Thermal Transition Strategy Study

Non-Pipeline Gas Alternatives to Gas Pipeline Replacement

Prepared for the

Massachusetts Department of Energy Resources

by Groundwork Data

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Interviewed Stakeholders

The project team appreciates participation and feedback from the following stakeholders in a series of presentations on the preliminary results of this work.

- The Acadia Center
- Conservation Law Foundation
- HEET
- RMI
- Sierra Club
- The Innovation Network for Communities
- Building Decarbonization Coalition
- National Grid

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Acronyms and Abbreviations

DOER	Department of Energy Resources
DPU	Department of Public Utilities
EEA	Executive Office of Energy and Environmental Affairs
GSEP	Gas System Enhancement Program
HEET	Home Energy Efficiency Team
LDC	Local Distribution Companies
LEAP	Local Energy Asset Planning
NGO	Non-Governmental Organization
NPGA	Non-Pipeline Gas Alternative

EXECUTIVE SUMMARY

In 2022, Massachusetts statutorily committed to achieving net zero greenhouse gas emissions by 2050.[1] Through this legislation, the Commonwealth further noted the critical role that building decarbonization would play in reducing emissions, given that buildings consume 54% of annual energy.[2] The Commonwealth also acknowledged that building decarbonization will have significant implications for regulated gas utilities, which operate 21,000 miles of gas distribution pipes and deliver over 123 billion cubic feet of gas to 1.6 million residential customers for heating and other appliance uses. Despite the targets and goals established through these climate planning exercises, the Commonwealth has laws and procedures supporting continued investment and reinvestment in the safety of the gas system, most notably the 2014 Gas Leaks Act. This law incentivizes gas local distribution companies (LDCs) to replace leak-prone fossil gas infrastructure by submitting annual Gas Safety Enhancement Plans (GSEP) that, when approved by the Department of Public Utilities (DPU), allow the LDCs to accelerate their cost recovery for pipeline replacement.

In a report titled *Regulating Uncertainty*, the conflicting incentives of the 2022 and 2014 laws have been highlighted by the Commonwealth's Attorney General's Office.[3] The Climate Act of 2022[4] established a GSEP Working Group to "develop recommendations and legislative changes to align GSEP with statewide emission limits."[5] Further, in a formal comment to the DPU's 20-80 "Future of Gas" docket, DOER recommended the development of a geographic marginal cost analysis for evaluating the costs and benefits associated with alternative strategies to gas pipeline replacement.[6] Similarly, in Regulating Uncertainty, the Attorney General's Office called for the development of an investment alternatives calculator to review the prudence of proposed gas system investments.

This report introduces the concept of Local Energy Asset Planning (LEAP), focused on a small geographical area, as a geographic marginal cost assessment tool to evaluate the potential of non-pipeline gas alternatives (NPGAs) that align with the Commonwealth's climate goals. Through a multi-indicator geospatially-resolved assessment, this study evaluates two specific and representative street segments that have previously undergone gas pipeline replacement projects under a utility Gas System Enhancement Plan (GSEP): an affluent single-family neighborhood in a municipal electric territory and a multifamily unit neighborhood in a "Justice 40" gateway community.

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[1] Executive Office of Energy and Environmental Affairs. "Massachusetts Clean Energy and Climate Plan for 2050 | Mass.Gov," December 21, 2022. https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2050.
[2] "High Performance Buildings | Mass.Gov." Accessed June 26, 2023. https://www.mass.gov/high-performance-buildings.
[3]" Tepper, Rebecca, Jo Ann Bodmer, Donald Boecke, Jessica Freedman, and Jessica Harmon. "Regulating Uncertainty." Maura Healey, Attorney General, May 2, 2022. https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/14922535.
[4] An Act driving clean energy and offshore wind, Pub. L. No. H.5060 (2022). https://malegislature.gov/Bills/192/H5060.
[5]https://www.mass.gov/info-details/gseps-pursuant-to-2014-gas-leaks-act#gas-system-enhancement-plan-working-group-
[6] Comments of the Massachusetts Department of Energy to MA DPU Docket #20-80 https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/15648607

Table ES 1. Intervention scenarios were evaluated in this study.

Scenario	Description
Continued Pipeline Gas	The gas pipeline will be replaced in 2025, with a like-for-like replacement of heating systems at their respective end of life.
Dual Fuel – Pipeline, Unmanaged	The gas pipeline will be replaced in 2025; air source heat pumps will be added with backup pipeline gas heating at the end of their life.
Dual Fuel – Pipeline, Accelerated	The gas pipeline will be replaced in 2025; air source heat pumps will be added while refurbishing existing pipeline equipment to provide pipeline gas in 2025.
Dual Fuel – Tank, Accelerated	The gas pipeline will be removed & air source heat pumps will be installed with existing gas equipment refurbished and converted to backup propane in 2025.
Electrification, Unmanaged	The gas pipeline will be replaced in 2025 & buildings will be fully electrified at the end of the life of existing equipment.
With Energy Efficiency	Above with envelope improvements.
Electrification, Accelerated	The gas pipeline will be removed & buildings will be fully electrified in 2025.
With Energy Efficiency	Above with envelope improvements.

The study evaluates eight scenarios (Table ES 1) across two example street segments, exploring degrees of electrification, efficiency, and intervention timing. Several metrics are used to assess these scenarios: methane leak risk, energy consumption and emissions, electric system impacts, and costs. This analysis finds:

- An unmanaged electrification, in which gas pipelines are replaced under current law and buildings steadily electrify, maximizes the risk of unrecovered costs and higher gas rates for ratepayers.
- All transition pathways bring risks and complex tradeoffs:
    - Segment electrification instead of costly pipeline replacement will reduce methane leaks and combustion emissions but will require electric system upgrades and significant acceleration of building electrification investment.
    - Incorporation of energy efficiency measures can lower the level of electric sector investment needed to support electrification.
    - Less dense segments are likely to have more cost-effective and flexible options, but dense multifamily segments offer an opportunity for a coordinated transition in populations historically underserved by energy services.
    - Segments with high-risk leaks may need to be urgently transitioned, lacking time to deploy options that require significant customer preparation.
- There is a significant option space for interventions beyond the full and partial building electrification explored in this study. Such options include distributed non-pipeline fuels or novel thermal energy networks. These strategies can play a role in managing intervention costs and electrical loads but may involve other tradeoffs.

- Integrated LEAP analysis of the gas transition at the hyper-local level can offer valuable insights for project identification and optioneering. However, participation by both gas and electric utilities will be needed to provide the data necessary to plan and act with confidence.

Based on these findings, this report recommends**:**

- Better data quality, uniformity, and availability.
- Guidance and support for cities/towns.
- Understanding the equity implications of segment-level transitions.
- Implementing pilot projects guided by LEAP.
- Applying LEAP to broader transitional questions.

Analytical Summary for Policymakers

Project Design

- This study evaluated the cost and emissions impacts of various scenarios for managing leak-prone pipes on Massachusetts single-family and multi-family street segments. 2022 GSEP filings were used to identify characteristic street segments. These filings provided pipeline replacement cost estimates used in the analysis.
- Building energy models representative of Massachusetts homes (developed by NREL) were used to simulate different intervention and decarbonization strategies under pipeline replacement and pipeline decommissioning scenarios. Cost data for each intervention was derived from MassCEC, Mass Save, and retail datasets.
- Scenarios with pipeline replacement include **Continued Gas** use as usual, where household equipment is replaced like-for-like at natural replacement cycles; **Unmanaged Electrification** in which homes are fully electrified at natural replacement cycles; and **Dual Fuel - Pipeline,** where homes are partially electrified at natural replacement cycles but still retain gas for peak heating needs. Scenarios with pipeline decommissioning include **Accelerated Electrification**, where homes are fully electrified in 2025, and **Dual Fuel - Tank,** where homes are partially electrified and some equipment is converted to propane for peak heating needs in 2025.

Results

- A summary of the single-family segment's impact analysis is shown in the included table.
- Pipeline replacement is a significant cost – $1.7M per mile (slightly less than the statewide average of $2M per mile) or $34K per home. It addresses safety and fugitive methane risks but does not create new value for the consumer or facilitate a decarbonization pathway. Direct capital costs are paid for directly by the utility, but ultimately, gas customers pay for such investment over time through their gas rates, allowing the LDCs to recover their capital, a rate-of-return, taxes, and operating expenses.
- Building interventions are also a significant cost (ranging from $22K for like-for-like system replacements to $37k-$41k for whole home electrification, depending on timing). Home sizes, in this case, are relatively large — averaging 3,400 square feet — resulting in relatively high building electrification costs. Mass Save incentives (~$17k) are sufficient to cover the cost differential between like-for-like replacements and whole home electrification. However, under **Accelerated Electrification**, there may be significant stranding of existing gas equipment due to an intervention outside natural replacement cycles. This is an additional homeowner cost not included in the summary but discussed in the report.
- Incremental electric sector impacts are relatively low, but fully electric scenarios require increasing transformer capacity at a street-wide cost of $80K or $4,200 per home. Dual fuel approaches allow such investment to be deferred. This is based on the assumption that there is sufficient feeder capacity and that increasing loads only requires local transformer upgrades. This assumption may not hold at increasing levels of electrification across multiple streets.
- Deeper and earlier electrification will lead to greater emissions reductions.
- Customer bill impacts (assessed in the report) depend significantly on future rate design. All electric homes tend to see modest bill increases in the near term. Still, such homes are insulated from the increasing costs of gas delivery (forecasted by the gas utilities in DPU Docket #20-80) and the possibility of increasing combustion compliance costs (e.g., a carbon tax or alternative compliance payment).

Implications

- Gas pipeline replacement costs are increasingly expensive. Decommissioning segments can avoid reinvestment.

- Building electrification is also a significant investment. While necessary for achieving climate targets, an **Unmanaged Electrification** with pipeline replacement will result in the highest system costs, redundant spending, and stranded gas utility assets.
- Pipeline decommissioning will require accelerated investment in the building stock. The cost of immediate electrification may exceed the cost of pipeline replacement but will reduce overall systems costs while advancing decarbonization goals.
- The **Dual Fuel - Tank** scenario demonstrates the utility of alternative strategies for managing the impact of full electrification. Propane conversions, along with the installation of ASHPs, may be appropriate for homes with recently installed highly efficient gas equipment or with strong consumer preferences. However, due to constraints on tank location in dense areas, this strategy may not be applicable everywhere.
- Alternative management strategies include thermal storage heat pumps or geothermal. These were not analyzed in this study and may face some situational constraints, but should be considered as potential interventions.
- This study demonstrates a framework for hyper-local integrated energy planning, similar to strategies proposed in utility Electric Sector Modernization Plans. Data needs and barriers to such planning are discussed in the report.

Considerations for Pilots

- Mass Save incentives should be sufficient for transitioning homes with gas equipment as they undergo equipment replacement and electrify: the cost of electrification ($25K-$40K) minus incentives ($17K) is equivalent or less than a like-for-like gas system replacement ($12-$25K). However, this depends on contractor fees and materials costs, which are rapidly changing. Coordinating contractors on a street-wide project may ensure that such costs are kept low.
- Even if the equipment has reached the end of its life, some customers may prefer to continue to use such equipment to avoid replacement costs for as long as possible. A pilot triggers these costs.
- Many homes on a street segment will have equipment that has not reached the end of its natural life cycle. These will be stranded assets under a pipeline decommissioning scenario. This could range from $5,000 to over $20,000 per home. Some may be recently installed high-efficiency (Mass Save-sponsored) gas furnaces or boilers. Cities such as Zurich have offered some compensation for these situations. Some existing equipment may be suitable for propane conversion, delivering transitional benefits such as avoiding electric peak impact.
- Addressing customer costs of such accelerated interventions for a pilot will require:
  - Additional incentives on top of Mass Save (averaging from $5K-$10K additional)
  - A framework for handling interventions and incentives on a house-by-house basis
  - A funding source which could be the gas utility (since the utility will realize avoided costs), Mass Save, or another entity.
- Pilot programs may require 2-3 year lead times for customer engagement, onboarding, and planning. This may constrain potential sites if avoiding leak-prone pipe replacement is the goal. Some leak-prone pipe mitigation efforts may require more rapid mitigation.
- Implementors of a pilot would need to navigate issues relating to the obligation to serve. These issues are discussed in this report from the New York University Institute for Policy Integrity: The Obligation to Serve in Massachusetts

Scenario	Gas Network (Utility/Ratepayer Costs)	Building (Customer Costs)	Electric Network (Utility/Ratepayer Costs)	System Capital Investment (Total: Gas + Building + Electric Costs)	Climate Target Risk (Leaks & Emissions)
Continued Gas	Gas pipeline replaced in 2025* Total Capital: $642K Per Home: $34K	At its end-of-life, gas equipment is replaced with similar equipment. Total Capital: $407K Per Home: $21K	No upgrades. All heating loads remain on the gas system.	*Gas System Reinvestment + Low Heating Reinvestment* Total: $1,049K Per Home: $55K	*Highest* Inconsistent with climate targets.
Dual Fuel - Pipeline		Gas furnaces are replaced with hybrid systems at end-of-life. Total Capital: $684K Per Home: $36K	No upgrades. Peak heating loads remain on the gas system.	*Gas System Reinvestment + Medium Heating Reinvestment* Total: $1,326K Per Home: $70K	*Medium* Partial reduction in combustion and leaks. Requires additional intervention.
Unmanaged Electrification		Buildings to be fully electrified when existing systems reach their end of life. Total Capital: $886K ($1,105 w/EE) Per Home: $47K ($58K w/EE)	Steady electrification requires preemptive transformer upgrades over time. Total Capital: $80K ($60K w/EE) Per Home: $4.2K* ($3.2K w/EE)	Gas System Reinvestment + High Heating Reinvestment + Additional Elec. Capacity Total: $1,608K ($1,827K w/EE) Per Home: $85K ($96K w/EE)	*Low* Buildings will be fully electrified by 2050
Dual Fuel - Tank	Gas service ended in 2025. Pipes are capped at a modest cost. Total Capital: $20K Per Home: $1.05K	Buildings are to be retrofitted in 2025 with a heat pump and supplemental tank propane. Total Capital: $429K Per Home: $26.8K	No upgrades. Peak heating loads shift from the gas system to tanked propane.	Medium Heating Reinvestment Total: $530K Per Home: $23.6K	*Medium* Partial reduction in combustion. Leaks eliminated in 2025 Requires additional intervention.
Accelerated Electrification		Buildings will be completely electrified in 2025. Total Capital: $703K ($878 w EE) Per Home: $37K ($46Kw/EE)	Steady electrification requires preemptive transformer upgrades over time. Total Capital: $80K ($60K w/EE) Per Home: $4.2K* ($3.2K w/EE)	High Heating Investment With Early Retirements + Additional Elec. Capacity Total: $783K ($958K w/EE) Per Home: $41K ($50K w/EE)	*Lowest* Leaks and combustion emissions are eliminated in 2025.

*Cost is borne by all ratepayers with additional revenue needed to cover rate of return, taxes, O&M | EE = Enhanced Envelope Energy Efficiency

Relevance to the Dept. of Public Utilities Order 20-80B

This analysis was conducted before the D.P.U. released its order[7] in its "Future of Gas" investigation (Docket D.P.U. 20-80) on December 6, 2023. The order offered extensive review, commentary, and direction on "Targeted Electrification" projects. "Targeted electrification" is largely synonymous with the segment or tactical decommissioning terminology[8] used in this document and was proposed by the utilities as part of their Net Zero Enablement Plans[9,10] to limit the costs of the system and align with state climate targets.

In the 20-80-B order, the DPU directed the LDCs to (quoted verbatim):

- Work with the relevant electric distribution company to study the feasibility of piloting a targeted electrification project in its service territory.
- Each LDC, in coordination with the applicable electric distribution company, shall propose at least one demonstration project in its service territory for decommissioning an area of its system through targeted electrification.
- The LDC should target a portion of its system that suffers from pressure/reliability issues and leak-prone pipes and target environmental justice populations that have borne the burden of hosting energy infrastructure.
- The Department expects the LDCs to engage with elected and appointed officials in the community, community-based organizations that work on energy, environment, labor, or ending poverty, and other interested residents.
- File its project proposal by March 1, 2026, for inclusion in its 2030 Climate Compliance Plan, working with its relevant electric distribution company and Program Administrator as necessary.

The report presented here on segment decommissioning supports the goals of targeted electrification management strategies: first, by demonstrating a framework for project evaluation; second, by identifying data needs that could be used for project "targeting."

[7] Van Nostrand, Jamie, Cecile Fraser, and Stacy Rubin. Order on Regulatory Principles and Framework, No. 20-80 (MA Department of Public Utilities December 8, 2023). https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/18297602

[8] While largely synonyms, segment decommissioning describes the application of strategies to decommission a gas distribution segment. Such strategies could include the use of a non-pipeline fuel as described in this report in tandem with some electrification.

[9] National Grid. "Net Zero Enablement Plan." https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/14633280 .

[10] Eversource. "Net Zero Enablement Plan." https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/14633282.

Chapter 1: Study Background and Context

This study was commissioned by the Massachusetts State Legislature and funded as part of the Commonwealth's allocation of American Rescue Plan Act funds from An Act relative to immediate COVID-19 Recovery Needs (St. 2021, c. 102, line item 2000-0103).[11] The project was overseen by the Department of Energy Resources (DOER) Policy, Planning & Analysis Division.

Massachusetts has statutorily committed to net zero greenhouse gas emissions by 2050 on a pathway defined by a series of interim targets.[12] The 2050 target requires an 85% reduction in "gross" greenhouse gas emissions, with residual emissions "netted" by carbon storage removals (e.g., storage of carbon in the state's natural and working lands and direct human-mediated removals of carbon dioxide from the atmosphere. As part of the Commonwealth's planning process, the Executive Office of Energy and Environmental Affairs (EEA) conducted several planning exercises culminating in near-term and long-term transition plans.[13] These exercises established the need for a drastic reduction in the consumption of pipeline-delivered gas to achieve the Commonwealth's climate targets. Still, the 2050 Decarbonization Roadmap noted:

> *"There are risks and challenges in implementing even a controlled or planned exit from widespread, primarily residential, use of the gas system. The potential for an* ***uncontrolled exit driven by market economics raises significant additional equity concerns****."*

The State's subsequent climate plans further noted that substantial planning would be necessary to address the challenges associated with the transition off gas:

> *Transitioning our buildings from oil and natural gas to electricity will have profound impacts on our electric grid and our natural gas distribution infrastructure. Responsible energy infrastructure planning is thus a key priority for building decarbonization.*
>
> **-Clean Energy and Climate Plan for 2025 and 2030**

> *The analyses of the needs and opportunities for gas and electric infrastructure upgrades will need to be done in a coordinated way to best guide the deployment of clean heating systems…the necessary reductions in natural gas throughput will require changes in how the gas system is operated and regulated and may require decommissioning significant parts of the gas system.*
>
> **-Clean Energy and Climate Plan for 2050**

At the center of these challenges is that the reduction in gas consumption and customers is expected to occur faster than the utility can recover its capital spending on gas plant or infrastructure. With a declining customer base, utilities must increase rates to spread their revenue requirement over fewer customers, at least under the current regulatory and ratemaking framework. Rising costs would further

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[11] ARPA State Fiscal Recovery Fund Allocations. https://www.ncsl.org/fiscal/arpa-state-fiscal-recovery-fund-allocations.

[12] Executive Office of Energy and Environmental Affairs. "Massachusetts Clean Energy and Climate Plan for 2050 | Mass.Gov," December 21, 2022. https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2050.

[13] Executive Office of Energy and Environmental Affairs. "Massachusetts 2050 Decarbonization Roadmap: Summary Report," 2020. https://www.mass.gov/doc/ma-2050-decarbonization-roadmap/download.

spur customers to leave the gas system; those without access to capital (low-income customers) or who lack agency (renters) would be left behind on an increasingly costly gas system and ultimately challenging utility financial viability.[14]

The pivot to declining gas consumption is underway. The Massachusetts gas system averaged a 1% customer growth rate over the past two decades, driven by new construction and oil-to-gas conversions in existing buildings. [15] Despite this growth, consumption has remained flat, largely thanks to energy efficiency gains achieved by equipment upgrades and the adoption of high-performance building practices in new construction. The 2022 update to the building energy code includes several mechanisms that will likely reduce new connections from new construction.[16] The 2022-2024 Mass Save Plan's expansion of incentives for electrification is also anticipated to reduce the aggregate growth of gas connections and begin a steady decline in consumption.[17]

At the same time, investment in the gas system continues largely to maintain existing service but at increasing cost. The bulk of this concerns the replacement of leak-prone distribution mains and services. Under the 2014 Gas Leaks Act, LDCs receive accelerated cost recovery to replace leak-prone distribution infrastructure. The Act requires the submission of an annual Gas System Enhancement Plans (GSEP) (see subsection below: The Challenge of Managing Gas Leaks and Leak-Prone Pipe), and replacement costs are subsequently recovered through rates typically over a multi-decade period corresponding to the useful life of the new mains.

Pipeline replacement costs are significant and increasing. A 2021 report titled *GSEP at the Six-Year Mark* found that the ratepayer costs of the law could exceed $20 billion ($2019) over a 30-year depreciation period.[18] Since then, costs of gas pipeline replacement projects have grown even further, with average per-mile replacement costs for National Grid's Boston Gas territory reaching $3.4 million in 2023.

For the first time in the program's history (see BOX: GSEP in 2023), four LDCs have hit the program's spending cap. This cap protects consumers today but defers GSEP cost recovery to future years, assuming the deferrals are approved by the DPU.

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[14] Walsh, Michael, and Michael Bloomberg. "The Future of Gas in New York State." Building Decarbonization Coalition, March 16, 2023. https://buildingdecarb.org/resource/the-future-of-gas-in-nys.
[15] "Massachusetts State Energy Profile." U.S. Energy Information Administration, 2022. https://www.eia.gov/state/print.php?sid=MA.
[16] "Summary of Proposed New 225 CMR 22.00 and 23.00." 2023 Stretch Energy Code Update and Municipal Opt-in Specialized Code. Massachusetts Department of Energy Resources, n.d. https://www.mass.gov/doc/summary-document-explaining-stretch-energy-code-and-specialized-opt-in-code-language/download.
[17] "Three Year Energy Efficiency Plan 2022-2024." Mass Save, November 1, 2021. https://ma-eeac.org/wp-content/uploads/Exhibit-1-Three-Year-Plan-2022-2024-11-1-21-w-App-1.pdf.
[18] Seavey, Dorie. "GSEP at the Six-Year Mark: A Review of the Massachusetts Gas System Enhancement Program," 2021. https://static1.squarespace.com/static/612638ab5e31f66d7ae8f810/t/61561b8c4955b93159a753a3/1633033102069/GSEPatTheSix-YearMark.pdf. Using new LDC data made available in the DPU 20-80 consultant reports, Seavey revised her estimate to $40 billion ($2019). See: MA Department of Public Utilities, Dorie Seavey, PhD Comments on DPU Docket No. 20-80: Investigation by the Department of Public Utilities on its own Motion into the role of gas local distribution companies as the Commonwealth achieves its target 2050 climate goals (DPU 20-80, May 2022), https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/14919653.

Given the challenges associated with a decline in gas demand as well as the issues facing the GSEP program, the Commonwealth has launched several initiatives to align efforts in managing the gas transition:

- Opened a "Future of Gas" proceeding (D.P.U. 20-80)[19] at the Department of Public Utilities (DPU), petitioned by the then Attorney General Maura Healey. As part of the investigation, the six investor-owned LDCs conducted their own statewide pathways study and proposed transition plans. The LDCs also submitted proposals for aligning their operations with the State's climate goals. On December 6, 2023, the DPU issued Order 20-80 B in the investigation. The Order establishes a new requirement for LDCs to consider non-gas alternatives to gas expansion projects. Additionally, the Order requires each LDC to file a Climate Compliance Plan with the Department every five years beginning April 1, 2025. Each Climate Compliance Plan must demonstrate how the LDC proposes to contribute to the prescribed GHG emission sublimits set by EEA; satisfy customer demand safely, reliably affordably, and equitably; use pilot demonstration projects to assist in identifying investment alternatives; incorporate the evaluation of previous metrics, and implement recommendations for future plans.
- The GSEP Working Group to propose changes to the Gas Leaks Act to align it with the State's emissions limits. [20] On January 19, 2024, The Working Group voted to approve a final report and recommendations for changes to the GSEP statute. The report was submitted to the DPU, the Joint Committee on Telecommunications, Utilities and Energy, the Senate and House Committees on Global Warming and Climate Change, and the Clerks of the Senate and House of Representatives. The report[21] is a compilation of recommendations from the working group to the legislature which could revise the current GSEP statute.
- The Department of Environmental Protection imposed annually declining methane emissions limits[22] on gas distribution companies using pipeline material-specific emissions factors, serving as another mechanism to incentivize gas pipeline replacement.
- The Commission on Clean Heat recommended the adoption of a clean heat standard framework advancing building electrification. [19] In November 2023, the Department of Environmental Protection established a draft program framework that established defined building electrification targets for achieving emissions reductions along with other mechanisms such as an alternative compliance payment.[23]
- Construction of thermal energy network pilot projects by Eversource and National Grid that aim to explore advanced strategies for efficiently transitioning mixed-use neighborhoods off of gas.

Each of these developments intersects with the question of how long to continue reinvesting in the gas system as opposed to pursuing alternative strategies, given the potential long-term costs of maintaining

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[19] "MA DPU 20-80." https://eeaonline.eea.state.ma.us/DPU/Fileroom/dockets/bynumber/20-80.

[20] "An Act Driving Clean Energy and Offshore Wind." Accessed August 13, 2022. https://malegislature.gov/Bills/192/H5060.

[21] GSEP Working Group Final Report and Recommendations, January 31, 2024. https://www.mass.gov/doc/gsep-working-group-final-report-and-recommendations-13124/download

[22] "Reducing Methane (CH4) Emissions from Natural Gas Distribution Mains & Services (310 CMR 7.73)|Mass.Gov." Accessed June 23, 2023. https://www.mass.gov/service-details/reducing-methane-ch4-emissions-from-natural-gas-distribution-mains-services-310-cmr-773.

[23] "Massachusetts Clean Heat Standard Draft Framework." Massachusetts Department of Environmental Protection, November 2023. https://www.mass.gov/info-details/massachusetts-clean-heat-standard.

the system under declining use. This document refers to such alternative strategies as non-pipeline gas alternatives (NPGAs). The most relevant example is decommissioning or retiring a gas pipeline that needs to be replaced by shifting current customers to a heating source other than pipeline gas.

It is unclear how much can be saved across the entire gas system by employing NGPAs. Much of the uncertainty depends on understanding how applicable such strategies are across the system. However, given the extremely high costs of continuing to modernize the gas system, even if NGPAs were deployed to only a material fraction of the system, the cost savings could reach into the billions and be realized mainly by ratepayers, with additional social benefits.

Other states have begun implementing strategies to manage gas demand and begin the transition off of gas. For example, California is embarking on efforts to identify and transition gas segments, including pilot projects[24] and developing a site selection and evaluation decision support tool.[25] See subsection below: *Non-Pipeline Gas Alternative Efforts in Other States* for more details.

The Commonwealth's LDCs have acknowledged the role of NGPAs, such as targeted electrification, in their Net Zero Enablement plans.[26,27] The DPU addressed NGPAs in its 20-80-B Order, requiring the examination of NGPAs to include electrification, thermal networked systems, targeted energy efficiency and demand response and behavior change and market transformation. Going forward, the LDCs will have the burden to demonstrate the consideration of NGPAs as a condition of recovering additional investment in pipeline and distribution mains. Additionally, a framework for how NGPAs can be incorporated into GSEP was recommended by members of the GSEP Working Group in its final report submitted to the legislature.

During this project, the project team and DOER became aware of efforts at LDCs in Massachusetts to identify opportunities for NPGAs using integrated gas and electric system planning in their combined service territories.[28] The project team conducted two information-sharing meetings with utility teams to compare approaches. This engagement emphasized the need for both utility-focused planning and a broader public-sector capacity to guide avoided reinvestment in the near term and more comprehensive efforts in the long term.

The need for broader stakeholder alignment on the gas transition was identified by the Regulatory Assistance Project in the report *Under Pressure: Gas Utility Regulation for a Time of Transition.*[29] The

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[24] Bay, California State University Monterey. "East Campus May Become California's Largest Electrification Project." Accessed June 5, 2023. https://csumb.edu/news/news-listing/east-campus-may-become-californias-largest-electrification-project/.

[25] Commission, California Energy. "GFO-21-504 - Development of a Data-Driven Tool to Support Strategic and Equitable Decommissioning of Gas Infrastructure." California Energy Commission. California Energy Commission, current-date. https://www.energy.ca.gov/solicitations/2021-11/gfo-21-504-development-data-driven-tool-support-strategic-and-equitable.

[26] Eversource. "Eversource Net Zero Enablement Plan." https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/14633282.

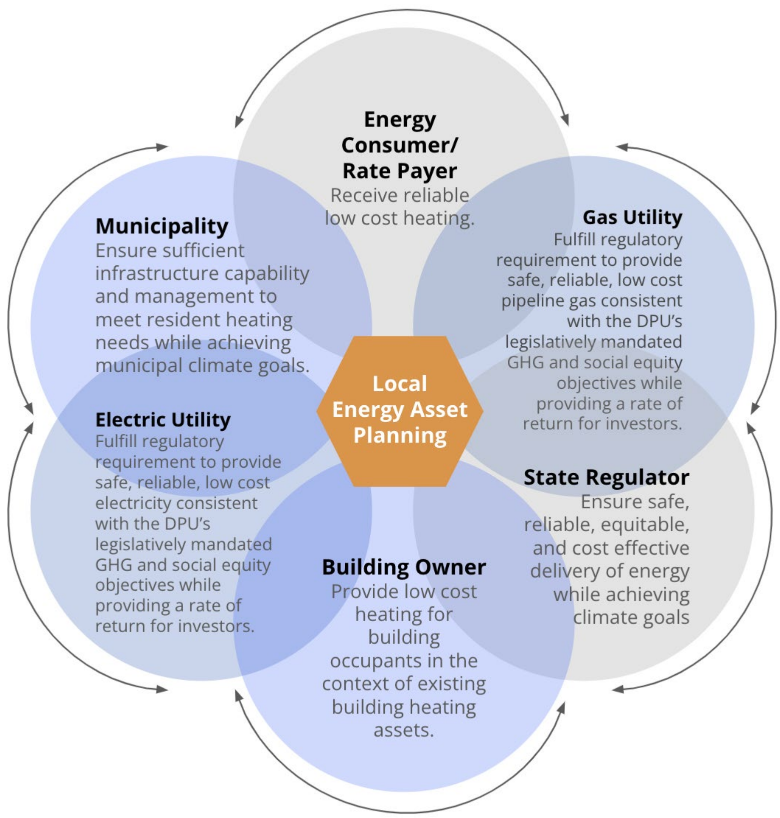
[27] National Grid. "National Grid Net Zero Enablement Plan." https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/14633280.

[28] Encoord. "Press Release - National Grid Licenses Encoord's SAInt Software for Integrated Planning." Accessed June 9, 2023. https://www.encoord.com/press-releases/National-Grid-Nov2022.

[29] Anderson, Megan, Mark LeBel, and Max Dupuy. "Under Pressure: Gas Utility Regulation for a Time of Transition." Regulatory Assistance Project, May 2021. https://www.raponline.org/knowledge-center/webinar-under-pressure-gas-utility-regulation-transition/.

project also underscored the challenge of siloed gas and electric planning efforts even when the same corporate entity provides both gas and electric services to the same customer.

Transitioning multiple buildings situated in a common neighborhood or on a common street off gas will require coordination by various entities (Figure 1). Such a framework requires engagement strategies and detailed options analyses conducted at a hyper-local level to assess existing energy resources, prioritize transition sties, and evaluate each site's option space.



Local	Building to neighborhood scale representation
Energy	Focuses on energy resources and energy consumption
Asset	Represents specific energy resources and demands at the asset level
Planning	Quantitatively robust analysis of multiple solutions to inform and engage stakeholders

Figure 1. LEAP and stakeholders required for alignment under this framework.

This study uses the Local Energy Asset Planning (LEAP) framework.[30] The framework allows for the evaluation of alternative NGPA. Additionally, LEAP can assist with implementation, regulation, and customer education.

In this project, LEAP was applied to two actual gas pipeline replacement projects that occurred in 2022. One involved a single-family street segment, and the second involved a multifamily street segment. The two projects allowed the team to explore several "counterfactual" NPGAs. We present these NPGA analyses, assess their implications, and identify potential improvements, such as higher quality data and establishing use cases.

[30] Walsh, Michael. "Local Energy Asset Planning." Groundwork Data, October 2022. https://www.groundworkdata.org/s/Local-Energy-Asset-Planning-v20221014-4.pdf.

This study's methodology for developing and applying a LEAP integrated analysis is presented in Chapter 2. The third chapter describes the example sites. The results of the LEAP integrated analysis are reviewed and discussed in Chapter 4. The report concludes with considerations regarding future applications of this framework as well as data needs, the role of pilots, and equity.

The Challenge of Managing Gas Leaks and Leak-Prone Pipe

Massachusetts faces a difficult energy transition calculus. Its significant inventory[31] of leak-prone pipes and gas end-use equipment poses climate, health, and safety risks. Those risks can be reduced only to uncertain degrees over an extended time frame with high levels of capital spending that raise the risk of infrastructure lock-in and the prospect of unrecovered costs.

Older cast iron and welded steel pipes are the primary sources of leaks from the distribution system due to fractures, cracks, and failed joints. More and larger leaks are observed in locations with such pipes.[32] Further, a few "super emitter" leaks are responsible for a disproportionate volume of the methane that escapes from the distribution system.

Pipeline gas contains trace amounts of potentially harmful VOCs[33] and is linked to tree mortality.[34] Leaked gas is an explosion hazard. Historically marginalized populations are disproportionately exposed to leaks, but these leaks are repaired more slowly than those found in other communities.[35]

A useful distinction should be made between leaks and leak-prone pipe. *Leaks* are point emissions of methane from gas infrastructure. Currently, utilities identify leaks from odor complaints, leak detection patrols, and direct inspections of high-risk pipes. *Leak-prone pipe* is a broad risk-oriented classification used to describe aging pipeline and services made of cast iron, steel (bare and non-cathodically protected), copper, and Aldyl-A plastic pipes. System operators use Distribution Integrity Management Program (DIMP) scores to assess pipe risk. Such scores are informed by multiple variables (including pipe age, leak history, material, and proximity to detected leaks) and are used to prioritize GSEP and other projects.

Currently, utilities identify leaks from odor complaints, leak detection patrols, and direct inspections of high-risk pipes. Notably, conventional utility patrols tend to significantly under-identify leaks compared to survey methods that use more advanced leak detection technologies.[36]

Leaks are then assessed using a grading system as defined by the *Gas Leaks Act*[37]:

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[31] PHSMA. "Cast and Wrought Iron Inventory," portal.phmsa.dot.gov/analytics/saw.dll?PortalPages&PortalPath=%2Fshared%2FPDM%20Public%20Website%2FCI%20Miles%2FGD_Cast_Iron.

[32] Weller, Zachary D., Steven P. Hamburg, and Joseph C. Von Fischer. "A National Estimate of Methane Leakage from Pipeline Mains in Natural Gas Local Distribution Systems." *Environmental Science and Technology* 54, no. 14 (July 21, 2020): 8958–67. https://doi.org/10.1021/ACS.EST.0C00437/ASSET/IMAGES/LARGE/ES0C00437_0006.JPEG.

[33] Michanowicz, Drew R., et al. "Home Is Where the Pipeline Ends: Characterization of Volatile Organic Compounds Present in Natural Gas at the Point of the Residential End User." *Environmental Science & Technology* 56, no. 14 (July 19, 2022): 10258–68. https://doi.org/10.1021/acs.est.1c08298.

[34] Schollaert, Claire, et al. "Natural Gas Leaks and Tree Death: A First-Look Case-Control Study of Urban Trees in Chelsea, MA USA." *Environmental Pollution* 263 (August 1, 2020): 114464. https://doi.org/10.1016/j.envpol.2020.114464.

[35] Luna, Marcos, and Dominic Nicholas. "An Environmental Justice Analysis of Distribution-Level Natural Gas Leaks in Massachusetts, USA." *Energy Policy* 162 (March 1, 2022): 112778. https://doi.org/10.1016/j.enpol.2022.112778.

[36] Weller, Zachary et al., Vehicle Based Methane Surveys for Finding Natural Gas Leaks and Estimating their Size: Validation and Uncertainty, *Environmental Science and Technology* (2018, Vol. 52, No.20), pp. 11922-11930, doi.org/10.1021/acs.est.8b03135.

[37] Commonwealth of Massachusetts. Gas Leaks Act, Pub. L. No. Chapter 149, § Section 105A, Chapter 164 General Laws (2014). https://malegislature.gov/Laws/SessionLaws/Acts/2014/Chapter149.

- A **Grade 1 Leak** "represents an existing or probable hazard to persons or property" and is required to be repaired as immediately as possible while being monitored. Grade 1 leaks are classified as a "probable hazard" due to their proximity to population or other infrastructure.
- A **Grade 2 Leak** "is recognized as non-hazardous to persons or property at the time of detection, but justifies scheduled repair based on probable future hazard." Repairs are usually required within 12 months and must be monitored at six months.
- A **Grade 3 Leak** "is recognized as non-hazardous to persons or property at the time of detection and can be reasonably expected to remain non-hazardous." Such leaks are not prioritized for repair, but generally require annual monitoring.

A **Grade 3 Leak with Significant Environmental Impact (SEI)** classification was adopted in 2019 by Act to Promote Energy Diversity[38] in order to accelerate the mitigation of large non-hazardous leaks with the specific intent of reducing methane emissions.

Leaks are mitigated by leak detection and repair practices. The risk of leaks are mitigated by intervening on a leak-prone pipe. There are a number of repair and modernization practices that are beyond the scope of this report, however, it is important to note that some practices (e.g., pipe replacement, Grade 3- SEI leak mitigation, and advanced leak repair) are eligible for GSEP cost recovery, while some are not (e.g., pipeline relining or segment decommissioning).

Due to their pervasiveness and variability, fugitive methane losses are difficult to quantify or attribute accurately (e.g., distribution system or behind the meter). While various methods of estimating methane losses exist, there is significant disagreement between "bottom-up estimates" estimates (built from counts of pipeline miles multiplied by gas loss rates) and "top-down" measurements such as airplane flyovers and atmospheric sampling of methane.

This poses a challenge for quantifying and regulating methane to align with climate goals. For example, the combustion of a quantity of methane releases a definitive amount of carbon dioxide, allowing this activity to have an accurate and certain emissions factor. Conversely, the condition of gas infrastructure varies, leading to a large variation in leak volume that is difficult to quantify, pinpoint and regulate in terms of the greenhouse gas emitted on a pipe-by-pipe basis.

There is an increasing national focus on leak detection and repair being spearheaded by Pipeline and Hazardous Materials Safety Administration (PHSMA). In May 2023 PHSMA initiated rulemaking to require gas utilities to adopt more rigorous advanced leak detection and repair practices.[39] The proposed rules have received significant industry pushback due to gas company concern with the resource and cost demands of the proposed practices.[40]

Despite replacing roughly 2,000 miles of mains and related services under GSEP, according to a recent

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[38] Commonwealth of Massachusetts. Act to Promote Energy Diversity, Pub. L. No. Section 144, § 188, General Laws of Massachusetts (2016). https://malegislature.gov/Laws/SessionLaws/Acts/2016/Chapter188.

[39] For the Federal Register notice, see https://www.federalregister.gov/documents/2023/05/18/2023-09918/pipeline-safety-gas-pipeline-leak-detection-and-repair. The notice was issued in response to Section 113 of the Protecting our Infrastructure of Pipelines and Enhancing Safety Act of 2020 (P.L. 114-183; PIPES Act of 2020). The Act directed PHMSA to reduce methane leaks as part of its traditional role as a pipeline safety regulator and as an environmental protection measure.

[40] American Gas Association. "Comments on Pipeline Safety: Gas Pipeline Leak Detection and Repair." Public Comment, August 16, 2023. https://www.api.org/~/media/files/news/2023/08/16/industry-ldar-nprm-comments

study by Sargent et al., no measurable change in metro-Boston methane emissions was observable between 2012 and 2020.[41] Additionally, a recent wave of research confirms that a significant amount of methane is released behind the meter from pipes in the building, dormant equipment, and through ignition cycling.[42,43,44]

This calls into question the efficacy of pipe replacement as a strategy for mitigating fugitive methane emissions from a climate perspective. Further, research from NYSERDA demonstrates the high relative abatement cost of pipeline replacement as a methane mitigation strategy.[45]

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[41] Sargent, Maryann R., Cody Floerchinger, Kathryn McKain, John Budney, Elaine W. Gottlieb, Lucy R. Hutyra, Joseph Rudek, and Steven C. Wofsy. "Majority of US Urban Natural Gas Emissions Unaccounted for in Inventories." *Proceedings of the National Academy of Sciences* 118, no. 44 (November 2, 2021): e2105804118. https://doi.org/10.1073/pnas.2105804118.

[42] Lebel, Eric D., Colin J. Finnegan, Zutao Ouyang, and Robert B. Jackson. "Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes." *Environmental Science and Technology* 56, no. 4 (February 15, 2022): 2529–39. https://doi.org/10.1021/ACS.EST.1C04707/ASSET/IMAGES/LARGE/ES1C04707_0004.JPEG.

[43] Lebel, Eric D., Drew R. Michanowicz, Kelsey R. Bilsback, Lee Ann L. Hill, Jackson S. W. Goldman, Jeremy K. Domen, Jessie M. Jaeger, Angélica Ruiz, and Seth B. C. Shonkoff. "Composition, Emissions, and Air Quality Impacts of Hazardous Air Pollutants in Unburned Natural Gas from Residential Stoves in California." *Environmental Science & Technology* 56, no. 22 (November 15, 2022): 15828–38. https://doi.org/10.1021/acs.est.2c02581.

[44] Nicholas, Dominic, Robert Ackley, and Nathan G. Phillips. "A Simple Method to Measure Methane Emissions from Indoor Gas Leaks." *PLOS ONE* 18, no. 11 (November 30, 2023): e0295055. https://doi.org/10.1371/journal.pone.0295055.

[45] "New York State Oil and Gas Methane Emissions Mitigation Potential." New York State Energy Research and Development Authority, January 2023. https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Energy-Analysis/23-10-Methane-Mitigation-Potential-Report-acc.pdf.

GSEP IN 2023

CY2023 GSEP plans for the six LDCs were approved on April 28, 2023, by the DPU with two important adjustments for National Grid's Boston Gas territory: the DPU denied National Grid's request to extend its Boston GSEP terminal date to 2044 along with its request to combine National Grid's two legacy companies into a single GSEP plan.

Four of the six LDCs asked to defer recovery of part of their GSEP spending to the next year because their GSEP-related revenue requirements exceeded the 3% cap.[46] This is the first time that so many have hit the cap. The increasing cost of pipe replacement may constrain the LDCs' ability to achieve their stated replacement goals unless the cap is increased, which will require higher ratepayer rates. The LDCs also cite labor retention and recruitment challenges for these projects driven by the current economic climate as the largest driver of cost increases.[47]

The total approved GSEP spending for 2023 is $816 million, approximately $800 million of which is for pipeline replacement (Table 1). The total miles of mains to be replaced is 271. The additional GSEP cost to be billed out to gas customers is approximately $263 million (the 2023 GSEP annual revenue requirement). See for further details.

Approved 2023 GSEP spending contains minimal amounts for eliminating significant environmental impact (SEI) leaks and advanced leak repairs:

- SEI: National Gird-Boston $1,958,642, Eversource $303,490, NSTAR $50,022.
- Advanced leak repair: National Grid-Boston $14,453,278 (this repair work will not be on GSEP-eligible pipe); NSTAR $1.5 million.

Over the next five years, LDCs expect to replace approximately 1,300 miles of vintage pipeline at a direct capital cost of $3.7 billion. Given the high unit cost increases that LDCs have reported in the last two years, previous estimates of the cumulative costs of GSEP may be lower than what will be incurred.

National Grid-Boston accounts for over half of the remaining vintage pipe and expects a per-mile cost for pipeline replacement of $3.4 million in 2023.[48] This cost will have increased at an average annual rate of 14% from 2017 to 2023.

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[46] GSEP legislation (M.G.L. ch.164 § 145f) puts a cap on the revenue requirement eligible for recovery ("revenue cap"). The cap was initially set at 1.5% of total firm revenues, but beginning in April 2019, the DPU has allowed increases to the cap up to 3%. DPU has the authority to approve a revenue requirement in excess of the cap to be deferred for recovery in subsequent years.

[47] *"[Eversource] is competing with the other Massachusetts, and perhaps regional, LDCs for the same labor sources for its internal workforce and for contractor resources to effectuate the accelerated infrastructure replacement. Thus, the single largest factor in completing replacement projects is expected to be contractor availability and cost."* Petition of Eversource Gas Company of Massachusetts d/b/a Eversource Energy for Approval of its 2022 Gas System Enhancement Plan, No. 21-GSEP-05.

[48] "Exhibit NG-AS/MT-2, GSEP-Table 15." National Grid Boston Gas, n.d. https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/15691907.

Table 1. GSEP proposed spending, average cost per mile, and approved 2023 revenue requirement.

Company	Docket number at online file room	Company's proposed CY2023 GSEP spending (including G3SEI & advanced leak repair) (000's)	Average unit cost per mile (calculated as a weighted average) (000's)	No. of miles to be replaced	Approved 2023 GSEP Revenue Requirement (000's)
Fitchburg Gas & Electric dba Unitil	22-GSEP-01	$12,140	$1,155	4.87	$4,497
Berkshire Gas	22-GSEP-02	$14,331	$2,020	10.4	$2,102
National Grid	22-GSEP-03	$443,845	$3,288	130	$131,414
Liberty Utilities (New England	22-GSEP-04	$36,644	$1,150	19.71	$20,234
Eversource Gas Co dba Eversource	22-GSEP-05	$132,268	$1,880	43	$37,709
NSTAR dba Eversource Energy	22-GSEP-06	$177,250	$2,100	62	$68,600
TOTAL		**$816,477**	**$2,199**	**269.98**	**$264,555**

Non-Pipeline Gas Alternative Efforts in Other States

Many states have begun to evaluate and adopt non-pipeline alternative frameworks because of their potential to enhance energy system reliability and operations while tailoring to customer priorities, including comfort, efficiency, and flexibility. These alternatives are becoming increasingly competitive with high-cost gas systems, drawing more interest from states as they commit to short- and long-term planning and investment decisions.

In 2019, New York's utility, Con Edison, received approval for its proposal for non-pipeline alternatives to support demand-side targeted energy efficiency and electrification.[49] Shortly after, in 2020, the New York Public Service Commission (PSC) initiated a process to address gas planning procedures, which involved proposing the establishment of NPGA frameworks.[50] Work towards these frameworks would support New York's Climate Leadership and Community Protection Act (20-G-0131). In February 2021, Commission staff presented a proposal for this framework that prioritized the creation of a cost-benefit analysis and solicited alternatives.[51] In May of 2022, the New York PSC voted to adopt this proposal to manage the growth in demand while synchronizing supply planning with Act 20-G-0131.[52]

In California, a 2021 amendment to the Public Utilities proceeding § 1701.1 requested the development of a long-term planning strategy. This strategy's outline explicitly includes exploring non-pipeline alternatives and their associated costs.[53] In December of 2022, the California Public Utilities Commission implemented a new framework to serve as the basis for retiring gas lines that includes:

- Pipeline Risk
- Existing environmental health burden
- Gas infrastructure cost savings
- Customer affordability and energy
- Need for pipeline gas

This framework requires utilities to report their planned long-term projects and outline information on non-pipeline alternatives for those scheduled to begin before 2028.[54]

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[49] St. John, Jeff. "New York Must Chart New Course for Gas Utilities to Hit Climate…." Canary Media, March 20, 2023. https://www.canarymedia.com/articles/fossil-fuels/new-york-must-chart-new-course-for-gas-utilities-to-hit-climate-targets.

[50] Brutkoski, Donna. "It's Time to Consider the (Non-Pipeline) Alternatives." Regulatory Assistance Project, November 1, 2021. https://www.raponline.org/blog/its-time-to-consider-the-non-pipeline-alternatives/.

[51] Ibid.

[52] Christopher, T. NY utility regulators approve climate-focused overhaul of gas system planning | S&P Global Commodity Insights. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/natural-gas/051322-ny-utility-regulators-approve-climate-focused-overhaul-of-gas-system-planning (2022).

[53] California Public Utilities Commission, Staff Proposal on Gas Distribution Infrastructure Decommissioning Framework in Support of Climate Goals (December 21, 2022, R.20-01-007 ALJ/CF1/fzs), https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/natural-gas/long-term-gas-planning-oir/framework-staff-proposal.pdf.

[54] Press Release. "CPUC Creates New Framework To Advance California's Transition Away From Natural Gas," December 1, 2022. https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-creates-new-framework-to-advance-california-transition-away-from-natural-gas.

The California Energy Commission sponsored a *Targeted Building Electrification and Gas System Decommissioning Pilot Project.*[55] Similar to this study, the pilot project's goal was to develop a replicable framework to identify street segments for tactical decommissioning and electrification to avoid gas system costs. The projects further sought to engage local communities and conduct stakeholder education and outreach. Gridworks, an energy-focused non-profit, oversaw the project, received analytical support from E3, partnered with a local community organization (East Bay Community Energy), and coordinated with the local utility (Pacific Gas & Electric). In June 2023, the project released an interim report.[56] The report touched upon many of the same topics as this study but had a broader implementation and site identification-focused scope including community engagement. This study is more focused on demonstrating the design and applicability of a scenario analysis. A more comprehensive analytical report from the California project is pending.

[55] Gridworks. "CEC Gas Decommissioning Northern California Pilot," April 14, 2023. https://gridworks.org/initiatives/gas-decommissioning/.

[56] Energy+Environmental Economics, Gridworks, and East Bay Community Energy. "Strategic Pathways and Analytics for Tactical Decommissioning of Portions of Gas Infrastructure in Northern California," June 2023. https://gridworks.org/wp-content/uploads/2023/06/Evaluation-Framework-for-Strategic-Gas-Decommissioning-in-Northern-California-Interim-Report-for-CEC-PIR-20-009.pdf.

Chapter 2: Analytical Approach

This chapter covers the Local Energy Asset Planning (LEAP) framework and aspects of the LEAP integrated analysis model. It outlines the analytical need, model architecture, data sources, assumptions, and key indicators.

Analytical Need: Hyper-Local Energy Asset Planning

The gas transition will likely be one of the most complex components of decarbonizing the economy. The reason for this is multifold:

1. *Methane:* There are health, safety, and climate implications of an energy system that relies on the transport and combustion of methane gas, a potent greenhouse gas emitted from various points in the system.
2. *Increasing cost of maintaining the gas system:* Efforts to replace leak-prone pipes are becoming increasingly costly.
3. *Old building stock in a cold climate:* Buildings have complex energy and energy transition needs, and there are consequences to electrifying heat on the electric distribution and generation systems on a rapidly decarbonizing grid.
4. *Interdependencies and misalignment of value:* Asset turnover and intervention points are misaligned among the gas system and the diverse number of buildings it serves. Replacement of a gas pipeline with buildings steadily electrifying at a pace aligned with climate goals will leave the gas asset stranded, ultimately burdening ratepayers, investors, or society. Removal of the gas pipeline today will leave gas-dependent assets — some recently installed, incentivized to be high-efficiency, and with embodied carbon — stranded in buildings.

Management of these features largely falls on public utility commissions, with some broader aspects managed by other entities of state or federal governments. Historically, such entities have sought to ensure that served customers can access safe, reliable, low-cost energy. Due to recent legislation, the Massachusetts DPU is required to prioritize reductions in greenhouse gases, equity, security, safety, reliability of service, and affordability.[57] More broadly, issues of employment, resilience, and customer adoption are integral to the transition. This creates a complex multi-objective optimization problem for regulators.

Historically, benefit-cost analysis (BCA) has informed decision-making. It determines the prudency of investments ranging from expanding or upgrading distribution systems to building energy efficiency programs. Notably, utilities in New York State have begun to develop guidance for non-pipeline

[57] General Court of Massachusetts. An Act creating a next-generation roadmap for Massachusetts climate policy, General Laws of Massachusetts § Chapter 8 (2021). https://malegislature.gov/Laws/SessionLaws/Acts/2021/Chapter8

alternative projects to incorporate some elements of BCA in project evaluation.[58] The cost-effectiveness of a strategy often incorporates factors such as:

1. Cost of CO_2 emissions.
2. Cost of direct gas system investment
3. Cost of direct electric system investment
4. Cost of gas supply and capacity
5. Cost of electricity supply and capacity
6. Other costs such as other fuels, health impacts, etc.

Once such costs are estimated, the net cost determines cost-effectiveness. Such approaches seek to distill down impacts to a single metric. While informative, such an approach can oversimplify actual impacts, particularly in a rapidly changing system. Single-indicator cost metric criteria can obscure significant tradeoffs and risks, especially when tackling issues of equity, which may involve managing complex and sometimes conflicting outcomes. Thus, standard BCA faces significant challenges in facilitating decision-making when evaluating multiple strategies in complex evolving systems.

LEAP integrated analysis goes beyond BCA, integrating multiple data sets to evaluate opportunities for a cost-effective, equitable transition to net zero at a hyper-local scale. The concept of LEAP is further elaborated in a whitepaper defining the concept.[59]

One utilization of LEAP could be similar to how state and national scale "pathways" analyses are conducted. These take a broad energy system view to evaluate the impacts of alternative scenarios using a variety of indicators.[60,61,62] While more involved, this approach is empowering for decision-makers and communication with impacted stakeholders. Each impact area is evaluated based on the assumptions, data, and uncertainties that went into its assessment.

This report applies this approach to evaluate NPGAs on leak-prone pipe intervention opportunities. Other applications and use cases are discussed in the Future Considerations section.

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[58] Con Edison. "Non-Pipeline Solutions to Provide Peak Period Natural Gas System Relief RFI," 2020. https://www.coned.com/-/media/files/coned/documents/business-partners/business-opportunities/non-pipes/non-pipeline-solutions-to-provide-peak-period-natural-gas-system-relief-rfi.pdf?la=en

[59] Walsh, Michael. "Local Energy Asset Planning." Groundwork Data, October 2022. https://www.groundworkdata.org/s/Local-Energy-Asset-Planning-v20221014-4.pdf.

[60] America, Net-Zero. "Net-Zero America." Net-Zero America. Accessed August 31, 2022. https://netzeroamerica.princeton.edu/.

[61] Jones, Ryan, Ben Haley, Jim Williams, Jamil Farbes, Gabe Kwok, and Jeremy Hargreaves. "Massachusetts 2050 Decarbonization Roadmap: Energy Pathways to Deep Decarbonization." Evolved Energy Research, 2020. https://www.mass.gov/doc/energy-pathways-for-deep-decarbonization-report/download.

[62] Energy+Environmental Economics and Scott Madden Management Consultants. "The Role of Gas Distribution Companies in Achieving the Commonwealth's Climate Goals, Independent Consultant Report--DRAFT, Part I: Technical Analysis of Decarbonization Pathways," February 15, 2022. https://thefutureofgas.com/content/downloads/2022-03-21/3.18.22%20-%20Independent%20Consultant%20Report%20-%20Decarbonization%20Pathways.pdf.

Model Architecture

At its core, the LEAP integrated analysis tool identifies and represents individual energy system assets for energy-consuming sectors or energy distribution (and, if present, generation) systems. Energy consumption and flows, asset values, and other attributes are mapped to individual utility and building assets. Assets include pipes, wires, meters, regulators, appliances, and building shells and are modeled as a network in an object-oriented programming language (Python) to simulate their interactions. When applicable, assets are geocoded.

Indicators

Multiple quantitative metrics from the LEAP tool are used to indicate the potential impacts of each retrofit scenario. Alternatives, however, need to be evaluated holistically. The tool outputs several indicators that highlight direct impacts and, when taken together, shed light on the downstream impacts of different actions (Figure 2). These indicators are tracked at the level of individual buildings and across utility network assets to understand and evaluate the relationship between the two. Limitations on the use of some indicators are discussed.

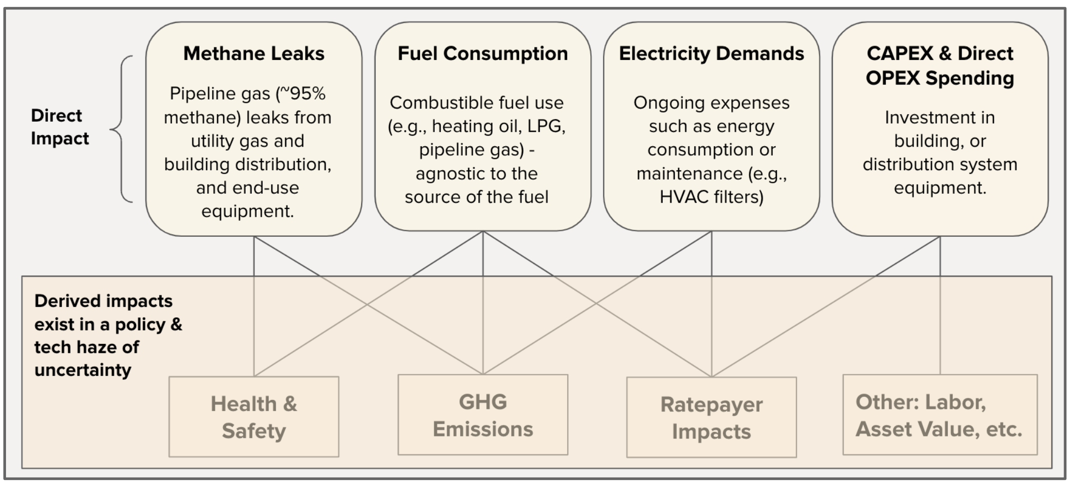

Figure 2. Direct and derived impact indicators

The main indicators tracked and reported by the tool are financial, consumption, and leak indicators. The financial indicators correspond to the capital costs of retrofitting assets, stranded values of assets replaced before the end of their useful life, and operational expenses of using assets. Consumption indicators include the total and peak consumption of various energy types. Leak indicators are derived from methane leaks in gas pipeline infrastructure and gas-consuming building assets. While various derived indicators can also be used, this report focuses on GHG emissions and ratepayer impacts.

Data Sources and General Assumptions

The LEAP integrated analysis model synthesizes multiple energy consumption and cost accounting datasets. Without intimate knowledge of individual buildings, the team used public and open-source data to approximate energy consumption and cost characteristics. A breakdown of data categories and sources is provided in Table 2.

Table 2. Data sources used for this study.

Metric	Data Source / Assumption
Building energy consumption data: aggregate energy consumption & load shapes by end use	ResStock (buildings),[63] EVI Pro[64] (vehicle charging)
Pipe Replacement Project Location & Costs	2022 GSEP Filings for Eversource[65] and Liberty[66]
Building electrification, electric distribution costs	MassCEC Whole Home Pilot,[67] Mass Save Program Administrator Filings,[68] NREL Distribution System Upgrades[69] with comparison to other studies.
Emissions factors	Standard EPA emissions factors for combustion.[70] NYSERDA Emissions factors for fugitive methane emissions from specific assets.[71] Marginal emissions factors from NREL's Cambium[72] consistent with Massachusetts Emissions targets were used to estimate electric sector emissions from heating electrification.
Future energy costs	To illustrate ratepayer impact, the analysis modeled an increasing compliance cost of fuel production (e.g., a price on carbon or alternative compliance payment starting at $100 per ton CO_2 in 2025 and escalating at 3% per year).[73] Consumer electricity prices were increased by 1% annually.

Various options exist for representing building loads. ResStock is an emergent tool that seeks high specificity for building types, which provide sufficiently representative load shapes that could be tailored to individual buildings based on square footage, building age, the number of dwelling units, and other factors. Load shapes for multiple interventions allowed for the exploration of various scenarios, but future work could be improved by using alternate methods that balance various analytical needs and

63 "ResStock." National Renewable Energy Laboratory. https://resstock.nrel.gov/datasets.

64 "EVI-Pro: Electric Vehicle Infrastructure – Projection Tool | Transportation and Mobility Research | NREL." Accessed June 28, 2023. https://www.nrel.gov/transportation/evi-pro.html.

65 Petition of Eversource Gas Company of Massachusetts d/b/a Eversource Energy for Approval of its 2022 Gas System Enhancement Plan, No. 21-GSEP-05. Accessed June 28, 2023.

66 Petition of Liberty Utilities Corp. for Approval of its 2022 Gas System Enhancement Plan, No. 21-GSEP-04.

67 "Whole-Home Air-Source Heat Pump Pilot." Massachusetts Clean Energy Center. Accessed June 30, 2023. https://www.masscec.com/program/whole-home-air-source-heat-pump-pilot.

68 Petition of Massachusetts Electric Company and Nantucket Electric Company each d/b/a National Grid, pursuant to G.L. c.25, §21, for approval by the DPU of its Three Year Energy Efficiency Plan for 2022 through 2024., No. 21-128.

69 Horowitz, Kelsey. "2019 Distribution System Upgrade Unit Cost Database Current Version." National Renewable Energy Laboratory - Data Golden, CO (United States); National Renewable Energy Laboratory, 2019. https://doi.org/10.7799/1491263.

70 US EPA, OAR. "GHG Emission Factors Hub." Overviews and Factsheets, July 27, 2015. https://www.epa.gov/climateleadership/ghg-emission-factors-hub.

71 "New York State Oil and Gas Sector: Methane Emissions Inventory." NYSERDA, 2022. https://www.nyserda.ny.gov/-/media/project/nyserda/files/publications/energy-analysis/22-38-new-york-state-oil-and-gas-sector-methane-report-acc.pdf.

72 "Cambium." National Renewable Energy Laboratory. https://www.nrel.gov/analysis/cambium.html.

73 The November 2023 MassDEP Clean Heat Standard Draft Framework proposes an Alternative Compliance Payment of $190 per ton CO_2 that could be revised after program review. It is unclear how this cost would be realized by energy consumers.

outcomes. Similarly, assumptions regarding intervention costs are highly uncertain but can be improved with more real-time data. As more pilot projects are executed, there will be more data to improve energy use and cost assumptions.

Intervention Strategies

The research team evaluated the following five scenarios (Table 3) designed to represent different intervention strategies for the existing building stock and energy distribution systems.

Table 3. List of scenarios in scope for this report. Replacement years are points where assets reach the end of life and would typically be replaced. Building replacement years are randomly distributed in the analysis or based on building age.

Scenario	Description
Continued Pipeline Gas	The gas pipeline will be replaced in 2025, like-for-like replacement of heating systems at their respective end of life.
Dual Fuel – Pipeline, Unmanaged	The gas pipeline will be replaced in 2025; air source heat pumps will be added with backup pipeline gas heating at the end of their life.
Dual Fuel – Pipeline, Accelerated	The gas pipeline will be replaced in 2025; air source heat pumps will be added while refurbishing existing pipeline equipment to provide pipeline gas in 2025.
Dual Fuel – Tank, Accelerated	The gas pipeline will be removed & air source heat pumps will be installed with existing gas equipment refurbished and converted to backup propane in 2025.
Electrification, Unmanaged	The gas pipeline will be replaced in 2025 & buildings will be fully electrified at the end of life of existing equipment.
With Energy Efficiency	Above with envelope improvements.
Electrification, Accelerated	The gas pipeline will be removed & buildings will be fully electrified in 2025.
With Energy Efficiency	Above with envelope improvements.

A Note on Liquefied Petroleum Gas (LPG) or Propane

LPG or, more generally, any non-pipeline fuel is an important factor in the gas transition in two ways. First, in a low-flow gas system with a high energy delivery cost per unit, LPG is a competitor to pipeline gas because it provides a comparable service at a competitive price. Although truck-delivered propane is more expensive than pipeline gas today, the cost of pipeline gas in a low-flow gas system could exceed that of truck-delivered propane.

Second, a non-pipeline fuel could meet various customer needs for combustion, thus removing a barrier to pipeline decommissioning. For example, a customer who prefers gas cooking need not be required to change behavior to retire the pipeline segment. Any remaining equipment would require a burner tip replacement, and the building would require a tank, the cost of which is included in the analysis.

Assuming partial electrification, which could reduce heating costs for most of the year, propane could serve heating needs in a fraction of the heating hours of conventional gas heating. This mitigates the historically high costs of propane relative to gas. At low consumption levels, the relative difference in propane (or oil) emissions intensity becomes less relevant. Leaked propane does not have as high a GHG impact as gas.

There are some practical barriers to propane and other non-pipeline fuels. Tank placement may be constrained in dense areas by building codes. Indeed, a screening of the multifamily segment (described below) found that one-third of buildings in that segment could likely not host a propane tank. Further, using a propane tank may increase building insurance costs, and buildings with internal leak-prone pipes may face a serious risk of propane leaks, which can be more hazardous than methane leaks.

While not universally applicable, LPG and other non-pipeline fuels could emerge as competitors to pipeline gas if utilities raised rates in response to declining throughput and customers to meet revenue requirements. The presence of such competition (in addition to non-fossil fuel strategies) would further challenge gas system economics.

A Note on Thermal Energy Networks

The project team considered including thermal energy networks in this framework. However, the novelty of such systems and the myriad of possible arrangements created analytical challenges for this initial demonstration. Notably, such systems offer significant promise for delivering heat and have become increasingly common in Europe. However, such systems often exhibit specific features that make their implementation extremely context-specific: "Even though some system concepts look similar, the exploitation of local sources makes each case unique."[74] The National Renewable Energy Lab further noted, "The complexity of process heating systems, which frequently involve multiple layers of integration as well as myriad competing options on the [Renewable Thermal Energy System] side, create a murky decision space."[75]

Future LEAP planning exercises can leverage lessons learned and data collected from thermal energy network pilot projects implemented by Eversource (Framingham, 2022 construction start) and National Grid (Lowell, 2023 construction start).[76]

In most cases, such strategies have been implemented in the context of new builds or campuses and not in the transition of distributed energy demand currently served by gas distribution systems. A notable exception is the transition of a neighborhood in Zurich from gas to a high-temperature district network using waste heat from a municipal solid waste incinerator.[77] The incorporation of such a system would involve a high "utility-scale" investment for the development of the network[78] and a low level of investment in the electric distribution network.

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[74] Buffa, Simone, et. al. "5th Generation District Heating and Cooling Systems: A Review of Existing Cases in Europe." *Renewable and Sustainable Energy Reviews* 104 (April 1, 2019): 504–22. https://doi.org/10.1016/j.rser.2018.12.059.

[75] Akar, Sertac, et al. "Renewable Thermal Energy Systems: Modeling Developments and Future Directions (Report 3)." National Renewable Energy Lab. (NREL), Golden, CO (United States), February 14, 2023. https://doi.org/10.2172/1957772.

[76] HEET. "Learning From the Ground Up." https://heet.org/legup/.

[77] "Decommissioning of the Gas Network in Zurich North."https://www-energie360-ch.translate.goog/de/energie-360/wissen/energieplanung/zuerichnord/.

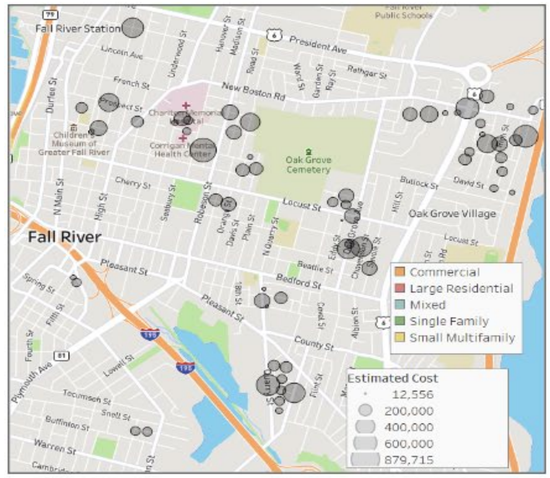
[78] Whether such systems are implemented using a regulated utility model is currently an open question.

Chapter 3: Site Selection & Example Street Segments

Overview of Site Screening

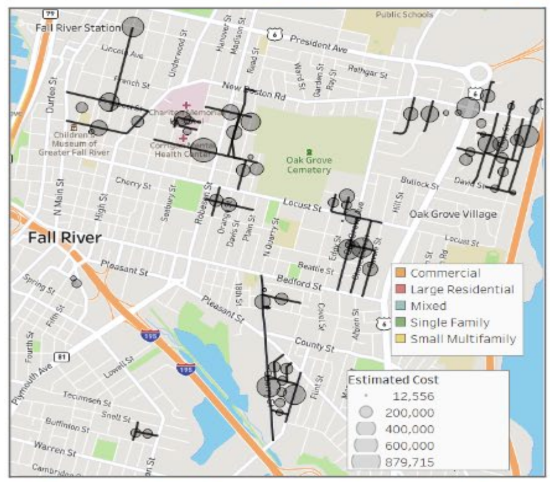
Step 1: Utility GSEP projects were geocoded by HEET projects based on the reported project address.

https://heet.org/gsep-mapping-process/

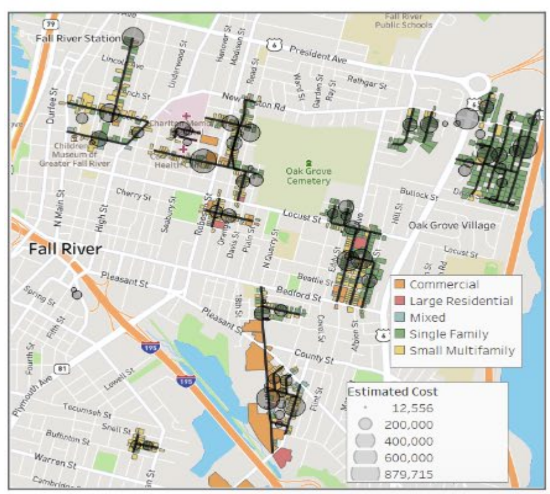


Step 2: HEET produced line segments from the [To-From Address] field.

30% yield due to address formatting challenges (e.g., dead ends, non-address references)



Step 3: Adjacent segmented parcels (buildings) are identified and down-selected for potentially viable pipelines.



The above diagram outlines this project's selection of potential project sites based on publicly available data.

Geocoded GSEP project locations were mapped as segments based on GSEP-provided start and end address points. Inconsistency of address formatting led to a low yield of potential sites. The above diagram maps data from an LDC territory (Liberty) with well-formatted addresses. Adjacent buildings were then identified using Massachusetts Parcel Data.[79]

This project's screening criteria focused exclusively on residential street segments and selected pipe segments that were 4 inches or less in diameter and appeared to be tendrils of the system (e.g., terminal branches or those on side streets). These criteria represent the research team's best representation of hydraulically feasible pipes that can be readily removed from operation without critically impacting other system parts and requiring mitigating measures.

Hydraulic feasibility refers to the ability to remove a pipe from the gas distribution system without significantly impacting the operations, safety, reliability, and redundancy of the gas system. Terminal branches such as those on a dead-end street, are typically considered to be the most feasible for removal. In contrast, central trunks serving substantial downstream demand are considered impractical for removal. Feasibility may exist on a tolerance continuum of certain impacts. For example, some redundancy is valuable, but safe operation and sufficient service can still be provided with reduced redundancy. Further, cost-effective mitigating measures could be taken to address some impacts of a removed pipe.

A formal hydraulic feasibility analysis would be necessary to identify segments suitable for decommissioning. Such an analysis would require utility data representing the pipe system and its operation. Future implementation of NPGAs would likely require close collaboration with the LDCs to identify which segments are feasible for removal.

Further prioritization and classification of sites could be based on pipeline risk (see subsection below: *The Challenge of Managing Gas Leaks and Leak-Prone Pipe*). Such risk is informed by pipe age, material, or proximity to detection leaks and is used to prioritize GSEP projects. System operators often aggregate these factors into Distribution Integrity Management Program[80] (DIMP) scores, which are reported by some utilities. Again, such prioritization would require significant participation by the LDC.

The following two sections describe the two street segments selected for this analysis using demographic data from the U.S. Census Bureau for 2020.[81]

[79] "MassGIS Data: Property Tax Parcels." https://www.mass.gov/info-details/massgis-data-property-tax-parcels.

[80] PHSMA, "Gas Distribution Integrity Management Program (DIMP)." https://www.phmsa.dot.gov/pipeline/gas-distribution-integrity-management/gas-distribution-integrity-management-program-dimp.

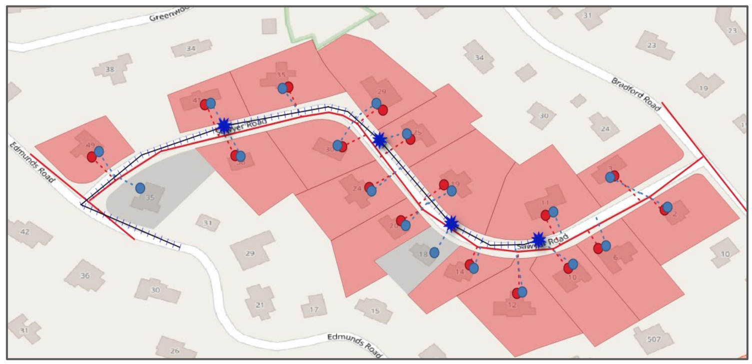
[81] Bureau, US Census. "2020 Census Results." Census.gov. https://www.census.gov/2020results.

Single-Family Segment

The single-family neighborhood of focus for this analysis is located in Wellesley, an affluent Massachusetts suburb that experienced gas system growth during the steel pipe era. The median home value in this area is $1.25 million, and the median household income is $225,250. 83% of the homes in this neighborhood are owner-occupied, and the poverty level is less than 5%. The neighborhood is 77% white/Caucasian.

In the study's example single-family street segment, there are 19 homes.[82] Twelve were built between 1930 and 1954, two between 1980 and 1990, and the remaining four are new builds from the last decade. The home floor space ranges between 2,000 and 6,000 square feet, with a total of 64,538 square feet on the street.[83] Seventeen of the homes on this street segment are powered by gas (shown in red in the image below), with the remaining two powered by oil (shown in grey). There is a mix of steam, hot water, and central air for heating.

This single-family neighborhood utilizes a primary line feeding four 37.5 kVA transformers. Its gas network includes 1,845 feet of welded two-inch steel pipe sets. There have been three Grade 3 and one Grade 1 leak since 2015. The alternative energy resources that could be used in this neighborhood include propane backup, as there is sufficient space for solo GSHPs in yards (soil and rock conditions are unknown).



Wellesley is served by a municipal electric utility, also known as a Municipal Light Plant (MLP). There was no information available on the electric distribution feeder servicing the street. Wellesley's combined electric supply and service rate is a $0.151 per kWh[84] plus some additional adjustment and optional renewable supply tariffs. This is substantially lower than the average state rate of $0.253 and average investor-owned utility rate of $0.288.[85] Other municipal utilities in Massachusetts have similarly low electric rates. These low electric rates allow customers switching to electric air source heat pumps to save money relative to gas, whereas in the majority of Massachusetts communities served by investor-owned utilities, it is typically cheaper to operate a gas furnace than a heat pump. This limits the applicability of the analysis conducted here to IOU-served municipalities, which will face more challenging economics for electrifying heating.

[82] This street is being used for illustrative purposes as a pipeline replacement project was completed on it in 2023.

[83] US Census Bureau. "2020 Census Results." Census.gov, n.d. https://www.census.gov/2020results.

[84] Wellesley Municipal Light and Power. "Billing & Payments," https://wellesleyma.gov/237/Billing-Payments.

[85] Energy Information Agency "Retail electricity sales to ultimate consumers: Annual Prices Residential Sector by State & Utility" 2022. https://www.eia.gov/electricity/sales_revenue_price/xls/table_6.xlsx

Multifamily Segment

The multifamily area of focus is in Fall River, a dense Gateway Community. It is a Justice40 neighborhood with a poverty rate of 19%. The median home value is $282,500, and the median household income is $33,036. The chosen street segment contains 15 multifamily homes, with 56 housing units in total. The homes were built in the 1900s with varying amounts of renovations over the last century, and together amount to 47,600 square feet, with unit sizes ranging between 600 - 1,400 square feet. Each home is connected to gas, with a mix of steam, hot water, and central air.

Like the single-family neighborhood, the multifamily street segment utilizes a primary line feeding four 37.5 kVA transformers. The gas system utilizes 587 ft of cast iron pipe and 47 ft of welded steel pipe, each having a 4” diameter. Due to limited space, there is less opportunity for propane backup or solo GSHPs. Thermal networks may require coordinated development of nearby open space and commercial blocks.

Note that this street is being used for illustrative purposes as a pipeline replacement project was completed on it in 2023.

CHAPTER 4: DEMONSTRATION OF LOCAL ENERGY ASSET PLANNING

This chapter evaluates the results of modeled runs for five intervention strategies on the two street segments described above. It reviews metrics for five primary indicators: fugitive methane emissions, fuel consumption and GHG emissions, electrical loads, costs, and ratepayer impacts.

The analyzed scenarios capture a range of potential impacts and implications for gas pipeline intervention projects. Table 4 summarizes the level of intervention and risks for each scenario, which are further detailed below. The quantitative data presented in the subsequent sections provide greater detail into the impacts of each strategy.

Table 4. Summary of interventions and primary risks related to energy use.

	System Interventions			**Risks**		
	Building	**Pipeline Gas**	**Electric**	**Fugitive CH_4**	**Fuel**	**Emissions**
Scenario	Heat pumps & efficiency measures	Pipeline replacement	Electric distribution and supply	Leaks from distribution and end-use equipment	Reliance on costly carbon-intensive fuels	Aggregate climate impact
Continued Pipeline Gas	Low	High (immediate)	Low	Moderate	High	High
Dual Fuel - Pipeline	Medium	High (immediate)	Moderate	Moderate	Moderate	Moderate
Unmanaged Electrification	High (steady)	High (immediate)	High (steady)	Moderate	Declining	Moderate
Dual Fuel - Tank	Medium (immediate)	Low	Moderate	None	Moderate	Moderate
Accelerated Electrification	High (immediate)	Low	High (immediate)	None	None	Low

Across these scenarios, there are tradeoffs between the level of system intervention applied — or needed — and the outcomes realized. The degree of such tradeoffs varies by location context. Some segments may have more capacity on their electric distribution system, allowing for more significant electrification. Others may have barriers to non-pipeline fuels.

Again, the authors note that these scenarios intend to be illustrative, but not exhaustive, regarding potential non-pipeline gas alternatives. In implementation, a range of strategies may be applied to overcome building- or location-specific barriers.

Leaks and Fugitive Methane Emissions

At the outset of this work, the project team sought to use quantitative methane emissions factors to estimate methane emissions as an indicator of health, safety, and climate risks. The results of this analysis are presented in Table 5, but are caveated in the following subsections.

This analysis uses NYSERDA's bottom-up accounting methodology and fugitive methane emissions factors for gas equipment, meters, and pipes.[86] This differs slightly from the methodology used in the Massachusetts GHG Inventory, which uses a per-house leak factor that is approximate to the aggregate post or behind-the-meter leak factors used here.[87] Using these factors, pipeline replacement reduces fugitive emissions by an approximate order of magnitude (Table 5). Elimination of gas from the system eliminates all fugitive methane emissions

Table 5. Bottom-up estimation of cumulative (2025-2050) distribution and building methane emissions (kg CH_4) for the single-family segment. A "No Pipe Replacement" scenario is included to illustrate the scale of impact of these strategies.

kg CH_4		Mains	Services	Buildings	Total
Single Family Segment	No Pipeline Replacement	7,800	1,799	884	10,483
	Continued Gas	264	21	884	1,168
	Dual Fuel - Gas (End of Life)	264	21	656	940
	Dual Fuel - Gas (Accelerated)	264	21	442	726
	Dual Fuel - LPG	0	0	0	0
	Unmanaged Electrification	233	11	428	672
	Accelerated Electrification	0	0	0	0
Multi-Family Segment	No Pipeline Replacement	3,601	1,071	832	5,504
	Continued Gas	90	22	832	944
	Dual Fuel - Gas (End of Life)	90	22	600	712
	Dual Fuel - Gas (Accelerated)	90	22	416	528
	Dual Fuel - LPG	0	0	0	0
	Unmanaged Electrification	70	10	368	447
	Accelerated Electrification	0	0	0	0

Discussion: Estimated Results in the Context of Leak and Fugitive Methane Observations

The authors caution that these results are based on single-value bottom-up estimates using emissions factors that obscure a high degree of variability in fugitive methane emissions. Unlike directly measurable gas transfers or combustion, which quantify fuel use and combustion emissions with high

[86] "New York State Oil and Gas Sector: Methane Emissions Inventory." NYSERDA, 2021. https://www.nyserda.ny.gov/-/media/project/nyserda/files/publications/energy-analysis/22-38-new-york-state-oil-and-gas-sector-methane-report-acc.pdf.
[87] Emissions Inventories." Massachusetts Department of Environmental Protection, 2023. https://www.mass.gov/lists/massdep-emissions-inventories.

relative precision and accuracy, the volume of methane emissions that evolve from leaks and ignition sources is much harder to quantify and varies significantly.

There is an increasing understanding that using bottom-up emissions factors in local and state-level inventories may represent a significant underestimate of methane emissions (See subsection in *Chapter 1: The Challenge of Managing Gas Leaks and Leak-Prone Pipe*).

The above estimates suggest that current total losses from the main services and the buildings of the single-family segment are approximately 0.85% of total methane consumed. This is likely an underestimate for leak-prone pipes, particularly given reported leaks near these segments and the literature (as much as 2.5%). The single-family street segment has had multiple reports of Grade 3 leaks, including one rated as a Grade 3 Significant Environmental Impact leak as far back as 2015. No leaks have been reported on the multifamily segment; however, a pair of Grade 3 leaks have been reported on neighboring streets.[88]

The discrepancy between the bottom-up estimates and the review of observational measurements highlights the increasing understanding that standard emissions factors and conventional inventories underestimate methane emissions. This results in several key challenges:

Bottom-Up Estimates Have Limited Applicability in Local Planning and Methane Emissions Accounting: The use of bottom-up estimates with established emissions factors will continue to undercount emissions, limiting the ability of a LEAP tool to forecast emissions impacts reliably. This limits the utility of such a tool to report emissions forecast impacts at any scale accurately. It also challenges the ability to regulate methane emissions on a measurement basis because it is difficult to measure and attribute fugitive methane from diffuse distribution systems directly.

Despite the limitations, the LEAP framework could continue to use bottom-up emissions factors but ensure that such factors are updated and calibrated based on the best available science. Given these challenges, estimates should be reported with sufficient context and uncertainty.

Identification of leaks can help guide planning for non-pipeline projects but requires advanced leak detection and modern data management: Focused on this cohort of leak-prone infrastructure but not exhaustively exclusive to it, the identification of leaks is a critical screening tool for site selection and prioritization. Currently, utilities identify leaks from odor complaints, patrols, and inspections of high-risk pipes (see subsection above in Chapter 1: *The Challenge of Managing Gas Leaks and Leak-Prone Pipe*). Repairs or pipe replacements are prioritized based on severity, with many minor leaks remaining unaddressed. Leak reports and actions to address leaks are reported to the Department of Public Utilities in each LDC's Annual Service Quality Reports.[89] The non-profit organization HEET subsequently scrubs and organizes submitted data to produce HEET's Annual Leaks Map.[90] Transparent and accessible leak data benefits the public interest and could be used to inform the implementation strategies of

[88] "Service Quality Reports." Department of Public Utilities. Accessed June 22, 2023. https://www.mass.gov/info-details/service-quality.

[89] MA. Dept of Public Utilities. "Service Quality." Accessed June 22, 2023. https://www.mass.gov/info-details/service-quality.

[90] HEET. "The Gas Leaks Map." Accessed June 19, 2023. https://heet.org/gas-leaks/gas-leak-maps/.

NPGAs at the utility and with multiple stakeholders. The adoption of a uniform geocoded leak reporting system would further benefit this process.

The urgency of some leaks creates a challenge for the implementation of NPGAs: The key challenge here is another misalignment in asset intervention timing. The applicability of an NPGA strategy depends on how quickly it can be implemented to allow for the decommissioning of a pipeline segment. Many pipe replacement projects need to be urgently addressed on a timeline that would likely be too short for segment-wide full electrification, given the need for sufficient lead times for customer outreach and transition.

Ultimately, the presence of leak-prone pipes and the number and types of leaks in a segment should inform project prioritization and the potential intervention options. Approximation of the amount of methane emissions may be informative but is secondary to using a leak-risk rating as a deterministic factor in planning.

Energy Consumption & Combustion Emissions

The decarbonization of heat is facilitated by the transition from on-site combustion of fossil fuels to the efficient use of ambient heat via electric heat pumps powered by a predominantly wind and solar grid. A limited "firming" use of fuels as a transitional strategy may be useful in limiting the size, cost, and grid impacts of electrification.

Figure 3 and Figure 4 show the progression of energy consumption across scenarios for the single-family and multi-family street segments, respectively. Figure 5 and Figure 6 show the corresponding emissions impacts (All figures are shown on the following pages for clarity). Increasing electrification leads to lower overall energy use and emissions, even when accounting for the marginal increase in electricity demand from electrification.

Electrification paired with efficiency measures brings significant reductions in energy consumption across the scenarios. Dual fuel approaches reduce fuel consumption by 40%. This result is highly dependent on modeling assumptions, the system's operation, and the choice of a heating source switchover temperature.

Early intervention maximizes emissions reductions. In addition to being influenced by the level of building intervention, cumulative fuel consumption is also influenced by the timing of retrofit intervention, which could vary differently depending on the pace of the stock transaction.

Figure 3. Total energy consumption by scenario for the single-family segment. "+ EE" scenarios indicate the addition of deep building efficiency measures to reduce total energy use and lower electric peak demand.

Figure 4. Total energy consumption by scenario for the multifamily segment.

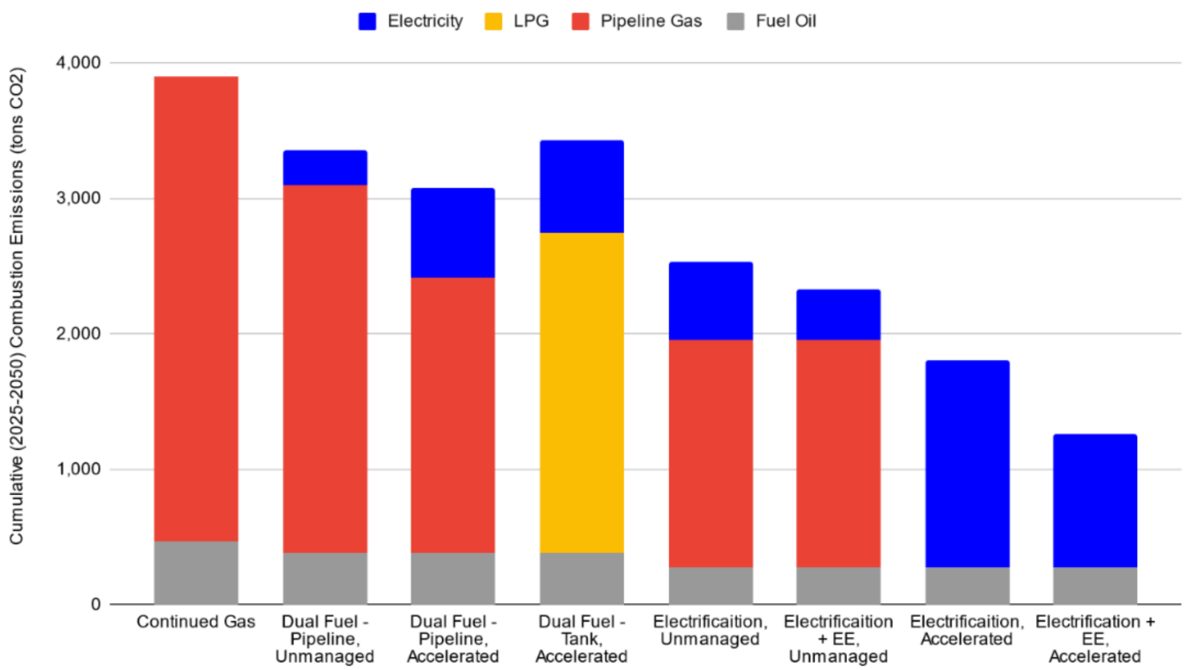


Figure 5. Cumulative (2025-2050) emissions from the single-family segment. Only electric sector emissions from new electrified loads are included.

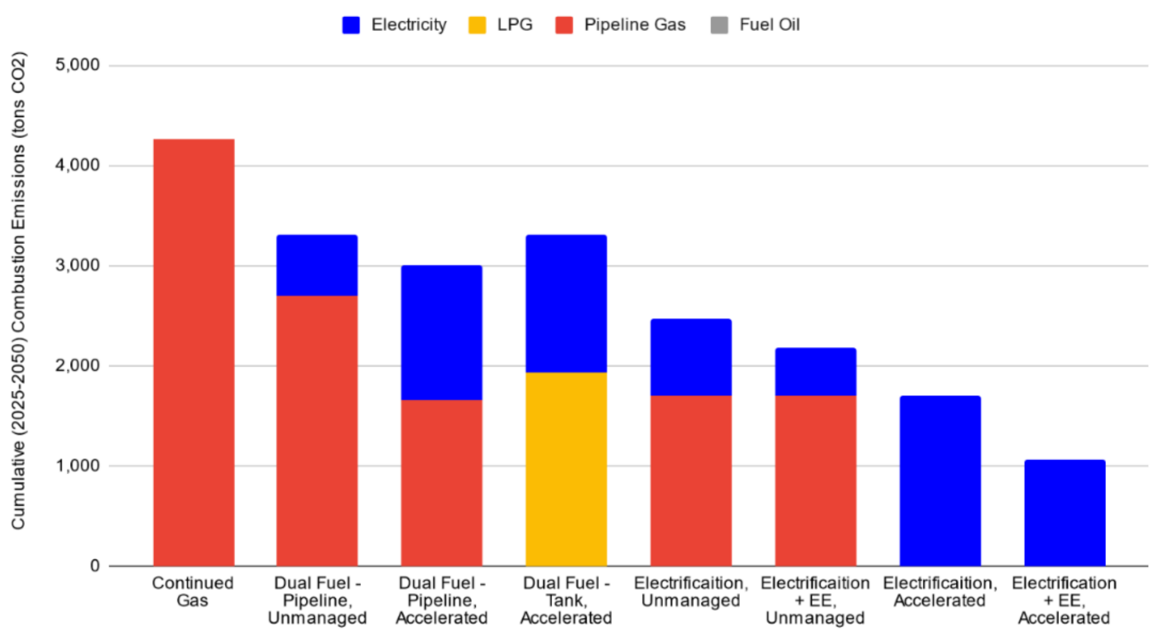


Figure 6. Cumulative (2025-2050) emissions from the multifamily segment. Only electric sector emissions from new electrified loads are included.

Discussion: Impacts of Reduced Fuel Combustion

Faster electrification reduces emissions even when accounting for electric sector emissions. Continued reliance on a significant amount of fuels presents a long-term challenge to achieving emissions reduction targets. Cumulative emissions reductions of dual fuel strategies are relatively modest. As a result, these homes face challenges to being decarbonized in 2050. Such results demonstrate that while dual-fuel approaches may offer some interim advantages, there will need to be a persistent effort to minimize their use in the building sector, likely through whole-building electrification at a later date.

This shift brings broader benefits that extend beyond climate. Combustion involves the generation of harmful air pollutants affecting indoor and outdoor air quality. Environmental justice populations typically face higher levels of cumulative exposure to the byproducts of combustion. Reduced combustion lowers this exposure.

Outdoor air quality impacts can be quantified using damage function risk assessment models such as EPA's COBRA Screening Model.[91] Impact assessment of indoor air quality changes is not as developed as a formal methodology but is an area that is seeing increasing interest. In both cases, impact assessment using a damage function at such a hyper-local level is likely unsuitable for decision-making. Indoor air quality assessments depend on several building-specific features. For example, a gas stove in a well-ventilated home is less of a concern than in an air-tight building occupied by a smoker.

Outdoor air quality assessment tools are designed for assessing large changes at coarser geographic scales. Given such limitations, the project team did not feel that using such quantitative methods suits this context. Instead, a LEAP assessment should consider the analysis's locational context and factors such as existing exposure and building stock properties.

Other impacts of electrification and reduced fuel consumption are evaluated in the following sections.

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[91] EPA. "CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)," n.d. https://www.epa.gov/cobra.

Electrical Loads

Estimated Changes in Electric Loads

The scenarios chosen and the underlying building simulations resulted in three illustrative tiers of potential electric system impacts (Figure 7):

1. Current levels of electricity demand are maintained by a continued reliance on fuels without intervention (Continued Gas).
2. Increased demand, but a level that is within the ability of the current distribution system's capacity meet that demand (Dual Fuel scenarios, but could also include high efficiency-electric technologies such as geothermal).
3. Demand that exceeds typical historical design considerations, driven by whole home electrification, necessitates distribution system upgrades.

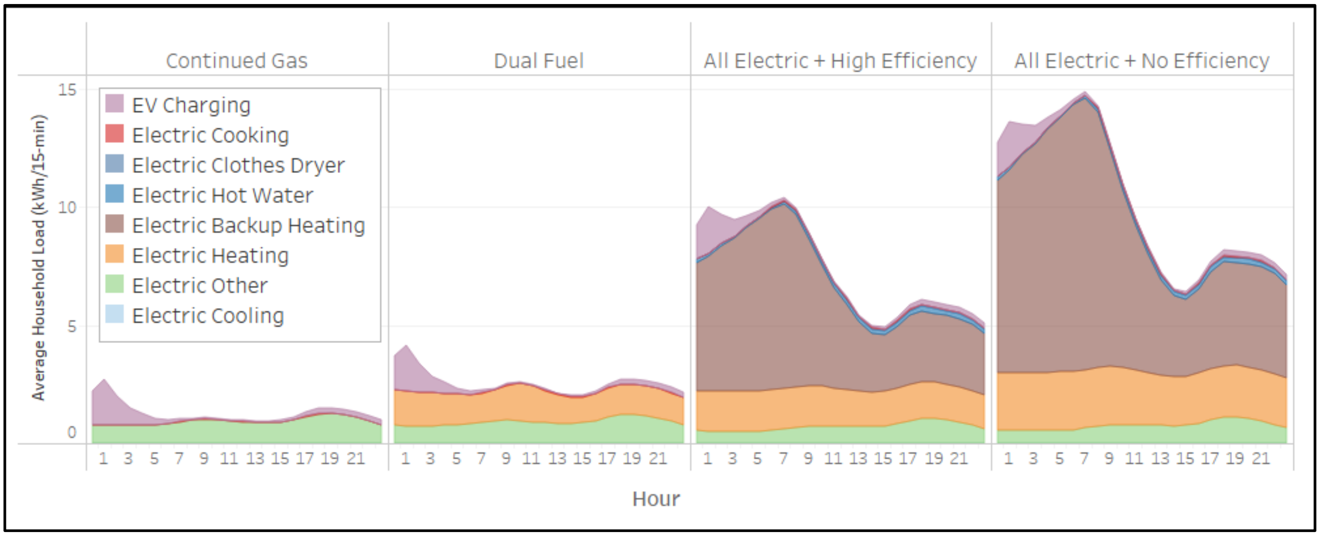

Figure 7. Daily loads on peak winter heating days for an example building from the single-family segment.

The strategy applied in the Accelerated and Unmanaged Electrification scenarios results in segment transformers being overloaded immediately and in the late 2030s, respectively. Figure 8 and Figure 9 show the impact of the coincident demand of such buildings on individual transformers analyzed. Utilizing fuels that avert this increase in demand avoids such potential overloading.

Figure 8. Peak loads for the single-family segment's four transformers under each scenario. Green represents peak load below the rated transformer capacity; red signifies the transformer capacity is exceeded.

Figure 9. Peak loads for the multifamily segment's three transformers under each scenario. Green represents peak load below the rated transformer capacity; red signifies the transformer capacity is exceeded.

Discussion: Implications of Growth in Electric Loads

The pipeline gas system has evolved to meet the peak heating needs of the buildings that it serves. Alternatively, most electric systems cannot meet thermal demands and would require upgrades ranging from services to distribution transformers to upstream feeders and substations.

The electrification of a handful of buildings on a distribution system, or the partial electrification of buildings, can benefit the economics of the electric distribution system if the electric load is increased without increasing the need for system upgrades (increasing the load factor). However, as demand approaches the ratings of local distribution transformers, such growth triggers the need for system upgrades.

The ability of the electric grid to manage the growth in such loads varies significantly but is largely obscure to all parties except the electric utility. Some parts of the distribution system are modern or have been recently modernized and could handle segment-level load increases with modest interventions such as transformer upgrades. Others are likely to be challenged by incremental additions of load.

For this project, the analysis team obtained transformer services and ratings from street-level imagery of these segments. Such a strategy is not scalable. However, the state's largest investor-owned utilities currently publish "Hosting Capacity Maps" for the siting of rooftop solar and similar distributed generation and storage projects.[92,93] These maps are regularly updated but may require methodological updates to reflect the capacity for peak heating loads. In their current form, they can serve as a rough guide for areas favorable for segment-level electrification. Additional mapping and capacity availability may be included as part of each EDC's electric sector modernization plans due to the Department of Public Utilities by the end of January 2024.

National Grid's hosting capacity map (Figure 9) for the vicinity of the multifamily segment demonstrates significant capacity on the surrounding primary lines. The feeder for the street was reported to have a 25.5% peak utilization in 2022 and is forecasted to remain well below the feeder rating through 2027. This suggests that the site may be suitable for electrification in the near term.

A hosting capacity map was not available for the single-family street segment as the segment is located in a municipal utility territory that does not publish such maps.

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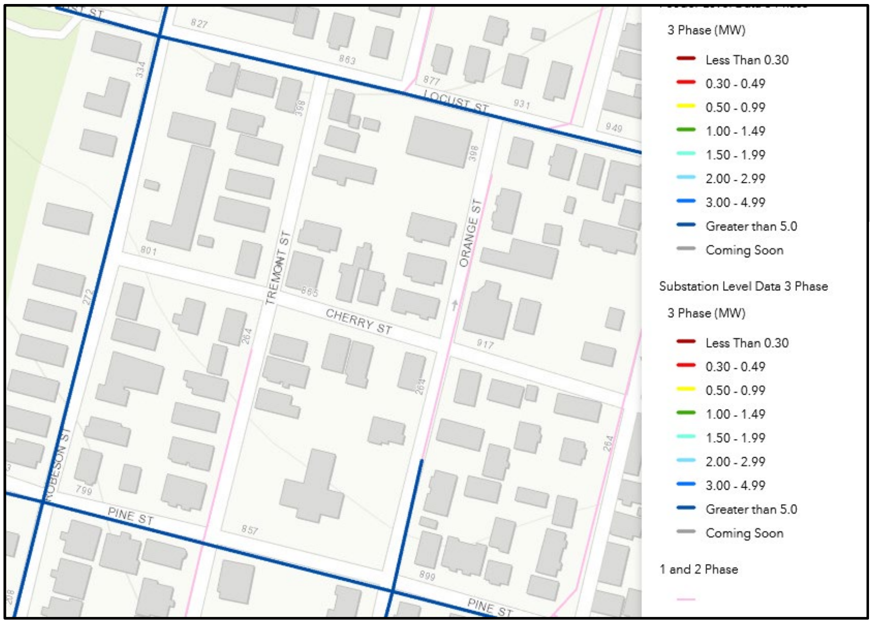
[92] Eversource. "Eversource Hosting Capacity Map Massachusetts." https://www.eversource.com/content/residential/about/doing-business-with-us/interconnections/massachusetts/hosting-capacity-map.

[93] "National Grid Hosting Capacity Map Massachusetts." https://systemdataportal.nationalgrid.com/MA/.



Planning Area	Fall River
Feeder	05_05_106W45
Substation	HATHAWAY
Operating Voltage (kV)	13.80
Summer Rating (MVA)	13.50
2022 Peak(%)	25.50%
2022 Peak (MVA)	3.40
2023 Forecast (MVA)	6.90
2024 Forecast (MVA)	6.90
2025 Forecast (MVA)	7.00
2026 Forecast (MVA)	7.00
2027 Forecast (MVA)	7.10
Last_Updated	3/29/2023

Figure 10. National Grid Hosting Capacity Map (left) and feeder utilization summary (right) for neighborhoods surrounding the single-family segment (Tremont St. between Pine St. and Locust St.). Source: National Grid

Costs

This section provides high-level estimates of infrastructure costs, including those of pipeline replacement, building upgrades, and electric system upgrades. It then evaluates total capital investment and briefly addresses the issue of stranded assets. The subsequent section extends this analysis to ratepayer impacts. Real costs are likely to be highly- case-specific; the cost estimates provided here are intended to be illustrative.

Example Pipeline Replacement Costs

Costs for pipeline replacement corresponding with each site were obtained from utility GSEP filings specific to each project and are presented in Table 6.[94,95] GSEP filings are typically estimates, with costing methodology, reporting formats and levels of detail varied significantly between the two utilities. Evaluation of filings by other utilities found significant variation, with some utilities reporting the costs of individual projects using program-wide averages (Eversource). Costs will vary significantly with each project. Actual project costs are filed in a reconciliation docket, and on average do not appear to vary significantly from project estimates.

Table 6. Summary of GSEP estimated project costs for the example street segments evaluated in this study. ***Bolded*** *values indicate values taken directly from filings. Values flagged with "?" indicate inferred approximations derived from the total project estimate.*

Project Element	Multifamily Segment (0.12 mi)		Single-Family Segment (0.35 mi)	
	Description	Cost	Description	Cost
Main Construction	4" pipe replacement, roadway repair	**$107,993**	Replace 2" welded steel pipe	$450,000?
Service Transfers	Replacing 6 cast iron pipes + 4 aldyl-A pipes, *R*econnecting 3 plastic services.	**$82,943**	10-13 services based on building age and reconnecting remainder.	$125,000?
Meter Costs	Meter replacements for replaced services	**$16,995**	10-13 buildings based on service transfers	$20,000?
Street Work	Inspector, police, engineering, ledge removal, gravel, etc.	**$32,978**	Inspector, police, engineering, ledge removal, gravel, etc.	$25,000?
Total Capital	**$240,909** $2M per mile $16,061 per building $4,302 per household		**$621,687** $1.7M per mile $36,570 per household	
Avoided O&M (Annual)	Avoided cost of leak repair for cast iron pipe: **$20,250** per mile	**$2,430**	Avoided cost of leak repair for steel pipe: **$6,750** per mile	**$2,362**

[94] Petition of Liberty Utilities (New England Natural Gas Company) Corp. for Approval of its 2022 Gas System Enhancement Plan, No. 21-GSEP-04.

[95] Petition of Eversource Gas Company of Massachusetts d/b/a Eversource Energy for Approval of its 2022 Gas System Enhancement Plan, No. 21-GSEP-05.

Such data can help stakeholders understand how costs of different project elements can change over time and location as well as the driving factors of costs. For example, the multifamily filing included details on the number of service pipes replaced and disconnected. On average, service pipes cost approximately $10,000 per building to replace. This number appeared consistent across several filings from other LDCs, but due to the diversity in reporting practices, it was unclear if this included meter replacements.

In addition to pipeline replacement projects, GSEP reporting also included costs of other projects, such as pipeline abandonment, which averaged approximately $13,000 per project in Liberty territory.

GSEP costs are typically communicated on a distance basis (per mile or foot). This may not be the most useful measure of cost-effectiveness for a project, especially given that costs are likely to vary by geography.[96] As Table 12 notes, total capital costs can vary significantly on a household or building basis, driven largely by the density of service of a given pipe.

While the total replacement cost and replacement cost per household of the multifamily street in this report are lower than the associated costs for the single-family street, this may not always be true. LDC filings indicate pipeline replacement projects are becoming more expensive and complex as they focus on urban areas, particularly in the Boston region.[97]

Inconsistencies in reporting make it challenging to conduct a detailed statewide analysis of GSEP projects by location. For this work, the project team, with support from HEET, had to geocode GSEP locations and line segments from street addresses in GSEP filings. The latter step resulted in over half of GSEP projects being excluded due to the inability to geocode pipeline segments confidently. This step would be relatively easy in modern utility GIS systems not fully utilized by Massachusetts LDCs.

Even in the selected multifamily street segment, the project team observed a discrepancy in the pipe service area (mapped with high confidence due to reported length and end and start streets) and the number of buildings it served. The filing reported 13 services, but there were 15 visually identified connections. A small discrepancy such as this can have a measurable impact on the estimated cost. To address this discrepancy, the project team modeled the cost of two additional service replacements on the gas side. Such discrepancies could be avoided if GSEP filings included a list of buildings served by the infrastructure included in a utility's GSEP.

Ultimately GSEP costs are estimates with estimate methodology varying by utility. Conducting a more detailed cost-benefit analysis may require more site-specific detailed costing than the current GSEP methodology.

Building Intervention Costs

Building intervention costs pose different challenges, especially given recent economic conditions and supply chain constraints. For this work, the project team attempted to calculate building costs using all publicly available building data, largely tax assessor's tables and various cost estimates. This process

[96] Seavey, Dorie. "GSEP at the Six-Year Mark: A Review of the Massachusetts Gas System Enhancement Program," 2021. https://www.gastransitionallies.org/gsep

[97] Ibid.

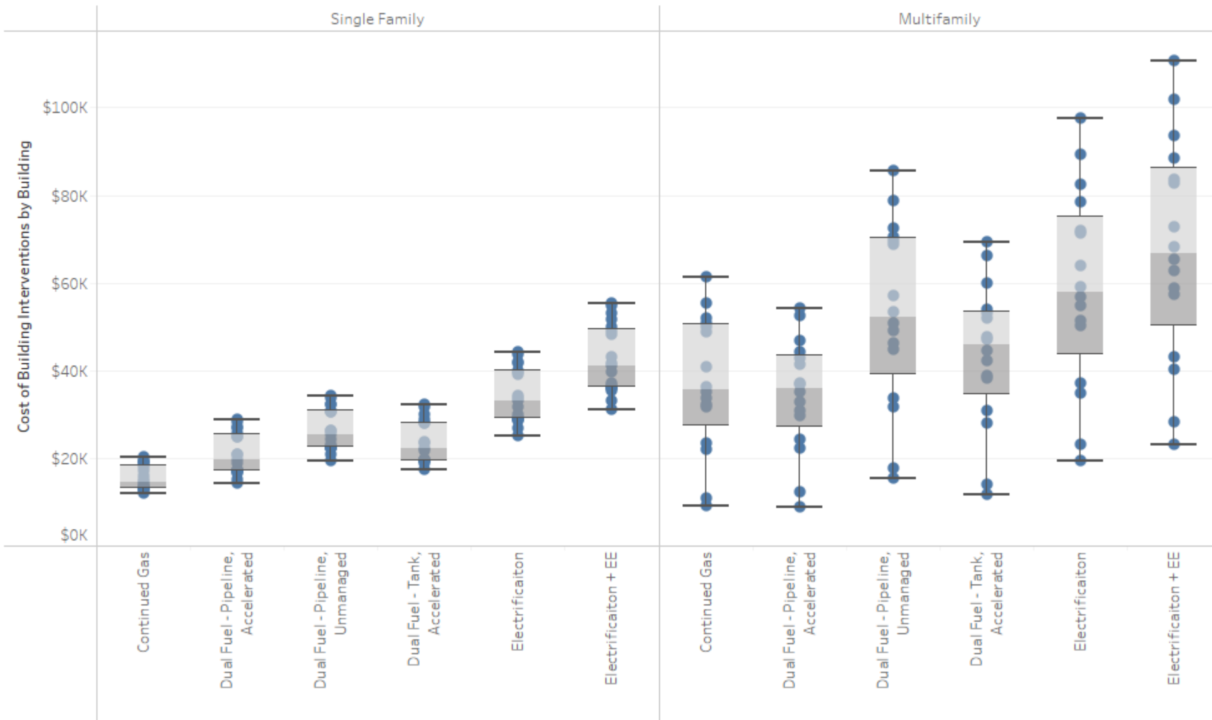
used the number of kitchens to determine the number of stove replacements. The number of units was used to estimate the number of clothes dryers, but a scaling function was added for larger multifamily buildings, given the likelihood of shared equipment or the use of a commercial laundromat. The number of hot water heaters, HVAC units, and shell improvements were modeled per unit, but the magnitude of the costs was scaled by average unit size.

Several datasets were used to calibrate the estimates, including MassCEC's Whole Home Heat Pump pilot program costs,[98] Mass Save energy efficiency program administrator measure filings,, and appliance costs from retailers. The model included estimates of labor, overhead, and taxes for each intervention. While this level of detail is inherently uncertain and requires continual calibration, it is a framework that can be extended and applied to future work.

Figure 11 (below) shows the range of costs generated by these estimates. Typically, like-for-like replacements of existing heat equipment (either at the same or greater AFUE) are the cheapest intervention due to the low intervention needs of such replacements. Adding heat pumps in a hybrid arrangement with existing gas equipment was modestly higher. Non-pipeline dual fuel interventions included an adder of approximately $1,250 to account for the additional cost of propane equipment. Whole home electric heat pumps tended to be the greatest cost due to larger size equipment and shell upgrades. While such costs are significantly variable, these estimates fall within the range of prior observations by MassCEC.[99]

In some cases in the multifamily segment, building retrofit costs for whole building electrification approached a significant portion (as much as 50%) of the building's assessed property value. This appears to be a significant element of building projects in low-income communities, which is simultaneously a challenge and an opportunity. A major facet of the challenge is that some of these buildings may need additional functional interventions before heating systems are updated or that heating interventions may not be the most critical need of the home. Further, low-income small multifamily rental housing has historically been the most challenging segment for energy efficiency programs. Segment-level interventions create an opportunity to streamline delivery to increase the participation of this cohort.

[98] "Whole-Home Air-Source Heat Pump Pilot." Massachusetts Clean Energy Center. https://www.masscec.com/program/whole-home-air-source-heat-pump-pilot.
[99] "Whole-Home Air-Source Heat Pump Pilot." Massachusetts Clean Energy Center. https://www.masscec.com/program/whole-home-air-source-heat-pump-pilot.



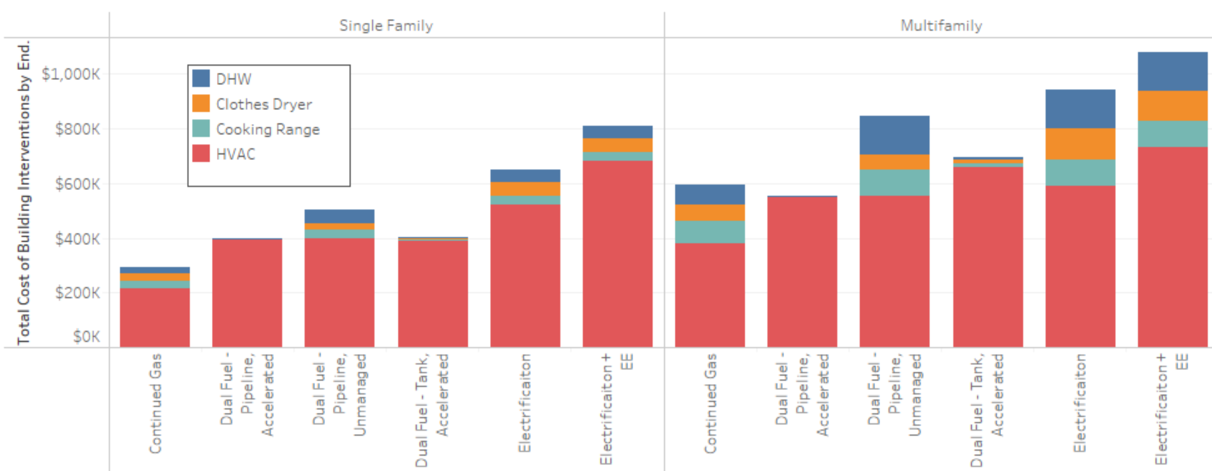


Figure 11. Estimated building costs for each scenario under each segment by building (top) and by segment with coloring for each end-use (bottom). Source: Groundwork Building Costing Model calibrated to Mass Save Program Administrator and MassCEC datasets. Differences in costs of Dual Fuel cases reflect assumptions surrounding the timing and application of retrofits specific to the design of each scenario.

These costs are calculated before any Mass Save or Inflation Reduction Act incentives or credits, and as such, the actual costs to the building owner will likely be lower.

While the cost of all-electric interventions may appear substantial, it is helpful to consider the incremental cost (Table 7) relative to reinvestment that would have been made anyways. There is consensus that some level of heating electrification and reduction in fuel use is necessary to achieve climate goals. However, some onsite uses of fuel have the potential to serve a transitional role by overcoming several implementation barriers. Switching over to a dual fuel system can achieve fuel reduction (see Energy Consumption Section above) at a low incremental cost to the baseline.

Still, such strategies are reliant on eventual pipeline replacement. The next most cost-effective step is a dual-fuel approach with LPG. This comes at a small incremental cost compared to the dual fuel with pipeline gas strategy. Eliminating the need for reinvestment in the gas system via a non-pipeline fuel is a significantly small incremental cost relative to the cost of pipeline replacement. Eliminating fuel use ends up being the highest incremental cost. Still, the incremental spending relative to keeping the pipeline in place is relatively small in the case of the single-family segment, where pipeline replacement costs are $36,500 per connected household. In the multifamily case, incremental costs are similar on a per-household basis but are more expensive than replacing the pipeline on a per-household basis ($4,300). All interventions become either cost-effective or competitive for the customer when factoring in Mass Save incentives and federal tax credits, which could exceed $10,000 if the system was going to be replaced anyways.

Table 7. Average and incremental costs for the single-family and multifamily street segments.

Single-Family Retrofit	**Per Building**	**Incremental**	
Continued Gas	$15,498	*To gas use as usual*	*To pipeline replacement with dual fuel.*
Dual Fuel - Pipeline, Unmanaged	$26,382	$10,884	
Dual Fuel - Pipeline, Accelerated	$20,917	$5,419	
Dual Fuel - Tank, Accelerated	$21,256	$5,758	$339
Electrification, Unmanaged	$34,185	$18,687	$7,803
Electrification + EE, Unmanaged	$42,552	$27,054	$16,170
Electrification, Accelerated	$34,185	$18,687	$13,268
Electrification + EE, Accelerated	$42,552	$27,054	$21,635
Multifamily Retrofit	**Per Housing Unit**	**Incremental**	
Continued Gas	$10,991	*To gas use as usual*	*To pipeline replacement with dual fuel.*
Dual Fuel - Pipeline, Unmanaged	$15,653	$4,662	
Dual Fuel - Pipeline, Accelerated	$10,222	-$769	
Dual Fuel - Tank, Accelerated	$12,906	$1,915	$2,684
Electrification , Unmanaged	$17,432	$6,441	$1,780
Electrification + EE, Unmanaged	$20,006	$9,016	$4,354
Electrification, Accelerated	$17,432	$6,441	$7,210
Electrification + EE, Accelerated	$20,006	$9,016	$20,776

All heating equipment, including gas, can be anticipated to fail and likely needs to be updated at a certain point. This assumption may be too general for some parts of the housing stock, which may patch older equipment to extend lifetimes. Doing so, however, often incurs a comparable levelized cost. While the scenarios map out various timelines for updating equipment, there is some uncertainty regarding the lifetime, particularly in the immediate dual fuel case, where some level of refurbishment of the existing asset is assumed. Given this uncertainty, these scenarios still represent illustrative examples of what could happen.

Electric System Upgrade Costs

Electric system costs were assumed to be incurred when transformer capacity was overloaded (see Figure 11 and Figure 12). An additional $20,000 was incurred for each additional 37.5 kVA of transformer capacity at each current transformer location. No direct upstream electric costs were included because there appears to be sufficient capacity on the circuit in utility hosting capacity data for the multifamily segment.[100] In the single-family segment, no data was available.

Costs here are challenging to estimate due to recent supply chain constraints for transformers that have tripled prices.[101] Similar challenges exist for estimating upstream costs.[102] Again, this is an instance where utility participation and data can help make informed decisions regarding feasibility and cost-effectiveness. Finally, an additional difficulty in estimating the costs of electric system upgrades is understanding the magnitude of upgrades electric vehicles require and how EVs can manage loads. LEAP integrated planning can help evaluate such scenarios.

[100] "National Grid Hosting Capacity Map Massachusetts." https://systemdataportal.nationalgrid.com/MA/.

[101] Utility Dive. "Utilities Sound Alarm over Distribution Transformer Shortage as Procurement Times Surpass 1 Year and Costs Triple." https://www.utilitydive.com/news/distribution-transformer-shortage-appa-casten/639059/.

[102] Lee, Tony L. "Implications of Heating Electrification on Distribution Networks and Distributed Energy Resources." Thesis, Massachusetts Institute of Technology, 2022. https://dspace.mit.edu/handle/1721.1/144976.

Total System Spending

Figure 11 and Figure 12 (following pages) show the cumulative spending in each scenario. Reinvestment in the gas system leads to higher overall spending. The key difference here is immediate utility spending at scale — a routine practice that broadly distributes costs — versus immediate building spending in which costs are concentrated on building owners.

Given the overhead capacity described above, these results do not include upstream electric costs, which could vary, but are likely incrementally negligible for the multifamily segment. Operational costs for maintaining the gas system — an average cost for monitoring and fixing leaks — were included but small for the replaced pipe.

Frequently, observers and commenters on these GSEP projects casually imply that the money saved from avoided pipe replacement can be used to invest in building electrification on the same site. Such perspectives are understandable and may generalize the system-wide implications, but they are oversimplified. However, the primary goal is to avoid gas system costs that are at risk of being unrecoverable.

Using gas ratepayer funds to fund electrification also directly raises questions of fairness, equity, and legal authority. However, such a situation can be viewed as analogous to charging a congestion fee to fund public transit, induce vehicle demand reduction, and avoid the need to expand a highway. The goal is to lower system costs while advancing social goals. The cost of building electrification may be mitigated by incentive programs (e.g., Mass Save or IRA) whose costs are more broadly subsidized. Pacific Gas and Electric's efforts to electrify gas segments in Monterey Bay, California, is an example of this approach in action.[103]

How such transfers affect equity largely depends on the implementation approach and strategy. First and foremost, the goal of the segment-level transition is to avoid increasing the cost of the gas system to future ratepayers. The Massachusetts 2050 Decarbonization Roadmap and the LDC's pathways analysis emphasized the likelihood that low-income customers are slower in migrating away from gas – assuming current customer behavior patterns such as early adoption trends by more affluent people and challenges transitioning rental properties. Avoided reinvestment through segment-level transition modestly reduces but does not mitigate the potential burden. Greater intervention will likely be necessary.

Segment-level transition could facilitate more equitable utilization of incentive programs. Low-income households in small homes (under five units) under-participate in Mass Save. However, coordination efforts by community action agencies and the Low-Income Energy Affordability Network achieve higher levels of participation than average in large multifamily homes (5+ units).

[103] California State University Monterey Bay. "East Campus May Become California's Largest Electrification Project." https://csumb.edu/news/news-listing/east-campus-may-become-californias-largest-electrification-project/.

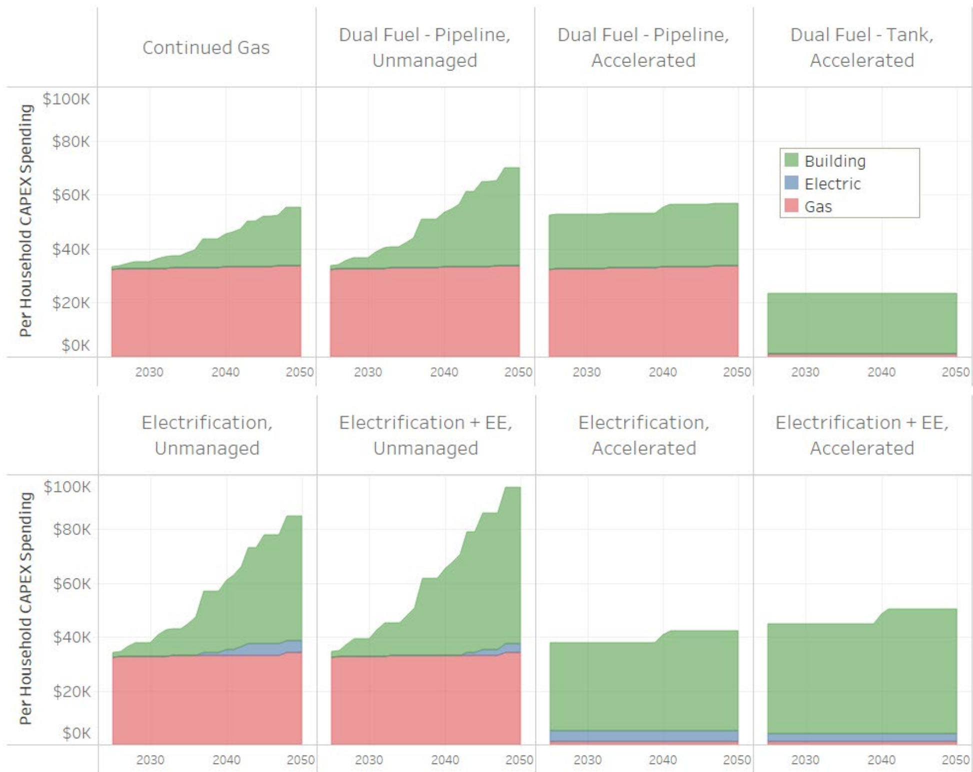


Figure 12. Cumulative spending on the single-family street segment in each scenario on a per-household basis.

Table 8. Single-family total system capital costs.

Scenario	Building	Electric Network	Gas Network	Total Capital
Continued Gas	Like-for-like @ EOL ($407K)	No upgrades	**Immediate** replaced pipeline ($642K)	$1,049K
Dual Fuel - Pipeline, Unmanaged	EOL pipeline hybrid building electrification. ($684K)	No upgrades	**Immediate** replaced pipeline ($642K)	$1,326K
Dual Fuel - Pipeline, Accelerated	**Immediate** pipeline hybrid building electrification. ($437K)	No upgrades	**Immediate** replaced pipeline ($642K)	$1,079K
Dual Fuel - Tank, Accelerated	**Immediate** non-pipeline hybrid building electrification ($429K)	No upgrades	Abandoned pipeline ($20K)	$449K
Electrification , Unmanaged	EOL Whole building elec. ($886K)	Eventual upgrades of all transformers ($80K)	**Immediate** replaced pipeline ($642K)	$1,608
Electrification + EE, Unmanaged	EOL Whole building elec. with EE ($1,105K)	Eventual upgrades of most transformers ($60K)	**Immediate** replaced pipeline ($642K)	$1,827
Electrification, Accelerated	**Immediate** building elec. with EE ($703K)	**Immediate** upgrades of all transformers ($80K)	Abandoned pipeline ($20K)	$783
Electrification + EE, Accelerated	**Immediate** building elec. with EE ($878K)	**Immediate** upgrades of most transformers ($60K)	Abandoned pipeline ($20K)	$958

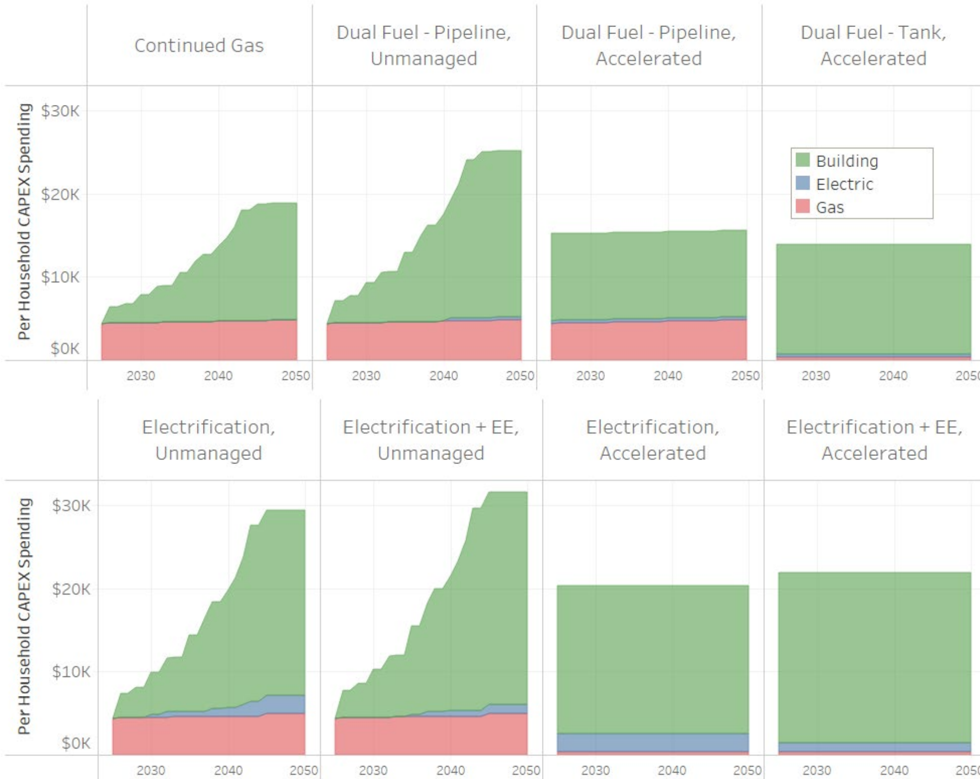


Figure 13. Cumulative spending on the multifamily street segment in each scenario on a per-household (or building) basis.

Table 15. Multifamily Capital Costs across Infrastructure Categories

Scenario	Building	Electric Network	Gas Network	Total Capital
Continued Gas	Like-for-like @ EOL ($783K)	No upgrades	**Immediate** replaced pipeline ($642K)	$1,053K
Dual Fuel - Pipeline, Unmanaged	EOL pipeline hybrid building electrification. ($1,117K)	Upgrade of one transformer ($20K)	**Immediate** replaced pipeline ($642K)	$1,406K
Dual Fuel - Pipeline, Accelerated	**Immediate** pipeline hybrid building electrification. ($586K)	Upgrade of one transformer ($20K)	**Immediate** replaced pipeline ($642K)	$875K
Dual Fuel - Tank, Accelerated	**Immediate** non-pipeline hybrid building electrification ($740K)	Upgrade of one transformer ($20K)	Abandoned pipeline ($20K)	$780K
Electrification , Unmanaged	EOL Whole building elec. ($1,247K)	Eventual upgrades of all transformers ($120K)	**Immediate** replaced pipeline ($642K)	$1,643K
Electrification + EE, Unmanaged	EOL Whole building elec. with EE ($1,431K)	Eventual upgrades of most transformers ($60K)	**Immediate** replaced pipeline ($642K)	$1,768K
Electrification, Accelerated	**Immediate** building elec. with EE ($999K)	**Immediate** upgrades of all transformers ($120K)	Abandoned pipeline ($20K)	$139K
Electrification + EE, Accelerated	**Immediate** building elec. with EE ($1,146K)	**Immediate** upgrades of most transformers ($60K)	Abandoned pipeline ($20K)	$1,226

Stranded Assets

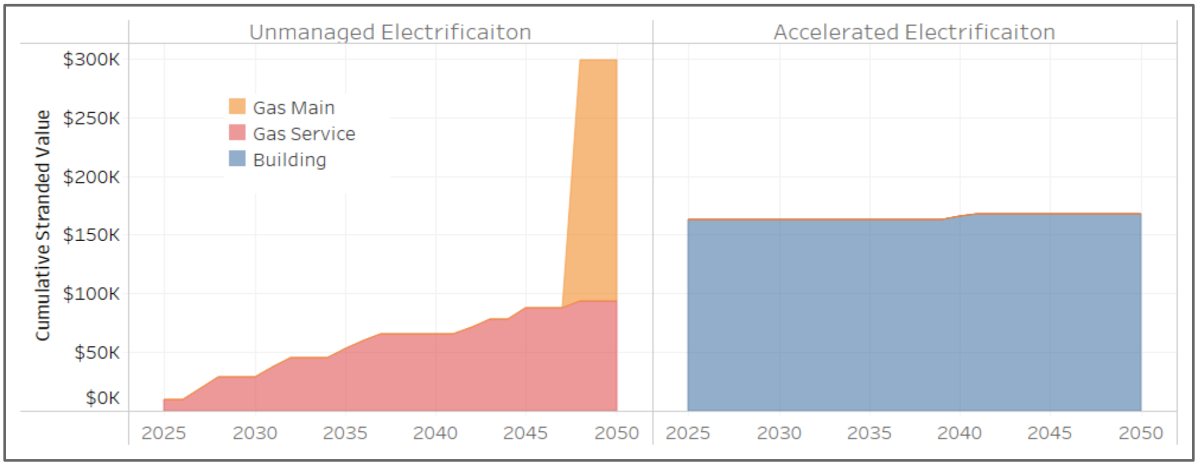


Figure 14. Cumulative stranded asset value of gas distribution and building assets in Unmanaged (left) and Accelerated (right) Electrification scenarios.

The core challenge of segment-level transition is the misalignment of gas pipeline replacement with a distribution of future replacement points over the next two to three decades. Figure 13 shows the two extremes of this challenge: either the gas pipeline is replaced, and homes are steadily electrified, leaving a substantial value stranded in the late 2040s, or immediate electrification results in a sizeable upfront stranding of fossil fuel building equipment when the pipeline is decommissioned in 2025. In the case of the former scenario, there is also a considerable steady stranding of gas services as homes electrify.

In addition to being a core indicator for segment-level evaluation and planning, it also may represent a level of compensation needed to support the transition. While avoiding pipeline replacement may be a cost-effective strategy, cutting gas service to a customer represents a discontinuation of expected service that underlies the customer's decision to invest in certain end-use equipment — perhaps even with a previous incentive from the Mass Save program. Additionally, certain heating systems or appliances may offer customers aesthetic value, for which customers may be unhappy to part with. In these situations, compensation for residual asset value, such as that offered in gas transition strategies underway in Zurich[104] may be justified and help to smooth the transition for customers, but may raise equity concerns in some situations.

Likewise, on the distribution system side, current expectations for the future of gas and the prudency of investments are in flux. However, the current regulatory framework anticipates that the gas system will still be used and useful past 2050. Investors expect and may be guaranteed a rate of return based on this framework, but maintaining the revenue requirement under declining use may challenge the financial viability of a gas utility. There are various ways that this could be managed; however, the key takeaway here is that gas pipeline replacement creates a significant risk of stranded value that will need to be absorbed in the future.

[104] "Zurich Turns off Gas to Fight Climate Change and Russia : NPR." https://www.npr.org/transcripts/1092429073.

Ratepayer/Customer Impacts

Assessing customer impacts is important for understanding the implications of alternative strategies. Given the hyper-local approach, changes in energy costs can be estimated with a high degree of confidence, assuming detailed information on building energy use and historical bills are included in the LEAP analysis. However, such assessments can only provide a close view of the implications. Rates and the cost of different energy services will likely change due to several policy-driven and more independent dynamics:

- The cost of electricity distribution depends on how future loads are managed and how much additional investment in the electric distribution system is needed.
- Electricity supply cost depends on various pathways for reducing emissions from generation but has recently been influenced by volatility in the energy markets.
- The cost of gas distribution is dependent on the degree of reinvestment in the gas system over the coming decades.
- The cost of gas supply is dependent on the cost of bringing gas consumption into compliance with emissions targets (e.g., carbon tax, the blending of RNG, or purchase of an emissions allowance).

Future energy supply costs can vary significantly. The Commonwealth, however, does not have a definitive pathway for regulating supply that can reliably forecast costs. Further, the future cost of gas delivery will largely depend on aggregate near-term decisions in pipeline reinvestment and the pace of declining consumption and customers — trends that will be influenced by aggregation of the immediate and incremental decisions that are the focus of this work.

A customer impact assessment can be used to evaluate the risk of alternative strategies in this context and should capture:

1. Near-term impacts based on current rates.
2. Long-term trends based on anticipated macro-energy trends.
3. Novel rate design practices that seek to manage better the costs and incentives associated with heating electrification.
4. Diversity in impacts based upon buildings and households analyzed.

Figure 15 and Figure 16 (on the following pages) integrate the near-term changes and long-term macro-energy trends for illustrative purposes here. This analysis assumes:

- Electricity supply costs grow modestly at about 1% per year, based on central trends in the MA 2050 Decarbonization Roadmap and the LDC 20-80 Pathways Assessment.
- Fuel costs increase due to the expected high cost of emissions compliance starting at $100 per year in 2025 and increasing by 3% per year. This could take the form of a carbon tax, emission allowance, or fuel blending requirement. Notably, the draft clean heat standard proposes a $190 per ton CO_2 alternative compliance payment,[105] however it is not yet clear how this cost would be passed on to energy consumers.

[105] "Massachusetts Clean Heat Standard Draft Framework." Massachusetts Department of Environmental Protection, November 2023. https://www.mass.gov/info-details/massachusetts-clean-heat-standard.

- Gas distribution costs are anticipated to rise at a rate similar to that forecasted in the LDC 20-80 analysis hybrid scenario.[106]

All households experience increases in energy costs, except those that received comprehensive energy efficiency measures along with electrification. The cost of electric heating is greater than the cost of gas today. Homes with greater reliability on fuels and/or pipeline delivery experience the greatest increases. In unmanaged electrification, homes still reliant on gas in the 2040s have the highest bills, again due to the high emissions compliance and distribution cost.

This analysis can be a useful tool for planners and implementers to understand and communicate the range of impacts more easily. With robust energy use data, bill impacts can also be evaluated at the household level. Figure 17 shows the distribution of energy bills across the single-family street segment.

[106] Energy+Environmental Economics and Scott Madden Management Consultants. "The Role of Gas Distribution Companies in Achieving the Commonwealth's Climate Goals, Independent Consultant Report--Part I: Technical Analysis of Decarbonization Pathways."

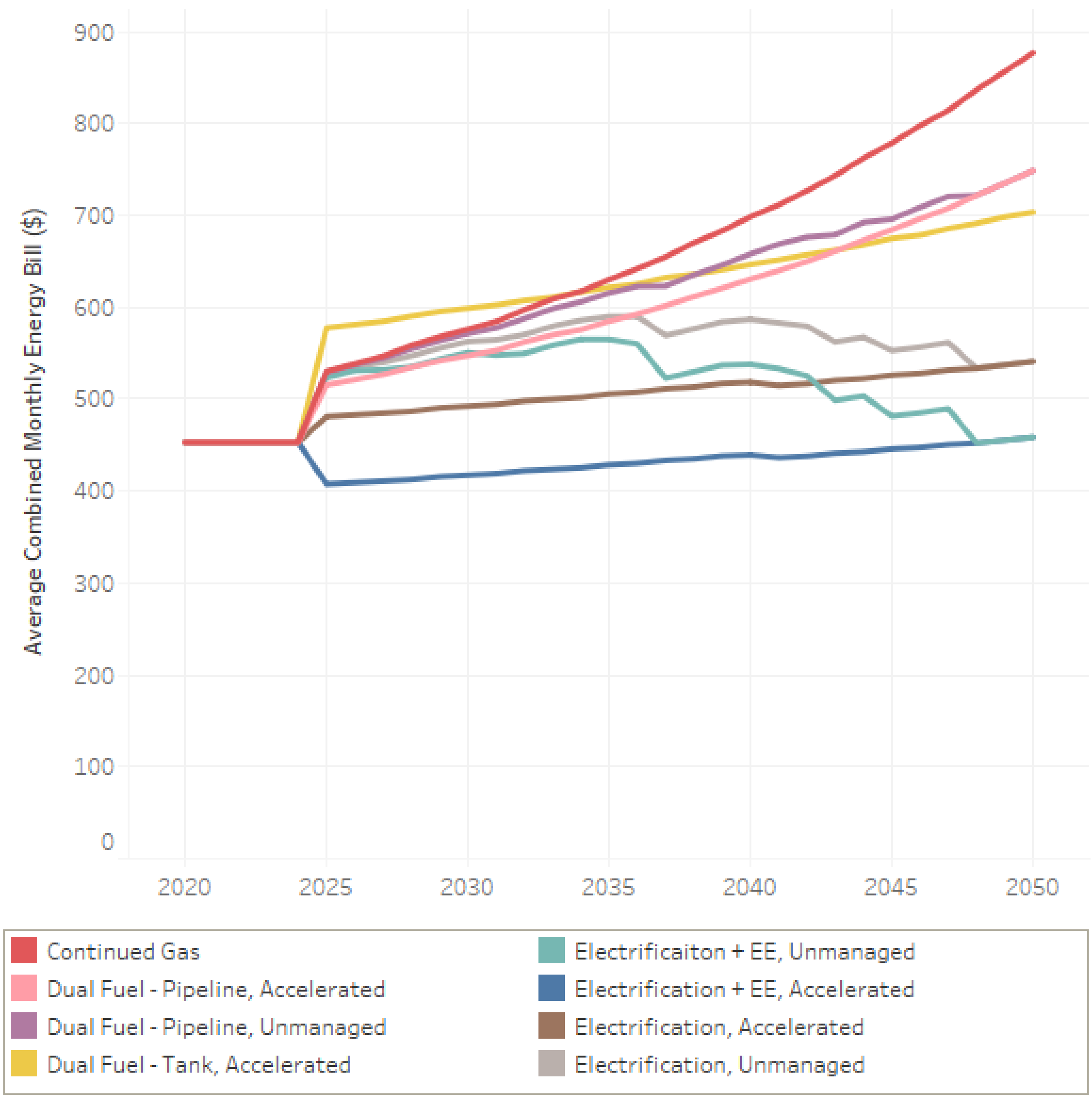


Figure 15. Average combined monthly energy bill for the single-family segment by scenario.

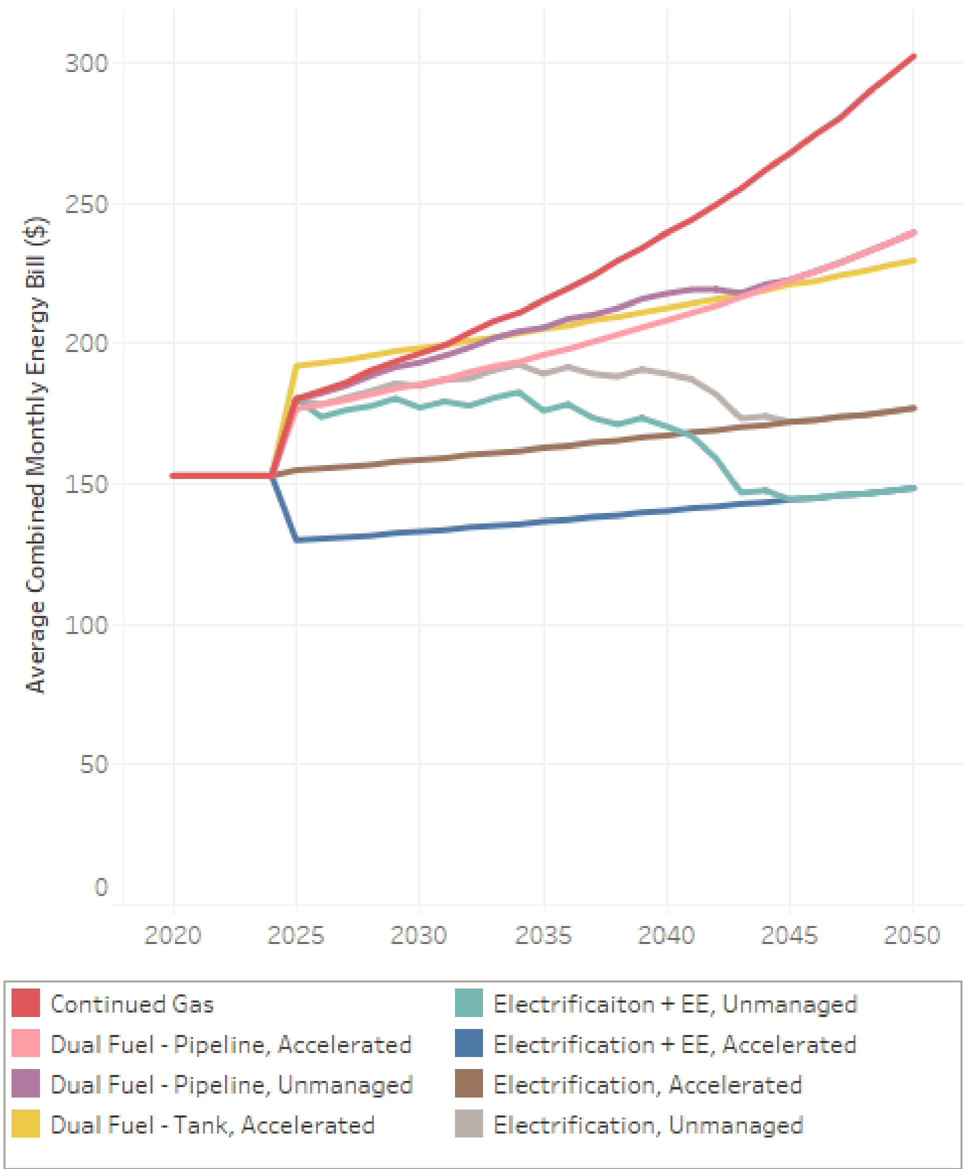


Figure 16. Average combined monthly energy bill for the single-family segment by scenario

Figure 17. Distribution of average combined (fuel + electric) annual energy bill for each scenario at 10-year increments for the single-family segment. Color indicates the use of heating fuel or all-electric. A similar figure for the multifamily segment could not be constructed due to lack of information on average housing unit size.

Synthesis of Results

This section reviews the results to evaluate challenges and opportunities for site selection in the context of the single-family (Table 9) and multifamily segments (Table 10). The authors underscore that this analysis is not intended to prioritize one over the other but instead demonstrate the application of LEAP in different contexts. Further, LEAP is extendable to other street segments and scales, but the immediate question of gas pipeline replacement, particularly on residential street segments, provides a valuable use case for demonstration. Both segments have unique characteristics that impact cost-effectiveness, climate mitigation risk, and customer services.

Across both segments, the replacement of leak-prone pipe locks in costly infrastructure that is redundant to high-efficiency electric heating and continues using fossil fuels incompatible with the Commonwealth's greenhouse gas reduction targets. If building electrification is going to happen, the cost of gas pipeline replacement appears to be excessive. With asset depreciation schedules ranging from 40-60 years, such infrastructure quickly becomes underutilized and ultimately stranded under anticipated building electrification goals. While building electrification can be costly, and if done instead of pipeline replacement, it results in stranded gas assets in buildings, it is a useful tool for avoiding the cost of pipeline replacement while aligning the building stock with climate goals. This study's exploration of these tradeoffs across a single-family and multifamily segment offers some additional insights.

The single-family segment has extensive flexibility in implementing NPGA strategies. The most significant constraint is the urgency associated with the pipeline replacement due to significant leaks. Such projects may need to be completed within a year. The timeline for educating customers and updating systems is approximately two years, given feedback from a utility stakeholder with experience implementing NPGAs. Such an urgency may not make this the most suitable site for a pilot project.

However, once segment-level transitions become practical, high-priority decommissioning projects could benefit from a mix of strategies. These include whole home electrification and dual fuel LPG as a transitional strategy to expedite homes that may not be ready or suitable to electrify immediately. Such an interim strategy would allow for longer lead times to more aggressive interventions, including geothermal strategies.

The multifamily segment is part of a concerted effort to update leak-prone pipe infrastructure across a gateway city. Similar projects are occurring based on project prioritization which can include coordination with other city infrastructure projects. Unlike the single-family segment, there is no major leak urgency, but the risk still exists. LPP replacement projects are prioritized in many situations based on their potential for coordination ("dig once'') with other infrastructure projects to reduce costs and disruption. While such project coordination is beneficial, if the pipe is likely to be decommissioned, such coordination may be irrelevant. If LPP does not necessitate immediate mitigation, a multi-year approach to NPGA can be implemented, possibly with partial electrification of buildings, such as a transitional dual fuel service or electrifying individual units at logical points. This could reasonably expand the transition period to a decade or more, given current GSEP timelines[107] and safety assurance.

[107] Seavey, Dorie. "GSEP at the Six-Year Mark: A Review of the Massachusetts Gas System Enhancement Program," 2021. https://gasleaksallies.org/gsep.

The buildings currently served by the segment are a diverse set of 100-year-old multifamily buildings in various configurations and conditions. Approximately two-thirds appear to be owner-occupied.

The density of the housing units poses several challenges. First, the cost of retrofits for this segment is high compared to the cost of pipeline replacement. It is important to re-emphasize here that the purpose of avoiding replacement is not for the street's resident’s individual cost savings but for the utility system's cost savings.

Second, the density limits the ability to install fuel tanks to support an NPGA dual fuel approach. Nearly half the properties were screened out in an application of tank placement requirements.

Despite this, the density provides an opportunity for thermal network district systems such as those piloted by Eversource and National Grid in similarly dense, mixed-use neighborhoods.

Here, decision-makers and project planners must be sensitive to community needs and burdens. As noted above, the cost to retrofit these homes is a significant portion of assessed property values. In some cases, installing a heat pump may be the first significant upgrade in a half-century. Such upgrades will provide benefits, especially if paired with comprehensive energy efficiency measures to reduce the cost burden of electrification. The transition to a greater reliance on electric service will likely have an impact on monthly residential energy costs, particularly for those renters where heat is otherwise covered in rent, but the electric bill is not.

Table 9. Synthesis and cross-contextualization of results for the single-family segment.

Indicator	Context	Challenges to NPGA	Opportunities
Leaks	Urgent need to address leaks: Three Grade 3, and two Grade 1 leaks have been reported on this segment.	Immediate need to address pipeline constraints alternatives.	May favor a rapid deployment strategy that uses backup propane
Building Upgrades	Large, older single-family homes create opportunities for energy upgrades.	N/A	Any number of interventions appear to be practical.
Customer Context	Affluent suburbanite homeowners	Customer reluctance may be high due to ingrained consumer preferences for gas cooking or fireplaces. Some customers may seek to hold out as a result.	Intervention may prompt customers who have been on the fence with embracing new strategies. Higher capacity for managing risks and burdens of electrification.
Costs	Clear opportunity for cost savings from alternative strategies.	Increase in energy costs for full electrification.	Hybrid strategies may limit cost increases in the near term.
Feasibility of Non-Pipeline Fuels	Sufficient parcel space for placement of modestly sized fuel tanks.	N/A	High potential for utilization of non-pipeline fuels.
Electric Upgrades	Distribution system is managed by a municipal electric utility. Segment is served by overhead wires, with some underground services. Most homes likely have sufficient service.	Separate energy providers and limited information on the state of the distribution system serve as a barrier. Unclear impact on upstream feeders due to lack of data.	Transformer upgrades are relatively straightforward but are challenged by supply chain constraints.
Alternative Strategies	Sufficient land space for geothermal drilling	N/A	Good potential for high-efficiency electrification.

Table 10. Synthesis and cross-contextualization of results for the multifamily segment.

Indicator	Context	Challenges to NPGA Implementation	Opportunities
Leaks	Leak prone pipe, but no immediate leaks: Several Grade 3 leaks have been observed in the surrounding area. This project does not appear to be a priority for leak mitigation, but rather part of overall GSEP management of leak-prone pipe.	N/A	The lack of immediacy at such sites offers more flexibility and time. Projects can be delayed to support deeper retrofits or implementation of multi-building services.
Building Upgrades	Old, unimproved building stock.	Substantial upgrades, including those of non-energy features, may be needed.	Retrofits are an opportunity to improve the health and livability of low-income building stock.
Customer Context	Low income, multifamily community with in which over 75% of units are rentals.	High burden risk. Many engagement points. Possible language barriers.	Well-designed interventions could lower costs, improve health, and enhance living spaces. Opportunity to design segment-level programs that target LMI.
Costs	Pipeline replacement costs are low relative to building retrofit costs. Building retrofit costs are a significant portion of building value.	NPGAs are less attractive under a conventional, site-focused cost-benefit framework.	Efficiency retrofits could deliver significant savings relative to continued gas use even with immediate electrification.
Feasibility of Non-Pipeline Fuels	High-density homes with limited space for tank placement.	Constrained yard space limits tank siting for half the homes.	N/A
Electric Upgrades	Feeders have sufficient capacity for additional load.	Street may require modest transformer upgrades. Building services may need to be upgraded.	Feeders can handle the additional load.
Alternative Strategies	High-density homes.	Conventional geothermal in yards may be difficult.	Density may allow for district-scale solutions.

CHAPTER 5: DISCUSSION & FURTHER CONSIDERATIONS

The illustrative exercise above demonstrates that a thorough evaluation of options for managing leak-prone pipes can help identify strategies that advance climate and cost-effectiveness goals. Specifically, this exercise has shown that:

- An unmanaged electrification, in which gas pipelines are replaced under current law and buildings steadily electrify, maximizes the risk of unrecovered costs and higher gas rates for ratepayers.
- All transition pathways bring risks and complex tradeoffs:
  - Alternatives that accelerate electrification instead of costly pipeline replacements reduce methane leaks and combustion emissions but will require electric system upgrades and significant upfront investments in buildings.
  - Less dense segments are likely to have more cost-effective and flexible options, but dense multifamily segments offer an opportunity for a coordinated transition in populations historically underserved by energy services.
  - Segments with high-risk leaks may need to be urgently transitioned, lacking time to deploy options that require significant customer preparation.
- There is a significant option space for interventions beyond the full and partial building electrification explored in this study. Such options include distributed non-pipeline fuels or novel thermal energy networks. These strategies play a role in managing intervention costs and electrical loads but can come with other tradeoffs.
- Integrated LEAP analysis of the gas transition at the hyper-local level, which requires focusing on matters concerning a small geographical area, can offer valuable insights for project identification and optioneering. However, participation by both gas and electric utilities will be needed to provide the data necessary to plan and act with confidence.

While the research demonstrates the technical and economic potential for non-pipeline gas alternatives to support an equitable energy transition, this exercise highlights several opportunities to improve and apply this practice of LEAP integrated assessment. These are included and explored in detail in the following subsections:

- Better data quality, uniformity, and availability.
- Guidance and support for cities/towns.
- Understanding of the equity implications of segment-level transitions.
- Implementation of pilot projects guided by LEAP.
- Applying LEAP to broader transitional questions.

The following sections detail these opportunities.

Better Data Quality, Uniformity, and Availability

Improved data formatting and availability will assist stakeholders and LEAP practitioners in understanding the current state of affairs and potential options. Access to quality data was a key challenge for this work, and the authors caution that applying a LEAP-integrated assessment using the data available for this work may not be sufficient for a robust analysis given some of these gaps.

This project integrated data sets from several utility filings, two municipalities, various cost tables, and several other sources. Many resources were not intended for this application and required substantial cleaning, formatting, and critical evaluation. Further, calculation errors, inconsistencies, and out-of-date data were regularly observed. The subsection below summarizes the major issues and gaps observed in this exercise.

Building Energy Use and Features

Actual data on buildings is fairly limited and of mediocre quality and utility. Physical data (size, vintage, and limited energy features) can be obtained from city assessors' tables; however, details on home energy features are limited and potentially outdated.

Some data can be inferred from national surveys, such as the Residential Energy Consumption Survey, that is used to inform building representation in tools such as ResStock.[108] Further utility energy consumption and Mass Save data can be used to understand consumption patterns better and calibrate baseline assumptions.

Energy consumption forecasts will be sensitive to both the model and assumptions used. ResStock was used here, but other tools and approaches are available. Such simulation would benefit from more detailed building assessments (e.g., Home Energy Score[109]) and data collected at early adopter or pilot sites.

Finally, it should be noted that building energy use is highly dependent on the actions and patterns of building occupants. Even with improved data on building appliances, the energy consumption of two similar buildings will vary by who uses the appliances. This can be supplemented by better calibration with historical data, but uncertainty increases when considering the energy use patterns of newer technologies like heat pumps. Pilot projects should prepare for this by improving data gathering after retrofits are complete to help shrink uncertainty in energy consumption forecasts.

Building Intervention Costs

The MassCEC's Whole Home Electrification Pilot Project's public cost tracking has been used by several researchers and programs to better understand the breakdown of costs for such projects.[110] Cost estimates are also buried in spreadsheet filings produced by the Mass Save program administrators.

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[108] "ResStock - NREL." https://resstock.nrel.gov/datasets.

[109] "About the Home Energy Score | Better Buildings Initiative." https://betterbuildingssolutioncenter.energy.gov/home-energy-score/home-energy-score-about-score.

[110] McBride, Jameson R. "Clean Heat at What Cost? Economic Optimization of Residential Space Heating in Massachusetts." Thesis, Massachusetts Institute of Technology, 2022. https://dspace.mit.edu/handle/1721.1/144617.

These resources were used to calibrate the cost model used for this study but are out-of-date and could be improved for estimating dimensions such as the cost of materials, labor, or other project needs.

Data collected from the 2022-2024 Mass Save program could be used to improve and maintain an understanding of building intervention costs. It could also be used to understand key drivers and how those drivers change over time.

Gas Leak and Pipeline Replacement Project Data

Planning around leak risk and pending pipeline replacement projects would benefit from a standardized data format for submitting data that is currently necessary under GSEP and the Annual Service Quality Report Program. Standardization should include harmonizing data fields, format, and level of detail. The project team's review of GSEP filings found that Liberty's GSEP submissions notably exceeded other utilities in communicating detailed project information in a standardized format. However, additional data and more standardization would assist in project evaluation.

Well-structured formatting will require separate tables for communicating projects, mains, services, and other asset changes. Geospatial data, including buildings and assets impacted, should also be included with linked identifiers. Reporting should include the feasibility of decommissioning rating that conveys the implications of decommissioning the pipe. It would also be beneficial to require all utilities to report using the same timeframes (currently, one of the utilities is only reporting 2022 and 2023-2024 instead of 2023-2026).

Finally, a work closeout report for conventional and potential non-pipeline projects provides the DPU and impacted parties with a clear understanding of project accomplishments and variances. This work-done report should detail, in a standard way using GSEP project identifiers, the GSEP work that was done in the previous plan cycle on at least the same reporting frequency as the GSEP plans reports. Reports should include costs incurred, segment lengths replaced, and work done.

Electric Distribution Data

Understanding electric distribution upgrade needs requires an understanding of the system's current condition. Such data is in the provenance of the electric utility and has only recently been opened to the public through hosting capacity and system planning maps.[111,112] These are used to meet multi-stakeholder needs in deploying distributed energy resources and new loads. Such maps tend to cut off at the feeder level and do not provide sufficient information to assess the current state of transformers and services. This project used Google StreetView to map out transformers and estimate their rating. Such an approach is neither scalable nor universally applicable. Improving these maps to inform building electrification is a logical next step for utilities. Unfortunately, such maps are not publicly maintained by Massachusetts' 40 municipal utilities.

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[111] "Eversource Hosting Capacity Map Massachusetts." https://www.eversource.com/content/residential/about/doing-business-with-us/interconnections/massachusetts/hosting-capacity-map.

[112] "National Grid Hosting Capacity Map Massachusetts." https://systemdataportal.nationalgrid.com/MA/.

Novel Data Sets: Thermal Energy Resources Assessment

Implementation of advanced electric heat strategies (GSHPs, thermal networks, and water-source heat pumps) would benefit from a greater awareness of where they would be most effective. New York City has conducted a resource assessment for ground source heat pumps.[113] In July 2023, DOER published its Technical Potential of Solar Study, which included rich data sources for evaluating cost and land use in the siting of solar projects.[114] A similar study could be undertaken for state-wide or local-level thermal energy resources.

Confidential and Sensitive Data

The issue of data confidentiality in public planning processes is constantly cited as a challenge by utilities and multiple stakeholders. For the utility, increasing data access creates risk with little apparent upside. This is the case with customer usage, system operations, or strategy data for privacy, security, and organizational management issues. Regulatory efforts to encourage better data utilization within and outside the utility should be sensitive to these issues as planning processes are developed.

Guidance to Support Cities and Towns to Prepare for Alternatives

The execution of this analysis at the street segment level emphasized that municipalities will play an important role in facilitating the energy transition. While it will take some time to define and institutionalize a greater degree of local energy asset planning, municipalities will have a role, and some steps can be taken now to prepare.

Align Municipal Duties and Offices with the Energy Transition

Improved local capabilities in planning and implementation will be essential. Municipal governments can provide data, local knowledge, and other resources to assist in segment-level transitions. They are also responsible for overseeing permitting and are involved in projects that may address multiple needs simultaneously (e.g., street repaving and gas pipeline replacement).

Facilitate Learning and Collaboration

Despite such barriers, more municipalities are becoming engaged in energy planning. The Multi-Town Gas Leaks Initiative, facilitated by the Metropolitan Area Planning Commission (MAPC), convenes several gas-served MAPC community energy planners, National Grid, and advocacy organizations to better understand and coordinate the many gas pipeline replacement projects in these towns and consider alternatives. Such networks can be effective at disseminating knowledge and best practices. Still, it is also becoming increasingly clear that municipalities will need more capacity to support planning and permitting highly integrated energy systems across the energy transition.

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[113] "Geothermal Screening Webtool Pre-Feasibility." New York City Mayor's Office of Sustainability, May 14, 2018. https://www1.nyc.gov/assets/ddc/geothermal/Geothermal%20Screening%20Webtool%20Pre-Feasibility.pdf.

[114] "Technical Potential of Solar Study." Massachusetts Department of Energy Resources, July 2023. https://www.mass.gov/info-details/technical-potential-of-solar-study.

Understanding the Equity Implications of Segment-Level Transitions

The equity implications of segment-level transitions should be considered with respect to two outcomes. The first has to do with the cost of pipeline replacement and the implications for future gas ratepayers. The second has to do with the transition of customers. Both of these concerns largely have to do with ensuring distributive justice.

First, the primary goal of a segment-level transition is to avoid additional investment in the system that will need to be recovered from future ratepayers or face long-term cost recovery challenges. The potential for avoided cost is uncertain but given projections for GSEP spending could be in the billions.[115] Under forecasted[116] declines in customers and gas consumption, the cost of pipeline reinvestment will be concentrated on a dwindling customer base. Without concerted policy action, this dwindling customer base could disproportionately include low-income populations with less agency to migrate away from the gas system; typically, they have less access to capital and resources that would help them to migrate.

Second, customers who transition off gas as a result of a segment decommissioning project face notable changes. For example, this analysis shows electrification, particularly without energy efficiency, significantly increases customer costs relative to their current bills.

It will therefore be crucial to coordinate strategic decommissioning plans with existing income-eligible programs through Mass Save that are aimed at incentivizing electrification and weatherization in low-income households.

Efforts to implement segment-level transitions should prioritize customer and occupant needs, especially in areas with vulnerable and historically burdened populations. Notably, segment-level transitions are an opportunity to ensure the delivery of high-quality and cost-effective retrofit practices. The community action agencies in the Low-Income Energy Affordability Network (LEAN) oversee the successful Mass Save income eligible coordinated energy efficiency programs, with historically lower program participation from low-income single-family and small multifamily households than in low-income households in large multifamily units. Here, the larger project size of multifamily improvements helps to facilitate coordination and third-party oversight that improves outcomes at lower costs.

The efficiency of such programs can serve as a model for coordinated segment-level transition. Further, coordinated segment-level transition strategies could be an opportunity for increasing participation in energy efficiency and electrification programs.

Near-term implementation of segment-level transitions in low-income communities could – if intentionally designed – benefit a subset of the population but does not directly address population-wide equity and energy justice issues beyond avoiding burdening future ratepayers. However, such deployments could be beneficial for understanding how to design coordinated electrification programs that could be deployed at a larger scale most effectively. Further, there are additional considerations for low-income segment transition projects that apply to the broader transition.

First, our analysis highlights the potential long-term burdensome costs of remaining on the gas system for non-migrating customers based on prior analysis and pending state policy. The potential impact on

[115] Seavey, Dorie. "GSEP at the Six-Year Mark: A Review of the Massachusetts Gas System Enhancement Program," 2021. https://static1.squarespace.com/static/612638ab5e31f66d7ae8f810/t/61561b8c4955b93159a753a3/1633033102069/GSEPatTheSix-YearMark.pdf.

[116] See for example 2025/2030 CECP, 2050 CECP, and Draft (Nov. 2024) DEP Clean Heat Standard targets.

customer bills can be mitigated by ensuring sufficient energy efficiency measures and using rate design to reduce the burden associated with heating electrification through heat-pump-friendly and low-income tariffs (see Unitil's recent rate case: DPU 23-80).

Second, electrification retrofits may require substantial building upgrades to alleviate other issues affecting the building (barrier mitigation), and the cost of such upgrades may reflect a significant portion of the building's asset value. This is complicated because many low-income housing are rentals, where necessary property improvements could drive unwanted displacement. While this is a challenging and complex problem, implementing segment-level transitions could help better understand and manage this problem. At the beginning of 2024 the DPU issued an order opening an investigation (DPU 24-15)[117] into issues surrounding energy affordability, particularly for those who are the most energy burned. The investigation could explore the issues surrounding gas-to-electric conversions, the discount rates associated with gas and electricity, and potential mechanisms for reducing the burden with electrification.

Workforce Considerations

Organized labor has historically worked closely with the LDCs to build and maintain the natural gas distribution system. The transition beyond gas will change the types of work available to organized labor and a careful workforce development strategy is important to ensure a just transition for the natural gas workforce and to ensure new work opportunities are made available to the skilled union workforce. In it Order in D.P.U. 20-80-B,[118] the DPU stressed the importance of the natural gas workforce and workforce development for ensuring the safe and reliable operation of the gas system. The DPU further noted the importance of ensuring support for the natural gas workforce as the transition continues. In the order, the DPU encouraged the LDCs to work with other stakeholders to establish a just transition framework for the workforce. While the order's comments on the workforce pertained to the overall aspects of the transition, the focus on "targeted electrification" by both the DPU and the LDCs merits focus on workforce transition issues related to segment decommissioning.

A formal workforce needs assessment was not conducted but could be implemented in future analyses. However, the results above show that pipeline decommissioning will increase labor needs for buildings improvements and impact labor needs for pipeline replacement projects, though ongoing operations of the gas system and new technologies such as ground-source heat pumps and thermal energy networks offer potential opportunities for those trained on pipeline construction and maintenance. The workforce implications of deploying segment transitioning ultimately depends on the pace of scaling of such strategies, which was outside the scope of this report.

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[117] MA Department of Public Utilities. "DPU Issues Notice of Investigation on Energy Affordability for Massachusetts Ratepayers," 1/4/24. mass.gov/news/dpu-issues-notice-of-investigation-on-energy-affordability-for-massachusetts-ratepayers.

[118] Van Nostrand, Jamie, Cecile Fraser, and Stacy Rubin. Order on Regulatory Principles and Framework, No. 20-80 (MA Department of Public Utilities December 8, 2023). https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/18297602

Advancing a Diverse Cohort of Segment-Level Pilots to Set the Stage for The Implementation of Non-Pipeline Gas Alternatives

Segment-level pilots will provide improved data for future analyses and decision-making, as well as surface unanticipated challenges and opportunities. Several networked geothermal pilots are moving forward in Massachusetts, but the State does not yet have plans to pilot other accelerated electrification scenarios modeled in this report. If funding is allocated, a State entity such as MassCEC – working closely with utilities – could immediately launch initial pilots of tactical thermal transitions. State-led and funded pilots should be able to move more quickly than utility-led, rate-based pilots that require DPU approval. However, to scale these efforts, DPU will need to approve a framework for accelerated electrification, so in parallel with any State-led efforts, utilities should propose pilots to the DPU, who should review these proposals expeditiously.

Pilots should focus on specific research questions that could include:

- What is the infrastructure need, cost, and implementation timeline for projects on street segments that do not have sufficient infrastructure capacity?
- How effective are different strategies (e.g., whole building electrification across the whole segment vs. use of non-pipeline fuels in challenging situations vs. geothermal) in addressing implementation timelines, electrical distribution system impacts, customer costs, and satisfaction?
- What are the potential benefits and challenges associated with segment coordination of building interventions among (possibly separate) utilities, contractors, and customers? Can separate corporate utilities collaborate effectively? Can economies of scale be gained by retrofitting multiple homes on a street segment at once?
- What is the impact of this transition on customer bills? Can alternative rate design structures lower customer burdens, help to optimize dual fuel arrangements, and incentivize smarter electrification?
- What are the specific needs of marginalized or burdened populations in the context of features of this population that may create barriers or opportunities: high proportion of rentals and difficulty in coordinating and incentivizing landlords (some of whom may reside out of state); possibility for questionable arrangements and poor building conditions in a single building complicating a multi-building project; language barriers; sensitivity to energy prices; vulnerability to extreme temperatures or outages in heating or cooling; and potential for benefits gained from improvements in building energy infrastructure?
- Can interim, hybrid, or bridging strategies be rapidly deployed to sites being targeted for the longer-term deployment of novel thermal energy networks?

Additional research questions and considerations should be elicited from the public via a request for information issued by the MassCEC to further inform the design of the pilot process. A preliminary approach follows here but could be augmented with findings from similar efforts in states such as California.[119]

Screen for Potential Project Sites Using LEAP in Partnership with Utility Companies

Pending pipeline replacement projects across the state can be screened for criteria that would yield sites suitable to answer the research questions of pilots. A preliminary screening process with data needs for each step is listed in Table 12.

Table 11. Framework for selecting and identifying potential pilot location sites.

Screening Step	Data Requirements
1. Identify potential pipe replacement projects and high-risk pipe segments.	High-quality leak-prone pipe prioritization and leak data.
2. Downselect for NPGA-feasible sites	LDC rating of pipe decommissioning opportunity based on removability of the segment.
3. Assess electric system capacity	Electric utility system capacity maps and data
4. Assess building stock	State and municipal parcel data, energy consumption, and building survey data.
5. Identify feasible interventions at each site	Thermal energy resources map; screen for tank-based fuel feasibility.
6. Assess social context	Prioritization of low-income projects. Community priorities.
7. Select a portfolio of project sites based on program goals	Stakeholder evaluation of the above data.

Screening should eliminate practically challenging sites (e.g., system critical segments) but generate a diverse portfolio of potential sites for stakeholder curation. This curation will downscale to a portfolio of pilot sites that can meet the project's research objectives. Figure 16 demonstrates how such projects could be evaluated in the context of each project's electric load impact and the presence of leak-prone pipes, barriers, and opportunities.

[119] Kahn, Matthew. "Strategic Pathways and Analytics for Tactical Decommissioning of Portions of Gas Infrastructure in Northern California," August 2023. https://gridworks.org/wp-content/uploads/2023/06/Evaluation-Framework-for-Strategic-Gas-Decommissioning-in-Northern-California-Interim-Report-for-CEC-PIR-20-009.pdf

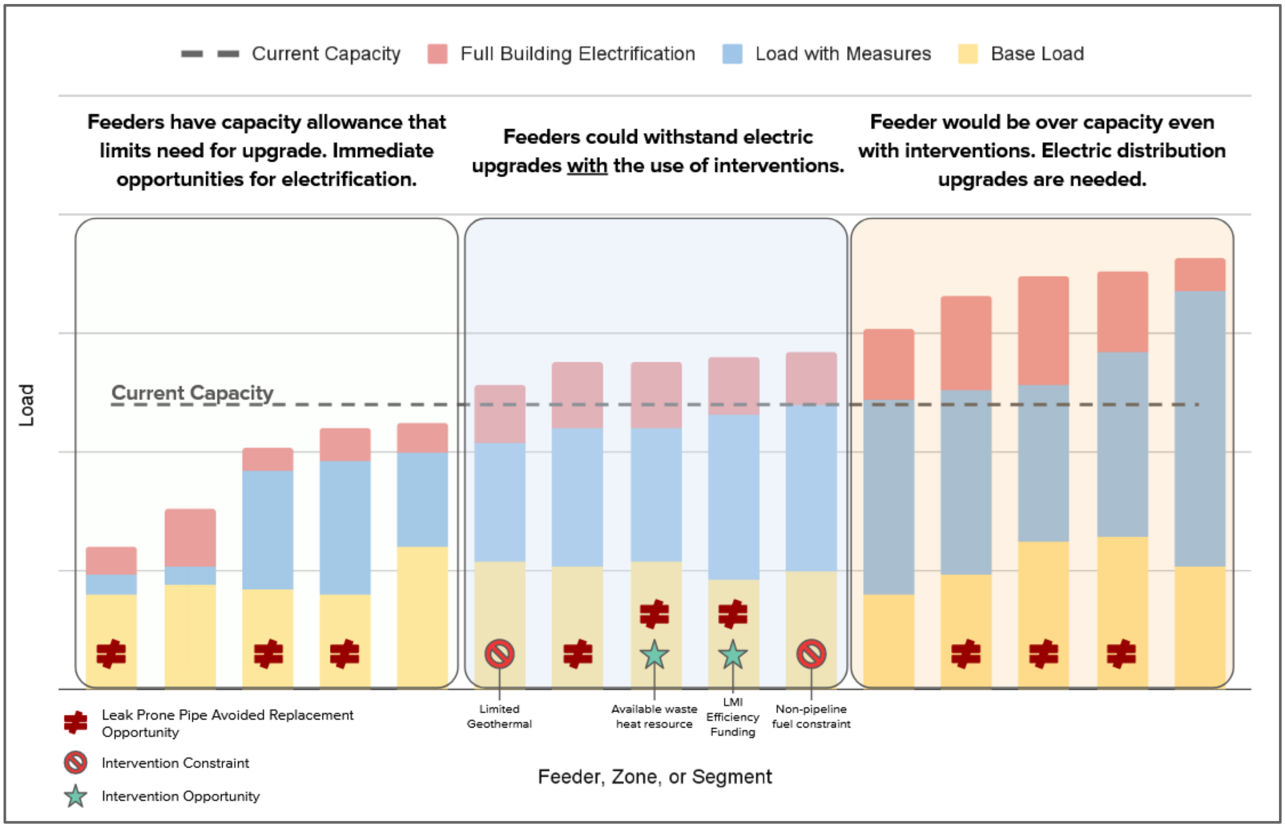

Figure 18. Illustrative site selection dashboard of street segments, zones, or feeders.

Optioneering of Site-Specific Non-Pipeline Gas Alternatives

Once sites are selected, a more detailed LEAP integrated options analysis can be performed on the site to evaluate alternative strategies. Such evaluation may include strategies not included in the analysis above, such as geothermal, thermal energy networks, or others. Including a status quo scenario may be useful for conveying the implications of doing nothing (e.g., increasing the cost of gas, climate risk). Such an exercise should be informed by actual data provided by the utilities (distribution network topology, customer energy demand) and building energy assessments.

The analysis serves as an optioneering tool and communication exercise among interested parties, including the utilities (often separate corporate entities), customers, contractors, and other cognate implementers.

Customer Education & Participation

Consumers need to understand why utilities may pursue non-pipeline gas alternatives and why such strategies seek to benefit consumers. Such communication and education needs to be both broad and targeted. Feedback from a utility with experience pursuing NPGAs has shown that customers need two-year lead times to exit the gas system to understand and prepare for the transition.

All gas customers need to understand why a managed and phased rightsizing of the gas system is necessary for climate, equity, and cost-saving reasons. From pilots to the adoption of an enduring NPGA framework, customers need to be informed that change will happen, that it will likely affect them, and that they will be protected and supported. This broad approach helps to set the stage for project-level engagement.

At project sites, a LEAP-integrated analysis can serve as a planning tool and be useful for educating and empowering customers and property owners through various scenarios.

Outreach efforts in California have faced some challenges.[120] As part of California's effort to pilot a segment-level transition project, contractors offered grants through an RFP totaling $120,000 for outreach to three pilot sites. The RFP sought community-based organizations to assist and engage with outreach to residents at project sites. Despite interviewing with several organizations, the project elicited no responses to the RFP despite promotional efforts. The California project subsequently pivoted to working more directly with the project municipality, hosting educational town halls on building electrification and conducting focus groups facilitated by a consultant to better understand customer needs during the transition.

Customer Energy and Retrofit Costs

The relative price of electricity to gas that consumers experience will influence the net impact consumers feel. Currently, the high cost of electricity relative to gas is a barrier to customer electrification. However, this fails to reflect long-term rate trends and the potential for novel rate design strategies that would favor electrification on an operational cost basis. LEAP can be used locally or statewide to assess the impacts of alternative rate design strategies on different classes of customers.

Address the Obligation to Serve for Pilots and Long-Term Implementation

The provision of "customer choice" is often invoked as a benefit of the gas system, but it is also one of its most significant risks. An increasing number of choices for provisioning heat will lead to a decline in gas usage. This will increase the cost per unit of energy delivered by the system, reducing its competitive advantage. This inspired the use of a scenario involving LPG; this scenario demonstrated the possibility of maintaining a certain level of customer preference for a combustible gas while at the same time avoiding a considerable socialized cost.

The decommissioning of a pipeline segment affects all the customers on that segment. Individuals cannot be a barrier to million-dollar decisions with impacts on ratepayers. Efforts to decommission pipe segments and shift customers off of gas in California and New York — primarily for load management — have faced challenges due to a small number of customer holdouts who are protected under each state's obligation to serve. The implementation of NPGAs, even through pilots,[121] would likely be challenged by current state law. It is unclear how much flexibility the DPU has in allowing such pilots. As noted above, communication will be invaluable but may not be sufficient.

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[120] Kahn, Matthew. "Strategic Pathways and Analytics for Tactical Decommissioning of Portions of Gas Infrastructure in Northern California," August 2023. https://gridworks.org/wp-content/uploads/2023/06/Evaluation-Framework-for-Strategic-Gas-Decommissioning-in-Northern-California-Interim-Report-for-CEC-PIR-20-009.pdf

[121] Eversource's Framingham geothermal pilot is optional and maintains the existing gas infrastructure and does not affect customer gas usage in cooking, hot water, or clothes dryers.

Explore Alternative Incentives for Gas Pipeline Replacement

Generally, utilities and their investors make money on capital investment. The continual growth of the system and the replacement of pipes is how LDCs make money. Operational expenses, such as repairs or leaks, do not typically qualify for such a return in Massachusetts. While removing the incentive for pipeline replacement is difficult, incentives could be expanded for other strategies by allowing pipeline repair or NPGAs to be capitalized on. Capitalization of home energy assets may be challenging. Alternatively, having a higher bar for pipeline replacement as a strategy for managing leak-prone pipes could effectively cap incentives. A LEAP-integrated analysis can be used to evaluate where such bars should be set.

Apply LEAP Integrated Analysis and Stakeholder Engagement to Broader Transitional Questions

LEAP is extendable and useful for guiding a managed phased transition. There are several avenues for extending this application.

First, the intervention option space can be expanded to include:

- Thermal energy networks.
- Ground source and water-source heat pumps.
- Phasing of strategies.
- Mixing of strategies across a segment or zone.

Second, the geography of analysis can be scaled to explore zonal transitions or even utility and statewide questions.

At the utility and state scale, this framework can be used to explore regulatory policy alternatives at the utility or state scale, including, but not limited to:

- Accelerated depreciation.
- Disallowed profit.
- Segmented tariffs.
- Securitization.

Finally, LEAP does not have to be limited to planners and practitioners of the energy transition. It can be a tool for educating a diverse population through interactive user interfaces, dynamic storytelling, and personalization of results (e.g., future bills and transition benefits realized).