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Final Technical Report (FTR)

Cover Page

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Signature of Certifying Official *Date*

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No DEIA activities were performed post January 20, 2025 EO.

Executive Summary

Motivation, Major Goals, and Objectives

The overarching motivation of this project is to provide stakeholder-engaged research and education to enable a clean, equitable, and resilient energy transition. Presently, low-income communities and people of color are disproportionately burdened by environmental harm, while also being routinely left out of planning processes and benefits from infrastructure improvements. The Energy Transition Institute (ETI) addresses these issues in three ways: community engagement, educating diverse future leaders, and cutting-edge research. As municipalities across the Commonwealth plan their transition to a climate-friendly energy system, research from ETI will advance technical and social understanding of heating electrification, energy storage, demand flexibility, reliability and resiliency of power distribution infrastructure, with attention to equity. This will benefit surrounding communities, cities and towns across Massachusetts, and the global research community

The main goals of this project are (1) to establish a paid internship to provide students with a multidisciplinary research experience focusing on community stakeholder engagement and education to enable a clean energy transition, and (2) to develop a research program integrating energy transition research with stakeholder engagement, with a focus on efficient infrastructure planning.

Technical Achievements

We completed the White Paper Equitable Energy Transition Planning in Holyoke Massachusetts: A technical analysis for strategic gas decommissioning and grid resilience; and have a paper that was published in Cell Reports Sustainability on co-undergrounding broadband and power lines. Additional papers were published in ACM Journal on Computing and Sustainable Societies and in Proceedings of the 14th ACM International Conference on Future Energy Systems. We hosted workshops and meetings with community members, the mayor’s office, and Holyoke Gas and Electric and partnered with OneHolyoke on green building workshops. We hosted numerous events that bring established research collaborations across campus. We have hosted about two dozen diverse undergraduate researchers during summers 2022, 2023, 2024, and 2025 and partially supported 7 graduate students.

Impact

The technical analysis of strategic gas decommissioning is an important step forward in helping communities, across the country, move toward net zero in an equitable and cost-effective manner. The development of relationships, both on campus and in the community, to support community-based participatory research will lead to years of fruitful research that is responsive not to academics but to the people on the ground who are affected. Graduate training and the undergraduate program are crucial aspects of human resource development in science and technology. This program provides opportunities to a wide range of students, including those woefully under-represented in this field.

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Background

Enabling an Equitable Energy Transition In Holyoke - Background [1]

The energy system transition refers to the shift toward more renewable, less polluting, and sustainable energy infrastructures [2], [3]. It includes changes in generation—such as replacing fossil fuels with clean or renewable sources—as well as in transmission, consumption, and storage. The transition also involves social dimensions, including consumer behavior, policy frameworks, and spatial inequalities shaped by power relations [4]. While experts model efficiency, demand, and renewable potential, many social actors struggle to envision what Emily Grubert and Sara Hastings-Simon term the “mid-transition”—the messy period when fossil-based and zero-carbon systems coexist (p. 1) [5]. Our research addresses the energy transition as a sociotechnical process by integrating community-based participatory research in affected communities with more technical research on energy modeling and engineering.

The primary location of our investigation is In Holyoke Massachusetts. In Holyoke, 47% of residents are reliant on gas for heat. 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 [6].

Below we discuss how current literature relates to the research areas undertaken during this project. Information is organized by theme.

Optimizing Carbon and Cost for Flexible Residential Loads [7]

Buildings account for 30% of global energy consumption and 26% of global energy-related emissions, as per the IEA [8]. Consequently, decarbonizing the building sector has emerged as a critical challenge in our society’s transition to a low-carbon future. Traditional methods to reduce a building’s carbon footprint have focused on increasing the penetration of renewable energy sources in the electric grid or installing distributed renewable systems, such as rooftop solar, directly on buildings. Other efforts have focused on electrification of gas-based building heating systems or the use of distributed energy storage systems [9], [10], [11]. While these approaches have proven effective, they come with substantial infrastructure investment costs and only partially address the broader decarbonization challenge [12].

In contrast to these supply-side methods, a complementary approach is demand-side carbon footprint optimization, where a building modulates its energy (and carbon) demand over time to optimize its overall carbon footprint. Since the carbon intensity of electric supply is known to vary over time—for example, due to intermittent generation from renewables—such demand-side techniques can schedule flexible building loads or time-shift them to periods of low carbon intensity, thereby performing the same work at a lower carbon footprint. While carbon-aware load scheduling in buildings is a relatively new problem, building load scheduling is well-studied in other contexts.

Scheduling of flexible loads via time shifting has been well studied in other contexts. For example, prior efforts have studied load scheduling techniques to address problems such as peak load shaving and cost optimizations in the presence of variable electricity pricing [13], [14], [15], [16], [17]. Automated demand-response optimization has also explored delaying or time-shifting loads to reduce energy demand during periods of grid stress [12], [18], [19]. More recently, researchers have begun to explore load scheduling for optimizing carbon footprint of buildings or grid loads [20]. While prior load scheduling approaches can provide inspiration for optimizing the carbon footprint of buildings, they cannot be applied directly for two reasons.

First, carbon reduction techniques solely focus on variations in energy's carbon intensity, measured in $g \cdot CO_2eq/kWh$; however, it does not account for variations in electricity prices, increasing the total electricity cost incurred while reducing carbon emissions. While users may want to reduce their buildings' carbon emissions, they may be unwilling to incur higher electricity bills or may even want to reduce them. This introduces carbon and cost tradeoffs that have not been addressed in prior work.

Second, scheduling techniques that rely on time-shifting flexible, low carbon, or low electricity cost periods can increase user inconvenience since loads, such as laundry cycles or EV charging, take longer to complete. Reducing user inconvenience by mapping user preferences to delays that are tolerable is an important aspect of the usability of such techniques. Such carbon-user convenience tradeoffs have also not been explored in prior work.

Motivated by the above challenges, one aspect of our work studies GreenThrift, a carbon-aware scheduler for flexible home loads, that utilizes real-time carbon intensity signals from the grid and variable pricing signals to reduce carbon usage while optimizing cost and meeting user constraints. Specifically, scheduling of flexible building loads in GreenThrift considers a three-way tradeoff between carbon, energy cost and user constraints. Through careful scheduling in the presence of real-world constraints, our GreenThrift approach demonstrates that it is possible to achieve meaningful carbon reductions in residential buildings while also optimizing electricity costs and reducing user inconvenience from such time-shifting methods. In designing, implementing, and evaluating GreenThrift, our article makes the following contributions:

We present an analysis of the potential conflict between energy's carbon intensity and prices to demonstrate scenarios where reducing carbon emissions may come at the expense of increasing monthly electricity costs.

We present GreenThrift Algorithm, a joint optimization approach that can optimize carbon usage and electric cost while respecting user constraints. We discuss how to embed this optimization into an online scheduling algorithm that can dynamically time-shift flexible loads in a building while leaving inflexible loads untouched.

We evaluate the efficacy of GreenThrift using real-world carbon intensity and variable electricity data from different regions of the United States.

Co-undergrounding Electric and Broadband Lines [21]

Most power distribution networks in the US rely on legacy infrastructure, with wires strung from utility poles. As of 2012, about 75% of new distribution and transmission lines built in the US were overhead [22]. While these systems generally maintain a high level of reliability, they remain susceptible to weather-related disruptions due to their exposure to external conditions [23], [24], [25], [26]. The telecommunications industry has similarly focused on developing wireless technologies and new business models, which have in some cases delayed the deployment of essential fiber optic infrastructure. This has left some regions, particularly those with older overhead broadband infrastructure, more vulnerable to service disruptions and less capable of meeting modern high-speed internet demands [27].

Given these vulnerabilities, the importance of reliable power and broadband services is becoming more apparent in the context of increasing climate impacts and the need for effective mitigation strategies. Extreme weather events, such as Hurricane Beryl [28] and Hurricane Maria [29], have highlighted vulnerabilities in the power grid, leading to notable outages in recent years [30], [31], [32]. A key strategy for climate change mitigation is electrification [33], [34], which has further highlighted the need for reliable electricity, especially in cold climates where a power outage could be extremely dangerous [35], [36]. Broadband is increasingly important with the growth of the internet [37], and its role in the power system is expected to expand, particularly as more intermittent renewable energy sources are integrated into the grid. Technologies such as virtual power plants, demand-side management, and smart appliances and buildings are likely to play a key role in managing a net-zero grid, all of which depend on reliable broadband access [38]. As such, efforts to improve the reliability of both power and broadband services are becoming more critical.

The potential benefits of undergrounding in minimizing disruptions caused by weather events are evident [24], [39], [40], [41]. Yet, there are significant challenges, including high installation costs, complex maintenance requirements [22], and negative environmental and safety impacts [42]. For instance, high-density cities have been undergrounding electric and telecommunication infrastructure since the late 18th century [43]. As an example, densely populated areas of New York City have benefited from underground distribution networks since the blizzard of 1888, with 86% of its electric lines now undergrounded to reduce service disruptions [44]. In contrast, less-dense cities, such as Riverside, California, face greater per capita costs of undergrounding, resulting in a patchwork grid of largely overhead wires [45]. Thus, the economic feasibility of such projects remains a topic of ongoing analysis [23], [24].

Recent technical improvements in physical and digital infrastructure, including alternative approaches such as pipe-lining technologies, design standardization, auger boring, fast micro-tunneling, and plowing-in cables, have significantly reduced the cost of underground installation by as much as one-third [46]. Co-undergrounding electric and broadband lines in the same trench can also significantly reduce costs, [47] while providing the benefits of resilient and reliable networks [48], [49]. This co-undergrounding approach is essential not only for cost efficiency but also for resilience, as it simultaneously protects these interdependent services and ensures operational continuity during disruptions.

Multi-purpose utility tunnels (MUTs) have been extensively studied as a solution for consolidating utility lines in dense urban areas, where shared tunnels reduce long-term costs and minimize maintenance disruptions [50], [51], [52]. These studies emphasize the role of public-private partnerships in cost-sharing [53], life-cycle-cost analyses that identify economic tipping points for MUT adoption based on utility density and excavation frequency [54] and models for cost-sharing fairness to ensure balanced benefits for participating utility companies [55]. Advanced construction techniques, such as trenchless and micro-tunneling methods, have also been explored for their potential to optimize project efficiency and reduce social disruptions, such as traffic delays and noise [56], [57], [58]. However, MUT studies primarily focus on urban environments and do not consider the unique challenges of less-dense areas, where higher per capita costs and dispersed infrastructure make such approaches less feasible. Moreover, these studies do not comprehensively address aspects such as environmental safety, aesthetics, and broader societal impacts, which are essential for evaluating the full implications of co-undergrounding.

Despite advances in undergrounding studies and related construction techniques, there remains a gap in comprehensive analyses of long-term cost-benefit trade-offs across various undergrounding strategies, especially in less-dense areas. A key gap in existing knowledge lies in understanding the specific conditions under which undergrounding becomes cost effective and how these conditions might vary when considering the co-deployment of fiber optic lines for broadband. For instance, while some studies indicate that outages in underground systems are substantially less frequent and shorter in duration compared with overhead systems [22], [24], others show smaller gains [59], [60]. This disagreement highlights the need for analysis that transparently incorporates assumptions on how undergrounding impacts the likelihood of outages. Additionally, despite advances in trenchless technology, improved materials, and innovative installation techniques [61] and substantial cost reductions from co-undergrounding fiber optic and electricity lines, no research has yet quantified the costs and benefits of a range of undergrounding strategies. Existing research often overlooks the integration of broadband infrastructure [22], [24], which is crucial not only for supporting a range of smart technologies essential for a low-carbon energy system but also for enhancing cost effectiveness. Moreover, comprehensive data-driven segment-specific cost models that incorporate local variability in environmental and demographic factors are lacking, which is critical because these factors can significantly impact the overall cost and feasibility of undergrounding projects.

To address these critical gaps, we develop a novel data-driven cost-benefit approach for evaluating a range of undergrounding strategies for electric and broadband networks, making several key contributions to advancing the financial feasibility and technical understanding of undergrounding utility lines. First, we develop a segment-specific cost model that incorporates local factors such as soil type and density, offering more precise estimates compared with regional averages. This model is validated through a detailed case study in Shrewsbury, Massachusetts and can be readily applied to other small cities to inform decision-making for similar municipalities. Second, our framework implements multiple policy dimensions, including both independent and co-undergrounding, across nine strategies, providing comprehensive insights for utility planners. We provide a clear understanding of cost effectiveness when considering the co-deployment of electricity and broadband lines, highlighting potential synergies and cost savings. Third, we examine the conditions under which undergrounding is justifiable in rural and semi-rural areas, thus addressing a major gap in the literature on less-dense regions. For example, this analysis parameterizes the effectiveness of undergrounding in terms of how it impacts the frequency and duration of outages. By addressing these gaps, our approach advances the technical and financial understanding of undergrounding, offering actionable insights for utility planners and policy-makers in diverse regions.

Residential Demand Response in low-income communities [62]

The electricity sector will be a key player in decarbonizing the energy system [63], as will the residential sector [64]. Satisfying peak demand has become one of the greatest challenges for utilities. As an alternative to increasing generation and infrastructure, Demand Response (DR) is an efficient and environmentally responsive alternative [65].

Early residential DR studies borrowed heavily from studies on the industrial [66] and commercial sectors [67], centering on modeling, incentive design, and technology deployment. These approaches soon proved insufficient for the disaggregated and diverse patterns of household energy use, where socio-economic, demographic, and social practices play a critical role [68], [69]. We investigate the literature on residential DR, with attention to the number of papers that address – or don’t address – topics relevant to low-income and other vulnerable households.

There is untapped potential in the residential sector [70], where energy use is both significant and variable [71]. Not only does DR have potential to reduce pressure on the electricity grid and reduce system costs, but it also has the potential to benefit consumers through increasing thermal comfort, reducing health risks, and reducing the cost of electricity bills [72], [73], [74]. If done well, it could enable financial benefits to low-income households [75], who have often been left out [76], [77].

Including vulnerable households in analyses of DR is important since energy burden and behaviors to avoid energy costs are significant for them [78], [79]. This issue is particularly pronounced in rural or minority communities, especially in the southern US [80], [81]. While allocating up to 20% of their income on utilities, compared to around 3.3% for higher-income households [82], [83], this segment of the population often struggles to meet basic energy requirements such as heating, cooling, and cooking, in addition to experiencing to persistent health and comfort issues [84], [85]. Vulnerability increases for households that do not own homes: landlords are not incentivized to seek energy savings since they often do not directly cover utility expenses, leading low-income renters to be exposed to higher utility costs or face increases in the rent [79], [86].

One aspect of our work was a review paper on residential DR programs, with a focus on the United States. We narrow our focus to the US as the specifics of the culture, the energy system, and regulatory environment differ from the EU and from less developed regions. The US is distinct in its specific historic racial injustices; and these have been shown to overlap with energy injustice [87]. Moreover, the open market configuration of the wholesale electricity market in the US, the fact that consumers in some states can choose their own provider [67], [75], [88], [89], and the prevailing rate structure with a flat base for the residential sector that reflects generation, transmission and distribution costs, have particular impacts on the most vulnerable households [90], [91].

We find that research about consumer-side motivations, habits, and needs is scarce in the already limited DR literature for the residential sector [85], [92]. Moreover, there is evidence that many DR programs have not effectively reached vulnerable group households [93], [81]. There is opportunity for future research to suggest effective ways of lifting barriers, and unlocking the potential DR can have to simultaneously benefit households and the grid.

Applying a Governance Lens to Renewable-Energy Siting [94]

We contribute to and extend a growing body of work that treats renewable energy siting and permitting not merely as regulatory bottlenecks but as challenges of institutional design within polycentric governance systems. Building on Ostrom's foundational theory of polycentric governance [95], [96], [97], which emphasizes multiple semi-autonomous decision centers requiring coordination, this research develops a Governance Trade-Off Matrix that operationalizes those theoretical insights. Prior analyses, such as Biehl et al. (2021) [98] and Juerges et al. (2018) [99], have shown that polycentric systems can improve adaptability and legitimacy only when accompanied by explicit coordination mechanisms. This project leverages that insight directly: the matrix identifies concrete coordination levers—including unified dockets, lead agencies, statutory clocks, and single administrative records—that make coordination measurable and institutionally actionable.

We also advance empirical research on variation in permitting authority across the United States. Drawing on Enterline and Valainis (2024) [100], who classify siting regimes by local, state, or contingent authority, the project anchors the "authority" dimension of its matrix in existing empirical typologies. Yet it extends that work by linking authority structures to outcomes of speed, voice, predictability, and veto opportunity, turning descriptive typologies into explanatory models. Similarly, the project builds on the National Academies of Sciences (2024) [101] recommendation that early, structured, and well-resourced engagement can accelerate consensus and reduce litigation risk. Within the matrix, these engagement practices are situated in the "extensive but coordinated" quadrant—formalizing when participation supports, rather than impedes, timely and legitimate outcomes.

At the same time, we deepen the literature on procedural legitimacy and local acceptance. Prior studies [102], [103], [104] document that local opposition often reflects procedural, rather than technological, dissatisfaction. By contrast, the Governance Trade-Off Matrix situates participation design—its timing, influence, and structure — within a broader institutional context, showing how engagement can be an instrument of both legitimacy and efficiency. Findings from Susskind et al. (2022) [105] and Nilson & Stedman (2023) [106] on the role of veto points are directly leveraged to identify governance configurations most vulnerable to procedural deadlock. Likewise, the project integrates environmental justice findings from Donaghy et al. (2023) [107] and O'Shaughnessy et al. (2023) [108], demonstrating that permitting delays and uncoordinated decision-making can prolong fossil-fuel exposure and spatial inequities, making design reform not only a question of speed but of fairness and accountability.

In sum, it distinguishes itself by transforming long-standing debates over "permitting reform" into a research-based design framework for institutional improvement. It shares with prior scholarship a commitment to procedural legitimacy and inclusive governance, but it uniquely links those normative goals to empirical, testable hypotheses about institutional configuration and performance. By synthesizing the latest evidence from governance theory, social acceptance research, and environmental justice scholarship, the Governance Trade-Off Matrix provides a systematic way to diagnose permitting bottlenecks and identify targeted, evidence-based reforms. In doing so, it situates this work squarely within—and advances—the contemporary state of the art in clean energy siting, offering a framework that is both analytically rigorous and practically implementable.

Modelling Shared Energy Storage in Marginalized Communities

Ensuring that the benefits of the energy transition are equitably realized is essential for the long-term success of today's planning decisions. Distributed energy resources that enable local ownership through tax rebates, price-based incentives, and other policy frameworks can improve local participation and community wealth. Yet, evidence [109], [110], [111] from studies of early adopters suggests these benefits have disproportionately flowed to higher-income households, revealing persistent barriers to entry for low-income consumers. Battery energy storage systems can serve as an equity asset that provide both energy system and non-energy benefits that enhance both community resilience and localize benefits [112], [113], [114]. Households can dispatch behind-the-meter storage to shave peak demand, easing stress on the grid, improving reliability and operational efficiency, and lowering bills for customers on time-varying rates. Thus, storage has the potential to deliver both system-level and household benefits with broader societal gains.

In vulnerable communities, energy storage systems can also reduce dependency on expensive and polluting peaking power plants and enhance local energy security during grid disruptions. Despite the increasing accessibility of these systems, they remain out of reach [115] for many marginalized communities [113], [116], [117], [118]. The affordability challenge is evident when examining the price of residential storage systems currently on the market. For example, the Tesla Powerwall 3 averages $9,300 for 13.5 kWh, while other systems such as the Enphase IQ Battery or Generac Pwrcell range between $3,000 and $20,000 depending on capacity. For many households already facing high energy burdens, these costs are unattainable without new ownership and financing structures.

Shared energy storage offers a potential pathway to overcome these barriers and extend the benefits of storage more equitably. By pooling resources, households can share the costs of a storage system, potentially lowering the financial threshold for participation [117], [119], [120]. Because individual households seldom peak at the same time, aggregating heterogeneous loads reduces peak coincidence and variance, yielding a smoother net-demand profile; shared batteries therefore cycle more regularly and at higher throughput than standalone units, improving effective capacity factor and economics [120], [121], [122]. In addition to cost savings and grid benefits, shared ownership structures can distribute risks more broadly and open up opportunities for building community wealth. These arrangements can create a sense of autonomy and control that is often missing when clean energy assets are owned and operated by utilities or third parties [117], [119].

Our study addresses key gaps in the literature on shared storage through several methodological innovations. First, we develop a simulation framework that systematically evaluates individual battery dispatch, pairwise optimization, and joint optimization across multiple households within geographically defined communities, moving beyond simplified collaborative scenarios to examine a wider spectrum of collaborative arrangements. Second, we explicitly model and investigate real-life household heterogeneity by selecting participants within census block groups and assessing how collaborative benefits vary across different consumption patterns and sociodemographic characteristics under various electricity pricing schemes. Third, we introduce equity-focused metrics that assess whether collaborative storage reduces, maintains, or exacerbates existing energy burden disparities within communities, connecting collaborative optimization with spatial equity assessment.

By integrating techno-economic optimization with spatially explicit equity analysis at the census block group level, this work contributes to understanding how collaborative energy storage can be designed and implemented to achieve both economic efficiency and distributive equity goals within real community contexts.

Climate Resilience Plans in Massachusetts

Adaptation, Resilience, and Transformative Change

The United States (U.S.) has a history of exposing lower income and minoritized communities to greater climate risks (e.g., extreme heat, flooding) and providing unequal access to resources before, during, and after disasters [123]. Dominant adaptation and resilience approaches tend to reinforce such injustices, for example by excluding those communities and ignoring root causes of social vulnerability [124], [125]. More just approaches to adaptation and resilience would influence how people survive and thrive in a climate changing world [126].

Shi & Moser (2021) [127] call attention to the imperative for transformative climate adaptation. They describe it as "…not just about 'climate-proofing' existing structures and systems but about deliberately and fundamentally changing systems to achieve more just and equitable adaptation outcomes" (p.2). While status quo adaptation addresses 'end-point vulnerability' (i.e., the most visible symptoms of it), transformative adaptation focuses on 'starting-point vulnerability' (i.e., the root causes of it) (Shi & Moser, 2021, p.2) [127]. Transformation means shifting the conditions that hold systems in place – which include policies, practices, resource flows, relationships, power dynamics, and mindsets [127]. All these conditions can shape systems, but deeper and more transformational change comes from relational and mindset shifts. Similarly, the 'transformations towards sustainability' literature refers to fundamental changes in socio- technical-ecological systems that lead to more sustainable and equitable interactions and outcomes [128].

Transformative governance refers to "…the formal and informal (public and private) rules, rulemaking systems and actor networks at all levels of human society that enable transformative change…" (p.21) [129]. These scholars propose that transformative governance must be simultaneously: 1) integrative (i.e., local solutions affect other issues and scales), 2) inclusive (i.e., empowering those whose interests are not being met), 3) adaptive (i.e., enabling learning, reflexivity, experimentation), and 4) pluralist (i.e., incorporating different knowledge systems) [129]. In resilience contexts, transformative governance would include representation of vulnerable groups and prioritization of their needs. It would aim to preserve a community's specific capabilities under threat from climate change [126], [130], with community knowledge as the basis for planning and action [124]. It would promote social learning [131] that fosters reflexivity and mindset change [127] towards just and sustainable values. This kind of governance requires, and can build, adaptive capacities (e.g., systems thinking) and relational ones (e.g., navigating emotion-laden dialogues) [132] within institutions and individuals.

Cattino & Reckien's (2021) [133] review found that a higher level of participation in local adaptation planning meant transformative outcomes were four times more likely. They characterized transformative adaptation as departing from the status quo, using innovative governance approaches, transforming both people and institutions involved, and laying the foundation for systemic equity changes. They noted conditions for transformation that appeared as themes, including: 1) recognition of all actors, especially the most vulnerable ones; 2) clear and meaningful engagement throughout the process; 3) full decision-making power of participants (i.e., to develop alternatives and direct the planning process); and 4) adaptation options and processes that support a logic of welfare. Their study suggests that the public has higher ambitions for adaptation than those in power.

Transformation in Massachusetts Resilience Program

Cities and towns across the U.S. have written climate resilience plans. In Massachusetts, many are using state grant funding to revisit their resilience priorities right now, with the explicit goals of centering social vulnerability and engaging vulnerable groups. The Municipal Vulnerability Preparedness (MVP) 2.0 program is an attempt to change the status quo in adaptation and resilience work by bringing new voices into decision-making power, recognizing their labor, addressing root causes of vulnerability, and investing in social infrastructure. It aims to build capacity for equity-focused community engagement within teams of municipal staff and community liaisons, expanding the stakeholders typically involved in resilience decisions.

MVP 2.0 is an example of the state attempting to shift material and structural conditions (i.e., policies, practices, resource flows) to influence more relational, procedural, and transformational ones (i.e., relationships, power dynamics, mindsets). The program is discussed by state actors with language of transformation (e.g., “paradigm shift” and “undoing systems”). As designed and written, the MVP 2.0 process explicitly calls on municipalities to consider such fundamental changes. For example, in the grant documentation, municipalities must report on whether the adaptation measures they intend to implement are indeed transformative – providing descriptions, concrete examples, and comparisons to more reactive or preventative measures.

One aspect of this project uses mixed methods research to explore implementation of this state grant program in several municipalities. Using ethnographic methods and interviews, this work investigates how municipalities navigate the process and how individuals make sense of their experiences in it.

Project Objectives

Overview

The objective of this project was to develop a stakeholder-engaged integrated research and education program, with a focus on marginalized communities and students from underrepresented groups as part of the Energy Transition Institute at University of Massachusetts (UMass) Amherst.[1] The main goals of this project were (1) to establish a paid internship to provide students with a multidisciplinary research experience focusing on community stakeholder engagement and education to enable a clean energy transition, and (2) to develop a research program integrating energy transition research with stakeholder engagement, with a focus on efficient infrastructure planning. As municipalities across the Commonwealth of Massachusetts plan their transition to a climate-friendly energy system, research from this project will advance technical and social understanding of heating electrification, energy storage, demand flexibility, and reliability and resiliency of power distribution infrastructure, with attention to equity. Leveraging the capabilities of the UMass' Energy Transition Institute, this project will support and enhance activities providing students with a research experience at the intersection of energy technology and equity, to the benefit of cities and towns across Massachusetts, and the global research community

The research and education internship program developed by this project will build capacity and workforce dedicated to community-based research to enable an equitable energy transition for Holyoke, Massachusetts, an environmental justice community. In this project, the energy transition refers to the transition from the current system to one that is net-zero carbon, with a focus on Holyoke. Presently, low-income communities and people of color are disproportionately burdened by environmental harm, while also being routinely left out of planning processes and benefits from infrastructure improvements. The project focuses work on three primary areas: (1) Strategic Gas Decommissioning and Undergrounding Electric Infrastructure in Holyoke, (2) Holyoke Community Engagement, and (3) a Community-based research incubator program.

Technical Scope Summary

This project builds a new research and education program under University of Massachusetts Amherst's Energy Transition Institute (UMass-ETI) focusing on community-engaged research to support an equitable and resilient energy transition, through the following activities:

- Conduct technical analysis for strategic gas decommissioning and undergrounding electric infrastructure efforts in Holyoke. This activity will pilot an approach to efficient infrastructure planning that will help Holyoke move forward with cost-effective and equitable infrastructure planning and provide a proof of concept that can be applied to a wide range of communities.
- Conduct stakeholder-engaged technical research and social science research in Holyoke that brings together (1) technical analysis, including data science, to identify and define geographic areas within the city that would be optimal for

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[1] The Energy Transition Institute @ UMass Amherst (energytransitionumass.org)

strategic gas decommissioning and electric undergrounding efforts with (2) engagement with the city at many levels, including working with community partners to reach and obtain feedback from diverse and low-income residents. We will hold community meetings that include information sharing on technical aspects of the energy transition and the infrastructure studies, as well as focus groups and activities aimed at understanding community preferences in the energy transition. We will gather feedback about the infrastructure projects, for example, identifying community perspectives on the impacts of decommissioning natural gas pipelines and other energy transition planning in Holyoke, such as a possible geothermal project. The outcome of the engagement will be an understanding of community preferences and priorities.

- Develop an incubator research program that will provide integrated research and education opportunities for diverse undergraduate students and spur innovative collaborative research across disciplines. We will have a Research Experience for Undergraduate (REU) program that will immerse students in research, and we will support graduate research assistants. We will conduct outreach activities, such as hosting community events to develop a network of community leaders, faculty, students, and other stakeholders to engage in research initiatives. Outreach activities can include, but are not limited to, co-sponsoring activities such as film showings combined with panel discussions, an Energy Transition Symposium, and participation in campus career days. Networking activities include co-sponsoring events like a sustainability mixer and an ideation activity with the Public Interest Technology group on campus, aimed at bringing together diverse disciplines to solve important problems at the intersection of energy technology and social equity. The outcomes from these activities will help to inform the trajectory of the research that takes place within the incubator research program.

Task 1.0: Technical Analysis for Strategic Gas Decommissioning and Undergrounding Electric Infrastructure Efforts in Holyoke.

Task Summary: Provide data services to the City of Holyoke, Massachusetts and Holyoke Gas & Electric in the form of collecting and evaluating existing public, utility, and proprietary data sources. The purpose of the data services is to support a clean, equitable, and resilient local energy transition. The outcome will be a technical analysis of the city's and municipal utility's (Holyoke Gas and Electric) infrastructure that identifies and defines geographic areas within the city that would be optimal for strategic gas decommissioning and electric infrastructure undergrounding efforts. The strategic gas decommissioning efforts are in response to the Commonwealth's review of "the future of gas" as it pertains to gas heating and the limited body of applied research on non-gas alternatives. The strategic undergrounding efforts build off previous UMass research on the benefit-to-cost ratio of undergrounding electric infrastructure when construction is coordinated with other activities. Previous analysis by UMass suggests that coordinated infrastructure activities, including gas line replacement or full electrification, may increase the benefit-to--cost ratio of undergrounding electric distribution infrastructure. Given the significant overlap in the data and modeling required for both evaluating non-gas alternatives and evaluating undergrounding costs, we believe that advancements can be made in research and local understanding of these activities. The deliverables of this task include a framework schematic for a computational model to support infrastructure analysis, a computational model, infrastructure data profile to enable site selection, a report on data gaps, modeled decarbonization scenario analysis, a municipal network asset registry and map using primary and non-primary data, and multi-asset scenario analysis of combined gas decommissioning and undergrounding electric infrastructure pathway. The deliverable for the final subtask will be accompanied by a report summarizing the work and findings of Task 1.

Subtask 1.1: Decarbonization Pathways Framework

Subtask Summary: Develop an analytical framework (i.e., mathematical and logical model) for evaluating the impact of different building decarbonization pathways on a set of buildings serviced by local gas and electric networks. The framework will be delivered in the form of a Word document to the City, municipal utility, and DOE.

Subtask 1.2: Pathways Computational Model

Subtask Summary: Convert analytical framework, developed in subtask 1.1, into a computational model that can be applied to the City of Holyoke and Holyoke Gas & Electric. A previously developed reference case for another municipality will be used as a baseline to develop the computational model for Holyoke. The model will evaluate costs, emissions, and infrastructure changes under specific scenarios applied to the buildings or the connected distribution systems. The model will be designed to incorporate both simulated and actual (utility-provided) energy consumption data. The pathways computational model will be presented in slide format to the utility stakeholder, with a copy provided to DOE. The pathways model, used as the planning intervention for pipeline replacement vs. decommissioning may create different impacts depending on the scenarios created in task 1.5. This will serve as the point for continuous feedback from the utility to ensure the model is accurately representing the operational challenges of the utility.

Subtask 1.3: Infrastructure Data Profile to Develop a Municipal Network Assets Map

Subtask Summary: Using a publicly accessible street network map, prepare a data inventory checklist that includes each street segment for the Holyoke city which will serve as the starting point to take inventory of data across individual asset classes. Data collection will include but not be limited to meter-level consumption data for gas and electricity, building characteristics (age, square footage, etc.), energy demand and costs at the appliance or end-use equipment level, road, water, and sewer infrastructure (e.g., age, etc.). Make progress on the data inventory checklist by identifying primary sources that represent the original source for that asset class and secondary sources that can be used to describe asset data that indicate the construction or replacement of assets on a specific street segment. For each asset dataset, prepare metadata that contain data description, data accessibility, and data quality. The infrastructure data profile and data dictionary will be provided to the City and DOE for review in the form of a Word document report and associated Excel file. The purpose of building an infrastructure data profile is to enable a site-selection process for large infrastructure projects that would enable potential cost-sharing between the City and utility.

Subtask 1.4: Infrastructure Data Gap Analysis
Subtask Summary: For each street segment, identify and list data gaps for each asset class. For each gap identified, specify a strategy to fill gaps using non-primary data. Combine gap analysis into a consolidated report and summarize findings. The infrastructure gap analysis will be provided to the City, municipal utility, and DOE for review in the form of a Word document report and associated Excel file. The purpose of the gap analysis is to provide the city and utility with specific guidance as to where primary data is missing on infrastructure assets and how they can go about filling those gaps.

Subtask 1.5: Initial Decarbonization Scenario Analysis
Subtask Summary: Conduct a scenario analysis using the computational model, developed in subtask 1.2, on at least two street segment typologies. For this project, we will have two contextual scenarios to describe the situational context (e.g., single-family home neighborhood vs. multifamily) to evaluate the impact of four alternative strategies for managing leak-prone gas pipe infrastructure:

1. Pipeline replacement
2. Pipeline replacement with partial electrification
3. Pipeline retirement with full electrification
4. Pipeline retirement with partial electrification and use of non-pipeline fuels (e.g. propane, oil, woodchips)

Research will be focused on 8 model runs, based on two contextual scenarios for each of the four strategies. We will review initial results with utility stakeholders and incorporate feedback. The decarbonization scenario analysis will be provided to the City, municipal utility, and DOE in the form of a Word document report.

Subtask 1.6: Network Asset Registry and Visualization
Subtask Summary: Fill in data gaps exposed in data audit using non-primary data. Non-primary data may be derived data from local conditions or estimated data from outside sources. Combine “primary data" + "derived data" + "estimated data" into a digital network asset registry. Specify which asset data belongs to each category. Visualize network data on a map that will visualize all street segments and associated networked infrastructure data along with details about where it was sourced from. The asset registry will be delivered in file format with sub-files containing data in CSV, GeoJson, and Shapefile formats. The network visualization will be a web-hosted visualization of the asset registry. The web-hosted visualization, which will be password protected, will enable our research team, as well as City and utility partners, to evaluate locations for potential energy transition efforts based on potential cost savings from coordinated construction.

Subtask 1.7: Multi-Asset Scenario Analysis
Subtask Summary: Combine strategic gas decommissioning computational model (subtask 1.2) with infrastructure asset registry data (subtask 1.6) and run separate

benefit-cost simulations for electrification and for undergrounding of electric distribution infrastructure to enhance resiliency. This analysis will focus on coordinating building decarbonization with the gas network to mitigate potential cost increase of gas as building owners transition to electrification. This subtask will perform analysis at the intersection of “the future of gas” and building decarbonization to ensure affordability. The asset registry appends municipal infrastructure data to street segment while enabling the city to also append census data, survey data, and any additional information collected so that infrastructure investments can be viewed in the context of the whole community and not just the asset itself. The multi-asset scenario analysis will take the form of a Word document report with associated diagrams that demonstrate where gas decommissioning and grid hardening efforts would produce the highest benefits to the city and utility at the lowest cost. Multi-asset refers to the networked infrastructure assets of the gas decommissioning model (electric and gas system), and the additional asset data in the infrastructure asset registry (roads, water, and sewer). The analysis refers to the co-optimization of the outputs from both models to surface opportunities for cost-minimization. In simplest terms, it is incorporating planned and projected capital investments in the city's non-energy networked infrastructure (roads, water, sewers) into the model for strategic gas decommissioning to find opportunities that would allow for maximum cost-sharing. We will conduct modeling that evaluates opportunities for co-optimization over a 5-year period.

Task 2.0: Holyoke Community Engagement

Task Summary: Develop a community engagement plan to engage a range of stakeholders in this project, including municipal officials, the municipal utility company, and residents. We will work with community partners to conduct outreach to and obtain feedback from residents, including historically underrepresented groups, as their participation and input is key to ensuring an equitable energy transition. Through interaction among our team members, we will seek opportunities for the technical infrastructural analysis and community engagement efforts to inform each other.

Subtask 2.1: Development of Community Engagement Plan and Outreach Activities

Subtask Summary: A community engagement plan will be developed to engage with residents, including low-income populations and people and color, on climate change and energy transition. Outreach activities will include the use of digital outreach, relational organizing, and in-person events. Host workshops to provide information on the energy transition, climate resilience, geothermal and infrastructural analysis to the community and to solicit community input on related priorities and concerns.

Subtask 2.2: Relationship Building with Holyoke Municipal Leadership

Subtask Summary: Hold introductory meetings and maintain ongoing communication with the Holyoke Director of Conservation and Sustainability, Director of Planning and Economic Development, Gas & Electric Manager, and Mayor. Provide technical information to support decision making and planning. These communications will involve discussions on how energy transition is related to climate resilience planning and the infrastructure technical analysis (Task 1).

Subtask 2.3: Collaborative Communication within Project Team

Subtask Summary: Develop a framework for collaborative interaction and maintain ongoing communication among our team members, seeking opportunities for the technical analysis (Task 1) and community engagement (Task 2) efforts to inform each other. Compile and internally share a matrix document that summarizes information on project tasks (including description, goal, planned outputs, and staffing), as well as related work by team members, other UMass colleagues and partner organizations. Hold team meetings that bring together staff from Tasks 1 and 2 and include discussion about the interaction between the tasks and how our collective work supports the project goal of enabling an equitable energy transition.

Task 3.0: Community-based research incubator program

Task Summary: Develop a community-based research incubator program, which will bring together multiple stakeholders and researchers, and help these diverse teams develop ideas and research projects related to an equitable energy transition. This task will deliver details on the operations and management of the research incubator program, and the establishment of the research experience for undergraduates as part of the incubator program. We will host events to build partnerships, network, and develop opportunities for convergence research across the UMass campus and with external organizations and industries. We will hold networking and ideation activities on campus to bring together researchers with a common interest in energy and equity. These activities will support the development of next generation ideas at the intersection of energy and equity.

Subtask 3.1. Development and Establishment of Research Incubator Program and Research Experience for Undergraduates (REU) Program

Subtask Summary: This task will deliver details on the operations and management of the research incubator program, including the organizational structure, vision/mission, and research incubator portfolio design describing 1) areas of research, 2) students and faculty recruitment activities, 3) desired outcomes, and 4) a plan for future funding sources to maintain the program beyond this project. In addition, this task will establish the Research Experience for Undergraduates (REU) program to provide 8-week intensive research experiences for undergraduate students. This community-based research program will support undergraduate students with a paid internship to investigate community impacts, opportunities, and priorities related to the clean energy transition. We will provide integrated research and education opportunities for diverse students, in including under-represented minorities in all fields, and women in engineering, computer science, and natural science. Students will be paired with identified faculty that are already committed to working with the students on projects at the intersection of energy technology and social equity, in a wide range of disciplines, from computer science and engineering to economics and history. A cohort of faculty has been identified to support the program. Faculty recruiting will be an activity throughout the academic year. We will integrate these students in the college of engineering REU and, if funded, a National Science Foundation REU, as a way to broaden the impact of equity considerations into the research activities, provide efficiencies in seminar dissemination, and enrich the student experience by growing the cohort. By the end of year one, ETI will have established its first class of REU graduates. The team together provide DOE with a summary of events, programming, attendance, and attendee survey.

Subtask 3.2: Recruitment of Undergraduate Students for Participation in the REU
Subtask Summary: Recruit 5-10 undergraduate students as the first class for the REU program. Taking lessons from existing programs, our goal is to recruit at least 50% of the students from historically excluded demographics (e.g., Black, Indigenous, Latinx) and at least 60% women into the program. We will focus recruiting on students from (1) two nearby nationally recognized liberal arts women's colleges, Smith and Mt. Holyoke; (2) local community colleges, particularly Springfield Technical Community College (STCC), an institution comprising over 1/3 students from underrepresented groups and over 1/2 women; (3) the University of Puerto-Rico Mayagüez; (4) Historically Black Colleges and Universities; and (5) identity-based professional societies and conferences. We will prepare materials and disseminate them widely, especially to diversity officers at a wide range of universities. We will work with the UMass College of Engineering (CoE) Director of Diversity Programs to advertise and recruit student applications. A letter of collaboration (LOC) will be provided from Rosalee Scannell, the associate director of UMass transfer admissions, who partners with the local community colleges, and from the Director of Diversity Programs at CoE, who handles recruiting through HBCUs and identity-based professional societies. We will also encourage faculty to reach out directly to students who apply, as well as to identify under-represented students on the UMass campus who may be interested. We will have a cohort of faculty to bring this summer REU opportunity to and will support the pairing of admitted students to faculty based on the backgrounds and interests of the REU students. The project will be developed with the faculty mentor and student in consultation with UMass ETI leadership.

Subtask 3.3: Professional and Technical Seminar Development and Implementation
Subtask Summary: Establish a technical seminar series and workshops dedicated to energy transition topics and interfaces with historical and current social inequities with the intention to train students. These events will mainly be presented by faculty and will cover a wide variety of relevant disciplines, including computer science, engineering, resource economics, and anthropology. The technical seminar series will focus on providing students with the skills necessary to successfully conduct research and promote student success in career development, including graduate school and industry. Students participating in the internship program will be required to attend these seminars and workshops.

Subtask 3.4: Field Trip Design, Implementation and Development of Research Topics.
Subtask Summary: With our community partner organization, design and implement a day-long field trip for students to Holyoke, which is an environmental justice community. Students may visit such places as historical sites of energy production, the canal

system, the hydro-electric dam facility, and/or other community sites of interest. The intention of the field trip is for students to begin building relationships with the communities with which they will work to inform their research topics. This approach will foster connections, not just between the students and their mentors, but between students and the broader communities. In addition, these activities will provide hands-on field experience outside the laboratory activities that will tailor research to community needs. The interaction between communities and students will allow for data collection activities and analysis as part of the research and educational program activities.

Subtask 3.5: REU Program Evaluation and Assessment

Subtask Summary: Conduct program evaluation. During and after the first REU cohort, we will collect and aggregate the data such as: 1) demographic data of the student participants, 2) undergraduate institutions and majors (if declared), 3) information on graduate and undergraduate degree programs after completing REU participation , 4) enrollment in a 4-year degree after REU completion. We will use the data to track our progress toward our goals that participating students from community colleges will go on to complete a 4-year degree and that all students participating in the program will continue to engage in clean energy and equity research (either at their home institutions, or via industrial internships) after the REU program. We will develop a student survey to be used as a data collection mechanism. The survey will be administered prior to starting REU and post REU participation. The survey will gather data with a self-assessment of their research skills, their interest in research, their plans/desire to complete a 4-year degree, their interest in STEM majors, if they have any prior knowledge of careers related to energy equity, and their career goals. After the REU internship, students will complete the same survey to track changes, as well as ask for their general feedback on their summer experience.

Subtask 3.6: Summary of events and convergence research activities

Subtask Summary: We will host at least 3 collaborative events on campus to bring together a network of researchers. We aim for events that increase networking, foster internal and external partnerships, and generate new ideas that inform energy and equity research.

Project Results and Discussion

Our research yielded a technical paper and several journal articles (published or in review) related to strategic gas decommissioning and electrification (Task 1). The stakeholder engagement portion of our project resulted in numerous interactions with city officials, utility staff, community-based organizations, and residents (Task 2). We built an REU program and interdisciplinary energy research community at UMass Amherst (Task 3).

See tasks and subtasks below for more specific information on completion dates, methods, and results.

Milestone: Task 1.0: Technical Analysis for Strategic Gas Decommissioning and Undergrounding Electric Infrastructure Efforts in Holyoke.

Completion Date: 8/31/2025
Methods: GIS-based analysis, interviews, online data collection, scenario analysis
Results / Outcomes: This research yielded a technical paper that analyzed geographic areas to prioritize for strategic gas decommissioning and coordinated construction on grid upgrades. It yielded additional papers (published or in review) relevant to the energy transition. These included an analysis optimizing carbon and cost of residential electricity loads, co-undergrounding electricity and broadband lines, an analysis of demand response literature, and investigating conflicts related to solar project siting.

Technical Paper on Strategic Gas Decommissioning [1]
This aspect of the project analyzed opportunities for electrification and strategic gas decommissioning in Holyoke Massachusetts. Two neighborhoods were chosen for a detailed analysis (Figure 1). The single family street segment is located in a low-income, environmental justice community. 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. The multifamily neighborhood is not in an environmental justice census tract but is immediately adjacent to one. There are 33 parcels on the multifamily street, 15 of which were built between 1820-1890, and the remaining 18 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.

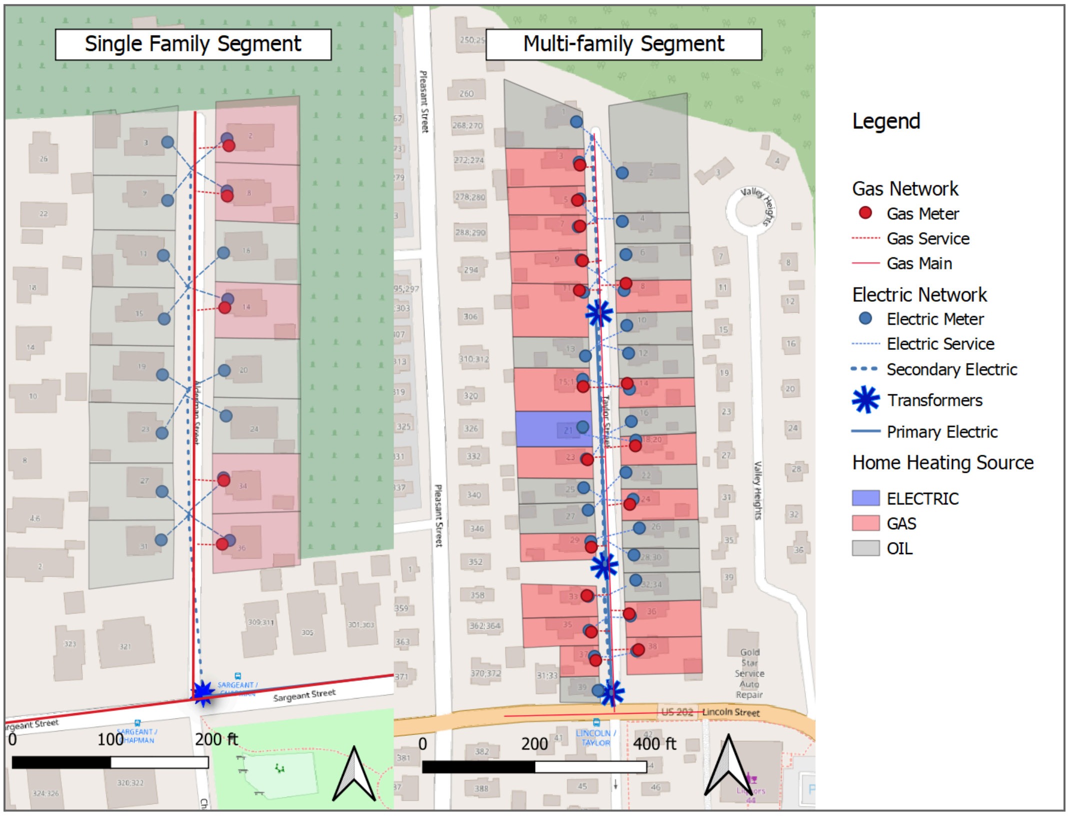

Figure 1 (Figure 6 from [1]). Single family and multifamily street segments used in the study.

We find that the cost of building electrification is significant (Figure 2 and 3), but so too 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.

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.

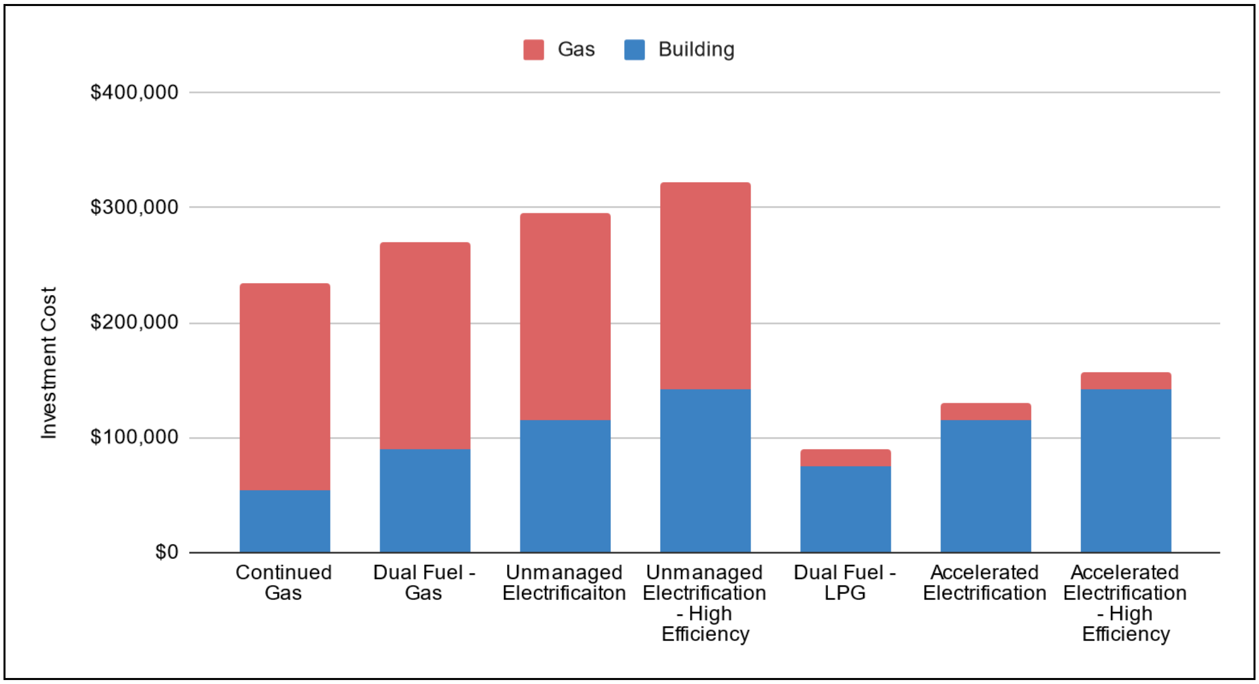

Figure 2 (Figure 13 from [1]). Summary of investment costs by scenario for the single family neighborhood.

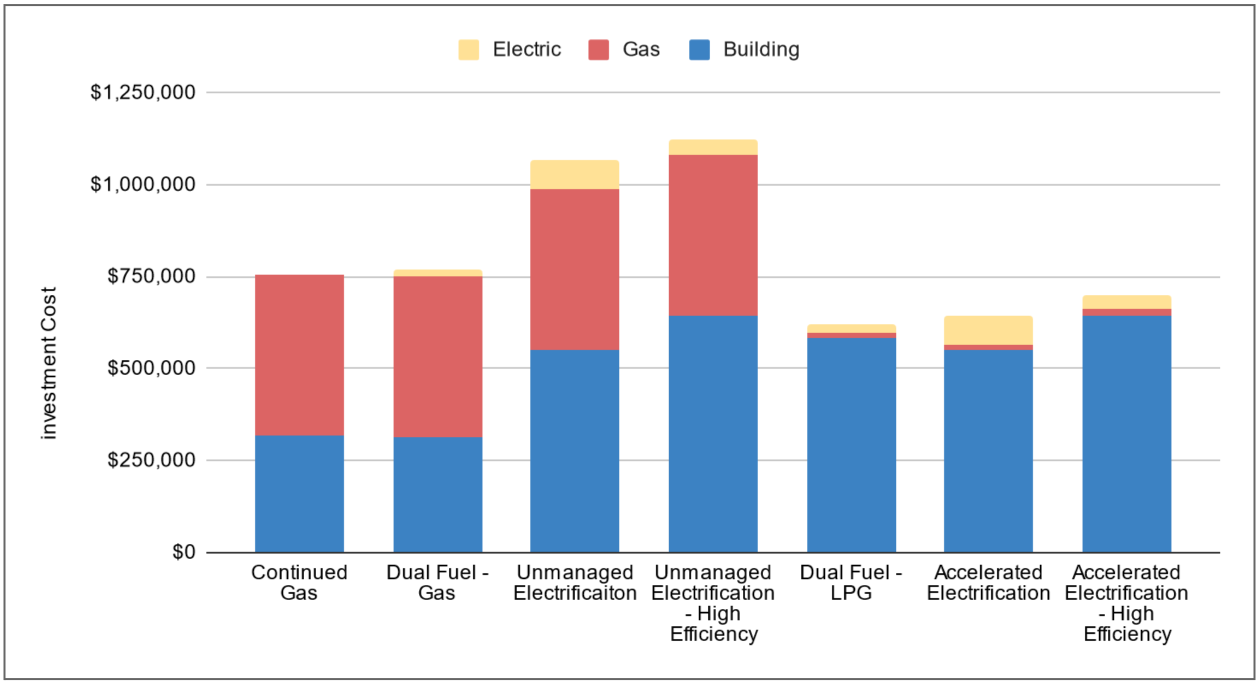

Figure 3 (Figure 14 from [1]). Summary of investment costs by scenario for the multifamily neighborhood.

Given the result that continued investments in gas infrastructure can be more costly than electrification, the study investigated which street segments in Holyoke could be prioritized for strategic gas decommissioning (Figure 4).

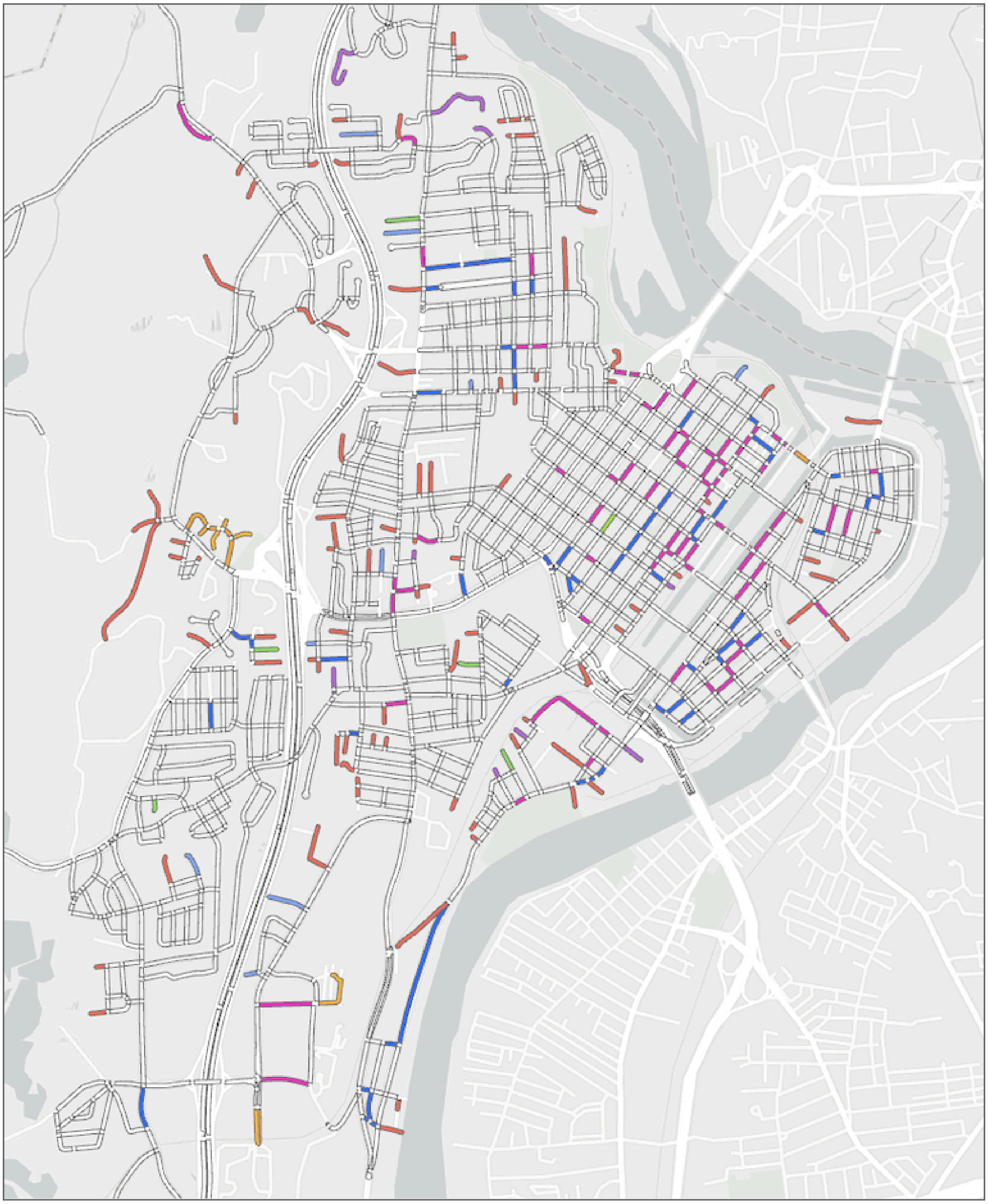

Figure 4 (Figure 24 from [1]). Terminal street segments in Holyoke highlighted by spatial multivariate cluster analysis, Method 1. Green, blue, magenta, and yellow streets are candidates for prioritization; purple, orange, and red are lower priority.

Optimizing Carbon and Cost for Flexible Residential Loads [7]
Our results show that GreenThrift can replicate the offline optimal behavior by retaining 97% of the savings when optimizing the carbon emissions. This study finds that GreenThrift can balance the conflict between carbon and cost and retain 95.3% and 85.5% of the potential carbon and cost savings, respectively. While applicable to Holyoke, this study investigated the carbon and cost savings across multiple regions. The data shows significant variability in savings within each region, highlighting how differences in household loads and appliance usage patterns can lead to diverse outcomes (Figure 5).

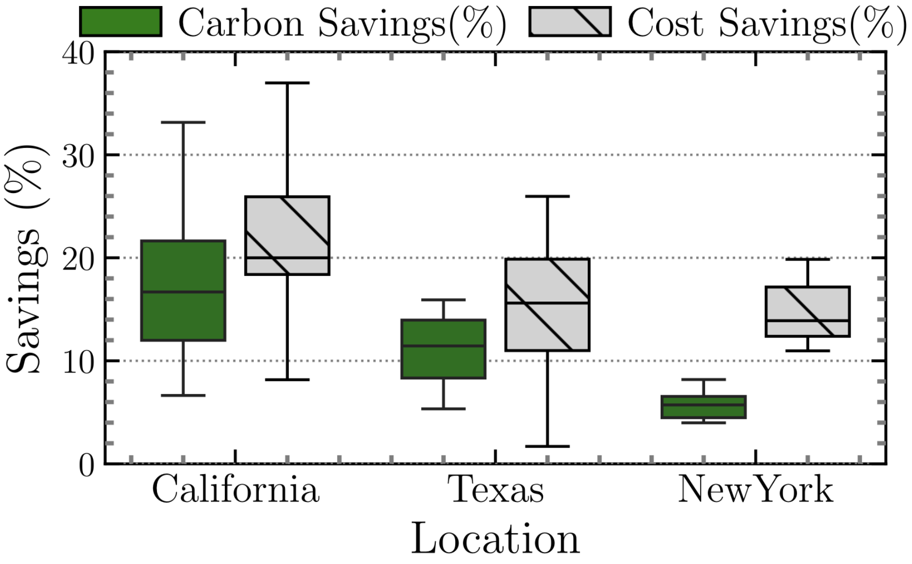

Figure 5 (Figure 13 from [7]): Carbon savings and cost savings from multiple houses in different regions using the balance policy.

Co-undergrounding Electric and Broadband Lines [21]
Aggressive co-undergrounding of electric and broadband lines is the most beneficial strategy when undergrounding is justified.

This study finds undergrounding is justified when it provides a positive net benefit. The viability of undergrounding depends crucially on the assumption about its effectiveness for reducing outages. We parameterize this using λ, which represents the effectiveness of undergrounding (proportion of outages that are responsive to undergrounding). Our baseline value, $\lambda = 0.6$, implies that full undergrounding would avoid 60% of the status quo outages. We found that the evidence for this value is sparse and widely divergent, with papers indicating that this value may be as low as 0.05 [134] or as high as 0.9 [135]. Figure 6 shows that when $\lambda < 0.5$, undergrounding is not justified. However, whenever undergrounding is justified, i.e., when $\lambda \geq 0.5$, the optimal strategy is always to aggressively co-underground electricity and broadband networks.

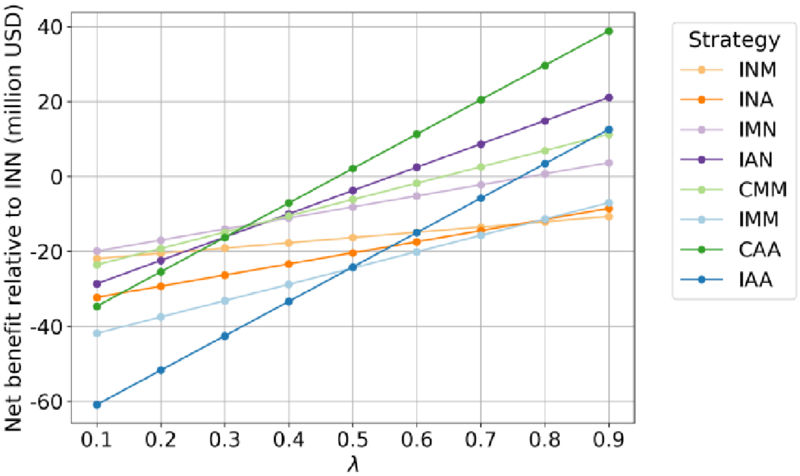

Figure 6 (from Figure 1 in [21]). The net benefit of undergrounding strategies as a function of the effectiveness of undergrounding λ.

Residential Demand Response in low-income communities [62]

We find that research about consumer-side motivations, habits, and needs is scarce in the already limited DR literature for the residential sector [85], [92]. Moreover, there is evidence that many DR programs have not effectively reached vulnerable group households [93], [81]. There is opportunity for future research to suggest effective ways of lifting barriers, and unlocking the potential DR can have to simultaneously benefit households and the grid.

Applying a Governance Lens to Renewable-Energy Siting [94]

This aspect of the project created a Conflict-Attention Index based on social media and news coverage for solar projects in the United States. It finds that the larger projects are associated with greater conflict (Figure 7).

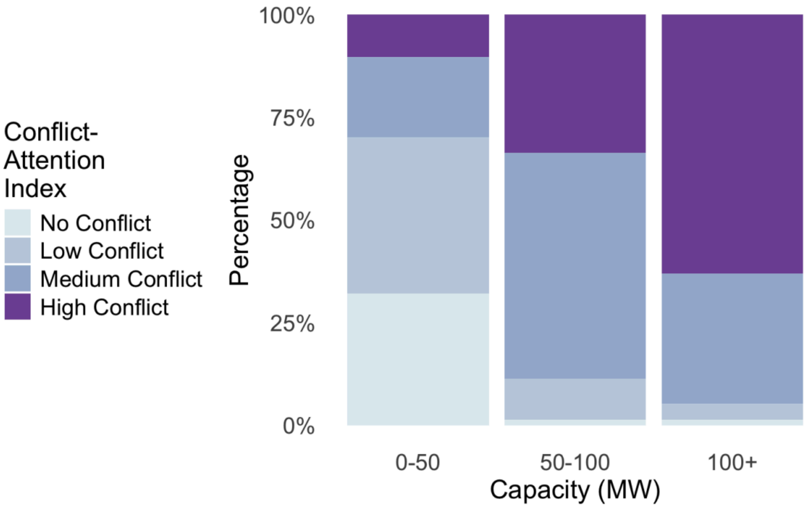

Figure 6 (from [94]). Analyzing conflict associated with utility scale solar (n=~700). Larger solar projects are associated with greater conflict.

Below we present subtask level information for Task 1.

Subtask 1.1: Decarbonization Pathways Framework
Completion Date: 2/1/2023
Methods: mathematical and logical model
Results / Outcomes: The analytical framework was successfully developed. It modeled the impact of different building decarbonization pathways on a set of buildings serviced by local gas and electric networks.

Subtask 1.2: Pathways Computational Model
Completion Date: 4/1/2023
Methods: computational model
Results / Outcomes: The analytical framework, developed in subtask 1.1, was refined into a computational model specific to the City of Holyoke and Holyoke Gas & Electric. The model evaluated costs, emissions, and infrastructure changes under specific scenarios applied to the buildings or the connected distribution systems. The model passed the QA/QC 90% accuracy threshold for estimation in relation to utility data.

Subtask 1.3: Infrastructure Data Profile to Develop a Municipal Network Assets Map
Completion Date: 4/1/2023
Methods: GIS-analysis
Results / Outcomes: A publicly accessible street network map was used to prepare a data inventory for future planning. This map includes >95% of municipal streets in Holyoke and includes primary data on road, water, and sewer infrastructure. Data includes asset age and material.

Subtask 1.4: Infrastructure Data Gap Analysis
Completion Date: 5/1/2023
Methods: GIS data review and estimation
Results / Outcomes: For each street segment, data gaps were identified for each asset class. A strategy to fill gaps using non-primary data was developed. The infrastructure gap analysis was shared with the City and municipal utility to provide specific guidance as to where primary data is missing on infrastructure assets and how they can go about filling those gaps.

Subtask 1.5: Initial Decarbonization Scenario Analysis
Completion Date: 9/15/2023
Methods: computational model scenario analysis
Results / Outcomes: Scenario analysis was conducted using the computational model, developed in subtask 1.2, on two street segment typologies (a single-family home neighborhood and a multifamily neighborhood). For each street segment, four scenarios were run: (1) Pipeline replacement, (2) Pipeline replacement with partial electrification, (3) Pipeline retirement with full electrification, and Pipeline retirement with partial

electrification and use of non-pipeline fuels (e.g. propane, oil, woodchips). The model passed the QA/QC 90% accuracy threshold for estimation in relation to utility data.

Subtask 1.6: Network Asset Registry and Visualization
Completion Date: 6/1/2023
Methods: GIS
Results / Outcomes: Data gaps exposed in early subtasks were filled in using estimation and non-primary data. A digital network asset registry was created and a map visualization of the network data was created. This visualizes all street segments and associated networked infrastructure data along with details about where it was sourced from. This enables researchers, Holyoke, and utility partners to evaluate locations for potential energy transition efforts based on potential cost savings from coordinated construction.

Subtask 1.7: Multi-Asset Scenario Analysis
Completion Date: 9/15/2023
Methods: GIS and scenario analysis
Results / Outcomes: This step combined strategic gas decommissioning computational model (subtask 1.2) with infrastructure asset registry data (subtask 1.6) and ran separate benefit-cost simulations for electrification and for undergrounding of electric distribution infrastructure to enhance resiliency. This analysis focuses on coordinating building decarbonization with the gas network to mitigate potential cost increase of gas as building owners transition to electrification. The model passed the QA/QC 90% accuracy threshold for estimation in relation to utility data. We find that strategic gas decommissioning has significant cost and emissions benefits compared to an unmanaged approach.

Milestone: Task 2.0: Holyoke Community Engagement

Completion Date: 8/31/2025
Methods: stakeholder engagement, community meetings, interviews
Results / Outcomes: We executed a community engagement plan that interfaced with a range of stakeholders. This included municipal officials, the municipal utility company, and residents. We worked with community partners (Neighbor 2 Neighbor and One Holyoke Development Corporation) to conduct outreach to and obtain feedback from residents, including historically underrepresented groups, as their participation and input is key to ensuring an equitable energy transition.

This yielded multiple workshops over the course of the project. An initial workshop occurred in collaboration with the Holyoke Community Energy Project. The goal of this workshop was to understand the desires and concerns of Holyoke residents, particularly those from the Black, Puerto Rican, and Afro-Caribbean communities, regarding the transition from fossil fuels to renewable energy. The 50 attendees joined eight focus group discussion tables facilitated by anthropologists, engineers, and other Energy Transition Institute researchers who learned from community members' knowledge of and experiences with the current energy system. Many participants face economic and energy vulnerability and reside in neighborhoods with a history of environmental injustice. Our collective inquiry focused on how the transition to renewable energy could address the historical exclusion of these communities from decision-making and the benefits of energy systems.

Informed by this first workshop, we supported three participatory design sessions to elicit feedback and ideas from the community on what it will take to make OneHolyoke's Flats Community Center into an accessible, net-zero building. This is the building where OneHolyoke hosts many community events, and it is a historic building (once the Portuguese American Club), but it needs renovation. This process provided an opportunity for residents to learn about net-zero buildings and to contribute ideas for a shared community space that has the most current building efficiency and clean energy systems. Additional workshops and events included a windows insert workshop to increase building energy efficiency in winter months, a workshop on demand response, and an Energy Justice Leaders tour of Holyoke that had about three dozen participants.

Subtask 2.1: Development of Community Engagement Plan and Outreach Activities
Completion Date: 6/14/2023
Methods: community outreach, organization, workshops
Results / Outcomes: A community engagement plan was developed to engage with residents, including low-income populations and people and color, on climate change and the energy transition in their city. Outreach and activities arising from this included workshops aimed at soliciting community input on related priorities and concerns and the use of digital outreach, relational organizing, and other in-person events.

Subtask 2.2: Relationship Building with Holyoke Municipal Leadership
Completion Date: 5/8/2023
Methods: outreach and communication
Results / Outcomes: We held introductory meetings and maintained ongoing communication with the Holyoke Director of Conservation and Sustainability, Director of Planning and Economic Development, Gas & Electric Manager, and Mayor’s office. This included providing technical information (from Task 1) and observations of community needs and desires (from Subtask 2.1) to support decision making and planning. We held several meetings in Holyoke, virtually, and at UMass over the course of the project.

Subtask 2.3: Collaborative Communication within Project Team
Completion Date: 5/16/2023
Methods: outreach and communication
Subtask Summary: We developed a framework for collaborative interaction to maintain ongoing communication among our team members, seeking opportunities for the technical analysis (Task 1) and community engagement (Task 2) efforts to inform each other.

Task 3.0: Community-based research incubator program

Completion Date: 8/31/2025
Methods: program building, event planning, survey

Results / Outcomes: We developed a community-based research incubator program, which brought together multiple stakeholders and researchers, and helped these diverse teams develop ideas and research projects related to an equitable energy transition. We established a Research Experience for Undergraduates (REU) program that had about two dozen participants. We hosted several events each year to stimulate convergence research at the intersection of energy and equity. These helped foster faculty collaborations, who went on to win several million dollars in external grant support. In the 2024-2025 academic year alone, we hosted 10 events at UMass. We also sponsored a high-profile annual Energy Transition Symposium each spring. This featured outside speakers and graduate and undergraduate research posters.

Subtask 3.1. Development and Establishment of Research Incubator Program and Research Experience for Undergraduates (REU) Program
Completion Date: 8/31/2025
Methods: program development, recruitment, survey
Results / Outcomes: The REU recruited about two dozen students to study topics related to energy and equity. Research areas were diverse and included: microgrid community engagement, solar powered community fridge, electrifying heat and grid integration, analyzing solar project siting debates, using hot water tanks to buffer grid demand, solar adoption equity, optimizing energy consumption in edge computing, and many more. A key outcome of the REU was to provide in-depth mentorship for future scientists. Over a dozen UMass faculty participated in the REU. Survey results showed that students reported a high level of value from REU activities such as technical seminars, professional development, poster session and a field trip to Holyoke. Students generally reported increases in their comfort in academic environments, openness to new professional experiences, ability to adapt to challenges, and ability to communicate.

Subtask 3.2: Recruitment of Undergraduate Students for Participation in the REU
Completion Date: 5/1/2025
Methods: advertising and recruitment
Results / Outcomes: We were successful in recruiting diverse cohorts of REU students that have been traditionally under-represented in STEM. For example, our 2024 cohort was 50% women and over half were african american or arab/middle eastern. Forty percent reported at least one disability.

Subtask 3.3: Professional and Technical Seminar Development and Implementation
Completion Date: 5/1/2025
Methods: develop seminar series
Results / Outcomes: A technical seminar series was established. Students participating in the first REU program reported high value for the seminar series.

Subtask 3.4: Field Trip Design, Implementation and Development of Research Topics
Completion Date: 11/1/2024
Results / Outcomes: Working with our community partner organization we designed and implemented a day-long field trip for students to Holyoke, which is an environmental

justice community. Survey results showed that REU students found a high level of value from this field trip experience.

Subtask 3.5: REU Program Evaluation and Assessment
Completion Date: 8/31/2025
Methods: survey
Results / Outcomes: We conducted a program evaluation via a pre and post REU-experience survey for our first REU cohort. Via this self-assessment we found positive levels of satisfaction with the REU experience. Students overwhelmingly reported increases in their comfort in academic environments, openness to new professional experiences, ability to adapt to challenges, and ability to communicate.

Subtask 3.6: Summary of events and convergence research activities
Completion Date: 8/31/2025
Methods: event planning and execution
Results / Outcomes: Throughout the project we hosted several high-profile events that attracted outside speakers and encouraged future research collaborations. These events typically had over 100 attendees and were of wide interest across numerous academic departments. Each spring we hosted an Energy Transition Symposium that featured timely topics and research in energy and energy equity. Symposiums featured panels, debates, outside speakers, and graduate and undergraduate student posters. The Symposiums are high-visibility events on the UMass campus. The 2024 event attracted over 100 attendees and 50 research posters.

Significant Accomplishments and Conclusions

This project resulted in several significant accomplishments. Our technical analysis of the gas and electricity infrastructure in Holyoke Massachusetts shows the potential for cost savings to rate payers and greenhouse gas emissions reductions from strategic gas pipeline decommissioning. The complimentary GreenThrift work reveals the potential for cost and emissions savings from optimizing automation systems that leverages the scheduling capabilities of smart appliances and knowledge of future carbon intensity in residential electricity loads. The work on co-undergrounding electricity and broadband lines, residential demand response programs, and the Conflict-Attention Index in solar project siting all provide policy relevant information on how communities can achieve carbon reductions and cost savings. This work directly benefits the city of Holyoke, but also has broad implications for cities and towns across the United States.

The community-engagement that was part of this work led to significant connections between research faculty at UMass Amherst and municipal and utility decision-makers, community partners and residents. The numerous meetings, workshops, and events boosted trust across parties and led to fruitful outcomes. For example, Holyoke Gas and Electric noted a significant increase in participation in their demand response program after one of our graduate students led a community workshop on that topic.

The Research Experience for Undergraduate program and the convergent research events were both successful. The REU trained about two dozen students. Many of these students came from historically under-represented STEM backgrounds. Participant survey results generally showed upticks in several measures related to these students’ confidence and desire to pursue a research career. Our convergent campus events provided opportunities to stimulate new research collaborations. Our Energy Transition Symposium, funded in part by this award, has become a major event on campus that draws in participants from dozens of departments and other programs (such as the School of Earth and Sustainability and the Integrated Concentration in STEM program). We will be continuing this event into the future. In 2024, the Energy Transition Institute sponsored 10 events that attracted over 500 participants. These have yielded new faculty collaborations that are leading to new grant applications.

Path Forward

We are continuing to work with the city of Holyoke to advise them on strategic gas decommissioning and discuss future research collaborations (Task 1). We will be looking for alternative funding to continue the REU programs (Task 2). The Energy Transition Institute will continue to sponsor events like the annual Energy Transition Symposium that bring together researchers and stimulate interdisciplinary research (Task 3).

Products

The following is a list of products emerging from this grant:

Publications

Accepted Manuscripts and Journal Articles

J. Katz and N. Baillargeon, “Balancing Participation and Speed: A Polycentric Governance Lens on Renewable-Energy Siting,” *Policy Stud. J.*, vol. 53, no. n/a, doi: 10.1111/psj.70091.

M. Bloomberg, M. Walsh, and V. Adibhatla, “Equitable Energy Transition Planning in Holyoke, Massachusetts: A Technical Analysis for Strategic Gas Decommissioning and Grid Resiliency,” University of Massachusetts, Amherst, MA (United States), DOE-UMass--10143-1, Dec. 2023. doi: 10.2172/2325964.
OSTI ID: 2325964

M. Arabi et al., “Benefits of aggressively co-undergrounding electric and broadband lines outweigh costs,” *Cell Rep. Sustain.*, vol. 2, no. 3, p. 100334, Mar. 2025, doi: 10.1016/j.crsus.2025.100334.
OSTI ID: 2563215

P. Bovornkeeratiroj, W. A. Hanafy, D. Irwin, and P. Shenoy, “GreenThrift: Optimizing Carbon and Cost for Flexible Residential Loads,” *ACM J Comput Sustain Soc*, vol. 3, no. 2, p. 14:1-14:21, May 2025, doi: 10.1145/3724408.
OSTI ID: 2563287

Under Review

X. L. Aristizabal and E. Baker, “A Systematic Literature Review on Residential Demand Response with a Focus on Opportunities for Low-Income Communities,” *Energy Res. Soc. Sci. Rev.*.

Website

Digital Network Asset Registry that compiles local data to understand the city of Holyoke’s infrastructure network. URL: https://public.tableau.com/views/Visualization_holyoke_segments/Dashboard?:showVizHome=no#1

Other Products

Annual Energy Transition Symposium

Significance of Contribution to the Project: Bring together researchers and other members of the UMass community to present related research

Annual Research Experience for Undergraduates Poster Session

Significance of Contribution to the Project: Culmination of our annual multidisciplinary research internship program

A Just Energy Transition workshops
Significance of Contribution to the Project: Interdisciplinary discussions related to our research on the energy transition in Holyoke, MA and beyond

SPARC workshop
Significance of Contribution to the Project: Connect faculty from across campus and supported development of research teams and funding proposals to build on the work of this project.

Energy Justice Leaders Workshops and Energy Tour of Holyoke
Significance of Contribution to the Project: Community engagement to engage a range of stakeholders in this project

Meetings with Holyoke, MA leadership and Holyoke Gas and Electric (HG&E) staff
Significance of Contribution to the Project: Stakeholder engagement in the project research and exploration of follow-up actions

Events with Professor Tony Reames (University of Michigan, formerly DOE)
Significance of Contribution to the Project: Supported development of research incubator program

Project Team and Roles

The following is a list of our project team and roles and focus areas:

Name	**Role**	**Focus area/s / Project**
Erin Baker	Principal Investigator	Strategic Gas Decommissioning, graduate student training, REU
Krista Harper	Principal Investigator	Holyoke MA energy justice through community-based participatory research
Nick Caverly	Project collaborator	Holyoke MA energy justice through community-based participatory research
Prashant Shenoy	Principal Investigator	Decarbonization and balancing cost and carbon
Joseph Krupczynski	Project collaborator	Green building workshops / Window inserts
Juniper Katz	Project collaborator	Solar siting project and graduate training as Natalie Baillargeon's advisor
Li Wu	Postdoc	Decarbonized computing
Ximena Aristizabal Clavijo	Graduate student	Community energy lab
Vivian Ogechi Nwadiaru	Graduate Student	Community energy lab/ shared battery storage
Teniel Rhiney	Graduate Student	Community energy lab/ Holyoke reunion tour
Andre Tarleton	Graduate Student	Community energy lab/ DR workshop
Natalie Baillargeon	Graduate student	Solar siting
Shannon Callaham	Graduate student	MVP2.0 Program (Climate plans), Energy Justice Leaders
Mahsa Arabi	Graduate student	Co-undergrounding broadband and powerlines
Jared Starr	Executive Director of ETI	n/a
Lauren Mattison	Director of Technical Services and Applied Research at ETI	n/a

OneHolyoke	Community partner organization	n/a
Groundwork Data	Community partner organization	n/a
Neighbor to Neighbor	Community partner organization	n/a

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