Equitable Energy Transition Planning in Holyoke Massachusetts

A Technical Analysis for Strategic Gas Decommissioning and Grid Resiliency

Prepared for the University of Massachusetts Amherst Energy Transition Institute (ETI) by Groundwork Data

December 2023

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Acknowledgements

Many people contributed their time and attention to the development of this report. We offer special thanks to Prashant Shenoy, Lauren Mattison, and Erin Baker of The University of Massachusetts for their thoughtful comments and suggestions, as well as Noman Bashir for his contributions to the modeling. We are also grateful for conversations and feedback on our technical analysis from the following reviewers:

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

Groundwork Data

Groundwork Data offers advisory, research, and technology services to accelerate a clean, equitable, and resilient energy transition.

University Advisory Team

Prashant Shenoy
Lauren Mattison
Erin Baker

Funding

Funding for this project was provided through the U.S. Department of Energy (DE-EE0010143)

Executive Summary

Buildings account for 30% of the emissions in Massachusetts[1] and are the largest source of emissions in the United States, along with transportation.[2] Pipeline-delivered methane gas is the dominant heating source in Massachusetts, representing 51% of heating in the state.[3] The current gas network in Massachusetts and across many other US states is aging, a relic of the coal gas era, with thousands of miles of cast iron and unprotected steel pipes that are considered leak prone.[4] Even newer plastic pipes are subject to degradation and in need of replacement, an upgrade that averages $2.8 million per mile of pipeline replacement across investor-owned utilities in Massachusetts.[5,6,7]

In Massachusetts, pipeline replacements are incentivized by the Gas System Enhancement Program (GSEP) and encouraged by Pipeline and Hazardous Materials Safety Administration (PHMSA) despite local, state, and national efforts to reduce fossil fuel consumption as well as increased data on the health and safety issues of gas. Electrification is moving forward in earnest, with heat pump installs outpacing gas furnaces, yet there remain challenges to install, especially cost. In Massachusetts, it costs an average of $8.55 per square foot for a heat pump, and there are also reliability concerns as electric outages increase due to storms.[8]

This is a U.S. Department of Energy (DOE) funded effort focused on equitable and resilient decarbonization, through coordinated infrastructure planning. The purpose is to provide the University, the City of Holyoke, MA ("City"), and Holyoke Gas & Electric ("Utility") with a framework for targeting geographic areas to prioritize equitable energy transition and grid resiliency planning, as well as to evaluate the impact of alternative strategies for managing leak-prone gas pipe infrastructure. This report presents the findings of this effort.

The report has two sections. Section I evaluates alternatives for gas pipeline replacement. Aging gas infrastructure is a widespread issue and requires modernization to minimize methane leaks which have significant health, safety, and climate implications. Holyoke, Massachusetts is a case study of this issue: the city's 125 miles of remaining leak-prone gas pipe will require an

[1] Massachusetts Clean Energy Center. https://www.masscec.com/our-focus/high-performance-buildings
[2] U.S. Energy Information Administration. https://www.eia.gov/energyexplained/energy-and-the-environment/where-greenhouse-gases-come-from.php
[3] Mass.gov. https://www.mass.gov/info-details/how-massachusetts-households-heat-their-homes
[4] Commonwealth of Massachusetts Assessment of Pipeline Safety. 2019. https://www.mass.gov/doc/dynamic-risk-phase-i-report/download
[5] 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.
[6] 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 Department of Public Utilities of its Three Year Energy Efficiency Plan for 2022 through 2024., No. 21-128.
[7] Petition of Liberty Utilities (New England Natural Gas Company) Corp. for Approval of its 2022 Gas System Enhancement Plan, No. 21-GSEP-04.
[8] Carbon Switch. Heat Pump Costs. https://carbonswitch.com/heat-pump-costs/

investment of $250 million based on projects completed in the last two years. As such, continued gas pipe replacement will require increasing rates for Holyoke gas customers. As heating electrification becomes increasingly cost-competitive with gas in Holyoke and driven by increasing federal and local incentives, some consumers will reduce or eliminate their gas use. This will yield an even smaller customer base that is left to pay for the increasing costs of the gas system.

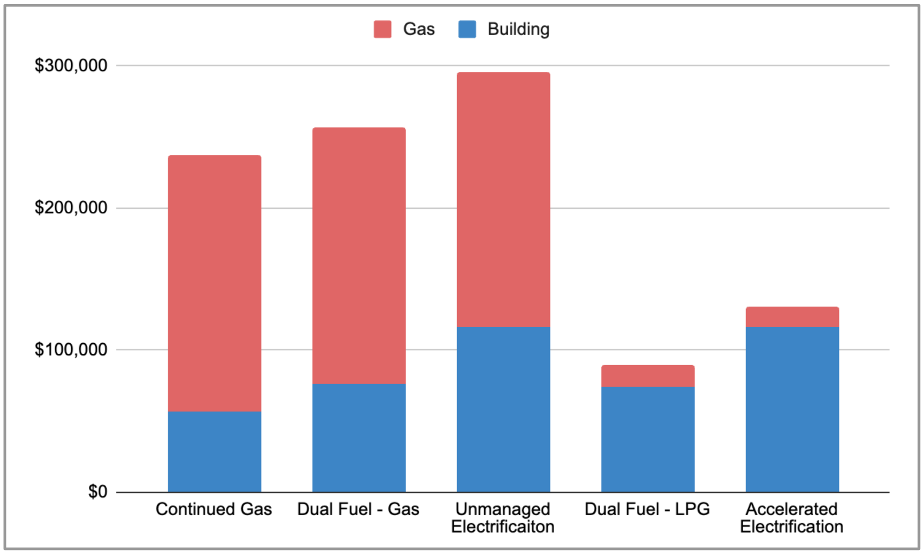
Holyoke has an opportunity to safely reduce spending on its gas system by implementing alternatives to leak-prone pipe replacement. This study evaluates five plausible scenarios that compare the baseline of continued pipeline gas to four alternative strategies. These scenarios range from continued pipeline gas use to accelerated electrification strategies.

Section I begins by presenting a structure for how the project team selected the two streets of focus in the model analysis using available data on the housing stock, street geometry, and other infrastructure. It then describes the methodology for evaluating these scenarios across two specific and representative (all single family and predominantly multi-family) street segments using several key indicators. These indicators include methane leaks, CO_2 emissions, building intervention and electric distribution costs, and ratepayer impacts.

This analysis finds avoided pipeline replacement:

- eliminates methane leaks from the distribution system and building;
- avoids six-figure or greater capital projects with comparable capital costs to building electrification on affected segments (Figure 1, Figure 2);
- prompts coordinated building decarbonization efforts that could accelerate emissions reductions.

Electrification is currently an advantageous strategy for customers in Holyoke because of the city's uniquely low electricity rates. Homes that electrify - partially or fully - are insulated from the increasing costs of pipeline gas. However, in some cases, limited use of non-pipeline backup fuels such as propane may help to address some implementation barriers.



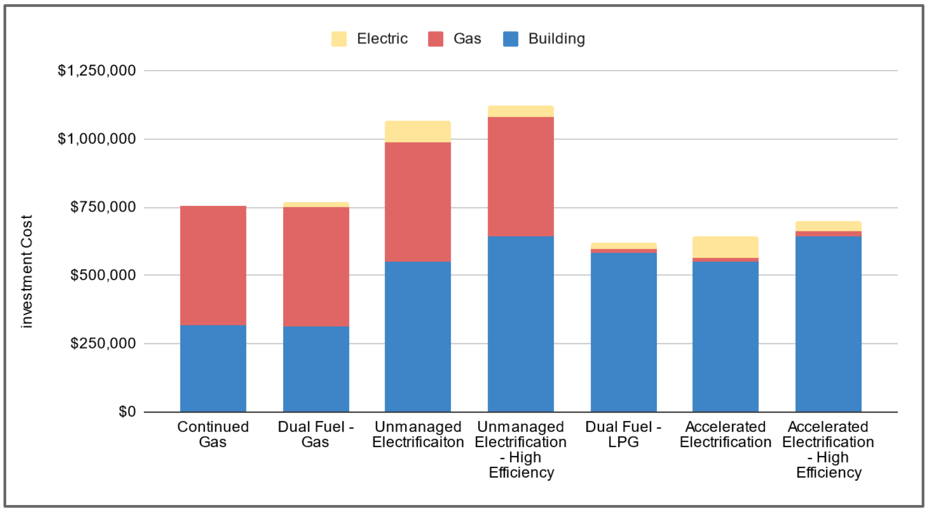


Figure 1, Figure 2. Summary of both regular and one-time costs by scenario for the single family (Figure 1) and multifamily (Figure 2) segment. Costs represent overall system costs. Energy distribution costs are assumed to be covered by utility rates, while building intervention costs are borne by the building owner but can be offset by rebates (e.g., HG&E) and tax credits (IRA). Building interventions costs include costs of retrofitting the buildings in each scenario (new appliances, increased insulation, etc). Gas and electric intervention costs include any upgrades to the system, such as repairing/replacing the gas pipes, pipeline decommissioning costs, and electric transformer upgrade costs.

Section II of this report demonstrates how different data sets can be integrated to better inform site selection of infrastructure projects. It demonstrates a framework for identifying both targeted geographic areas to prioritize and opportunities for coordinated efforts; identifying sites where the rehabilitation of aging sewer or water assets can be coordinated with undergrounding electric distribution lines and gas pipeline decommissioning can save on trenching and utility relocation costs. Such costs often make up a significant portion of any capital planning project. Prioritizing specific street segments for decommissioning allows for cities to plan more efficiently, increasing reliability and resiliency.

This section introduces the use of a Digital Network Asset Registry as a means of gathering localized data to better understand a city's infrastructure network. It then details how grouping street segments based on three categories - dead-end segments, planned permits, pavement, or water works projects, and residential area - can allow agencies to easily visualize and prioritize street segments best suited for decommissioning.

- Street segments that should be prioritized for decommissioning are ones with:
  - Dead-end segments: Segments that can effectively be decommissioned without impacting other gas system parts, increasing feasibility of removal and thus ideal streets for selection.
  - Planned permit, pavement, or water work projects: Coordinating multiple projects at once can save on costs by only needing to "dig once".
  - High amount of residential area: Single family and small multifamily homes are more cost-effective sites for gas decommissioning compared to dense, high-energy intensity commercial space.

The project team's analysis utilized two methods to group streets based on how many of the above criteria were met. Each group was given a color which was then visualized on a map, allowing a user to quickly identify which streets should be prioritized first. Method 1 looked only at terminal street segments and then grouped them based on the other criteria, and Method 2 looked at all street segments in Holyoke.

Based on Method 1 (Figure 3), green and blue streets should be prioritized for coordinated decommissioning as their removal would not impact other parts of the gas system and could cut costs by only having to "dig once". 19 streets in Holyoke meet this criteria. Magenta and yellow streets, which together account for 31 streets in Holyoke, should be prioritized second; yellow streets are more cost-effective given the high amount of residential area but low coordination potential, and magenta have coordination potential with one type of planned project. Red street segments are not ideal for decommissioning as they have no opportunity for coordination with other projects or residential parcels.

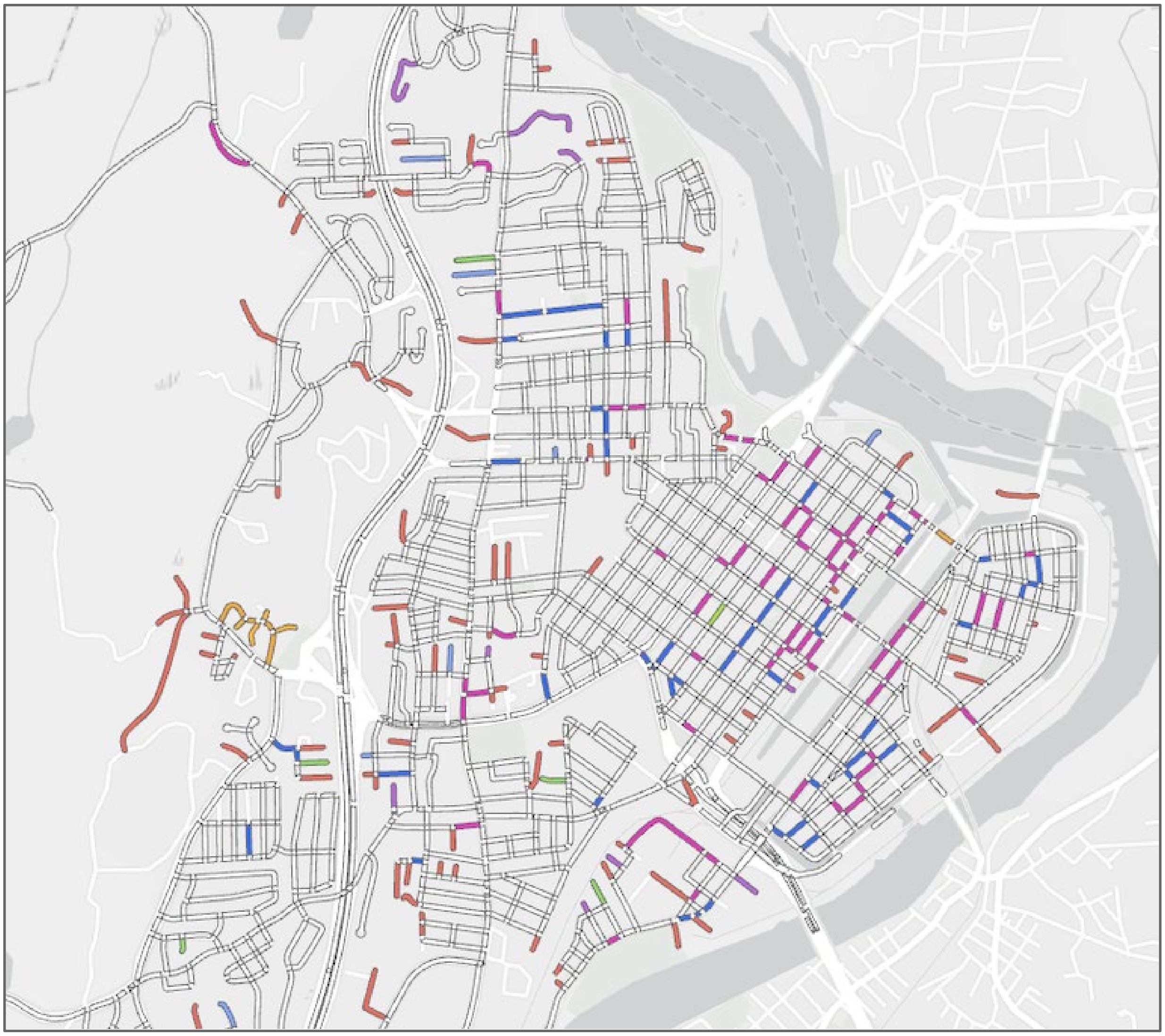


Figure 3. Terminal street segments in Holyoke highlighted by spatial multivariate cluster analysis, Method 1. Colors represent the level that a street should be prioritized for decommissioning: green streets have the highest priority, followed by blue, magenta, and yellow. Red streets should not be prioritized.

Method 2, which looks at all street segments in Holyoke, provided similar results. Green streets are ideal for decommissioning as they are terminal streets with high residential area and water works projects, but there is only one street meeting this standard in Holyoke. The 62 blue streets should be prioritized second as they have high potential for coordination across pavement and water works projects. Yellow streets - which are cost-effective for gas decommissioning compared to dense, high-energy intensity commercial space, but do not have coordination potential - and magenta streets - which have coordination with permit projects - should be prioritized after green and blue streets. There are 83 yellow and magenta streets together. As with Method 1, red street segments are not ideal for decommissioning as they are not terminal segments and have no opportunity for coordination with other projects or residential parcels.

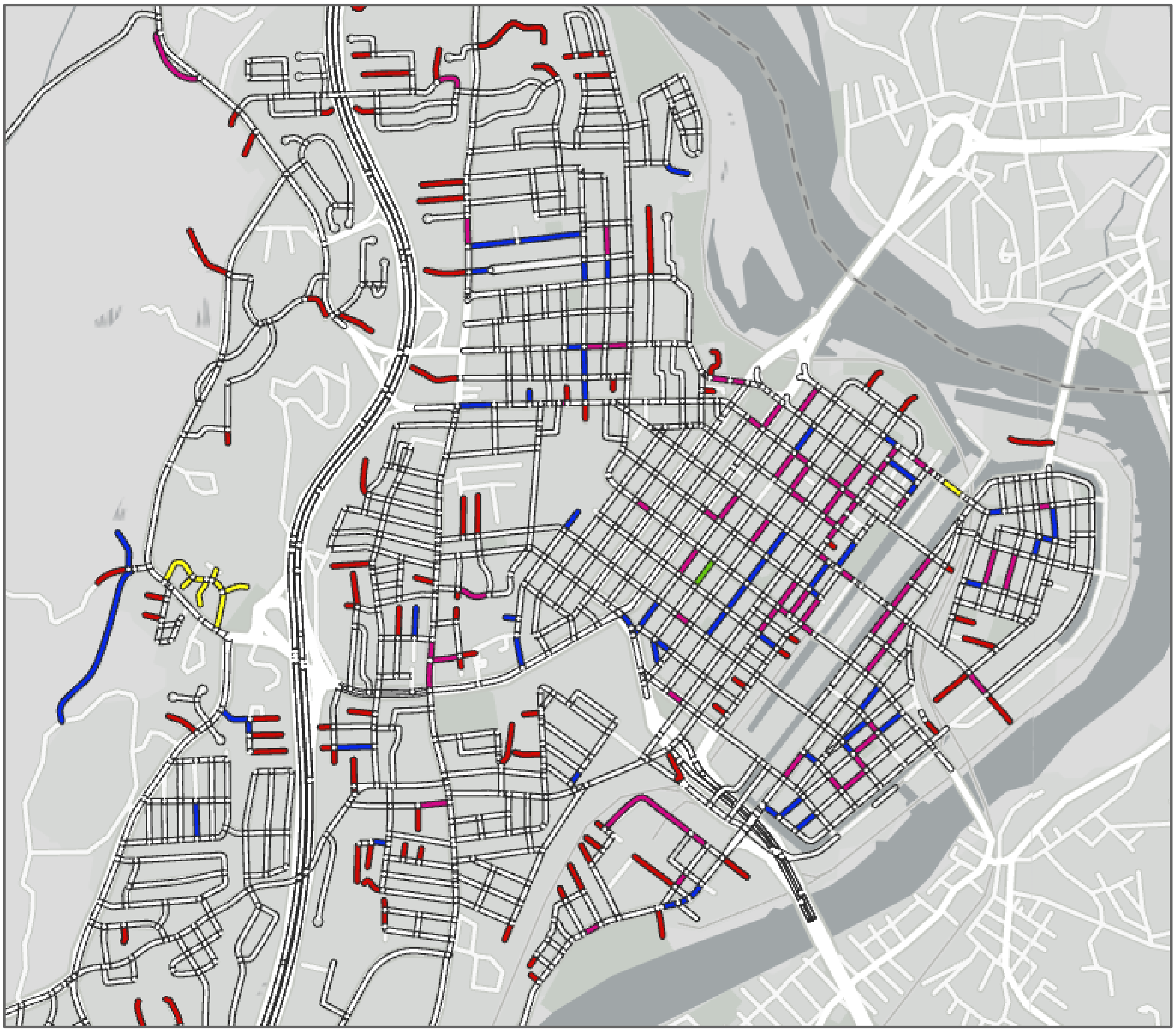


Figure 4. All street segments in Holyoke highlighted by spatial multivariate cluster analysis, Method 1. Colors represent the level that a street should be prioritized for decommissioning: green streets have the highest priority, followed by blue, magenta, and yellow. Red streets should not be prioritized.

After the user leverages the clustering analysis maps to identify streets to prioritize, they can then examine detailed data on their streets of interest using the Digital Network Asset Registry. The DNAR lists over 150 data fields for each street, granting the user access to information such as how many parcels on the street run on gas or the total area. These types of fields would allow the user to calculate more exact cost savings of decommissioning.

Master planning projects are often partitioned, involving acquiring, normalizing, and overlaying data from multiple sources and working with different stakeholders independently. Each of these tasks alone is cumbersome and creates multiple disjointed projects. Utilizing a DNAR connects different entities under a common planning framework to enable better cross-agency planning of infrastructure projects. The registry allows a city to conduct planning scenarios more efficiently, answer complex questions using unified data sets, and identify projects with the potential for coordination. Coordination of capital projects - allowing multiple capital projects to occur at once - shares and lowers overall costs.

Through coordination with state utilities and agencies, a Digital Network Asset Registry can be created to represent any city and a LEAP model can be utilized to better understand pathways off the gas system for that area. This would allow them to:

- **Pilot coordinated energy infrastructure projects.** Such projects could include the coordinated deployment of thermal networks, gas decommissioning, and segment electrification, undergrounding of electric and communication wires, or water and sewer maintenance.
- **Educate other customers and stakeholders**. Local energy planning can be used to inform and educate key constituencies to help accelerate the renewable energy transition.
- **Ensure equitable outcomes.** Integrating socio-demographic data with infrastructure data can help assess current disparities and improve planning or targeted actions to improve equitable outcomes.
- **Create shared, inclusive, and evidence-based action plans.** Using data acquired directly from stakeholders in the community of focus, they can be tailored to represent the specific needs of the community.

Enabling an Equitable Energy Transition In Holyoke

In Holyoke, 47% of residents are reliant on gas for heat.[9] As competition from non-fossil alternatives grows in the form of improved electric technologies and there are increased incentives to switch from gas to electric appliances, ratepayers with the ability to do so are reducing or eliminating their reliance on gas. While this can reduce the costs to these customers, it has an adverse effect on those left on the gas system due to the significant fixed costs of operating gas infrastructure. As a result, those who can least afford to leave the gas system are those left to pay the bill. This is a significant concern in gas consuming territories nationwide, but especially in Holyoke, where 26.5% of the population is low income.[10]

To-date, Holyoke has been viewed as a leading city in the energy transition, with abundant hydroelectricity, replacement of a coal plant with battery storage, and numerous pilots from its municipal utility HG&E. That said, Holyoke is still the 2nd poorest city in the state based on median household income, and as such is in need of outside support; this puts them at the mercy of state and federal spending, which is often inconsistent.[11] This study looks into ways that Holyoke can enable an equitable transition through a changing approach to their infrastructure planning: utilizing the avoided costs of long-term investments in the gas network to offset the short-term costs of building electrification, thus enabling more uniform access to clean, healthy energy.

The City of Holyoke was the first planned industrial city in the United States, built in a grid system around the South Hadley Falls in the Connecticut River in the mid-1800s.[12] The falls provided an opportunity for dam construction and drew interest from industrialists and investors, resulting in the rapid development of Holyoke's industry and building construction.

As the population of Holyoke expanded in response to the growing economy, its industry was able to diversify, a new stone dam replaced the initial wood construction, and many mixed-density buildings were built to house the growing number of residents. The city is largely defined by these buildings, 64% of which were built before 1959.[13]

Servicing the city with power was Holyoke's independent electric utility company, supported by the availability of water power from the falls. While wires provide power overhead, the city's streets were crisscrossed with miles of cast iron gas distribution pipe during its early boom and welded steel when the city expanded outward following World War II. Due to their age and material, these pipes have a high propensity for leaks that have serious implications for public

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[9] United States Census Bureau. https://www.census.gov/quickfacts/holyokecitymassachusetts
[10] Ibid
[11] Ibid
[12] History of Holyoke. City of Holyoke https://www.holyoke.org/history-of-holyoke/.
[13] Metropolitan Area Planning Council. Basic Housing Needs Assessment for Holyoke, MA. www.housing.ma/holyoke/report.

health, safety, and the climate.[14] The cost of modernizing these pipes on residential streets ranges from $20,000 - $30,000 per household based on the analysis of this report below.

Today the City of Holyoke is home to 37,700 residents and has a median home value of $209,900. Many of Holyoke's census tracts are designated by the Commonwealth of Massachusetts as environmental justice communities, as they meet at least one of the following criteria outlined in Table 1.

Table 1. Environmental Justice Criteria outlined by MA and the metrics that qualify Holyoke to meet that criteria.

Environmental Justice Criteria	**Holyoke Metric**
The annual median household income is 65 percent or less of the statewide annual median household income.	The median household income in Holyoke is $45,045, over 65% less than the national median of $70,784. 26.5% of residents fall below the poverty line.
Minorities make up 40 percent or more of the population.	Hispanic and Latino populations account for 53.5% of residents.
25 percent or more of households identify as speaking English less than "very well".[15]	On average, 20% of residents speak English less than very well, and 45% of people speak a language other than English at home.[16]

Bringing Holyoke forward to align with ambitious climate goals and enhance resilience for its residents will require substantial investment to modernize the City. Such investment will result in many benefits for Holyoke residents but will require effective coordination to minimize costs and overcome barriers to implementation.

Holyoke's unique energy context is very advantageous for its residents. Despite having the lowest incomes in the state, energy burdens are relatively low because the city's municipal utility is able to provide its residents with low-cost electricity and gas. Springfield, for example, has similar socioeconomic demographics, but its households have higher energy costs and thus higher energy burdens - the fraction of income spent on energy.[17]

Despite this, Holyoke is exposed to higher future energy costs, given the need to modernize its gas distribution system. Further, as infrastructure projects become more expensive, the city's budget will become increasingly stretched as it seeks to execute on such projects.

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[14] PHMSA FY 2022 Natural Gas Distribution Infrastructure Safety and Modernization Grants. https://www.phmsa.dot.gov/about-phmsa/working-phmsa/natural-gas-distribution-infrastructure-safety-and-modernization-grants

[15] Environmental Justice Populations in Massachusetts | Mass.gov. https://www.mass.gov/info-details/environmental-justice-populations-in-massachusetts.

[16] US Census Bureau. "Language Spoken at Home." Census.gov. Accessed August 29, 2023. https://www.census.gov/programs-surveys/acs/.

[17] Energy.gov. "LEAD Tool." https://www.energy.gov/scep/slsc/lead-tool.

A recent report by the Urban Sustainability Directors Network (USDN) titled *Equity and Buildings: A Practical Framework for Local Government Decision Makers*[18] identified six critical issues related to the building energy transition:

1. Housing Affordability
2. Gentrification and Displacement
3. Health
4. Economic Inclusion
5. Cultural Recognition, Identity, and Tradition
6. Resilience to Disaster and Disruption

This report directly addresses housing and energy affordability, health and safety concerns, and economic inclusion. Section I evaluates the cost-effectiveness of replacing leak-prone gas infrastructure by comparing continued gas pipeline use to four alternatives. It discusses health and safety concerns[19,20] by using fuel consumption and methane leaks as key indicators in evaluating scenarios. Finally, it analyzes coordinated segment-level building retrofit strategies that will likely capture populations that have been historically underrepresented in energy efficiency programs.[21]

Section II considers affordability by demonstrating a framework for collecting localized data to support coordinating multiple building and infrastructure projects. It evaluates how geospatial screening can be used to coordinate projects in targeted communities to improve inclusion.

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[18] Urban Sustainability Directors Network. “Equity and Buildings: A Practical Framework for Local Government Decisionmakers.” https://www.usdn.org/projects/equity-in-buildings-framework.html#/.

[19] Lebel, Eric D.,et al. “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.

[20] 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.

[21] Os, H, : Leupold, and Ellis. “Residential Nonparticipant Customer Profile Study MA19X06-B-RESNONPART,” 2020.

Section I: Evaluation of Four Alternative Strategies for Building Decarbonization at the Gas Segment Level

This section covers the analytical framework used to evaluate four potential pathways for the gas-to-electric transition across two street segment typologies. It first provides context on the gas transition in Holyoke, establishing the need for a managed, phased transition from gas. Such a transition should seek to avoid reinvestment in the gas system predominantly by avoiding the replacement of leak-prone pipes. This section then describes the methodology, assumptions, and outputs used to evaluate pipe replacement alternatives for two illustrative street segments. Finally, the section will review the results of this evaluation.

Background: Heating and Gas Transition Context

The electrification of heat and other end-uses is a critical step in the decarbonization of the building sector in pursuit of ambitious emissions reduction targets.[22] Statewide studies in Massachusetts have identified the need to install nearly 100,000 heat pumps a year over the next decade to achieve the Commonwealth's climate goals,[23,24] a rate that would imply 600 installations per year in Holyoke.

The 2022 Inflation Reduction Act includes various incentives to support heat electrification, notably enhanced subsidies for low to moderate-income households. Additionally, Holyoke Gas & Electric (HG&E) offers incentives for building electrification, including rebates for the installation of heat pumps and whole home electrification.[25]

Heat Pumps are Relatively Cost Competitive in Holyoke

Holyoke has unique contextual features that favor electrification, most notably its production and use of hydroelectricity as a source of low-cost, low-carbon electricity for consumers.[26] This

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[22] "Net-Zero America." https://netzeroamerica.princeton.edu/.

[23] 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.

[24] Executive Office of Energy and Environmental Affairs. "Appendices to the Massachusetts Clean Energy and Climate Plan for 2025 and 2030," 2022., 173. https://www.mass.gov/doc/appendices-to-the-clean-energy-and-climate-plan-for-2025-and-2030/download

[25] Holyoke Gas and Electric. "Air Source Heat Pump and Mini-Split Incentives." Accessed July 12, 2023. https://www.hged.comresidential/ee-home/Rebates/heating-cooling-rebates/heat-pump-rebates/default.aspx.

[26] "Annual Return 2022." City of Holyoke Gas Electric Department, 2022. https://www.mass.gov/files/documents/2023/06/15/City%20of%20Holyoke%20Gas%20%20Electric%20Department%20DPU%20Report%202022.pdf.

contrasts with the regional grid, which largely depends on fossil gas and oil to meet electricity demands. However, a considerable amount of low-carbon electricity is provided by nuclear, Canadian hydro, and a growing amount of renewables in Holyoke.[27]

In contrast to the electric service, gas service in Holyoke is relatively expensive compared to that delivered by other utilities in the state.[28] An older distribution system needing maintenance coupled with a constrained supply that needs to be managed with expensive peaking infrastructure puts upward pressure on gas rates.

This dichotomy results in a unique dynamic in which Holyoke electric rates are only 2x that of gas rates per unit of energy delivered. This contrasts with relative prices outside of Holyoke, where electricity prices are three to four times greater than gas.[29]

This difference means that **heat pumps are cost-competitive with gas on an operational basis in Holyoke,** in contrast to other areas. For heating electrification to be competitive with gas, efficiency gains must exceed the cost premium of electricity relative to gas. For example, a typical air-source heat pump has a nameplate coefficient of performance of 3.2 (heat produced divided by electricity consumed) which is nearly 4 times more efficient than a typical gas furnace efficiency of 0.85 (heat produced divided by gas consumed). In Holyoke, this gain is sufficient for electric technology to be cost-competitive with gas based on current rates, where electricity only costs 2.5 times as much as gas.[30] In contrast, in investor-owned utility territories where electricity costs are much higher, such gains are insufficient to compete with gas, given the higher relative electricity cost.

In addition to such benefits and increasing subsidies for electrification, consumer interest is growing, given the potential value creation offered by electric technologies.[31] Heat pumps also provide cooling in the summer and, in tandem with energy efficiency upgrades, can improve home thermal comfort. Induction stoves and electric cooking are becoming more popular due to increasing concerns regarding indoor air pollution.

This poses a significant challenge for Holyoke's gas system, exacerbated by age. As electrification reduces gas demand and customers, **the increasing costs of maintaining the gas system will need to be borne by a declining customer base.**

[27] "Regional Electricity Outlook." Accessed July 9, 2022. https://www.iso-ne.com/about/regional-electricity-outlook/.

[28] "Annual Return 2022." City of Holyoke Gas Electric Department, 2022. https://www.mass.gov/files/documents/2023/06/15/City%20of%20Holyoke%20Gas%20%20Electric%20Department%20DPU%20Report%202022.pdf.

[29] Eversource Gas and Electric Rates for Massachusetts https://www.eversource.com/content/residential/account-billing/manage-bill/about-your-bill/rates-tariffs

[30] Holyoke Gas and Electric. "Residential Rates." Accessed August 29, 2023. https://www.hged.comresidential/res-rates/default.aspx.

[31] Shemkus, Sarah. "Mass. Heat Pump Installer Network Gains Momentum." Energy News Network, March 3, 2023. http://energynews.us/2023/03/03/massachusetts-heat-pump-installer-network-has-momentum-in-second-year/.

Holyoke's Aging Gas System Needs Expensive Modernization to Continue to Operate

Holyoke's gas distribution system is in many places as old as the neighborhoods that it serves. This system consists largely of cast iron pipes in parts of the city that grew at the turn of the 20th century. Steel pipes carry gas to homes for the city's more suburban post-war neighborhoods. Compared to modern plastic pipes, these legacy pipes are prone to leak due to their material and age through fractures and degraded joints.

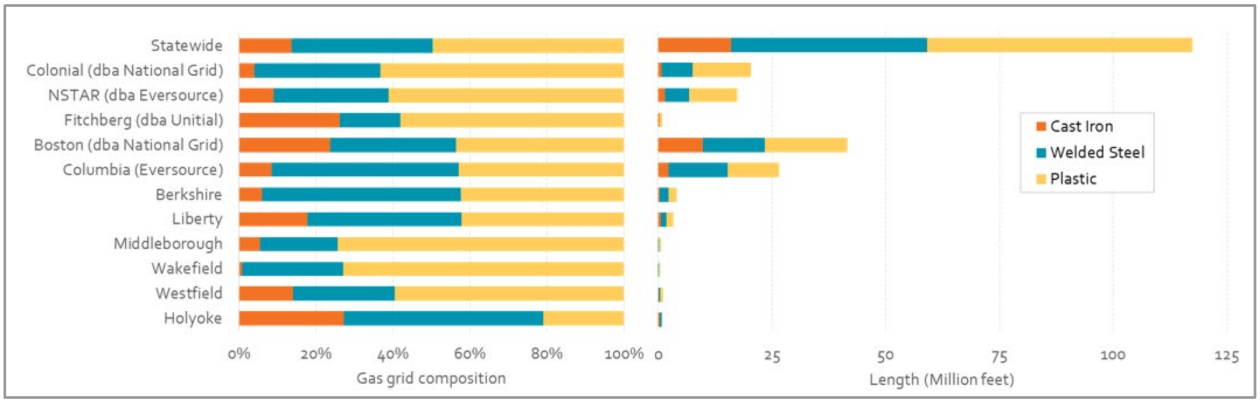

Figure 5. Inventories of cast iron pipes for Massachusetts utilities. Source: 2019 Utility Annual Returns to the Department of Public Utilities.[32]

Of all the utilities in the state, HG&E has the highest proportion of cast iron and welded steel pipes (Figure 5), largely because HG&E covers a century-old urban environment while other utility territories include a higher proportion of suburban areas developed more recently with more modern gas infrastructure. This distinction creates a specific challenge for HG&E and the City.

Assuming continued gas system use, such leak-prone infrastructure must be modernized to address health safety and climate concerns. While there are a variety of options for addressing leak-prone pipe, costly pipeline replacement projects tend to be the most common method. Indeed, HG&E has begun replacing some of its old leak-prone pipes and recently received a $10 million grant from the federal Pipeline Safety and Hazardous Materials Agency (PHSMA) to accelerate this process. Similarly, investor-owned utilities in Massachusetts are currently required to develop and execute annual Gas Safety Enhancement Plans (GSEP) to modernize - largely through pipeline replacement - their leak-prone infrastructure.[33] Costs for this currently

[32] Financial and Operating Returns to the DPU (2019). https://www.mass.gov/financial-and-operating-annual-returns-to-the-dpu

[33] "GSEPs Pursuant to 2014 Gas Leaks Act | Mass.Gov." Accessed June 19, 2023. https://www.mass.gov/info-details/gseps-pursuant-to-2014-gas-leaks-act.

average $2.8 million per mile of pipeline replacement across investor-owned utilities in Massachusetts.[34,35,36]

Projects in Holyoke have been on the low end of this spectrum; in 2022, HG&E replaced just over two miles of pipe at roughly $2 million per mile. Still, taking this value and applying it to Holyoke's 125 miles of leak-prone pipe would imply an investment need of $250 million. For reference,[37] 2022 gas revenue was $28 million, and the value of HG&E's total plant (or combined assets of land, equipment, gas mains, meters, services, etc.) was $61 million. While HG&E is not subject to the GSEP program, it should be noted that the investor-owned utilities anticipate modernizing their pipeline systems by the mid-2030s.

While the cost of the GSEP is a significant concern,[38] such costs in the investor-owned utility territories will be distributed over a large customer base. With Holyoke's high proportion of leak-prone pipe, the costs will be more acutely felt by ratepayers. Federal funding can lessen this problem but will not solve it.

Replacing pipes will result in rapidly increasing rates. Given increasing consumer interest and favorable economics for building electrification, it is likely that some consumers will reduce or eliminate their gas use in the face of increasing rates. While this benefits them, it leaves an even **smaller customer base to pay for the increasing costs of the gas system**. These are more likely to include households with less agency to electrify, such as low-income households and renters. Ultimately, the gas system becomes financially unsustainable. Such an outcome is undesirable and inequitable.

The Benefits of a Managed Phased Transition

Avoiding high and inequitable costs of upgrading the gas system will require a managed and phased transition that includes a rightsizing of the gas system to limit costs and align with ambitious climate goals. Such management involves:

Avoiding new investment that expands the gas system.

Due to capacity limitations on the Northampton Tennessee Gas Pipeline Lateral that serves HG&E and several other Pioneer Valley communities, HG&E has instituted a moratorium on new gas connections and has taken steps to increase capacity via the demand side (efficiency

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[34] 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.

[35] 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 Department of Public Utilities of its Three Year Energy Efficiency Plan for 2022 through 2024., No. 21-128.

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

[37] 2022 HG&E Annual Return https://www.mass.gov/files/documents/2023/06/15/City%20of%20Holyoke%20Gas%20%20Electric%20Department%20DPU%20Report%202022.pdf

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

and fuel switching incentives) and supply side (liquified natural gas storage) interventions.[39] The moratorium and demand-side interventions avoid new investment in the gas system. However, HG&E has recently proposed expanding its ability to provide gas on peak days by expanding the capacity of its liquefied natural gas facility. [40]

Minimizing reinvestment in the gas system, such as replacing leak-prone pipes.

Massachusetts, especially in Holyoke, has a high inventory of leak-prone pipes due to its aging gas pipe infrastructure. These leaks can be left alone with risk, managed through different intervention strategies such as pipe repair or replacement, or eliminated through decommissioning parts of the gas system. Despite the implementation of policies that accelerated leak detection, advanced pipe repair, and pipeline replacement in 2014, no measurable change in Boston-area methane emissions was observed between 2012 and 2020. This calls into question the efficacy of pipe replacement as a strategy for mitigating leaks in the long run.

Long-term planning and implementation of zonal transition strategies.

Long-term neighborhood or zonal-scale planning of alternative energy strategies, similar to that currently being implemented in some European cities, will be necessary for fully rightsizing the gas system for net zero.[41] Such strategies can include whole building electrification with air-source heat pumps, deployment of ambient temperature heating and cooling networks (often referred to as 5th-generation district energy or thermal energy networks), heating hybridization using non-pipeline fuels, or a mix of these strategies.

Such plans are likely to evolve over decades. In the meantime, there may be a significant opportunity to reduce reinvestment in the gas system, particularly by implementing alternatives to replacing leak-prone pipes. This study focuses on this issue by demonstrating **how the City and HG&E could evaluate alternatives to leak-prone pipe replacement.**

[39] "Services | Natural Gas | Natural Gas Moratorium | Natural Gas Moratorium | Holyoke Gas and Electric, Holyoke, Massachusetts." Accessed July 20, 2023. https://www.hged.com/services/gas-service/ng-moratorium/default.aspx.

[40] Holyoke Gas and Electric. "LNG Infrastructure & Resiliency Project." https://www.hged.comnews/LNG/default.aspx.

[41] "Zurich Turns off Gas to Fight Climate Change and Russia : NPR." Accessed June 16, 2022. https://www.npr.org/transcripts/1092429073.

Approach & Methods for Evaluating Opportunities for Avoided Reinvestment

Identifying opportunities for avoided reinvestment requires a multi-step site selection and alternatives evaluation process, detailed in this section.

Site Selection: Critical Evaluation of Potential Sites Based on Segment Characteristics

A central goal of this work is to develop a framework for the selection of candidate sites for avoiding reinvestment in the gas pipeline system via segment decommissioning rather than pipeline replacement. The steps below outline both the approach used in this project and further considerations for an ideal implementation approach. The former approach was necessary for this work due to data availability limitations. However, working within such limitations provided insights into how certain datasets could be integrated and how project evaluators can work within common data limitations.

Step 1: Identify Leak-prone Pipe

Definition: The presence of leak-prone pipes, as well as the number and types of leaks in a segment, should inform where a project should be prioritized as these can pose health, safety, and climate risks. Site-specific leak identification can also be used as a deterministic factor in planning.

Approach: To identify appropriate sites, various infrastructure datasets were integrated into a coordinated framework described in Section II. Street segments were then screened by the typical age of their buildings using city tax assessor data to identify segments with leak-prone pipes. Streets with predominantly pre-1980 buildings (used here as the cut-off for modern gas pipe) were retained since streets with older homes are more likely to be served by the original pipe, likely installed around the time of construction of those homes.

Further Considerations: Ideally, utility asset inventories, maintenance logs, and reported leaks could be used for such screening but were unavailable to the project team. Such maps could then be used to prioritize interventions based on pipe risk.

Step 2: Assess Removal Feasibility

Definition: Sites with high feasibility of removal typically include terminal or “dead-end” street segments. These segments can effectively be decommissioned without impacting other gas system parts. Conceivably, many pipe segments with two connections could also be decommissioned.

Approach: To identify sites with high feasibility of removal, the project team screened for terminal or “dead-end” street segments.

Further Considerations: Identifying such segments could require a more sophisticated assessment of the impact of removal on the physical operation of the gas system. This is often referred to as a hydraulic feasibility assessment and was outside the capabilities of this project, given the unavailability of utility data to the team.

Step 3: Candidate Site Selection

Definition: This work prioritized site selection for small residential and multifamily buildings with only 2-3 units. These sites are likely to be the more cost-effective sites for gas decommissioning compared to dense, high-energy intensity commercial space. Such site selection can be further informed by sociodemographic data to prioritize historically neglected communities.

Approach: The project team looked at the identified dead-end segments in older neighborhoods and screened them for the desired compositions of single family and small multifamily homes using parcel data.

Further Considerations: It would be ideal for cities to maintain a tool that can easily screen street segments for desired building types (e.g., residential vs. commercial) as well as intervention criteria (e.g., geothermal or backup fuels).

Step 4: Coordination with Other Projects

Definition: Coordinating multiple projects at once can save on costs by only needing to “dig once”.

Approach: The project team assessed if there was an opportunity for coordination with other projects using both planned and recent water projects. The two street segments identified for this part of the study largely represented the overall city in terms of its residential building stock and population. The application of this strategy is further discussed in Section II.

Further Considerations: Ideally, utilities and towns would maintain integrated datasets that identify opportunities for coordinated digging interventions when applicable.

Summary of Selected Sites

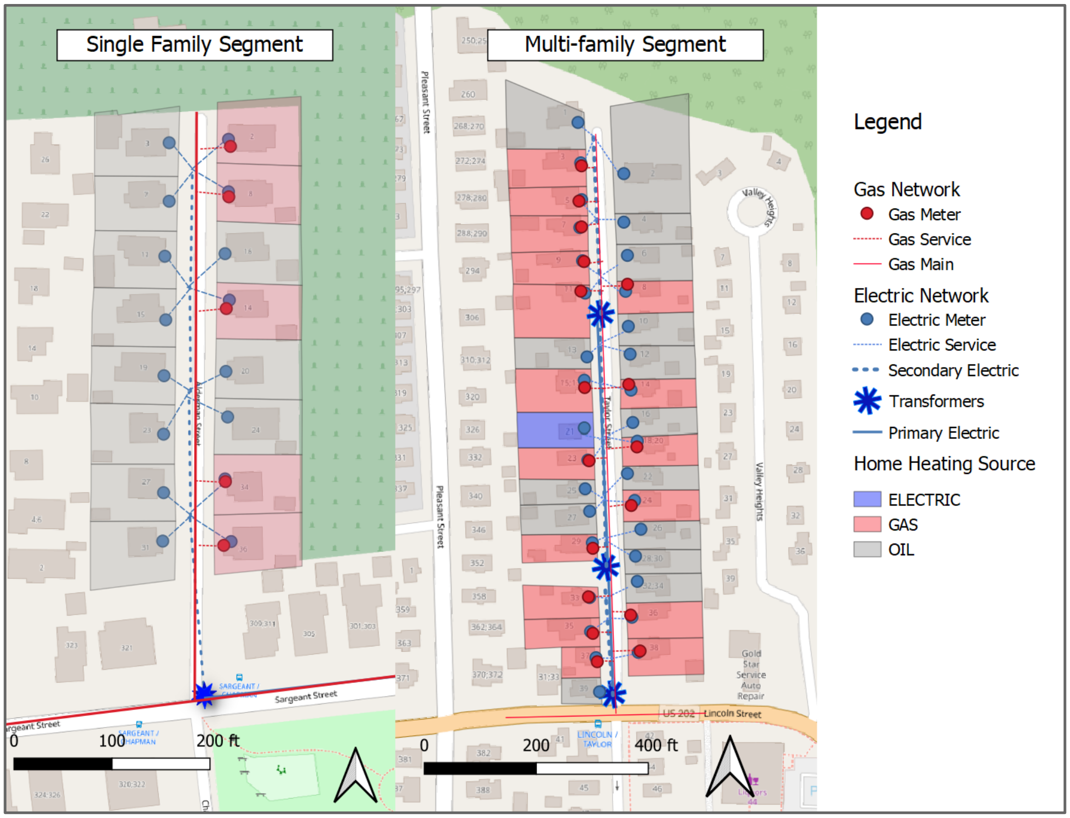

Figure 6. Single Family and Multifamily Street Segments

Our single family street segment is located in a low-income, environmental justice community. The neighborhood has a predominantly minority population, with Hispanic or Latino individuals accounting for 56% of residents. The census tract is considered disadvantaged and underserved, as it is in the 95th percentile of communities with households classified as impoverished and the 94th percentile of communities with linguistic isolation.[42] The street has 16 homes, built between 1900 and 1935, with an average square footage of 1,445. Eleven homes are fueled by oil, and the remaining five by gas. The primary heat type is steam. The street utilizes a secondary electric line fed by one 75 kVA transformer.[43]

Our multifamily neighborhood is not in an environmental justice census tract but is immediately adjacent to one. The population is 84% white, with Hispanic or Latino individuals only constituting 10% of residents. The community is in the 44th percentile of communities with households with linguistic isolation and in only the 22nd percentile of households classified as low-income. With that said, the street of focus extends into a community that is classified as disadvantaged, indicative of the overall demographics of Holyoke, MA.[44] There are 33 parcels on our multifamily street, 15 of which were built between 1820-1890, and the remaining 18

[42] U.S. Census Bureau https://www.census.gov/quickfacts/fact/table/holyokecitymassachusetts/PST045222
[43] MassGIS Data: Property Tax Parcels: .mass.gov/info-details/massgis-data-property-tax-parcels#downloads-
[44] U.S. Census Bureau https://www.census.gov/quickfacts/fact/table/holyokecitymassachusetts/PST045222

constructed between 1900-1984. There are 58 housing units, implying a high number of renters. 15 are fueled by oil, 17 by gas, and one by electricity, and the heat type varies, including steam, forced hot water, forced air, and electricity. There are three 37.5 kVA transformers on the street, fed by both a primary and secondary line.[45]

A visual inspection of the multifamily neighborhood observed street work consistent with a prior gas pipeline replacement. Given that this analysis demonstrates how sites could be identified and evaluated, the project team decided to analyze this site even though the gas segment was likely replaced. The fact that it was done demonstrates that our screening approach has yielded sites that are likely intervention points going forward.

[45] MassGIS Data: Property Tax Parcels: .mass.gov/info-details/massgis-data-property-tax-parcels#downloads-

Evaluating Alternatives on Identified Street Segments

Modeling Methodology

A transition from residential gas consumption requires coordination across disparate stakeholders and an understanding of how changes at the building scale can influence the operation of an energy supply network. The impacts of intervention strategies can be understood by using a hyper-local model representation of the energy system, or local energy asset planning (LEAP).[46]

LEAP integrates multiple data sets into one comprehensive view of energy consumption, emissions, costs, and asset values across utility and building assets. These assets include wires, pipes, meters, regulators, appliances, and building shells. The concept of LEAP is further elaborated in a whitepaper defining the concept[47] and is summarized in Figure 7. It can be used as a scenario planning and optioning tool to identify strategies and outcomes for various energy transition goals.

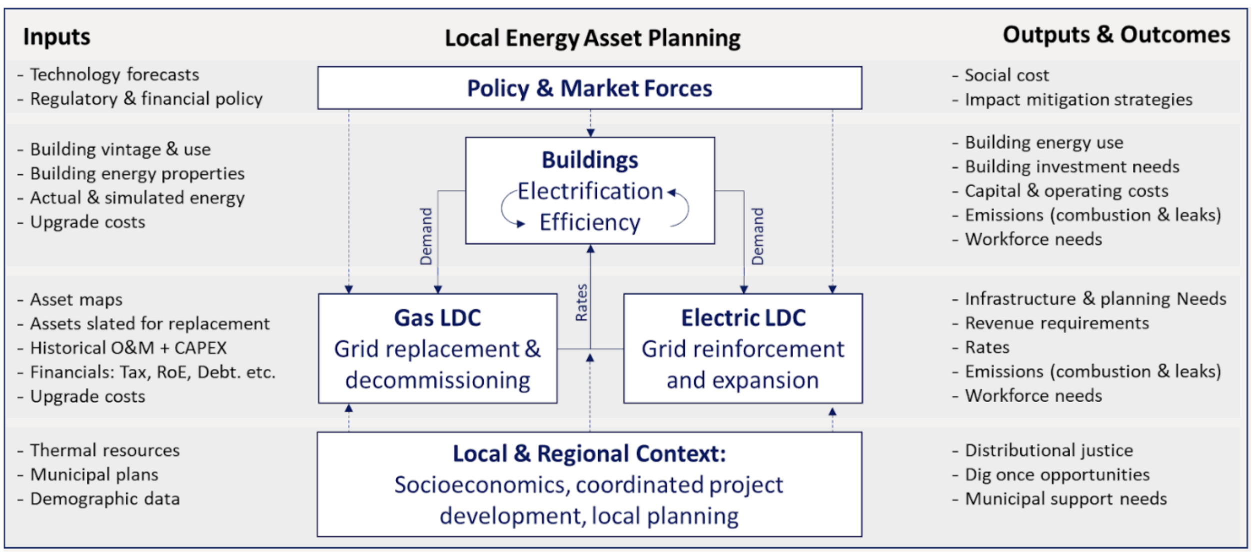

Figure 7. Local Energy Asset Planning Methodology

The model described here uses the LEAP framework and is developed in Python. Individual assets (pipes, wires, meters, building appliances, etc) are modeled as discrete objects that interact with and influence one another. Input data for all assets in the scenario is defined exogenously and includes the following:

- Installation cost of the asset
- Installation year of the asset
- Useful lifetime of the asset

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46 Walsh, Michael. "Local Energy Asset Planning," October 2022.
47 Ibid.

- Energy consumption of the asset over time, by energy source (electricity, pipeline gas, etc)
- Relationship to other assets (for example, which meter is a given heat pump connected to)

Using the relationships between assets, the model constructs a network which can be used to perform bottom-up accounting of features across the system. This accounting is calculated across the parts or nodes of the network over time. In this way, the model details how changes over time to a single asset or multiple assets propagate throughout the system and impact individual energy consumers as well as the local energy grid.

As an example, the change in peak energy demand from one building switching from pipeline gas for heating to a heat pump in a given year is calculated “up” the electric distribution network by the model to show how this single change can impact the peak electric demand (and resulting electricity bill) of the home, the peak loading on the connected transformer, and the throughput of the gas system. Similar calculations are performed to determine how building-level interventions impact cost and emissions upstream. These indicators are then used to evaluate impacts such as how increased electric demand downstream necessitates investments in the utility network to serve demand.

Evaluating multiple indicators is a tenet of the LEAP framework. This is an improvement on traditional benefit-cost analyses (BCAs) that summarize all impacts into a single metric. By combining all impacts into a single value, BCAs can hide the ways in which interventions act across multiple axes. Highlighting multiple indicators empowers decision-makers and improves stakeholders’ understanding of intervention strategies. Indicators output by the Groundwork tool include methane leaks, CO_2 emissions, costs, ratepayer impacts, and infrastructure impacts. These indicators can be evaluated at multiple levels of the system to understand the impact on individual energy customers, individual buildings, and various points in the energy grid.

Data Input and Indicators

The Groundwork tool uses public and open-source data to model the energy consumption and intervention costs for the modeled street segments. Where possible, data is localized to the city of Holyoke or the state of Massachusetts. These data sources are summarized in Table 2 below.

Table 2. Data sources used for this study

Metric	Data Source / Assumption
Building parcel data	MassGIS Property Tax Parcels[48]
Building energy consumptions data: Aggregate Energy Consumption & Loadshapes by End Use	ResStock (buildings),[49] EVI Pro[50] (vehicle charging)
Pipe Replacement Project Location & Costs	2022 Holyoke Gas and Electric Annual Return[51]
Building Electrification, Electric Distribution Costs	MassCEC Whole Home Pilot,[52] MassSave Program Administrator Filings,[53] NREL Distribution System Upgrades[54] with comparison to other studies.
Emissions factors	Standard EPA emissions factors for combustion.[55] NYSERDA Emissions factors for fugitive methane emissions from specific assets.[56] Marginal emissions factors from NREL's Cambium[57] consistent with Massachusetts Emissions targets were used to estimate electric sector emissions from heating electrification.
Future Energy Costs	Using current HG&E rates as a basis, the analysis modeled an increasing compliance cost of fuel production (e.g., a price on carbon starting at $100 in 2025 and escalating at 3% per year). Consumer electricity prices were increased by 1% annually.

The model uses these assumptions to calculate impacts in four areas of focus:

1. Methane Leaks
2. CO_2 Emissions
3. Energy System Changes and Direct Costs

[48] MassGIS Data: Property Tax Parcels: .mass.gov/info-details/massgis-data-property-tax-parcels#downloads-
[49] "ResStock - NREL." https://resstock.nrel.gov/datasets.
[50] "EVI-Pro: Electric Vehicle Infrastructure – Projection Tool | Transportation and Mobility Research | NREL." Accessed June 28, 2023. https://www.nrel.gov/transportation/evi-pro.html.
[51] Holyoke Gas and Electric 2022 Annual Return to the MA Department of Public Utilites. https://www.mass.gov/files/documents/2023/06/15/City%20of%20Holyoke%20Gas%20%20Electric%20Department%20DPU%20Report%202022.pdf
[52] "Public Records Requests | MassCEC." https://www.masscec.com/public-records-requests.
[53] 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 Department of Public Utilities of its Three Year Energy Efficiency Plan for 2022 through 2024., No. 21-128.
[54] Horowitz, Kelsey. "2019 Distribution System Upgrade Unit Cost Database Current Version." Golden, CO (United States); National Renewable Energy Laboratory, 2019. https://doi.org/10.7799/1491263.
[55] US EPA, OAR. "GHG Emission Factors Hub." Overviews and Factsheets, July 27, 2015. https://www.epa.gov/climateleadership/ghg-emission-factors-hub.
[56] "New York State Oil and Gas Sector: Methane Emissions Inventory." NYSERDA, 2022. nyserda.ny.gov/-/media/project/nyserda/files/publications/energy-analysis/22-38-new-york-state-oil-and-gas-sector-methane-report-acc.pdf.
[57] "Cambium.". https://www.nrel.gov/analysis/cambium.html.

4. Ratepayer Impacts

Scenarios

The research team evaluated the following five scenarios, including a high and baseline energy efficiency case for both the unmanaged and accelerated electrification frameworks, designed to represent different intervention strategies for the existing building stock and energy distribution systems, outlined in Table 3. These scenarios were selected because they map out the extremes of the option space, ranging from moderate to comprehensive interventions in buildings and with different levels of action in developing utility energy distribution networks. While scenarios apply the building scale interventions uniformly, actual implementation may involve different combinations of interventions (e.g., whole building electrification, geothermal, or use of backup fuels).

Table 3. List of scenarios in scope for this report. *Replacement years are when 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. More detailed descriptions of building energy models can be found in the ResStock 2022.1 Technical Documentation*[58]

Continued Pipeline Gas	The gas pipeline will be replaced in 2025, and like-for-like replacement of heating systems at their respective end of life. (ResStock Measure Package 1)
Dual Fuel - Pipeline	The gas pipeline will be replaced in 2025 & air source heat pumps will be added in 2025, allowing for a dual fuel arrangement where heat pumps provide primary heat while back-up or peak heating demand is met by pipeline gas (ResStock 2022.1 Measure Package 5)
Unmanaged Electrification	The gas pipeline will be replaced in 2025 & buildings will be fully electrified in their respective replacement year.
- Baseline Efficiency	Building insulation is representative of the current building stock. (ResStock 2022.1 Measure Package 8)
- High Efficiency	Insulation levels in buildings are improved. Areas of improvement include attic floors, ducts, walls, rim joists, foundation walls, and air sealing. (ResStock 2022.1 Measure Package 10)
Dual Fuel - Tank	The gas pipeline will be removed & air source heat pumps will be installed with existing gas-based heating systems converted to backup propane in 2025. In this arrangement, heat pumps are the primary heating source, while the legacy gas equipment, now converted to run on delivered propane stored in a tank on-site, provides back-up or peak heating service. (ResStock 2022.1 Measure Package 5)
Accelerated Electrification	The gas pipeline will be removed & buildings will be fully electrified in 2025.
- Baseline Efficiency	Building insulation is representative of the current building stock. (ResStock 2022.1 Measure Package 8)
- High Efficiency	Insulation levels in buildings are improved. Areas of improvement include attic floors, ducts, walls, rim joists, foundation walls, and air sealing. (ResStock 2022.1 Measure Package 10)

[58] "End-Use Savings Shapes: Residential Round 1 Technical Documentation and Measure Applicability Logic." NREL https://oedi-data-lake.s3.amazonaws.com/nrel-pds-building-stock/end-use-load-profiles-for-us-building-stock/2022/EUSS_ResRound1_Technical_Documentation.pdf.

Figure 8 and Figure 9 below show the progression of building interventions for each scenario across both segments. The scenarios are designed to reflect the implications of certain interventions with respect to timing. If the pipeline is replaced, whole or partial retrofit strategies progress at a natural pace of stock turnover - a pace that is simulated here based on random distribution. Partial retrofits include smaller heat pumps with backup fuel for supplemental heating, while whole could be larger heat pumps and weatherization or insulation of the home. Alternatively, if the pipeline is closed, interventions are applied at the time of pipeline closure. In the unmanaged electrification scenario, we assume that no more customers will be connected to the pipeline by 2050, effectively turning it into a stranded asset.

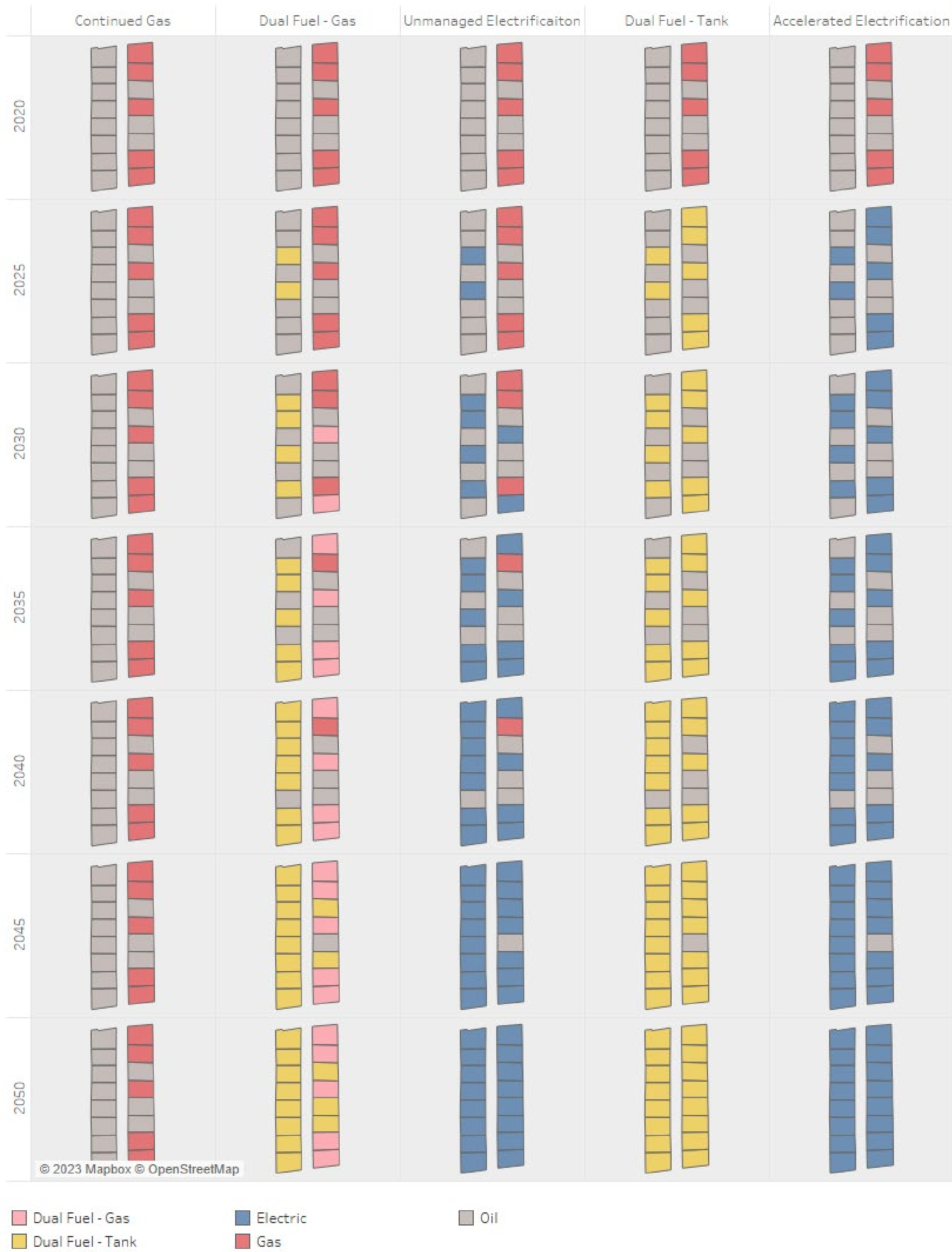


Figure 8. Progression of interventions for each scenario on the single family segment. Intervention progression in the electrification scenarios are identical for the high and baseline energy efficiency cases.

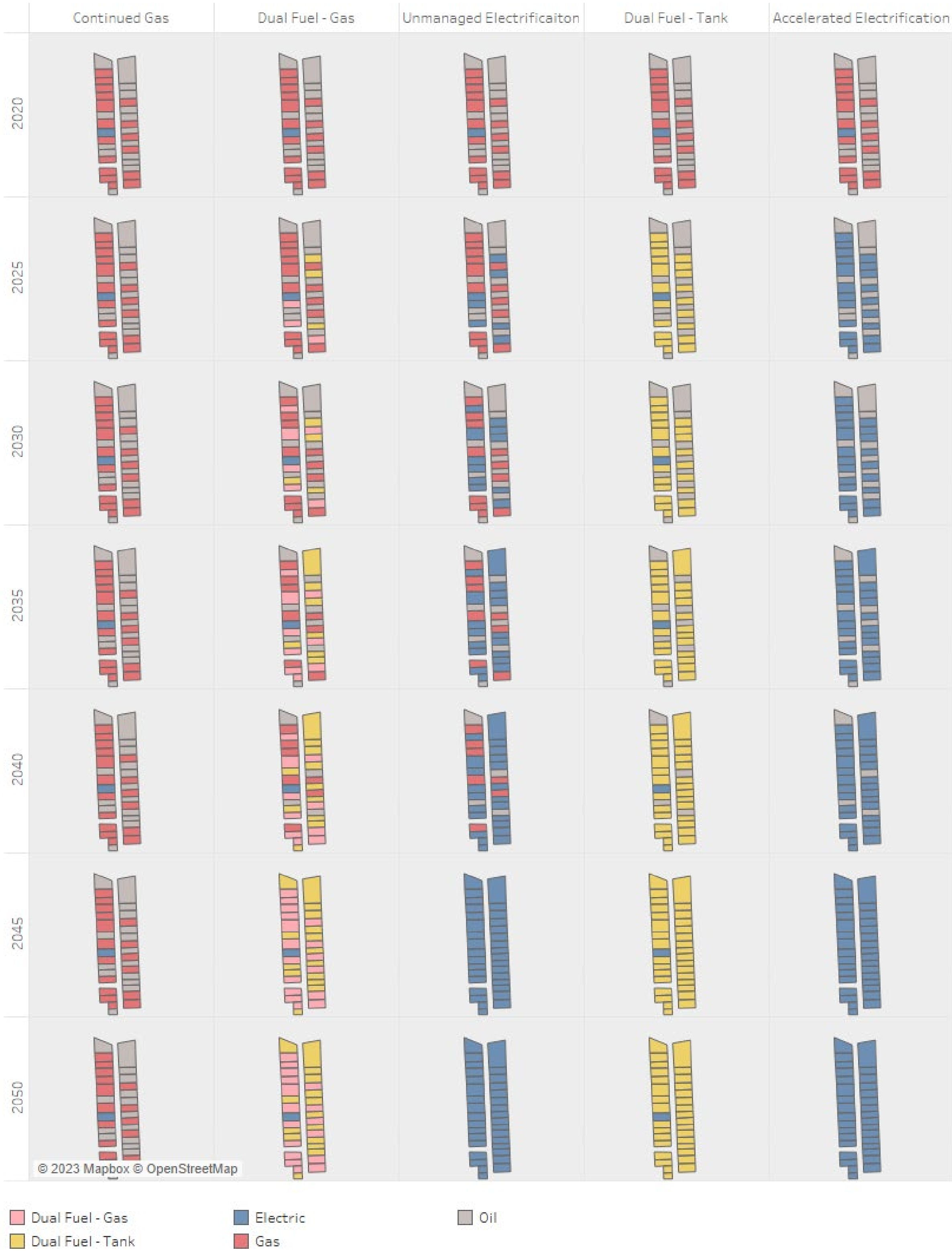


Figure 9. Progression of interventions for each scenario on the multifamily segment. Intervention progression in the electrification scenarios are identical for the high and baseline energy efficiency cases.

Results: Evaluation of Alternatives to Gas Pipeline Replacement

This chapter presents the results of assessing the alternative segment-level scenarios across the two street segments described above. The results summarize the impact of these strategies across several indicators of relevance to an energy provider (such as HG&E), building owners, residents and ratepayers, and the municipality. The specific indicators synthesized in this report cover safety, cost, and climate impacts through a focus on methane leaks, carbon dioxide emissions, cost of gas replacement, costs of electrification, and ratepayer impacts.

Impacts of Avoided Gas Pipeline Replacement on Methane Leaks

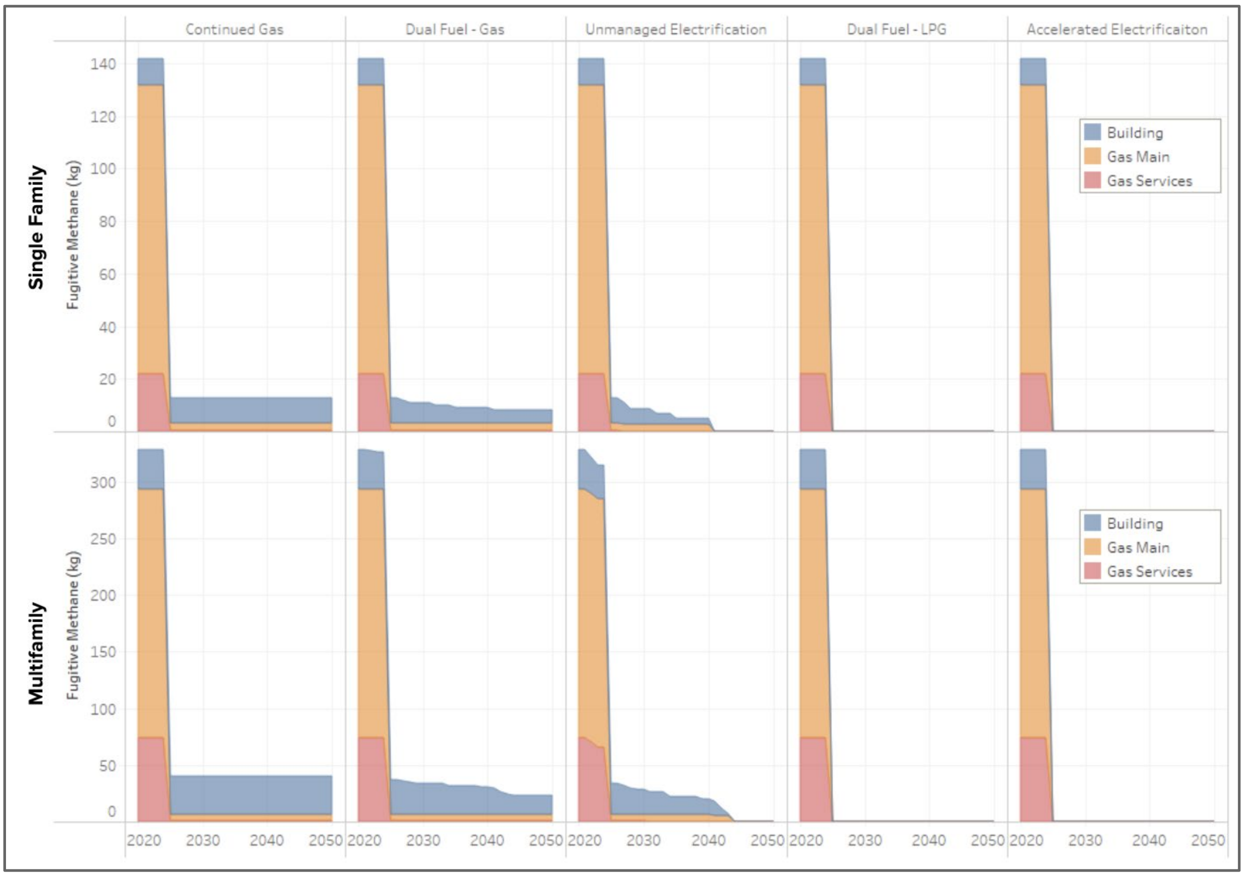


Figure 10. Fugitive methane emissions by scenario. Emissions factors used in the calculation of fugitive methane are sourced from NYSERDA.[59] Leak emissions in the electrification scenarios are identical for the high and baseline energy efficiency case.

All interventions are expected to reduce methane emissions due to the modernization of leak-prone infrastructure or the elimination of methane infrastructure (Figure 10). It should be noted that the impact of leaks is highly uncertain; unlike combustion processes where the released CO_2 is largely definitive and consistent by fuel, emissions from leaks can vary widely due to

[59] "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.

variability in the integrity and features of the gas system. As a result, emission factors have high levels of uncertainty and variability. Without direct measurements of methane emissions at the segment level, it is difficult to estimate fugitive emissions accurately.

Notably, recent top-down studies of methane emissions have demonstrated that leakage rates of existing and modernized assets can greatly exceed values calculated using standard emissions factors, such as those estimated here.[60] Additionally, leak repair work does not appear to be reducing fugitive methane emissions. Despite six years of accelerated pipeline replacement in the Boston region, no significant change in regional methane emissions has been observed. Many emissions will evolve from behind-the-meter sources, such as building distribution pipes and end-use equipment.

Given these recent findings, the results above should be interpreted cautiously, as fugitive emissions may be higher currently and with any intervention that maintains the gas system.

CO_2 Emissions

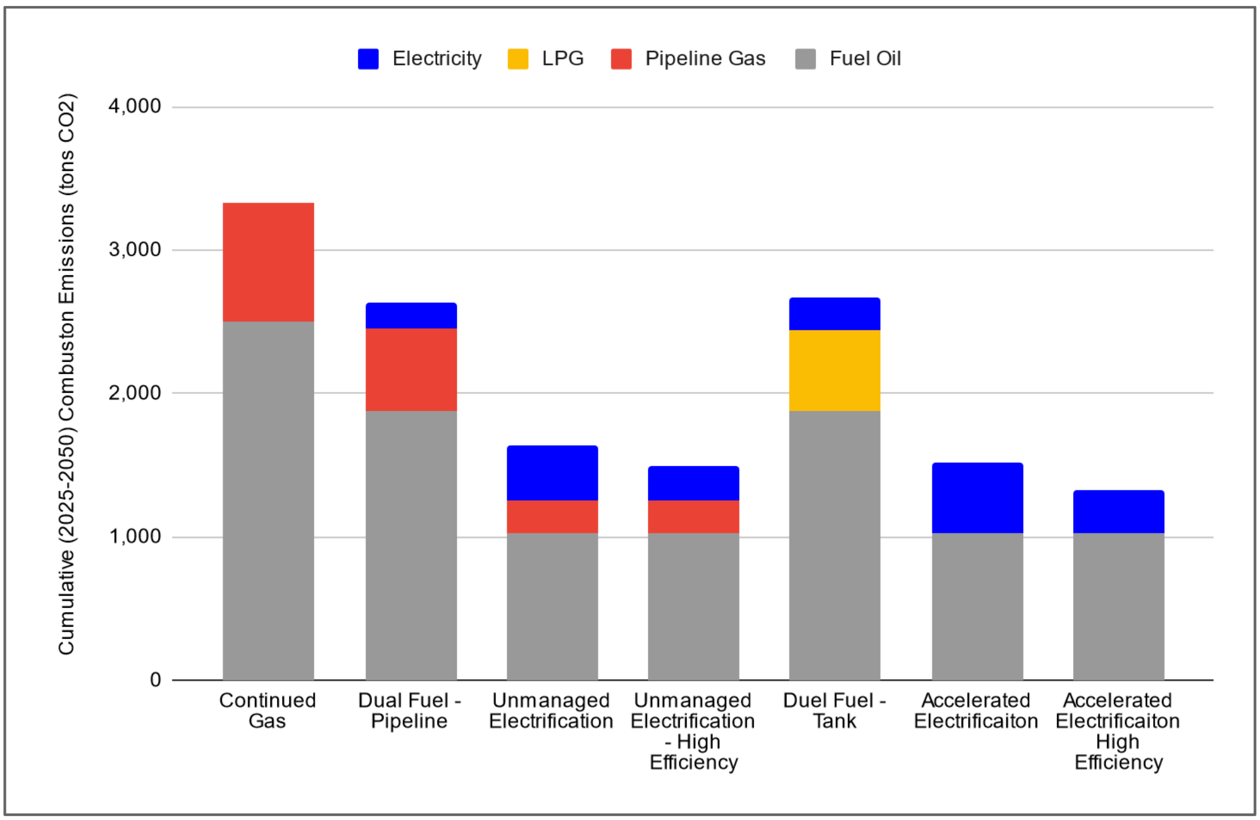


Figure 11. Cumulative (2025-2050) combustion and marginal electricity CO_2 emissions for the single family street segment. Electric emissions exclude baseline electricity consumption.

[60] 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 of the United States of America* 118, no. 44 (November 2, 2021). https://doi.org/10.1073/PNAS.2105804118/SUPPL_FILE/PNAS.2105804118.SAPP.PDF.

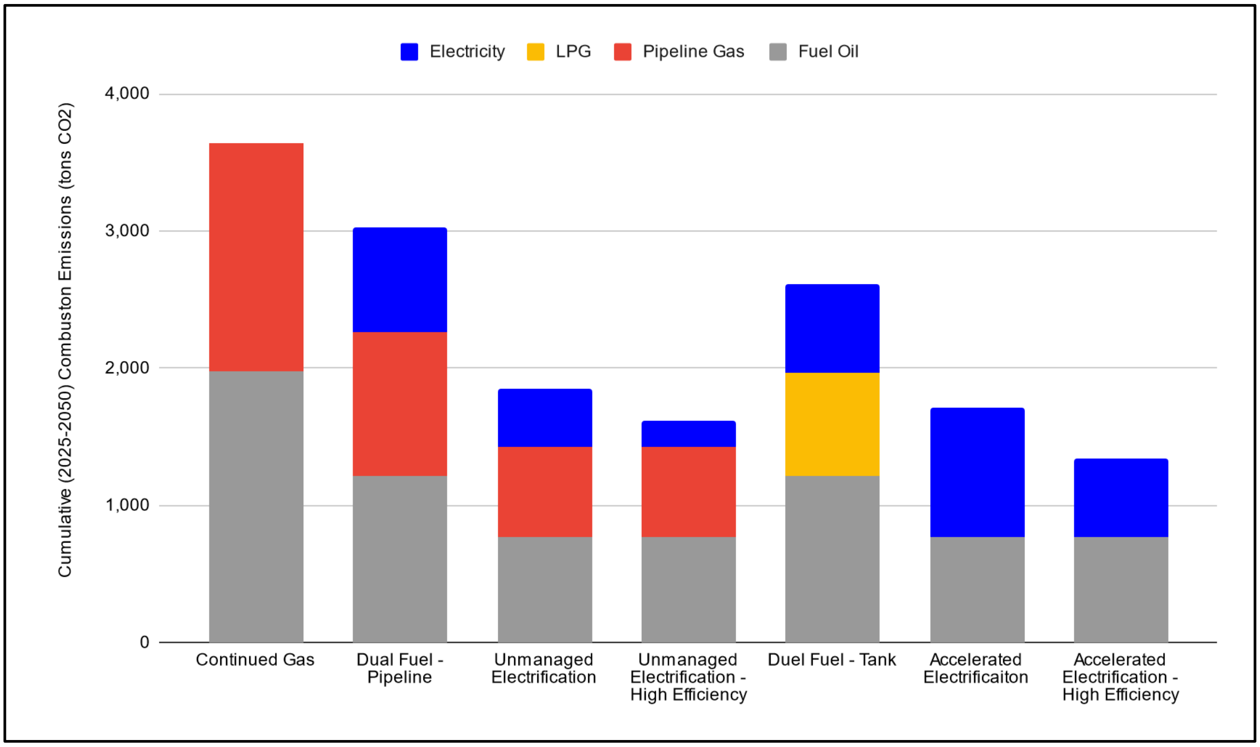


Figure 12. Cumulative (2025-2050) combustion and marginal electricity CO_2 emissions for the multifamily street segment. Electric emissions exclude baseline electricity consumption.

Figure 11 and Figure 12 show cumulative emissions between the intervention date and 2050 for the whole segment, including oil-heated homes. Emissions are estimated using standard emissions factors[61] for fuels and marginal emissions factors for electricity that best reflect Massachusetts' anticipated electric emissions intensity necessary to achieve mitigation goals.[62] These factors are used in place of Holyoke's carbon intensity to reflect the opportunity costs of Holyoke's electricity supply. These factors also reflect uncertainty about the implications of large increases in electricity demand due to electrification that may exceed Holyoke's capacity to generate additional low-carbon electricity in the future.

The reader can thus interpret the electricity emissions in Figure 11 and Figure 12as a very conservative assumption. Even with such conservative assumptions, faster electrification leads to faster emissions reductions. Hybrid dual fuel scenarios lead to modest emissions reductions. However, these forecasts assume that dual fuel heating is maintained. Future policy may create incentives to go fully electric to align with net-zero targets before 2050.

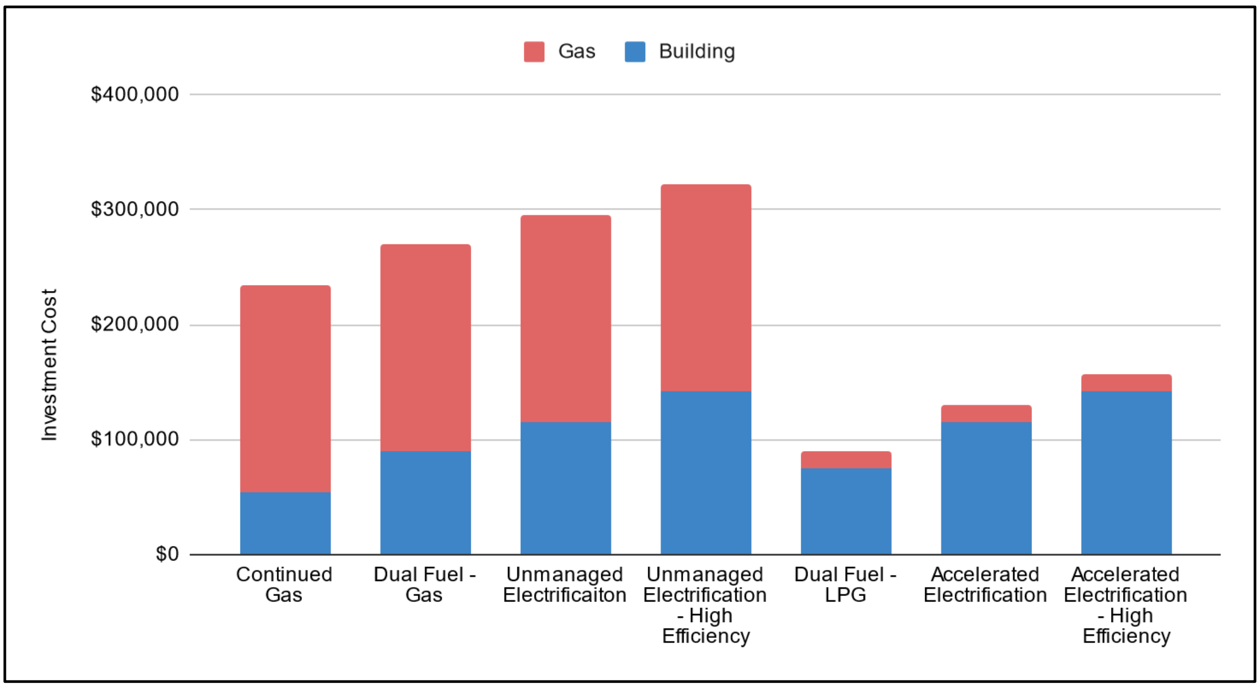
The impact of efficiency measures in the electrification scenarios on cumulative emissions is modest, but more significant in the accelerated electrification case which front loads emissions when the grid is more carbon intensive.

[61] US EPA, OAR. "GHG Emission Factors Hub." Overviews and Factsheets, July 27, 2015. https://www.epa.gov/climateleadership/ghg-emission-factors-hub.
[62] "Cambium."https://www.nrel.gov/analysis/cambium.html.

Energy System Costs and Drivers of Costs

This section reviews the implications of various levels of building intervention, specified in each separate scenario, on the buildings themselves and on the electrical grid. Our approach seeks to demonstrate several levels of intervention concerning electrical load impacts by exploring the implications of whole-building electrification alongside dual fuel strategies that are used to keep electrical demands below peak capacity. This section also reviews the assumptions utilized to estimate gas system costs and then uses a pipeline and non-pipeline dual fuel pathway to illustrate potential options for avoiding gas system reinvestment while keeping electrical grid impacts low. Here we refer to system costs as those that reflect specific capital and operational outlays for the design and operation of the system. These differ from rate and bills which are assessed in the following section.

Cost Synthesis



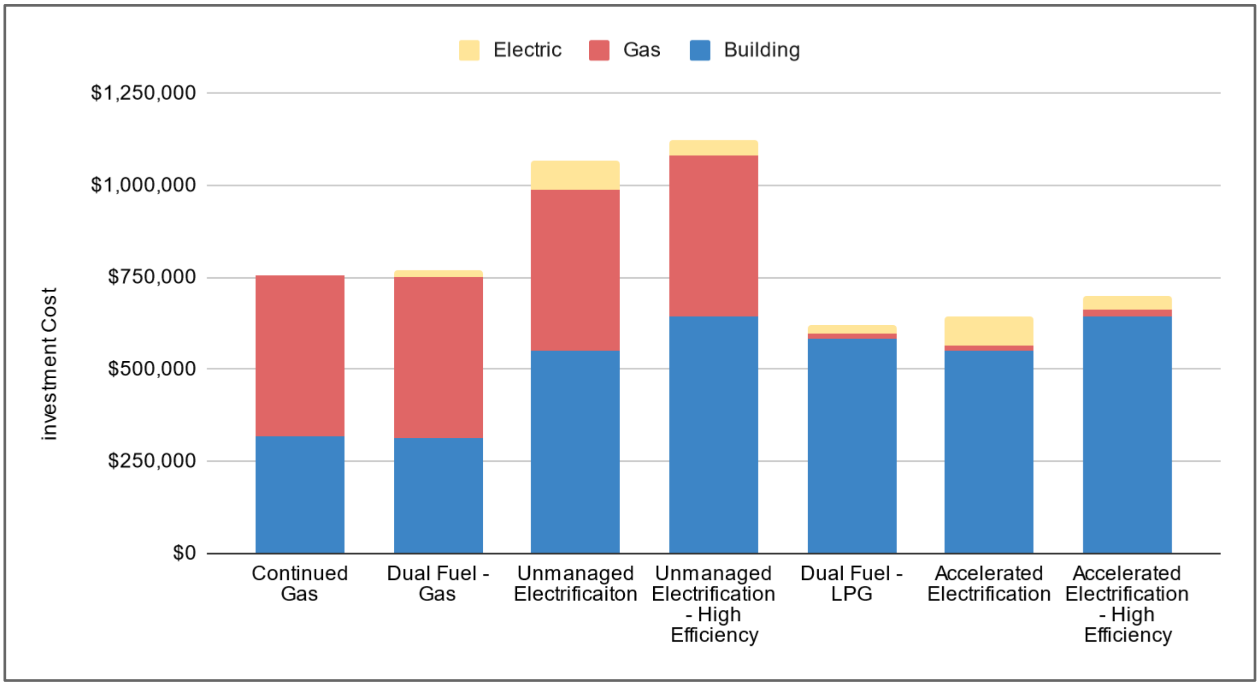


Figure 13,Figure 14. Summary of investment costs by scenario for the single family (top) and multifamily (bottom) segment. Costs represent overall system investment costs. Energy distribution costs are assumed to be covered by utility rates, while building intervention costs are borne by the building owner but can be offset by rebates (e.g., HG&E) and tax credits (IRA). Building interventions costs include costs of retrofitting the buildings in each scenario (new appliances, increased insulation, etc). Gas and electric intervention costs include any upgrades to the system, such as repairing/replacing the gas pipes, pipeline decommissioning costs, and electric transformer upgrade costs.

Figure 13 and Figure 14aggregate the cost data from the interventions to each sector across scenarios. While the cost of building electrification is significant, so is the cost of pipeline replacement and continued maintenance of gas equipment, which is often overlooked in forecasts of decarbonization pathways at the local level.

In the case of the single family segment, replacing the pipeline exceeds the cost of electrifying the buildings immediately. On the multifamily street segment, the costs of electrifying the segment immediately exceed the costs of replacing the pipe. However, this should be viewed with the understanding that even with replacing the gas pipeline, building owners will eventually need to replace their gas furnaces and equipment at their end of life. To further illustrate this, we synthesize all cost data below after assessing the grid impacts.

The impact of energy efficiency measures increased the total investment costs but reduced the cost of needed electric infrastructure investments in some specific situations. Other benefits included reduced energy demands, discussed below in the Ratepayer Impacts section.

Given decarbonization goals and state, federal, and local incentives, some degree of electrification is expected, and there is a materially significant chance that buildings will be driven to full electrification through various policy mechanisms. The gas pipeline will become an underutilized and possibly stranded asset. This suggests that efforts to replace the pipeline may be a misallocation of resources.

A more detailed breakdown of these costs is reviewed in the following subsections.

Gas System Costs

Gas pipeline replacement costs were estimated from HG&E's annual filing with the MA Department of Public Utilities and are shown for the past three years (Table 4). For comparison, average pipeline replacement costs for Massachusetts' investor-owned utilities are currently approaching $3M per mile on average.[63] These separate estimates may not be directly comparable due to different reporting approaches. However, HG&E's value is consistent with values observed in territories outside the metro Boston region.

These costs include activities such as digging and trenching (ledge removal), pipe replacement, restoring the earth and road, permitting, traffic and safety control, and engineering and design expenses. Some investor-owned utilities will estimate these costs as part of their Gas Safety Enhancement Plans.[64]

Without such detailed data, we apply a per-mile replacement cost of $1.3M for gas mains and an $11,000 per service line estimate to the two project sites to estimate the cost of pipeline replacement on each of these streets.[65]

Table 4. Average annual cost per mile of pipeline replacement

Year	Feet Replaced	Cost Per Mile
2020	7,199	$1.02M
2021	11,797	$1.35M
2022	11,718	$1.85M

Pipeline decommissioning costs are likely $20,000 per segment for the cost of cutting the connection with the feeder-pipe and capping the end. This value is based on GSEP reporting by an investor-owned utility in a Massachusetts Gateway City.[66] This also assumes that the pipeline can be safely abandoned in place without impacts on other infrastructure, an assumption that may not be universally applicable.

The costs of replacement, decommissioning, and investment to maintain the gas infrastructure are totaled in Table 5. When viewed on a per-building basis, these costs are strikingly high and can be compared to the incremental costs of electrification. Even when normalized to the number of housing units on the multifamily street, the cost of pipeline replacement is significant.

[63] Groundwork review of 2023 GSEP filings.
[64] Petition of Liberty Utilities (New England Natural Gas Company) Corp. for Approval of its 2022 Gas System Enhancement Plan, No. 21-GSEP-04.
[65] Ibid.
[66] Petition of Liberty Utilities (New England Natural Gas Company) Corp. for Approval of its 2022 Gas System Enhancement Plan, No. 21-GSEP-04. Accessed June 28, 2023.

Table 5. Average annual cost per mile of pipeline replacement.

Costs	Single Family	Multifamily
Project Cost	$180,000	$437,000
Per Building Cost	$36,000	$25,706
Per Household Cost	$36,000	$15,069

In practice, these costs are broadly socialized across the utility and are further moderated by a municipal utility's low cost of capital. Pending replacement project costs will likely be covered by federal grants aimed at municipal utilities. Still, such investment may not be the most prudent use of such funds, given the long-term challenges associated with managing the gas transition noted above. These investments also lock in gas infrastructure and operating costs, which will be redundant and eventually underutilized with increasing heating electrification. Further, such investments seek to safely maintain the existing service and don't generate any novel value for the consumer, such as cooling or enhanced comfort.

Building Interventions & Costs

The analyzed scenarios vary when end uses are upgraded and what the upgrade is at each building. The building model outputs energy consumption before and after the upgrade and the total cost, including installation costs and any stranded value of replaced assets.

The retrofits assumed across each scenario are shown in Table 6.

Table 6. The building interventions assumed in each gas pipeline scenario.

Continued Pipeline Gas	Like-for-like replacement of heating systems at their respective end of life. (ResStock Measure Package 1)
Dual Fuel - Pipeline	Air source heat pumps will be added in 2025, allowing for a dual fuel arrangement where heat pumps provide primary heat while back-up or peak heating demand is met by pipeline gas (ResStock 2022.1 Measure Package 5)
Unmanaged Electrification	Buildings will be fully electrified in their respective replacement year.
- Baseline Efficiency	Building insulation is representative of the current building stock. (ResStock 2022.1 Measure Package 8)
- High Efficiency	Insulation levels in buildings are improved. Areas of improvement include attic floors, ducts, walls, rim joists, foundation walls, and air sealing. (ResStock 2022.1 Measure Package 10)
Dual Fuel - Tank	Air source heat pumps will be installed with existing gas-based heating systems

	converted to backup propane in 2025. In this arrangement, heat pumps are the primary heating source, while the legacy gas equipment, now converted to run on delivered propane stored in a tank on-site, provides back-up or peak heating service. (ResStock 2022.1 Measure Package 5)
Accelerated Electrification	Buildings will be fully electrified in 2025.
- Baseline Efficiency	Building insulation is representative of the current building stock. (ResStock 2022.1 Measure Package 8)
- High Efficiency	Insulation levels in buildings are improved. Areas of improvement include attic floors, ducts, walls, rim joists, foundation walls, and air sealing. (ResStock 2022.1 Measure Package 10)

Figure 15 and Figure 16show the total cost of building interventions on each street segment by intervention component. Note that costs of enhancements to the building envelope in the high efficiency scenario are included in the “HVAC” cost category. The costs for the single family segment are relatively low due to the low proportion of gas services (5) on the street and the fact that each of these buildings only requires intervention to one heating system and one set of appliances.

Conversely, while the multifamily segment is longer, it also has a higher proportion of gas-served buildings (17), several of which have multiple units (29 total gas-served units).

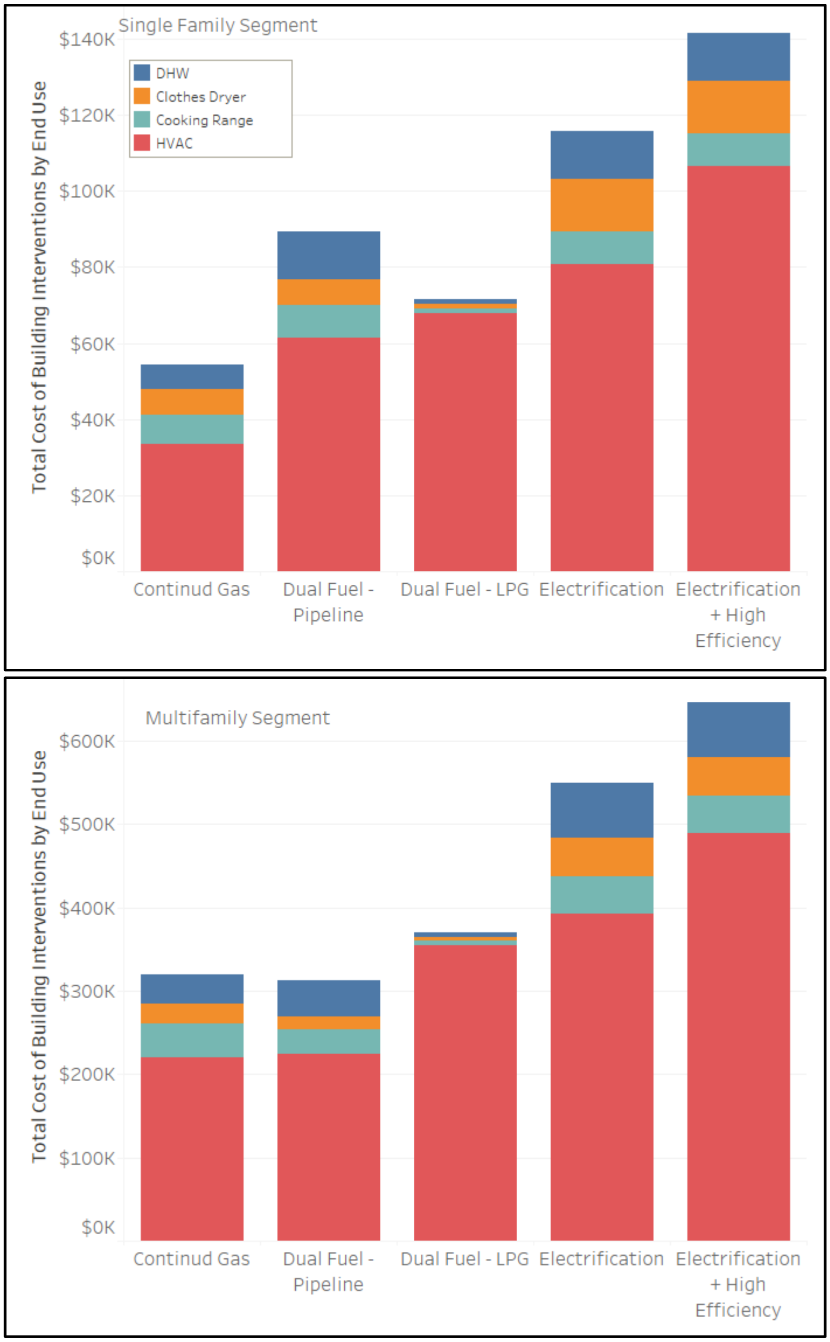


Figure 15 and Figure 16. Total intervention costs broken down by appliance for the single family (top) and multifamily (bottom) segments.

Grid Impacts & Costs

Increases in electricity demand will impact the electric distribution system, including services, wires, transformer capacity, feeder capacity, and substations. The project team was not able to fully evaluate the impacts across the system due to data access limitations. Instead, the project team used street view data to identify transformer locations and capacity to create a topology of the street segment's distribution network. Aggregate loads were then calculated for each network asset, including EV growth for each scenario. The electrification of oil-heated buildings was also simulated in the full electrification scenarios.

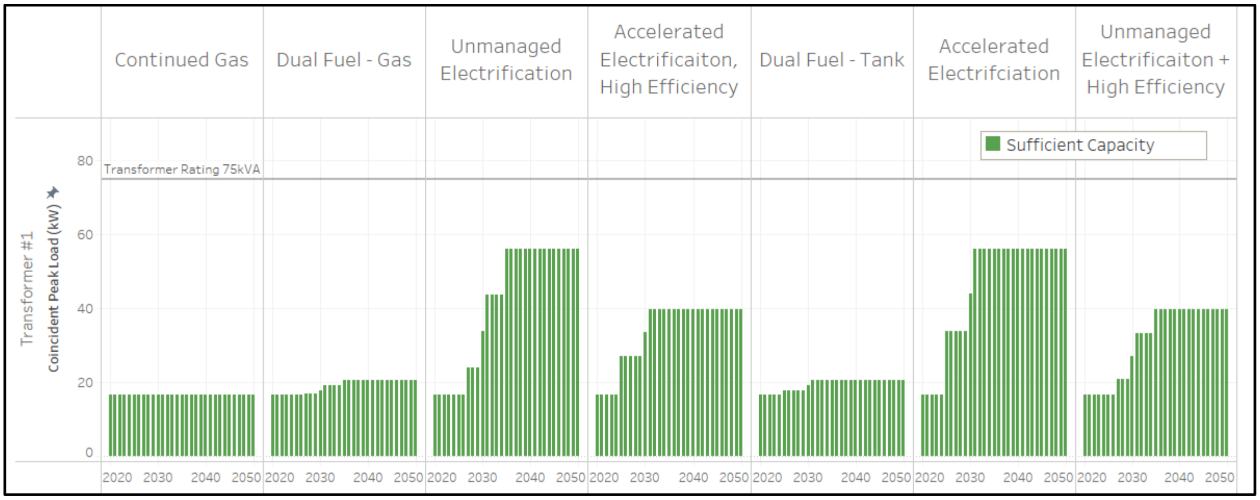


Figure 17. Transformer peak loads for the single family segment by year.

The impacts of the various strategies ranged from modest to threefold increases in peak demand. The single family street segment is served by a single 75 kVA transformer which provides sufficient capacity for future electrification, despite a threefold increase (Figure 17).

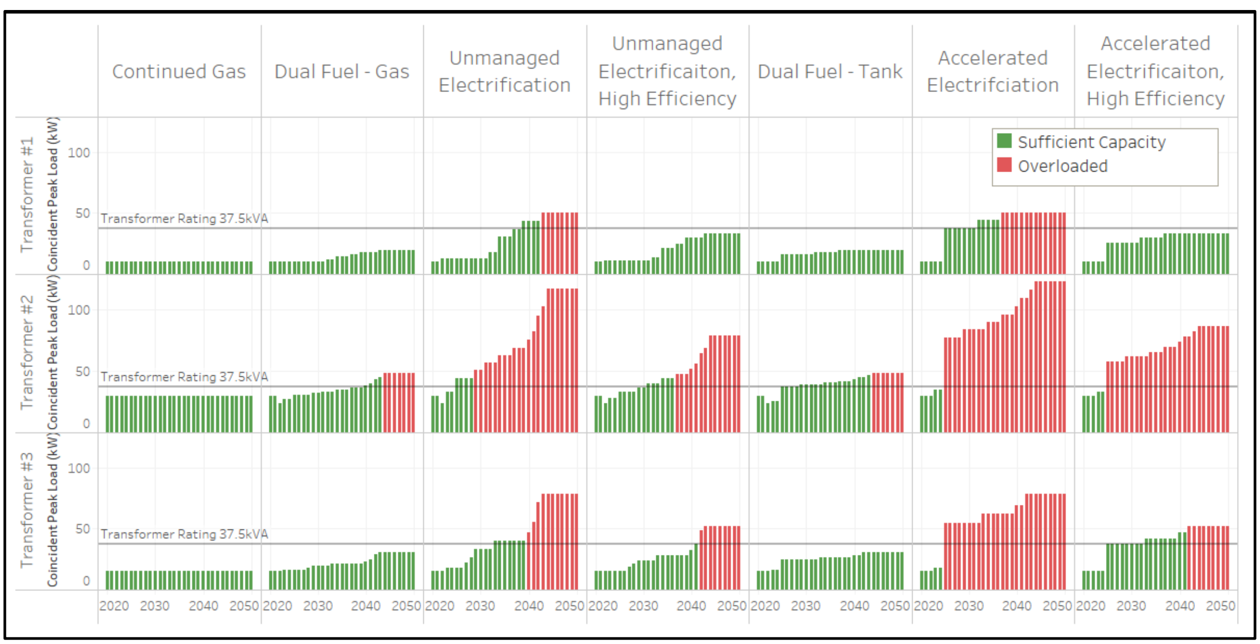


Figure 18. Transformer peak loads for the multi-family segment by year.

The multi-family segment is served by three 37.5 kVA transformers, with one currently approaching capacity (Figure 18). In the full electrification scenarios, all three transformers would need to be upgraded with an additional 150 kVA of transformer capacity added at an estimated cost of $80,000, assuming $20,000 for each additional 37.5.[67]

Both street segments highlight the impact that enhancements to building enclosures can have on peak load and the local electric grid. This is most obvious for the multifamily street segment; enclosure enhancements avoid roughly $40,000 in transformer upgrade costs on this street when buildings are fully electrified. While the single family street segment does not overload the transformer in any scenarios, peak load reductions from enclosure enhancements provide more capacity (about 20 kW) in the local network for any future increases in load.

While there may be sufficient capacity on the street, there may be more constraints on the feeder line that connects the substation to the transformer. While such data was unavailable to the project team, several investor-owned electric utilities provide hosting capacity and distribution system upgrade data for planning purposes.[68,69] Solar and other project developers use this data to assess local project feasibility.

While it is unlikely that the electrification of two single streets will result in challenges for distribution feeders, a growing number of electrification projects will increase upstream loads, necessitating the need for running new feeders and upgrading substation capacity. Future work should incorporate an assessment of upstream impacts.

Energy Bill Impacts

The electrification of two single streets will have a significant impact on ratepayers by shifting them off of gas and onto electricity. Average impacts are shown in Figure 19. Future costs are based on the assumption that:

- Electricity supply costs remain constant.
- Fuel costs increase due to a policy such as a carbon tax or cap and trade system.
- Gas distribution costs are anticipated to rise at a rate similar to that forecasted in the statewide Future of Gas Docket MA DPU 20-80.[70]

As such, prices are largely driven by these assumptions and the energy consumption under each scenario.

In both situations, we observe two key outcomes:

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[67] Estimate from average cost of transformer upgrade in HG&E 2022 Annual Return https://www.mass.gov/files/documents/2023/06/15/City%20of%20Holyoke%20Gas%20%20Electric%20Department%20DPU%20Report%202022.pdf

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

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

[70] 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."

- In Holyoke, due to its low electric rates, heating electrification can be more cost-effective than pipeline gas.
- Homes that electrify - partially or fully - are insulated from the increasing costs of pipeline gas delivery and consumption.

Figure 20 shows the distribution of monthly costs across the households in the segment to illustrate how costs range among households. This reinforces the fact that different homes are going to be affected differently at different times by both changes in energy rates and the timing of interventions. Homes that remain on fuels longer, largely due to the life cycle of their equipment, will pay greater energy costs but have lower stranded asset costs. It should also be noted that - like with electric grid upgrades - costs are reduced with the addition of enhanced insulation in homes.

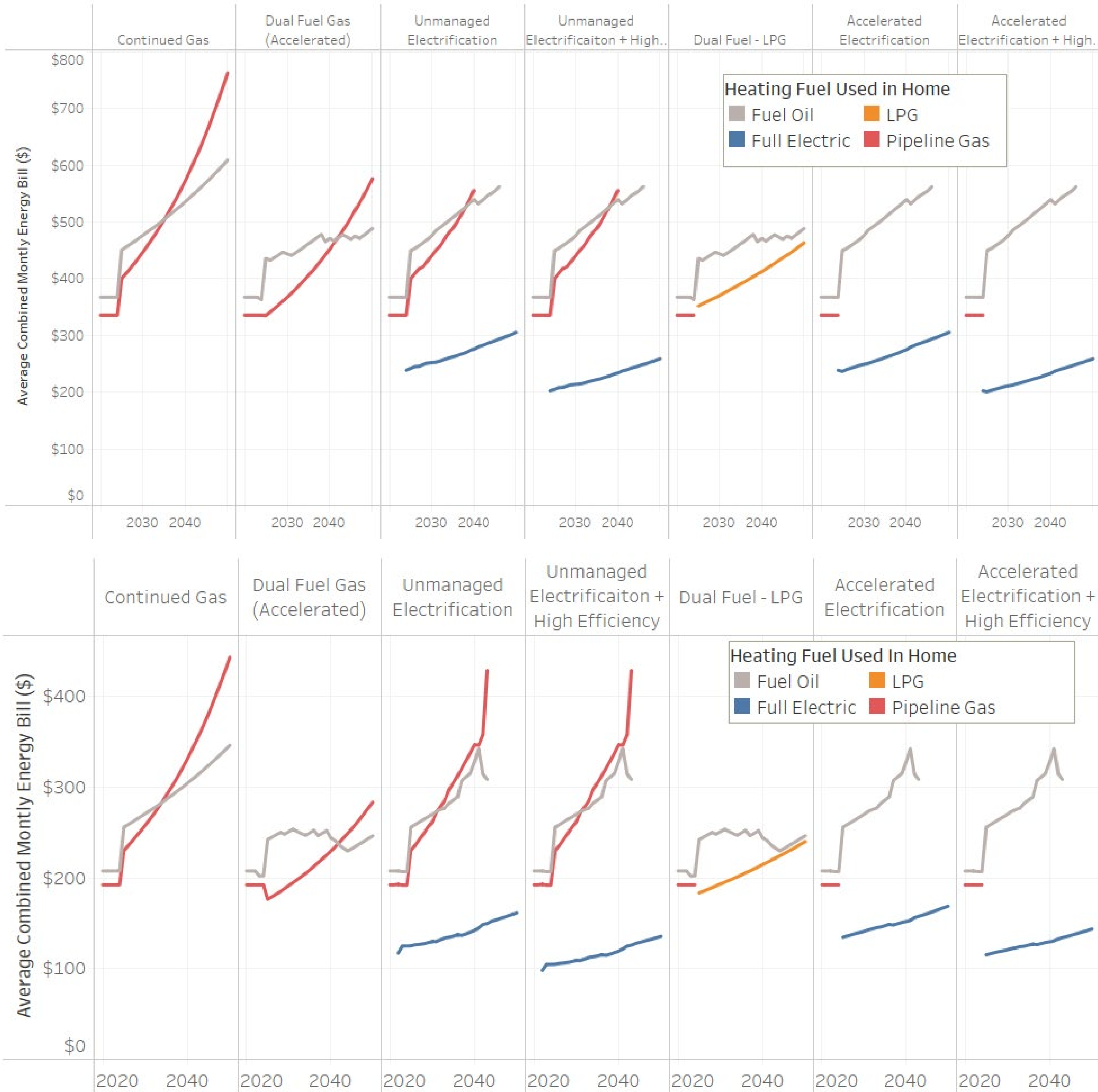

Figure 19. Average household combined monthly energy bill by scenario and fuel used in the home for the single family (top) and multifamily (bottom) segments.

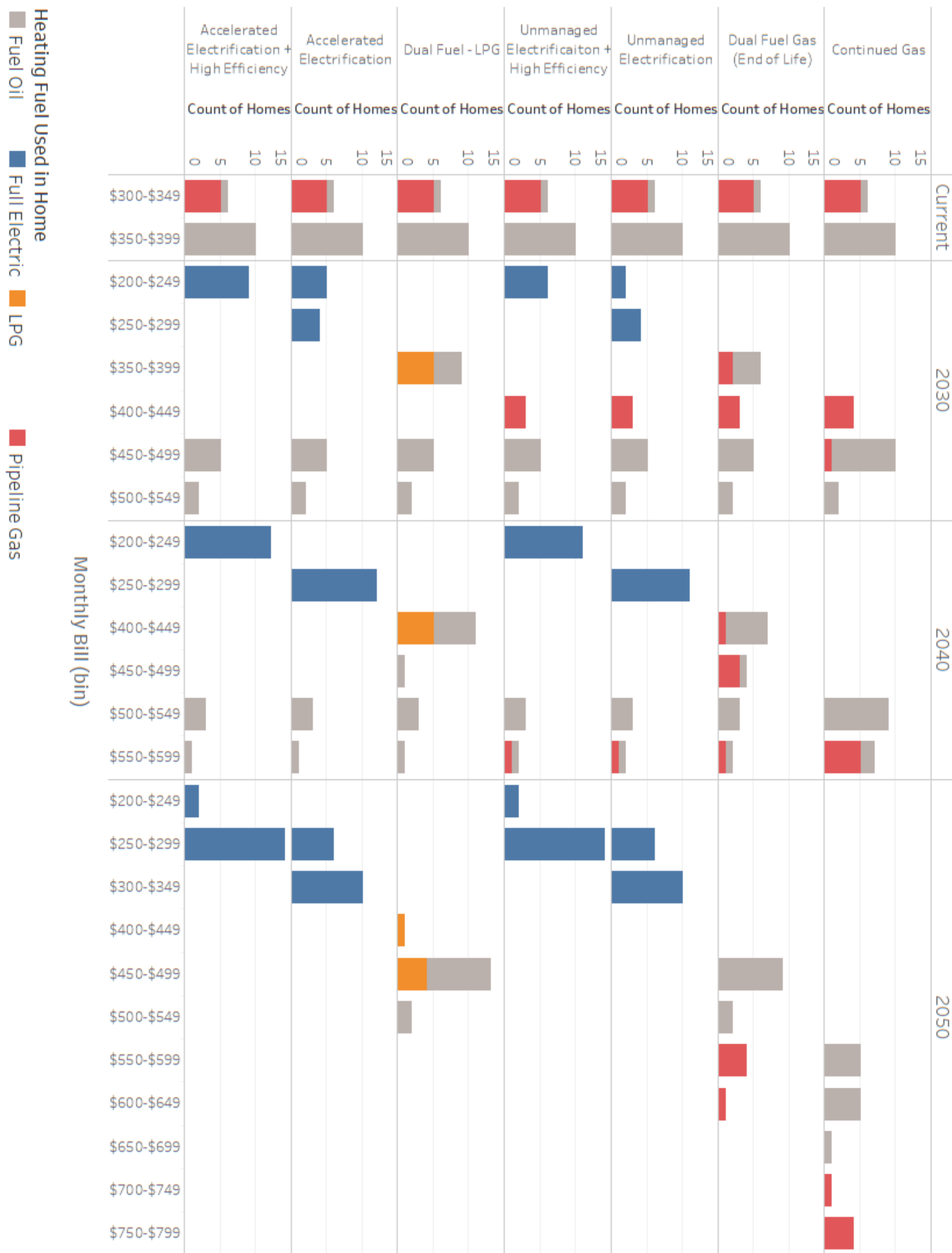

Figure 20 A-Single Family. Distribution of average combined monthly energy bill for each scenario at 10-year increments for the single family (top) and multifamily (bottom) segments. Color indicates the use of heating fuel or all-electric.

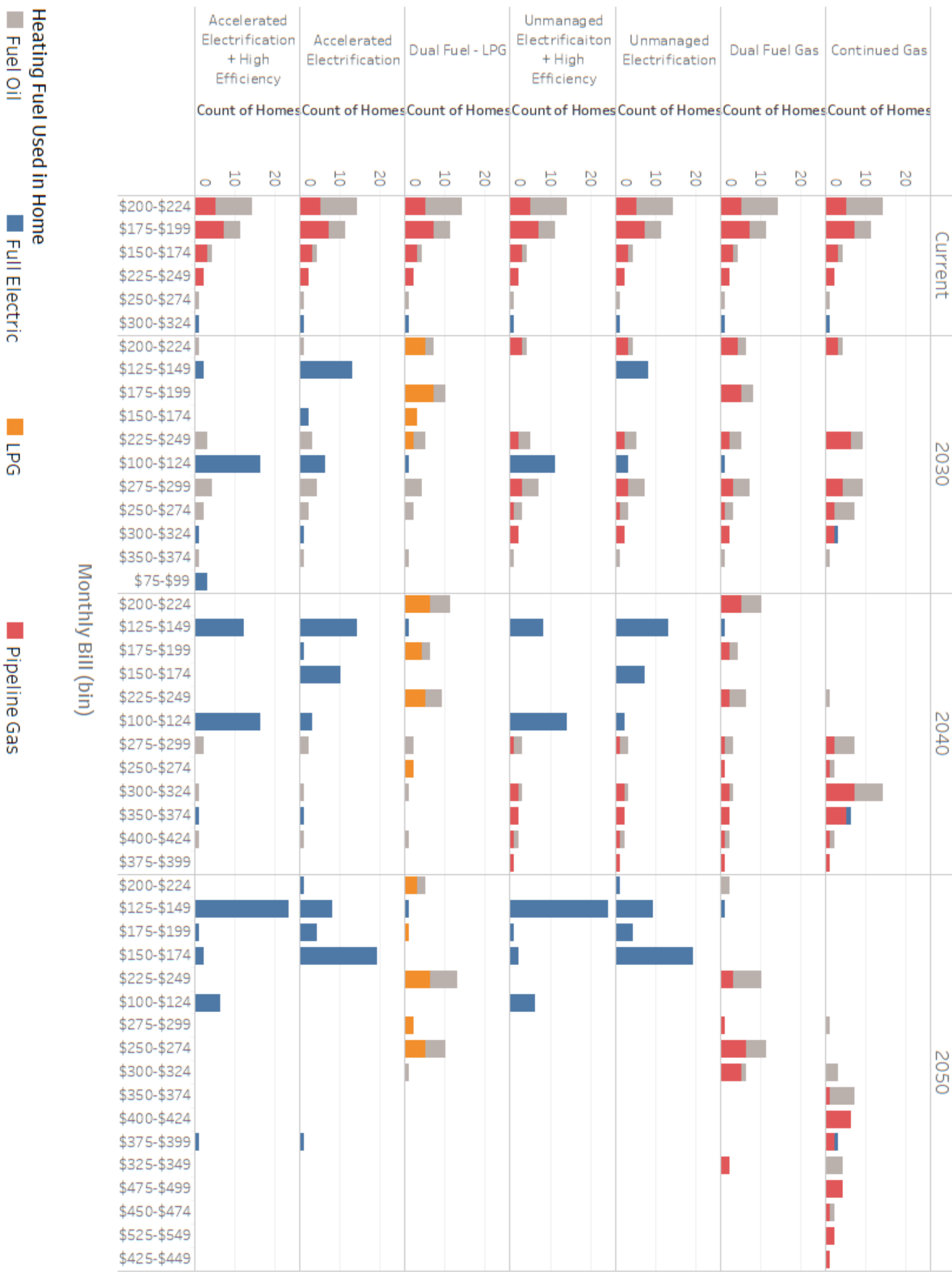

Figure 20 B-Multifamily. Distribution of average combined monthly energy bill for each scenario at 10-year increments for the single family (top) and multifamily (bottom) segments. Color indicates the use of heating fuel or all-electric.

Summary

In this study, several scenarios were analyzed for cost and emissions reduction effectiveness. Pipeline replacement to maintain existing gas service while modernizing the distribution system incurs a high upfront capital cost, resulting in the "lock-in" of that investment. In addition to the high costs, there is a high likelihood these pipeline investments will continue to conflict with state and local climate goals due to their role in transmitting gas.

Alternatively, avoiding pipeline replacement:

- Eliminates methane leaks from the distribution system and buildings.
- Avoids six-figure or greater capital projects with comparable capital costs to building electrification on affected segments.
- Prompts decarbonization in buildings to accelerate emissions reductions cost-effectively.
- Shifts customers to lower-cost heating systems while providing them with cooling and enhanced comfort.

The concept of a segment-level transition off of gas is novel. It is currently being piloted in California,[71] and is being explored in states such as New York, Rhode Island, and Massachusetts. This study highlights the impacts of different strategies across two street examples, but as segment-level transitions become more practical, decommissioning projects will likely benefit from a mix of strategies. Local energy asset planning will be increasingly important in understanding the trade-offs of different paths forward in these scenarios.

Massachusetts utilities, and by proxy ratepayers are expected to spend $20-$40 billion dollars on replacing leak-prone pipes over the next 15 years.[72] While some pipe segments will likely need to be replaced, a good portion of this investment could be redundant as homes electrify. This analysis shows that non-pipeline strategies, particularly on low-density streets can be a more cost effective strategy with avoided reach into the billions.

Implementation in Holyoke faces challenges but also offers opportunities. Holyoke's residential building stock is old and likely underinvested in. The cost of electrification and efficiency retrofits may be significant relative to the value of the housing stock. In many cases, buildings may have urgent or prerequisite interventions to address before the intervention packages modeled here.

In some cases, a dual fuel approach may be a helpful transition strategy for homes facing physical or social barriers to electrification. However, such backup options may need to be phased out to achieve decarbonization goals.

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[71] Kahn, Matthew. "Strategic Pathways and Analytics for Tactical Decommissioning of Portions of Gas Infrastructure in Northern California," 2023

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

Ultimately, investment in buildings rather than the pipeline distribution system will benefit homeowners and residents. These benefits include increased property values, reduced energy bills, increased comfort, and improved indoor air quality.

Advancing segment-level transitions would help to improve participation by low-income residents and renters who are less likely to take steps to decarbonize and more likely to remain on the gas system as its costs spiral. Currently, low-income affordability programs operated by community action agencies across the Commonwealth are highly effective at retrofitting large residences while they struggle to retrofit small residences.[73] This is largely due to easier access to managers of large public and private residential buildings that enable structured coordinated retrofits on a large number of units at once. Segment-level interventions create an opportunity for the coordination of retrofits in smaller buildings.

[73] Os, H, : Leupold, and Ellis. "Residential Nonparticipant Customer Profile Study MA19X06-B-RESNONPART," 2020. www.dnvgl.com.

Section II: Data Collection to Identify Targeted Geographic Areas for Equitable Energy Transition Projects.

This section demonstrates how integrating different local data sets can help identify street segments to target for grid resilience projects. It introduces the use of a Digital Network Asset Registry, a collection of localized data, as a way to better understand a city's infrastructure network. It then demonstrates a "clustering analysis" on the data collected, which describes different criteria that can be used to rank street segments by how high they should be prioritized for decommissioning. This work helps identify the streets that could be analyzed by integrated cost benefit analysis methods such as those described in Section I.

Background

The purpose of this project is to identify targeted geographic areas to prioritize for equitable energy transition and grid resiliency planning projects. The collection and evaluation of existing public, municipal, utility, and proprietary data was performed in support of coordinated planning for decarbonization, enhanced reliability, and greater resiliency. To facilitate this collection and evaluation, this project created a digital network asset registry (DNAR), a data integration framework that can provide multiple stakeholders with enhanced capability to target and prioritize equitable energy transition and grid resiliency projects.

A typical master planning project is siloed; it involves acquiring, normalizing, and overlaying data from multiple sources and working with different stakeholders independently. Each of these tasks alone is cumbersome and creates multiple disjointed projects. This work aims to connect different entities under a common planning framework to enable better cross-agency planning of infrastructure projects. By developing and maintaining a unified DNAR, the city can conduct planning scenarios more efficiently, answer complex questions using unified data sets, and identify projects with the potential for coordination. Coordination of capital projects - allowing multiple capital projects to occur at once - shares and lowers overall costs.

A user can employ a DNAR to identify sites where the rehabilitation of aging sewer or water assets can be coordinated with undergrounding electric distribution lines or gas segment decommissioning. Trenching and utility relocation costs that often comprise a significant portion of any capital planning project can be shared or even eliminated. By examining the entire system, a collaborative environment of policy, regulation, and investment can be fostered to accelerate deployments of energy transition efforts that fit Holyoke's needs.

In service of this project, the Groundwork Data team utilized data provided by Holyoke Water Works and the Holyoke Department of Public Works to develop a baseline map for recent and future large infrastructure projects.

Modeling and Approach

Data Collection

The infrastructure data required to plan city-scale energy transition includes three basic components:

1. **Network Geometries (Shapes)** of each infrastructure asset class (Roads, Water, Sewer, Gas, Electric). These are often contained in GIS systems and describe each asset class as line geometries.
2. **Age of Each Asset** for each asset specified in the GIS system containing the asset data.
3. **Type of Material and Condition** for each asset specified in the GIS system containing the asset data.

A data inventory checklist guided data-sourcing activities for the components listed above. This inventory allowed the project team to track data availability across individual asset classes for each street segment in Holyoke. Primary and secondary sources were identified across assets to highlight data requirements. When a primary data source was not found, alternate sources were identified. For example, public works permits were used to understand the installation of a new gas pipe in a certain year. This allowed the team to determine the age of the gas asset for a particular street segment. The data needs, identified sources, and statuses are detailed in a comprehensive table (Table 7).

Table 7. Data requirements and current status of data across each asset class.

Asset Class	Data requirements	Primary Sources	Secondary Sources	Status
Gas	A digital representation of Holyoke's Gas system in GIS format; Age (Year Installed) Type (Material)	Holyoke Gas and Electric	Estimation through planned project database from Holyoke	Data identified from secondary source
Electric	A digital representation of Holyoke's Electric system in GIS format.	Holyoke Gas and Electric	Estimation through planned project database from Holyoke	Data identified from secondary source
Roads-Geometry	Shapefile describing the city-wide road network layout	MassDOT via MassGIS Holyoke PMS	Open Street Map	Data identified from Primary Source
Roads - Attributes	For each street managed by the city, - Age (Year Installed) - Condition	DPW's Pavement Management System	811 Tickets	Age data identified from Primary Source
Parcel	For parcel contained within city limit, - Age (Year built) - Area, Rooms, Value	City of Holyoke MassGIS	Federal / Private	Data identified from Primary Source
Public Works Permits	Historical records showing Excavation / Trenching activities across Holyoke	DPW's Pavement Management System	811 Tickets	Data identified from Primary Source (Original data was not geocoded)
Water	Shapefile describing the city-wide water network layout as well as Age (Year Installed) of Water main and Condition of Water main	Tighe & Bond, an engineering consulting firm located in Massachusetts, handles Holyoke Water Works (HWW) GIS. HWW was established in 1872 and still utilizes critical pipelines that predate the City's incorporation. Thus, the accuracy of the installation year may be difficult to establish for the area of the City.	811 Tickets	Data identified from Primary Source (Holyoke Water Works)
Sewer	Shapefile describing the city-wide sewer network layout as well as Age (Year Installed) of Sewer main and Condition of Sewer main			

** Please note that a request was not made for broadband information as the project team was informed that this data would not be available. Telecom data is not publicly available.*

The project team then coordinated with the owners of each primary source, who represented key stakeholders for this project and included the City, Holyoke Gas and Electric, Holyoke Water Works, and Massachusetts Department of Transportation (DOT), to receive the necessary data from each. Data was requested for the following categories across infrastructure types:

1. **Planned Capital Projects** - Capital Projects that have been identified or planned for the foreseeable future. *These allow the project team to identify areas where coordinating capital projects is possible. Replacement project data also allows us to infer the age of the asset based on the install year in the case that the city does not maintain records of asset age.*
2. **Previous Capital Projects** - Capital Projects that have been completed. *Replacement project data also allows us to infer the age of the asset based on the install year in the case that the city does not maintain records of asset age.*
3. **Age of Assets** - Any available information on age - either in the form of paper maps or data stored in GIS software - for all other assets that have not had replacement activity (planned or completed replacement). *This allows the project team to identify streets that have not had a recent replacement and thus have old pipeline infrastructure that is more prime for decommissioning.*

Through coordination across entities, the project team received essential data files and integrated each separate component into a unified representation of infrastructure assets. This allowed for the identification of opportunities for coordinating infrastructure projects, areas with older gas infrastructure, terminal street segments, or areas with specific building types as described in the methodology section below.

Digital Network Asset Registry Methodology

The Digital Network Asset Registry was created by implementing a novel spatial data engineering workflow. This workflow involved cleaning street data and linking individual street segments with parcel, permit, and census data to represent a unified map of networked asset information. An illustration of this workflow is provided in Figure 21.

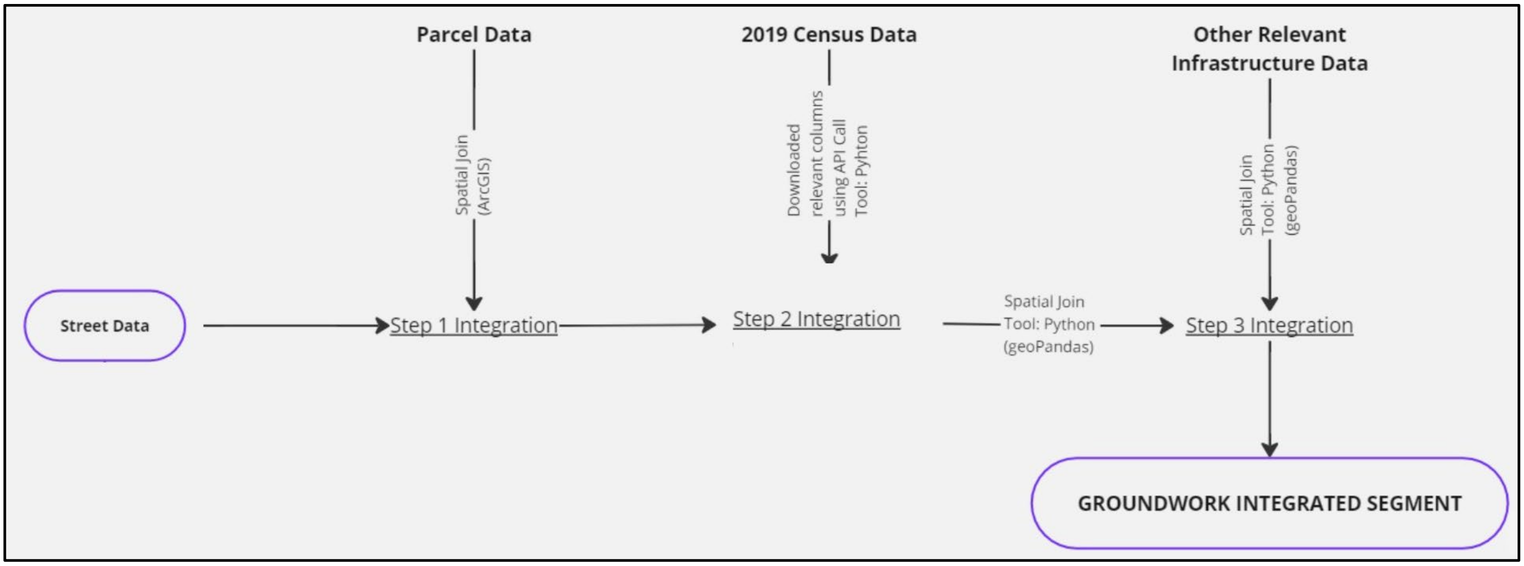

Figure 21. Spatial data engineering workflow to prepare a digital asset registry.

Once the street network map was created, gas, water, and sewer data sets were spatially linked. The linking was done through a series of spatial join operations that match features from the street segment layer to asset layers based on their relative spatial locations. All attributes from the asset layers features are appended to attributes of the individual street segments. For example, if a single gas segment runs through multiple street segments, the attributes from the gas segment are appended to all the street segments that it is connected to. The spatial join operation was repeated across all individual asset layer data.

The resulting output is a single file containing all attributes from individual asset layers appended to each street segment, forming the DNAR file. This file offers a comprehensive digital representation of all citywide networked infrastructure for energy transition and reliability planning.

Results

Utilizing the Digital Network Asset Registry

The DNAR was developed into a web-hosted map displaying individual street segments, which is available **here**. The maps, visualized in Figure 22 and Figure 23, represent a common operating picture that color codes street segments by the degree of maintenance required and allows a user to review different data fields associated with each.

The categories for repair include:

- **Major Rehabilitation:** structural enhancements that both extend the service life of an existing pavement and/or improve its load-carrying capability
- **Minor Rehabilitation:** non-structural enhancements made to the existing pavement sections to eliminate age-related, top-down surface cracking that develop in flexible pavements due to environmental exposure
- **Preventative Maintenance:** planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without significantly increasing the structural capacity)
- **Routine Maintenance:** work that is planned and performed on a routine basis to maintain and preserve the condition of the system or to respond to specific conditions and events that restore the system to an adequate level of service
- **No Maintenance:** road does not require any structural or non-structural enhancement work[74]

[74] Federal Highway Administration, “Pavement Preservation Definitions” https://www.fhwa.dot.gov/pavement/preservation/091205.cfm

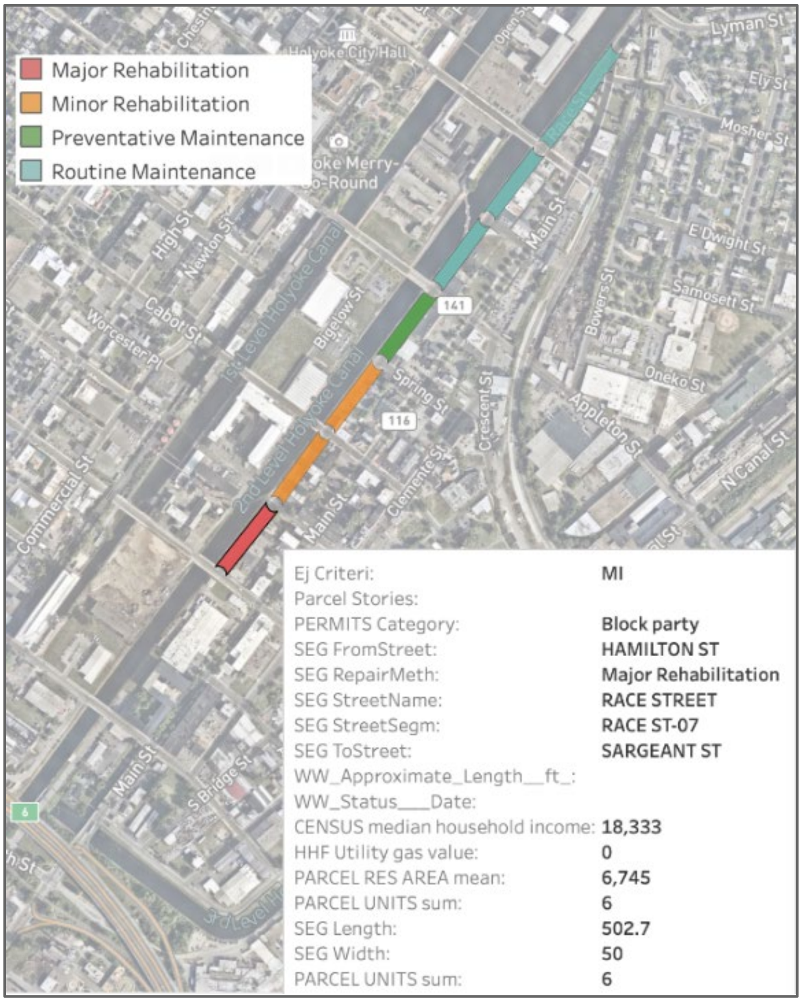

Figure 22. The Web-Hosted Digital Network Asset Registry displays Race Street in Holyoke, MA.

The segments on Race Street vary in enhancement needs from routine maintenance to major rehabilitation. The Digital Network Asset Registry allows the user to identify the street segments requiring major rehabilitation and click on them to access more holistic information, such as the type of street, the number of parcels, and gas utility information (including how many parcels utilize gas). Sergeant Street is highlighted below in Figure 23.

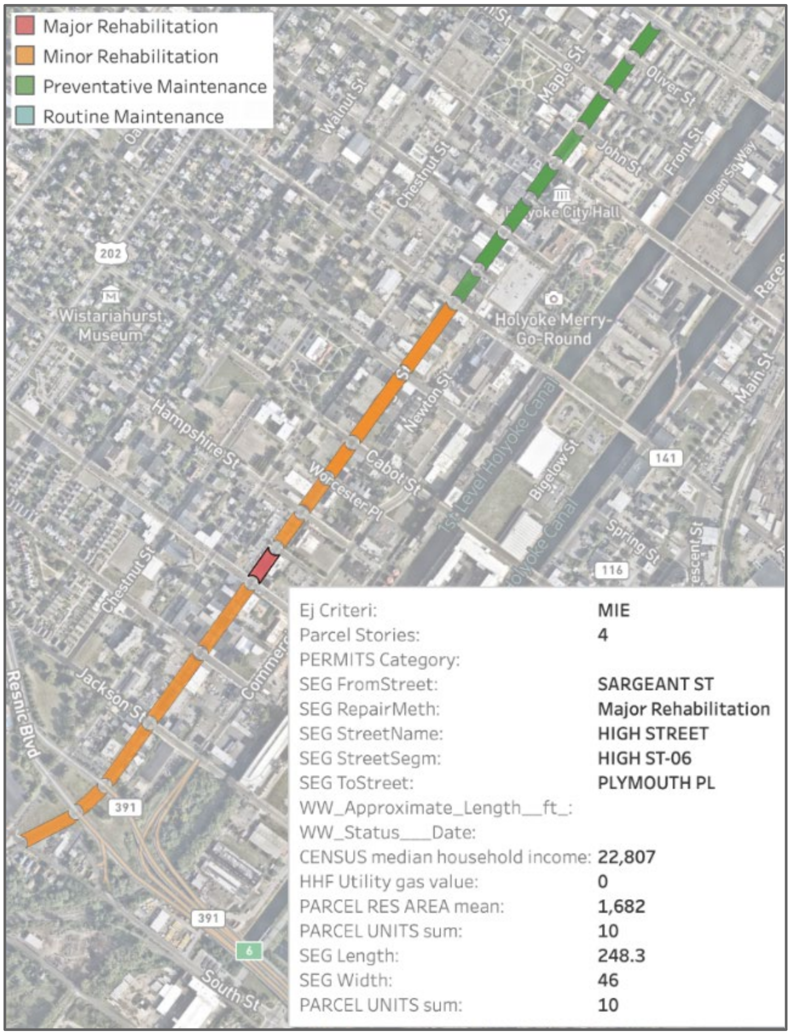

Figure 23. The Web-Hosted Digital Network Asset Registry displays Sergeant Street in Holyoke, MA.

In Figure 23 the Digital Network Asset Registry displays that a majority of street segments on Sergeant Street only require minor rehabilitation. One street segment requires major rehabilitation, and when analyzed further by clicking on that specific street, one can see that it meets all three environmental justice criteria and has 10 parcels, but none of those parcels utilize gas as their primary heating source based on the HHF Utility Gas Value field. This would therefore not be an ideal street segment to prioritize for decommissioning.

The data fields highlighted on each of the maps above are outlined in Table 8 and represent a selection of the 170+ data fields compiled for the digital network asset registry.

Table 8. Data attributes visualized in the web-hosted DNAR and a description of each.

ute Name	Description
eria	Criteria that classifies that block under environmental justice MIE: Minority Population, Low Income, Langu Isolation
Stories	Parcel Indicators - Number of stories on the parcel
ITS Category	Attributes from Pavement Management Software - Category of Infrastructure permit
epairMeth	Street Segment Attributes - Method used to repair the segment
reetName	Street Segment Attributes - Name of the street to which the segment belongs
reetSegm	Street Segment Attributes - Id Assigned to the segment of the street
Approximate_Length_Ft	Attributes from Holyoke Water Works Data - Existing Length of pipe in proposed project
Status_Date	Attributes from Holyoke Water Works Data - Status Date on the project project completion
JS Median Household Income	Median Household Income ($)
tility Gas Value	House Heating Fuel Attributes - The number of homes (in the census block associated with that segment) th use gas as their heating fuel.
L RES AREA Mean	Mean Area of Residential Parcels
L UNITS Sum	Total Parcel Units in Segment
ength	Length of Segment (Feet)
Vidth	Width of Segment (Feet)

The comprehensive metadata collected for the tool can be accessed here, and a summary of these data fields and their source category is shown in Table 9. This table summarizes the aggregation of primary, secondary, and estimates of individual infrastructure asset data at the street level. It allows the user to quickly understand the granularity of data inputs based on where the data category was received from.

Table 9. Summary of the Master Network Asset Registry attributes and sources.

COUNTUNIQUE of Column	*Source Type*				
Data Field Category	Asset - Internal	Asset - Primary	Asset - Secondary	Non Asset - Demographics	Grand Total
Census Data				31	31
Detailed Street Data		18			18
Environmental Justice Demographic Data				11	11
GIS-Generated Data	21				21
House-Heating Fuel Data		5			5
Parcel Data		53			53
Pavement Project Data		13			13
Permit Data			13		13
Water Works Data		7			7
Grand Total	**21**	**96**	**13**	**42**	**172**

Site Selection: Demonstration

This section demonstrates how the Digital Network Asset Registry is applied to site selection for coordinated strategic gas decommissioning, electrification, or undergrounding of electric distribution infrastructure. The main criteria used in this evaluation are listed below:

Dead-end Segments
Segments that can effectively be decommissioned without impacting other gas system parts, increasing feasibility of removal and thus ideal streets for selection.

Opportunity for Coordination with Other Projects (using both planned and recent water projects for a broader screen)
Coordinating multiple projects at once can save on costs by only needing to “dig once”. In this analysis, the data received from Holyoke Water Works, Holyoke’s Pavement Management System, and the City did not include data points for *planned* projects - only completed or not planned. For the purpose of this analysis, the project team therefore used the completed projects in place of planned ones, assuming that completed projects were not actually finished and could still benefit from coordination. If planned project data was provided, it could easily be integrated into the analysis.

Representative Street Segments
Street segments that represent the overall city in terms of the composition of single family and small multifamily homes, as well as environmental justice communities that are minority, low-income, or communities with language isolation. Single family and small multifamily homes also face less practical barriers to whole-building electrification compared to dense, high-energy intensity commercial space, and decommissioning should prioritize historically neglected communities.

These criteria were based on the project team's assessment of suitable locations for pilot projects that have a low risk of impacting other services but still could be used to demonstrate broader application. The project team utilized the collected data inputs and street identification criteria to perform a clustering analysis, resulting in two separate rankings of streets across Holyoke: one prioritizing only dead-end streets for gas decommissioning and one prioritizing all streets in the city.

Prior to the clustering analysis, terminal segments in Holyoke were identified and mapped to permit, pavement, and waterwork data outlining any planned or proposed projects. A list of terminal segments that have at least one permit, pavement, or water works project planned on them as well as their total residential area, is detailed in Table 10. All terminal segments that have at least one planned project on them also have residential parcels. As mentioned above, it is important to note that the project team assumed completed projects as planned for the purpose of this analysis, as no data on planned projects was received from the City.

Table 10.Terminal street segments in Holyoke and the types of project that have been completed on them.

Terminal Segment	Type of Project	Residential Area (Sqft)
Yoerg Circle	Water Works	196705
Barrett Avenue	Water Works	196705
Elting Circle	Water Works	196705
Hadley Mills Road	Permits	126747
Hanover Street	Permits	94777
Hampton Knolls Road	Permits	92674
Taylor Street	Permits	69826
Jefferson Street	Permits	68550
Berkshire Street	Permits	55705
Kelly Way	Water Works	50746
Quirk Avenue	Pavement	41625
Ivy Avenue	Water Works, Pavement	36380
LindBergh Avenue	Pavement	31476
Madison Avenue	Permit, Pavement	30578
Steiger Rd	Permit, Pavement	30207
Bay State Road	Water Works, Pavement	28066
Hampshire Street	Permit	27510
Roosevelt Avenue	Permit	27222
Alderman Street	Permit	23579
Arbor Way	Pavement	22863
Veron Street	Pavement	22604
Primrose lane	Permit, Pavement	21954
Shepard Drive	Permit, Pavement	21447
Columbia Street	Permit	20189

Michelle Lane	Water Works	20060
Gordon Drive	Pavement	19514
Magnolia Avenue	Water Works	16985
George Frost Drive	Water Works	16608
Yale Street	Permit, Water Works	14708
Isabell Street	Permit	12326
James Street	Permit	11614
Sky View Street	Permit	10597
Memorial Circle	Pavement	8437
Coit Street	Permit	4659
Blaine avenue	Water Works	3954
Oscar Street	Water Works	3315

Scaling Identification Using Multivariate Clustering

The approach to identifying areas in Holyoke that are the most conducive for strategic gas decommissioning and electrification, as well as undergrounding of electric distribution infrastructure, involved using a specialized spatial multivariate clustering algorithm.

The algorithm looks for a solution where the features within each cluster are as similar as possible and the clusters themselves are as different as possible. The algorithm then employs a connectivity graph to find natural clusters in the asset registry data and metrics describing each. Feature similarity is based on a set of input attributes specified by the project team. The project team used two clustering methods that supplied the algorithm with different sets of variables from the asset registry dataset.

Method 1 - Only Terminal Segments

The first method performed spatially constrained multivariate clustering for **only terminal segments** in Holyoke, with four equally weighted features that include:

- Percentage of residential area
- Count of permits
- Count of pavement projects
- Count of water works projects

A map of the results is shown in Figure 24, and represents the spatial location of the terminal segments that have been assigned a color based on the cluster that they belong to. A description of the clusters, their color, how many street segments fall under each, and their importance in the decision-making process can be found in Table 11.

Table 11. Cluster Descriptions and Count for Clustering Method 1.

Color	St. Count	Description	Importance
Green	10	Terminal streets with **very high** pavement and water works project counts.	Prioritized **first** for decommissioning as they have the greatest opportunity for coordination with other projects.
Blue	9	Terminal streets with **high** pavement and water works project counts.	Prioritized second for decommissioning as they have a high opportunity for coordination with pavement and water work projects, which save on costs.
Magenta	24	Terminal streets with **high** permit counts.	Prioritized after Green and Blue streets as they have potential for coordination, but with only one type of project.
Yellow	7	Terminal streets with a **high** percentage of residential area but	Prioritized after Green and Blue streets as they have potential for cost savings

		none of the other features.	when compared to other building types.
Red	101	Terminal streets with **none** of the selected features.	Should not be prioritized for decommissioning as there is no opportunity for project coordination (and therefore cost savings) and no small residential homes (cheaper than dense commercial area)

The clustering analysis used in Method 1 allows a user to easily identify which terminal streets are optimal for strategic gas decommissioning or undergrounding of electric distribution infrastructure. As discussed in the Site Selection Method portion of Task I, terminal or dead-end street segments have the highest feasibility of removal because they can be effectively decommissioned without impacting other gas system parts.

Using the map created by Method 1, a user can quickly visualize which dead-end segments also have a high amount of pavement or water work projects planned. These streets, highlighted in green and blue, are prime for coordinated decommissioning and could cut costs by only having to “dig once”. A magenta street segment could be prioritized for this reason as well, but the coordination potential is slightly smaller as these street segments only have one type of other planned project on them - permits.

A user could also look at the map and pinpoint streets flagged as yellow, which should also be prioritized for decommissioning as they are home to many small residential buildings. These sites are more cost-effective for gas decommissioning compared to dense, high-energy intensity commercial space. Red street segments are not ideal for decommissioning as they have no opportunity for coordination with other projects or residential parcels.

The user could then select street segments with a high number of other projects, dead-end street segments, or exclusively residential areas and also visualize how many parcels run on gas to estimate costs. This is a data feature available in the map, but was not included in the clustering analysis as the data on gas usage was available only at the census block level and not at the street or parcel level.

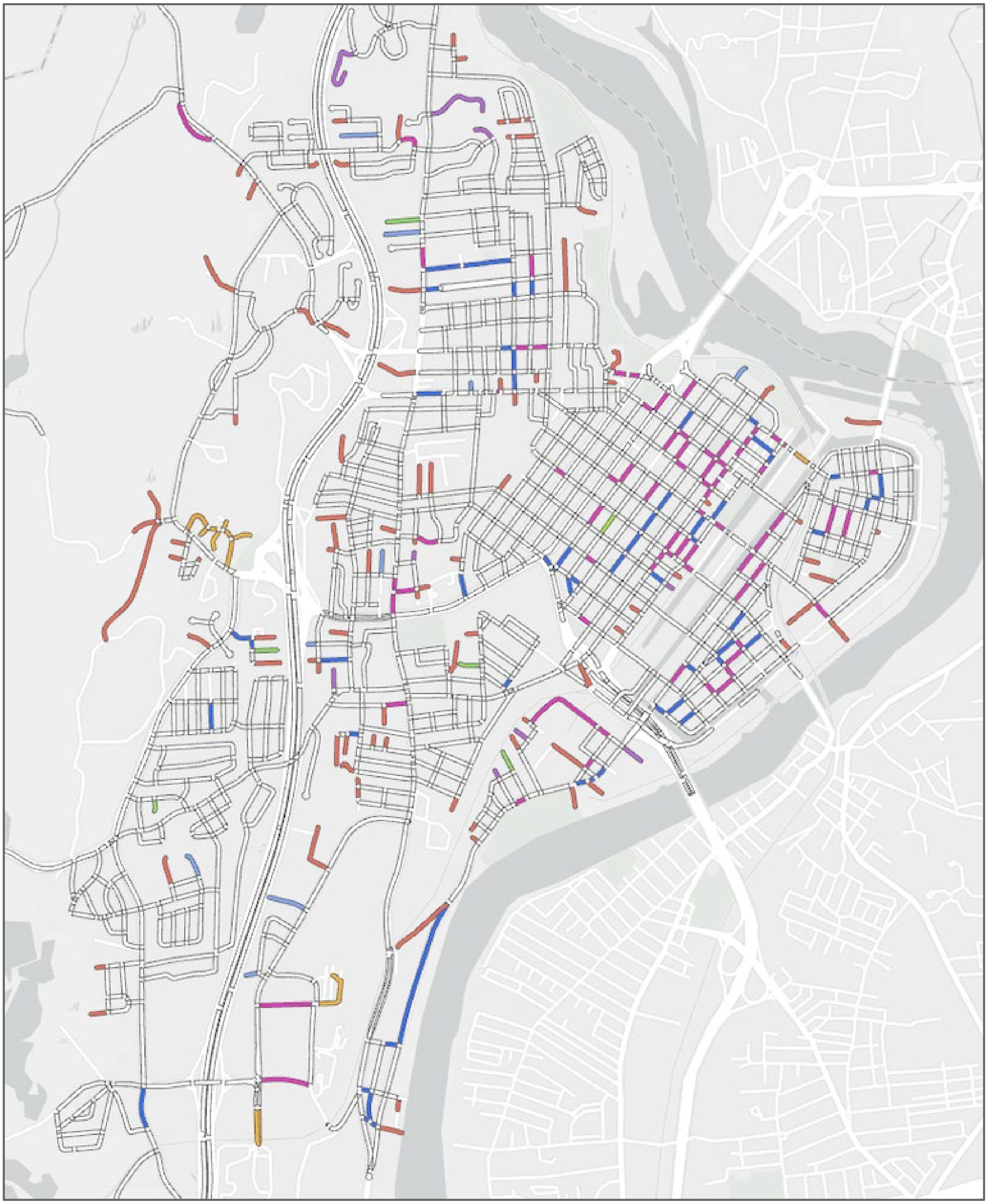

Figure 24. Terminal street segments in Holyoke highlighted by spatial multivariate cluster analysis, Method 1. Green, blue, magenta, and yellow streets are candidates for prioritization; purple, orange, and red are lower priority.

Method 2 - All Holyoke Segments

The second method performed multivariate clustering with weighted features where the highest weightage was given to terminal segments and equal or lower weight was given to the other features. These additional features are the same as in Method 1 and include:

- Percentage of residential area
- Count of permits
- Count of pavement projects
- Count of water works projects

A map of the results for Method 2 is shown in Figure 25, and represents all the street segments in the city. They are each assigned a color based on the cluster that they belong to, which are described in Table 12.

Table 12. Cluster Descriptions and Count for Clustering Method 2.

Color	St. Count	Description	Importance
Green	1	Streets with a high percentage of residential area, dead-end segments, and water works projects.	Prioritized **first** for decommissioning as they have the greatest opportunity for coordination with other projects.
Blue	62	Streets with **high** counts of pavement and water works projects.	Prioritized second for decommissioning as they have a high opportunity for coordination with water work projects, which save on costs.
Magenta	70	Streets with a **high** number of permit counts.	Prioritized third for decommissioning as they have a high opportunity for coordination with water work projects, which save on costs.
Yellow	13	Streets with a **high** percentage of residential area but **none** of the other features.	Prioritized third as they have potential for cost savings when compared to other building types.
Red	132	Streets with **none** of the selected features.	Should not be prioritized for decommissioning as there is no opportunity for project coordination (and therefore cost savings) and no small residential homes (cheaper than dense commercial area)

As with Method 1, a user could utilize the map outputted by Method 2 to visualize prime streets for gas decommissioning. The key difference between the two processes is that Method 2 does not restrict streets in focus to dead-end segments but ranks all the streets in Holyoke. Terminal segments are still weighted heavily in the clustering, given more priority than other features, but the full ranking integrates the other elements listed above. This gives the user a more comprehensive view of an area while still allowing them to visualize streets with high counts of residential parcels, water works projects, and permits.

Green streets are most ideal for decommissioning as they are terminal streets with high residential area and water works projects. This indicates that they could be decommissioned without impacting other gas system parts and will be the most cost effective due to coordinated project planning and low density housing units. Blue streets should also be prioritized as these streets have high potential for coordination across pavement, and water works projects.

Streets flagged as magenta and yellow should be prioritized after the above streets as they have coordination potential with permit projects (magenta) or will be cost-effective for gas decommissioning compared to dense, high-energy intensity commercial space, but do not have coordination potential (yellow). As with Method 1, red street segments are not ideal for decommissioning as they are not terminal segments and have no opportunity for coordination with other projects or residential parcels.

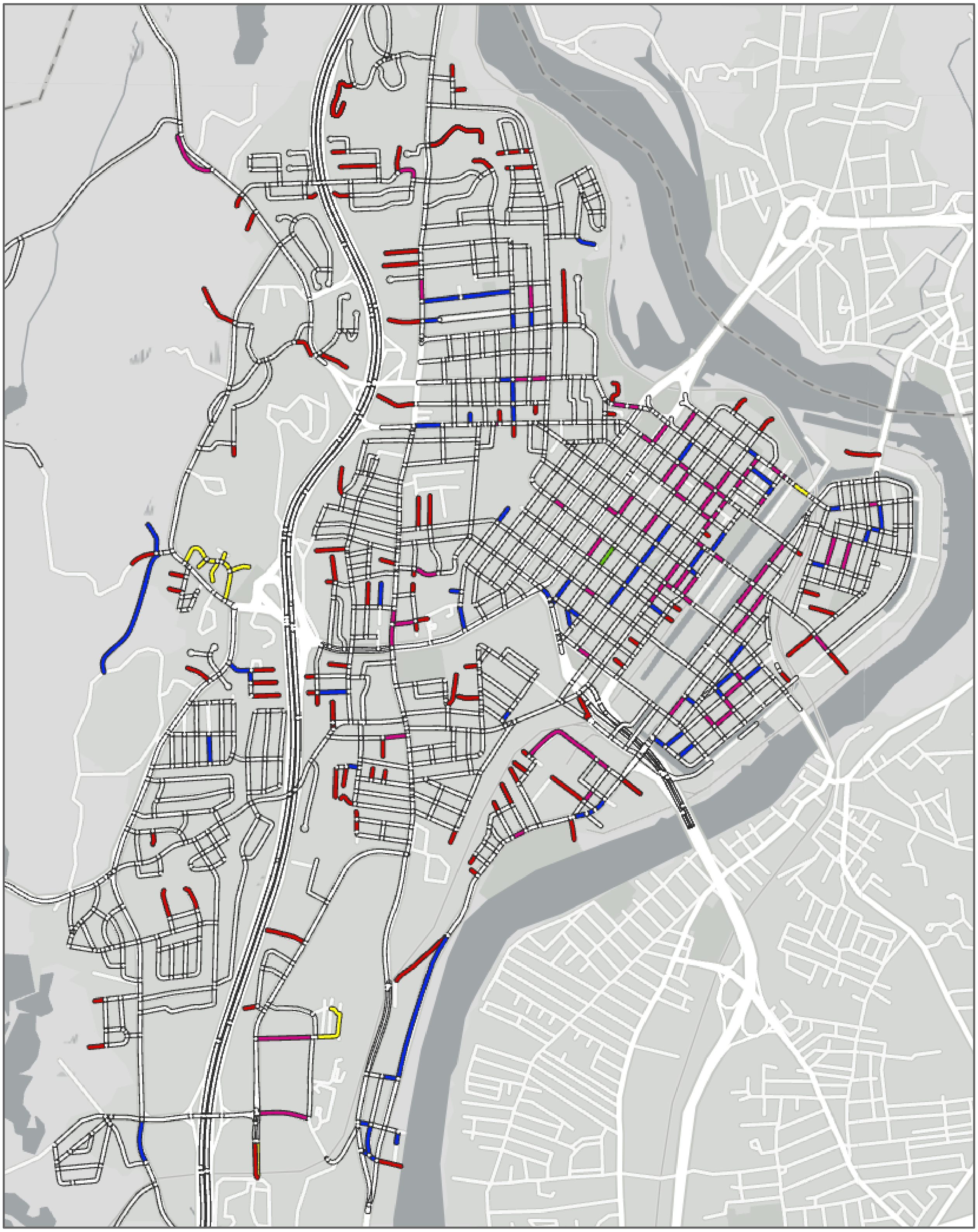

Figure 25. All street segments in Holyoke highlighted by spatial multivariate cluster analysis. Green, blue, and magenta street segments should be prioritized for decommissioning.

It is important to note that both approaches were run on limited data availability and can reveal better quality results if the algorithm has access to datasets such as historical 811 excavations, which is the number that must be called before digging can begin, related to gas main replacements and/or utility system data revealing the age of individual assets.

Recommendations and Discussion

For nearly a century, pipeline delivered methane gas has been the fastest growing source for building heating in Massachusetts and many other states across the US; as such, it has become the number one or two contributing fuel to greenhouse gas emissions in 38 states.[75] With a statewide goal of net-zero emissions by 2050, major reductions in methane gas use are required. Despite this reality, investment in gas infrastructure is increasing as aging pipes and other components of the system need to be replaced, resulting in increasing delivery costs to customers. The combination of increasing multi-decade fixed cost investments with a need to decrease gas consumption is creating an environment for financial and social disaster as higher rates push more people off the gas system and onto alternatives. While customer abandonment of gas for emerging electric alternatives is a win for emissions reduction, the burden of maintaining the legacy gas system will fall on those who can least afford it, creating a negative feedback loop, referred to as a utility death spiral.

This report demonstrates an alternative approach to business-as-usual operations and unmanaged customer departure from the gas system by introducing the concept of Local Energy Asset Planning to deliver a managed phased transition off of pipeline gas.

LEAP can support a coordinated and managed phased approach at the segment level; a novel path forward, but one that increases implementation feasibility as phasing moderates its impacts across several indicators, including cost and energy reliability. In a phased transition with zonal planning goals, there are opportunities for coordinated investment across stakeholders to decrease costs and accelerate clean energy infrastructure development.

Holyoke's legacy of being the nation's first planned industrial community makes it well positioned for the pending energy transition that will decarbonize energy consumption and enhance resiliency. Notably, its hydropower, originally intended for textile mills, is economically delivered by a municipal utility to provide residents with cheap electricity. A changing climate and ongoing energy transition efforts provide a new opportunity to plan and deploy infrastructure to improve Holyoke's economy and provide its residents with affordable energy to support their livelihoods.

Today, however, Holyoke is not starting with a blank slate ready for a plan. Its existing infrastructure plays an important role but will require modernization. To underground wires, build thermal energy networks, and deploy energy efficiency measures and heat pumps, coordinated planning will be needed to cost-effectively deploy the capital that pays dividends in affordable clean energy security. In order to achieve coordinated planning, the integration of data from these key institutions is necessary.

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[75] State energy-related carbon dioxide emissions by fuel. U.S. Energy Information Association 2023. https://www.eia.gov/environment/emissions/state/

This report demonstrates the value of segment-level planning concerning the built environment and the infrastructure supporting it. It conducts an integrated analysis of the gas transition focused on the building stock, the gas distribution system, and the electric distribution system. It further demonstrated how multiple energy datasets can be integrated to inform decision-making and coordinate projects to save on costs. While both demonstrations were innovative and can provide value to decision-makers, they were hindered by various data limitations and constraints.

These limitations and the strategies for overcoming them are listed in Table 13. It should be noted that such data integration is becoming increasingly common in Europe. Zurich, for example, operates a data warehouse[76] of infrastructure that will be used to support its transition off gas.[77] In the UK, government bodies at all levels have created a framework for data-driven, collaborative, and cost-effective net-zero action plans called "Local Area Energy Planning" (LAEP). These plans outline long-term visions for an area at a level of detail similar to a master plan and recommend near-term projects needed for the local energy system and the built environment.[78]

Table 13. Limitations and potential strategies for overcoming limitations.

Limitation	Strategy for Overcoming Limitation
Assessor's data is outdated and provides a limited understanding of building energy assets	Expand assessor's tracking to include specific building energy attributes. Regularly update data using permits and building owner outreach. Coordinate with the municipal utility to update utility service information in the assessor's tables.
Lack of detailed information on the location of leaks and leak-prone pipes.	Follow regulatory requirements of state investor-owned gas utilities. Create an annual update of pending and conducted leak-prone pipe replacement projects. Provide a more detailed public report on the state of Holyoke's distribution system, including leaks and leak-prone pipe location.
Lack of detailed information on the electric distribution systems.	Follow practice by state investor-owned electric utilities by publishing system maps describing the "hosting capacity" and utilization of feeder lines.
Risks associated with increasing data access including data confidentiality and sensitivity.	Regulatory efforts to encourage better data utilization within and outside the utility should be sensitive to these issues as planning processes are developed.

76 "Map and Data Reference - City of Zurich." Accessed July 21, 2023. https://www.stadt-zuerich.ch/ted/de/index/geoz/plan-und-datenbezug.html.
77 "Zurich Turns off Gas to Fight Climate Change and Russia : NPR." Accessed June 16, 2022. https://www.npr.org/transcripts/1092429073.
78 "Local Area Energy Planning: Catapult". Accessed July 27, 2023. https://es.catapult.org.uk/tools-and-labs/local-area-energy-planning/

Improving data and information limitations will be a critical step in transition planning in Holyoke and in the nation at large. Improvements can allow project planners to:

- **Pilot coordinated energy infrastructure projects.** Such projects could include the coordinated deployment of thermal networks, gas decommissioning, and segment electrification, undergrounding of electric and communication wires, or water and sewer maintenance.
- **Educate other customers and stakeholders**. Local energy planning can be used to inform and educate key constituencies to help accelerate the renewable energy transition.
- **Ensure equitable outcomes.** Integrating socio-demographic data with infrastructure data can help assess current disparities and improve planning or targeted actions to improve equitable outcomes.
- **Create shared, inclusive, and evidence-based action plans.** Using data acquired directly from stakeholders in the community of focus, they can be tailored to represent the specific needs of the community.