technical Results – Sensitivity analyses	
5. What statutory, regulatory, or stakeholder requirements and/or preferences exist that represent constraints on possible pathways for reducing gas system emissions consistent with the Act?			To be discussed in Policy Development phase
6. What final scenarios, including alternative testing and sensitivity ranges, should be included in RIE's scope for the Technical Analysis the company will perform?	✓	Decarbonization Pathways Scenario design	

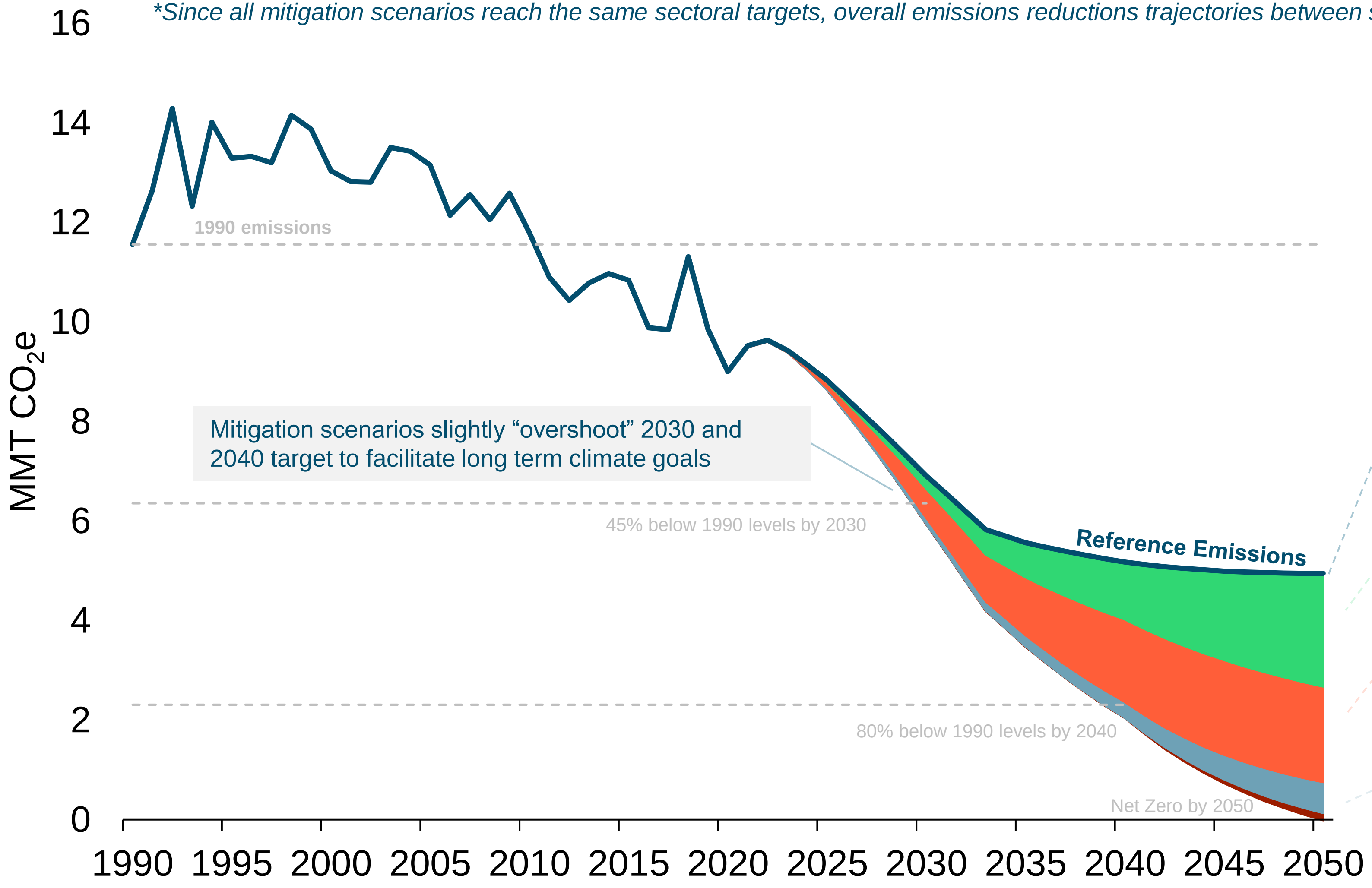
Summary and Key Findings

Energy+Environmental Economics

Emissions: All mitigation scenarios achieve the Act on Climate, large focus on buildings and transportation required

Rhode Island Statewide Emissions Reductions – Mitigation Scenarios*

**Since all mitigation scenarios reach the same sectoral targets, overall emissions reductions trajectories between scenarios are similar.*



Reference scenario emissions:
57% emissions reduction by 2050.

The Reference scenario falls short of achieving the AoC Net Zero by 2050 target

Transportation sector:
- Growth in EV penetration for LDV and MHDV consistent with Advanced Clean Cars II and Advanced Clean Trucks

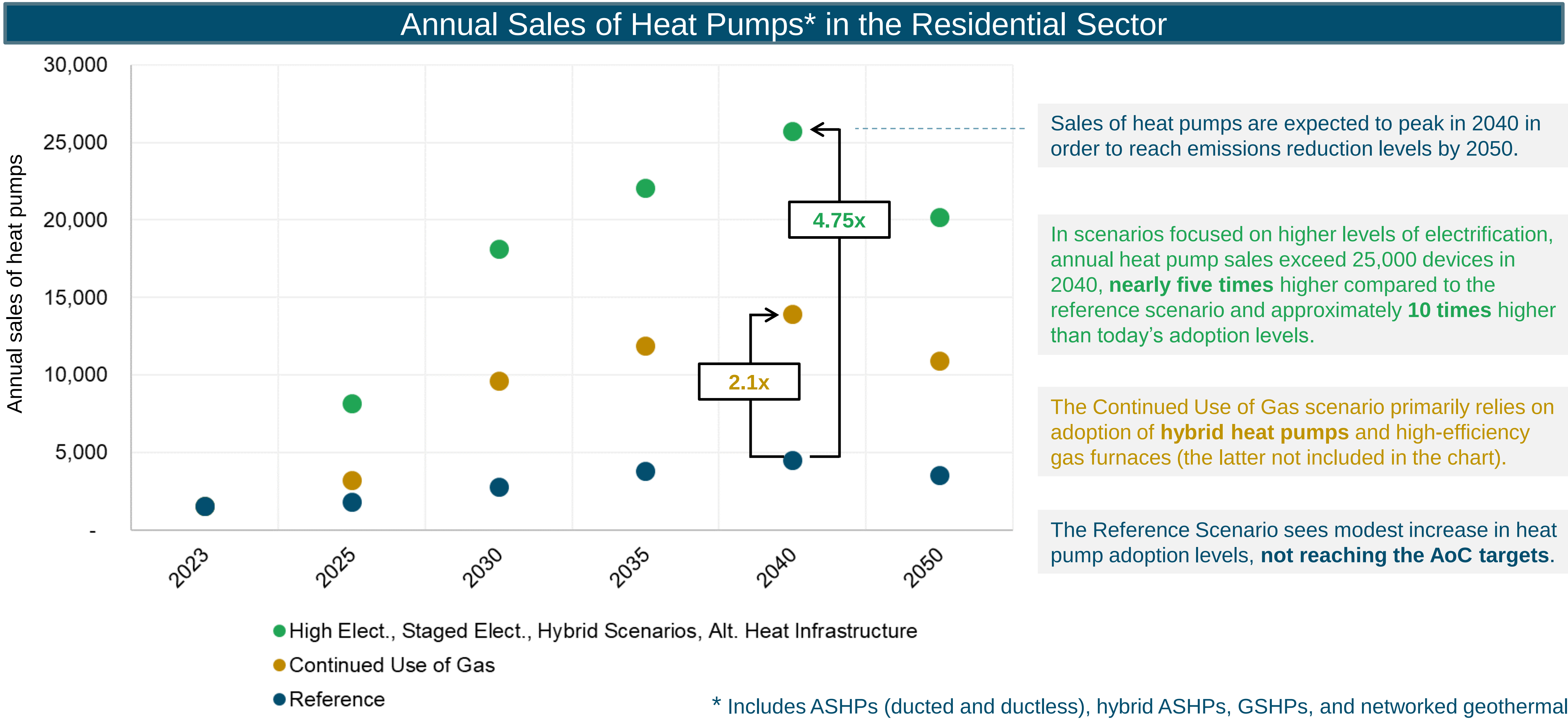
Building sector:
- All-electric and hybrid ASHP adoption; key variations by scenario
- Networked geothermal adoption in High Electrification and Alt. Heat Infrastructure
- Variations in renewable fuels blending

Industrial sector:
- The industrial sector decarbonizes through a range of electrification and fuel-switching measures, as feasible

DRAFT / PRELIMINARY

Emissions reductions from sector: Transportation | Buildings | Industry | Gas distribution | Sinks & NETs

Technology adoption: Annual adoption of decarbonization technologies needs to increase significantly to support AoC



Sales of heat pumps are expected to peak in 2040 in order to reach emissions reduction levels by 2050.

In scenarios focused on higher levels of electrification, annual heat pump sales exceed 25,000 devices in 2040, **nearly five times** higher compared to the reference scenario and approximately **10 times** higher than today's adoption levels.

The Continued Use of Gas scenario primarily relies on adoption of **hybrid heat pumps** and high-efficiency gas furnaces (the latter not included in the chart).

The Reference Scenario sees modest increase in heat pump adoption levels, **not reaching the AoC targets**.

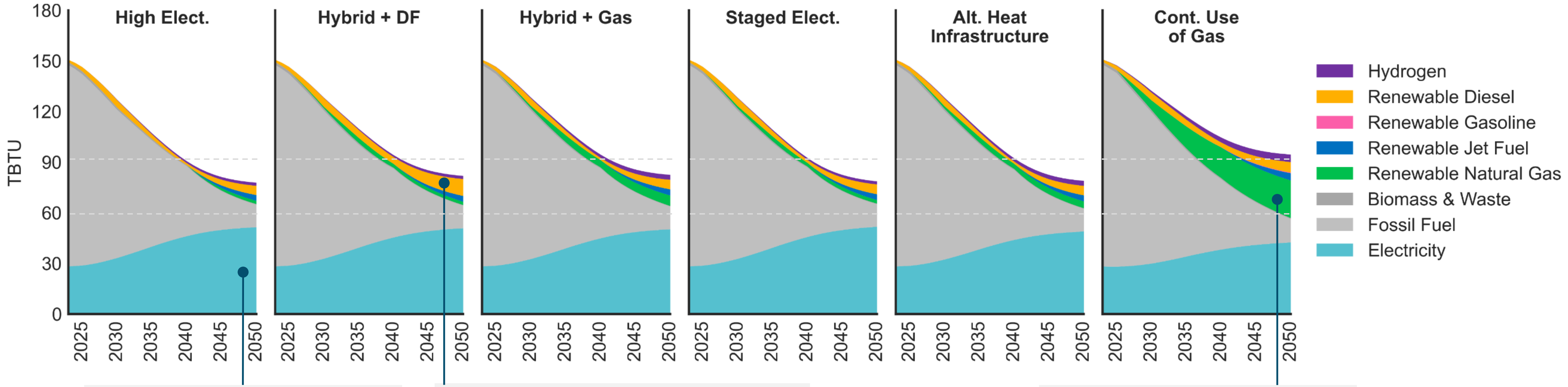
* Includes ASHPs (ducted and ductless), hybrid ASHPs, GSHPs, and networked geothermal

<u>Fuels:</u> By 2050, 40-60% of final energy demand is served by electricity while the need for renewable fuels increases

Across scenarios, **some level of renewable fuel blending** is needed to meet the 2050 emissions targets.

Scenarios with lower levels of electrification see higher renewable fuel blending to comply with AoC goals.

Change in economy-wide final energy demand across scenarios: 2023 - 2050



Lowest levels of renewable fuels

Highest levels of renewable diesel due to hybrid + DF HPs

Highest levels renewable natural gas and hydrogen

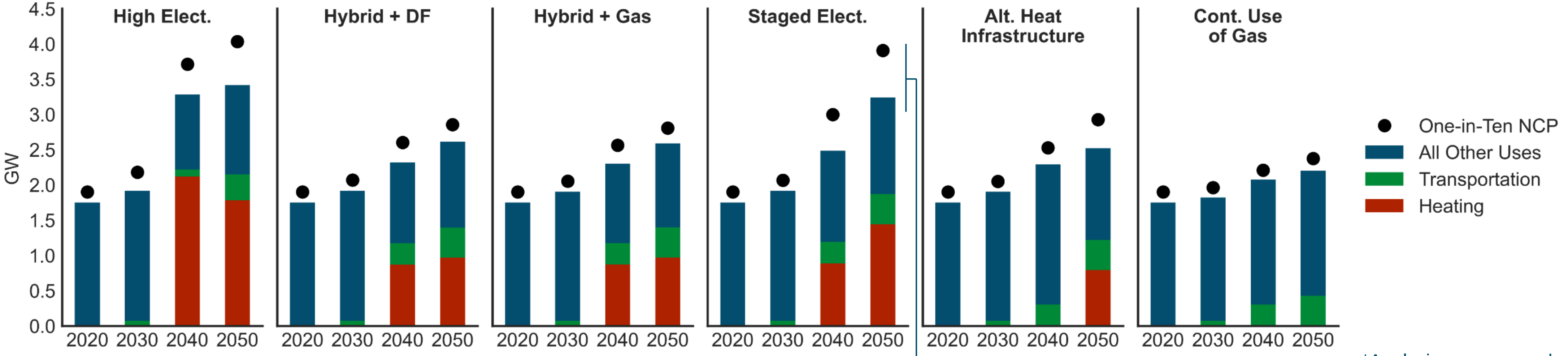
All scenarios comply with the Biodiesel Heating Oil Act of 2013, requiring 20% blend in 2025 and 50% blend in 2030

All scenarios rely on renewable fuels to meet emissions targets; lower electrification scenarios require higher levels.

<u>Electric system:</u> Most scenarios switch to a winter peaking system; scenarios with backup heat reduce electric impacts

Scenarios with high adoption of heat pumps switch to winter peaking in the 2030s. **Median peak demand doubles in the High Electrification scenario** – this effect is substantially mitigated in the hybrid scenarios that see a +/- 1 GW reduction in median peaks.

Post-Flexibility* Median Peak Loads by Contribution and 1-in-10 Total Noncoincident Peak (GW)



Scenarios with high reliance on either whole-home or hybrid HPs become winter peaking in the 2030s.

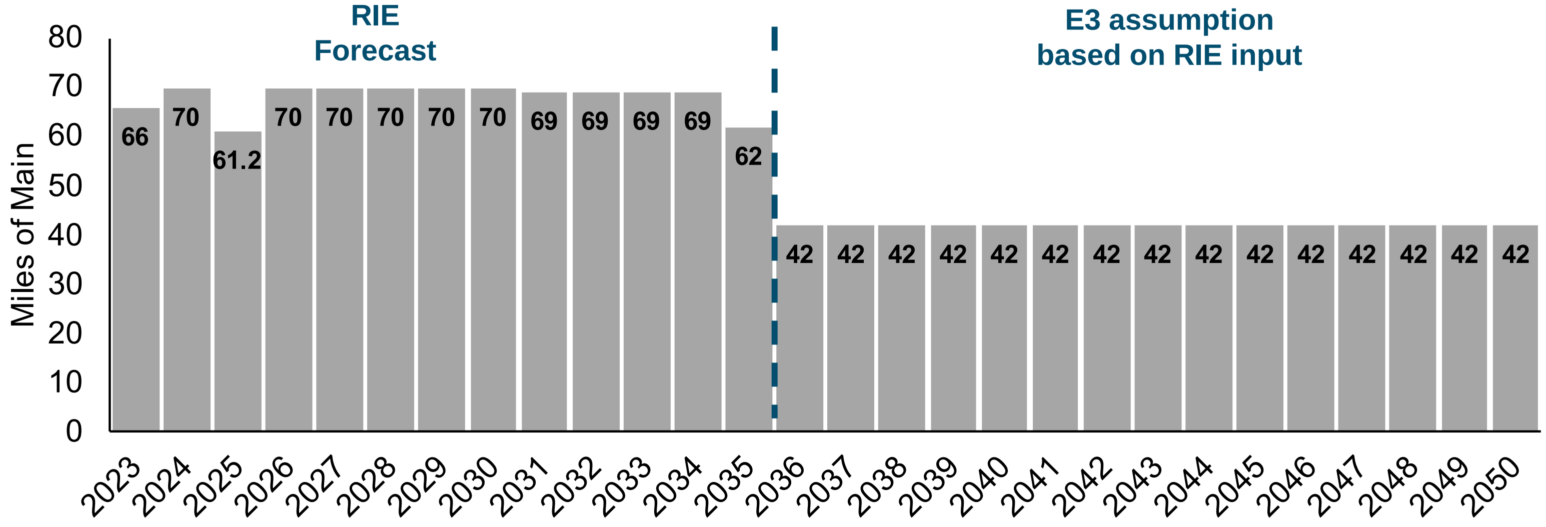
Peak loads in scenarios with high reliance on whole-home HPs are more sensitive to changes in weather. The High and Staged Electrification scenarios' 1-in-10 peaks grow more quickly than the Hybrid scenarios.

Scenarios with fewer ASHPs transition to winter peaking later or remain summer peaking.

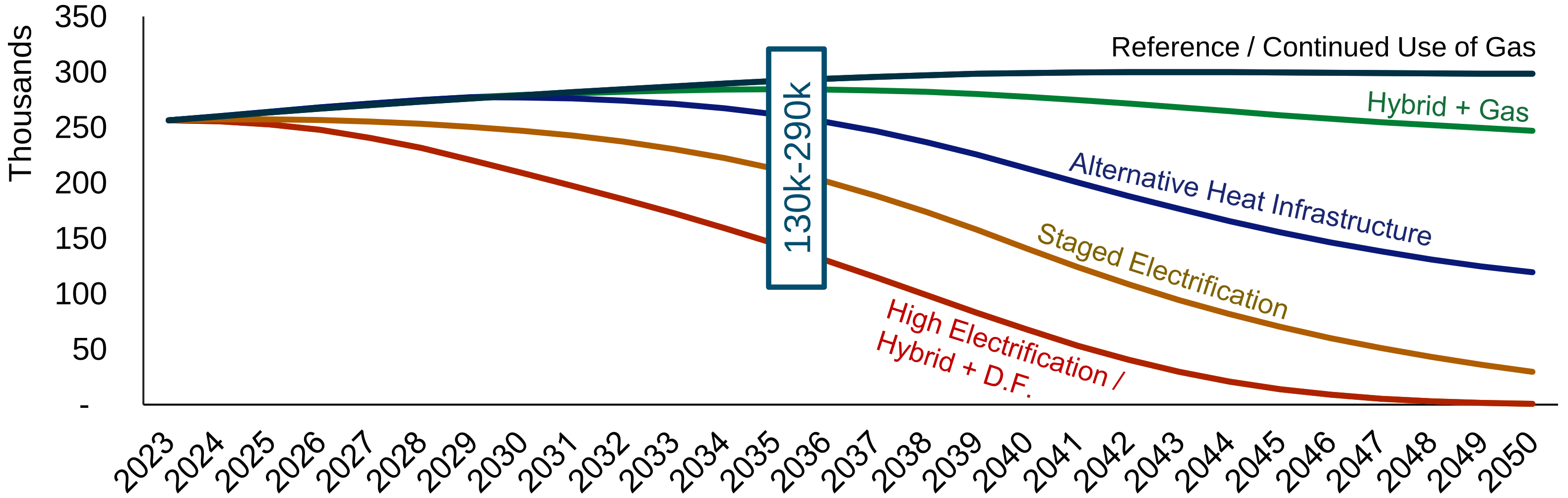
*Analysis assumes substantial levels of load flexibility that allows peak contributions for several categories to shift load to different hours of the day. Assumptions include 50% LDV flexibility, 25% water heating flexibility, 5% space heating flexibility.

Gas system: In most scenarios, pipeline replacements driven by ISR will serve fewer customers over time

Replacement Miles (Mains)



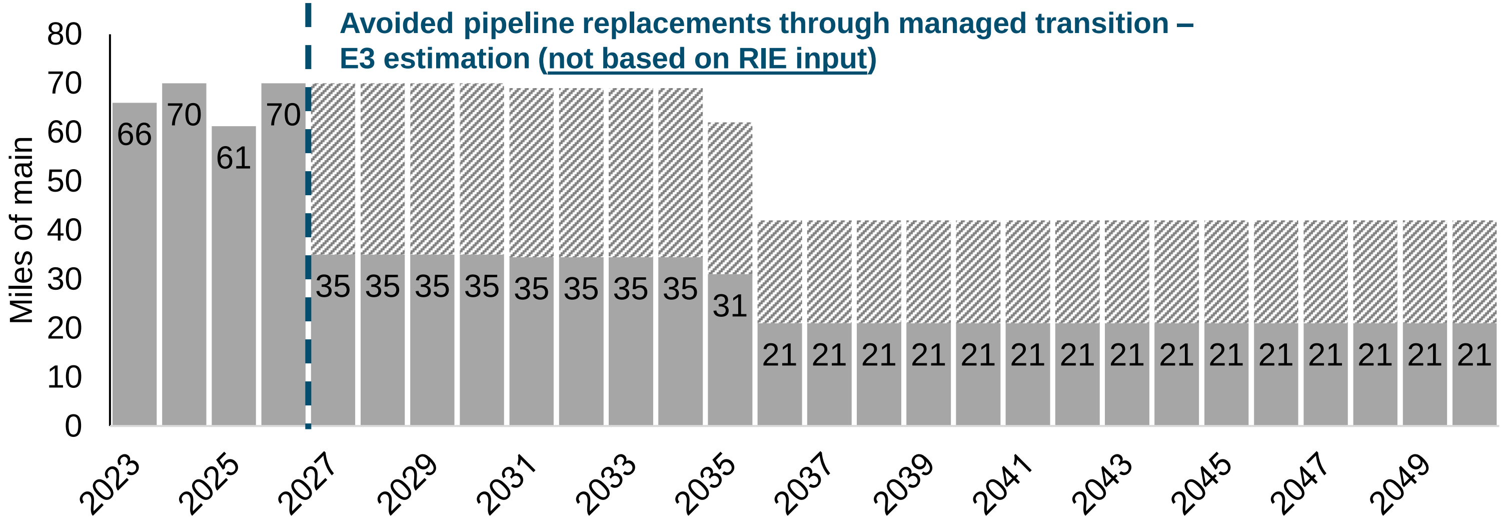
Customers with a gas connection



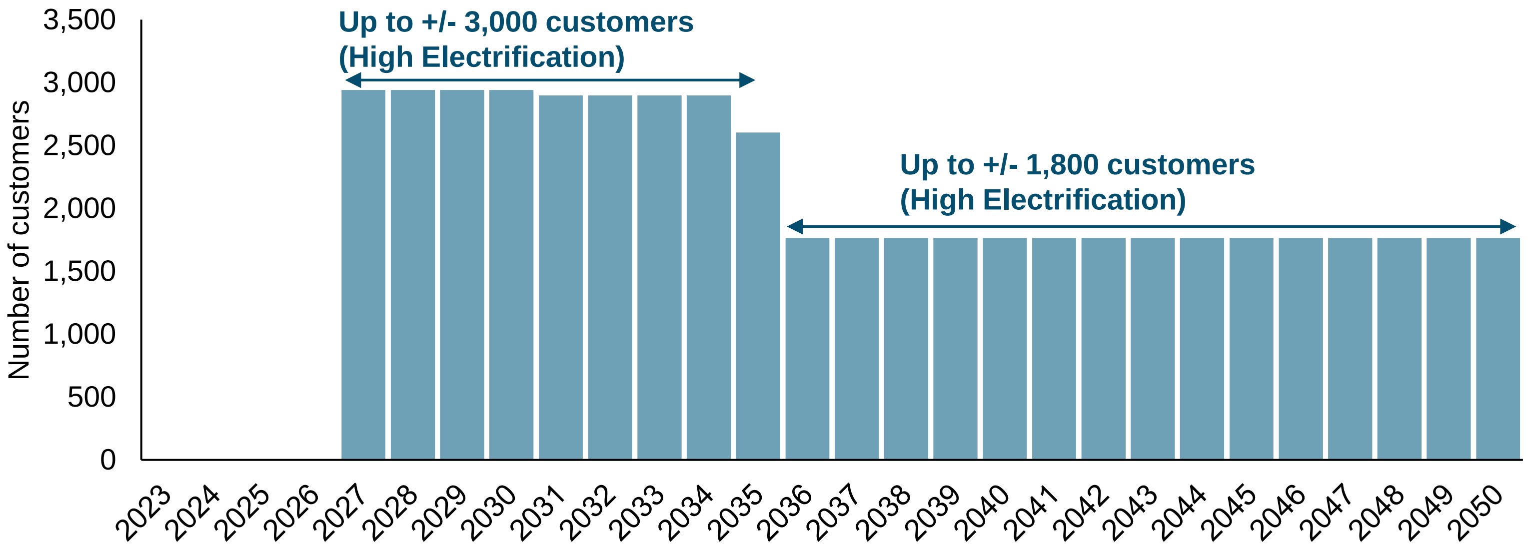
- The Infrastructure, Safety & Reliability (ISR) Plan ensures safe and reliable service of gas in the next decade, with a strong focus on **replacement of Leak Prone Pipe (LPP)** infrastructure.
- The ISR program is expected to replace up to 900 miles of pipe in the next decade, reaching **completion in 2035.** Post-2035, RIE expects to continue to replace (plastic) mains.
- In 4 out of 6 mitigation scenarios, electrification drives a reduction of gas customers. The High Electrification and Hybrid Delivered Fuels Backup scenarios have approximately 130,000 customers remaining by the end of the ISR program, **a reduction of +/-50% compared to today**.

Gas system: A managed transition may avoid replacements, but requires significant levels of targeted electrification

Replacement Miles (Mains)



Required targeted electrification customers

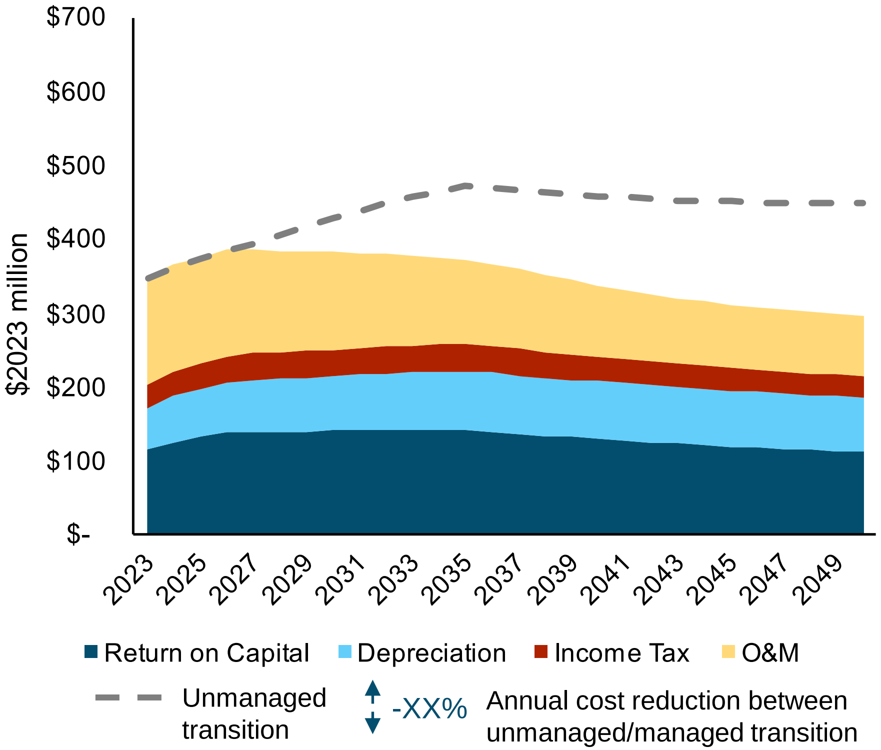


- In a managed transition, investments and incentives will be **geographically focused** to allow parts of the gas system to be decommissioned.
- To retire a gas pipeline, it must be considered ***hydraulically feasible,*** meaning the gas system maintains gas flow and the minimum allowable pressure.
- For the purpose of this study, E3 assumed that up to 50% of pipeline replacements may be avoidable in a managed transition***; this assumption is not based on input from RIE*** and needs significant additional study.
- If 50% of pipeline replacements are avoidable, up to 3,000 customers per year need to electrify their heating system in a targeted manner, with implications for customer choice.

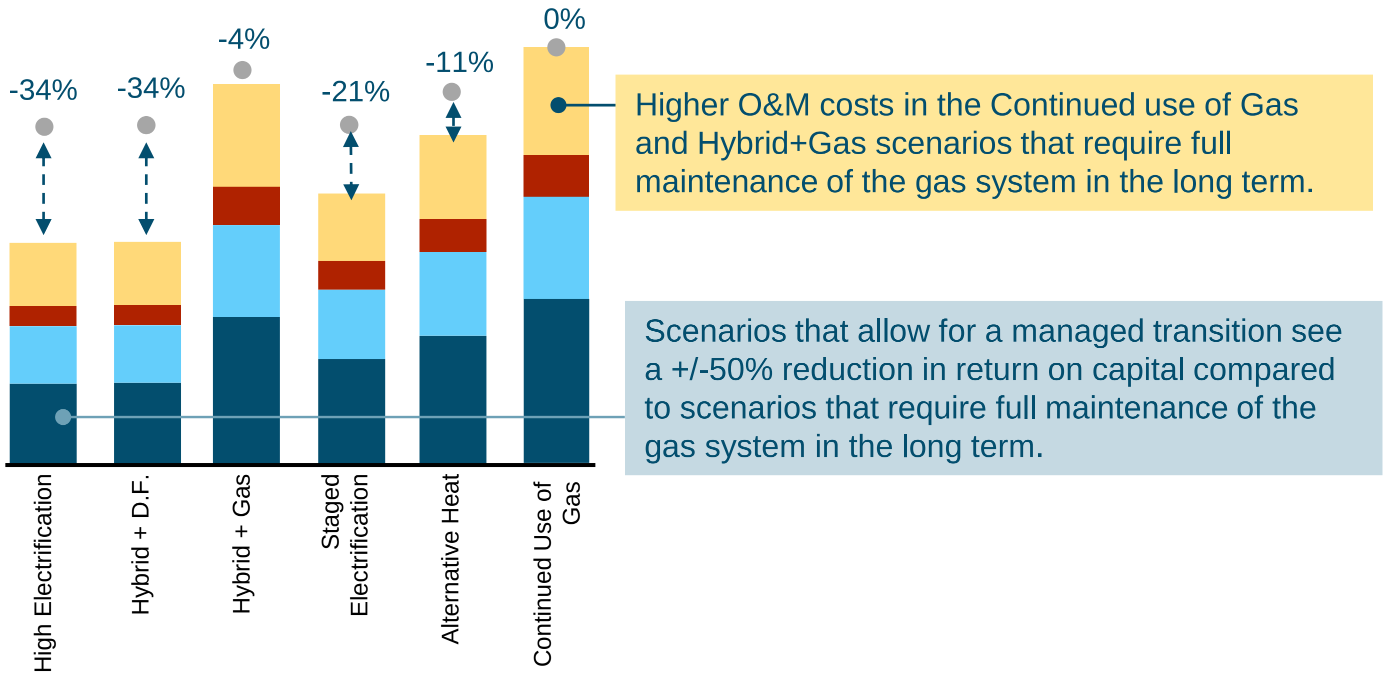
Gas system: If a managed transition is achieved, substantial gas system costs can be avoided in the long term

A managed transition could reduce the costs of the gas system by nearly 35%, or approximately $150 mln/year compared to an unmanaged transition by 2050, primarily in scenarios that transition away from the gas system in the near term (High Electrification, Hybrid + Delivered Fuels, Staged Electrification).

RIE Gas Revenue Requirement (RR) in the High Electrification scenario (managed)



2050 Mitigation Scenarios (unmanaged vs. managed)



Implications of scenarios can be viewed across multiple evaluation criteria to assess risks, benefits and challenges

Scenarios see different levels of benefits, risks and challenges across multiple evaluation criteria. The matrix below provides a first step in assessing the implications of scenarios across the evaluation criteria discussed with the Stakeholder Committee.

Evaluation Criteria	Key Metric		Detail on slide	High Electrification	Hybrid + Delivered Fuels Backup	Hybrid + Gas Backup	Staged Electrification	Alternative Heat Infrastructure	Continued Use of Gas
Economy-wide Costs	Cumulative NPV in $bln*		62-65	$16-20	$15-20	$14-19	$15-19	$17-23	$16-26
Customer choice	Number of targeted electrification customers in 2035	*Unmanaged*	46-48. 66	0	0	0	0	0	0
		Managed	46-48. 66	3,000	3,000	0	1,200	700	0
Long-term affordability	2050 monthly total cost of ownership for migrating customer		67-68	+/- $800	+/- $800	+/- $800	+/- $800	+/- $900	+/- $800
Cost shifting to non-migrating customers	2050 monthly total cost of ownership for non-migrating customer		67-68	> $3,000	> $3,000	+/- $1,500	> $3,000	> $3,000	+/- $800
Workforce Impacts	*Not yet assessed*								
Air Quality Impacts	Change in statewide fuel combustion between 2020-2050 (%)		69	-85%	-82%	-81%	-85%	-82%	-65%
Reliance on (out-of-state) fuels	Total annual volume of renewable fuel required by 2050 (Tbtu)		70-71	11	15	15	11	13	33
Technology Readiness	Likely range of Technology Readiness Levels required to achieve AoC**		72-73	8-10	7-10	7-10	8-10	6-10	6-11
Pace of Electric System Expansion	Total increase in distribution system capacity by 2035 (GW)		74	1.2	0.5	0.4	0.5	0.4	0.2

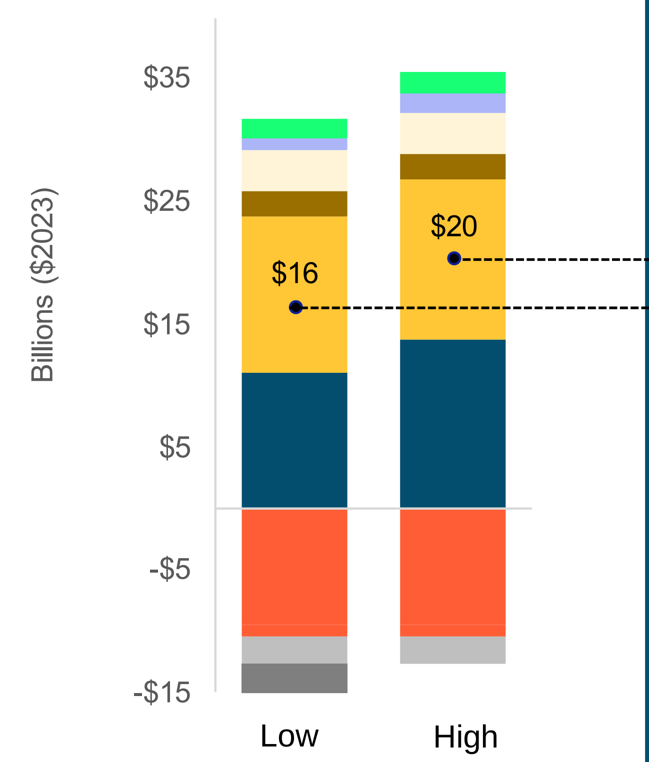
Initial considerations:

- Higher cost risk due to uncertainty in costs of large-scale renewable fuels
- High customer choice impacts if managed transition is achieved
- Relative affordability of heat pumps improves as delivery & supply costs of gas rise. Cost shift risk exist for scenarios with high levels of customer departure.
- Air quality benefits across scenarios, lower benefits for scenarios with more fuel combustion
- Higher risk of out-of-state fuel reliance for scenarios with higher levels of renewable fuels
- Reliance on networked geothermal or synthetic fuels to meet AoC targets
- Rapid electric capacity needs increase risk of system congestion

* Expressed as cumulative Net Present Value (NPV) between 2023-2050, incremental to a reference scenario. Costs shown for “unmanaged” transition.
** Detail on Technology Readiness Level (TRL) ranges provided on slide 72.

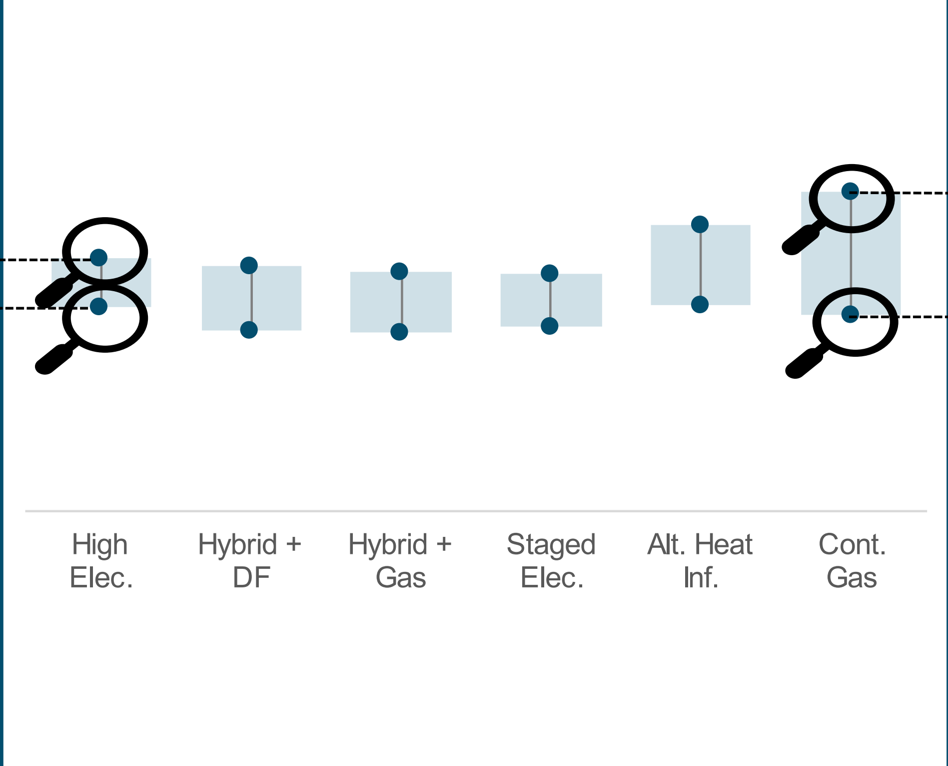
Evaluation criteria example: Economy-wide costs show similar ranges with highest uncertainty in cost of renewable fuels

Detail by category: High Electrification



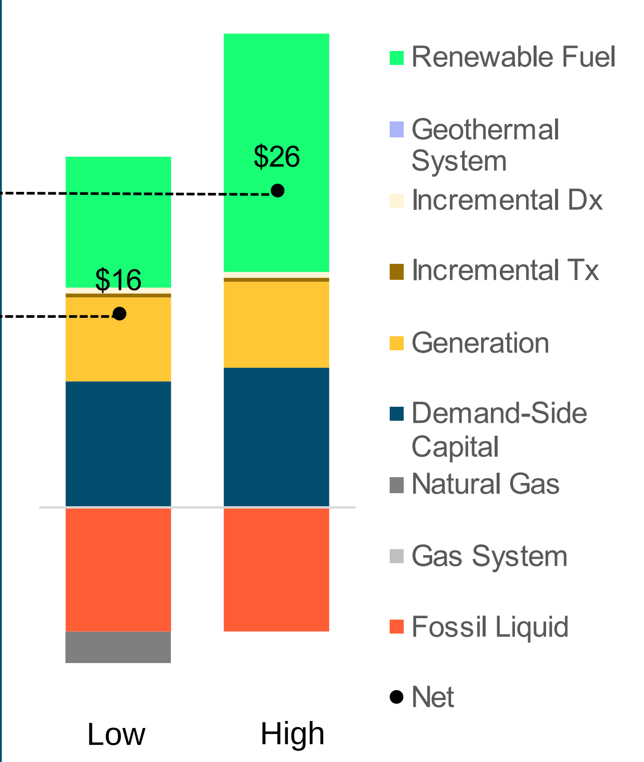
Device adoption and electric sector drive cost. Scenario shows the smallest range between optimistic and conservative cases due to limited role of fuels

Range of cumulative net NPV* costs across scenarios



Scenarios with a role for hybrid heating are favorable under both conservative and optimistic parameters

Detail by category: Continued Use of Gas

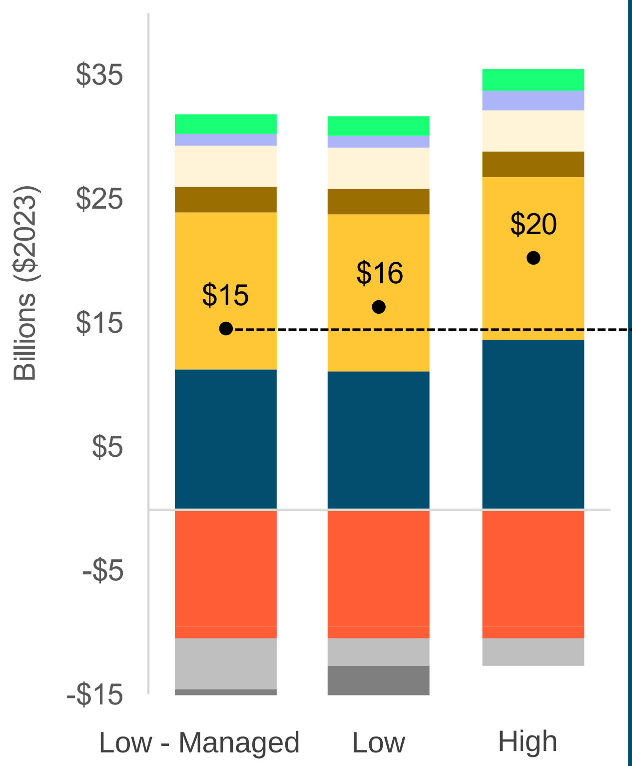


Uncertainties in renewable fuel costs drive highest variability in Continued Use of Gas scenario.

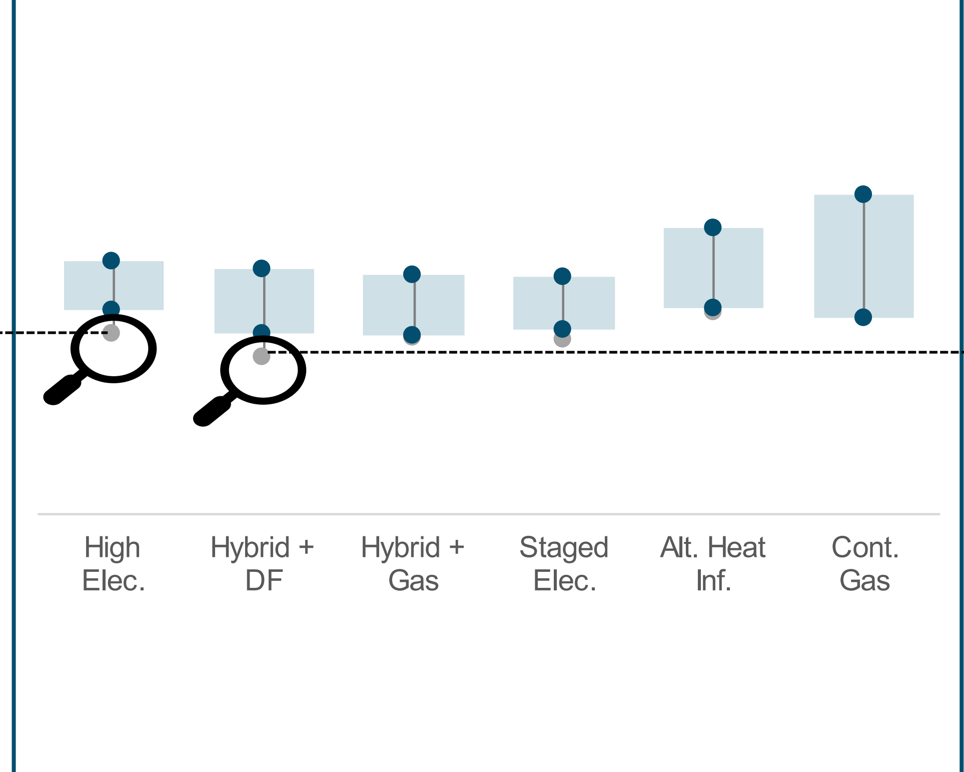
* Expressed as cumulative Net Present Value (NPV) between 2023-2050, incremental to a reference scenario. Discount Rate = 1%.

Evaluation criteria example: A managed transition can reduce costs if long-term gas infrastructure is avoided

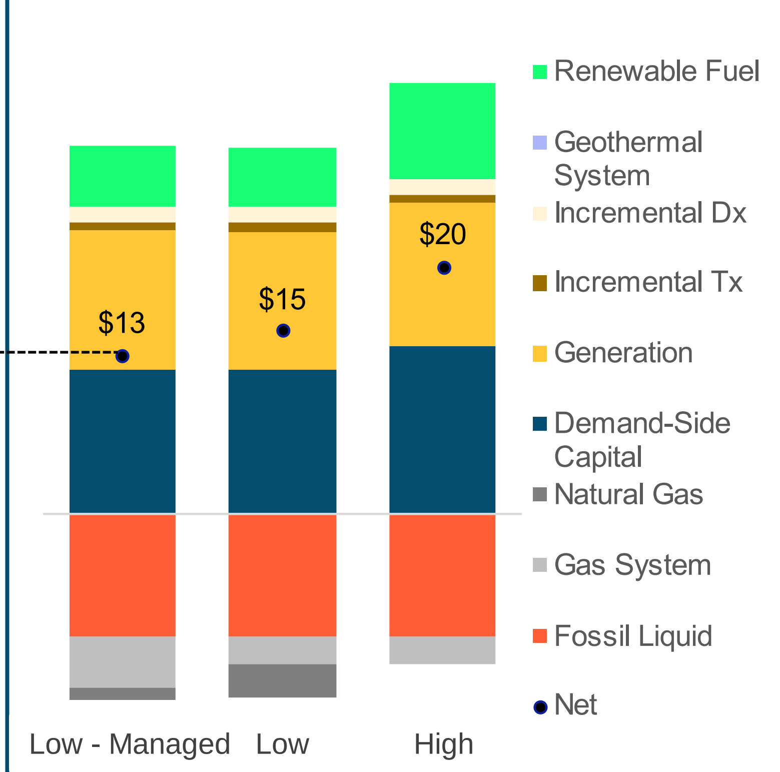
Detail by category: High Electrification



Range of cumulative net NPV* costs across scenarios



Detail by category: Hybrid + Delivered Fuels Backup



A managed transition reduces economy-wide costs, mostly in scenarios that are able to avoid long-term gas infrastructure.

* Expressed as cumulative Net Present Value (NPV) between 2023-2050, incremental to a reference scenario. Discount Rate = 1%.

Outstanding Questions and Study Needs

The Technical Analysis raises key outstanding questions on the implementation and (technical) feasibility associated with decarbonizing the gas system, in particular related to a managed transition.

+ **Technical feasibility and costs**
  - What parts of Rhode Island Energy (RIE)'s system can be classified as "hydraulically feasible", i.e. can potentially be decommissioned while maintaining the gas flow and minimum allowable pressure required to ensure safe and reliable service of other parts of the gas system?
    - The Technical Analysis does not model the performance and operations of the gas system, nor does it provide a geographical representation of cost avoidance opportunities. Additional study by RIE is necessary to understand the magnitude of opportunity associated with targeted decommissioning.
  - What parts of the gas system are cost-effective to electrify through targeted decommissioning?
    - Other studies* have identified the cost-effectiveness of targeted electrification through neighborhood-specific study of key parameters, such as system density, pipeline age, replacement costs, cost of electrification, etc. This type of study is necessary in Rhode Island to better understand the feasibility and opportunity associated with targeted electrification.
  - What additional costs, if any, are associated with decommissioning of the gas system that are not yet captured in the current accounting of asset removal costs recovered by RIE in the annual revenue requirement?
+ **Implementation and customer choice**
  - How can implementation of neighborhood-specific targeted electrification be planned for and achieved without jeopardizing key principles such as customer choice?
  - How does a managed transition affect different types of customer classes? To what extent are C&I classes affected through targeted electrification?

Other key questions that arise through the Technical Analysis, such as those related to policy & regulatory options needed to mitigate affordability and equity issues associated with the transition will be addressed in the Policy Development phase of this Docket.

*See, for example: E3 - Benefit-Cost Analysis of Targeted Electrification and Gas Decommissioning in California;
Groundwork Data - Equitable Energy Transition Planning in Holyoke Massachusetts - A Technical Analysis for Strategic Gas Decommissioning and Grid Resiliency.

Decarbonization Pathways Technical Results

Preliminary overview of findings

Energy+Environmental Economics

Summary of preliminary findings in this section (1/2)

Emissions

- Existing policies achieve significant emissions reductions relative to 1990 and today, achieving 40% reductions by 2030, largely driven by reductions in the electricity sector. Despite significant emissions reductions from existing policies and industry trends in a Reference Scenario, ***additional mitigation measures are required to achieve the Act on Climate***.
- ***All mitigation scenarios achieve AoC goals under RI's current GHG accounting framework***. Scenarios with higher levels of renewable fuels may have higher emissions under alternative accounting frameworks.
- ***Delayed achievement of ACCII/ACT requires deeper measures to achieve AoC***, primarily in the long term. The 2030 AoC target can be met with accelerated building sector measures that are already required to facilitate longer term climate goals.

Technology

- Mitigation scenarios achieve AoC through a distinct mix of technology adoption in the residential and commercial sector; Scenarios focused on higher levels of electrification require heat pump adoption levels by 2030 and 2040 that are ***nearly 10 times higher than today's adoption levels.*** Scenarios with lower levels of electrification still require a 5x increase.
- Industrial sector sees significant efficiency across scenarios and varying levels of industrial electrification; ***industries that are harder to decarbonize leave a role for pipeline gas and see increased adoption of dedicated hydrogen***.

Fuels

- All scenarios see ***transformational changes*** in the way Rhode Island uses energy; across scenarios, final energy demand ***decreases between ~40-50%*** by 2050 as a result of efficiency & electrification.
- RI will see increased use of biofuels through Biodiesel Heating Act. By 2050, ***~50-70% of the fuel mix across scenarios consists of renewable fuels***, with largest reliance in Continued Use of Gas scenario.
- Gas throughput in Rhode Island ***declines by ~45-95% across scenarios***; supply costs of gas may increase by 4-5x post 2035.

Summary of preliminary findings in this section (2/2)

Gas system impacts

+ Planned levels of capital expenditures through the Infrastructure, Safety and Reliability (ISR) program and additional customer connections in a Reference Scenario cause ***annual gas revenue requirement to nearly double towards 2050***, assuming an ***unmanaged transition.*** Scenarios that do not assume additional customer connections reduce annual costs by approximately 20% by 2050.
+ A ***managed transition could reduce the costs of the gas system by up to 35%*** in scenarios that transition away from the gas system in the near term (High Electrification, Hybrid + Delivered Fuels, Staged Electrification).
+ Except for the Continued Use of Gas scenario, ***all mitigation scenarios lead to untenable long-term gas delivery rates***; a managed transition can only partly mitigate this effect.
+ Risk of stranded costs exists for scenarios with high levels of customer departures; potentially unrecovered rate base in 2050 ***between $2,6M (unmanaged) and $1,5M (managed).***

Electric system impacts

+ By 2050, 40-60% of final energy demand is served by electricity. Scenarios with high levels of electrification see ***nearly doubling load by 2050*** compared to today's levels.
+ Scenarios with high adoption of heat pumps switch to winter peaking in the 2030s, ***median peak demand doubles*** in High Electrification scenario by 2050 and is ***mitigated by approximately 1 GW in hybrid scenarios***.
+ Renewables become a major source of generation in the New England and Rhode Island electricity portfolio. ***Total cost of electric service increases*** across all scenarios driven by (1) higher electric demand and (2) higher cost of electric generation to meet the 100% Renewable Energy Standard.
+ Cost of service increases are ***largely offset by increased loads***, especially for scenarios with high load factors. In a Reference Scenario, ***achieving the 100% Renewable Energy Standard increases rates by ¢1.3-2.3/kWh by 2035.***

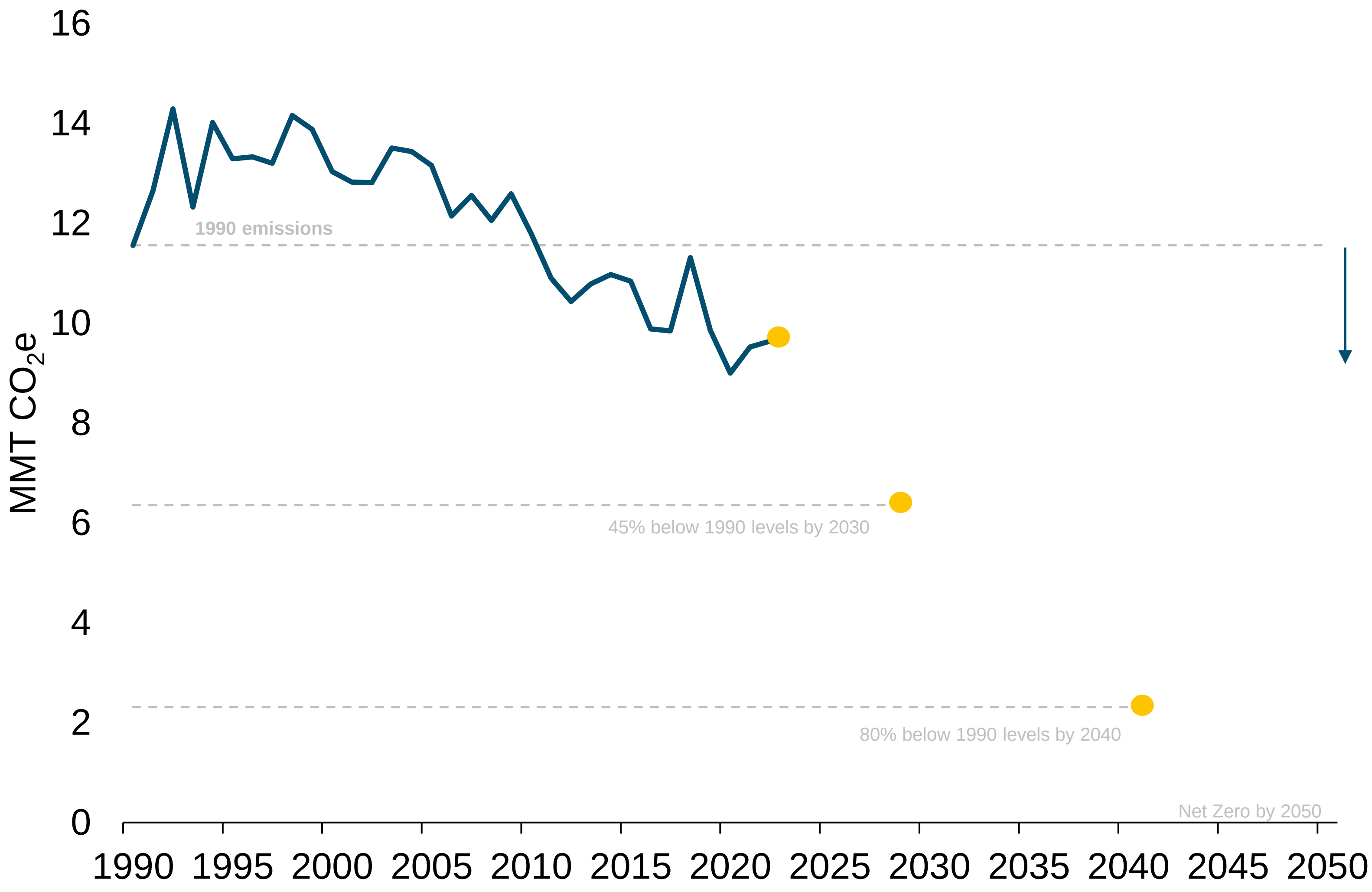
Decarbonization Pathways Technical Results

Impact on Emissions

Energy+Environmental Economics

Rhode Island's latest GHG Inventory shows a 20% reduction in emissions in 2020 compared to 1990 levels

Rhode Island Statewide Emissions Reductions – 1990-2020



2020 emissions: 22% below 1990 levels.

Key emissions reductions between 1990-2020 are attributed to:

- Electricity sector: - 27.7%
- Residential heating: -21.9%
- Transportation sector: -23.4%
- Fugitive methane emissions: -21.2%

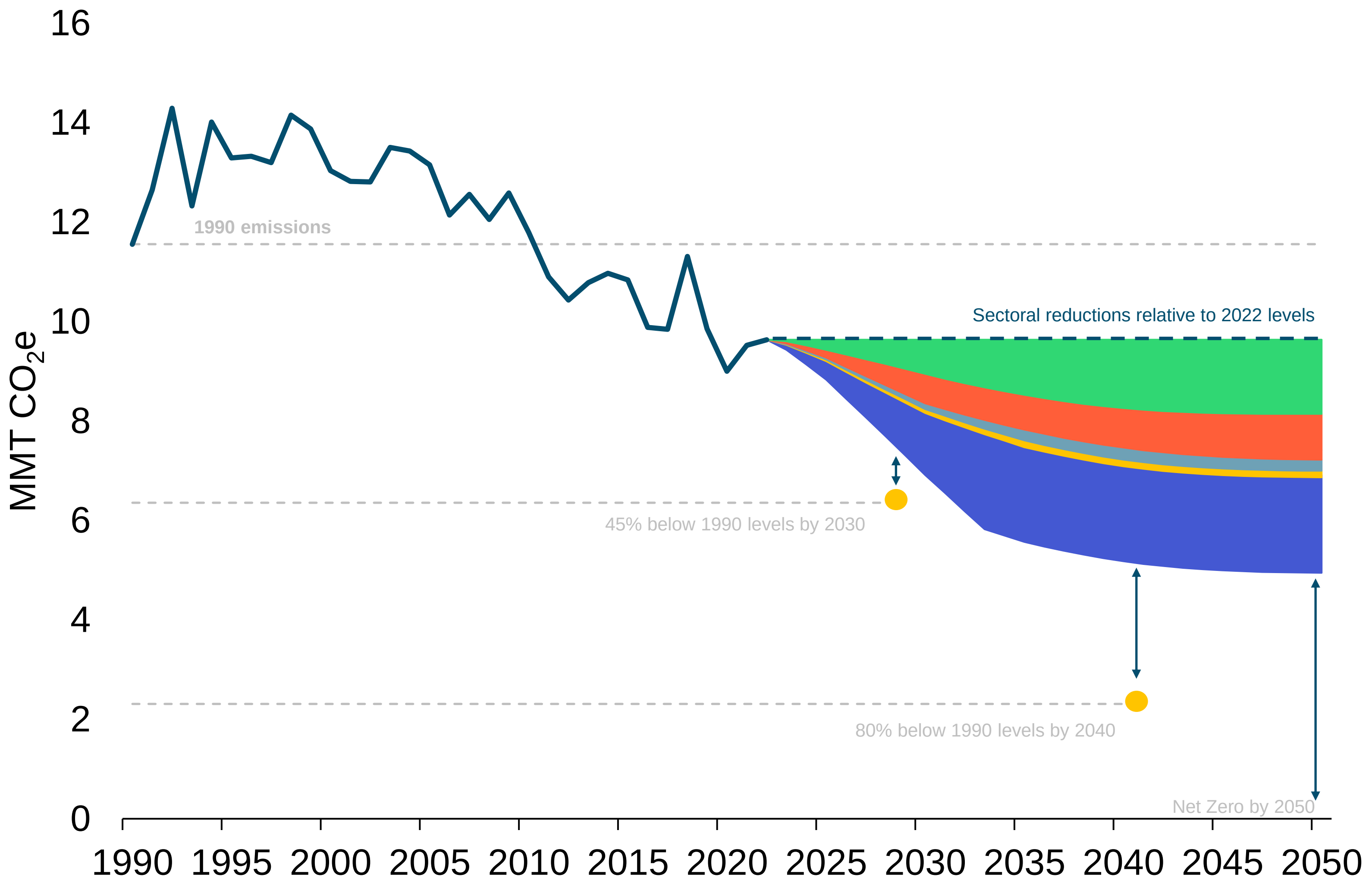
Emissions from hard-to-decarbonize sectors, such as non-road sources and industrial process emissions, saw a slight increase.

Source: 2020 Rhode Island Greenhouse Gas Emissions Inventory: https://dem.ri.gov/environmental-protection-bureau/air-resources/greenhouse-gas-emissions-inventory

DRAFT / PRELIMINARY

Existing policies and industry trends are expected to result in significant near-term emissions reductions

Rhode Island Statewide Emissions Reductions – Reference Scenario



Major emissions reduction contributions in reference scenario:

Transportation sector:
- Growth in EV penetration consistent with historical levels and EC4 target (10% of stocks by 2030)
- Modest levels of ZEV for MDV/HDV
- No adoption of ACCII/ACT

Building sector:
- Heat pump adoption & EE retrofits based on historical trends
- Biodiesel Heating Act: 50% biodiesel blending by 2030
- 100% sales shares of efficient gas furnaces by 2029
- Oil-to-gas conversions

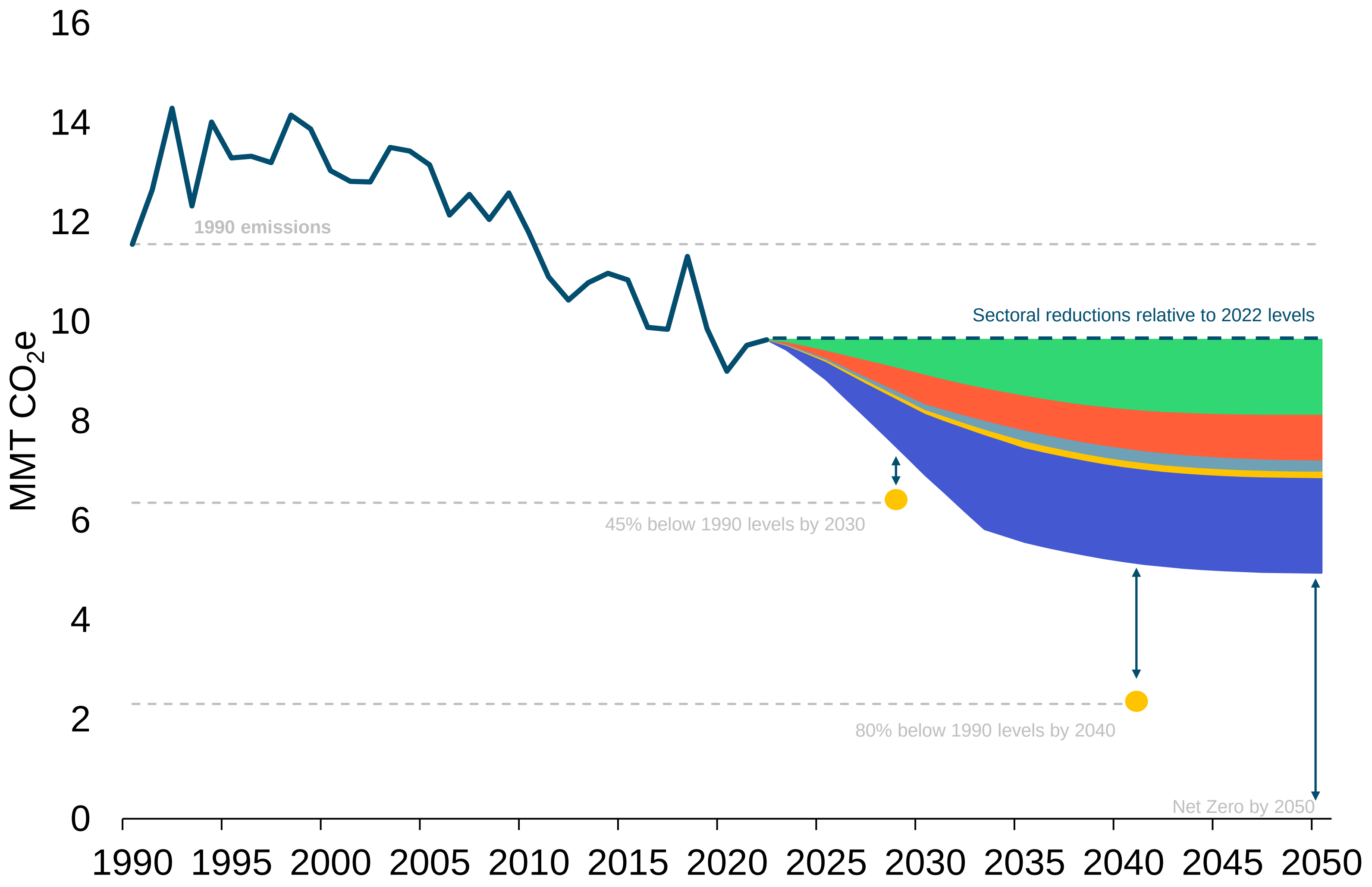
Electricity sector:
- 100% Renewable Energy Standard by 2033

DRAFT / PRELIMINARY

Emissions reductions from sector: Transportation | Buildings | Industry, Waste & Sinks | Gas distribution | Electricity

Despite significant emissions reductions, additional efforts are required to achieve the Act on Climate

Rhode Island Statewide Emissions Reductions – Reference Scenario



2022 emissions: 9.7 MMT CO_2e (-16%)
Between 2020-2022, emissions are expected to increase as a result of post-COVID activity.

2030 emissions gap to achieve AoC:
0.7 MMT CO_2e

2040 emissions gap to achieve AoC:
3.0 MMT CO_2e

2050 emissions gap to achieve AoC:
5.1 MMT CO_2e

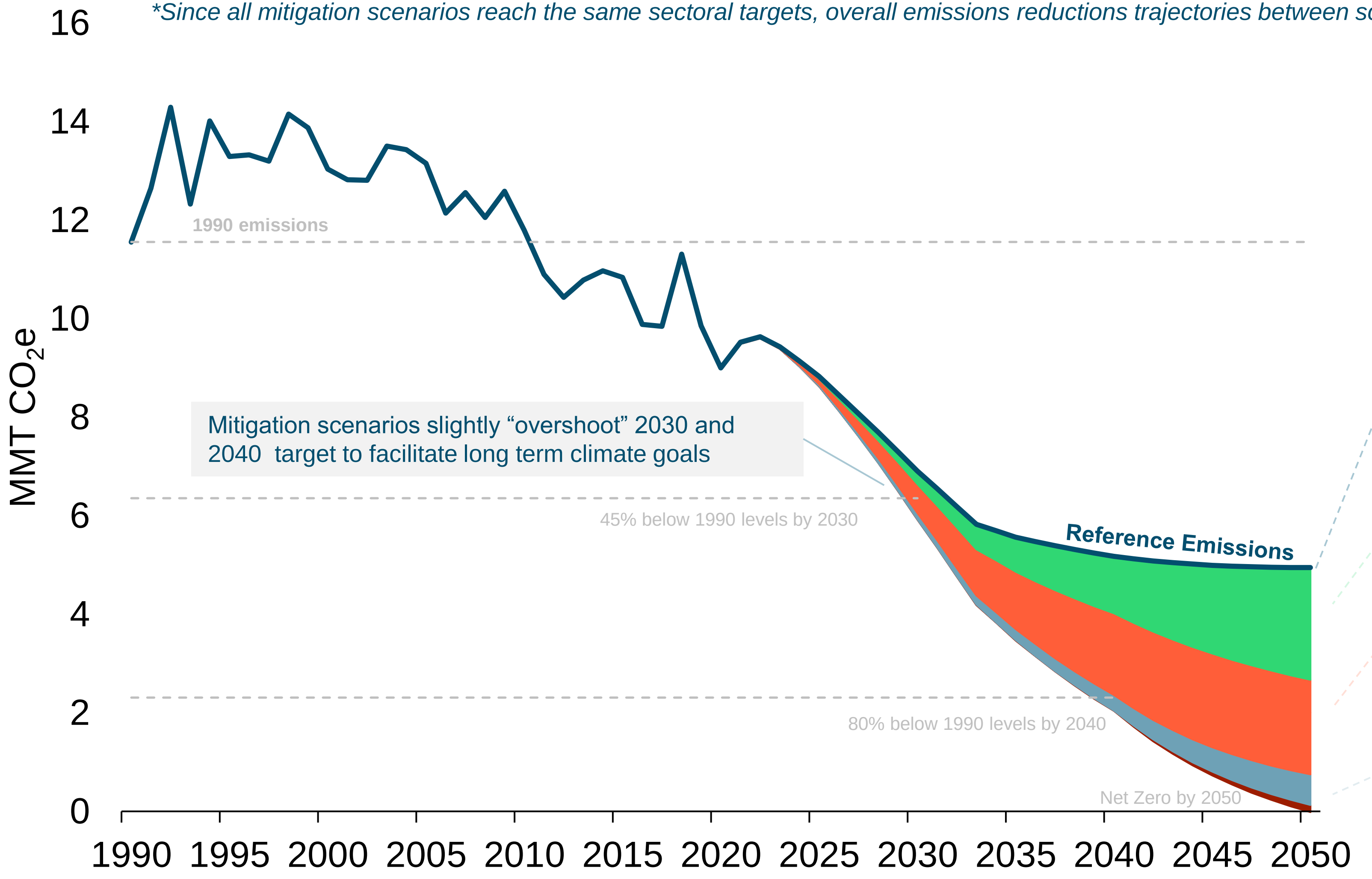
DRAFT / PRELIMINARY

Emissions reductions from sector: Transportation | Buildings | Industry, Waste & Sinks | Gas distribution | Electricity

All mitigation scenarios achieve the Act on Climate, large focus on buildings and transportation required post 2030

Rhode Island Statewide Emissions Reductions – Mitigation Scenarios*

**Since all mitigation scenarios reach the same sectoral targets, overall emissions reductions trajectories between scenarios are similar.*



Reference scenario emissions:
57% emissions reduction by 2050.

The Reference scenario falls short of achieving the AoC Net Zero by 2050 target

Transportation sector:
- Growth in EV penetration for LDV and MHDV consistent with Advanced Clean Cars II and Advanced Clean Trucks

Building sector:
- All-electric and hybrid ASHP adoption; key variations by scenario
- Networked geothermal adoption in High Electrification and Alt. Heat Infrastructure
- Variations in renewable fuels blending

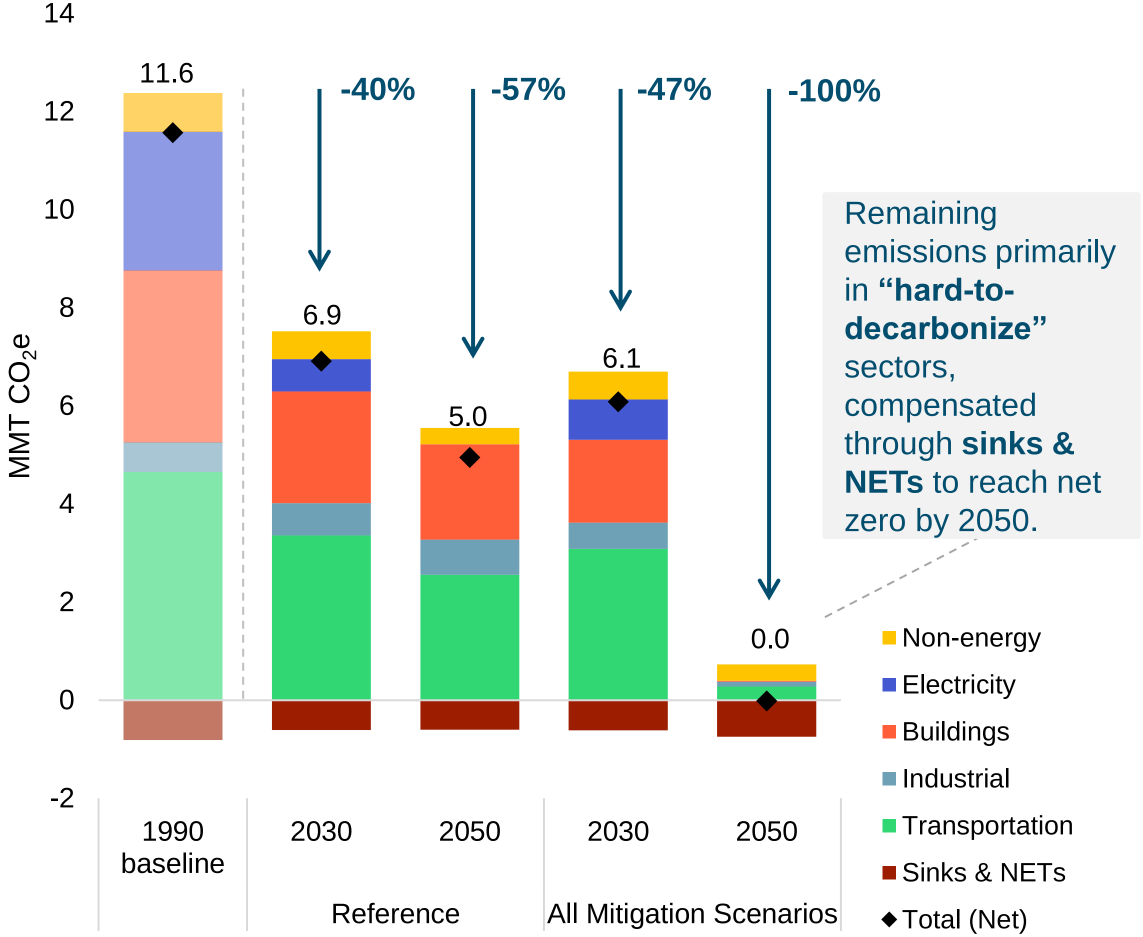
Industrial sector:
- The industrial sector decarbonizes through a range of electrification and fuel-switching measures, as feasible

DRAFT / PRELIMINARY

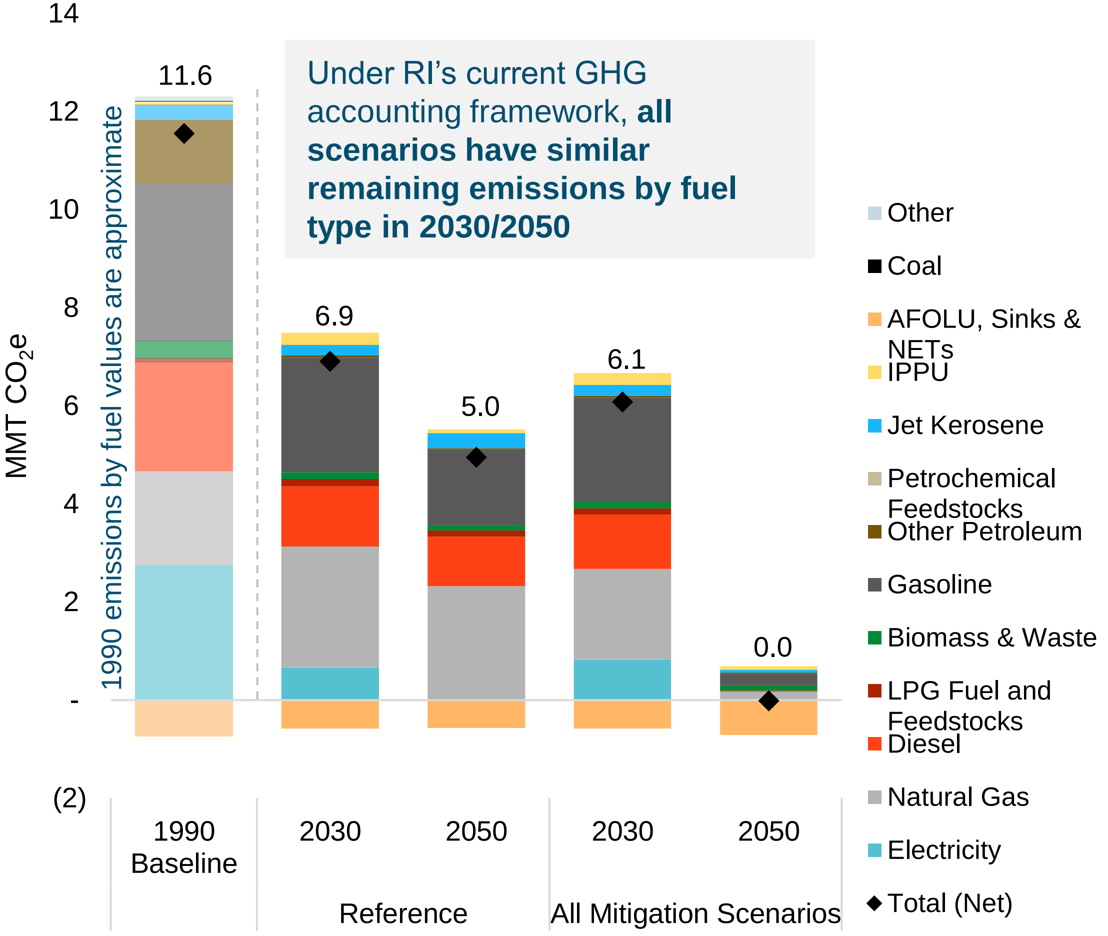
Emissions reductions from sector: Transportation | Buildings | Industry | Gas distribution | Sinks & NETs

By 2050, remaining emissions from harder-to-decarbonize sectors are offset by sinks & NETs

2030/2050 remaining emissions by sector



2030/2050 remaining emissions by fuel

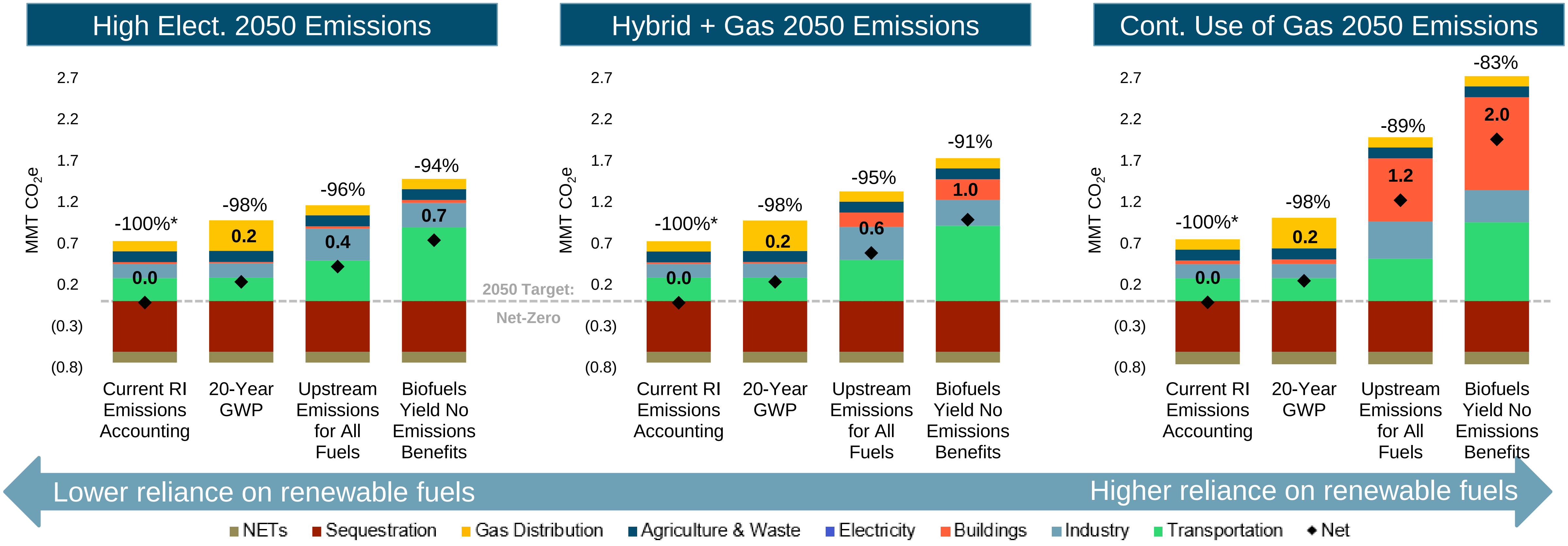


AFOLU = Agriculture, Forestry, and Other Land Use
IPPU = Industrial Processes and Product Use

Scenarios with higher levels of renewable fuels may have higher emissions under alternative accounting frameworks

The Technical Analysis is based on emissions accounting **consistent with federal and RI's accounting standards**.

Through **sensitivity analysis**, E3 assessed scenario-specific differences under other types of emissions accounting methodologies. This analysis shows that scenarios that **rely more heavily on renewable fuels** are most sensitive to the use of alternative accounting frameworks.

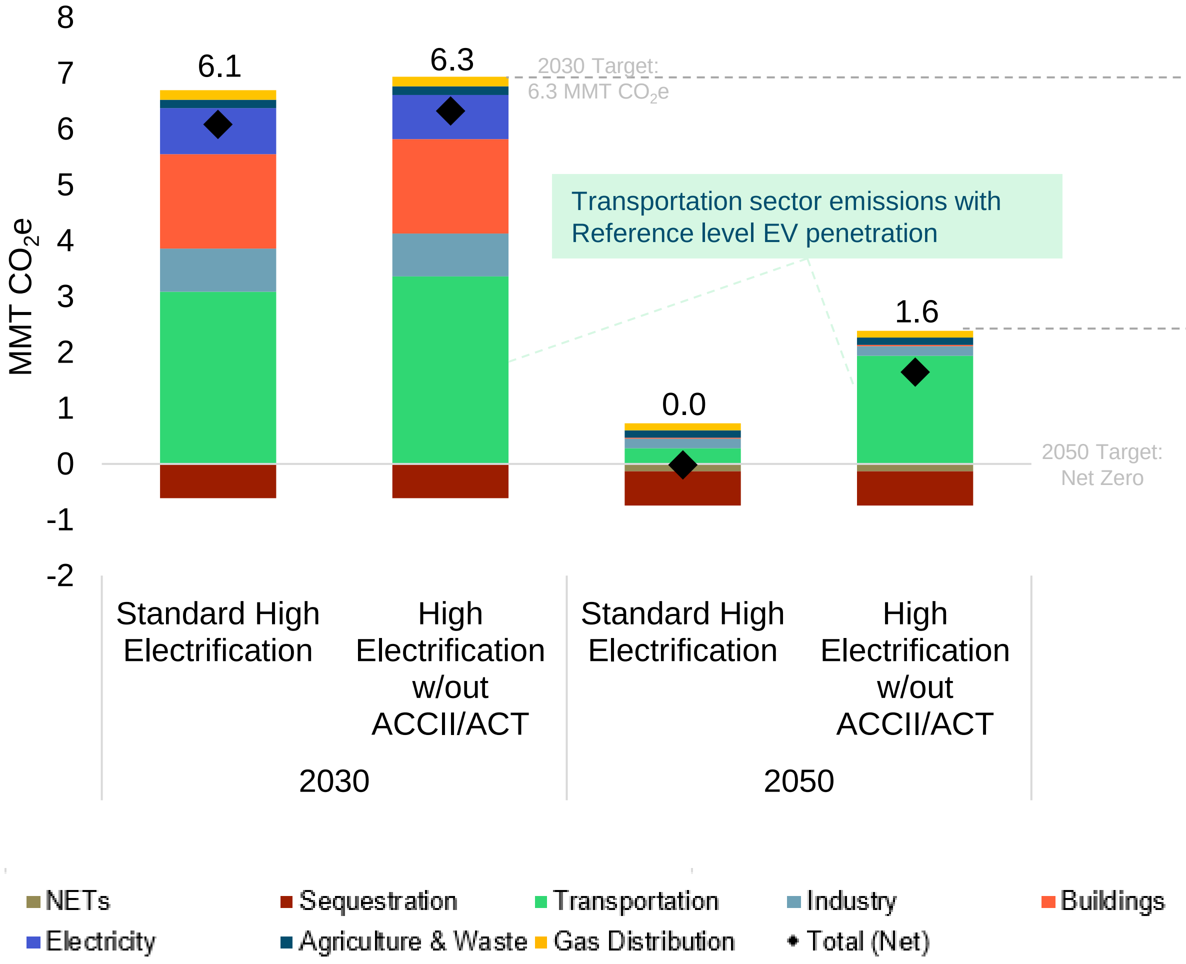


DRAFT / PRELIMINARY

* Compared to 1990 emissions levels. The impact on other scenarios is provided in the appendix.

Delayed achievement of ACCII and ACT requires deeper measures to achieve AoC, primarily in the long term

Remaining Emissions w/ and w/out ACCII/ACT – High Electrification scenario



High Electrification **would meet the 2030** target even if ACCII/ACT follows a slower trajectory in the short term. This is due to accelerated action in the buildings sector that are required to reach longer term climate goals*

By 2050, High Electrification will have approx. 1.65 MMT CO_2e remaining in 2050 without achievement of ACCII/ACT, thus missing the target by about 14%

If EV penetration is consistent with historical levels and EC4 target (10% of stocks by 2050) instead of ACCII/ACT, RI will not meet the 2040/2050 AoC targets without higher renewable fuel blending or deeper measures in other sectors.

In High Electrification, the buildings sector is completely electrified. Thus, if the ACCII/ACT is not achieved, higher renewable fuel blending in the Transportation sector will be required.

In other mitigation scenarios, deeper building electrification measures can be adopted if the ACCII/ACT is not met.

*Note: The High Electrification scenario is designed to avoid blending of renewable fuels in the long term. As a result of slow stock rollover, accelerated adoption of building electrification in the near term is required to achieve this objective, resulting in deeper emissions reductions than required in the AoC.

Decarbonization Pathways Technical Results

Impact on Technology Adoption

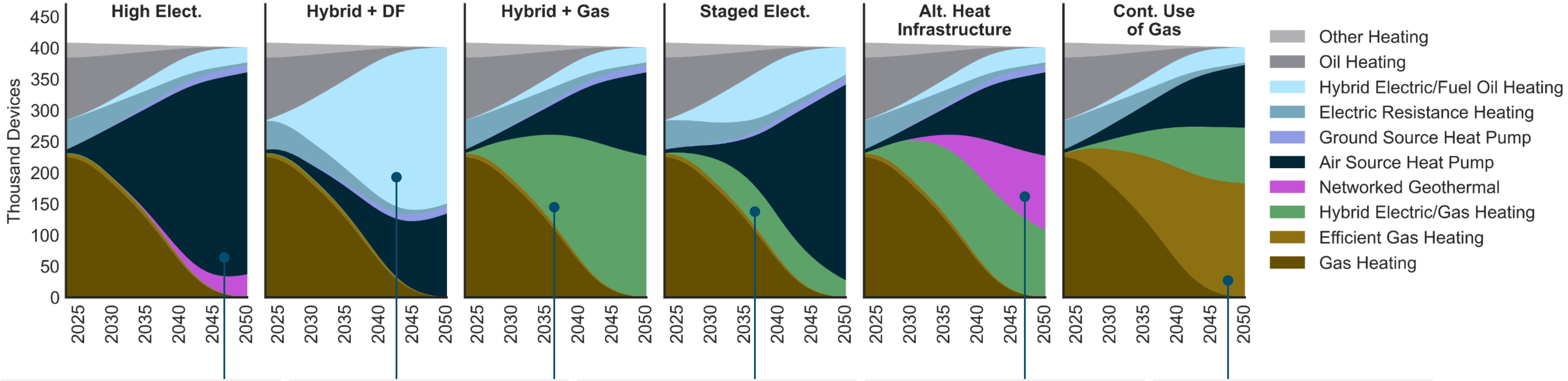
Energy+Environmental Economics

Mitigation scenarios achieve AoC through a distinct mix of technology adoption in the residential sector

Across scenarios, buildings reach similar **levels of emissions reductions** using a variety of decarbonization technologies.

All mitigation scenarios **require rapid adoption** of space heating decarbonization technologies in the residential sector.

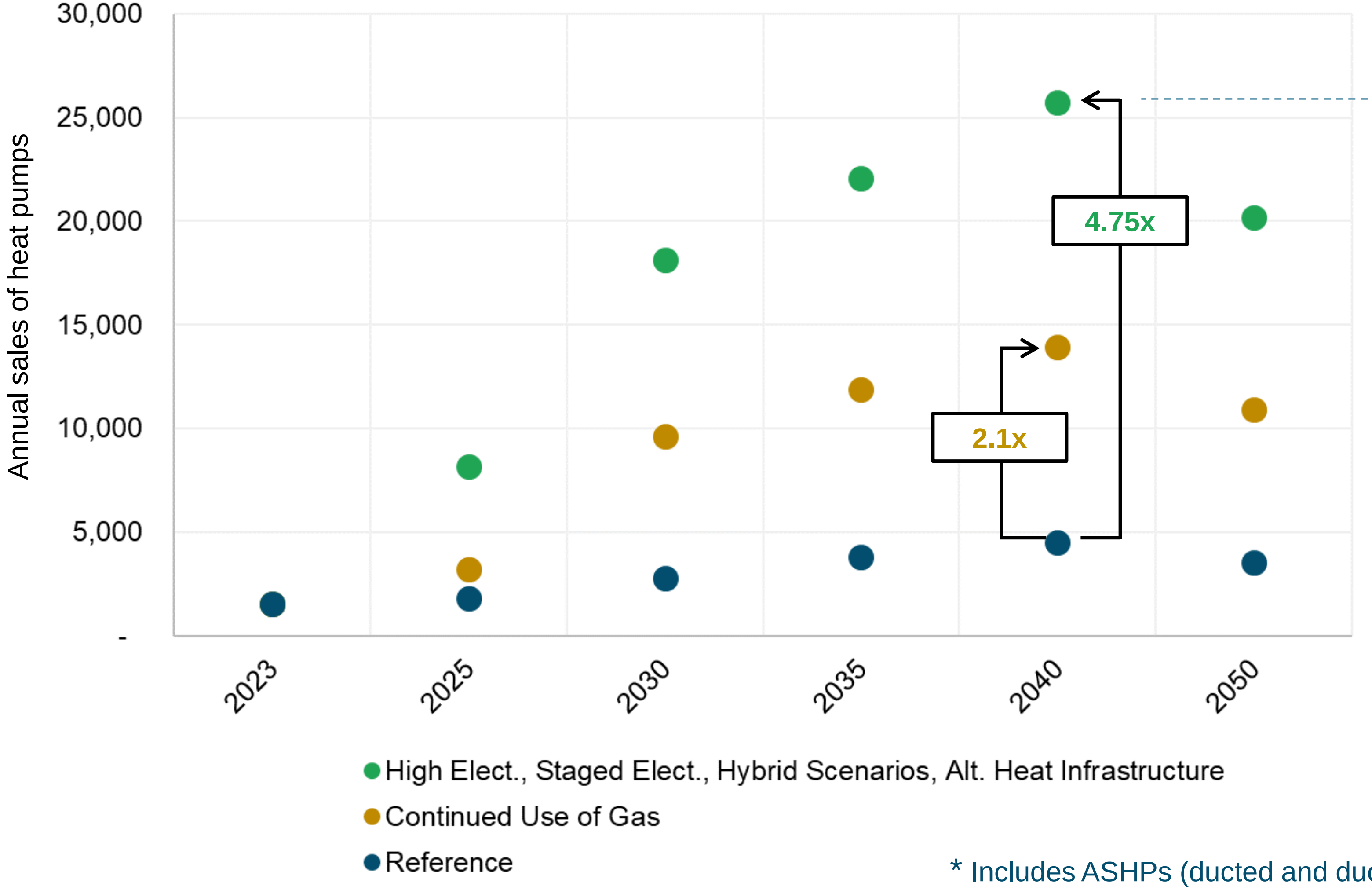
Residential Household Heating Equipment Adoption in Rhode Island



High Elect.	Hybrid + DF	Hybrid + Gas	Staged Elect.	Alt. Heat Infrastructure	Cont. Use of Gas
Focus on ASHP adoption, “niche” levels of networked geothermal	Same number of hybrid adoption, with different types of backup	Near-term adoption of hybrids, long-term conversion to ASHP	Combination of hybrids and networked geothermal systems	Continued adoption of high-efficiency gas, including hybrids	
By 2050: 93% all-electric 6% hybrid	**By 2050: 36% all-electric 62% hybrid**	**By 2050: 81% all-electric 17% hybrid**	**By 2050: 66% all-electric 33% hybrid**	**By 2050: 25% all-electric 28% hybrid**	

Annual adoption of decarbonization technologies needs to increase significantly to support AoC

Annual Sales of Heat Pumps* in the Residential Sector



Sales of heat pumps are expected to peak in 2040 in order to reach emissions reduction levels by 2050.

In scenarios focused on higher levels of electrification, annual heat pump sales exceed 25,000 devices in 2040, **nearly five times** higher compared to the reference scenario and approximately **10 times** higher than today's adoption levels.

The Continued Use of Gas scenario primarily relies on adoption of **hybrid heat pumps** and high-efficiency gas furnaces (the latter not included in the chart).

The Reference Scenario sees modest increase in heat pump adoption levels, **not reaching the AoC targets**.

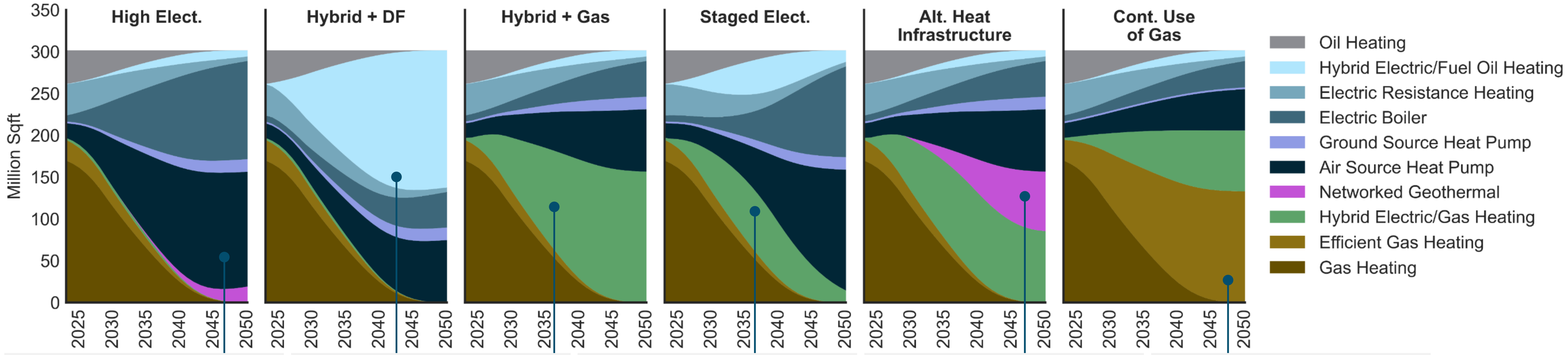
* Includes ASHPs (ducted and ductless), hybrid ASHPs, GSHPs, and networked geothermal

Commercial sector sees similar levels of technology adoption to residential; larger focus on boilers

Across scenarios, buildings reach similar **levels of emissions reductions** using a variety of decarbonization technologies.

All mitigation scenarios **require rapid adoption** of space heating decarbonization technologies in the commercial sector.

Commercial Heating Equipment Adoption in Rhode Island

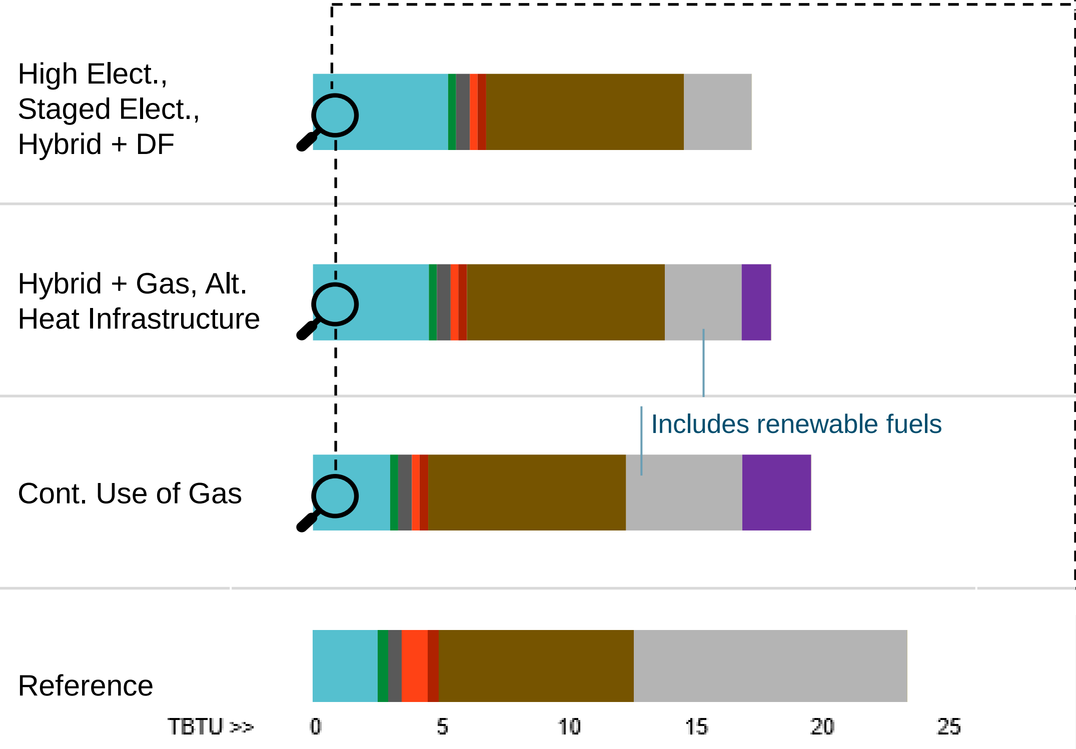


High Elect.	Hybrid + DF	Hybrid + Gas	Staged Elect.	Alt. Heat Infrastructure	Cont. Use of Gas
Focus on ASHP and electric boiler adoption with some networked geothermal	Same number of hybrid technology adoption (HPs and boilers), with different types of backup	Near-term adoption of hybrid HPs and boilers, long term conversion to all-electric	Combination of hybrid HPs, hybrid boilers, and networked geothermal systems	Continued adoption of high-efficiency gas, including hybrid HPs and hybrid boilers	
By 2050: 96% all-electric 2% hybrid	**By 2050: 44% all-electric 54% hybrid**	**By 2050: 89% all-electric 9% hybrid**	**By 2050: 67% all-electric 31% hybrid**	**By 2050: 28% all-electric 27% hybrid**	

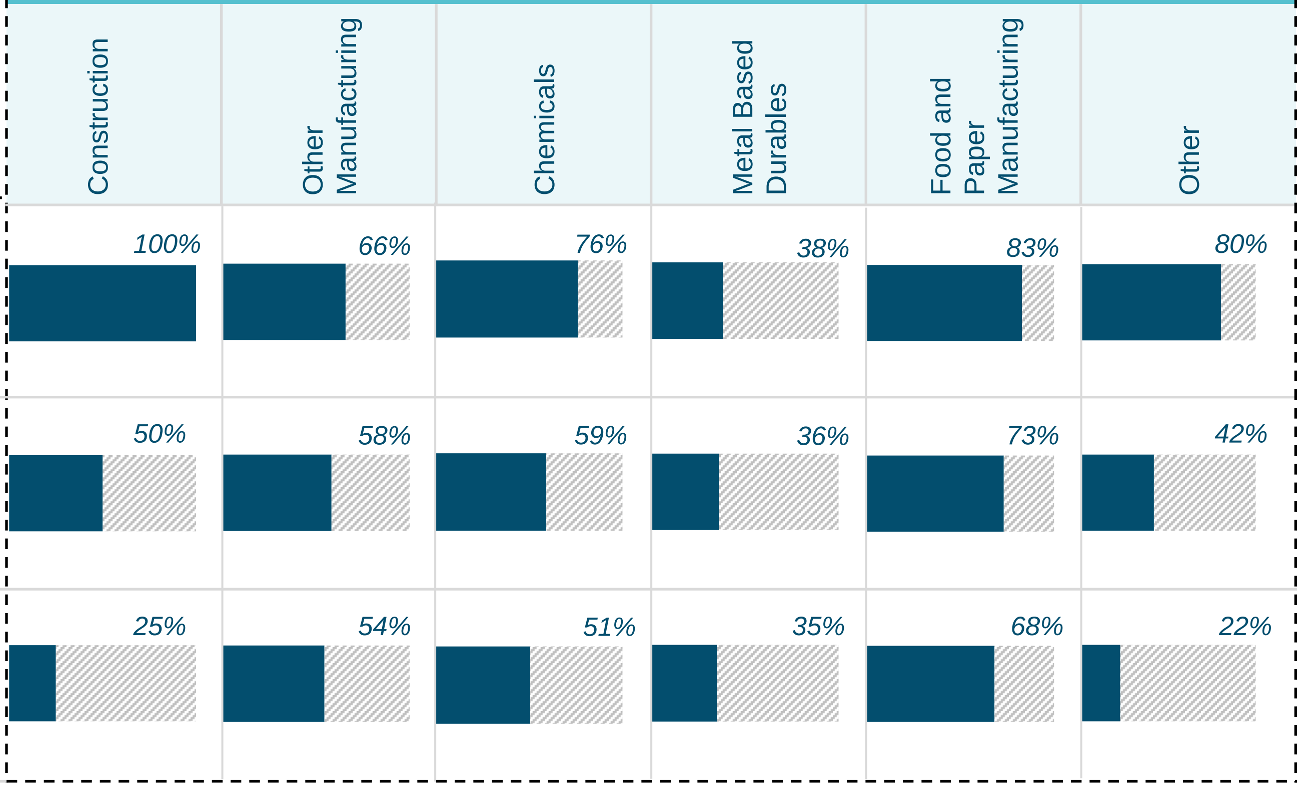
Industrial sector sees significant efficiency across scenarios; reliance on electrification vs. fuel-switching varies

Energy Demand in 2050 (TBTU)

Energy demand shrinks in all scenarios compared to the Reference trajectory due to efficiency and electrification, though levels of electrification vs. fuel switching varies



Industrial Subsector Electrification Levels in 2050 (%)



Subsectors with **high electrification potential are primarily electrified** across scenarios, with more aggressive adoption levels in the high electrification scenario. Subsectors that are harder to decarbonize **leave a role for pipeline gas** and see **increased adoption of dedicated hydrogen**.

DRAFT / PRELIMINARY

Electricity, Biomass & Waste, Gasoline, Jet Kerosene, Diesel, LPG Fuel and Feedstocks, Other Petroleum, Pipeline Gas, Hydrogen, Petrochemical Feedstocks

Electrified, Not Electrified

Decarbonization Pathways Technical Results

Impact on Fuel Usage

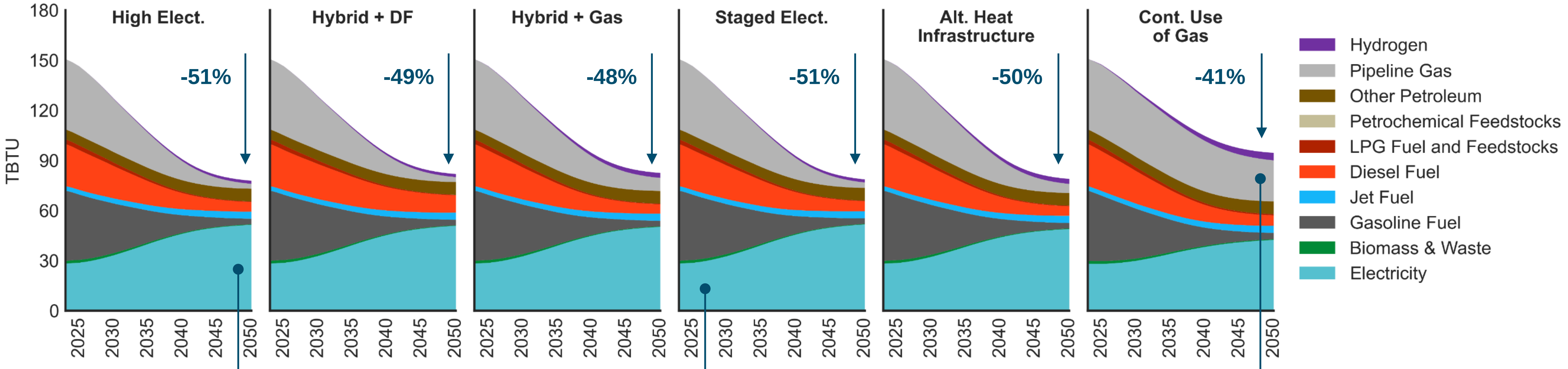
Energy+Environmental Economics

Final energy demand declines across scenarios as a result of efficiency and fuel switching

Across scenarios, **final energy demand decreases between ~40-50% by 2050** as a result of efficiency & electrification.

All scenarios see **transformational changes** in the way Rhode Island uses energy.

Change in economy-wide final energy demand across scenarios: 2023 - 2050



Highest levels of EE due to electrification

Highest levels of remaining pipeline gas* & hydrogen

None of the scenarios fully eliminate gas. Scenarios with high levels of electrification leave gas usage in the industrial sector

All scenarios see **increased levels of electricity load** and a significant **reduction in gasoline and diesel fuel**

DRAFT / PRELIMINARY

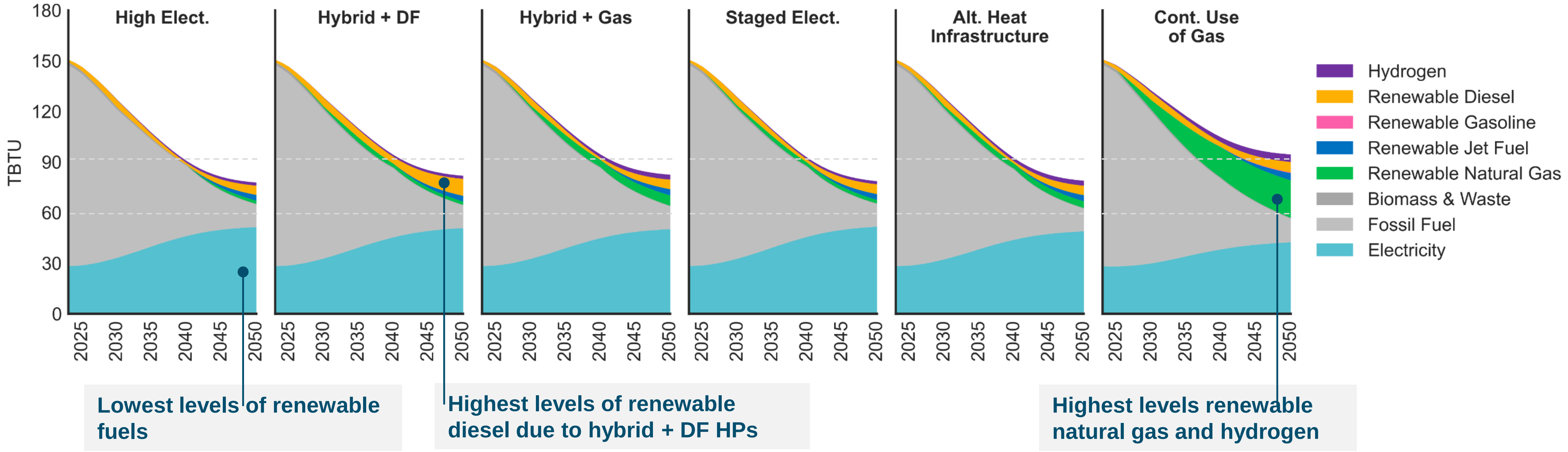
*Includes renewable fuels, visualized on the following slide.

By 2050, 40-60% of final energy demand is served by electricity while the need for renewable fuels increases

Across scenarios, **some level of renewable fuel blending** is needed to meet 2050 emissions targets.

Scenarios with lower levels of electrification see higher renewable fuel blending to comply with AoC goals.

Change in economy-wide final energy demand across scenarios: 2023 - 2050



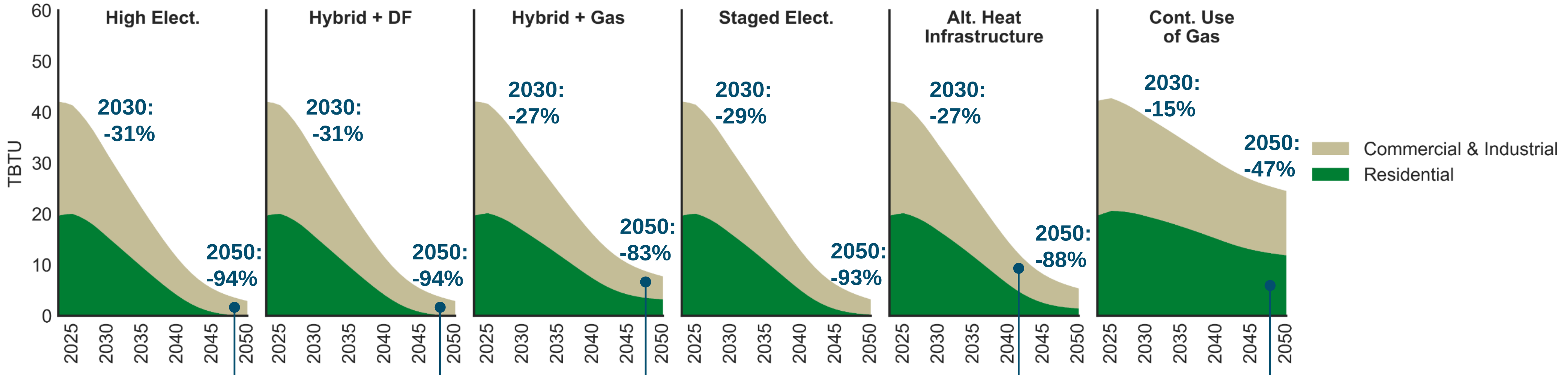
All scenarios comply with the Biodiesel Heating Oil Act of 2013, requiring 20% blend in 2025 and 50% blend in 2030

All scenarios rely on renewable fuels to meet emissions targets, lower electrification scenarios require higher levels.

Gas throughput in Rhode Island declines across all scenarios

Across scenarios, **final gas throughput decreases between ~45-95% by 2050** as a result of efficiency & electrification.
Some levels of gas throughput remain in the Commercial & Industrial sector.
All scenarios see some level of **RNG blending** by 2050, with higher levels in scenarios that rely more heavily on gas.

Change in levels of gas throughput: 2023 - 2050



Gas use remains in small portions of the system to serve hard-to-decarbonize C&I loads

Residential & commercial gas use primarily for winter backup heating

35% of industrial use switches to hydrogen

By 2050: 70% RNG blend

By 2050: 72% RNG blend

By 2050: 82% RNG blend

By 2050: 70% RNG blend

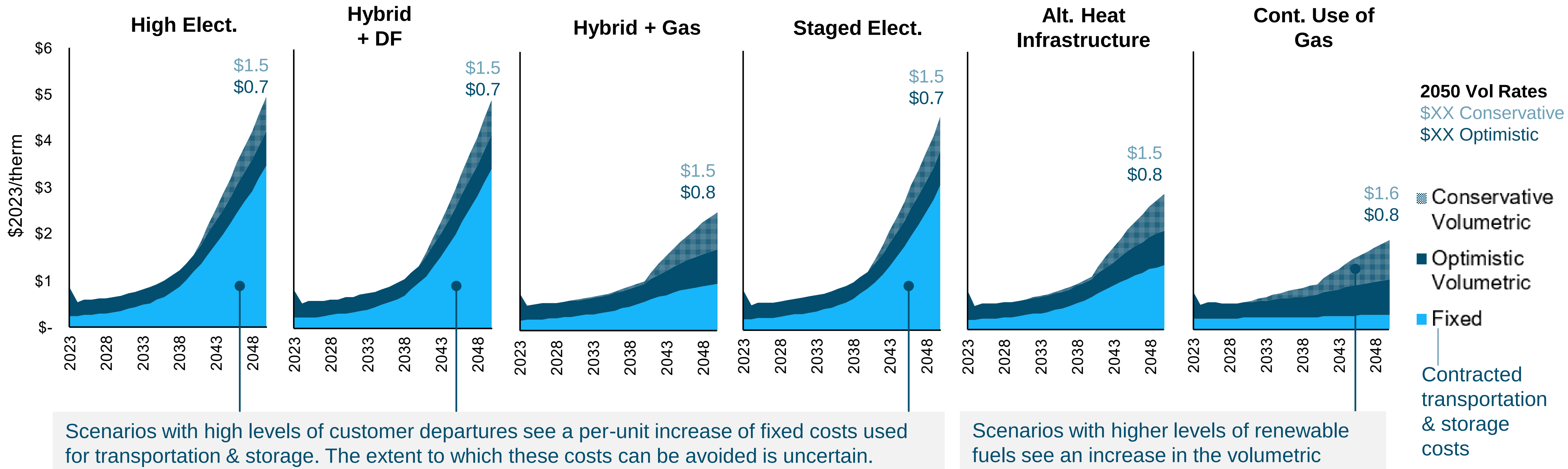
By 2050: 78% RNG blend

By 2050: 92% RNG blend

Costs of gas are expected to rise for gas customers as a result of increased RNG blending

As a result of increased blending of renewable fuels and a decline of system throughput, **the cost of gas is expected to rise**. In scenarios with high levels of electrification, fixed costs (transportation & storage) rise as the costs are spread among fewer customers. After 2040, C&I customers are expected to rely on higher levels of RNG increasing volumetric costs. Residential costs of gas are provided in the Appendix.

Costs of C&I gas supply across scenarios, distinguishing fixed & volumetric components*: 2023-2050



Scenarios with high levels of customer departures see a per-unit increase of fixed costs used for transportation & storage. The extent to which these costs can be avoided is uncertain.

Scenarios with higher levels of renewable fuels see an increase in the volumetric (commodity) component of the costs of gas.

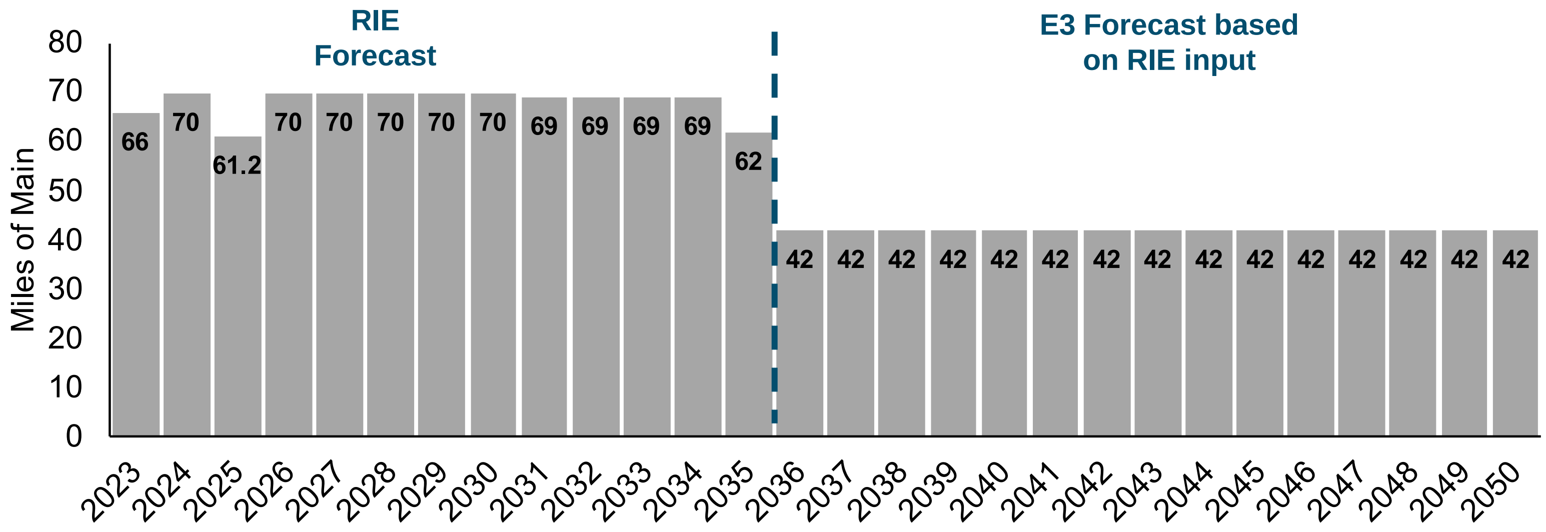
*Fixed component includes the costs of storage & transportation contracts. ***Delivery costs of gas are not included on this slide.***

Decarbonization Pathways Technical Results

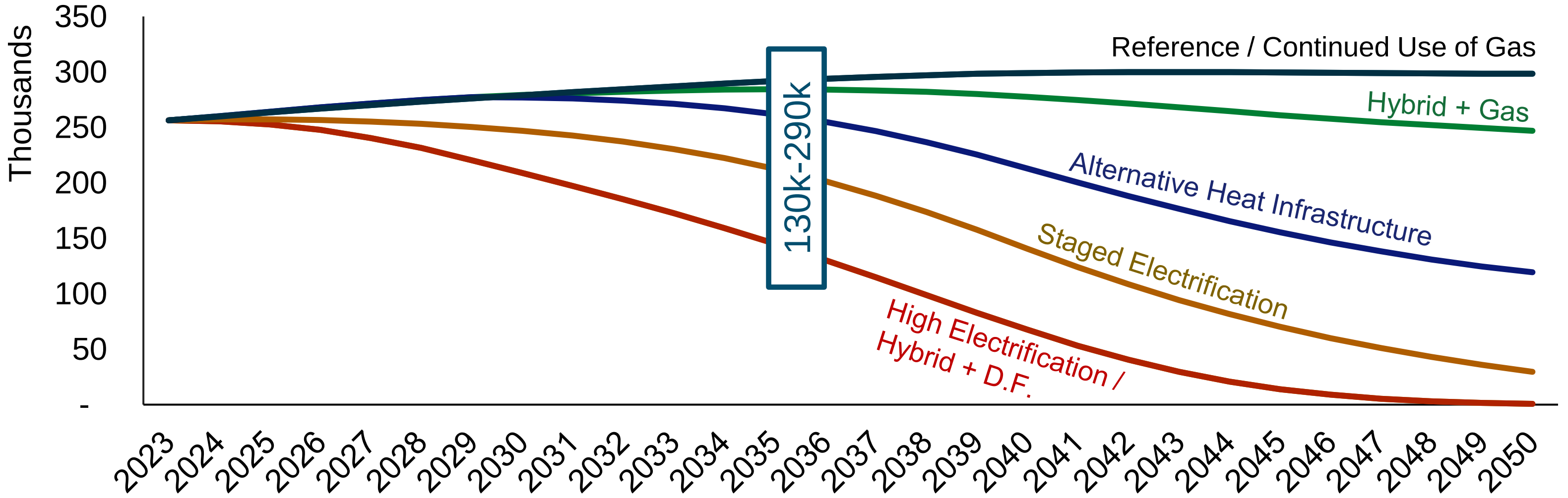
Impact on Gas System

In most scenarios, pipeline replacements driven by ISR will serve fewer customers over time

Replacement Miles (Mains)

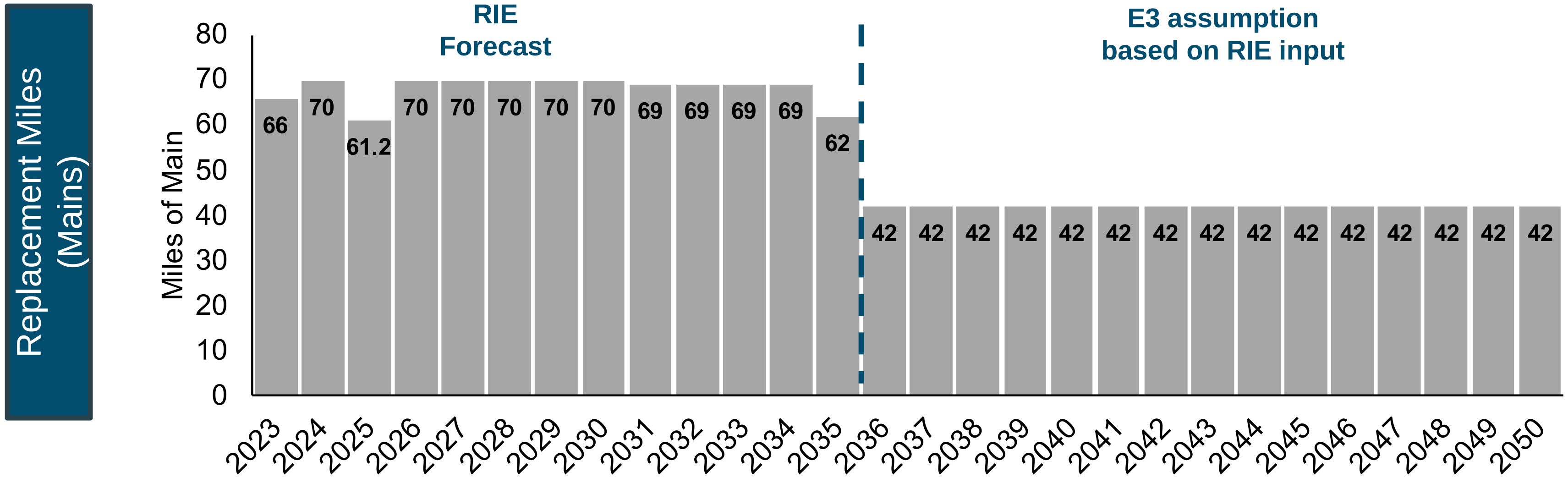


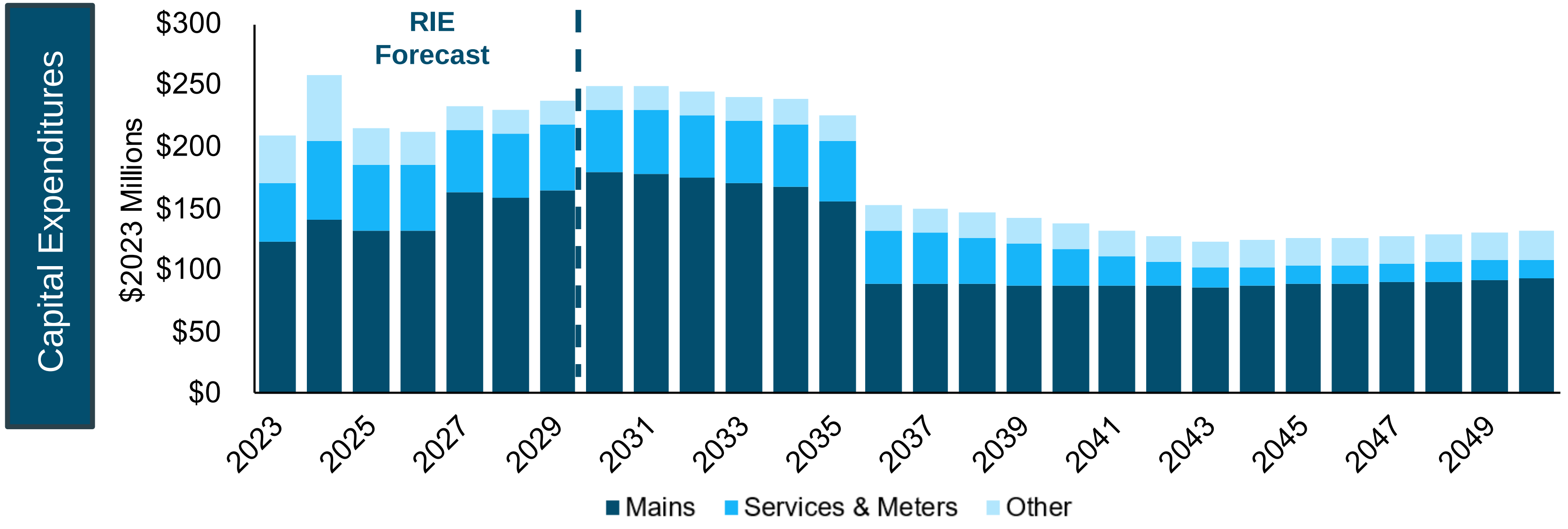
Customers with a gas connection



- The Infrastructure, Safety & Reliability (ISR) Plan ensures safe and reliable service of gas in the next decade, with a strong focus on **replacement of Leak Prone Pipe (LPP)** infrastructure.
- The ISR program is expected to replace up to 900 miles of pipe in the next decade, reaching **completion in 2035.** Post-2035, RIE expects to continue to replace (plastic) mains at end-of-life
- In 4 out of 6 mitigation scenarios, electrification drives a reduction of gas customers. The High Electrification and Hybrid Delivered Fuels Backup scenarios have approximately 130,000 customers remaining by the end of the ISR program, **a reduction of +/-50% compared to today**.

High level of capital expenditures are expected in the next decade through the Infrastructure, Safety & Reliability Plan





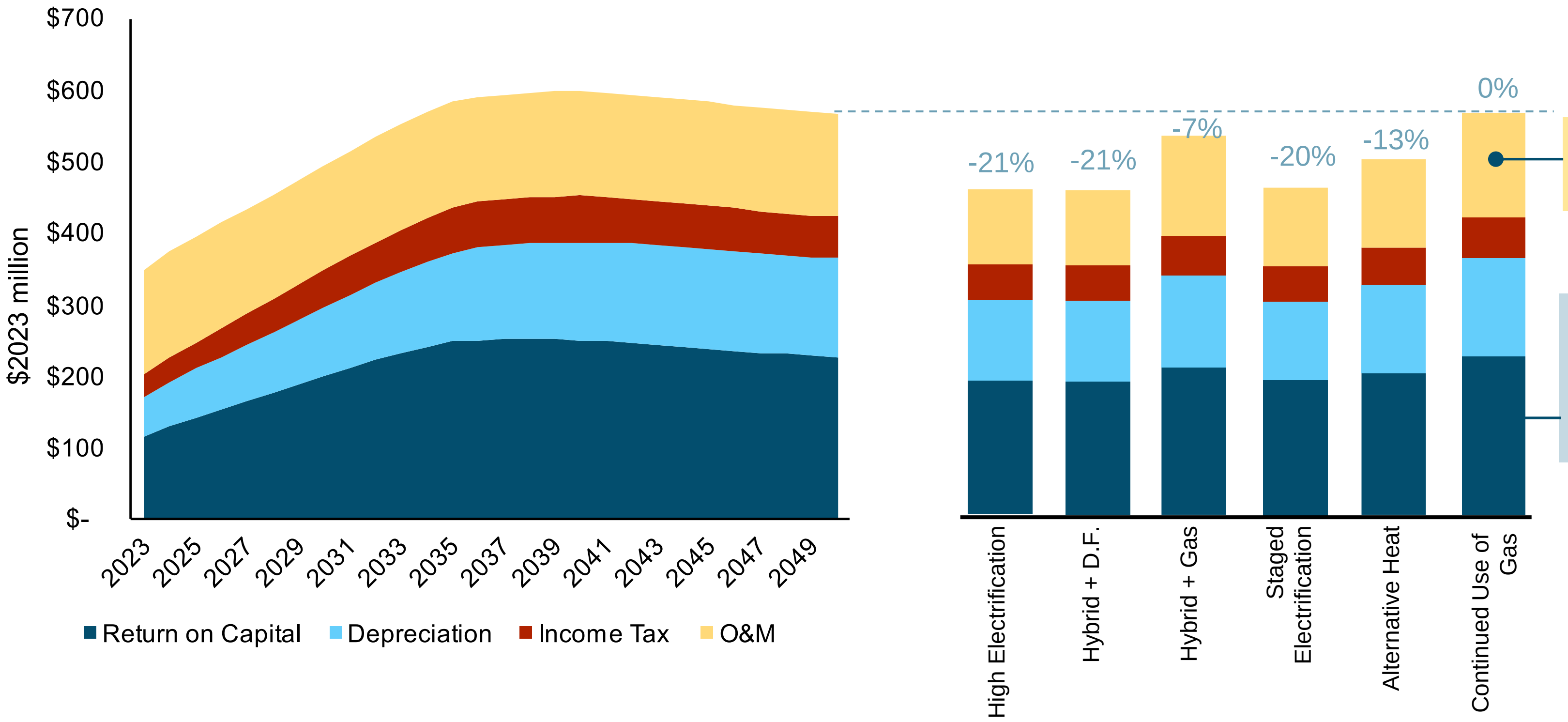
- Elevated capex through 2035 reflects the high **rate of mains and service replacements** for newer, plastic pipes. Beyond 2035, RIE expects a continuous replacement program for mains & services that are reflected in the CAPEX forecast, assuming CAPEX cost escalation.
- CAPEX related to new gas ***customer connections***, representing oil-to-gas conversions are also represented on the (bottom) chart. On this chart, total CAPEX including new customer connections are shown for a Reference Scenario. In an unmanaged transition, the CAPEX trajectory will show slight variations across scenarios due to differences in customer connections.

In an unmanaged transition, costs of the gas system will continue to rise

Planned levels of capital expenditures through ISR program and additional customer connections in a Reference Scenario cause **annual costs of the gas system to nearly double towards 2050**, assuming an *unmanaged transition.* Scenarios that do not assume additional customer connections reduce annual costs by approximately 20% by 2050.

RIE Gas Revenue Requirement (RR) in Reference Scenario

2050 Mitigation Scenarios (unmanaged)



Variations in O&M are a result of differences in customer departures and customer additions.

Return on capital costs increases across all scenarios as a result of capital expenditures. Scenario variations are the result of lower new customer connections compared to the Reference.

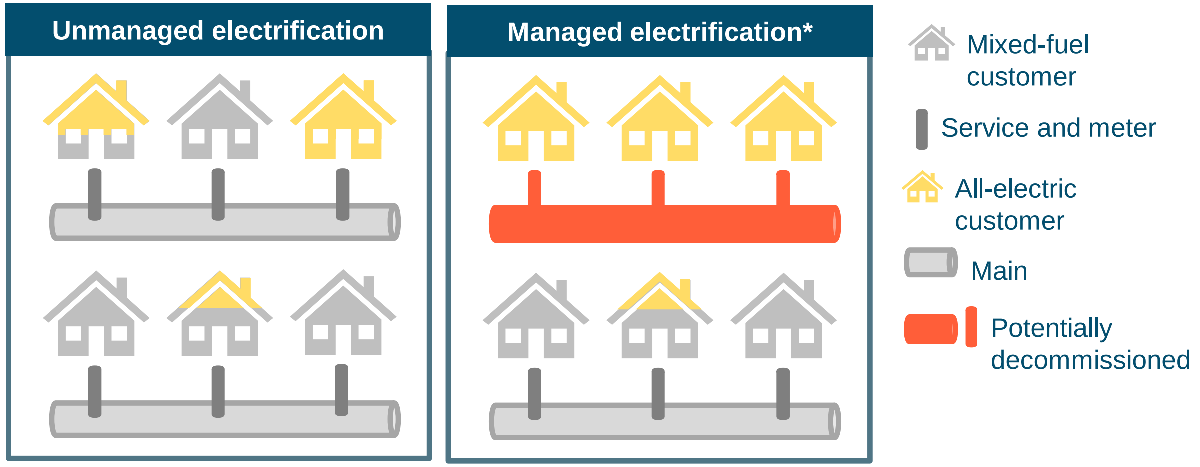
A managed transition assumes a portion of planned capital replacement costs can be avoided

All RIE Gas Distribution Mains — **~3,200** miles

Scheduled Replacements — **~1500** miles by 2050*

Hydraulically feasible — **~750 miles** (50% of scheduled replacements - E3 illustrative assumption; requires RIE-specific study)

? ⟷ **Cost Effective** — *For further investigation (out of scope for this study)*

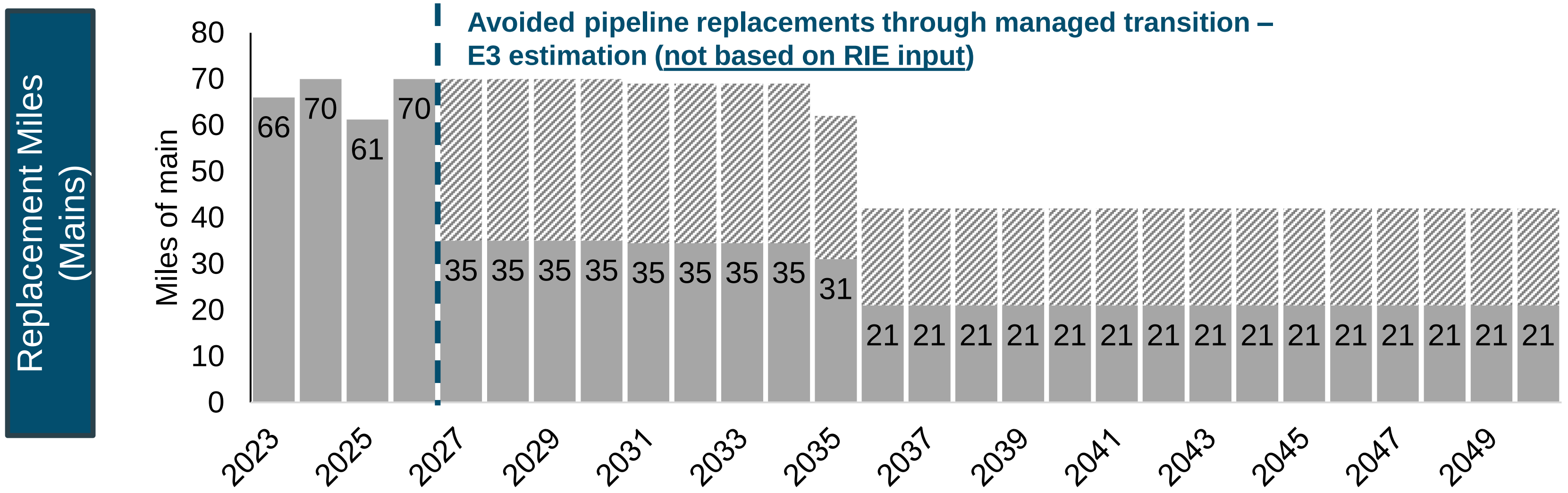


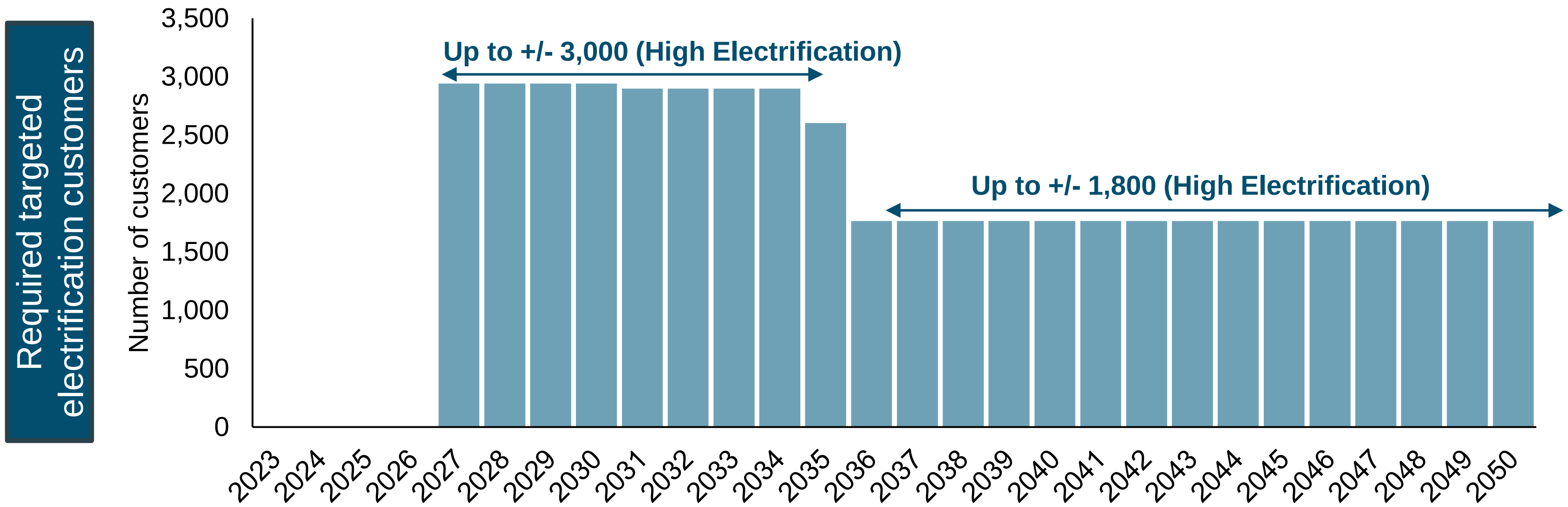
*Also referred to as "**targeted/zonal electrification and gas decommissioning**"

- In a managed transition, investments and incentives will be **geographically focused** to allow parts of the gas system to be decommissioned
- Between now and 2050, **only a portion of RIE's gas mains are up for replacement** and can result in avoided capex if retired. Capex is not avoided when retiring undepreciated gas mains.
- To retire a gas pipeline, it must be considered ***hydraulically feasible,*** meaning the gas system maintains gas flow and the minimum allowable pressure

* Based on RIE's estimation of replacement miles between 2023-2050 (see slide 43). Represents all cast iron + unprotected steel, plus additional post-2035 plastic mains that are expected to reach end of life.

A managed transition may avoid replacements, but requires significant levels of targeted electrification



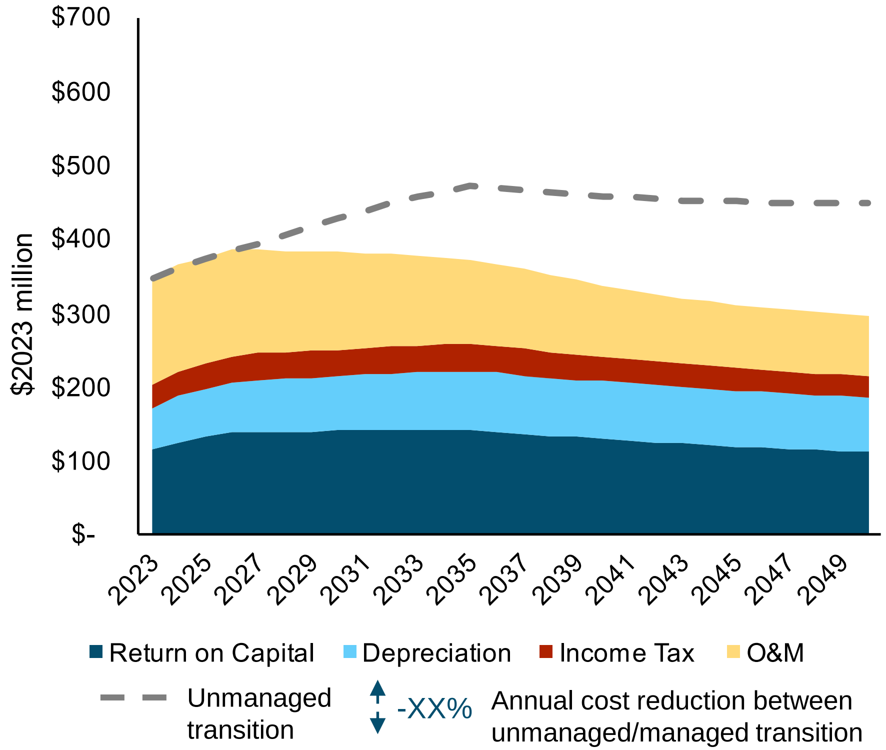


- In a managed transition, investments and incentives will be **geographically focused** to allow parts of the gas system to be decommissioned.
- To retire a gas pipeline, it must be considered ***hydraulically feasible,*** meaning the gas system maintains gas flow and the minimum allowable pressure.
- For the purpose of this study, E3 assumed that up to 50% of pipeline replacements may be avoidable in a managed transition***; this assumption is not based on input from RIE*** and needs significant additional study.
- If 50% of pipeline replacements are avoidable, up to 3,000 customers per year need to electrify their heating system in a targeted manner, with implications for customer choice.

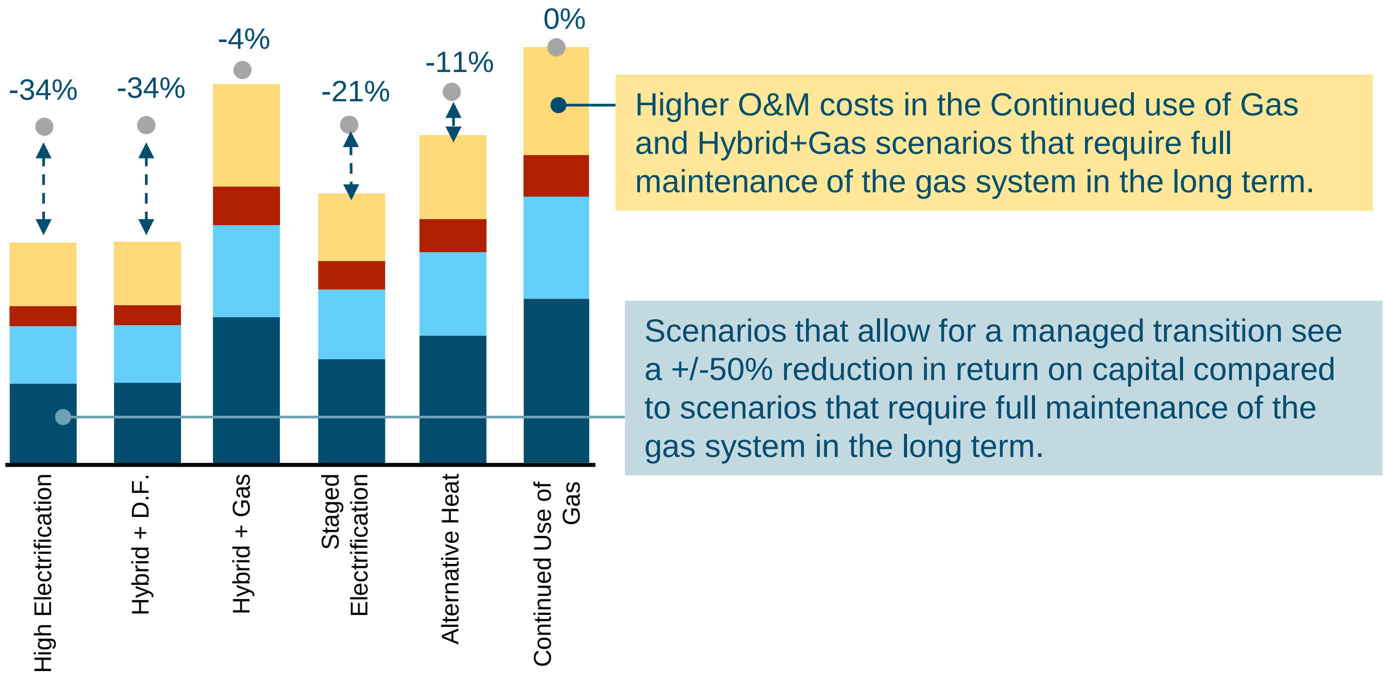
A managed transition can substantially reduce the costs of the gas system

A ***managed transition can reduce the costs of the gas system by nearly 35% compared to an unmanaged transition***, primarily in scenarios that transition away from the gas system in the near term (High Electrification, Hybrid + Delivered Fuels, Staged Electrification). This translates to +/- $150 mln/year by 2050.

RIE Gas Revenue Requirement (RR) in High Electrification scenario (managed)



2050 Mitigation Scenarios (unmanaged vs. managed)

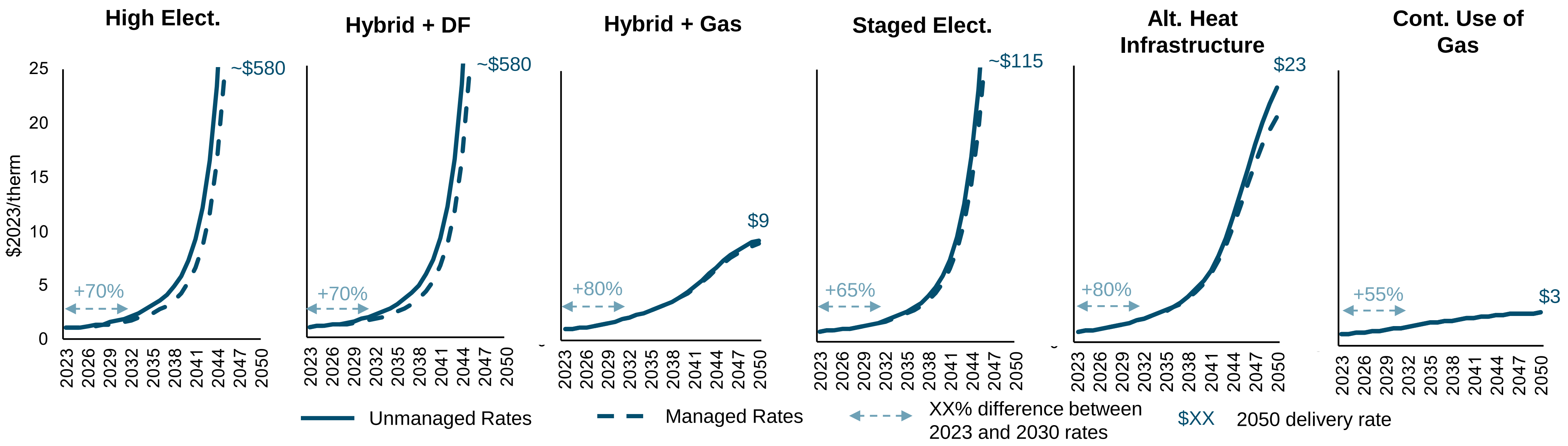


All mitigation scenarios lead to increased delivery rates; a managed transition can only partly mitigate this effect

Except for the Continued Use of Gas scenario, ***all mitigation scenarios lead to untenable long-term delivery rates in the long term*** for residential customers, driven by a combination of increased gas system costs and throughput decline. This effect mostly starts to materialize post-2035. A managed transition has a relatively small impact on this dynamic.

In the near-term, gas system cost increases combined with gas demand efficiency leads to substantial unit rate increases.

Residential gas rates in a managed versus unmanaged transition

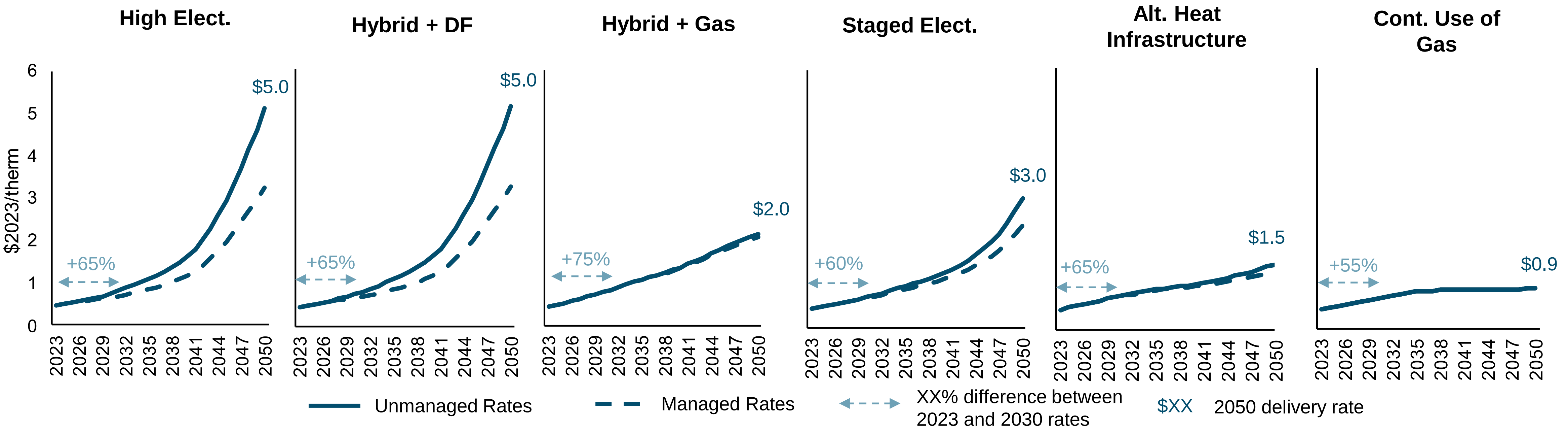


All mitigation scenarios lead to increased delivery rates; a managed transition can only partly mitigate this effect

Also for C&I customers, ***most scenarios lead to an increase in long-term delivery rates***, driven by a combination of increased gas system costs and throughput decline. This effect is not as significant as for the residential sector and mostly starts to materialize post-2035. A managed transition has a higher impact than for residential customers.

In the near-term, gas system cost increases combined with gas demand efficiency leads to substantial unit rate increases.

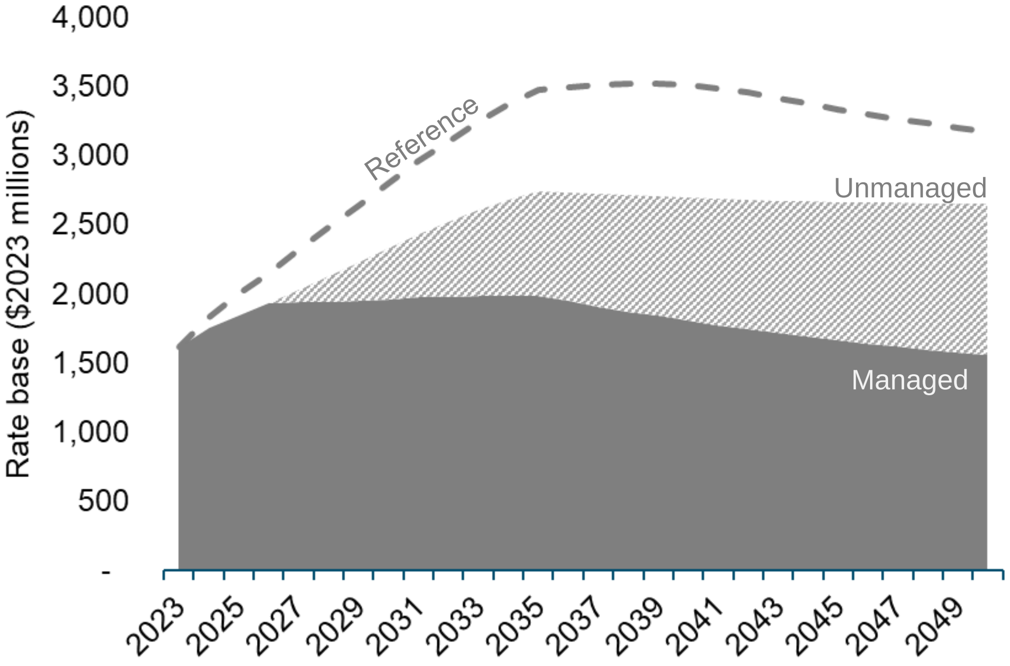
C&I gas rates in a managed versus unmanaged transition



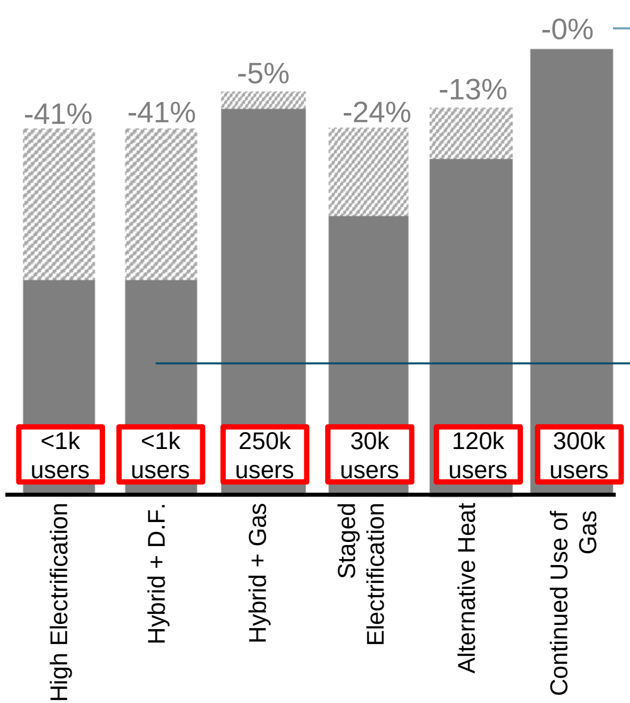
A managed transition could mitigate risks related to potential unrecovered costs in scenarios with customer departures

As the number of gas customers in a scenario declines, the **risk of unrecovered costs** on the system increases. In scenarios with high levels of electrification, remaining customers may not be able to shoulder the remaining system costs. A managed transition can help reduce remaining system costs (= rate base) by +/- 40% by 2050.

RIE Gas Rate Base in High Electrification scenario (managed vs. unmanaged)



2050 Mitigation Scenarios Rate Base (unmanaged vs. managed)



Difference in 2050 remaining rate base between unmanaged and managed transition

Continued use of Gas scenarios does not have opportunity for reduced gas system costs

A managed transition can reduce remaining rate base by 2050 by 41%. These scenarios have the lowest number of gas customers by 2050, and therefore the highest risk of unrecovered costs.

XX users — Number of gas customers remaining on the system that can participate in cost recovery

Decarbonization Pathways Technical Results

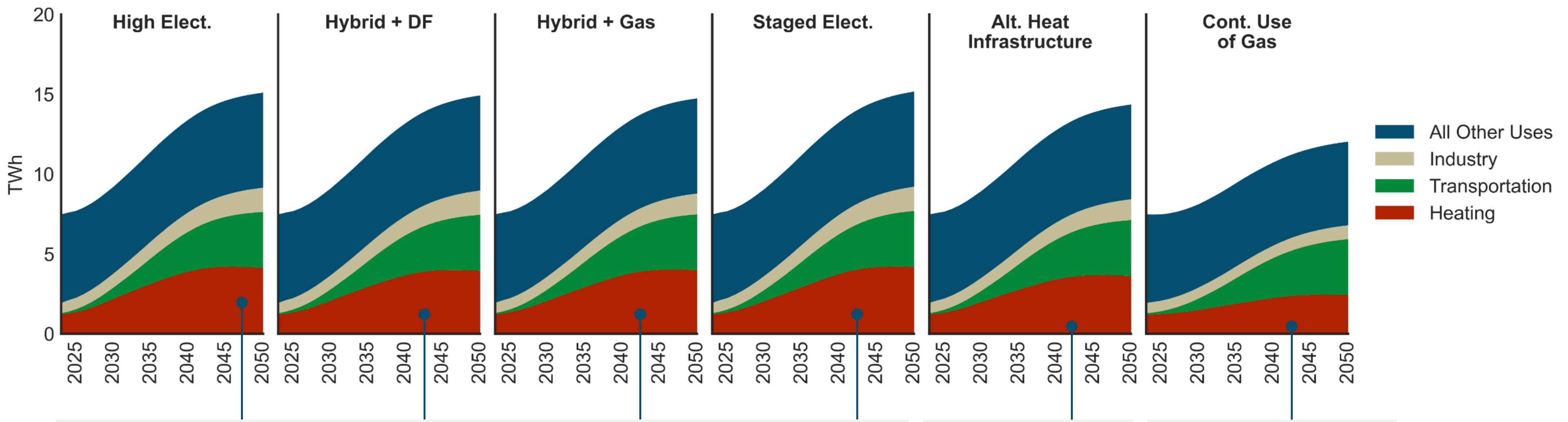
Impact on Electric System

Energy+Environmental Economics

Scenarios see varying levels of annual electric load growth, driven by heating and transportation electrification

Scenarios with high levels of electrification ***nearly double electric system load by 2050*** compared to today's levels. The primary driver of load increase is electrification of heating in scenarios with high levels of heat pump adoption, followed by transportation electrification (equal across scenarios).

Annual Rhode Island Electric Loads (TWh)



Scenarios with high reliance on either whole-home or hybrid HPs have similar amounts of total heating load growth. Hybrid heat pumps only have a minor impact on load growth.

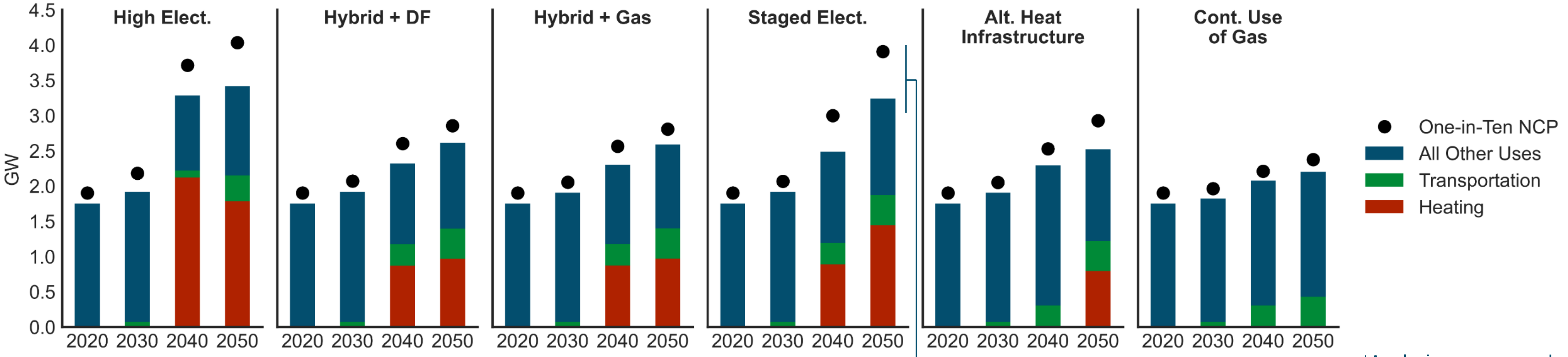
Networked geothermal mitigates some annual heating load growth

A lower pace of heating electrification results in lower heating load growth

Peak demands in RI may double towards 2050, scenarios with backup systems reduce electric impacts

Scenarios with high adoption of heat pumps switch to winter peaking in the 2030s. Median peak demand doubles in the High Electrification scenario – this effect is substantially mitigated in the hybrid scenarios that see an approximately 1 GW reduction in median peaks.

Post-Flexibility* Median Peak Loads by Contribution and 1-in-10 Total Noncoincident Peak (GW)



Scenarios with high reliance on either whole-home or hybrid HPs become winter peaking in 2030s

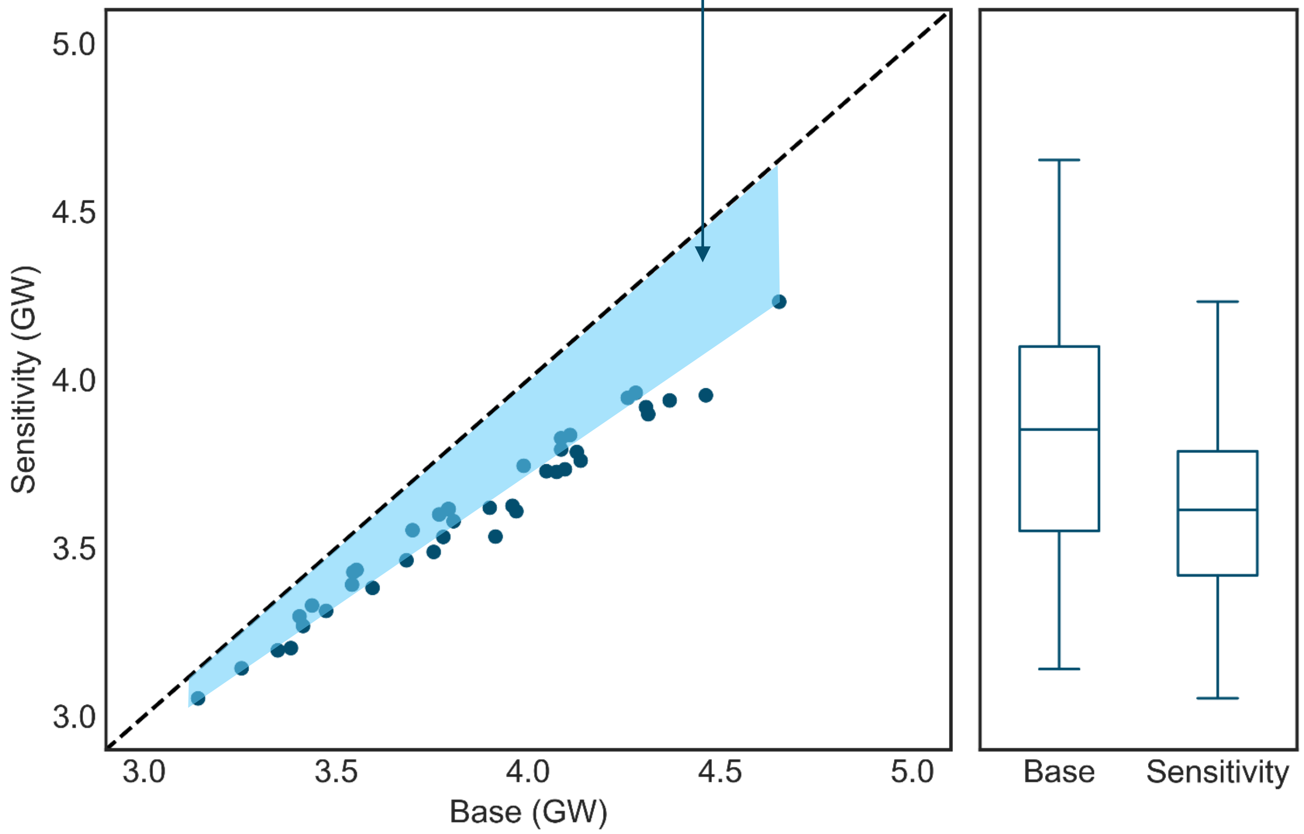
Peak loads in scenarios with high reliance on whole-home HPs are more sensitive to changes in weather. The High and Staged Electrification scenarios' 1-in-10 peaks grow more quickly than the Hybrid scenarios.

Scenarios with fewer ASHPs transition to winter peaking later or remain summer peaking.

*Analysis assumes substantial levels of load flexibility that allows peak contributions for several categories to shift load to different hours of the day. Assumptions include 50% LDV flexibility, 25% water heating flexibility, 5% space heating flexibility.

High-efficiency, whole-load heat pumps help to avoid peak load in the High Electrification scenario

Sensitivity analysis shows that ***higher efficiency heat pumps can avoid system peak impacts by approximately 250-300 MW*** under median peak heating conditions. High-efficiency heat pumps increasingly avoid peak load under increasingly extreme conditions by (1) avoiding supplemental electric resistance and (2) operating the compressor itself at higher levels of efficiency.



Loads shown in the chart are for 2050 and are *before load flexibility.*

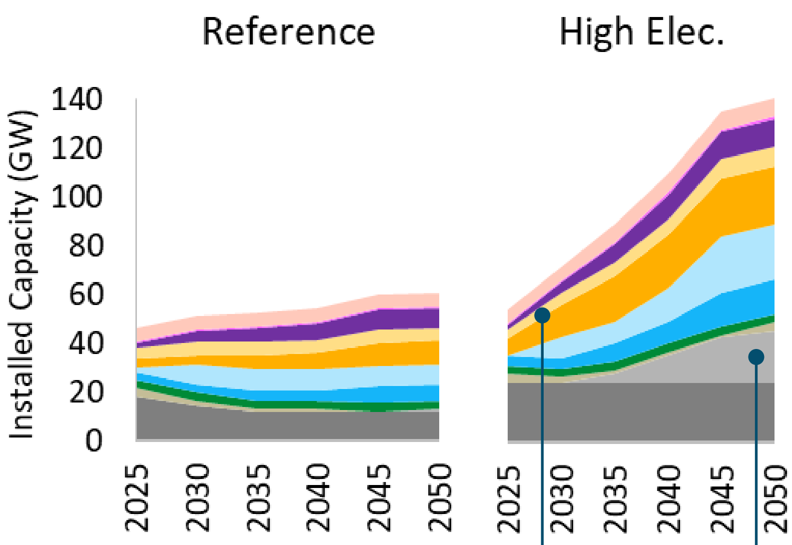
Under the most extreme conditions, high-efficiency heat pumps can avoid up to 500 MW of peak load before load flexibility.

Under median conditions, high-efficiency heat pumps can avoid up to 250-300 MW of peak load before load flexibility.

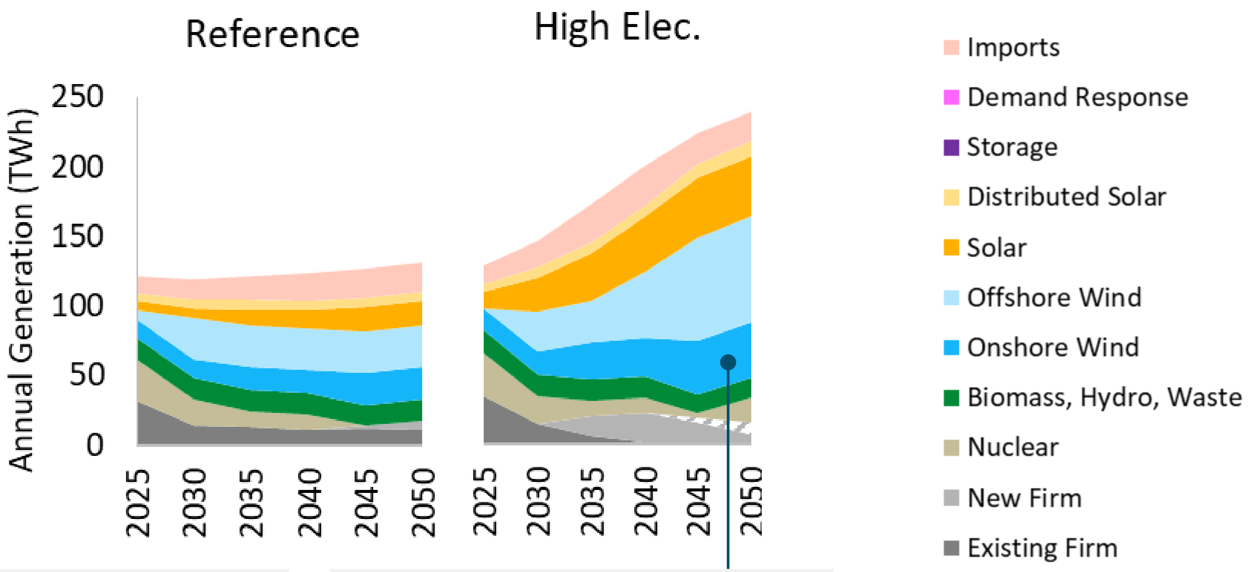
The New England electric system is expected to see transformational changes in generation and capacity

Renewables become a major source of electricity across all scenarios in New England, including in the Reference Scenario.
The need for firm (gas) capacity drops in Reference due to relatively flat load profiles, ***while new firm capacity is required in the other scenarios*** to reliably serve increasing demand from electrification.

Installed Capacity across ISO NE (GW)



Generation Mix across ISO NE (TWh)



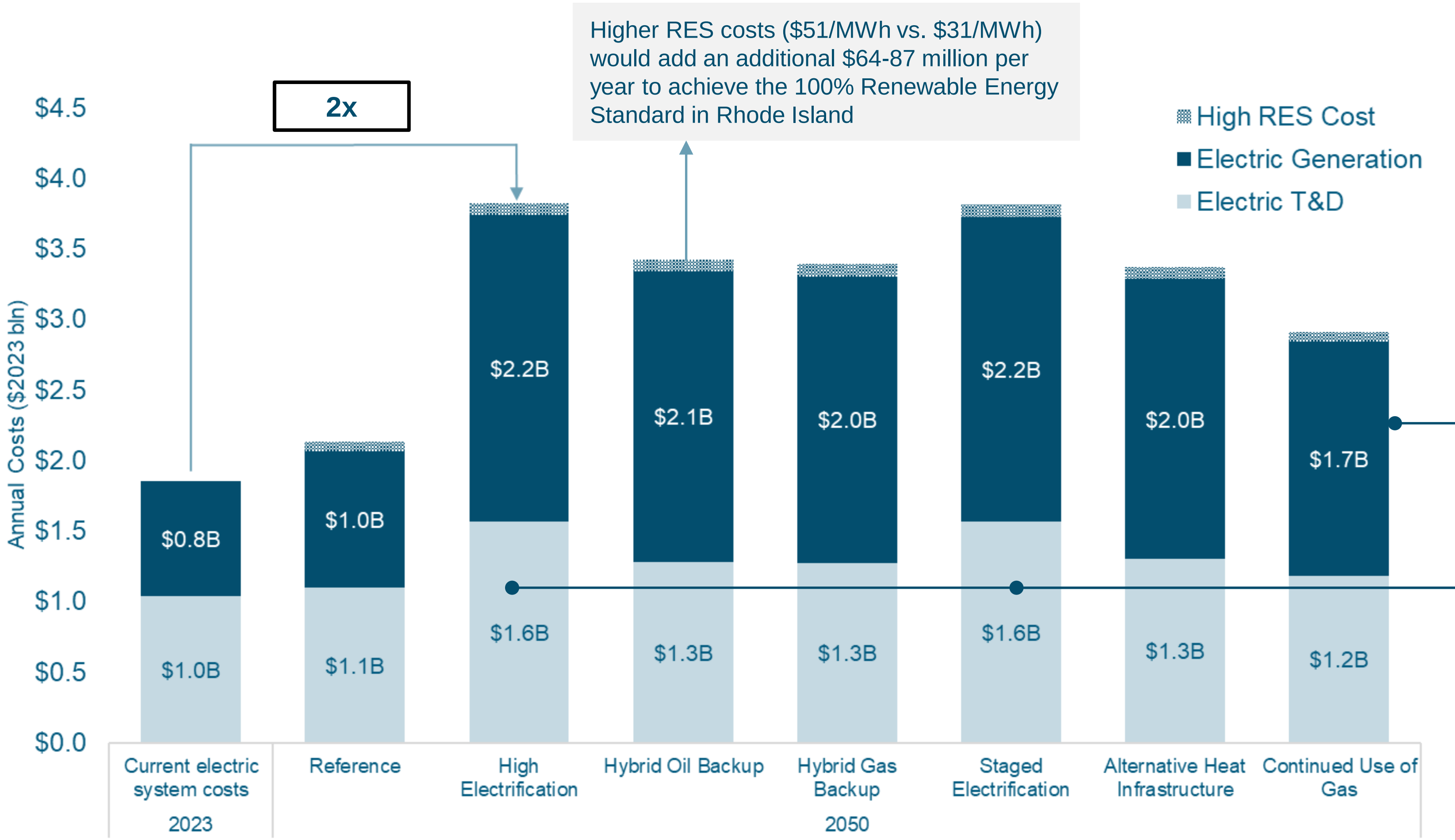
Substantial increase in renewables lead to nearly 3x higher installed capacity needs by 2050.

High Electrification increases the need for firm capacity to serve electric peak needs

Renewable generation in NE dominated by wind and solar

Total cost of electric service in Rhode Island approximately doubles by 2050 due to increased renewables & capacity needs

Current and 2050 Total Cost of Electric Service (2023$ Billion)



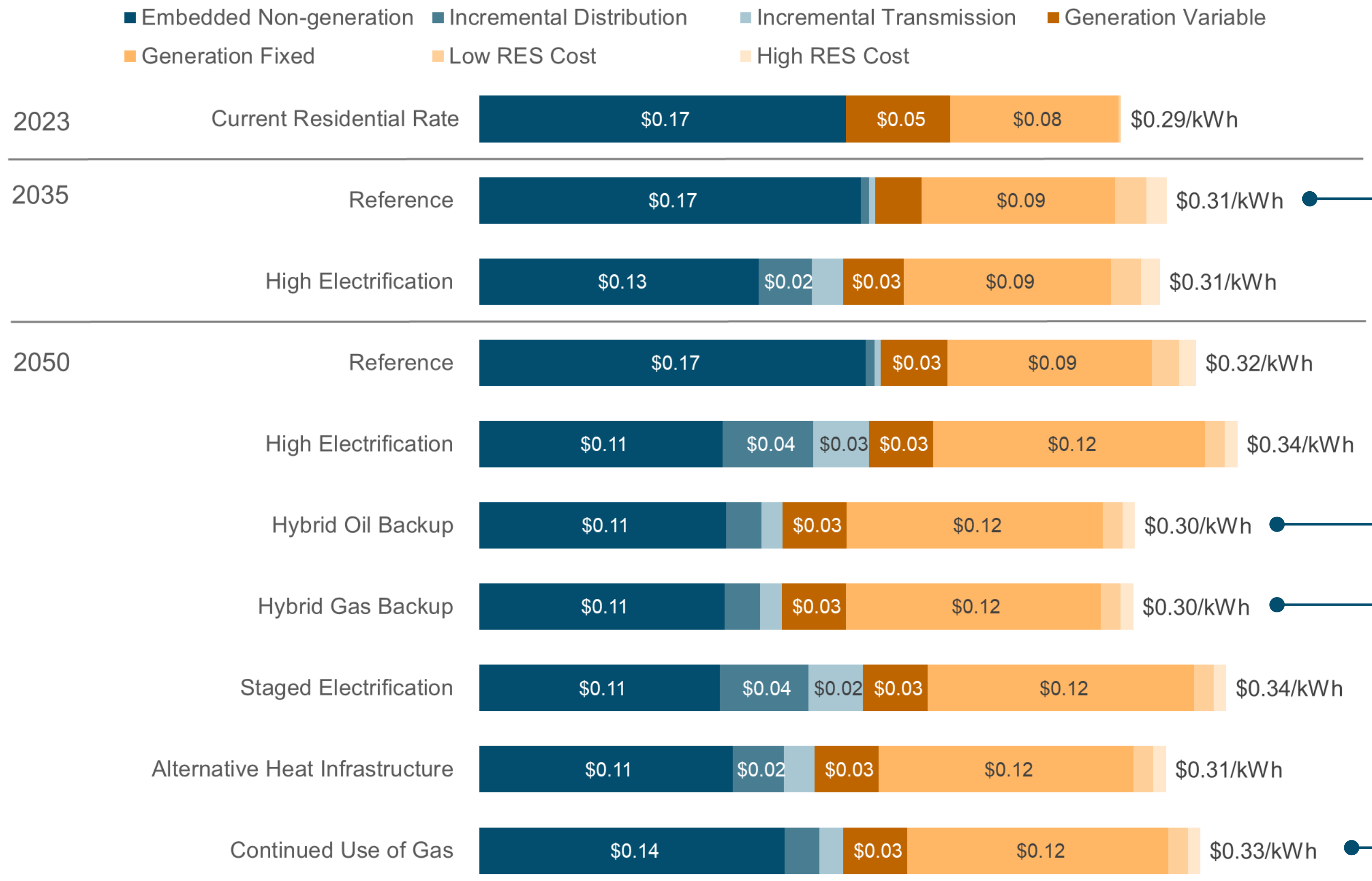
Total cost of electric service increases across all scenarios driven by (1) higher electric demand and (2) higher cost of electric generation to meet the 100% Renewable Energy Standard.

Continued Use of Gas scenario sees lowest costs of generation

Higher levels of T&D in the long term due to heat pump capacity needs

Cost of service increases are largely offset by increased loads, especially for scenarios with high load factors

Residential Electric Rates by Scenario and impact of RES



Residential rates increase across scenarios but are mitigated through load growth.

Achieving RES increases rates by ¢1.3-2.3/kWh* by 2035. By 2050, unit costs of RES are lower in mitigation scenarios due to load growth (¢0.9-1.5/kWh)

Higher heating load from all-electric heat pumps requires more capacity resources per MWh increase in load to ensure system reliability, thus driving up rates

Alleviated peak impacts reduce the need for capacity resources, increasing scenario load factors and therefore lowering the cost per MWh to serve electrification load

Relatively high rates due to lower levels of load increase with similar RES requirements

DRAFT / PRELIMINARY

*Range represents REC prices of $31-51/MWh

Decarbonization Pathways: Assessment and Implications

Energy+Environmental Economics

Implications of scenarios can be viewed across multiple evaluation criteria to assess risks, benefits and challenges

Quantitatively assessed

Metric	Units
Economy-wide Costs (E3)	• Total incremental resource costs compared to reference scenario (cumulative NPV and annual costs) • $/ton abated by subsector

Customer Impacts (affordability, cost shifts) (E3)	• Number of targeted electrification projects in 2035 (customer choice)
	• Monthly customer bills for migrating and non-migrating customers (including amortized appliance costs)
	  • *Migrating = customer adopting the decarbonization technology representative of the respective scenario*
	  • *Non-migrating = customer not adopting a decarbonization technology that remains reliant on gas for heating*

Workforce Impacts (supported by RI Dept. of Labor & Training)	• # of jobs lost in gas sector • # of jobs gained in clean energy sectors • Job quality (wage) impact **Note: workforce impacts are not yet assessed in this presentation**

Qualitatively assessed based on quantitative outcomes

Metric	Evaluation	Based on
Air quality impacts (E3)	Air quality impacts tied to variations in fuel combustion	Levels of fuel combustion across scenarios
Reliance on (out-of-state) fuels (E3)	Reliance on level of renewable fuel that, given Rhode Island's footprint, will likely need to be imported from and producers that are out of state	Volume of renewable fuels
Technology Readiness (E3)	Reliance on commercially available technologies	Range of TRLs that are likely going to needed in scenario to comply with AoC.
Pace of electric system expansion (E3)	Pace and scale of electric sector infrastructure needs	Near-term (up to 2035) T&D investments and new installation of electric generation resources (e.g. offshore wind).

Implications of scenarios can be viewed across multiple evaluation criteria to assess risks, benefits and challenges

Scenarios see different levels of benefits, risks and challenges across multiple evaluation criteria. The matrix below provides a first step in assessing the implications of scenarios across the evaluation criteria discussed with the Stakeholder Committee.

Evaluation Criteria	Key Metric		Detail on slide	High Electrification	Hybrid + Delivered Fuels Backup	Hybrid + Gas Backup	Staged Electrification	Alternative Heat Infrastructure	Continued Use of Gas
Economy-wide Costs	Cumulative NPV in $bln*		62-65	$16-20	$15-20	$14-19	$15-19	$17-23	$16-26
Customer choice	Number of targeted electrification customers in 2035	*Unmanaged*	46-48. 66	0	0	0	0	0	0
		Managed	46-48. 66	3,000	3,000	0	1,200	700	0
Long-term affordability	2050 monthly total cost of ownership for migrating customer		67-68	+/- $800	+/- $800	+/- $800	+/- $800	+/- $900	+/- $800
Cost shifting to non-migrating customers	2050 monthly total cost of ownership for non-migrating customer		67-68	> $3,000	> $3,000	+/- $1,500	> $3,000	> $3,000	+/- $800
Workforce Impacts	*Not yet assessed*								
Air Quality Impacts	Change in statewide fuel combustion between 2020-2050 (%)		69	-85%	-82%	-81%	-85%	-82%	-65%
Reliance on (out-of-state) fuels	Total annual volume of renewable fuel required by 2050 (Tbtu)		70-71	11	15	15	11	13	33
Technology Readiness	Likely range of Technology Readiness Levels required to achieve AoC**		72-73	8-10	7-10	7-10	8-10	6-10	6-11
Pace of Electric System Expansion	Total increase in distribution system capacity by 2035 (GW)		74	1.2	0.5	0.4	0.5	0.4	0.2

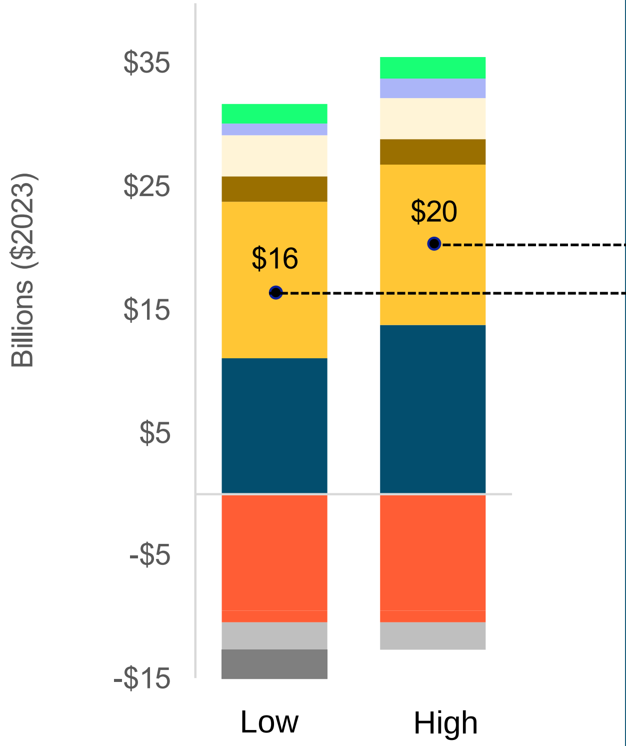
Initial considerations:

- Higher cost risk due to uncertainty in costs of large-scale renewable fuels
- High customer choice impacts if managed transition is achieved
- Relative affordability of heat pumps improves as delivery & supply costs of gas rise. Cost shift risk exist for scenarios with high levels of customer departure.
- Air quality benefits across scenarios, lower benefits for scenarios with more fuel combustion
- Higher risk of out-of-state fuel reliance for scenarios with higher levels of renewable fuels
- Reliance on networked geothermal or synthetic fuels to meet AoC targets
- Rapid electric capacity needs increase risk of system congestion

* Expressed as cumulative Net Present Value (NPV) between 2023-2050, incremental to a reference scenario. Costs shown for "unmanaged" transition.
** Detail on Technology Readiness Level (TRL) ranges provided on slide 72.

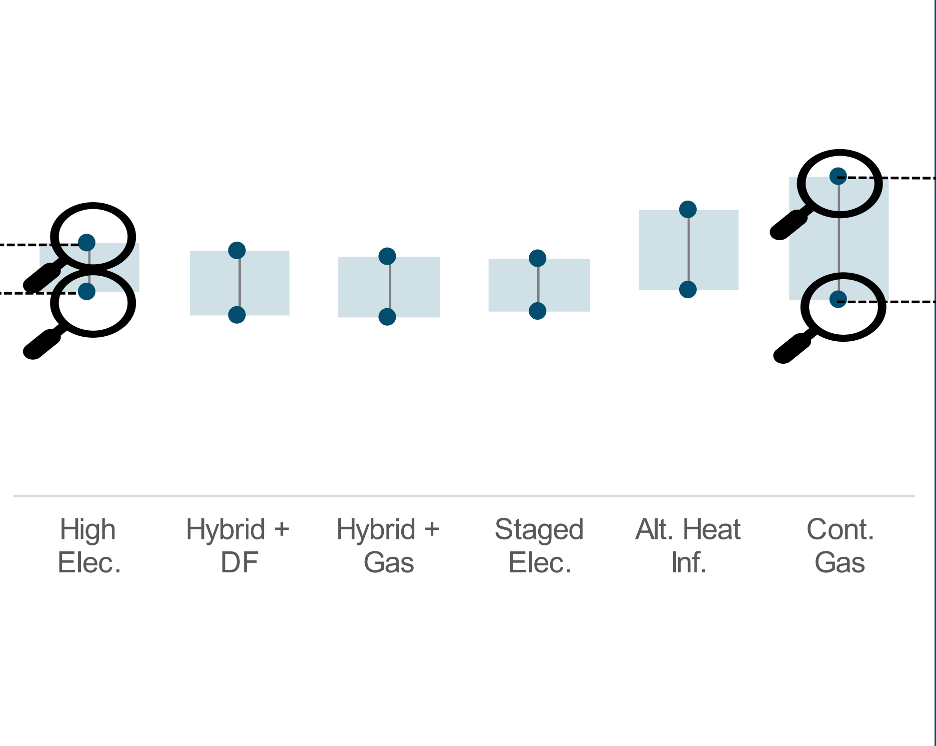
Economy-wide costs: Economy-wide costs show similar ranges with highest uncertainty in cost of renewable fuels

Detail by category: High Electrification



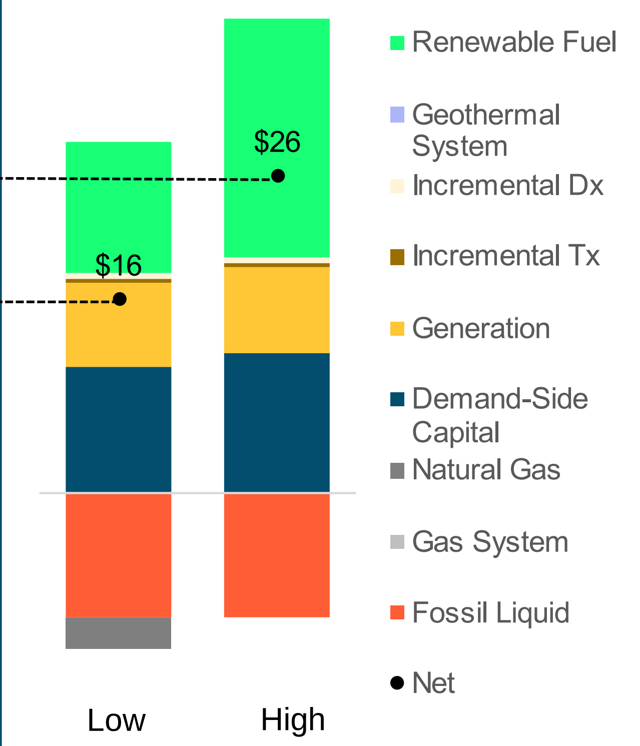
Device adoption and electric sector drive cost. Scenario shows the smallest range between optimistic and conservative cases due to limited role of fuels

Range of cumulative net NPV* costs across scenarios



Scenarios with a role for hybrid heating are favorable under both conservative and optimistic parameters

Detail by category: Continued Use of Gas



Uncertainties in renewable fuel costs drive highest variability in Continued Use of Gas scenario.

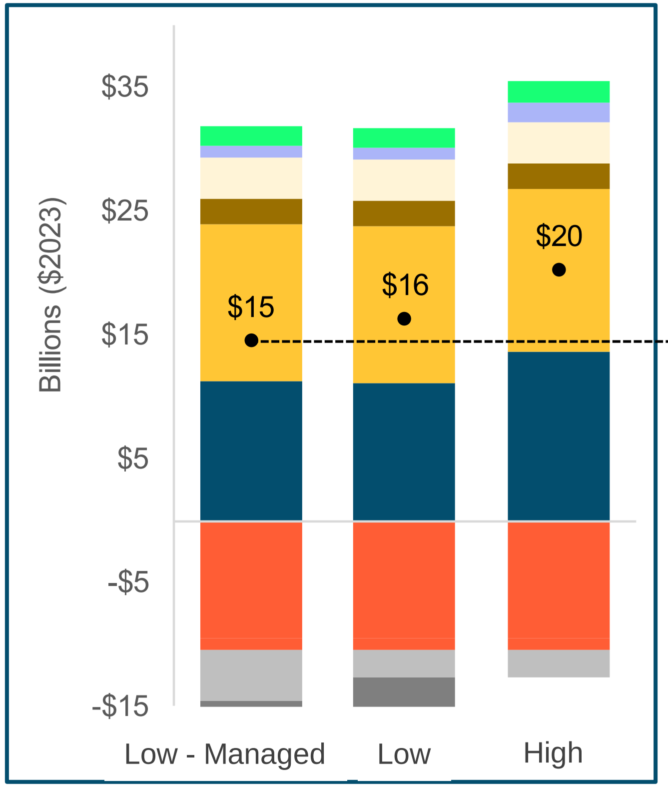
* Expressed as cumulative Net Present Value (NPV) between 2023-2050, incremental to a reference scenario. Discount Rate = 1%.

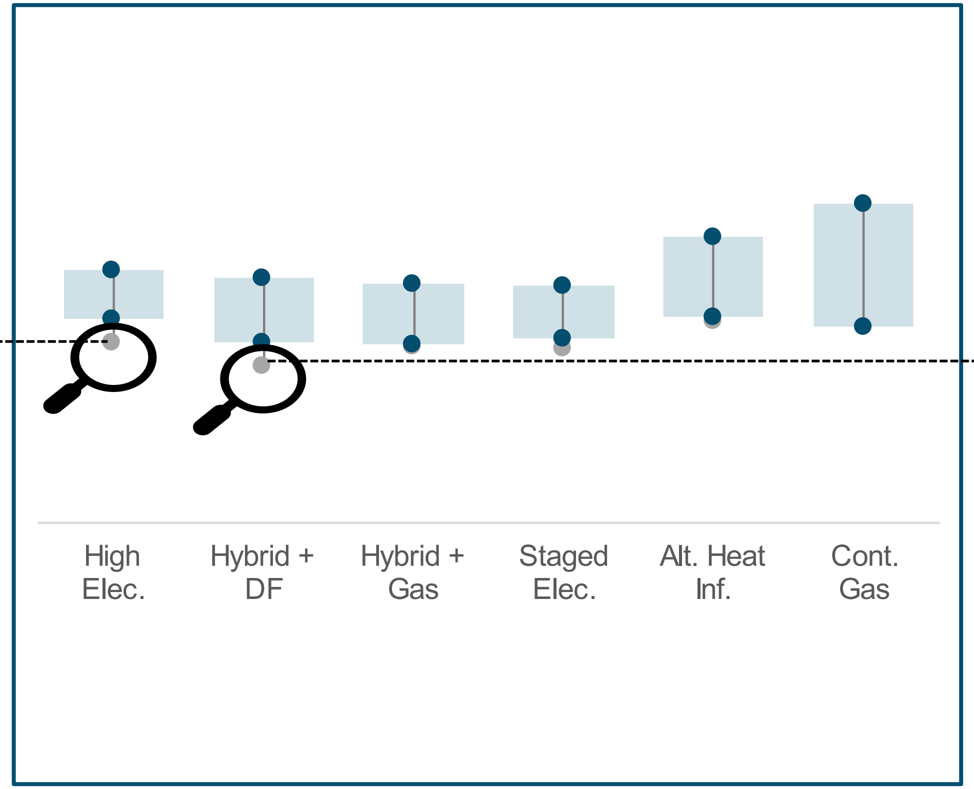
Economy-wide costs: A managed transition can reduce costs if long-term gas infrastructure is avoided

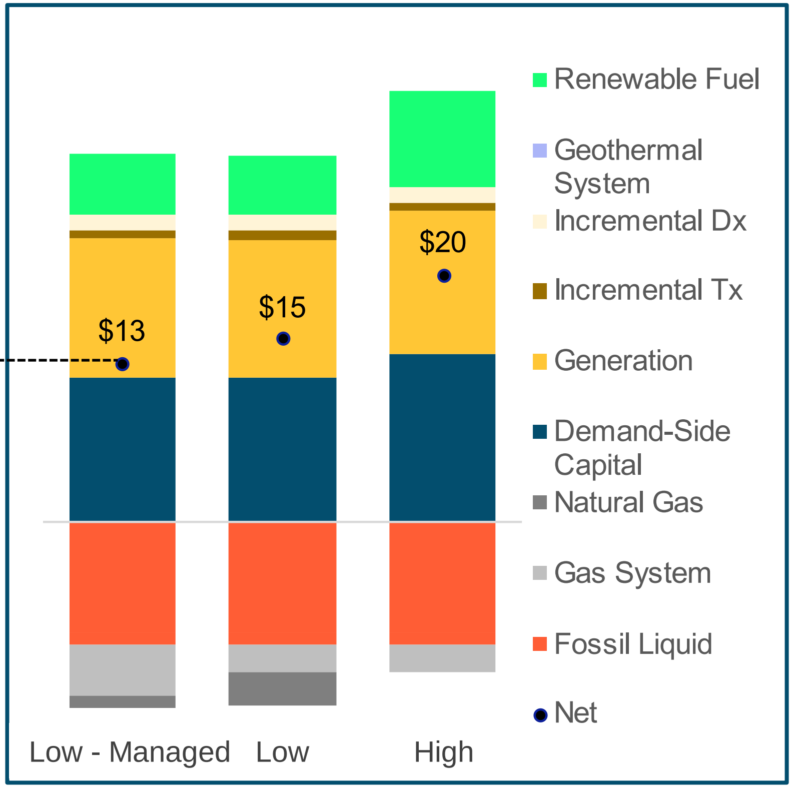
Detail by category:
High Electrification

Range of cumulative net NPV* costs across scenarios

Detail by category:
Hybrid + Delivered Fuels Backup







A managed transition reduces economy-wide costs, mostly in scenarios that are able to avoid long-term gas infrastructure.

* Expressed as cumulative Net Present Value (NPV) between 2023-2050, incremental to a reference scenario. Discount Rate = 1%.

Economy-wide costs: Uncertainty analysis shows highest levels of risk for renewable fuels and networked geothermal

Sensitivity →

← Scenario

	Incremental cost above Reference ($2023 billions cumulative NPV)						
	Low bound	Man. Trans.	High Heat Pump	High RECs	High Renew Fuel	High Net. GSHP	High bound
High Electrification	$16.4	$14.6	$19.1	$16.8	$16.8	$17.0	$20.3
Staged Electrification	$14.9	$14.1	$17.2	$15.2	$16.4	$14.9	$19.1
Alternative Heat Infrastructure	$16.7	$16.3	$18.6	$17.0	$18.7	$18.9	$23.1
Continued Use of Gas	$15.8	$15.8	$16.9	$15.9	$24.5	$15.8	$25.8
Hybrid Gas Backup	$14.5	$14.3	$16.5	$14.8	$16.9	$14.5	$19.3
Hybrid DF Backup	$14.6	$12.7	$16.6	$15.0	$17.5	$14.6	$19.8

	Uncertainty across scenarios and sensitivities ($2023 billions cumulative NPV)						
	Low bound	Managed Trans.	High Heat Pump	High RECs	High Renew Fuel	High Net. GSHP	High bound
High Electrification	$1.9	$1.9	$2.5	$2.0	$0.4	$2.5	$1.2
Staged Electrification	$0.4	$1.4	$0.7	$0.4	$0.0	$0.4	$0.0
Alternative Heat Infrastructure	$2.2	$3.6	$2.1	$2.2	$2.3	$4.4	$4.0
Continued Use of Gas	$1.3	$3.1	$0.4	$1.1	$8.2	$1.3	$6.7
Hybrid Gas Backup	$0.0	$1.6	$0.0	$0.0	$0.6	$0.0	$0.2
Hybrid DF Backup	$0.2	$0.0	$0.1	$0.2	$1.1	$0.2	$0.7

Uncertainty analysis is based on Regret Analysis from Decision Theory[1]. “Regret” is defined as the extra cost of a given scenario above the lowest cost scenario within each sensitivity (column). A regret of zero indicates that scenario was the lowest cost scenario within that sensitivity. All sensitivity costs are shown as incremental to the lowest costs values, changing one variable at a time.

DRAFT / PRELIMINARY

[1]Peterson M. *An Introduction to Decision Theory.* Cambridge University Press, 2013.

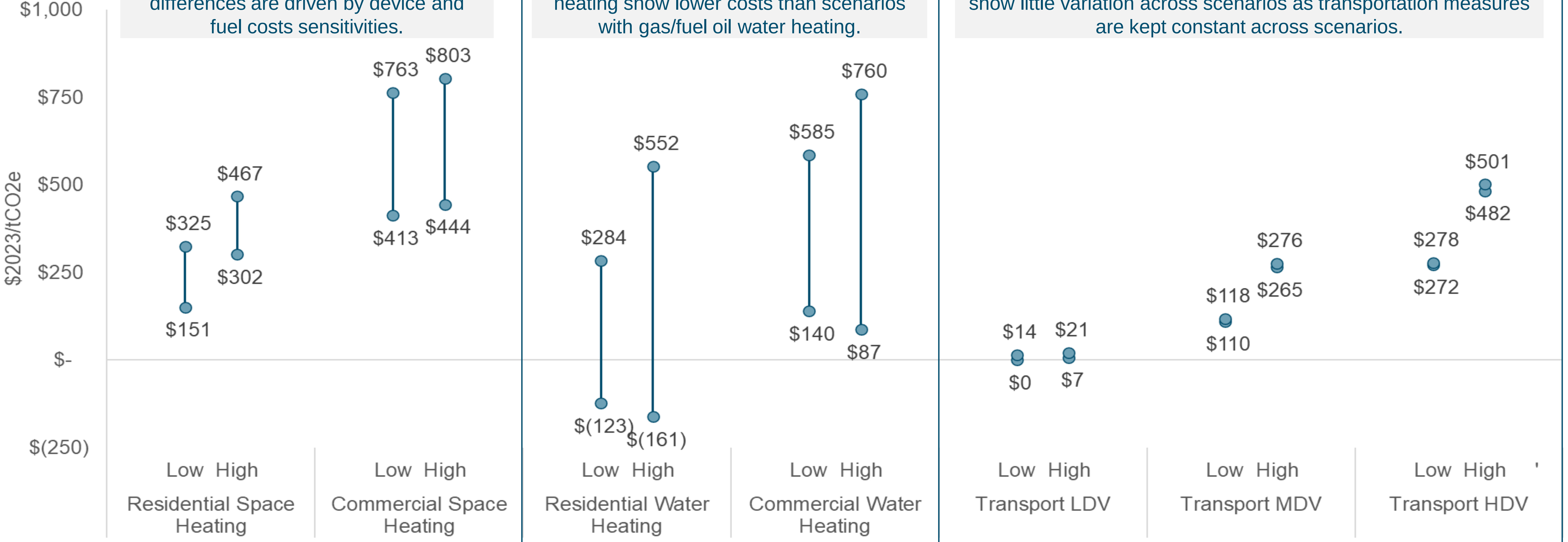
Economy-wide costs: abatement costs show differences in cost-effectiveness across subsectors

Range of abatement costs* for each subsector found across scenarios, broken out by low/high cost parameters

Space heating electrification shows lower cost for the residential than commercial sector. Low/high differences are driven by device and fuel costs sensitivities.

Large variation in costs is driven by technology adoption differences across scenarios. Scenarios with electric water heating show lower costs than scenarios with gas/fuel oil water heating.

Across categories, LDV electrification is most cost-effective. Differences between low and high MDV and HDVs costs are due to the cost uncertainty associated with renewable fuels. Ranges show little variation across scenarios as transportation measures are kept constant across scenarios.

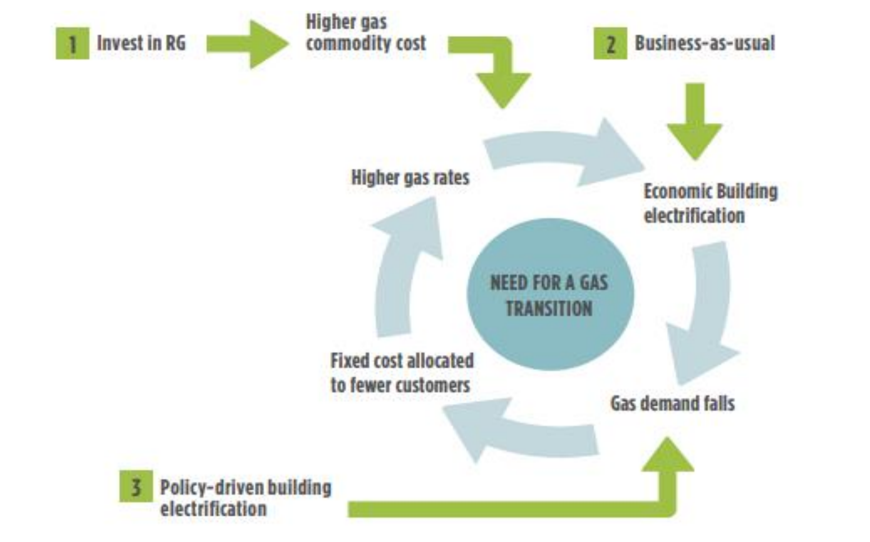


% economywide emissions reductions	Residential Space Heating	Commercial Space Heating	Residential Water Heating	Commercial Water Heating	Transport LDV	Transport MDV	Transport HDV
	24%	10%	6%	1%	25%	3%	7%

DRAFT / PRELIMINARY

* Based on cumulative NPV of costs and emissions reduced between 2023-2050. The bars represent the range of abatement costs found across scenarios. The difference in low/high represent sensitivities in cost input parameters (low = optimistic, high = conservative).

<u>Customer impacts:</u> Unmanaged transition creates higher cost-shift risks; managed transition harms customer choice



In an ***unmanaged transition***, a reduction in gas demand leads to higher gas rates for remaining customers, which could lead to a spiraling effect as the cost-effectiveness of electrification increases.

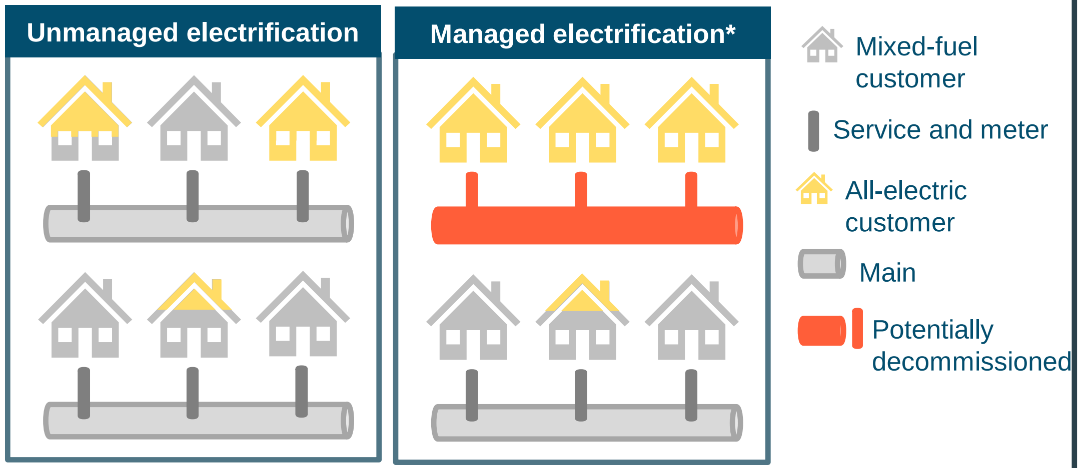
As the upfront cost of electrification are high, this effect could create ***equity issues*** as low-income customers are less likely to be able to afford electrification.

Scenarios with higher levels of customer departures, such as ***High Electrification and Staged Electrification*** see more equity risks; although hybrid scenarios may lead to similar impacts without ***rate design adjustments***.

In a ***managed transition***, neighborhood-specific targeted electrification projects are based on gas mains replacement schedules are required in order to avoid gas system costs.

This strategy requires a 100% opt-in from customers ***<u>or</u>*** has significant implications for ***customer choice***, as customers will need to agree to convert from gas to electric and or/geothermal systems.

The customer choice risk is only applicable to scenarios with ***near-term gas system departures***.

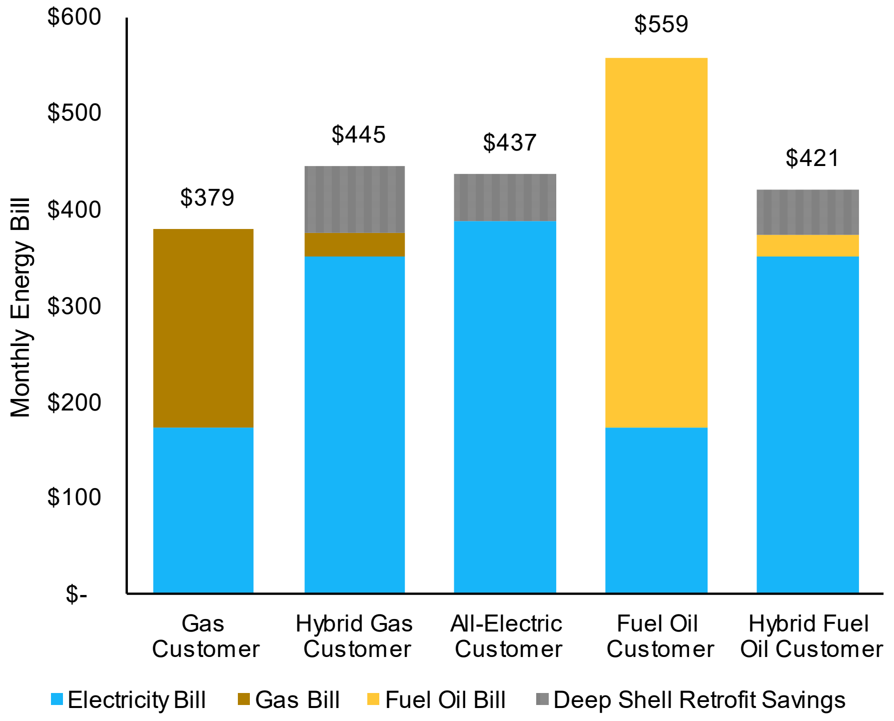


*Also referred to as "**targeted/zonal electrification and gas decommissioning**"

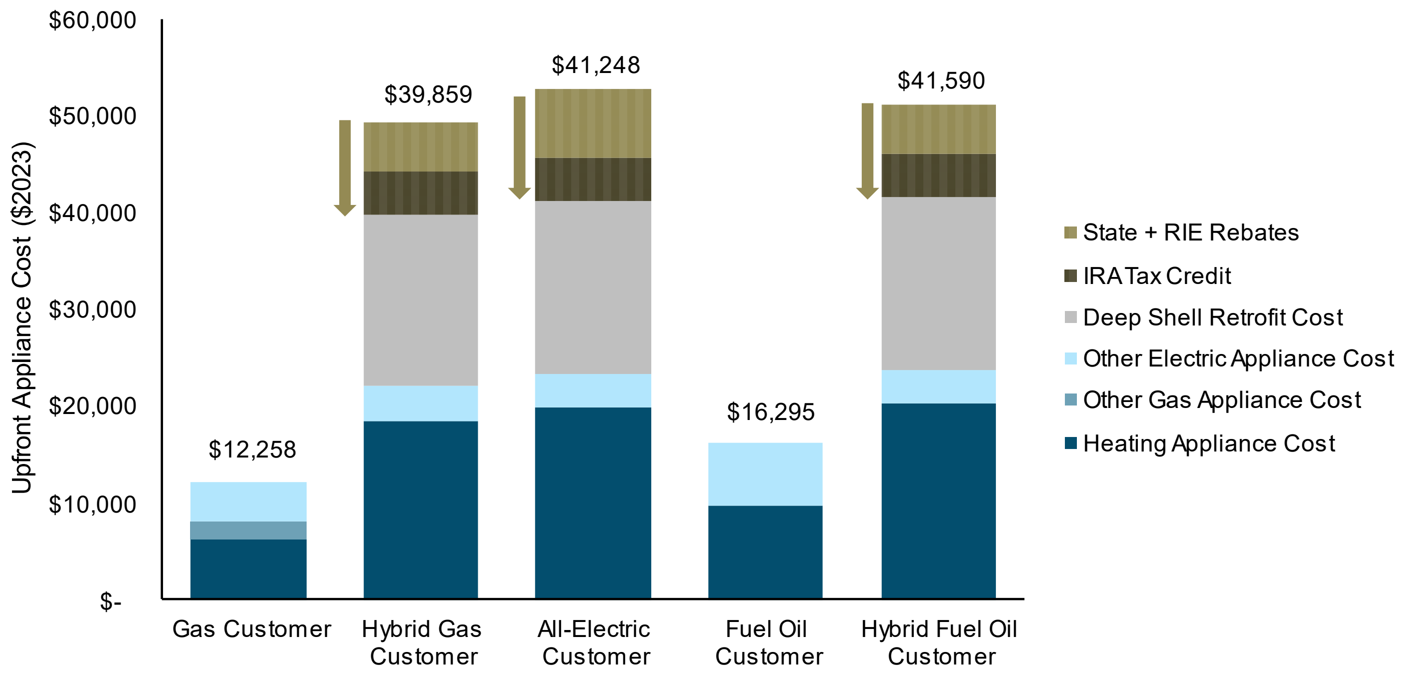
Customer impacts: Energy affordability is going to be key in understanding customer decisions

At current rates, **electrification is more expensive than using natural gas for heating and cooking purposes**, looking at energy bills only. This excludes the significant upfront costs associated with all-electric conversions. Energy bills could be reduced with deep shell retrofits, requiring larger upfront investments.

Energy Affordability in 2023 (residential monthly energy bills for Single Family pre-1960s home)



Upfront Cost in 2023 (residential appliance costs for single family pre-1960s home)

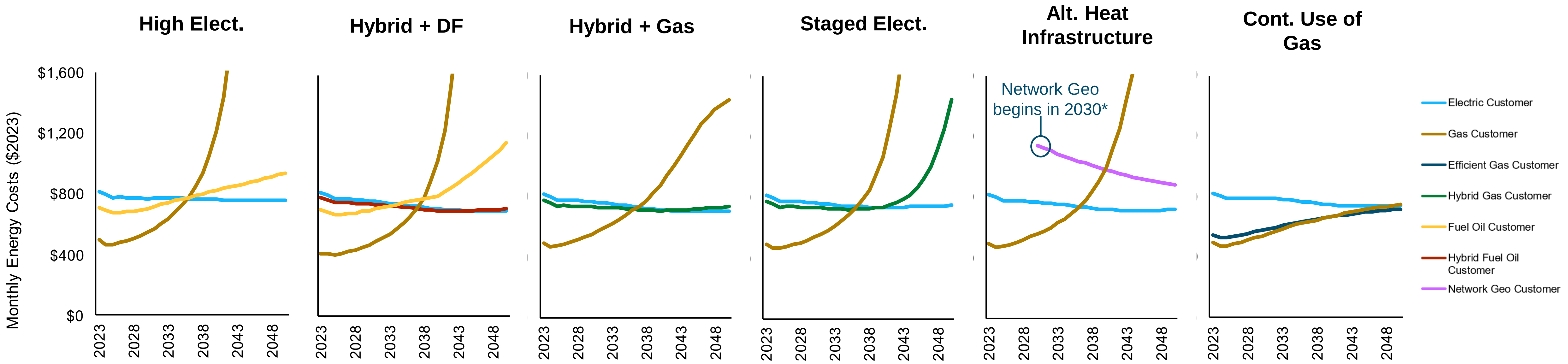


Note: Costs and energy impacts are shown inclusive of deep shell retrofits. In the PATHWAYS analysis, by 2050 34% of customers are assumed to receive a deep shell retrofit, and 58% a "basic" (cheaper) shell retrofit. These numbers are similar across scenarios.

Customer impacts: Scenarios with gas customer reductions see a significant risk of cost-shifting

- Energy affordability is a challenge across all scenarios
- Gas customers face the highest energy costs in the long-term in all scenarios except Cont. Use of Gas
- The upfront cost of electric appliances and a building shell retrofit draws out the payback period for electric and hybrid customers

Monthly energy costs (energy bills + levelized upfront costs) for a residential single-family household under each scenario's rates

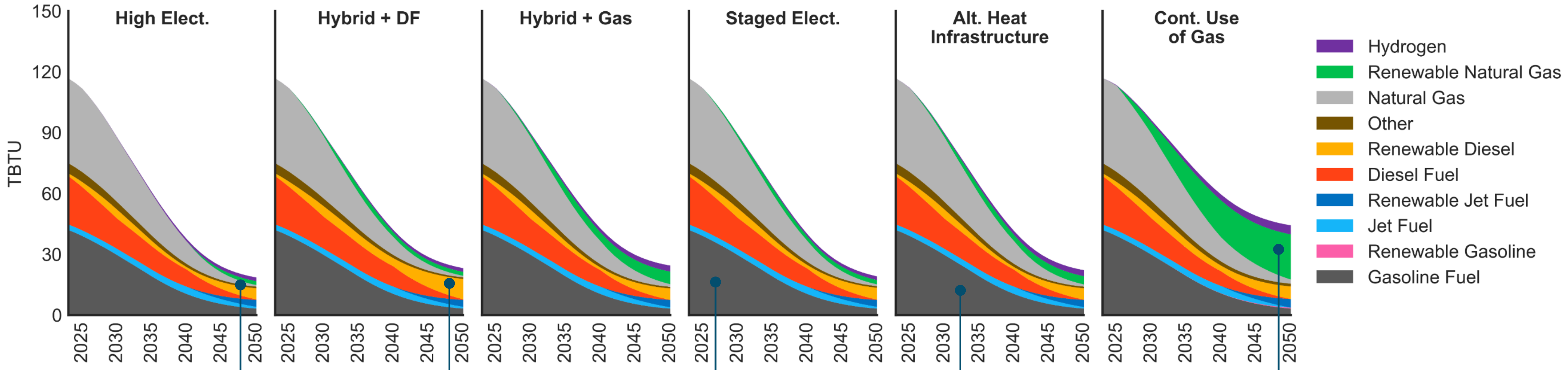


*Network geothermal costs are not socialized among geothermal and gas customers. The costs are assumed to be borne by geothermal customers only.

<u>Air quality:</u> Fuel combustion will decrease across all scenarios, greatest improvements in scenarios more electrification

The combustion of fuels produces emissions of pollutants, such as PM 2.5 and NOx. E3 assumes that the reduction of fuel combustion positively impacts air quality in Rhode Island. **Across scenarios, fuel combustion declines as a result of efficiency and electrification** in the transportation and buildings sector, implying air quality improvements. Scenarios with lower levels of electrification leave more fuel combustion.

All fuel combustion over time: (2023-2050)

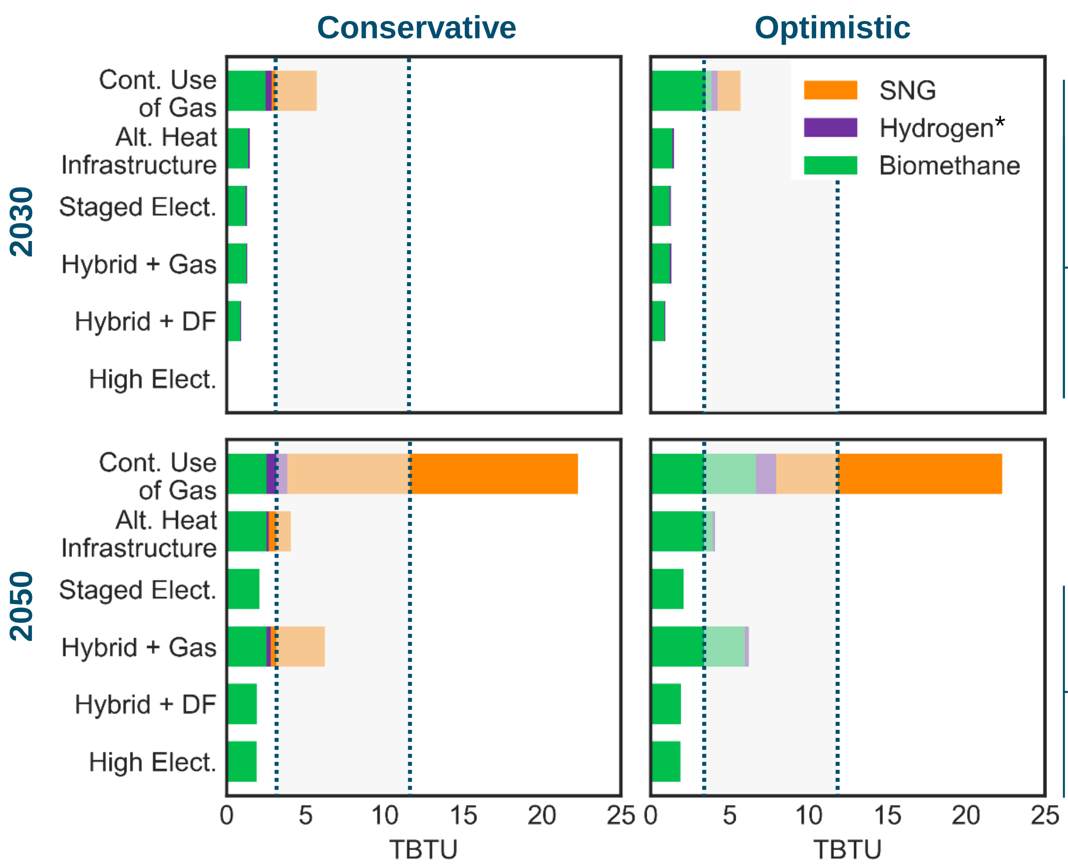


Scenarios with the largest reductions in combustible fuels are assumed to have the highest benefit in air quality improvement (scored as "lower level of challenge" on the assessment matrix.

The Continued Use of Gas scenario reduces combustion of fuels substantially, but leaves more fuel combustion by 2050 compared to other scenarios.

Reliance on out-of-state fuels: Reliance on high amounts of renewable gas likely requires more synthetic fuels

Renewable pipeline gas demand: Conservative/optimistic availability



Shaded range represents a "fair share" of east-of-Mississippi biomass potential <u>if all biomass would be converted to renewable natural gas</u>. This range is not a cost-effective, market-based, or policy-driven allocation, but is instead based on industry natural gas demand (low end) or population (high end) weighted share.

E3 developed "conservative" and "optimistic" estimates of biofuel availability.

- Conservative: Thermal gasification is not commercialized within the timeframe of the study, leading to lower amounts of biomethane availability
- Optimistic: Thermal gasification is commercialized after 2030, resulting in higher amounts of biomethane availability

Scenarios with high amounts of direct decarbonization, such as electrification, will likely require relatively small amounts of biomethane and hydrogen.

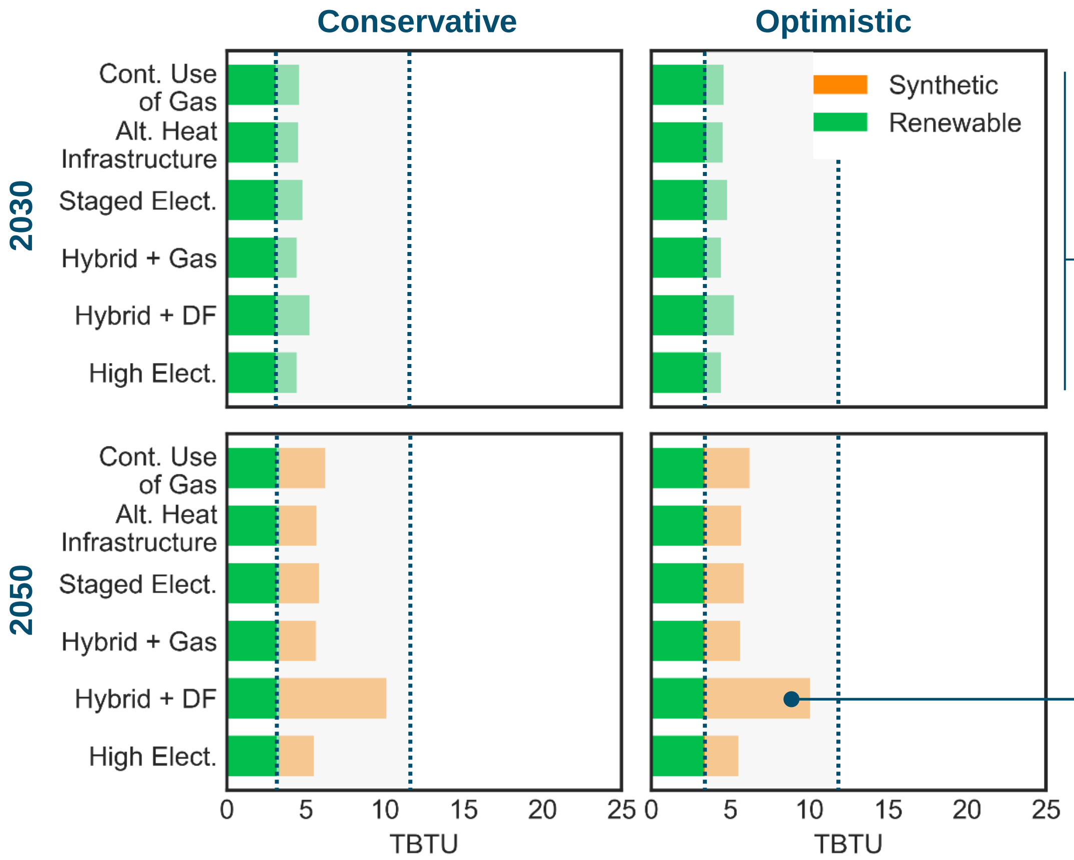
Full electrification can mitigate or entirely avoid the potential for synthetic gas.

- While not shown here, the **Hybrid Delivered Fuels Backup** scenario requires an increased amount of synthetic diesel to hit the economywide emissions target.
- The **Staged Electrification** scenario "threads the needle" by accelerating full electrification after 2030 and avoiding high synthetic fuel demand.

*Use of "pure" hydrogen (H2) in gas network, as opposed to CH4 (SNG and biomethane)

<u>Reliance on out-of-state fuels:</u> Reliance on high amounts of renewable diesel likely requires more synthetic fuels

Renewable diesel demand: Conservative/optimistic availability



Shaded range represents a "fair share" of east-of-Mississippi biomass potential <u>if all biomass would be converted to renewable diesel</u>. This range is not a cost-effective, market-based, or policy-driven allocation, but is instead based on industry natural gas demand (low end) or population (high end) weighted share.

E3 developed "conservative" and "optimistic" estimates of biofuel availability.

- Conservative: Thermal gasification is not commercialized within the timeframe of the study, leading to lower amounts of biomethane availability
- Optimistic: Thermal gasification is commercialized after 2030, resulting in higher amounts of biomethane availability

All scenarios rely on similar amounts of renewable diesel to satisfy the Biodiesel Act requirements.

The Hybrid Delivered Fuels Backup scenario requires an increased amount of synthetic diesel to hit the economywide emissions target.

Technology Readiness: Technology readiness is a key dimension to assess the risk of decarbonization options

Scale of Technology Readiness Levels as defined by IEA

CONCEPT	1	**Initial idea** Basic principles have been defined
	2	**Application formulated** Concept and application of solution have been formulated
	3	**Concept needs validation** Solution needs to be prototyped and applied
SMALL PROTOTYPE	4	**Early prototype** Prototype proven in test conditions
LARGE PROTOTYPE	5	**Large prototype** Components proven in conditions to be deployed
	6	**Full prototype at scale** Prototype proven at scale in conditions to be deployed
DEMONSTRATION	7	**Pre-commercial demonstration** Solution working in expected conditions
	8	**First of a kind commercial** Commercial demonstration, full scale deployment in final form
EARLY ADOPTION	9	**Commercial operation in relevant environment** Solution is commercially available, needs evolutionary improvement to stay competitive
	10	**Integration needed at scale** Solution is commercial and competitive but needs further integration efforts
MATURE	11	**Proof of stability reached** Predictable growth

Decarbonization scenarios rely on technologies with varying levels of readiness.

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 need R&D and/or commercialization support.

Portfolios of decarbonization options that rely on lower TRL measures carry additional risk. For example, some scenarios may need to rely more strongly on synthetic fuels (see previous section), a technology that is still in prototype/demonstration phase.

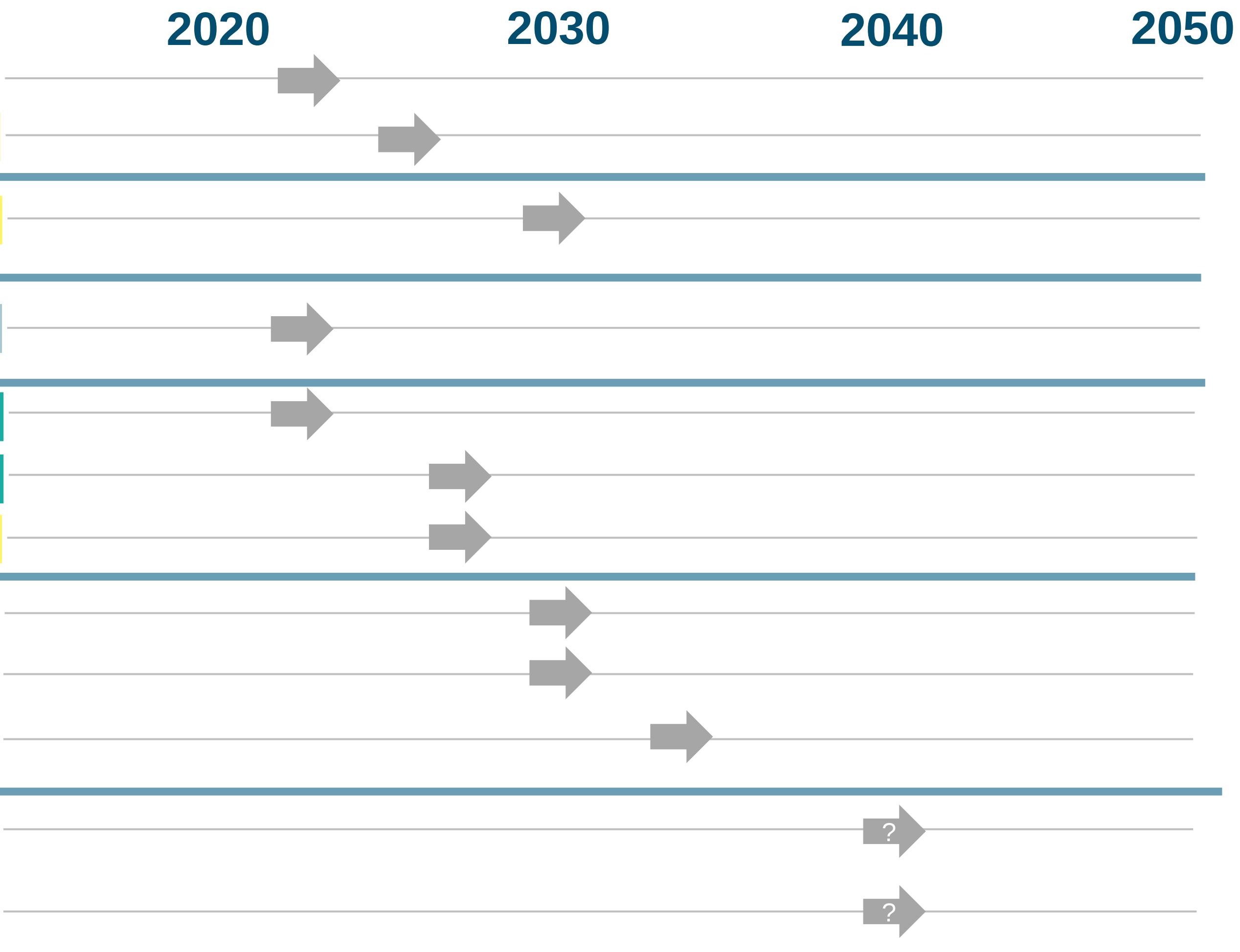
E3 and other deep decarbonization researchers generally screen out technologies that are low (<5) on the TRL scale because of their speculative nature and the short time horizon of mid-century climate goals.

Technology Readiness: Decarbonization technologies need to reach maturity in order to meet the scale of RI’s climate goals

TRL = Technology Readiness Level

Technology	Application	Today’s TRL
Cold-Climate ASHP Most scenarios	Res/Small Commercial	10
	Large Commercial	8
Networked Geothermal In Alternative Heat Infrastructure scenario	Residential/commercial	7
Efficient Gas Appliances Continued Use of Gas scenario	Condensing furnaces	11
Biofuels All scenarios	Biodiesel	10
	RNG - Anaerobic digestion	10
	RNG - Bio-gasification	7
Hydrogen All scenarios for power gen and transportation sector, some scenarios for dedicated pipeline delivery	Alkaline electrolyzers	9
	H2 blending	7
	Dedicated hydrogen network & use	6
Synthetic Fuels Likely required in Continued Use of Gas, Hybrid + DF, Hybrid + Gas	Synthetic biodiesel	6
	Synthetic gas with climate-neutral carbon source	6

Expected timing of technology ramp-up in scenarios



DRAFT / PRELIMINARY

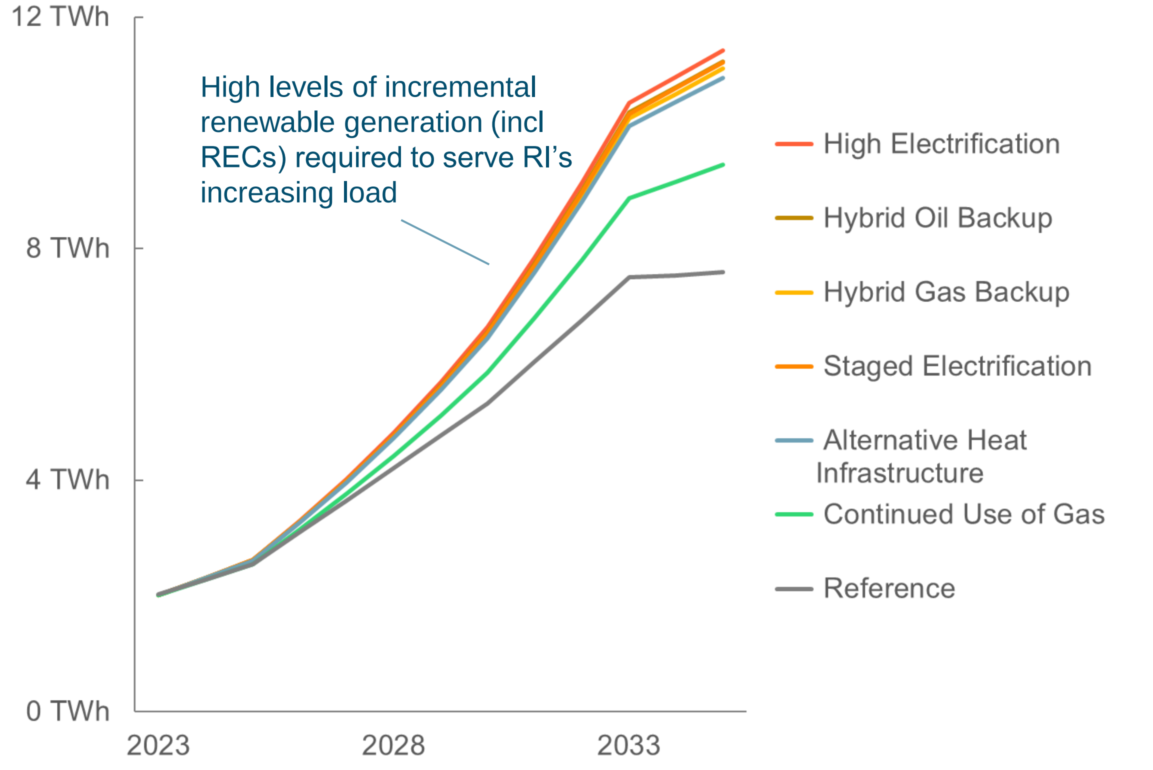
Note: TRLs are based on values from an IEA database, modified in some cases by E3 based on our professional judgement, including an assessment of RI specific context.

Pace of Electric System Expansion: All scenarios require significant renewable buildouts to comply with 100% RES

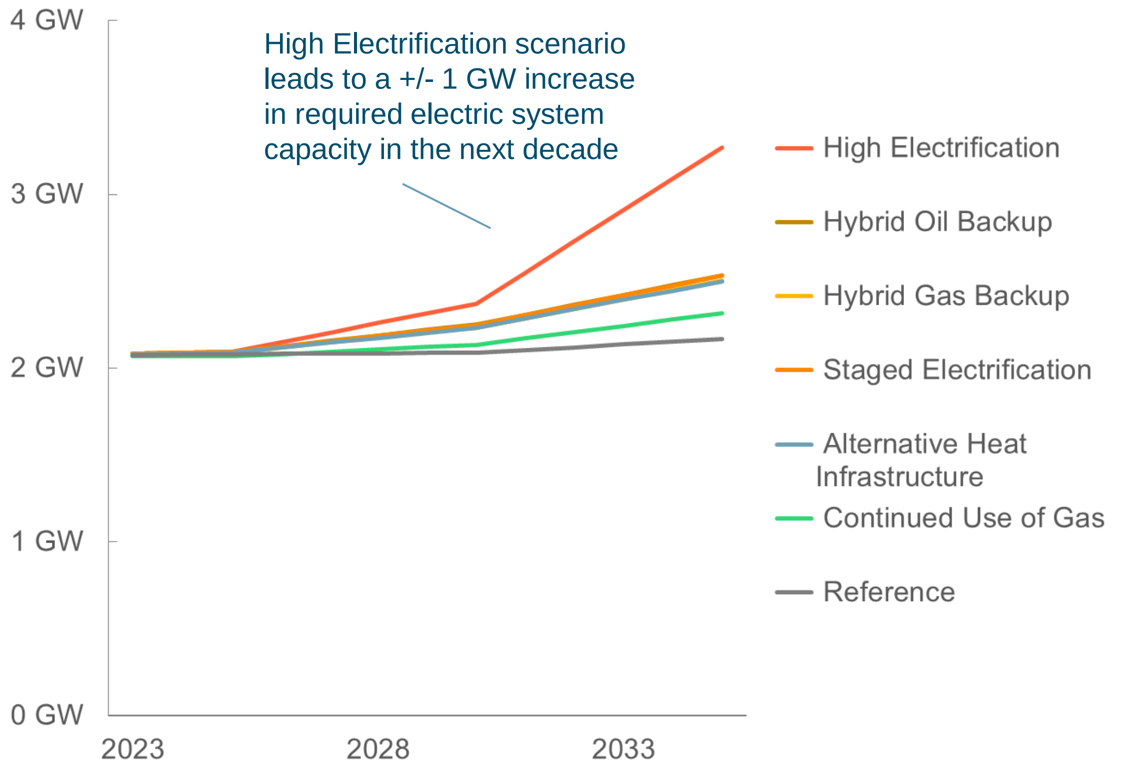
+ **All scenarios require rapid expansion of renewables to achieve 100% Renewable Energy Standards by 2033**

+ **Expanding T&D infrastructure build is driven by higher peak demand from electrification**

Annual Renewable Energy Generation by Scenario (TWh)



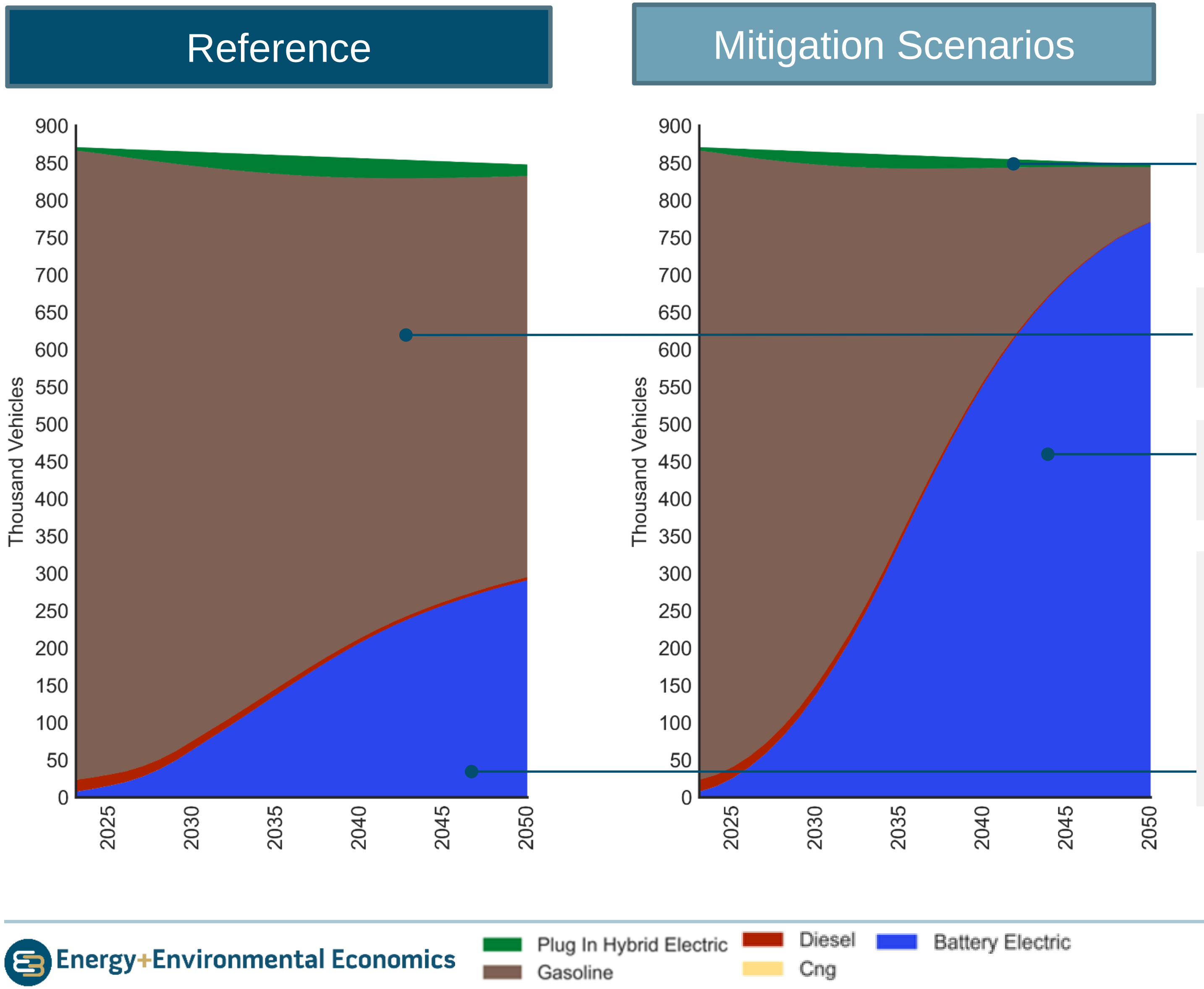
One-in-Ten Noncoincident Peak by Scenario (GW)



Appendix

Energy+Environmental Economics

LDV ZEV adoption in all scenarios is driven by ACCII/ACT; Reference trajectory consistent with historical growth



Long-term ZEV growth in both Reference and mitigation scenarios is **driven primarily by all-electric EVs** rather than plug-in hybrids

Reference LDV stocks are dominated by gasoline ICE vehicles

Mitigation **scenario growth in LDV ZEV penetration is consistent with ACCII/ACT**

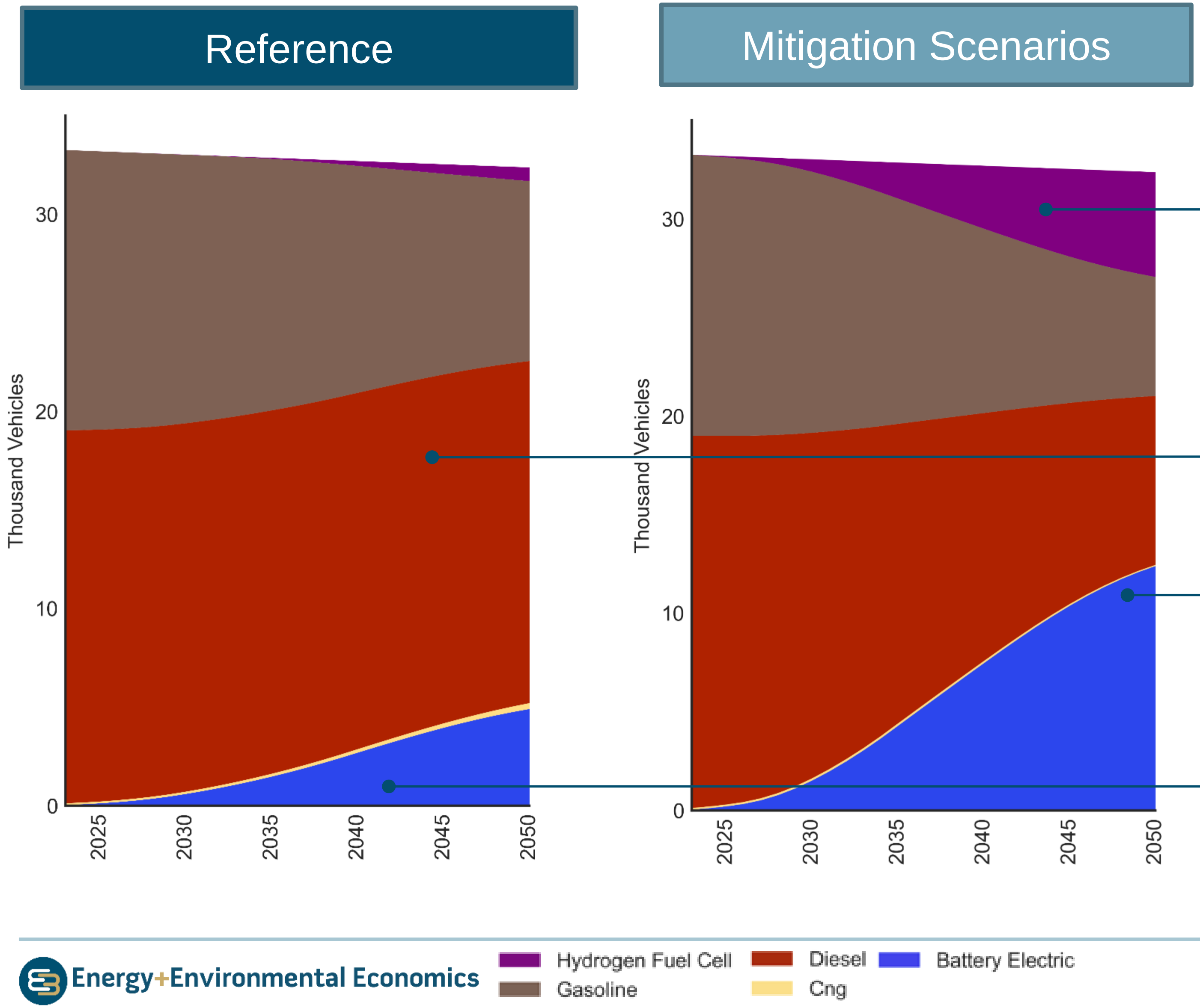
Reference case growth in **LDV ZEV penetration is consistent with historical levels** and EC4 target (10% of stocks by 2030)

No adoption of ACCII/ACT in Reference

DRAFT / PRELIMINARY

LDV = Light-Duty Vehicle
ZEV = Zero-Emission Vehicle

MHDV ZEV adoption in all scenarios is driven by ACCII/ACT; Reference trajectory consistent with historical growth



Hydrogen fuel cell vehicles are classified as ZEVs under ACCII/ACT; growth in MHDV ZEV penetration is consistent with ACCII/ACT

Reference MHDV stocks are dominated by diesel and gasoline ICE vehicles

Mitigation **scenario growth in MHDV ZEV penetration is consistent with ACCII/ACT**

The **Reference case includes modest growth MHDV ZEVs**

No adoption of ACCII/ACT in Reference

DRAFT / PRELIMINARY

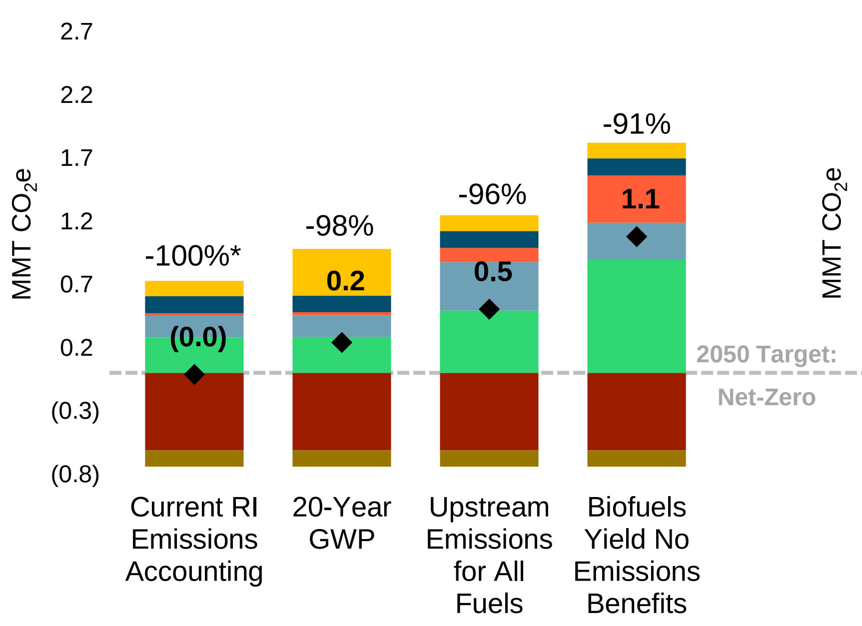
MHDV = Medium- and Heavy-Duty Vehicle

Scenarios with higher levels of renewable fuels may have higher emissions under alternative accounting frameworks

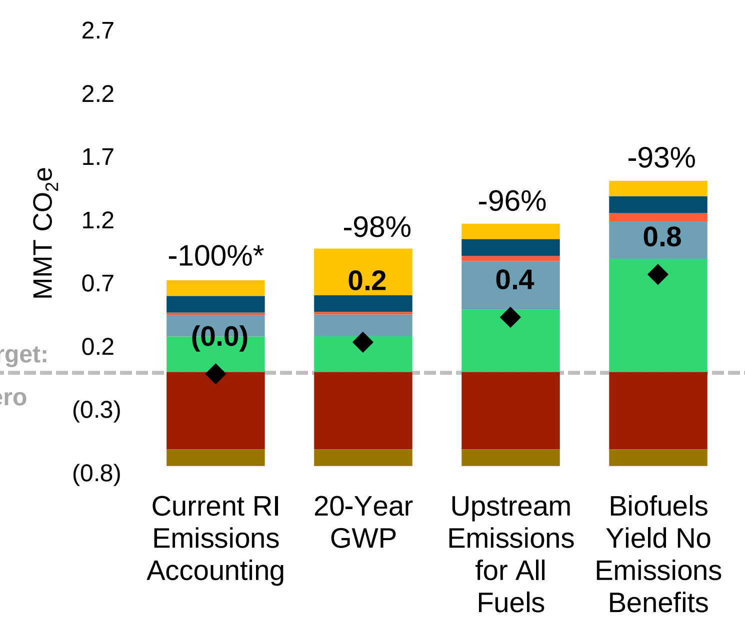
The Technical Analysis is based on emissions accounting **consistent with federal and RI's accounting standards**.

Through **sensitivity analysis**, E3 assessed scenario-specific risks of other types of emissions accounting methodologies. Results for High Electrification, Hybrid + Gas, and Continued Use of Gas are shown on Slide 30. The sensitivity analysis results for remaining scenarios are shown below.

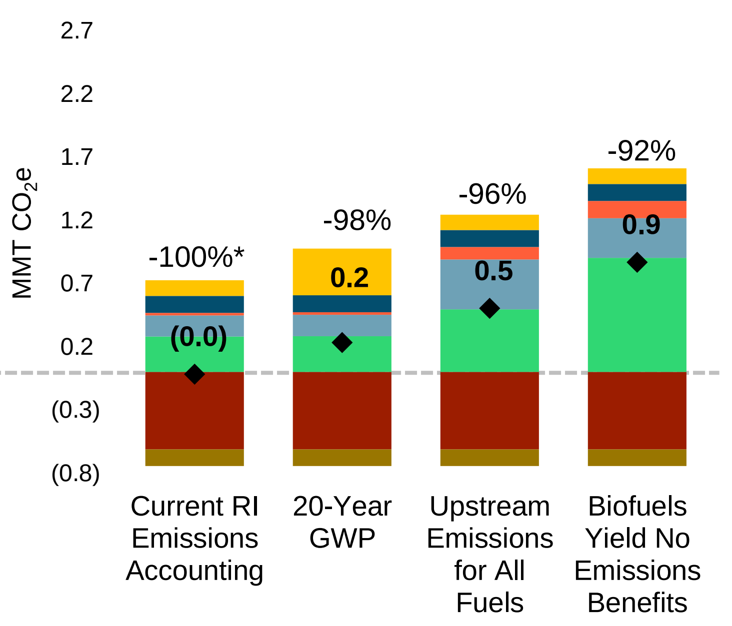
Hybrid + Oil. 2050 Emissions



Staged Elect. 2050 Emissions



Alt. Heat Infra. 2050 Emissions



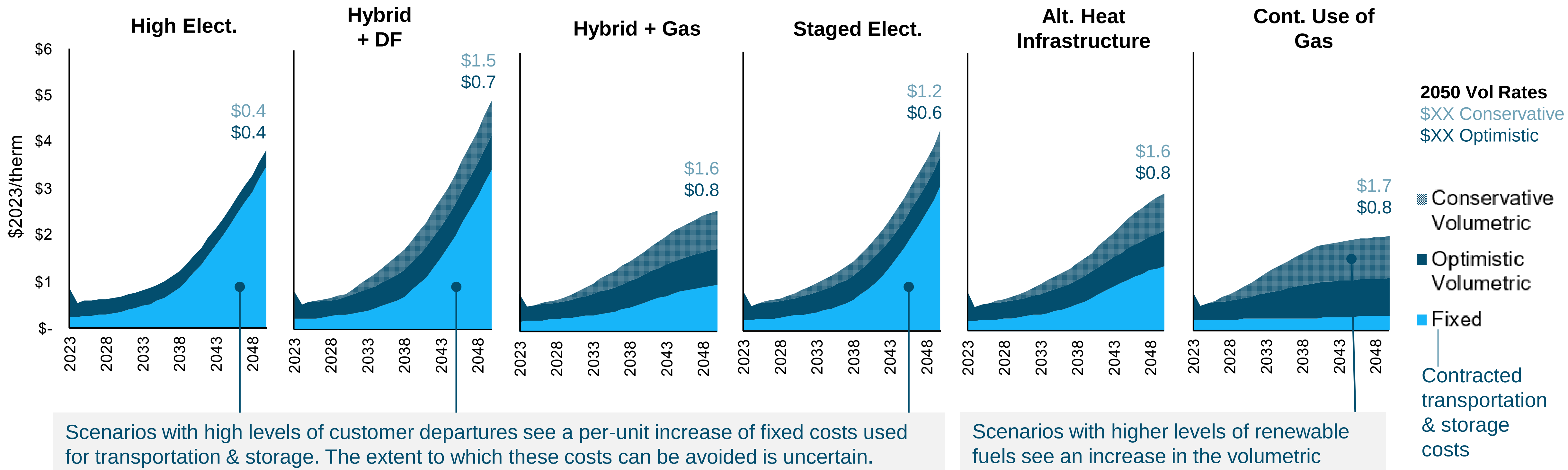
NETs | Sequestration | Gas Distribution | Agriculture & Waste | Electricity | Buildings | Industry | Transportation | Net

* Compared to 1990 emissions levels

Supply costs of gas are expected to rise for residential customers as a result of increased RNG blending

As a result of increased blending of renewable fuels and a decline of system throughput, **the cost of gas is expected to rise**. In scenarios with high levels of electrification, cost increases are due to fixed (transportation & storage) costs shared over a lower volume of customers.

Costs of residential gas supply across scenarios, distinguishing fixed & volumetric components*: 2023-2050

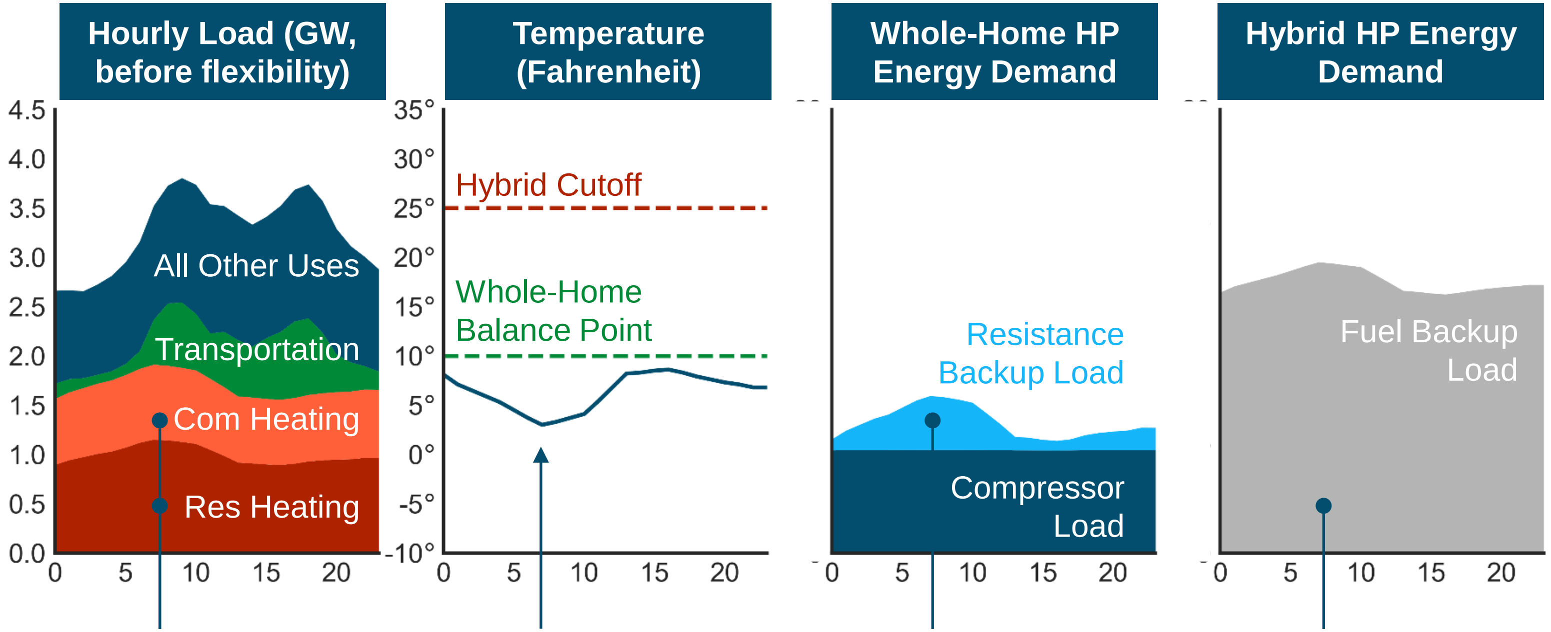


Scenarios with high levels of customer departures see a per-unit increase of fixed costs used for transportation & storage. The extent to which these costs can be avoided is uncertain.

Scenarios with higher levels of renewable fuels see an increase in the volumetric (commodity) component of the costs of gas.

In scenarios with high penetrations of all-electric heating, low temperatures drive peak load

System dynamics in High Electrification scenario on 2050 peak day



The system peak is driven by higher residential and commercial space heating.

The temperature at peak is below both whole-home and hybrid HP balance points.

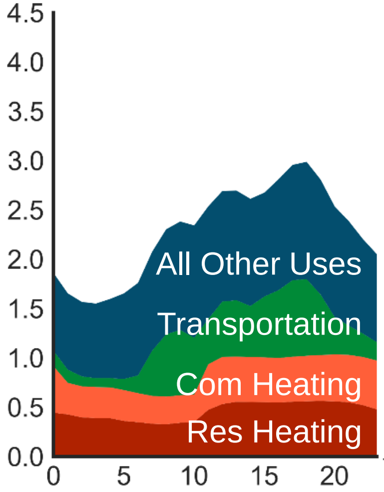
As a result, whole-home heat pumps rely on backup resistance to supplement compressor output.

Because hybrid compressors are not operating, whole-home heat pumps drive the entirety of the space heating contribution to the peak.

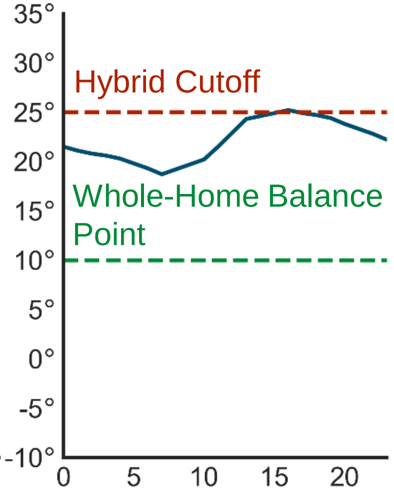
In scenarios with high penetrations of hybrid heating, transportation/peak hybrid heating coincidence drives peak

System dynamics in Hybrid + Gas Backup scenario on 2050 peak day

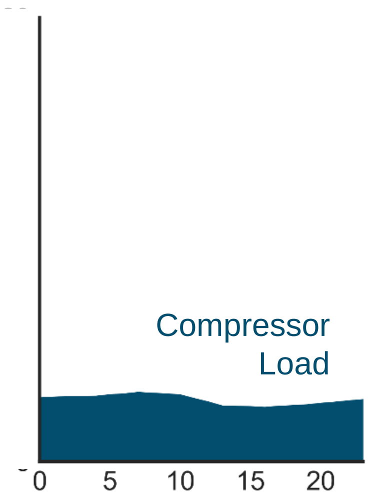
Hourly Load (GW, before flexibility)



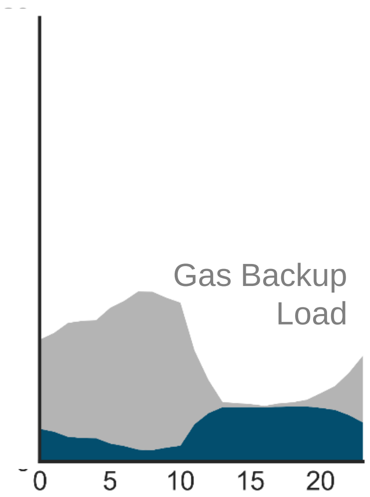
Temperature (Fahrenheit)



Whole-Home HP Energy Demand



Hybrid HP Energy Demand



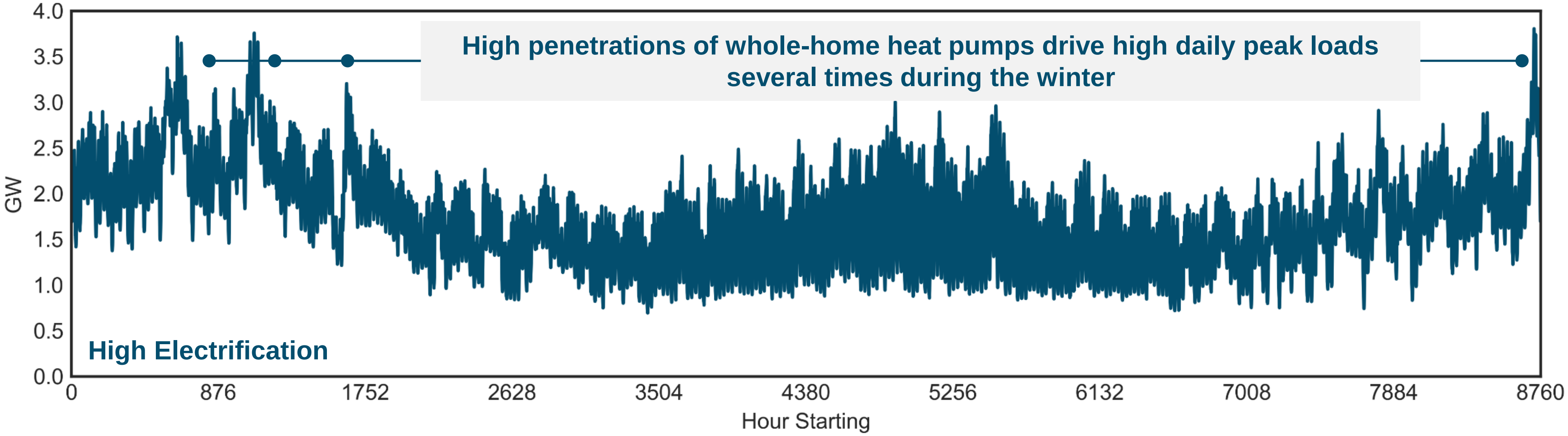
The system peak is driven by the coincidence of transportation and evening hybrid heat pump compressor operation.

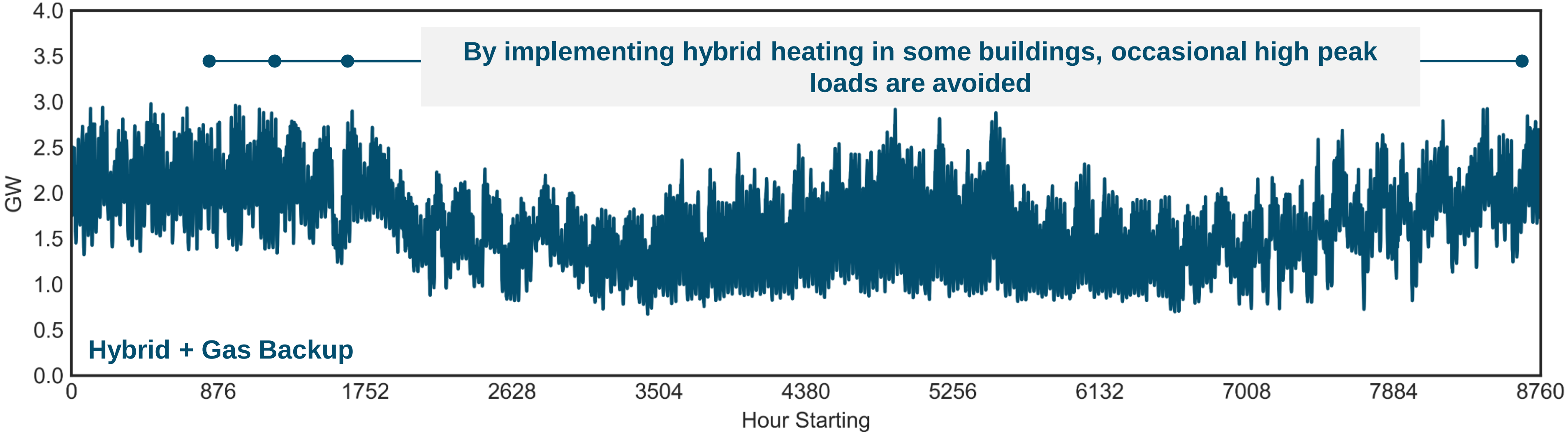
The temperature at peak is very close to hybrid heat pump cutoff.

As a result, whole-home heat pumps are operating below capacity but are still contributing to the peak.

Combined with hybrid heat pump compressor operation near its cutoff, both types of heat pumps contribute to the peak.

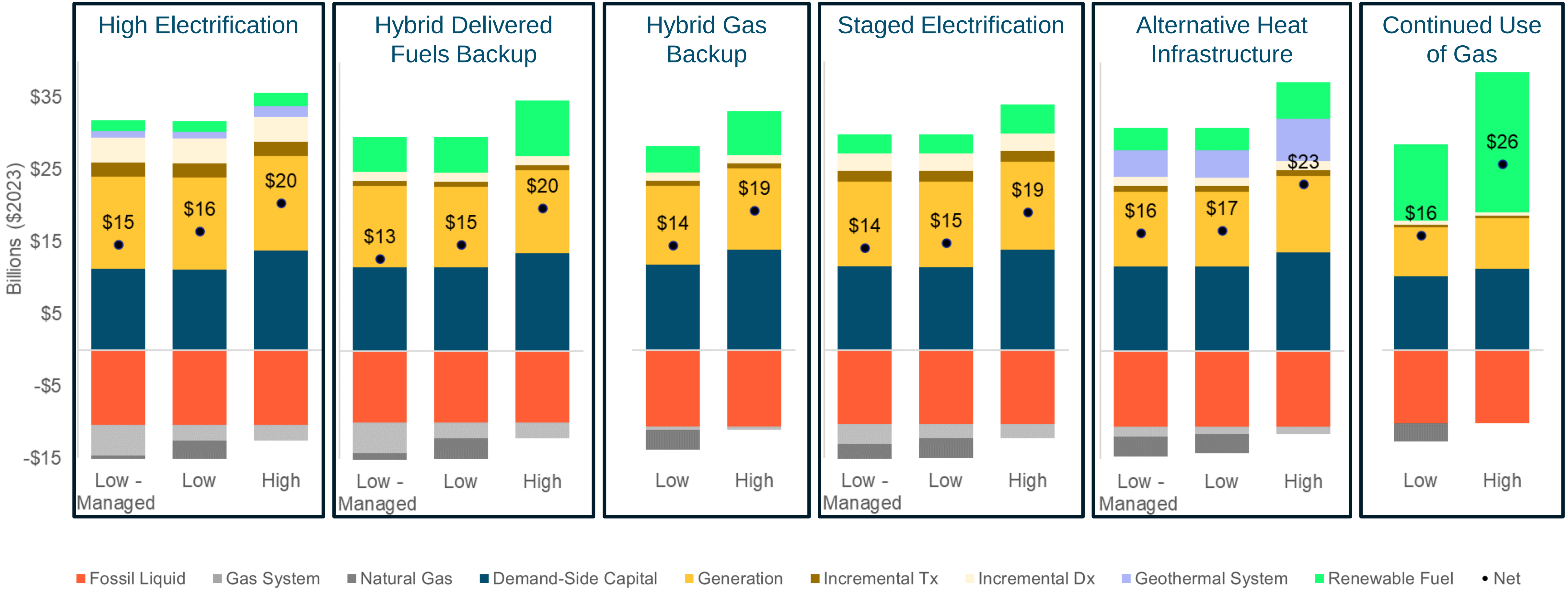
Hybrid heating avoids high system peaks driven by whole-building heating electrification





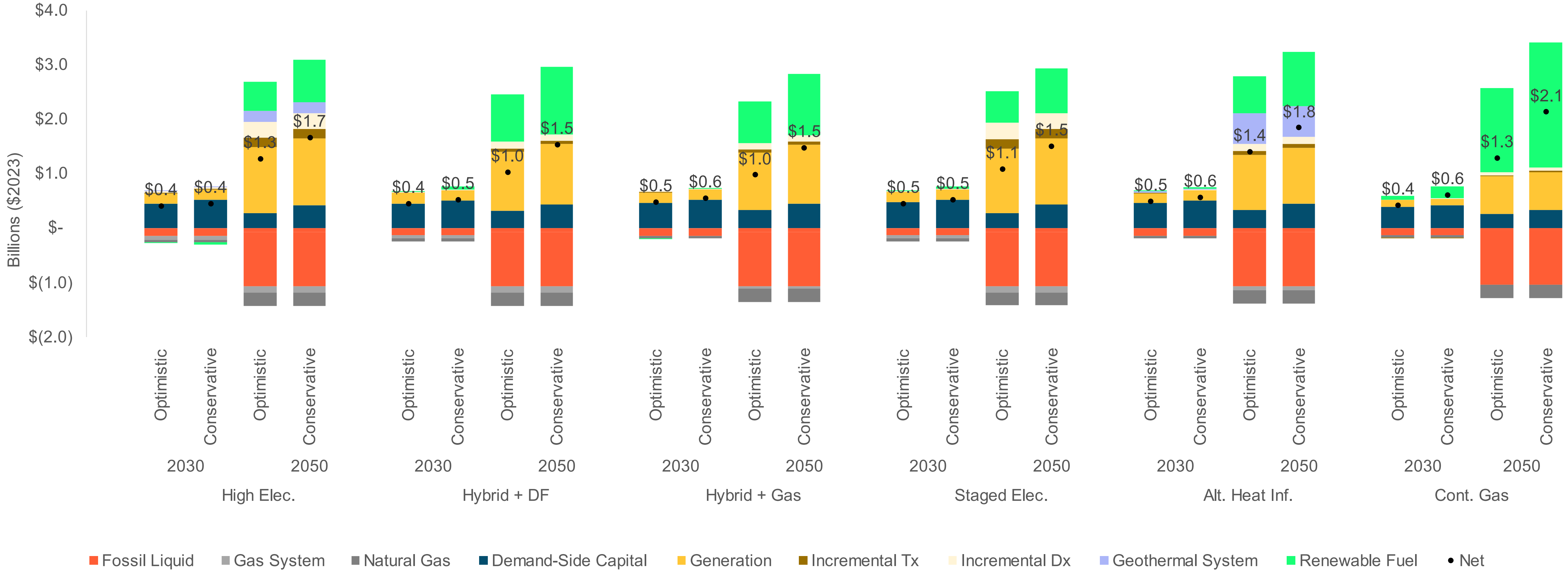
Economy-wide costs show similar ranges with highest uncertainty in cost of renewable fuels

Detailed Cumulative NPV Costs by category:



Economywide costs shower highest level of variations in the long term under annual cost projections

Annual economywide costs across scenarios (snapshots for 2030 and 2050)



Thank You