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Philadelphia Gas Works Business Diversification Study

Identifying Opportunities for Philadelphia Gas Works to Thrive in a Lower-Carbon Future

Energy & Environmental Economics
Amber Mahone
Dan Aas
Niki Lintmeijer
Ari Gold-Parker
Anthony Fratto

Econsult Solutions Inc.
Steve Wray
Carlos Bonilla

Portfolio Associates
Beverly Harper
Henry Felsman

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The results and conclusions of this Study are the responsibility of the study authors and do not necessarily reflect the views of others, including the organizations that provided funding to support this research.

Foreword

On January 15th of this year, Mayor James F. Kenney announced the City of Philadelphia's commitment to achieving carbon neutrality by 2050. In one of his first acts in the Oval Office, President Joseph Biden signed an executive order to have the United States rejoin the Paris climate agreement, the largest international effort to curb global warming. These are ambitious goals, and achieving them will require new and creative solutions and collaboration across broad coalitions.

In Philadelphia, these challenges may be even more complicated. Philadelphia is the owner of the Philadelphia Gas Works (PGW), the largest municipally-owned gas utility in the nation. Transitioning PGW's business model while lowering carbon emissions is an enormously complex task, with implications for residents, workers, the regional economy, and the City's financial well-being. In an effort to begin this dialogue, the City's Office of Sustainability and PGW have partnered on this Business Diversification Study.

The report that follows is a first step to help envision a successful, lower carbon future for PGW, a future in which energy is affordable for all residents, jobs are protected and economic opportunity is expanded, public health is improved, and the utility is a national leader in the fight against climate change.

This study highlights some of the challenges the City and PGW face. It validates some of the steps that the City and PGW's management team are already taking around methane reduction, weatherization, energy efficiency and renewable energy. It adds depth and detail to those topics, while adding new concepts to the conversation like geothermal systems, strategic electrification, and alternate business models. The report also confirms the obstacles the City faces in achieving sustainability goals and highlights the importance of mitigating unintended consequences of our actions, particularly around affordability, health and safety, reliability, and workforce. The steps we take will have very real ramifications on the finances of PGW and the City itself. Therefore, we require a practical approach that considers direct and indirect impacts and existing regulatory parameters, based on an honest assessment of the trade-offs of near-term and longer-term transformations.

We are incredibly appreciative of the time and effort put in by both our steering committee and the hundreds of individuals who participated in the study through public engagement sessions or through written comments. It is clear that our goals for a sustainable future and our concern for the complexity of the potential solutions are shared across the city.

Together, the City and PGW leadership commit to stakeholder engagement and transparent decision-making around PGW's future. We owe it to PGW workers, ratepayers, and residents of the city to be proactive in understanding the impacts of these changes in order to protect high quality jobs, address the city's high energy burden, and ensure the City of Philadelphia's fiscal health. Listening to the insights, innovative ideas and concerns of a diverse set of stakeholders will ensure that PGW's future plans work for all of Philadelphia now and in the future.

We are grateful that together we were able to take this first step in ensuring that PGW will continue thrive for another 200 years.

Thank you.

Christine Knapp
Director of Sustainability
City of Philadelphia

Seth Shapiro
President & Chief Executive Officer
Philadelphia Gas Works

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Executive Summary

Philadelphia Gas Works ("PGW") is the largest municipally owned gas utility in the country, employing over 1,600 workers resident in Philadelphia and distributing natural gas to around 500,000 customers across the city. Philadelphia Gas Works ("PGW") is the largest municipally-owned gas utility in the country, employing over 1,600 workers in Philadelphia and distributing natural gas to around 500,000 customers across the City. The City of Philadelphia ("the City") has committed to achieving net-zero emissions by 2050. This poses a complex challenge: how might the City and PGW reduce emissions from natural gas while maintaining customer affordability and supporting PGW's workforce?

The purpose of this Study

The purpose of this Business Diversification Study ("the Study") is to support the City and PGW in considering different business models that could allow PGW and its workforce to thrive in a lower carbon future. This report is not a plan, but rather it summarizes the findings from an initial first study that marks the beginning of a transition for the gas utility, consistent with the City's goals. The Study's objectives are:

- To examine technological pathways to **reduce greenhouse gas (GHG) emissions from heating, cooking, and other uses for natural gas** in line with the City's climate and air quality goals, and evaluate the impact of those pathways on PGW's current business model and its customers;
- To identify near-term **business strategies** for PGW that help sustain jobs and maintain customer affordability; and
- To identify near-term **promising pilot projects** for PGW that have the potential to reduce GHG emissions, benefit low-income customers, and result in long-term workforce opportunities.

As this report only provides a first look into a complex problem, the Study recommends actions for the City and PGW on how to move forward in future phases of the transition.

What have we learned?

This Study, informed by many stakeholders in Philadelphia, offers the following findings:

<u>Findings from literature & regulatory review</u>

- Diversifying a municipally-owned natural gas utility poses a **multi-dimensional challenge** that lacks a silver bullet solution; this challenge has not been fully addressed for gas utilities anywhere in the U.S.
- A **diverse set of existing and emerging technology and business options** will be necessary to reduce GHG emissions from gas utilities, particularly in dense urban environments and colder climates.

- PGW's operations are guided by a **complex set of city, state, and federal laws and regulations**; as PGW's needs and role evolve, so too must its regulatory landscape.

<u>Findings from the examination of GHG reduction scenarios</u>

- Achieving net-zero emissions in the City of Philadelphia is challenging, but it is **technologically feasible** with a range of scenarios that are not mutually exclusive: decarbonized gas, electrification, hybrid electrification, and networked geothermal systems.
- In any of these pathways, the necessary **scale of transformation is significant**, indicating that near-term action is required in order to achieve net-zero emissions by 2050.
- Household decisions and other market trends, along with legal and regulatory environments, will greatly influence which pathway(s) are pursued.
- Each of the GHG reduction pathways presents **tradeoffs between costs and feasibility:**
    - Transitioning to **decarbonized gases** makes strategic use of PGW's existing assets, but comes at a risk of limited available resources, high fuel costs and limited air quality improvements. If used in large amounts, decarbonized gases could harm the competitiveness of PGW's service compared to alternatives like electrification.
    - **Electrification of buildings** may improve air quality and may result in lower customer bills, but comes at higher upfront customer capital costs, could result in a large amount of stranded PGW assets (potentially resulting in bill increases for customers that do not electrify), and requires a long-term strategy to transition PGW's workforce to equally high-quality jobs.
    - **Hybrid electrification** keeps PGW's assets and workforce in place while mitigating the effect on gas utility customer bills relative to an Electrification scenario but poses cost recovery, feasibility, and regulatory challenges.
    - **Networked geothermal systems,** if owned and operated by PGW, may provide a diversification option for PGW, but this solution is likely to require significant capital investments and regulatory analysis; more study is needed to assess the exact costs and feasibility of the concept in Philadelphia.
- **In the short-term,** PGW can take measures that are likely to be compliant with its current regulatory framework, that decrease GHG emissions and provide benefits for customers without causing significant ratepayer impact. These include the blending of limited amounts of biomethane into the pipeline and expanding energy efficiency measures such as weatherization services.
- **In the long term** however, the evaluation of the greenhouse gas reduction pathways shows that **PGW's current legal and regulatory structure and cost recovery model** –

recovering the costs of the gas system through utility rate structures - **may pose significant challenges, mainly related to customer costs and affordability.**

Regardless of the greenhouse gas reduction pathways pursued, PGW's existing legal and regulatory structure and cost recovery mechanism does not position the utility to be able to support achievement of the City's carbon neutrality goal. For example, building electrification, though potentially beneficial to customers who can electrify their buildings, and supportive of the City's climate and equity goals, at scale, reduces PGW's long-term financial viability under the current regulatory framework.

<u>Findings from analysis of business diversification strategies</u>

- The long-term need for alternative business models can be **partly addressed through near-term business diversification strategies** for PGW that provide additional sources of revenue. These options range from choices that are close to PGW's existing business of revenue. These options range from choices that are close to PGW's existing business model (for which additional regulatory modifications may be needed), such as expanding weatherization services, to options in which PGW would play a significantly new role, such as providing strategic electrification or community solar services.
- Although these options may provide a way for the City and PGW to facilitate parts of the low-carbon energy transition while supporting jobs and providing value to customers, they **do not result in sufficient additional long-term revenues** for the utility to cover its costs.
- As a result, strategies that go beyond revenue diversification are required regardless of the GHG reduction pathways deployed:
    - In greenhouse gas reduction scenarios relying heavily on decarbonized gas, higher fuel prices are likely to occur suggesting that strategies would be needed to protect low-income customers from bill increases. In addition, this scenario carries the risk of defection from customers switching from gas to electric;
    - In greenhouse gas reduction scenarios relying heavily on electrification, including in the hybrid and network geothermal pathways described above, a more comprehensive long-term transition strategy would be needed.

Pilot project recommendations

Based on the diversification options evaluated, the consulting team recommends consideration of the following near-term pilot programs for PGW:

- ***A weatherization program with novel financing opportunities***, where PGW and the City will work together to support low- and moderate-income customers in the upfront financing and implementation of weatherization applications, such as home insulation.
- ***A feasibility study for networked geothermal systems***, where PGW investigates the technical and geological potential of block-level networked geothermal district systems as well as the utility financial model for such a system.
- ***A local decarbonized gas program***, where PGW works together with other City departments, such as Streets and the Water Department, to convert City waste into biomethane, making use of local resources to reduce carbon emissions.

Additional recommendations

The scenarios and diversification options evaluated in this Study indicate that creative solutions will be needed in the short term to facilitate a low-carbon future. The consulting team makes the following additional recommendations to the City and PGW as a way to turn the findings of this analytical study into actional next steps beyond the recommended pilot projects:

- ***The City should work together with PGW to define mid-term (i.e., 2025 and 2030) GHG reduction targets for PGW that are consistent with achieving the City's carbon neutrality target by mid-century.*** PGW should provide the City with regular progress updates on the status of its pilot program(s) to diversify its business and reduce GHG emissions as well as regular updates on PGW's current and projected GHG emissions.
- ***The City should work together with PGW's regulatory bodies (the Philadelphia Gas Commission and the Pennsylvania Public Utilities Commission) to consider options to better align the legal and regulatory constraints, and cost-recovery mechanisms, of PGW with achieving the City's climate neutrality and air quality objectives.*** A key challenge, highlighted by this Study, is that there is not currently a clear legal or regulatory path forward for PGW to pursue many of the diversification and decarbonization strategies discussed in this report. Regulatory considerations might include efforts to reduce costs of the gas system, changes in how gas system costs are recovered and allocated, and programs to protect low- and moderate-income customers from rising costs.
- ***The City, together with PGW, should collaborate on a Greenhouse Gas Reduction Implementation Strategy for Philadelphia's buildings.*** Expanding on the Philadelphia Climate Action Playbook (2021) and as a follow-up to this Business Diversification Study, the consulting team recommends that the City develop a GHG Reduction Implementation Strategy for Philadelphia's buildings that outlines concrete plans, commitments, and

programs for achieving GHG reductions in buildings, while prioritizing equity, affordability, environmental justice, and air quality consistent with the City's goals. In addition, the development of the implementation strategy should consider potential impacts to PGW's revenue, workforce, and PGW's customers. The implementation strategy should include plans for new construction buildings as well as existing residential and commercial buildings.

- ***The City should work closely together with PGW to conduct a PGW Workforce Impact Study.*** Such a study would consider the impact of different decarbonization pathways on PGW's existing workforce over the coming decades as well as strategies to mitigate potential negative impacts to PGW's existing workforce, including opportunities for workforce training and pension protection.

1. Introduction

1.1. Background

Philadelphia Gas Works (PGW) is the largest municipally-owned gas utility in the United States. Founded in 1836, PGW delivers natural gas to around 500,000 customers and employs over 1,600 workers today. In past years, PGW's gas consumption per residential customer has been declining due to improved appliance efficiencies, conservation efforts, and a warming climate. These factors are likely to intensify as temperatures continue to rise and policymakers place a stronger focus on reducing the greenhouse gases (GHGs) in the atmosphere.

The use of natural gas in Philadelphia's buildings and industrial sector contributes to climate change. In 2018, the Intergovernmental Panel on Climate Change (IPCC) stated that severe climate change impacts could only be avoided by limiting global warming to a maximum of 1.5°C. In order to achieve that goal, global emissions of carbon dioxide (CO_2) will need to fall by about 45 percent from 2010 levels by 2030, reaching worldwide carbon neutrality in 2050.[1] For Philadelphia, climate projections indicate hotter temperatures and storms that are more frequent and more severe, which, combined with sea level rise, will lead to more local flooding, as stated in the Philadelphia Climate Action Playbook.[2] Consistent with the global decarbonization trajectory and related Paris Agreement commitments, in 2021, Mayor Jim Kenney committed Philadelphia to achieving carbon neutrality and moving to 100 percent clean energy by 2050.

In Philadelphia, the combustion of natural gas accounts for around 24% of GHG emissions.[3] In order to reach the City's long-term climate goals, the City needs to reduce its carbon emissions over the next few decades, including the emissions from Philadelphia's natural gas consumption. At the same time, 23% of Philadelphians live below the poverty level and many residents in the City of Philadelphia face a high energy burden:[4] Philadelphian households on average spend around 6.7% of their income on energy, about double the national average, making Philadelphia one of the most energy-burdened cities in the United States.[5] In addition to energy poverty, environmental harms such as air pollution in Philadelphia tend to threaten the most vulnerable communities, contributing to inequality in health and wellbeing. PGW has programs in place for low-income customers, such as the Customer Responsibility Program and senior citizen discounts,

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[1] Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by government. Available at: https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/

[2] Philadelphia Climate Action Playbook (2021).

[3] Based on Philadelphia 2016 GHG Inventory.

[4] Available at: https://data.census.gov/cedsci/table?q=philadelphia&t=Income%20and%20Poverty&tid=ACSST1Y2019.S1701&hidePreview=false

[5] Available at: https://www.equitymap.org/philadelphia-energy-burden-impacts

that seek to address some of the inequities through rate protections. Stakeholders in Philadelphia have identified a just and affordable transition for the City's residents as a central component of achieving a cleaner energy future.

As a gas-only municipal utility, PGW, and the City as its owner, set out to investigate how the utility can provide necessary energy services in a low-carbon future while sustaining the jobs PGW provides for Philadelphians, protecting ratepayer interests, and ensuring equity. The City of Philadelphia - led by the City's Office of Sustainability (OOS) and joined by PGW - has begun to address this challenge through this PGW Diversification Study that aims to identify and evaluate new opportunities for PGW to diversify its business model in a low-carbon future.

In 2018, Philadelphia was selected as one of 25 cities to participate in the Bloomberg Philanthropies American Cities Climate Challenge (Climate Challenge). The Climate Challenge aims to support cities with ambitious climate action goals in cutting GHG emissions from the buildings and transportation sectors. In applying to the Climate Challenge, the City secured a commitment from PGW to undergo a diversification study as one of the focus areas for the two-year challenge period.

1.2. About this Study

This Study investigates pathways and business strategies for PGW to support the City's GHG reduction goals while considering equity and sustaining jobs and economic opportunity. The Study explores different energy futures, or GHG reduction pathways, for the City of Philadelphia that are consistent with the City's carbon neutrality goal, and it investigates the role PGW could play in each of these futures. The strategies explored in this Study span a multi-decade time horizon, which involves uncertainties. However, building from the best available assumptions, this Study begins to identify potential opportunities and risks each GHG reduction pathway offers.

The City of Philadelphia engaged a consulting team consisting of Energy & Environmental Economics (E3), Portfolio Associates (PA) and Econsult Solutions Inc. (ESI) to provide the analysis and engage with stakeholders in the City of Philadelphia. It's important to note that this report is a study, not a plan. This means the consulting team did not set out to determine a preferred decarbonization trajectory, nor preferred diversification strategies. Instead, the study sets out to explore a wide variety of different futures to provide insights into a complex challenge and a better understanding of the feasibility, considerations and trade-offs of different options. This study therefore marks the beginning of an iterative process by PGW, the City and broader Philadelphia community to develop strategies that are consistent with the City's carbon neutrality, equity, jobs and public health objectives.

Many stakeholders informed the PGW Diversification Study. The Diversification Study was developed with oversight from a Working Group consisting of a variety of members from City government and PGW, as outlined in Table 1. Throughout the process, the Office of Sustainability and consulting team engaged environmental organizations, businesses, governmental organizations, union representatives and community-based organizations to gauge perspectives on evaluation criteria, promising energy solutions and potential diversification options for PGW. An overview of the stakeholder process is provided in Appendix A.

Table 1. Working Group members, PGW Diversification Study

Name	Position
Mike Carroll	Deputy Managing Director, Office of Transportation, Infrastructure and Sustainability
Jim Engler	Mayor's Chief of Staff, Member of Philadelphia Facilities Management Corporation
Derek Green	City Councilmember, Chair of Philadelphia Gas Commission
Joseph Golden	Executive Vice President and Acting Chief Financial Officer, PGW
Raquel Guzman	Senior Vice President, Legal and General Counsel, PGW
Keith Holmes	President, Local 686, Utility Workers Union of America
Christine Knapp	Director, Office of Sustainability
Emily Schapira	Executive Director, Philadelphia Energy Authority
Seth Shapiro	President & Chief Executive Officer, PGW*
Greg Stunder	Vice President, Regulatory and Legislative Affairs, PGW
Leigh Whitaker	Chair, Philadelphia Facilities Management Corporation

* Note: Seth Shapiro was the Chair of the Philadelphia Facilities Management Corporation when the study began.

2. About Philadelphia Gas Works

PGW was founded in 1836 to deliver gas lighting for streets, businesses, and homes in Philadelphia. Today, PGW manages and maintains a system of over 6,000 miles of gas mains and service pipes that deliver around 78 billion cubic feet of natural gas per year to residential, commercial, and industrial customers in Philadelphia. Over its lifetime, PGW has transitioned its business model several times to accommodate changing energy needs. In 1926, PGW helped the City of Philadelphia become one of the first cities in the United States to actively replace coal-fired hot water heaters with water heaters powered by natural gas.[6] PGW grew substantially in the early 1950s as most residents and businesses adopted gas heating. At that time, PGW expanded its services by maintaining retail appliance stores and switching production from coal gas to the purchasing of natural gas.[7] A large part PGW's infrastructure stems from this expansion period, or even earlier, and as a result around 45% of PGW's distribution system today consists of relatively old cast iron material. According to the Pipeline and Hazardous Materials Safety Administration, PGW ranks fourth in absolute miles of cast iron mains across the United States.[8] With an accelerated main and service replacement program in place, PGW expects to replace over 30 miles of pipeline per year, planning to fully replace its older pipelines by 2058. In June 2021, PGW announced advanced efforts to reduce methane emissions by 80% by 2050.[9] Additionally, PGW joined the Environmental Protection Agency's Methane Challenge by committing to the annual replacement of 2% of its cast iron mains along with replacing its steel service lines in order to further reduce methane emissions.

2.1. PGW's customer base

PGW delivers gas for both heating and non-heating purposes to around 484,000 residential customers, 25,000 commercial customers and 700 industrial customers. In contrast to Philadelphia's population decline in the decades prior to 2010, the City's population has steadily increased in the past 10 years.[10] As a result, PGW has added service to over 8,000 new homes since 2010 and Philadelphian households continue to be the majority of PGW's customer base. In addition, PGW provides gas to Philadelphia's existing district steam system (operated by Vicinity Energy) and delivers gas to customers who choose a natural gas supplier other than PGW.[11] Around 1.3% of total gas deliveries are Lost and Unaccounted For (LAUF), which includes gas

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[6] See: https://www.pgworks.com/about-us/our-history

[7] See: https://philadelphiaencyclopedia.org/archive/philadelphia-gas-works/#:~:text=PGW%20originated%20in%20the%201830s,lacked%20a%20municipal%20gas%20works

[8] PHMSA Cast and Wrought Iron Inventory. Available at: https://www.phmsa.dot.gov/data-and-statistics/pipeline-replacement/cast-and-wrought-iron-inventory

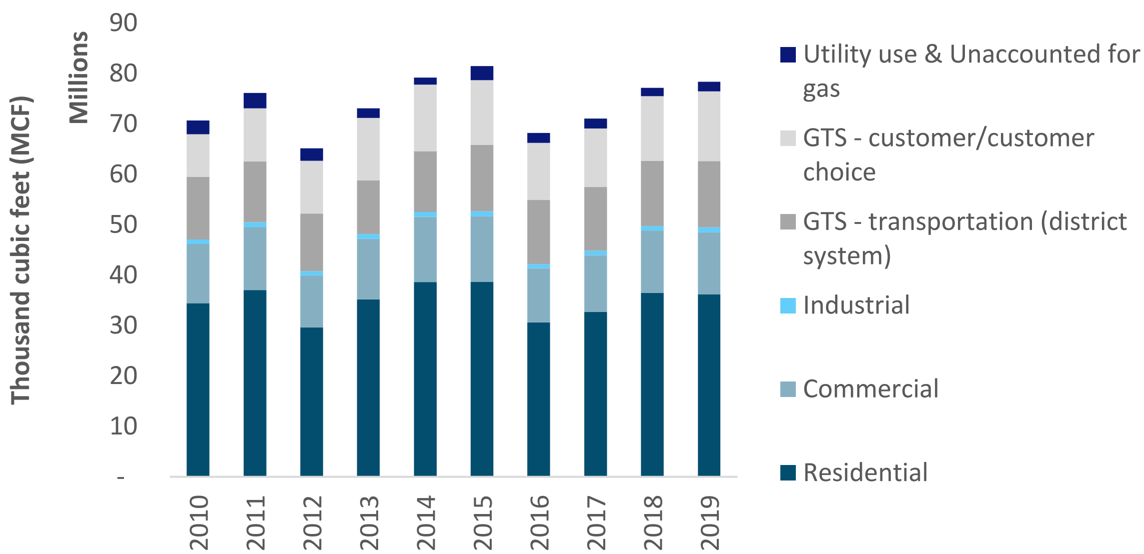
[9] See: https://www.pgworks.com/community-impact/newsroom/pgw-announces-advanced-efforts-to-cut-methane-emissions-by-2050

[10] U.S. Census 2020 Population Dataset.

[11] These deliveries are shown on Figure 1 as Gas Transportation Services (GTS).

pipeline leakage, and additional gas is consumed for utility purposes.[12] Figure 1 provides an overview of PGW's gas deliveries from 2010-2019. The annual fluctuations in gas deliveries are primarily driven by weather; gas deliveries increase in colder winters and decrease in warmer winters.

Figure 1. PGW's historical gas deliveries. Note: gas consumption fluctuates per year due to weather conditions.



2.2. How does PGW collect revenues?

PGW is funded through revenue collected from rates. PGW collects revenues through both a fixed component ("customer charge") in Philadelphia and through a volumetric component to recover costs to maintain the gas distribution system. PGW also collects revenues from other operations including Transportation Service operations, maintaining and repairing customer appliances, and LNG operations. These activities represent around 12% of PGW's annual operating revenues, with the majority coming from Transportation Services.

The City of Philadelphia issues bonds for PGW to finance portions of capital expenditures required to maintain the gas distribution system. PGW's annual revenue requirement is based on a cash flow methodology that determines the rates adequate to cover its operating expenses, depreciation allowances, and a margin sufficient to meet bond coverage requirements and internally generated funds (for instance used for capital improvements).[13]

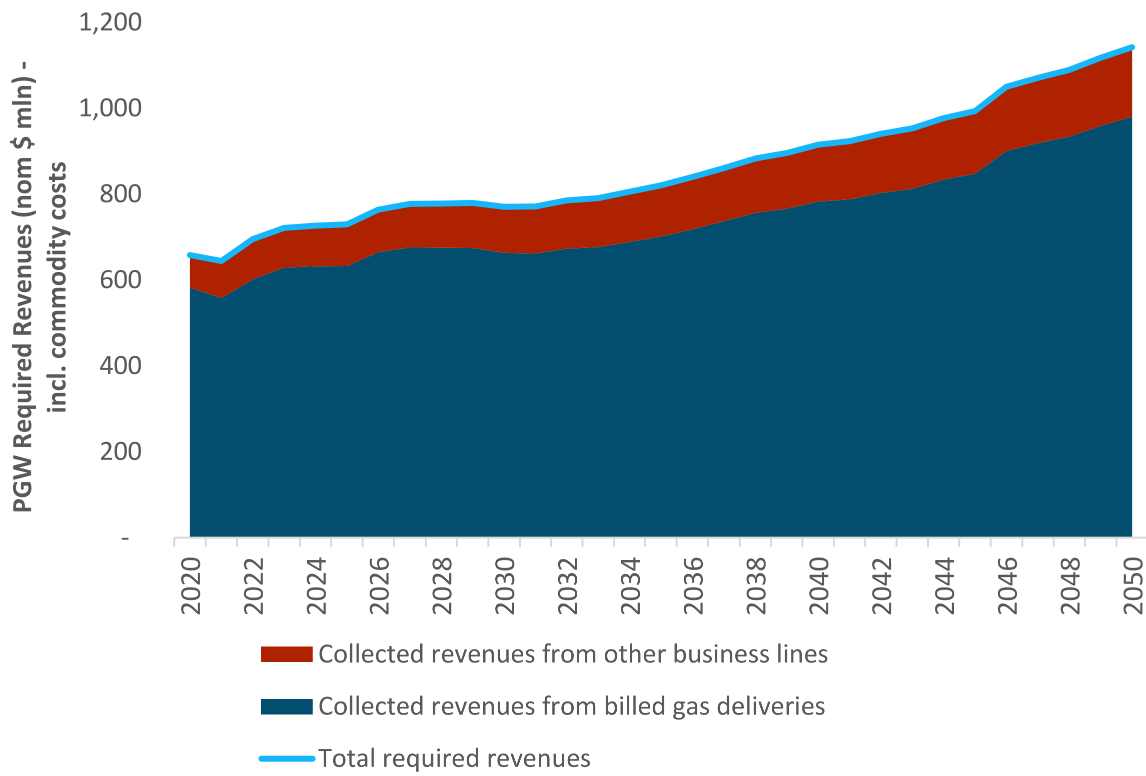
For the purpose of this project, the consulting team established a model to forecast PGW's future revenues under different energy scenarios and business models. This model is a simplification of

[12] Philadelphia Gas Works ("PGW") Unaccounted for Gas report for Fiscal Year 2020. Available at: https://www.puc.pa.gov/pcdocs/1679182.pdf

[13] Testimony of Joseph. F. Golden, Jr. on behalf of PGW before the PUC (February 2020).

PGW's financials but offers a useful platform to allow for "what-if" scenarios that explore the impacts of decarbonization scenarios on PGW's revenues. A revenue forecast under a "business-as-usual" scenario is provided in Figure 2.

Figure 2. PGW Revenue Forecast. "Total required revenues" represents the revenues PGW needs to collect to recover its operating expenses. "Revenues from other business lines" include revenues from Transportation Services and, for instance, appliance repairs.

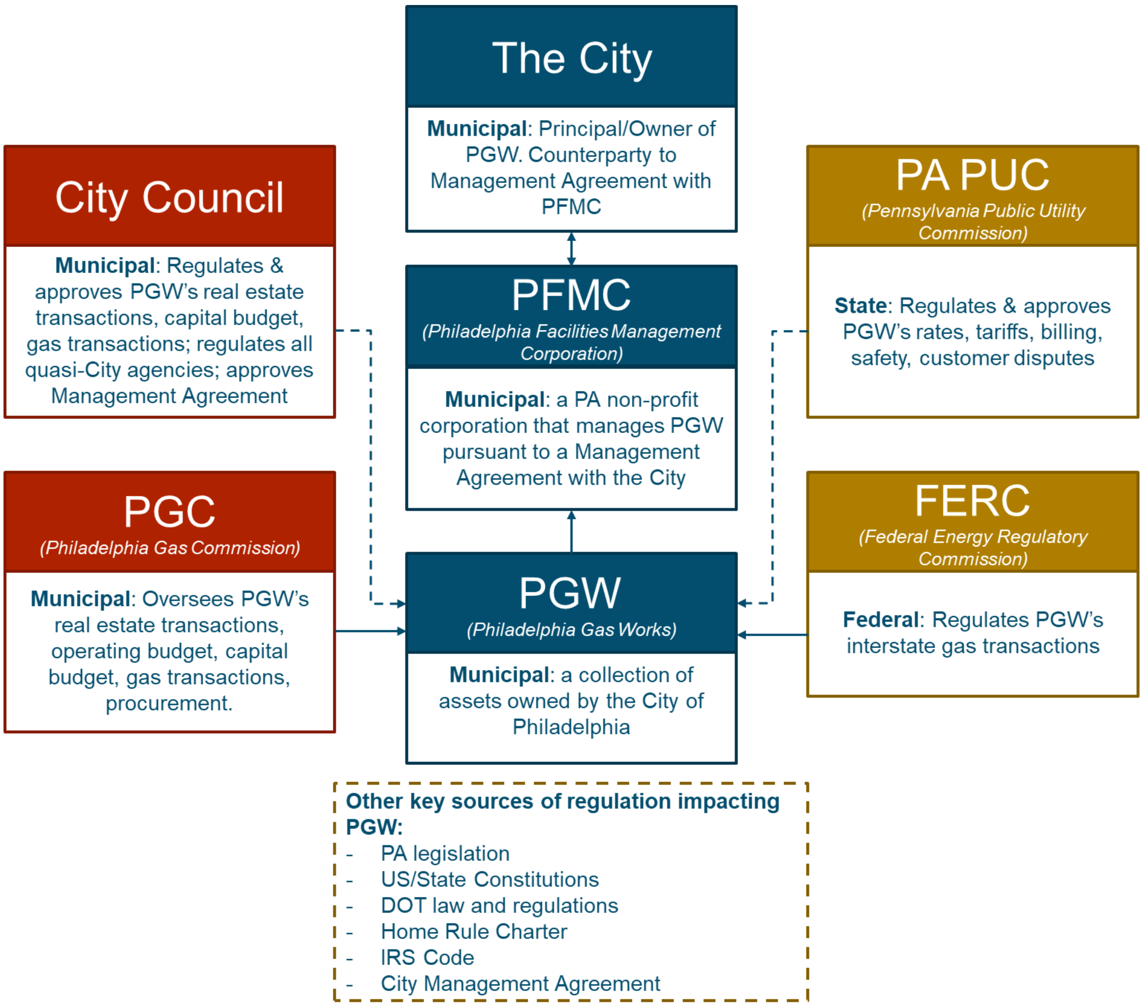


2.3. PGW's regulatory structure

PGW is owned by the City of Philadelphia and is considered a component unit of the City. PGW is managed by a non-profit corporation, the Philadelphia Facilities Management Corporation ("PFMC"), through the terms and conditions of a "Management Agreement." The Philadelphia Gas Commission ("PGC") oversees PGW's management, operating and capital budgets, and gas transactions. Some issues, such as PGW's capital budget, also require direct approval from the Philadelphia City Council. PGW is also subject to the jurisdiction of the Pennsylvania Public Utility Commission ("PUC"), which operates under the Pennsylvania State Public Utility Code and associated regulations.

Given the complexity of the regulatory environment in which PGW operates, changes to PGW's business model could require approval from the PGC, the PUC, legislative action from the state or federal government, or even approval directly from the voters of Philadelphia, depending on the specifics of the changes being pursued. This Study does not include a detailed evaluation of the legal and regulatory implications of potential changes to PGW's business model, but the regulatory challenges are considered at a high level in the business diversification strategies in Chapters 5 and 6. For more information about PGW's regulatory structure, see Appendix B.

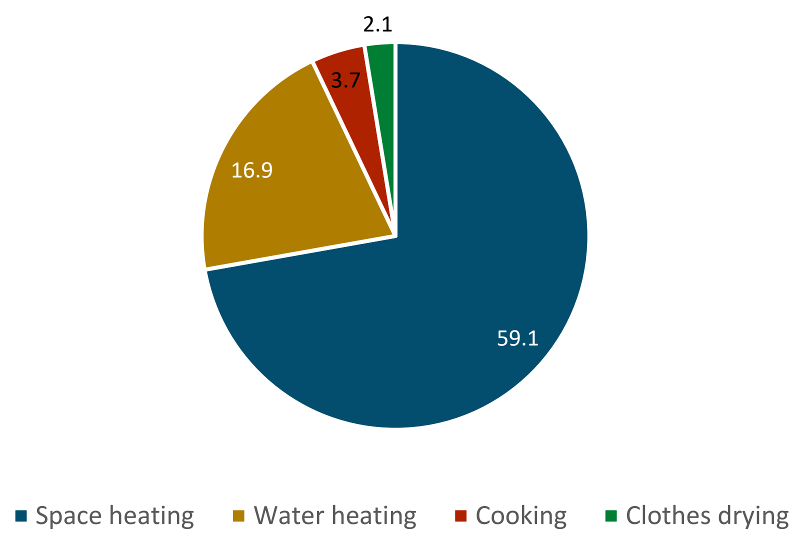
Figure 3. Governance and Regulatory Structure of PGW



3. Options to decarbonize gas end-uses in Philadelphia

In Philadelphia, over 70% of households rely on natural gas for their main source of heating.[14] Households use natural gas primarily for space heating (using a gas furnace or gas boiler), as well as for water heating, cooking, and clothes drying. The average PGW residential customer uses 73 thousand cubic feet (MCF) of gas per year.[15] In Philadelphia, around two-thirds of households live in single family homes.[16] A breakdown of natural gas consumption in an average single-family Philadelphia home is given in Figure 4.

Figure 4. Average annual gas consumption in a typical Philadelphia single family home (total = 81.8 mcf))[15]



In addition to PGW's large residential customer base, commercial businesses and industrial facilities represent around 5% of PGW's direct customers.[17] E3 estimated the average annual gas consumption of these customers at 480 and 1270 MCF per year respectively for the heating of buildings and operational processes.

Overall, the combustion of natural gas results in GHG emissions and contributes to the release of other air pollutants like PM 2.5 and nitrogen oxides, which are precursors to ozone. Reaching the City's climate goals requires Philadelphia homes and commercial buildings to transition from natural gas to alternative sources of heating. Studies across the United States and abroad have

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[14] Derived from U.S. Census data.

[15] Baseline consumption level based on weather-normalized historical usage. The breakdown of building types and consumption per building type and per end-use application is based on Census Data and EIA RECS data respectively.

[16] Derived from U.S. Census data.

[17] See Chapter 2: "Direct customers" exclude Gas Transportation Services indicated on Figure 1.

identified a variety of pathways to do so, ranging from the transition to decarbonized gases, such as biomethane and hydrogen, to building electrification.

Energy efficiency is a key pillar in any GHG reduction pathway, as it reduces reliance on fuels and leads to lower customer bills. Key energy efficiency measures include:

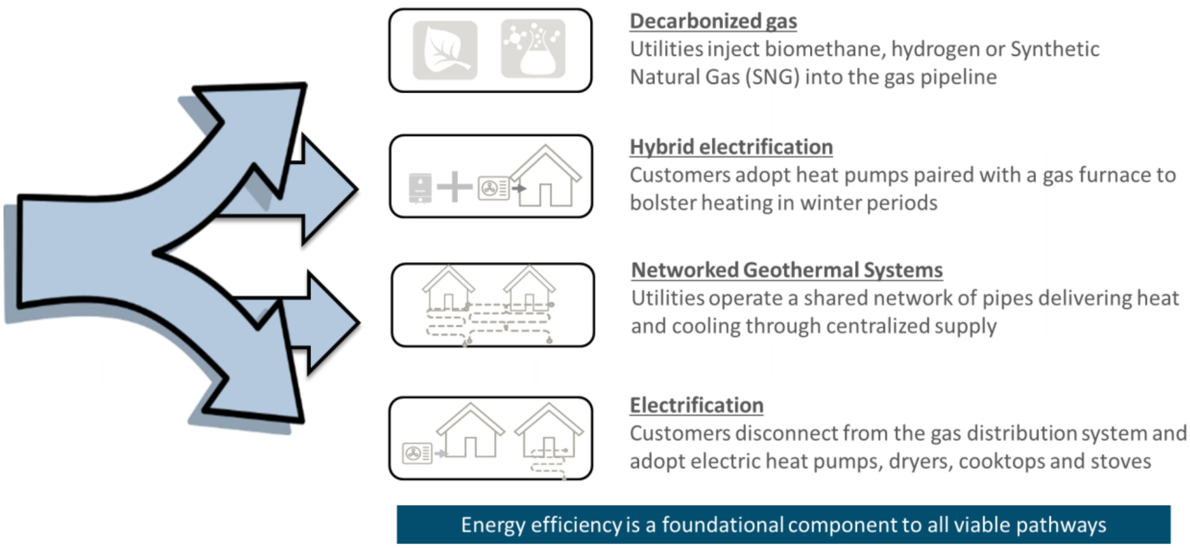
- Building weatherization and envelope improvements;
- More efficient gas or electric appliances;
- Technologies like electric heat pumps, gas-fired heat pumps, micro combined heat and power (CHP), and others.

Philadelphia has a higher-than-average share of both low-income households and old, poorly insulated homes.[18] The median age of a Philadelphian home is 93 years old; around 40 years older, on average, than homes in other major U.S. cities. These factors - along with Philadelphia's climate - make energy efficiency through building weatherization and envelope improvements particularly relevant in Philadelphia as energy efficiency both improves home conditions and reduces monthly energy bills. The importance of weatherization in Philadelphia, and the current and potential roles PGW can play in this option, are further outlined in Chapter 5.

However, energy efficiency alone is not sufficient to meet the City's climate, health, and equity goals. Beyond energy efficiency, this Study analyzed four pathways to decarbonize heating energy supply, as shown in Figure 4. These pathways are not mutually exclusive; in fact, a combination of these strategies may be needed to cost-effectively decarbonize natural gas end-uses given the variety of building types, heating demands, and availability of technologies. For any of these pathways to occur equitably, policies and programs that support their implementation must prioritize the needs of low-income, energy-burdened communities.

[18] See: https://whyy.org/articles/old-homes-high-poverty-make-philadelphia-housing-less-than-affordable-for-some/

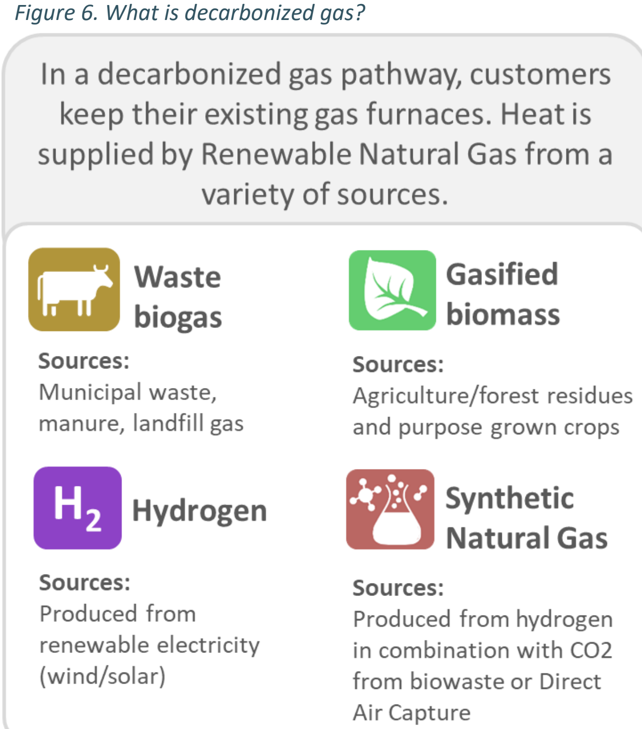
Figure 5. Overview of decarbonization options



For the purposes of comparing options to decarbonize natural gas end-uses in Philadelphia, E3 researched each pathway individually. The following sections provide a high-level overview of each of the pathways, as well as the associated tradeoffs and potential implications for PGW.

3.1. Decarbonized Gas

Figure 6. What is decarbonized gas?



"Decarbonized gas" is an umbrella term that encompasses several zero- or low-GHG substitutes for fossil natural gas. E3 distinguishes several types of decarbonized gases: biomethane derived from waste biogas or gasified biomass, hydrogen, and Synthetic Natural Gas (SNG). Both biomethane and SNG consist of the same molecular structure as natural gas (CH_4), which means they can be blended into the existing natural gas distribution pipeline without technical constraints, as long as the biomethane supply meets pipeline quality standards. Hydrogen (H_2) is a different type of gas and can only be blended into the pipeline up to a certain point (often assumed to be a maximum of 7% hydrogen blends by energy) without having to significantly upgrade the distribution system to withstand higher blend rates. All decarbonized gases are generally assumed to have a net neutral impact on the climate, if gas leakage is prevented.[19]

The use of decarbonized gas in Philadelphia has both advantages and drawbacks. First, the use of decarbonized gas repurposes existing infrastructure, causes minimal consumer disruption as customers keep their existing gas furnace and other gas appliances, and allows for a diverse range of fuels to be procured. However, decarbonized gases are generally more expensive to produce than natural gas, do not contribute to air quality improvements, and are limited in terms of commercialization or total availability as investigated by several studies across the U.S. For example, in a study for the American Gas Foundation, ICF estimated that between 1,660 and 3,780 trillion Btu (Tbtu) of biomethane resources could be produced in the U.S. annually for pipeline injection by 2040.[20] Using Philadelphia's share of population within the U.S., that amount would be equivalent to around 10-23% of total gas consumed in Philadelphia today, considering competing needs in other sectors of the economy. Although it is unclear how much biomethane supply would be available in the region, a full transition to decarbonized gases in Philadelphia would likely require significant amounts of synthetic natural gas, a source of methane that is not yet commercialized, but is not resource constrained if available. However, decarbonized gases do provide a potentially important piece of the puzzle to transition to net zero by 2050 and would make use of PGW's current assets and expertise.

What are other regions doing?

Several gas utilities across the U.S. have started projects or programs to blend decarbonized gases into the pipeline or have committed to blending targets. For instance, Southern California Gas and Vermont Gas strive to blend 20% decarbonized gases in the pipeline by 2030, Liberty Utilities in New Hampshire proposed the development of a landfill gas facility supplying 6% of annual gas sales, and National Grid works together with New York City to convert biogas from city wastewater to Renewable Natural Gas.[21]

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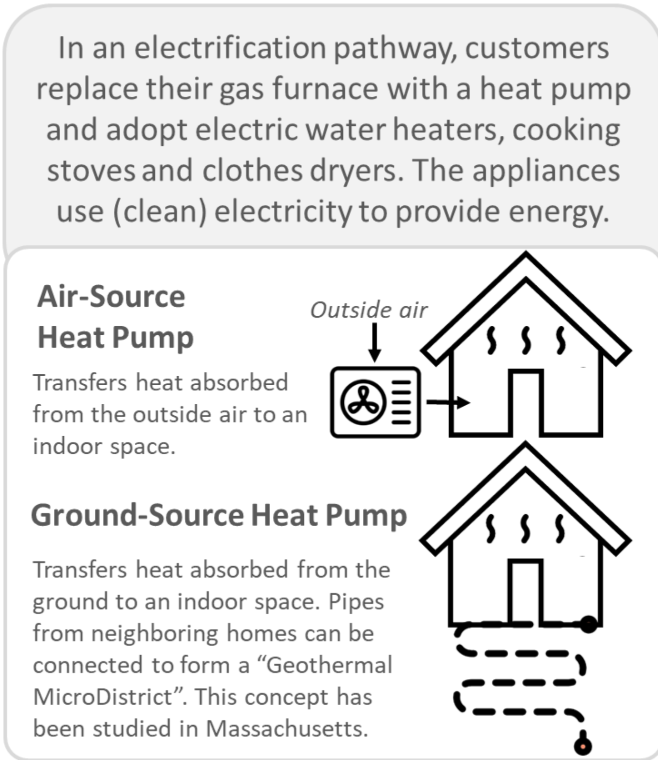
19 Although biomethane and SNG still release CO2 into the atmosphere at the point of combustion, they release the same amount of CO2 that has been captured by the organic matter throughout its growth or, in the case of SNG, by technology that captures CO2 from the air. These sources are therefore commonly referred to as carbon neutral under IPCC GHG accounting standards. Some jurisdictions, such as New York State, instead account for the lifecycle carbon emissions of fuels, and therefore do not treat these fuels as net carbon neutral. However, for the purposes of this Study, they are treated as carbon neutral fuels.

20 American Gas Foundation (2019). Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment.

21 See: https://www.nationalgridus.com/News/2019/04/Delivering-the-future-of-heat/

3.2. Electrification

Figure 7. What is electrification?



Building electrification is another decarbonization option that is growing in popularity around the country (see Figure 4). Building electrification refers to the shift from using fossil fuels, such as natural gas, to electricity for heating and cooking purposes. Households that fully electrify replace their gas furnaces, water heaters, and cooking stoves with electric heat pumps and induction stoves, eliminating their reliance on the gas system. Under PGW's current business model, which is focused on distributing natural gas, full electrification would reduce PGW's customers.

Electrification of heating and cooking, even with today's electricity grid mix, results in GHG emissions reductions relative to natural gas combustion, as outlined in more detail in Chapter 4.[22] It is important to note that achieving *net-zero* emissions is only possible when the electricity grid mix is fully derived from clean and zero-GHG sources such as solar and wind. A challenge in such an electricity system is maintaining reliability throughout the year, which requires sufficient firm generation resources to deliver energy when output from variable resources is low.

[22] See Figure 11 derived from PJM's emission data: https://www.pjm.com/~/media/library/reports-notices/special-reports/2019/2019-emissions-report.ashx. PJM's grid mix. Today, around 43% of electricity generation supplied to Philadelphia comes from zero-GHG energy sources (35% from nuclear resources).

What are other regions doing?

Many jurisdictions across the U.S. have identified building electrification as a promising decarbonization strategy and have implemented targets and funding programs to stimulate the adoption of heat pumps. As documented by the American Council for an Energy Efficient Economy (ACEEE), Maine enacted a goal of adding 100,000 heat pumps by 2025 and offers rebates of $1,000 per home, Massachusetts has set a goal of 1 million electrically heated homes by 2030 and offers several rebate programs, and the New York State Clean Heat incentive program invests $454 million through 2025 to support customer adoption of heat pumps.[23]

The use of heat pumps in Philadelphian buildings has several advantages. Electric heat pumps operate at high efficiencies and can achieve coefficients of performance that reach 250-400% depending on weather conditions, which means one unit of electric input energy provides 2.5-4 units of heat output. For reference, a typical natural gas furnace or boiler has an efficiency of around 80%. Heat pumps provide both heating and cooling, proving a more efficient source of air conditioning compared to window units, which is critical given the increasing frequency and duration of heat waves the City is expected to continue experiencing. In addition, since heat pumps do not combust fuels, they improve air quality, contributing to public health objectives. For instance, the Massachusetts 2050 Decarbonization Roadmap estimates that complete building electrification would result in 200 avoided deaths from cardiovascular and respiratory illness and contribute $2.2 billion annually in health benefits in the state by 2050.[24]

Electrification of buildings also presents challenges. First, electric heat pumps are generally found to be more expensive than their gas (furnace or boiler) counterparts, particularly in retrofit situations and in homes that would not otherwise need air conditioning. Since heat pumps for space conditioning provide both heating and cooling, the cost of these systems is often comparable to, or higher than, the cost of a gas furnace plus an air conditioning unit. Although studies show different ranges in capital costs, to date heat pumps for single family homes are found to cost $10k-$20k to install.[25] In addition, although heat pumps are an efficient means to deliver heating, the associated efficiency decreases as outdoor temperatures drop. Electrification strategies, especially in colder climates, could require substantial electric system upgrades in the future once a sizable percentage of buildings are electrified to ensure that heat can be delivered throughout the coldest hours of the year. A recent study exploring *Pathways to a Carbon Neutral NYC,* for instance, noted that electrifying 60% of the city's buildings without energy efficiency

[23] ACEEE (2020). Programs to Electrify Space Heating in Homes and Buildings; Massachusetts Clean Energy and Climate Plan for 2030.

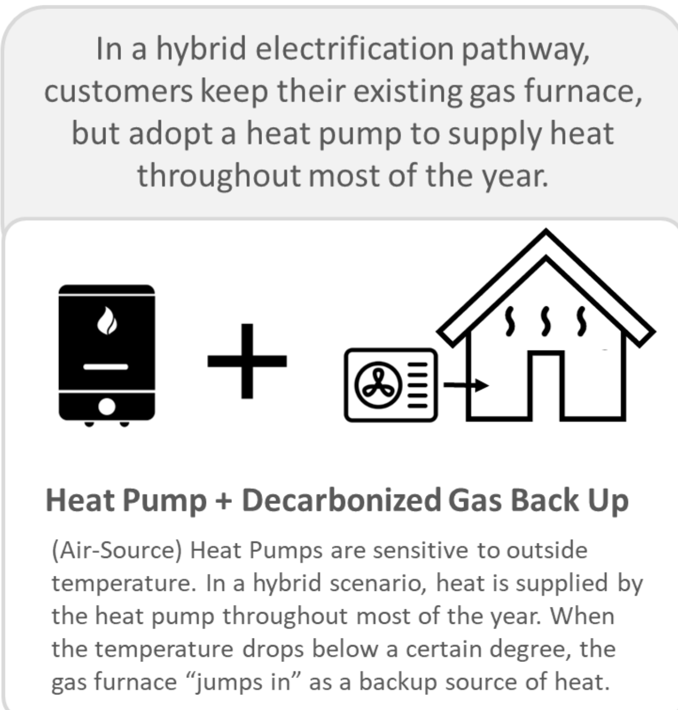
[24] Massachusetts 2050 Decarbonization Roadmap

[25] This figure represents the range of costs found by E3 across an extensive literature research. An example database with many reported heat pump costs can be found through the MassCEC website: http://files-cdn.masscec.com/ResidentialASHPProjectDatabase%2011.4.2019.xlsx. Costs for the Philadelphia market will be assessed in more detail through PEA's Built to Last Program.

measures increases New York's system peak by 75%, requiring substantial additional electric system upgrades which are ultimately recovered through customer rates.[26] Although current cold-climate heat pumps are expected to reach relatively high levels of efficiency at low temperatures[27] and heat pump technology continues to improve, the "peak-heat" challenge remains an important long-term concern. In Philadelphia, this challenge is likely to only occur with large-scale adoption of building electrification, as the current summer peak reported by PECO, Philadelphia electricity provider, is around 1.6 GW, or 24%, higher than its winter peak.[28] In fact, in the near- to mid-term, this headroom may allow for more efficient use of electric infrastructure, thereby putting downward pressure on electric rates.

3.3. Hybrid Electrification

Figure 8. What is Hybrid Electrification?



In a hybrid electrification strategy, consumers pair an air-source heat pump with a gas furnace or boiler that supplies backup space heating in winter, reducing the need for more expensive electric system upgrades. In the pathways examined by E3, customers are assumed to fully electrify other gas uses such as water heating and cooking. In a hybrid electrification decarbonization strategy, PGW's customers would remain connected to the gas system, though they would significantly reduce their annual gas demand. Remaining annual gas demand would be supplied by decarbonized gases.

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[26] NYC Mayor's Office of Sustainability, Con Edison & National Grid (April 2021); Pathways to Carbon Neutral NYC, page iv

[27] See NEEP's Cold Climate Air -Heat Pump Product List

[28] PJM 2020 Load Report. Since heat pump demand peaks in winter, additional capacity is only required after the summer peak is surpassed.

What are other regions doing?

The hybrid electrification option is mostly studied in Europe, where it is evaluated as a more cost-effective option than all-electric for colder regions.[29] *Although hybrid heat pumps have not been implemented at scale in the United States, several recent studies across North America emphasize the potential benefits of a hybrid strategy in colder areas. For instance, MaRS Cleantech found that lifetime energy costs for a Hybrid scenario in existing homes in Ontario, Canada, are significantly lower than for a full-electric system while providing flexibility. National Fuel's report on Scenarios for Decarbonizing New York's Economy notes that "a dual-fuel heating option mitigates growth in winter peak demand and improves system resilience in cold climate regions." Washington Gas includes hybrid heating through heat pumps that displace 60% of annual gas demand in their Climate Business Plan for Washington D.C.*[30]*.*

Advantages of hybrid strategies include the reduced electric capacity requirement compared to full electrification and reduced reliance on costly decarbonized gases. In addition, hybrid heat pumps may help building owners avoid substantial building upgrades as they generally require smaller sized heat pumps and less advanced compressor systems. However, hybrid strategies also pose challenges. First, hybrid electrification requires that customers limit their use of the gas system, which results in cost allocation issues. In fact, hybrid strategies may impose significant changes to the utility business model, as volumetric recovery of costs would no longer make sense in a system with low utilization. As the hybrid strategy mostly provides value for the electric system, adopting hybrid electrification would require solutions for potential cost recovery mechanisms for gas utilities. Second, similar to a Decarbonized Gas scenario, the emissions benefits of hybrid electrification are highest if PGW reduces methane emissions within its system. Lastly, a better understanding of the suitability of this electrification strategy in Philadelphia's housing stock is necessary to evaluate its feasibility.

3.4. Networked Geothermal Systems

A fourth potential decarbonization option for Philadelphia includes the large-scale adoption of networked geothermal district heating systems. Generally, district heating refers to the supply of heating and cooling to buildings through heat distribution systems, where heat is generated in one or several central or decentralized location(s) and transported through a network of insulated pipes in the form of water. In some European countries, such as Denmark and Poland, district heating already serves a large share of heat demand (51% and 34% respectively) and several

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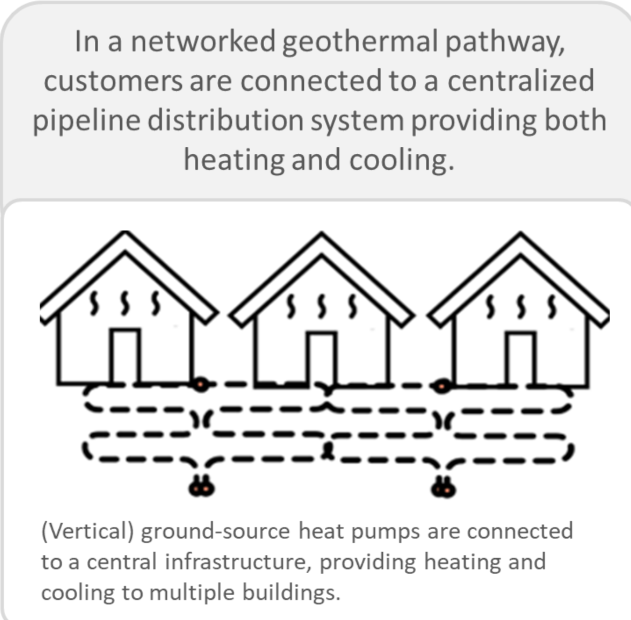
[29] Examples of evaluations include Poyry (2018): Fully Decarbonizing Europe's Energy System by 2050, Imperial College (2018): Analysis of Alternative UK Heat Decarbonisation Pathways. Netherlands Environmental Assessment Agency (2019). Impacts of the Climate Accord (in Dutch).

[30] National Fuel Gas Distribution Corporation (2021, provided by Guidehouse): Meeting the Challenge: Scenarios for Decarbonizing New York's Economy; MaRS Cleantech (2018): Future of Home Heating; E3 for Calpine Corporation (2020). (WGL). March 2020. Natural Gas and its Contribution to a Low Carbon Future – Climate Business Plan for Washington D.C.

Figure 9. What are networked geothermal district systems?



European cities have proposed the expansion or construction of renewable district systems.[31] Philadelphia has an existing district system providing steam to sections of Center City and West Philadelphia.

A district heating concept gaining ground in the United States is the Networked Geothermal concept researched by Home Energy Efficiency Team (HEET) and BuroHappold in Massachusetts, which refers to ground source heat pump systems that connect several homes to a central infrastructure, taking advantage of buildings' coincident heating and cooling demands.[32] In this Study, we refer to these systems as networked geothermal systems.

What are other regions doing?

Several gas utilities in the U.S. are exploring the concept of networked geothermal systems. For example, Eversource in Massachusetts filed a proposal for a networked geothermal demonstration project, piloting the installation of this concept in types of neighborhoods (total of 140 units with estimated installation costs of $10 million).[33]

In the City of Amsterdam, the Netherlands, district heating (using centralized heating systems) is one of the main strategies for replacing its aging gas infrastructure in a dense urban region. The City identified a detailed block-level approach that determines the most appropriate heating source by neighborhood based on gas infrastructure characteristics and socioeconomic factors.[34]

Networked geothermal systems provide several benefits. First, the installation of ground source heat pump systems over air-source heat pumps reduces weather dependency, making the system less likely to spur electric system upgrades. In addition, more buildings connected to the system can help "smooth" demand patterns, as one building's cooling load can help supply another building's heating demand. The use of a variety of thermal sources, ranging from geothermal or solar thermal energy to using residual heat from local industrial sources, can help continuously

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[31] IRENA (2017). Renewable Energy in District Heating and Cooling.

[32] HEET & BuroHappold (2019). GeoMicroDistrict Feasibility Study

[33] NSTAR Rate Case D.P.U. 19-120 Exh. 31-11

[34] Amsterdam Heating Transition Vision (in Dutch)

lower demand. This type of system requires distribution service and maintenance that could be similarly structured to today's utility gas business model, providing long-term opportunities for PGW and its workers. One potential advantage of this model is that the infrastructure required for networked geothermal is similar to natural gas infrastructure. This could mean that PGW's existing workforce could be retrained to build and maintain these systems. Because the costs of networked geothermal systems are highly dependent on local (geological) conditions and load density, the possibility of establishing them is uncertain in the Philadelphia context. However, demonstration projects and currently installed systems suggest that geothermal systems are relatively expensive to install, and levelized system network costs are generally found to be more expensive than gas networks.[35] European distribution costs of district systems range from $15-37/MMBtu (note that these systems are different from the networked geothermal concept piloted in Massachusetts) and are highly dependent on scale and density.[36] For reference: gas delivery costs in Philadelphia are around $7.5/MMBtu.

[35] For instance, the Eversource demonstration pilot proposed installation costs of around $10 million to supply heat to 140 households. BuroHappold refers to installation costs of $13,000 per ton of capacity.

[36] see: IRENA (2017). Renewable Energy in District Heating and Cooling

4. Evaluating decarbonization scenarios for the City

4.1. Scenario definition

To assess the potential impacts of the decarbonization options described above on PGW, its workforce, customers, and the broader Philadelphia community, the consulting team conducted a scenario-based analysis, examining four potential pathways for fully decarbonizing PGW's firm sales and firm transportation customers by 2050.[37] These scenarios are not meant to define an optimal or even preferred outcome, but instead set out possible outcomes in the face of an uncertain future. Given the multi-decade time horizon of this Study, not every uncertainty can be accounted for. However, building from best available assumptions, we can begin identifying the opportunities and risks offered by each decarbonization option.

The four scenarios examined largely mirror the decarbonization options described in the previous section and include:

- Decarbonized Gas: Where PGW continues to serve a similar number of customers as it would in a business-as-usual scenario. However, over time the gas supply provided by PGW (currently entirely natural gas) would be replaced by decarbonized gases. The blending of decarbonized gases would start with low-cost and commercially available resources like landfill gas or manure, but over time would include biomethane produced via gasification of biomass, hydrogen from electrolysis of water powered by renewable energy, and synthetic natural gas. For this analysis, E3 assumed a blending rate of 15% by 2030 (in accordance with activities and targets established by other North American utilities), 40% by 2040, and 100% by 2050.
- Electrification: Where most households in Philadelphia adopt an air-source heat pump to heat their homes, as well as other electric appliances such as electric cooking stoves and clothes dryers. In the Electrification scenario, heat pumps steadily gain market share in the near-term, with nearly 30% of PGW's customers having electrified by 2030. Beyond that point, heat pump adoption accelerates such that nearly all of PGW's customers have electrified by 2050.
- Hybrid Electrification: Where most buildings in Philadelphia electrify but do so using hybrid heat pumps that combine an air-source heat pump with a gas furnace or boiler. Other appliances, including water heating and cooking are assumed to convert to electricity. It is important to note that the Hybrid Electrification scenario results in a significant reduction of annual gas consumption and is therefore similar to the Electrification scenario. The gas system is used to supply approximately 25% of

[37] These include all residential, commercial and industrial customers PGW sells gas to. Gas Transportation Services are not included in this analysis.

customers' annual space heating demands, consistent with E3 modeling outcomes for similar climate regions.

- Networked Geothermal Systems: Where PGW develops networks of heating systems that use ground-source heat pumps to provide heating and cooling services. Replacing gas infrastructure with networked geothermal systems would require retrofits at a block or even neighborhood scale. Given that challenge and by means of example, the consulting team assumed that the installation of these systems would be limited to around 25% of PGW's customers by 2050. In this scenario, the remaining customers are assumed to adopt hybrid heat pumps leading to a sustained use of PGW infrastructure across the City. However, a networked geothermal system can in practice be complemented with any other decarbonization strategy defined in this Study.

Throughout this chapter, the four decarbonization scenarios are evaluated taking PGW's existing business model as a starting point. This means that no additional revenues from diversification options are assumed, and the gas system continues to be maintained in its existing form. For the Electrification-based scenarios, this implies that costs of the gas system would not decline with customers departing the system, assuming gas infrastructure needs to be maintained on the long-term to provide reliable service to non-electrifying customers. Alternative business models and diversification options for PGW are further described and evaluated in Chapters 5 and 6.

4.2. Scenario evaluation criteria

In order to draw meaningful comparisons between the scenarios, the consulting team worked with stakeholders[38] to define evaluation criteria. Ultimately four criteria were identified, two of which are related to emissions and two related to the business and finances of PGW and its customers.

Emissions evaluation criteria include:

- GHG Emissions. A key goal of this Study is to identify future roles for PGW in the context of achieving the City of Philadelphia's decarbonization goals. To that end, each scenario is defined such that it achieves net-zero GHG emissions in 2050.[39]
- Air Quality. Most buildings in Philadelphia are currently heated through combustion of natural gas. Combustion creates air pollutants (like particulate matter and oxides of nitrogen, a precursor of ozone) that can harm human health. Decarbonization strategies like energy efficiency and electrification may lead to improvements in air quality as they reduce the combustion of gas. This Study does not include a quantitative treatment of

[38] Additional details on stakeholder engagement in this project can be found in Appendix A.

[39] For this analysis, decarbonized gases are assumed to have a neutral carbon effect, as described in footnote 19, and emissions from the electricity sector are assumed to reach zero in 2050. The analysis takes all of PGW's customers as well as downstream emissions into account. Gas Transportation Services are excluded.

those impacts, which requires intensive modelling of air chemistry and transport, but instead considers air quality impacts qualitatively.[40]

Financial and business evaluation criteria include:

- Customer Affordability. As noted in Chapter 1, 23% of households in Philadelphia live below the poverty level, and the City is one of the most energy-burdened across the U.S.[4] An important question, therefore, is how to achieve decarbonization while minimizing impacts on customer bills. Customer bills in this analysis are defined as the annual fuel costs households pay for space heating, water heating, cooking, and clothes drying. Central to that question are how costs are borne by those who are "participants" in decarbonization options versus those who are "non-participants," which raises questions on how to ensure low-income customers are included in the transition towards carbon neutrality.[41] It is important to note that PGW's low-income customers are eligible for PGW's Customer Responsibility Program (CRP) that limits the energy burden for low-income customers. As such, increased system costs are likely to be borne by non-CRP customers.
- PGW Revenues and Workforce Retention. PGW, and by extension the City of Philadelphia, owns and operates a network of assets with a net-book value of over $1.3 billion. Those assets are maintained by a 1,600 strong workforce, including members of Local 686 of the Utility Workers of America. Identifying viable paths forward for both PGW's workforce and assets is a central consideration for this Study.

4.3. Emissions: Greenhouse gases and air quality

4.3.1. Greenhouse gases

Each scenario is designed to achieve zero direct-use GHG emissions for PGW's customers by 2050. Energy efficiency is a common driver of emissions reductions across scenarios. Improvements in both appliances and building shells in Philadelphia homes and businesses reduce the amount of natural gas and electricity sold and associated emissions. Where the scenarios differ is in their approach to decarbonized energy supply.

The Decarbonized Gas scenario sees an increase of carbon neutral fuels in PGW's supply mix. In the near-term, low-cost biomethane is blended into the pipeline. However, once that limited resource is exhausted, hydrogen and synthetic natural gas are added to the supply mix to achieve

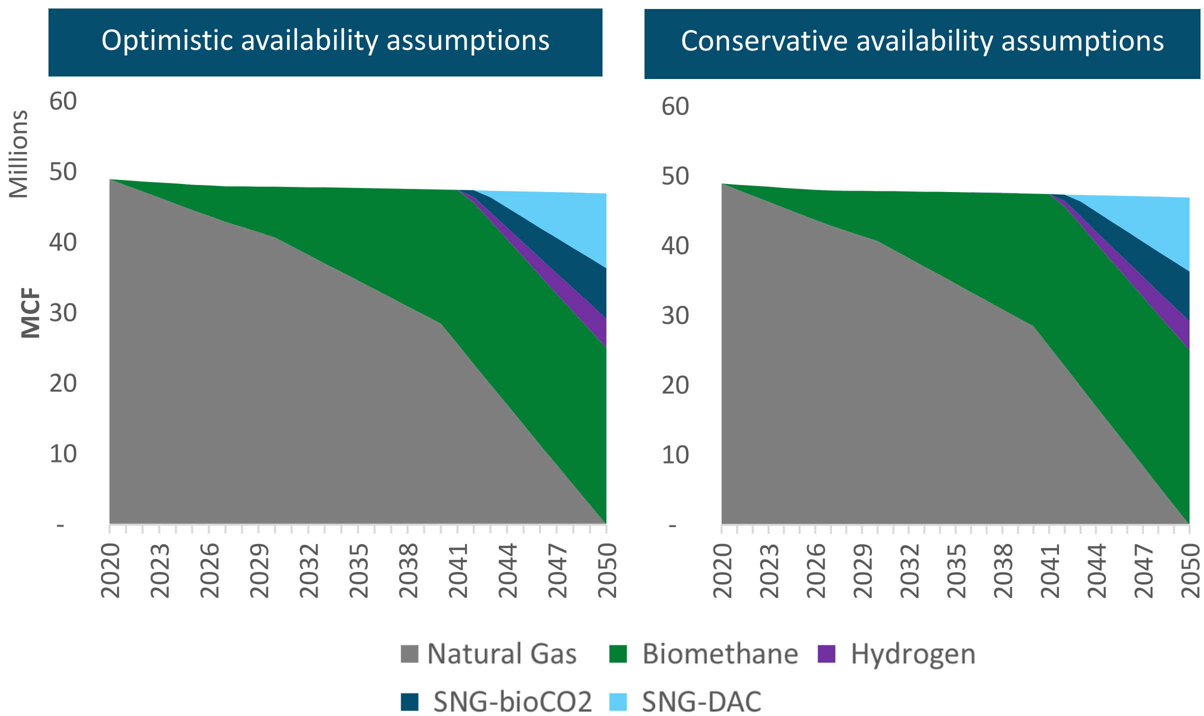
[40] The air quality impacts of electrification have been assessed quantitively in other studies. See, for instance: https://iopscience.iop.org/article/10.1088/1748-9326/abe74c, https://www.mass.gov/doc/ma-2050-decarbonization-roadmap/download

[41] A "participant" is referred to as a customer that is participating in a utility program. In the case of electrification, adopting a heat pump. A "non-participant" refers to a customer who is not participating in electrification and as such remains connected to the gas system, while others electrify.

deeper levels of emissions reductions. Figure 10 shows PGW's assumed gas pipeline composition for its bundled customers under both an optimistic and conservative biomethane availability scenario. These scenarios are based on two bookend assumptions:

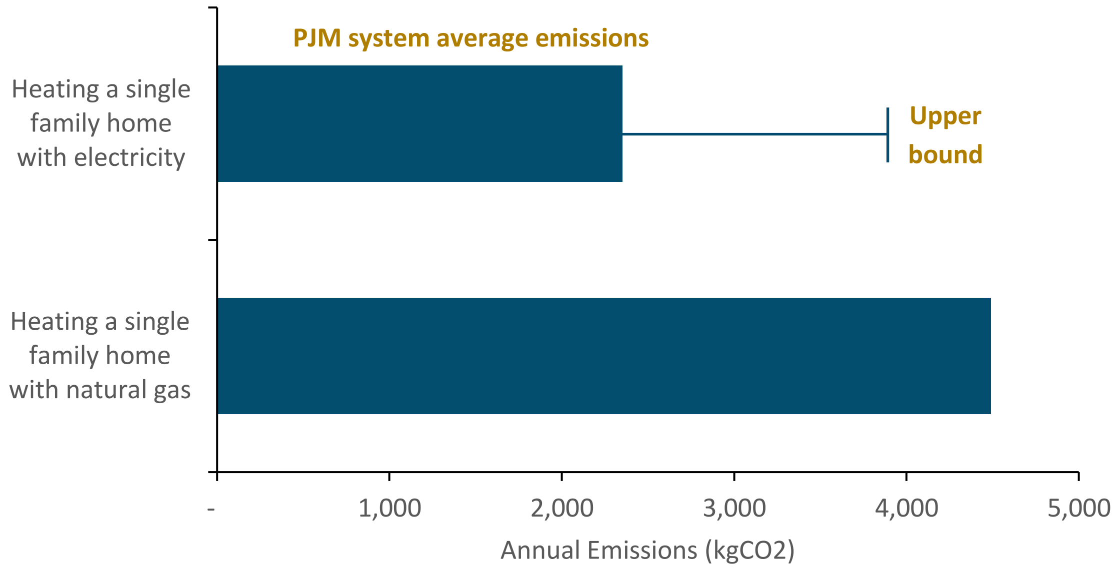
- Optimistic scenario (low-cost bookend): PGW has access to a national biofuels market without competition from other markets (i.e., gasoline, diesel, and jet fuel industries). PGW's access to available gas is downscaled based on its customers as share of the national population.
- Conservative (high-cost bookend): PGW only has access to in-state biofuel volumes with assumed competition from other markets. PGW's access to available gas is downscaled based on its customers as share of the national population.

Figure 10. Composition of gas sales to PGW's firm customers in the Decarbonized Gas scenario. Left: gas supply based on an optimistic biomethane availability scenario. Right: gas supply based on a conservative biomethane availability scenario.



The remaining scenarios rely on electrification to decarbonize heating in Philadelphia. Furnaces and boilers are replaced by electric heat pumps, reducing direct-use natural gas emissions in buildings. Like PGW's gas supply, the electric mix of PJM is not GHG-free. However, even today a high-efficiency electric heat pump reduces emissions relative to direct use of natural gas, as shown in Figure 11. Those emissions savings reflect an ongoing downward trend in PJM GHG emissions as coal generation has been replaced by natural gas and renewable energy.

Figure 11: Comparison of annual GHG emissions in 2019 for a single-family home (SFH) in Philadelphia heated by electricity and a home heated by natural gas, at today's electric grid emissions. Emissions in the electric home assume that space- and water-heating demands are served via air-source heat pumps. Electric sector emissions are drawn from PJM data and are reported in terms of both average and marginal emissions.[42]

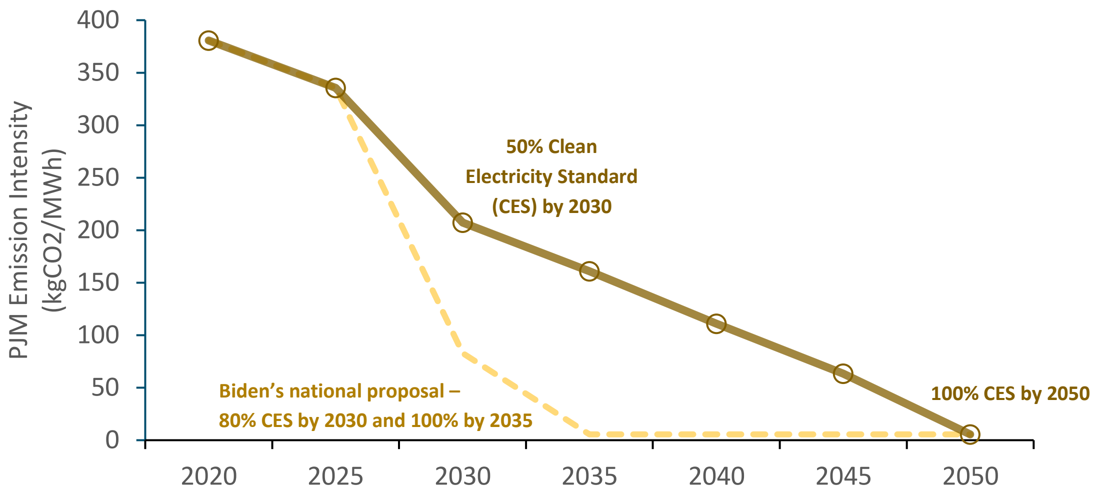


For the purposes of this analysis, we assume that the electric sector continues to decarbonize, achieving the equivalent of a 50% Clean Energy Standard (CES) by 2030 and a 100% CES by 2050.[43] This pace goes beyond current policy mandates in PJM, which vary state to state, but is not as aggressive as current federal policy proposals that target a 100% CES by 2035.

[42] See: https://www.pjm.com/~/media/library/reports-notices/special-reports/2019/2019-emissions-report.ashx

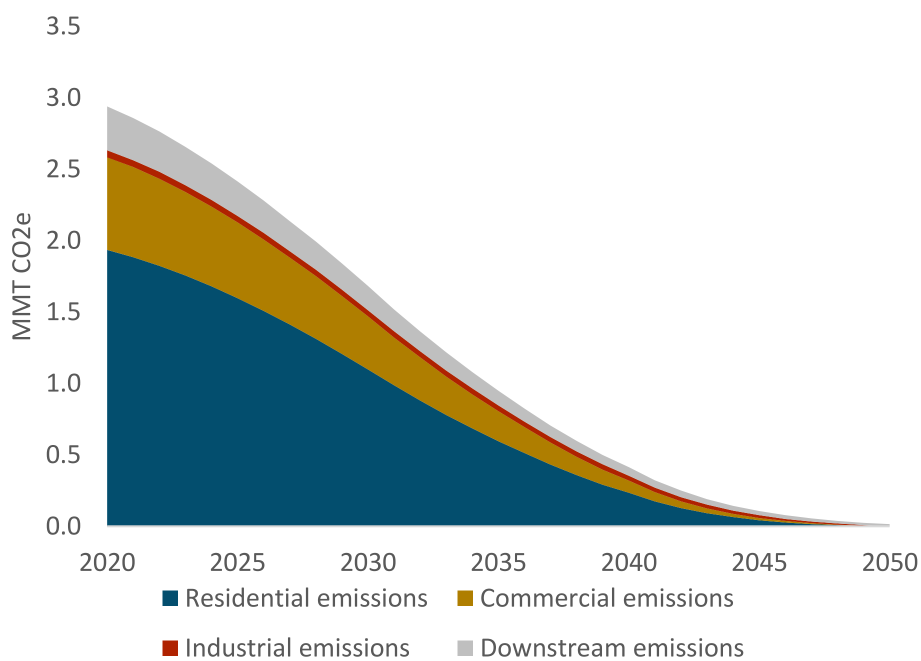
[43] The trajectory of electric sector decarbonization and associated costs used in this Study are drawn from E3's 2020 report *Least Cost Carbon Reduction Policies in PJM.*

Figure 12: Electric sector decarbonization modeled in this analysis (solid line) versus the decarbonization trajectory targeted in current federal proposals



In both the Decarbonized Gas and Electrification scenarios, decarbonization occurs gradually in the 2020s and accelerates in the 2030s and 2040s. This pace is consistent with the rate of building equipment stock-turnover modeled in economy-wide decarbonization scenarios and the timelines on which decarbonized fuels, particularly those that are not yet commercialized, could become available.

Figure 13: Decarbonization trajectory by source from the Electrification scenario. The pace of decarbonization is similar across scenarios. Note: chart excludes emissions from Transportation Services.



4.3.2. Air quality

A comprehensive assessment of the air quality implications of different diversification options is beyond the scope of this analysis. However, given the disproportionate impacts of poor air quality on disadvantaged communities, the Study team developed a qualitative assessment of how the different scenarios might compare. As indicated in existing research, the reduced combustion of fossil fuels results in a reduction of local air pollutants like PM 2.5 and NOx.[44]

The extent of net air pollution impacts in Philadelphia and elsewhere will depend on how electrification impacts emissions from electric generation. If gas- or coal-fired generators are used to supply incremental electric demands, there could be an increase in total air pollutants emitted due to the lower efficiency of those generators compared to direct use of gas. However, the impacts of those emissions on Philadelphians and residents of neighboring communities will depend on atmospheric chemistry and transportation: factors that go well beyond the ability of a qualitative review to evaluate.[45] Over time, combustion in the electricity sector can be expected to decline as shares of renewable energy rise, increasing the likelihood that electrification will improve air quality in Philadelphia and elsewhere.

The scenarios that rely on electrification to decarbonize heating in Philadelphia (Electrification, Hybrid Electrification and Networked Geothermal) reduce combustion of natural gas in Philadelphia's buildings by between 82% and 95%, likely resulting in air quality improvements. In contrast, the Decarbonized Gas scenario maintains a similar combustion level in buildings as today, so it is likely to result in little to no change in air quality.

4.4. Financial metrics: Customer affordability, PGW revenues and workforce impacts

The scenarios considered in this Study imply substantial changes to cost of gas sold by PGW, the volumes of gas PGW delivers, and the number of customers it serves. Decarbonized gases come at a cost premium to natural gas, so blending them into PGW's supply mix will increase the utility's gas supply cost. Scenarios that see a substantial change in the number of customers or volumes of gas sold through PGW's system also implicate the utility's revenues and rates. As volumes sold or customers served fall, the average cost of service for remaining customers will increase.

Under a traditional utility model, if either the cost of gas rises or throughput falls, the retail cost of gas rises. However, given the scale of transformation implied by the scenarios described above, there is a prospect that both gas commodity costs or delivery costs could increase to levels that make PGW's service uncompetitive with alternatives or unaffordable for customers. In such cases, some costs may not be recoverable through rates, which means additional revenues, or cost reductions, would be required.

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[44] See, for instance: https://www3.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf

[45] Additionally, electrification may result in improvements in indoor air quality, particularly in homes with gas cooking and poor ventilation. See, for instance; https://academic.oup.com/ije/article/42/6/1724/737113

In order to assess both the scale of potential customer and utility revenue impacts, E3 explored two distinct perspectives on how the costs of decarbonization are covered and allocated. It is important to note that for this analysis, no major cost declines nor additional revenues from PGW's system are assumed. Potential ways for PGW to earn additional revenues that could mitigate customer costs, are evaluated in Chapter 5.

- In the Customer Affordability perspective, the costs of PGW's system are recovered entirely from its customers. If the cost of gas increases, or the number of customers on the system falls, bills for PGW customers increase. Key to this perspective is the distinction between the costs borne by participants (e.g., those who electrify) and non-participants (e.g., those who do not). Note that the customer affordability perspective only considers the impact of the scenarios on rates and annual customer bills, excluding upfront capital costs required under these scenarios. In addition, as the figures in this report show average bills for a single family home, subsidization programs offered by PGW are not taken into account.
- In the PGW Revenue perspective, for illustrative purposes, customer bills are capped at current levels.[46] This means that if the number of customers on PGW's system falls, so do the company's revenues. We then report the difference between revenues collected and revenues required as a metric that illustrates the scale of cost challenge PGW may face in each scenario. Note that these results assume no changes in PGW's business model or cost structure. For instance, the Electrification scenario assumes that PGW would still need to recover the costs of the entire gas system on the long term, assuming no strategic decommissioning strategies take place. Approaches to overcome the challenge of potentially declining revenues are described in Chapters 5 and 6.

4.4.1. Customer affordability perspective

Impact of scenarios on bills

Throughout this analysis, the consulting team refers to customer affordability as the ability for PGW customers to pay their annual bills for space heating, water heating, cooking, and clothes drying. Customer affordability related to the scenarios is analyzed as the total annual operating bill for a customer using energy for space heating, water heating, cooking, and clothes drying (both for electric and gas consumption) measured against a business-as-usual (reference) case. Apart from customer bills outlined below, upfront capital costs are an important consideration in customer affordability, which is addressed in the next section.

Customer bills consists of several components and vary by scenario:

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[46] Bills only increase at the rate of inflation (2%).

- In the Electrification and Hybrid Electrification scenarios, participant costs are mostly determined based on the electricity required to operate electric appliances such as heat pumps. Electricity rates are based on a forecast of residential PECO rates, as described in Appendix C, and include upgrades to the electricity system required under an electrification scenario In the Hybrid Electrification scenario, bills also include the portion of heating and non-heating costs that is supplied by gas.
- In the scenarios that rely on gas, including Electrification non-participants, bills consist of gas delivery costs (all costs required to maintain and operate PGW's system) and gas commodity costs, which include the cost of decarbonized gases such as biomethane and hydrogen. As these commodity costs are uncertain and dependent on numerous factors, E3 developed both an optimistic and a conservative commodity cost forecast in line with the supply graphs shown earlier in Figure 10. A forecast of gas commodity costs in the Decarbonized Gas scenario, where decarbonized gases are blended into the pipeline towards 100% in 2050, is provided in Appendix C.

Figure 14. Gas commodity costs in the Decarbonized Gas scenario under optimistic and conservative cost assumptions. Note that decarbonized gas costs are different across scenarios as they are determined by supply.

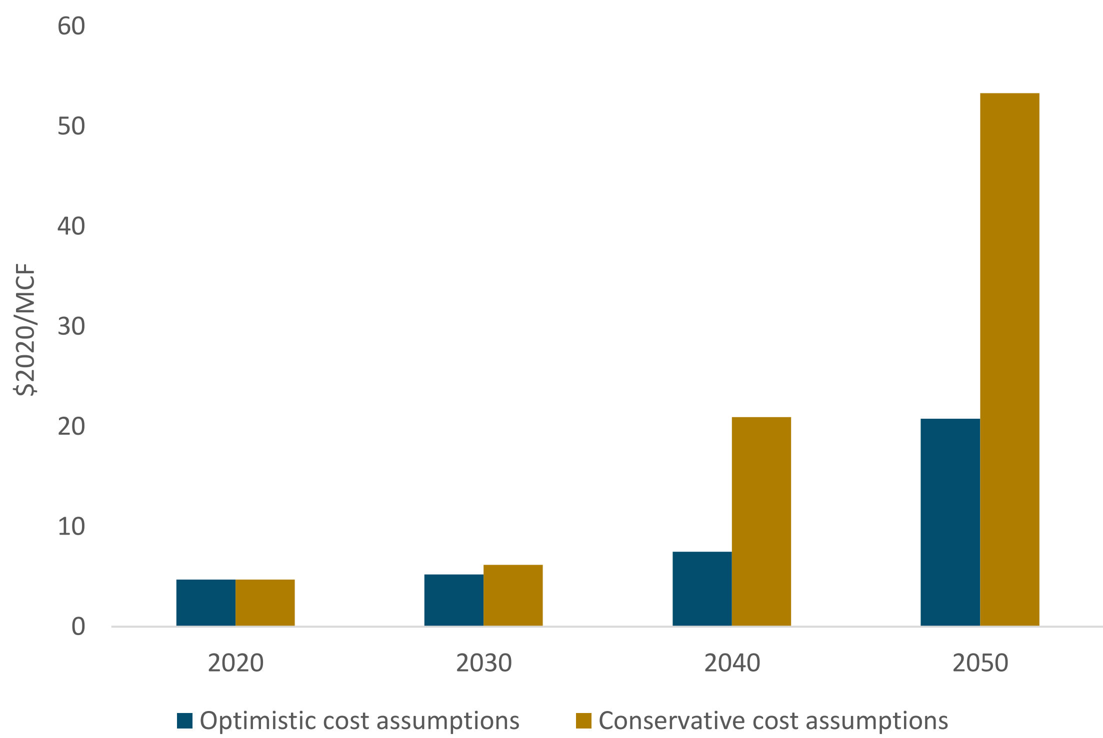
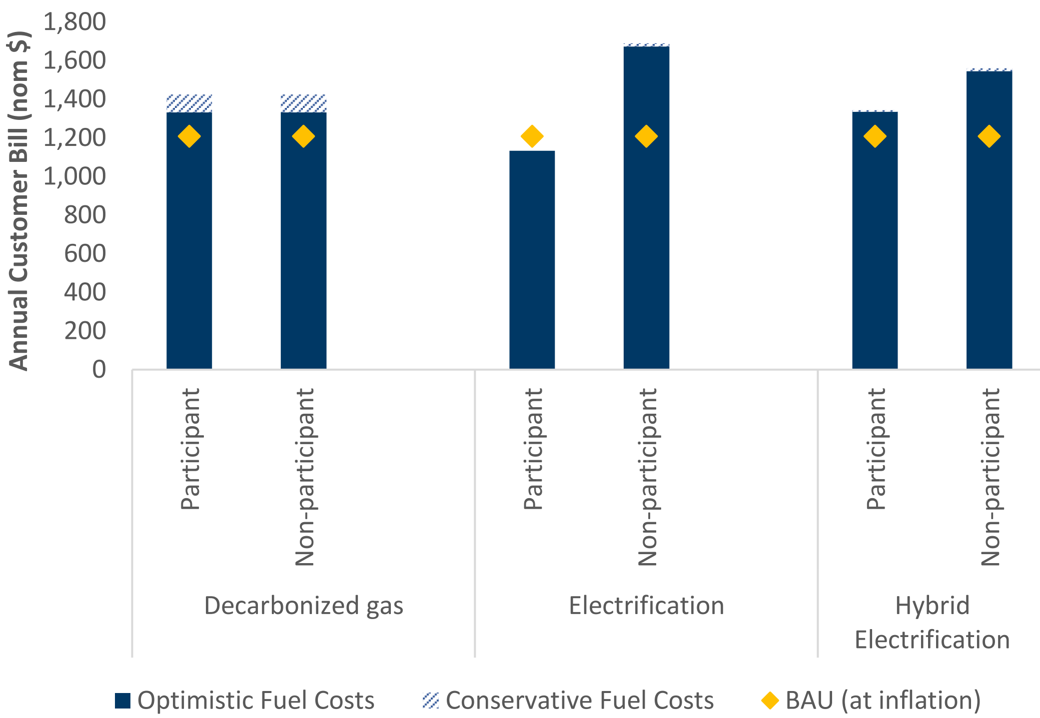


Figure 15 compares participant and non-participant customer bills in 2030 across decarbonization scenarios.

Figure 15: Annual customer energy bills in 2030 for a single family home. Note that this chart only shows fuel costs (gas + electricity) for space heating, water heating, cooking, and clothes drying. Chart does not include upfront capital costs, nor the effect of weatherization on bills. Costs of electricity system upgrades in the Electrification scenario are embedded in the electricity rates, as explained in Appendix C. "Participant" indicates customer takes action in line with the indicated scenario (e.g., Electrification) whereas "Non-participant" indicates customer does not take any individual action and remains on the prevailing gas system in each scenario. Chart does not show the difference in PGW's CRP versus non-CRP customers.



In the Decarbonized Gas scenario, customer bills rise relative to Business-as-Usual as a result of blending 15% decarbonized gas into PGW's gas supply. There is no distinction between participants and non-participants in this scenario because all customers are assumed to remain connected to the gas system and pay for decarbonized gas to the same extent.

In contrast, the Electrification scenario sees a marked difference in costs between participants and non-participants. Those who electrify (the participants) see bill savings[47], while those who do not (the non-participants) pay around $330 more per year in their gas bills relative to a business-

[47] Electric rates are assumed to see upward pressure due to the low load factor of electric space heating loads. However, under current rate designs the costs associated with serving those peak demands are socialized across all electric customers so the impacts on bills are small.

as-usual scenario. This result occurs because the fixed costs of PGW's system are spread among a smaller customer base, increasing the average cost of service for those who remain connected to the gas system. As noted earlier, the participant perspective does not include the upfront costs required for customers to install a heat pump.

The Hybrid Electrification scenario sees an increase in customer bills compared to a business-as-usual scenario for participants of around $130/year, driven by the fact that these customers pay for both electric bills and for costs of the gas system with increased levels of decarbonized gas. The Hybrid Electrification scenario sees a similar effect between participants and non-participants compared to the Electrification scenario, though the difference is smaller as the cost of the PGW system are borne by a more stable customer base. Yet, the Hybrid Electrification scenario also results in customer affordability challenges as both participants and non-participants are expected to see a bill increase in the absence of additional revenues for PGW.

The annual bills for networked geothermal customers are not shown on the charts. Although the energy cost component for these customers is beneficial compared to an electrification customer (energy costs are assumed at around $830 (nominal) per year in 2030, or around $620 if installed today),[48] the delivery component of the system is uncertain and dependent on cost allocation. Starting in 2025, the systems are assumed to replace expenditures related to PGW's cast iron mains replacement program. Those costs are expected to be approximately $90 million per year in 2025, whereas the capital cost of installing networked geothermal systems is estimated at around $170 million.[49] However, these costs are highly dependent on building typology and density and geological factors, which have not been assessed by the consulting team in this Study and would therefore require additional research. In addition, the total costs allocated *per customer* would depend on 1) whether installation costs are socialized over PGW's entire customer base or over the users of the system, and 2) how PGW would be able to finance such a system.[50]

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[48] Based on the HEET GeoMicroDistrict feasibility Study, the consulting team assumes a COP for heating for the geothermal heat pumps of 5. This value is slightly conservative; other studies report networked geothermal efficiencies of around 600% or higher (see for instance: AEC (2021). Inflection Point: When Heating with Gas Costs More.

[49] We assume that the utility infrastructure of a networked geothermal system costs $13,000 per ton of capacity required, based on the HEET GeoMicroDistrict feasibility Study. As part of the cast iron replacement program, around 5,000 customers are assumed to switch to networked geothermal systems per year. More research on both the costs, feasibility, and potential locations of these systems is required.

[50] PGW regularly finances capital investment using 50% debt and 50% cash. A similar construction for a networked geothermal system would require relatively large amounts of upfront cash, which would raise costs per customer compared to a solution where a higher amount of debt borrowing would be possible.

Figure 16: Annual customer energy bills in 2050 for a single family home. Note that this chart only shows fuel costs (gas + electricity) for space heating, water heating, cooking, and clothes drying. Chart does not include upfront capital costs, nor the effect of weatherization on bills. Costs of electricity system upgrades in the Electrification scenario are embedded in the electricity rates, as explained in Appendix C. "Participant" indicates customer takes action in line with the indicated scenario (e.g., Electrification) whereas "Non-participant" indicates customer does not take any individual action and remains on the prevailing gas system in each scenario. Chart does not show the difference in PGW's CRP versus non-CRP customers.

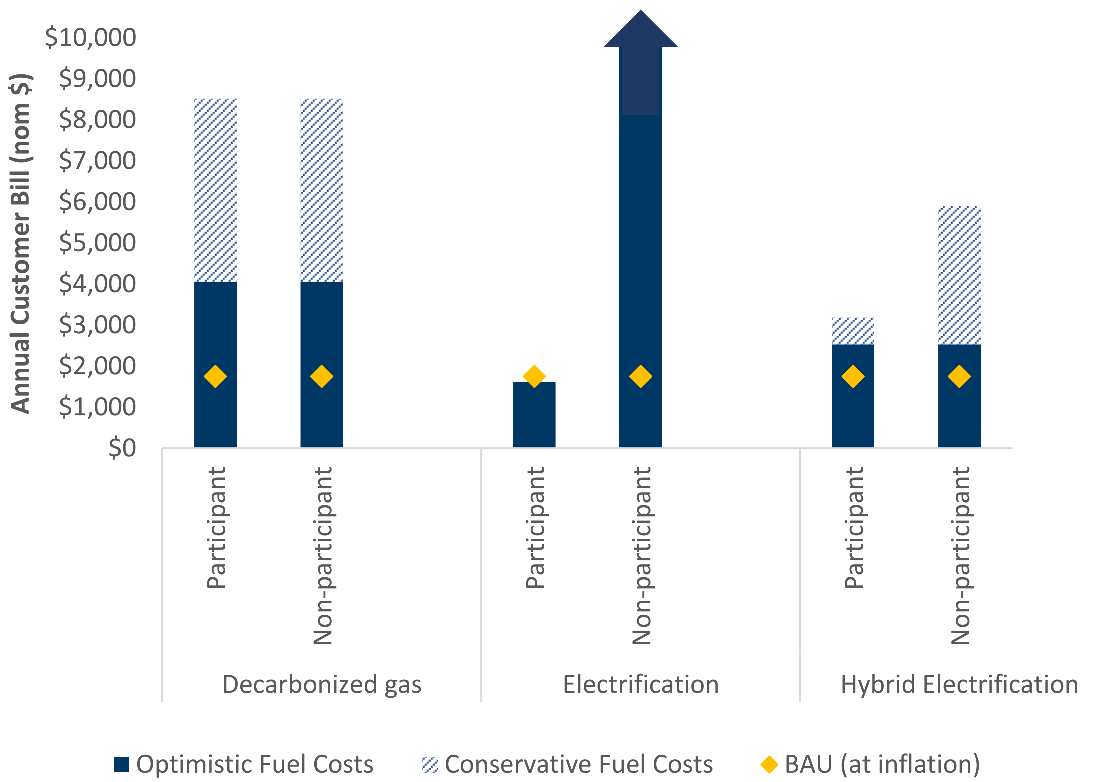

Figure 16 shows customer bills in 2050. The relative outcomes across scenarios and between participants and non-participants are similar to 2030, but the scale is markedly different. Even under optimistic fuel cost assumptions, the Decarbonized Gas scenario would more than double customer bills relative to business-as-usual. Bills for participants in the Electrification scenario are stable but impacts on non-participants are significant. It is important to note in this scenario that by 2050 95% of customers are expected to have electrified. It is reasonable to assume that by that timeframe under these levels of electrification, the proportion of the gas system will likely not be the same as today. Chapters 5 and 6 evaluate options that can be used to mitigate the energy bills for non-participants, both in the form of additional revenue streams for PGW or in the form of strategic cost reductions.

The Hybrid Electrification scenario shows a more equal balance of costs for participants and non-participants, though costs are still markedly higher than business-as-usual. Note that under this scenario, a change in rate design is assumed after 2040 from volumetric rates to fixed rates, which means that both participants and non-participants pay the exact same share of cost recovery for the gas system. As the Hybrid Electrification scenario is relatively novel, more research into adequate rate design structures for this option is required.

Impact of scenarios on upfront cost requirements

The annual bill impacts outlined in the previous chapters only show part of the customer affordability perspective. Another important component relates to the upfront costs required to install electric- or gas-based appliances. Electrification of homes and businesses will require building retrofits. The cost of those retrofits can vary substantially based on building type, vintage, condition, and a host of other factors. In general, electrification measures can be expected to come at a cost premium over gas alternatives. For example, costs for cold-climate air-source heat pumps reported in the literature range from $10,000 to $20,000 per single family household,[51] while the counterfactual option of a gas furnace and a central air conditioner fall in the $7,000 to $10,000 range. Hybrid systems typically carry a smaller price premium over a gas furnace and central air conditioner than all-electric solutions because the heat pump can be sized smaller and cold-climate equipment is not required.[52] Electric heat pump water (storage) heaters range in cost from $2,500 to $4,700, while gas storage water heater costs range from $1,000 to $2,600.[53] The building retrofits required to convert buildings to geothermal systems are estimated at around $12,415 for a single family home (behind the meter, excluding the cost of the district system), though those costs can vary significantly based on building characteristics.[54]

Figure 17 shows the upfront capital costs and energy bills for customers, for different types of home heating equipment, based on a lifecycle cost perspective. The figure shows the total (net present value) costs a customer is expected to pay for both the equipment and the fuel (gas + electricity) *over the lifetime of the equipment,* assumed at 15 years. The costs shown are for a single family home and include the purchase of space heating equipment (gas furnace or air-source heat pump), water heating (gas or heat pump water heater), cooking, and clothes drying (gas or electric).

The figure shows two perspectives: a cost comparison for a customer purchasing this equipment in 2021, and a cost comparison for customers purchasing this equipment in 2035. In 2021, a customer adopting a gas furnace supplied by a limited blend of decarbonized gases, consistent with the Decarbonized Gas scenario, is expected to pay lower costs overall over the lifetime of

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[51] See, for example: costs reported by NREL in the Electrification Futures Study, costs reported in the MassCEC Database, or costs reported in the American Gas Association Study on Residential Electrification.

[52] See, for instance: https://be-league.com/wp-content/uploads/2020/03/Surveillance-Beneficial-Electrification-Dual-Fuel-Heating-March-2020.pdf

[53] E3 (2019). Residential Building Electrification in California.

[54] Based on HEET (2019). GeoMicroDistrict Feasibility Study. Note that the pilot proposed by Eversource in Massachusetts assumes higher building retrofit costs.

appliances than a customer adopting an air-source heat pump (consistent with the Electrification scenario). However, a customer adopting an air-source heat pump in 2035 is expected to pay similar or lower lifecycle costs than a customer with conventional gas heating. This is due to an increased blend of decarbonized gases required to reach the City's climate target, combined with expected cost declines for heat pump appliances. In the 2035 time-frame shown here, the Decarbonized Gas scenario carries a risk from a customer perspective due to the uncertainty in the future costs of decarbonized gases.

Figure 17. Lifecycle costs of appliances and fuel from a customer perspective for a single family home. Costs include appliance costs, as well as gas and electricity costs, for space heating, water heating, cooking, and clothes drying. Assumes no incentives or rebates for equipment and no carbon price on fossil fuel use.

Overall, a just transition for Philadelphians for any of these scenarios, particularly an Electrification scenario, would require financing solutions that provide support to low- and medium-income customers. PGW could potentially play a role in such solutions, as outlined in Chapter 5.

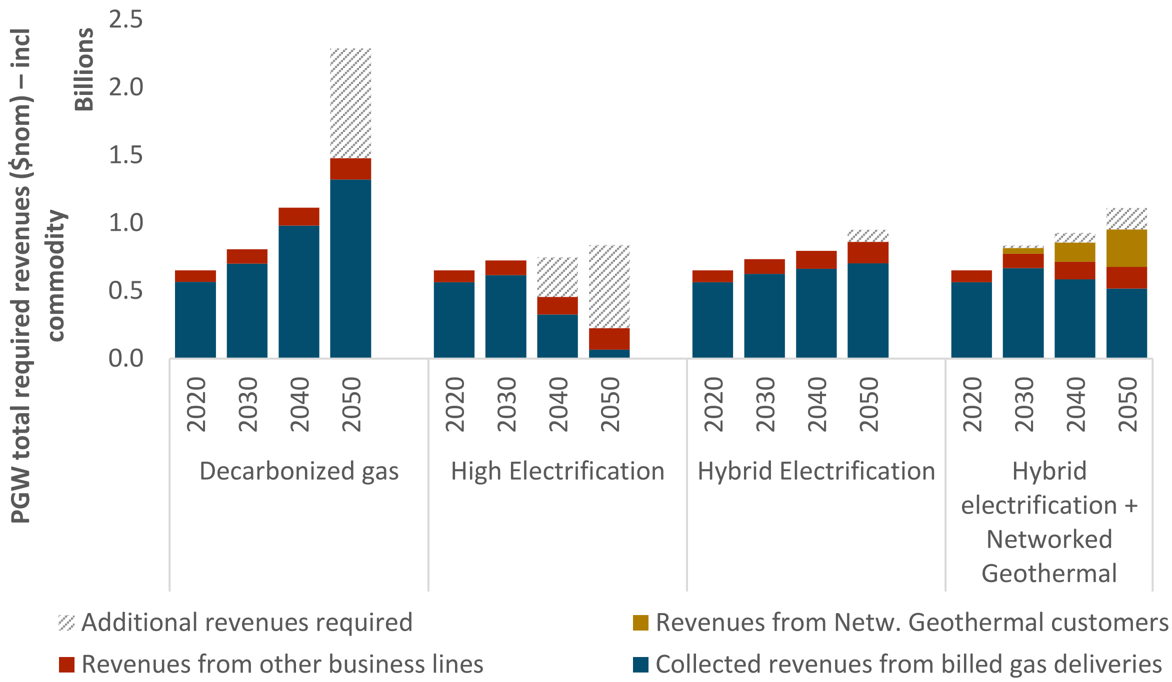
4.4.2. PGW revenue perspective

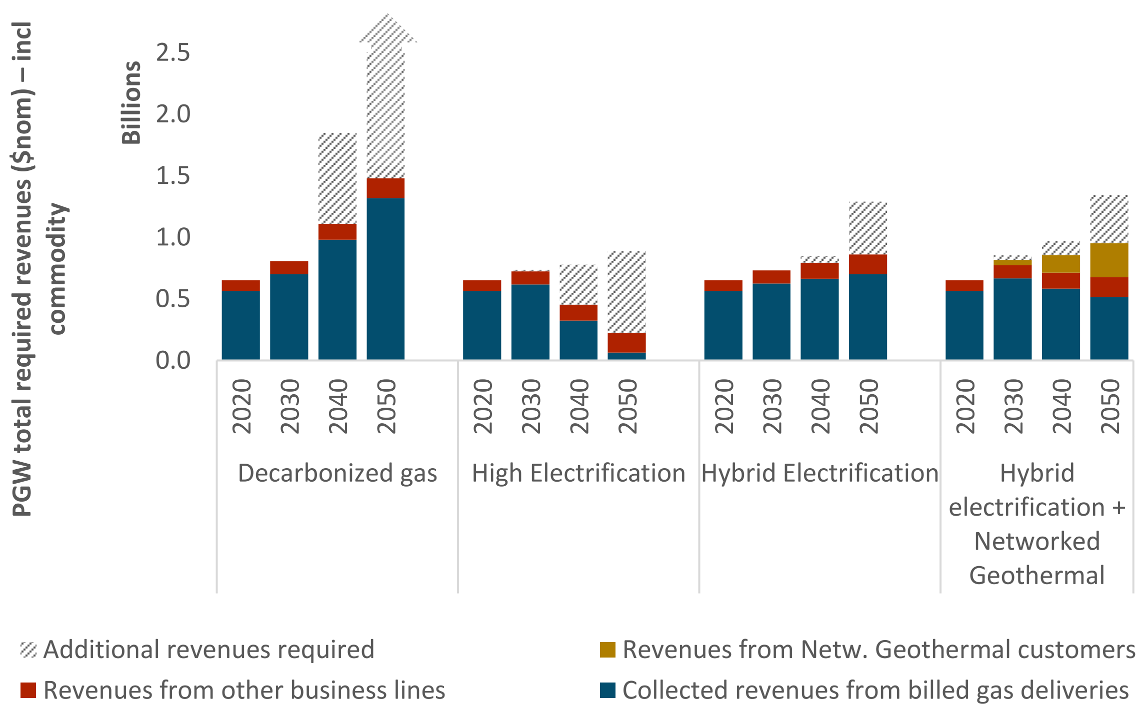
The customer affordability section offers a perspective in which customer costs are significantly affected by decarbonization scenarios, depending on the scenario. However, as affordability is an important criterion of this Study, the consulting team also assessed the impact on PGW revenues in a case where customer bills remain stable. In order to assess the impact of those changes in cost to PGW's revenues, E3 modeled a future where two conditions hold:

1. PGW's infrastructure and maintenance costs are equal to a business-as-usual trajectory. This condition holds if PGW's infrastructure continues to be used to deliver gas and, in the Electrification scenario, if electrification occurs in an unstructured manner, where gas infrastructure costs cannot be reduced.
2. Customer bills do not exceed current levels. This condition is both consistent with achieving customer affordability and is used to illustrate the scale of potential revenue impacts in each scenario.

With those two conditions, E3 developed an assessment of the magnitude and timing of the gap between revenues earned without increasing bills and revenues required to cover PGW's costs, shown for each scenario under optimistic and conservative decarbonized gas assumptions in Figure 18.

Figure 18: Revenue impacts of each scenario over time with Optimistic (top) vs. Conservative (bottom) decarbonized gas costs, assuming stable customer bills. Figure includes commodity costs. Analysis assumes no significant long-term cost reductions take place and revenues from existing business lines remain stable. Rate stability assumes 2% annual inflation.





Decarbonized Gas

The Decarbonized Gas scenario offers a near- to mid-term pathway that, when paired with energy efficiency, allows PGW to begin to decarbonize its system without raising customer bills relative to today. However, after 2030, higher quantities of decarbonized gases that are both costly and not yet commercialized will be required to decarbonize building heating. By 2050, $840 million of additional annual revenues are required to cover the incremental cost of decarbonized gas under optimistic assumptions and over $3 billion in additional annual revenues would be required under conservative cost assumptions.[55]

The wide divergence in results and outcomes for the near- and long-term reflect the advantages and disadvantages of PGW utilizing biomethane and hydrogen as a decarbonization strategy. A key advantage of decarbonized fuels from a revenue and workforce perspective is that they allow PGW to continue to use its system to deliver energy to Philadelphia homes and businesses. A key drawback is that the strategy can only cost-effectively decarbonize those homes and businesses to a point, after which costs rise substantially as more expensive sources of gas are required. It is important to note that significant revenue challenges under this scenario only occur in the long-term.

Electrification

In the Electrification scenario, PGWs revenues fall steadily over time as volumes of gas sold decline and customers depart the gas system as they adopt electric appliances. By 2040, in the absence of cost mitigation strategies, between $290M-$330M in "revenue gap" exists to maintain customer bills at current levels for the optimistic and conservative case respectively, a figure that rises to $615M-$670M per year in 2050.

The fundamental challenge of this scenario for PGW is that utilization of its infrastructure falls over time. With declining utilization comes increasing average costs that, as shown above, reach levels that are unlikely to be bearable by PGW's customers. This raises the prospect that, in this scenario, alternative strategies to collect revenues would be needed or the total cost of PGW's system would need to be reduced.

The scope of this analysis is aimed at defining alternative business strategies and diversification options that would maintain PGW's level of revenue and workforce, as further outlined in Chapter 5. An assessment of potential cost reductions to mitigate effects on customer affordability, and the mechanisms to achieve these reductions, is beyond the scope of this analysis. However, a series of recent studies have begun to explore issues related to large-scale electrification and have identified options such as targeted electrification, changes in depreciations strategies, or the introduction of exit fees as potential options related to gas distribution systems that mitigate cost

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[55] All costs are in nominal dollars.

increases on the long term. Questions of how to regulate and finance such transitions are in early stages of exploration across the U.S.

Hybrid Electrification

The Hybrid Electrification scenario could potentially mitigate, though not eliminate, the revenue challenges identified in both the Decarbonized Gas and Electrification scenarios, especially under optimistic assumptions on the cost of decarbonized gas. By electrifying most building heating demands, the Hybrid scenario avoids the need to procure large quantities of costly and commercially speculative synthetic gas. Unlike the Electrification scenario, in the hybrid case PGW has a stable customer base among whom the costs of its system could be shared. The total "revenue gap" in the Hybrid scenario ranges from $150 million in the Optimistic scenario to $500 million in the Conservative scenario in 2050.

A scenario in which PGW continues to maintain gas infrastructure to serve building demands during peak heating conditions is markedly different from today but could nonetheless offer a path forward for stable revenues while mitigating customer cost impacts compared to other decarbonization pathways and achieving deep GHG emissions reductions in Philadelphia buildings. However, in order for this strategy to work, PGW's business model would need to shift primarily from a stand-alone energy delivery utility to a company that provides capacity services to both local and regional electricity systems. In such a business model, as further explored in Chapter 5, PGW's gas system would be used as a source of backup during cold periods, providing a source of value to the electricity system. Such a transformation would, in turn, require changes in regulation and rates such that the services PGW and its hybrid customers provide to the electric system are compensated.

Hybrid Electrification + Networked Geothermal Systems

The Hybrid Electrification + Networked Geothermal Systems scenario would also require additional revenues to maintain constant customer bills, ranging from $200 million in the Optimistic scenario to $440 million in the Conservative scenario in 2050. In addition to the costs associated with hybrid electrification just described, this scenario would require PGW to collect costs of installing networked geothermal infrastructure. Where today PGW delivers heat via a network of gas mains and services, in this future PGW would instead deliver heating and cooling through a network of pipes that circulate water. While this represents a very different form of heat provision, supplied by electric heat pumps, much of the delivery infrastructure is similar to what PGW's workers install and maintain today. In addition, it is likely that the networked geothermal system would require backup sources of heat to be able to supply both heating and cooling throughout the year. This backup heat could for instance be served by CHP systems running on decarbonized gas, which is an operation close to PGW's current business model. Other aspects of this infrastructure, namely operating the ground-source heat pumps, would require new skills within the PGW workforce (or PGW would need to contract out those services).

4.4.3. Workforce Implications

Although an in-depth study on the implications of decarbonization strategies on PGW's workforce was beyond the scope of this Study, the consulting team qualitatively evaluated potential implications of the scenarios on jobs.

In the Decarbonized Gas scenario, the main purpose of the gas system, to deliver gas to customers in Philadelphia, remains unchanged. It is therefore likely safe to assume that a scenario in which PGW supplies decarbonized gas would largely retain or increase its current workforce.

In the Electrification scenario, the utilization of the gas system declines over time. Several studies have begun to examine the impacts of electrification on gas utility workers. For example, the 2019 report *California's Gas System in Transition,* developed after a series of engagements with a diverse group of stakeholders that included PG&E's gas union, identified that *"the gas delivery system transition will occur over several decades"* and a workforce will still be needed over the longer term, which means the transition is unlikely to significantly impact current employees in the next decade.[56] Furthermore, the report identifies that gas workers will have an important, long-term role in the process of both safely maintaining remaining gas infrastructure and decommissioning segments of the gas system where appropriate. Indeed, the City of Palo Alto Utilities, a municipal gas utility like PGW, estimated the labor required to decommission its system and found that its gas workforce would need to see an increase over a sustained ten-year period to reduce the size of its system.[57]

It is important to note that an Electrification scenario would also create new opportunities for employment across the City of Philadelphia in non-gas related sectors. These opportunities have been analyzed in both Massachusetts[58] and California,[59] where gains in employment have been forecasted in the construction sector to support building electrification retrofits, shell improvements, and additional local renewables development connected to the higher loads associated with electrification. Notably, these jobs would require a different set of skills than those employed by gas utility workers today but as noted above, given the long-time horizon of any gas transition, PGW's current workforce is unlikely to be impacted in the near-term.

In a Hybrid scenario, PGW's workforce would continue to perform the same set of tasks as today. Aging infrastructure would need to be replaced and assets in service would need to be

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[56] Gridworks (2019). California's Gas System in Transition: Equitable, Affordable, Decarbonized and Smaller

[57] City of Palo Alto (2020). Electrification Impact Study.

[58] Massachusetts 2050 Decarbonization Roadmap/

[59] See: https://innovation.luskin.ucla.edu/2019/11/13/move-to-all-electric-buildings-will-trigger-significant-demand-for-skilled-workers/

maintained. The largest departures from today would likely be operational, with reduced flows on the gas system during most hours of the year.

Lastly, the Networked Geothermal scenario may present an option for PGW workers to acquire new skills that are similar to today's operations. This concept offers an opportunity for a shift in the PGW business model, but one that continues to use many of the same skills employed by gas utility workers today.

4.5. Discussion

Table 2 summarizes the preceding discussion by providing the consulting team's assessment of how each scenario impacts the evaluation criteria identified by stakeholders. While no single decarbonization strategy fully meets all of the evaluation criteria, it is clear that there are paths forward that could, for instance, achieve deep GHG emissions and continue to maintain a central role for PGW in providing heat and related services to Philadelphia's homes and businesses. These options are outlined in more depth in Chapter 5.

Table 2. Assessment of the impacts of each decarbonization scenario on evaluation criteria

	Impact on GHG emissions	Impact on air quality	Impact on affordability	Impact on revenues* & workforce
Business-as-Usual (BAU)	Does not achieve City's Net-Zero goals by 2050.	No significant improvement in air quality.	No significant impact on customer bills relative to today.	No revenue gap, current gas system maintained.
Decarbonized Gas	Achieves City's Net-Zero goals as a result of blending 100% decarbonized gases by 2050.	No significant improvement in air quality.	Increases SF bills by 11-18% by 2030 relative to BAU (at 15% blend), up to 5 times by 2050 (at 100% blend).	Limited short-term impacts; results in annual revenue gap of $850 million to $3 billion by 2050, current system maintained.
Electrification	Achieves City's Net-Zero goals as a result of building electrification.	Improves air quality as gas combustion is reduced.	Reduces SF bill by around 6% by 2030 relative to BAU; results in cost shifts to non-electrifying customers; requires retrofit costs.	Limited short-term impacts; results in annual revenue gap of $615 M-670Mby 2050, potential long-term workforce impacts.

	Impact on GHG emissions	Impact on air quality	Impact on affordability	Impact on revenues* & workforce
Hybrid Electrification	Achieves City's Net-Zero goals as a result of building electrification combined with decarbonized gases.	Improves air quality as gas combustion is reduced.	Increases SF bills by 11-12% by 2030 and 40-80% by 2050 relative to BAU; mitigates cost shifts to non-electrifying customers; requires retrofit costs.	Limited short-term impacts; results in annual revenue gap of $150-500 million by 2050, current system maintained.
Hybrid Electrification with Networked Geothermal	Achieves City's Net-Zero goals as a result of building electrification combined with decarbonized gases.	Improves air quality as gas combustion is reduced.	Requires system capital investments; customer bills dependent on cost allocation.	Limited short-term impacts; results in annual revenue gap of $200-440 million by 2050, presents additional workforce opportunities.

SF = Single Family, BAU = Business-as-usual

* The "Revenue Gap" is defined as additional revenues or cost reductions required by PGW if customer bills remain stable, assuming no significant cost reductions take place.

The decarbonization analysis conducted in this Study also helps to clarify both short- and long-term considerations for PGW as it pursues different business model options.

Table 3. Summary of short-term and long-term considerations associated with each diversification strategy

	Short-term considerations	Long-term considerations
Energy Efficiency	Measures such as weatherization are relatively easy to install and directly reduce energy bills while increasing home comfort.	Energy efficiency should play a significant role in any long-term transition to limit the use of expensive decarbonized gases, to mitigate peak effects on the electricity system and/or to reduce bills.
Decarbonized Gas	Can be blended into the pipeline to achieve GHG benefits with relatively small impacts on gas rates.	Likely to be costly and to require non-commercial technologies at scale. However, this does not rule out a potentially important role of decarbonized gas in the future. Even relatively costly forms of gas could have an important role in the long term, for instance with hybrid heat pumps or as backup for district systems in CHPs, leveraging PGW's existing infrastructure to deliver energy on peak. Potential to connect to City's zero-waste goals.

	Short-term considerations	Long-term considerations
Electrification	Given the long lifetimes of building equipment, electrification will take time to scale. This means that both the benefits and drawbacks of electrification-based decarbonization strategies are likely to be modest in the near-term. However, the scale of building retrofit required in an Electrification scenario may warrant progress in the near-term.	The long-term impacts of building electrification depend in large part on the extent to which they reduce PGW's ability to cover the costs of its system. Electrification alone could lead to sharply reduced gas sales and customer departures. In that case, challenges related to the financial viability of PGW and retaining its workforce become acute. Hybrid electrification may offer a more stable path forward, provided customer incentives are aligned with peak demand value and other potential sources of value provided by PGW's system. Although additional research on the customer acceptance of this approach is required, it may provide an opportunity for continued use of PGW's infrastructure and workforce.
Networked Geothermal Systems	Like building-by-building electrification, networked geothermal systems will take time to scale. Additionally, their technical feasibility in Philadelphia has not yet been examined. Work to examine the feasibility of these systems is required in the short-term. In addition, short-term scaling may be difficult assuming these systems will replace aging infrastructure (which are currently retrofitted at 35 miles of mains per year).	If networked geothermal systems prove to be feasible in Philadelphia, they could offer a long-term business opportunity for PGW that leverages the skills of its workforce. A key question will be whether the costs of this strategy can be competitive with alternatives, as installation costs can be significant.

5. Diversification Strategies for PGW

The preceding section highlights that decarbonization of PGW's loads will put pressure on customer bills and PGW's revenues. Therefore, a key question is whether additional revenues can be earned, which can then be used to reduce the impacts of decarbonization on customers. This section summarizes research done by the study team to describe potential diversification options that:

1. Are consistent with the decarbonization and affordability trajectory the City of Philadelphia has embarked upon.
2. Provide an opportunity for PGW to earn additional revenues or retain workforce in the long-term.

The goal of this research and analysis is to describe potential roles PGW could play in a variety of business diversification options. The potential diversification options explored include options that can be considered an extension of PGW's current business, as well as options in which PGW would play a significantly new role. It is important to note that these options may be used in various combinations and are not mutually exclusive. In many cases, PGW could choose to become active in a number of these diversification options together, for example pairing weatherization with electrification, solar, or heat as a service. PGW could also choose whether to deliver these services directly, or rather to be a facilitator of arrangements between customers and existing providers of some of these services. Some of the options are more closely related to PGW's current activities, while others represent significantly new markets or roles. All of these potential new roles also require significant review for regulatory approval and/or political feasibility.

Table 4. PGW's potential role in business model diversification strategies

Business model	PGW playing a role in…*
Options close to PGW's current business model	
Weatherization services provider	Facilitating and/or installing building energy efficiency and weatherization services to existing customers.
Networked geothermal systems developer and operator	Distributing heat from geothermal heat pumps to buildings that are connected to a shared infrastructure.
RNG operations	Operating or procuring Renewable Natural Gas (biomethane, hydrogen, etc.).
LNG and CNG Supply	The operations and sales of Liquefied Natural Gas (LNG) or Compressed Natural Gas (CNG) to regional customers
Potential new business models	
Strategic electrification services	Facilitating the transition of customers to electrification (i.e., installation/maintenance of heat pumps).

Financing services	Facilitating of investments in customer-side energy upgrades, for instance through tariffed on-bill financing.
Heat as a Service	Selling heat to customers under the provision of agreed indoor temperatures at certain times for a fixed fee, instead of charging for energy use on a per-unit basis.
Demand response aggregator	Providing demand response services to the electricity market by using the gas system as winter backup mechanism
Energy storage & Microgrids	Facilitating integrated energy systems consisting of interconnected loads and generation (e.g., renewables, bio-CHP)
Community solar	Installing and operating shared solar systems.

* Note: The potential options described in this table may result in legal and regulatory barriers within the current regulatory framework. These barriers are not evaluated in this section. Key regulatory considerations related to these options are provided in Chapter 6.

5.1. Options close to PGW's current business model

5.1.1. Weatherization Services Provider

Weatherization involves protecting a building and its interior from outside influences, particularly from sunlight, precipitation, cold temperatures, and wind, and modifying it to reduce energy consumption and optimize energy efficiency. Typical weatherization measures include wall and rooftop insulation, air sealing, repair of ventilation systems, installation of energy efficient light sources, and insulation of water heating pipes.

The benefits of weatherization can be significant. Weatherization reduces energy costs, increases energy equity, creates jobs, reduces GHG emissions and stress on the power grid, and, in turn, makes homes and buildings more comfortable and resilient to the effects of climate change. There was a high level of interest in weatherization programs among participants in the City's energy burden conversations (see Appendix A). Many of these participants noted that while they were low-income, they earned too much to qualify for many programs to help reduce their costs.

In this option, PGW would extend the weatherization services it offers beyond the Low-Income Usage Reduction Program (LIURP), which targets at low-income customers, to include all customers. That could include either brokering weatherization to its customers through third parties or having PGW employees provide these services directly.

Weatherization Services Summary

Economic model	Often paid for through **federal, state, and/or utility programs targeting low-income customers**. Some providers are considering fee-for-service business models to help fund their low-income weatherization activities.
Customer base	Mostly deployed for residential customers

PGW's role	1) Extend and intensify weatherization installation services, in which PGW employees would install weatherization services to customers directly, or 2) continue and expand its assistance in brokering weatherization services to its customers
Economic impact	Based on PGW's current customer base, an 80% weatherization adoption rate over 30 years and a potential margin of 5%, the consulting team estimates potential net revenues at $3-5 million per year.

5.1.2. Networked Geothermal Systems Developer and Operator

The operating concept of networked geothermal system is similar to that of natural gas where PGW would install, own, and maintain the pipelines. Benefits of a district system include the potential to "smooth" demand patterns and take advantage of coincident heating and cooling loads, connect a variety of thermal sources, and reduce weather dependency compared to electric sources of heating. In some more energy dense applications networked geothermal systems may require supplemental sources of heat during very cold weather. This could open up the potential for RNG-powered CHP systems to operate alongside ground-source heat pumps.

Economic model	Often installed and maintained by a single utility-type entity that is responsible for the continuous supply of heat into the system. Revenues are incurred on a $/therm basis consisting of recovery of the distribution system and the (commodity) cost of heat.
Customer base	Mostly deployed for residential and commercial customers
PGW's role	Owner and operator of distribution system
Economic impact	This concept could provide substantial revenues to replace billed gas deliveries but raises the costs of the distribution system (outlined quantitatively on Figure 18),

5.1.3. Decarbonized gas operations

As outlined in the previous chapters, decarbonized gas is found to be a valuable, but relatively expensive form of carbon reduction. Decarbonized gases are pipeline-quality gas that are fully interchangeable with natural gas. Decarbonized gas blending therefore refers to the procurement of low-carbon methane for injection into existing gas pipelines.

Economic model	Two models are possible: Decarbonized gas can be procured from an external source similar to the procurement of natural gas and sold to customers on a 1-1 basis. Vendors are typically local operators that produce and upgrade biogas from local organic sources or parties involved in hydrogen production. Alternatively, PGW could become involved in the production of RNG, in which case a wider range of economic business models are possible.
Customer base	Can be deployed for PGW's entire customer base
PGW's role	Supplier and/or operator of decarbonized gas (facilities)

Economic impact	Procuring or producing decarbonized gas provides an economic opportunity for PGW to continue its current business model to a point. However, procuring too much RNG could make PGW's services uncompetitive compared to alternatives.

5.1.4. LNG and CNG Supply

Liquefied Natural Gas (LNG) refers to natural gas that has been cooled to a liquid state for storage or transport. LNG can be used for PGW's own needs in meeting peak demand or for external needs, such as fueling internal combustion engines in the transportation industry. Compressed Natural Gas (CNG) refers to natural gas that has been compressed to less than 1% of its volume, which can similarly be used as a mode of storage, transport, or as fuel in the transportation industry.

PGW currently operates two LNG facilities to manage its gas supply. The extension of LNG or CNG facilities would provide a reduced need for PGW's winter gas purchases and more flexibility in the timing of gas purchases as the opportunity for seasonal storage is expanded. In addition, both LNG and CNG could be sold to external parties, such as the transportation sector, increasing potential revenues for PGW. However, this option does not contribute to achieving the City's carbon neutrality goals in the long term.[60]

Economic model	In the current model, PGW operates the LNG facility developed and financed by private partners. PGW leases the facilities and sells LNG production services to the private partner for a fee. This model ensures additional external revenues for PGW which reduce customer rates.
Customer base	To date, most of PGW's sales of LNG have come from trucking and natural gas extraction customers, but potential sales to the broader transportation industry or to electric generators are possible.
PGW's role	Similar to today (operator of LNG/CNG facilities)
Economic impact	According to the Kleinman Center for Energy Policy, the expansion of LNG facilities could bring additional net revenues of $7.7-$10 million annually.[61]

5.2. Potential new business models

5.2.1. Strategic electrification services

With PGW's current large residential customer base of nearly 500,000 households, it has access to customer use trends and a deep understanding of customer needs. With that knowledge, PGW could play a role in selling or leasing new appliances and services to its customers, and/or working

[60] An alternative model would be to consider liquefaction facilities for hydrogen. Hydrogen may have an important role in maintaining electric reliability and in decarbonizing certain heavy duty transportation segments.

[61] https://kleinmanenergy.upenn.edu/wp-content/uploads/2020/08/PGW-LNG-Expansion-Efforts-FINAL-2-1.pdf

with customers to replace current natural gas equipment with electrically powered equipment. This would require sales and marketing staff skilled at customer service, and installation and maintenance staff with knowledge of the equipment, installation, and repair. Alternatively, PGW could serve as a facilitator for its customers as they make the transition to electric heating/cooling equipment and appliances. In this case, PGW sales and marketing staff would connect customers to private providers, installers, and maintenance staff who would be under contract or license agreement as preferred providers for PGW.

Economic model	Expanding the deployment of electric energy equipment, such as grid-connected water heaters or heat pumps, presents challenges. Barriers such as high upfront equipment costs and limited consumer awareness about these technologies complicate these efforts. Apart from economic models related to the installation of equipment, energy service subscription models for these systems can be used to overcome some of the barriers while expanding access (see: financing services, heat as a service). However, this does require PGW's workforce to gain significant expertise in installing electric equipment.
Customer base	Strategic electrification can occur within a variety of contexts, and thus the potential customer base spans several different industries. Potential customers include residential homeowners, commercial operators, and institutions, such as universities or hospitals.
PGW's role	Providing strategic installation services, in which 1) PGW employees install appliances to customers directly, or 2) PGW provides electrification brokering services to its customers.
Economic impact	Based on PGW's current customer base, the electrification adoption rate occurring in the Electrification scenario, and a potential profit margin of 7%, the consulting team estimates the *maximum* net revenue impact of installation services at around $15 million per year (average over a 30-yr period). However, the extent to which PGW can collect these revenues depends on the share of customers they would be able to serve, taking competition of installation services into account.

5.2.2. Financing services

Utility-led financing includes a variety of approaches for utilities to facilitate investments in customer-side energy upgrades that reduce utility costs and mitigate carbon emissions. One promising model gaining traction due to its accessibility to low-income customers and renters, along with its scalability potential, is tariffed on-bill financing where a utility facilitates energy upgrades and assigns site-specific cost recovery to the customer meter. In a tariffed on-bill program, a utility would pay for cost-effective energy improvements for residential customers, such as heating appliances or building shell upgrades, and recover the costs over time through a dedicated charge on the utility bill that is less than the estimated savings from the improvements. This form of utility investment and site-specific cost recovery could naturally exist in combination with weatherization or strategic electrification services.

Economic model	In tariff-based utility-led financing, PGW or a private lender would invest directly in customer energy upgrades. PGW would use its existing cost recovery mechanism to recover the investments through tariffs. The investment in energy savings is tied not to an individual customer but to the location until the value of the utility's investment is recovered.[62]
Customer base	The main customer base for utility-led financing is likely to include the residential sector, especially low-income families.
PGW's role	Under a new financing model, PGW would need expanded legal authority and billing arrangements to facilitate site-specific investments for its customers. PGW would either facilitate private financing or serve as a financial intermediary for its customers.
Economic impact	In this model PGW would need to access financing secured by future bills in order to make the upfront purchase of equipment. Future federal infrastructure bills could provide such resources, or the company could partner with the City to offer this alternative to customers. PGW could either offer this type of financing at zero interest, at cost, or with a margin.

5.2.3. Heat as a Service

Heat as a Service (HaaS) is a way to position heat as something customers buy directly, as an outcome rather than the result of its constituent parts.[63] Instead of paying for an appliance (such as a boiler), and then separately for fuel and maintenance, homeowners would pay directly for the end result – thermal comfort (either in the form of heating only, or expanded to also include cooling). The environmental benefit is that by selling warmth rather than energy, there is now a commercial incentive for the company to provide heat as efficiently as possible. The more efficient people's homes and heating technology, the wider the potential profit margin. It also breaks open the energy market in new ways. Rather than firms competing to sell customers electricity and gas, they could offer heat plans based around heat pumps, insulation, or heating controls. In addition, heat as a service allows the large upfront cost of installing new appliances to be incorporated into monthly payments that also cover fuel and maintenance.

Economic model	The subscription would take the form of a monthly payment that would cover everything required to produce heat or cooling, which could be sold in comfort hours, whereby homes are supplied with a particular number of hours at a given temperature; or it may be that consumers simply pay a fixed fee to have their home kept to a specific temperature schedule. It is important to note that only a few utilities, mainly across Europe, have piloted this business model.

[62] See: Utility Guide to Tariffed On-Bill Programs (https://mk0southeastene72d7w.kinstacdn.com/wp-content/uploads/SEEA_TOBGuide_FINAL_UPDATED_2020_04_13.pdf)

[63] See: Introduction to Heat as a Service (https://es.catapult.org.uk/reports/ssh2-introduction-to-heat-as-a-service/)

Customer base	The main customer base for Heat as a Service is likely to be the residential sector, especially low-income customers.
PGW's role	As a HaaS provider, PGW would move from providing natural gas to providing heat, bundling the combination of energy and heating and cooling equipment.
Economic impact	The economic impact of this model depends on the regulatory structure and design of the heating service. Assuming fixed bills in combination with financing services, revenues could be similar to today, though PGW would need to access upfront financing. This option has not been researched fully across the U.S.

5.2.4. Demand Response Aggregator

Demand response aggregators are entities that engage customers to reduce or shift loads during periods when electric demand is high. Today, demand response aggregators in Philadelphia can earn revenues through the PJM Capacity Market, which allows demand-side resources to compete against supply-side alternatives.

In a future with high levels of electrification and high levels of renewable energy supplying electricity, winter is likely to be the most constrained period for the region's electric system. Given that, the ability of PGW's system to deliver non-electric energy during those constrained periods could be a source of revenues for the utility. For example, hybrid heat pumps could be controlled to switch from electric to gas heating as part of a capacity market construct. Alternatively, hybrid heat pumps could be used to arbitrage between PGW's gas supply cost and wholesale electricity market prices during periods where electric demands are high. Finally, hybrid heat pumps could earn revenues as a "non-wires alternative" that avoids network upgrades on PECO's electric system. [64]

Other opportunities for demand response could include operation of back-up CHP units as part of a Networked Geothermal project or dual fuel boilers serving process heating loads.

Economic model	PGW could earn revenue by offering demand response (in the form of gas backup) on the PJM Capacity Market in periods when the electricity system is constrained.
Customer base	Demand response aggregators work with both large and small customers. Traditionally, large customers with sophisticated energy managers and discreet interruptible loads have been the largest share of demand response programs. However, there is an increasingly rich market of firms that work to unlock load flexibility within the residential and small commercial segments.
PGW's role	Operator and aggregator of demand response services, working closely with the electricity sector.

[64] These, and several other, revenue streams for hybrid heat pumps were explored in the FREEDOM pilot study conducted by two utilities in the UK including Western Power Distribution (electric) and Wales and West Utilities (gas). For more information please see https://www.westernpower.co.uk/projects/freedom

Economic impact	Based on the peak demand impacts of electric heat pumps estimated at 4 kW on average in Philadelphian homes, a program in which PGW would serve demand response for 50% of its (hybrid) customers and estimated capacity value of 100 $/kW-yr, additional net revenues could add up to revenues in the order of $140 million/year in 2050. However, this model would only be valid under a hybrid electrification pathway and implies gas backup is valued in the future capacity markets.

5.2.5. Community Solar

Community solar or shared solar is an energy model where the energy produced from a local solar system or facility is shared by community members. The solar systems are typically built on public or jointly -owned land, and the energy is made available to community members through two models: ownership or subscription. Community solar ownership is when the community member purchases a portion of panels on the system. With the subscription method, the customer is charged an agreed upon rate for the power plus administrative fees. Community solar is currently not permitted in Pennsylvania, but several bills in the Pennsylvania legislature are being considered to enable community solar which would have impact on business model feasibility.

Economic model	The most common is the utility sponsored model. In this model, the utility or a third party owns the installation, and customers buy electricity from the utility, but will receive a credit on their bills corresponding to their share of the installation's power production, which they may purchase either on a monthly basis, or up front in a lump sum.
Customer base	Residential customers and commercial, particularly office or retail. A community solar installation could also support a microgrid installation as a backup power source.
PGW's role	In the Community Solar option, PGW would install solar systems and then market the electricity generated by the solar systems to residential customers. Customers could either purchase a portion of the panels for their use or use a subscription model to receive electricity from PGW owned solar installations. PGW would need to have a sales team to work with customers, and then decide whether it would install and maintain the solar installations with its own workforce or by contracting with local installers and maintenance companies. Overall, this option involves a role substantially different from PGW's current business model.
Economic impact	There is only one existing community solar project in Philadelphia, but it serves as a useful reference for the potential market that PGW could serve. The Navy Yard solar project is a 440 kW system with an annual yield of 930,000 kWh. Assuming PGW would operate community solar systems similar in size to the Navy Yard project, and would add an additional system every 3 years to account for operating constraints, additional net revenues could add up to $2 million in 2050.

5.2.6. Energy Storage and Microgrids services

Microgrids are integrated energy systems consisting of interconnected loads and distributed energy resources that can be controlled as a single entity and operate in parallel with the grid or in an intentional islanded mode. By "islanding" from the grid in emergencies, a microgrid can both continue serving its included load when the grid is down and serve its surrounding community by providing a platform to support critical services from hosting first responders and governmental functions to providing key services and emergency shelter.

Microgrids could be complementary with a networked geothermal model, where a combination of local solar, battery storage and bio-CHP could serve as complement and back up to grid power.

Economic model	The market is still in the early stages of development, so there is lack of consensus on clear, identifiable business models that would be profitable across all market segments. However, the fastest growing business model is the microgrid-as-a-service model (MaaS), where the installing entity owns and finances the microgrid on behalf of the subscribing customers or power purchasers. The MaaS market is expected to grow to $2 billion by 2022, up 160 percent from 2015.[65]
Customer base	The most viable customers include single-owner facilities, such as a commercial buildings, institutional campuses or data centers, or potential single-owned residential blocks. Other potential customers include multi-tenant business campuses or industrial sites.
PGW's role	PGW would be building and supporting a microgrid and then marketing the reliability and service provided by the microgrid to customers, including specific communities, business districts, campuses, and business or industrial parks. Alternatively, in combination with other options, PGW could provide RNG or solar electricity to private microgrid operators to serve as a backup source of power to the microgrid.
Economic impact	Given the novelty of this concept it is difficult to forecast what the impact of microgrids on PGW's revenues would be.

5.3. Diversification option evaluation

The following table provides an overview of the most prominent options, with analysis of the complexity, workforce implications, economics, and importance for decarbonization. As noted at the beginning of this chapter, this table does not provide an assessment of potential legal and regulatory barriers. Regulatory considerations related to these options are provided in Chapter 6.

[65] See: https://www.smart-energy.com/regional-news/africa-middle-east/microgrid-service-2-2bn-2022/

Table 5: Comparison of Diversification Options

Diversification option	Complexity	Workforce Impact	Revenue Opportunity	Decarbonization Value
Weatherization	Well understood, but moving beyond current model may be difficult.	Could make use of existing PGW workforce, though additional skillsets are necessary.	Due to strength of customer base, could bring in new revenues and provide heating savings to customers.	Reduces demand for heating sources (though is not a standalone decarbonization option). Other benefits include improvement of air quality and home comfort.
Networked geothermal systems Operator	Very similar business model to natural gas, would require coordination with other utilities.	Infrastructure is similar that maintained by PGW staff today.	Stable to growing revenues if networked geothermal is competitive with alternatives.	Renewable alternative to current carbon sources.
RNG Operations	Complexity ranges from commercially available projects today to more speculative synthetic gas.	Could enable continued use of gas infrastructure and ongoing role for PGW workforce.	Could sustain revenues from PGW's traditional business, but only to a point. High blends could make PGW uncompetitive compared to alternatives.	Replaces natural gas with renewable gas. Lifecycle GHG benefits depend on production process. Does not lead to air quality benefits.
LNG & CNG Supply	Well understood and already implemented business model for PGW.	Would increase or retain current workforce.	Provides opportunity to grow revenues beyond current revenues from LNG facilities.	Does not lead to decarbonization.
Strategic Electrification	PGW has sold and serviced appliances in past but requires switch to electricity as base heating model.	Could make use of existing PGW workforce, though additional skillsets are necessary .	PGW would recover cost and earn margin on markup from sales and sales of maintenance contracts. Revenues gained appear to be substantially lower than losses from traditional business.	Electrification reduces GHGs today and those benefits are likely to increase as the electric grid decarbonizes.

Diversification option	Complexity	Workforce Impact	Revenue Opportunity	Decarbonization Value
Heat as a Service	PGW no longer sell volumes of gas, but units of heat. Different regulatory and billing model.	Varies depending on what services are supplied.	Stable source of revenue that allows PGW to maintain its current infrastructure where appropriate and transition where possible.	Incentivizes PGW to provide the lowest cost heating options. Achieving decarbonization via this strategy therefore requires ensuring price signals internalize social costs.
Demand Response Aggregator	Demand response markets are mature, but PGW would need to expand its operations and skillset to participate in them.	Staff to manage load aggregation. Revenues earned would support current workforce who maintain the gas system for peak services.	PGW would earn payments based on capacity savings achieved via hybrid heat pumps.	Avoids additions of new peaking generation and operations of less efficient generators,
Financing Services	Very different model for PGW with likely significant regulatory hurdles.	On-bill tariff would utilize similar billing workforce, but PGW is not a loan generator (partnerships would be necessary).	PGW could choose revenue neutral (finance appliances/improvements through customer savings) or earn return from interest/margin on financing or investments.	Helps to reduce customer costs and increase demand for weatherization and strategic electrification services.
Community Solar Developer	Very different model for PGW. Not currently permitted by state.	Very different workforce model than current PGW workforce.	PGW could recover costs and earn returns by selling electricity back into grid.	Totally renewable source of energy.
Energy Storage and Microgrid Operators	Very different model for PGW, would require significant partnerships and collaboration.	In scenarios using RNG or even natural gas as supplemental fuel for private microgrids (CHP), would preserve some of the existing workforce.	The economic model would be based on a risk management model, where the microgrid provides load management and outage protection for the electric grid. The value of these services could increase as more energy demands are electrified.	Helps support electrification options by providing reliable backup for essential businesses or institutions.

5.4. Diversification options in the context of decarbonization scenarios

As noted above, the diversification options described are not mutually exclusive. Yet not all diversification options are applicable in all decarbonization scenarios. For instance, an option in which PGW provides strategic electrification services would naturally only be applicable in a world in which customers electrify. In addition, the diversification options described in this chapter vary in the types of benefits they can provide. As an example, weatherization services will not provide large incremental revenues for PGW but do provide an essential role in contributing to objectives like reducing GHGs, maintaining customer affordability, and improving home comfort and air quality while providing employment opportunities. Some options have the short-term potential to smooth a longer-term transition towards other options, while others might make sense across all timeframes.

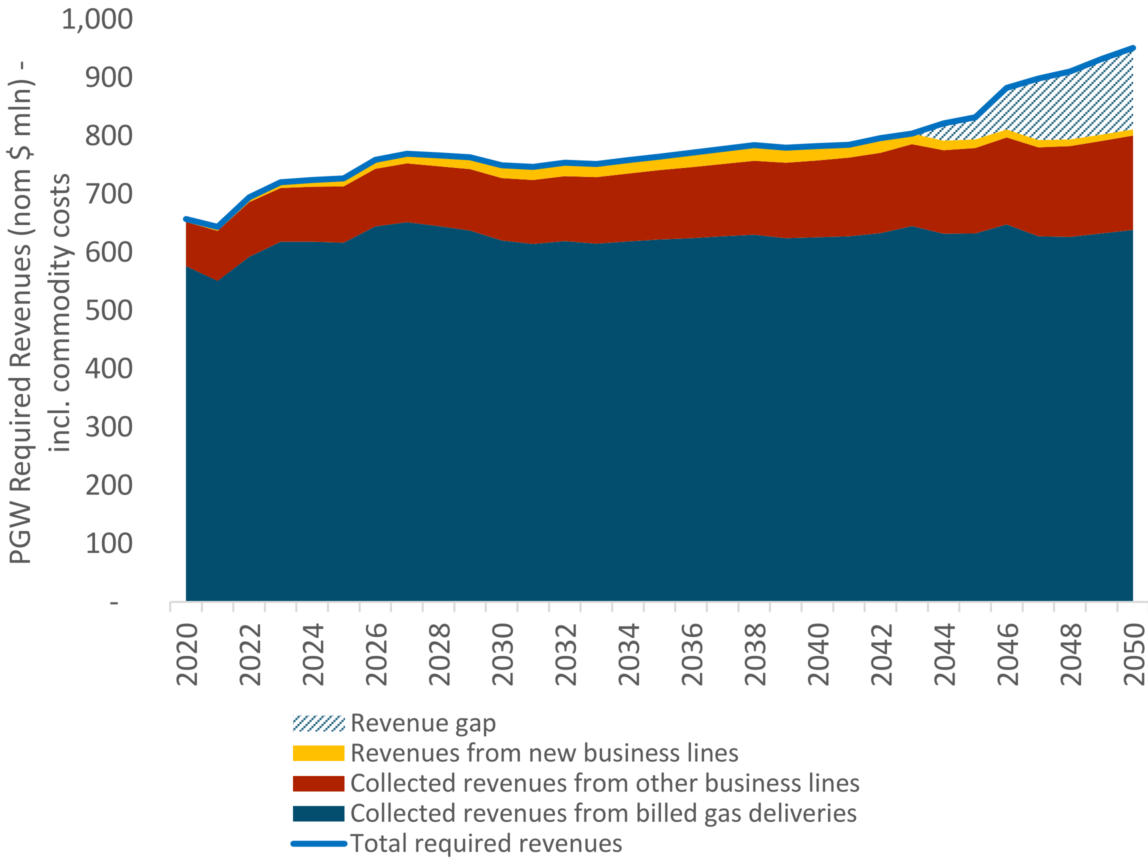
Although more combinations of energy scenarios and business models are possible, the figures below provide a few examples of PGW's revenue forecast using a combination of diversification options, in the context of the decarbonization options described in Chapter 4. The figures included below are only examples, and focus on those scenarios that show the smallest long-term revenue gap, namely the Hybrid Electrification scenario and hybrid electrification with Networked Geothermal Systems scenario.

5.4.1. Example 1: Hybrid electrification with weatherization, strategic electrification services and community solar

This example builds on the Hybrid Electrification scenario. In it, most of PGW's customers have electrified most of their heating energy via hybrid heat pumps, but PGW continues to deliver gas to homes and businesses during peak hours. This results in a small "revenue gap" if customer bills do not increase.

To close that gap, this example considers a future in which PGW has a role in weatherization, strategic electrification, and community solar. Figure 19 shows the margins earned by PGW from those activities that can be applied to fill the revenue gap identified in this scenario and reduce customer bills. At an average of around $17 million per year, the additional revenues are relatively small compared to PGW's total business but are large enough to maintain revenue stability through most of the study period. In later years, as more costly forms of decarbonized gases are added, the magnitude of the gap begins to exceed revenues earned from diversification measures.

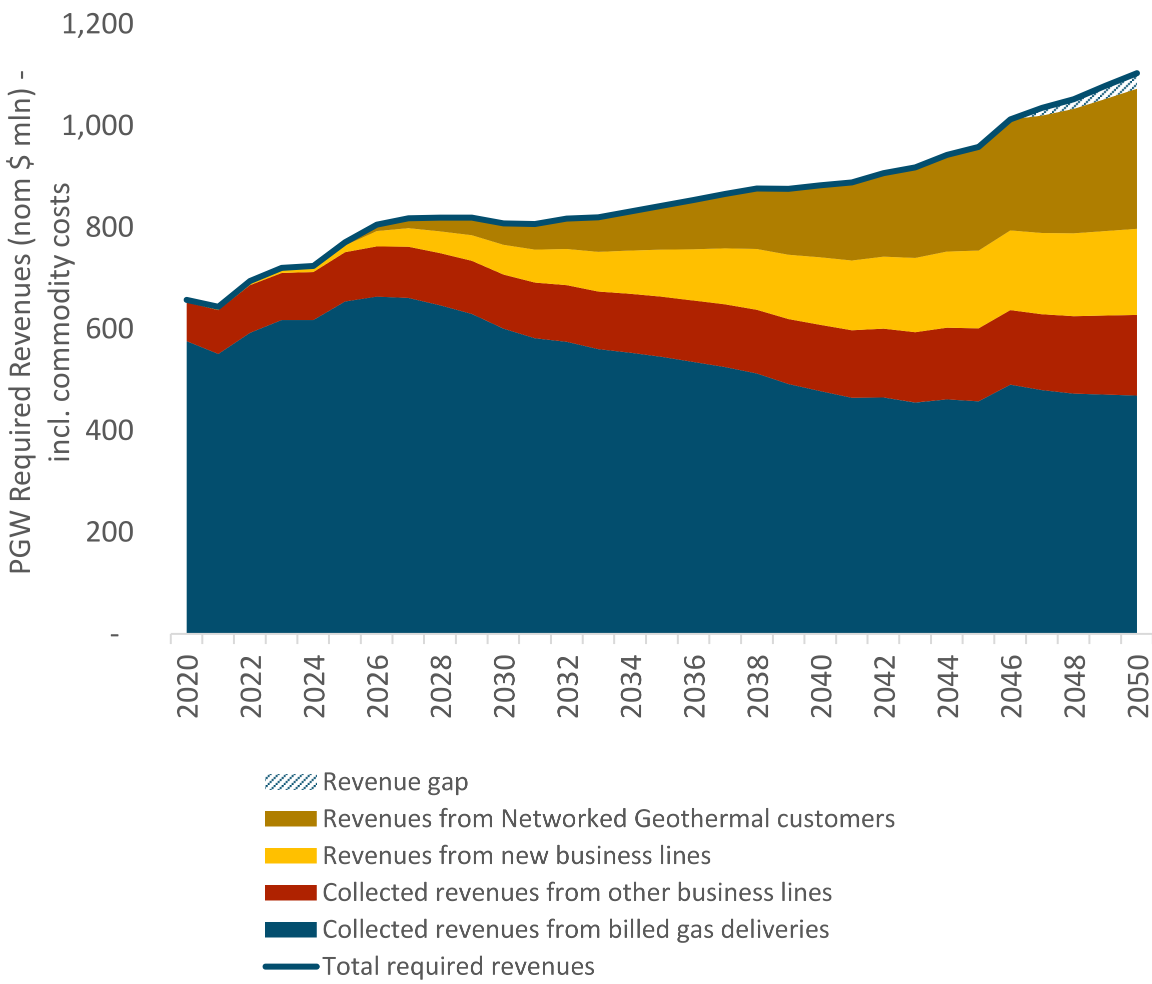
Figure 19. Example 1: Hybrid Electrification scenario with optimistic decarbonized gas costs where PGW would provide weatherization services to 80% of its customer base, strategic electrification services to 50% of its customer base and up to 4 GW of community solar in 2050.[66]



5.4.2. Example 2: Hybrid Electrification with Networked Geothermal, PGW Demand Response Aggregation

This example builds on the Hybrid Electrification with Networked Geothermal scenario. In that scenario, a combination of the cost of decarbonized gases used in hybrid heat pumps and the cost of networked geothermal creates a revenue gap if stable bills are maintained. In this example, PGW expands its business to include demand response aggregation services. This involves dispatching the combustion portion of hybrid heat pumps or gas backup to networked geothermal systems during cold-snaps or otherwise constrained periods on the grid. Given the fact that Philadelphia and the regional PJM electricity system are both currently summer peaking, this option is not assumed to be available until after 2030. However, after that point PGW earns $30M per year in 2030, rising to over $100M by 2050. Those additional revenues serve to largely reduce the revenue gap in the Hybrid Electrification with Networked Geothermal scenario. Note that these services are highly novel and do not exist on today's market in the proposed form.

Figure 20. Example 2: Hybrid electrification with Networked Geothermal scenario with optimistic decarbonized gas costs where PGW would provide demand response aggregator services for 50% of its hybrid and networked geothermal customer base.[66]



[66] The yellow area represents an example of additional net revenues PGW could earn by providing additional services. Weatherization and Strategic Electrification services are based on PGW earning a 5% and 7% profit margin respectively, in line with sector averages. The demand response aggregator role assumes winter demand response capacity revenues would become available on the PJM system at 100 $/kW-yr.

6. Recommendations for pilot programs and additional research

6.1. Pilot program opportunities

The challenges and opportunities for PGW's future outlined in this Study require a long-term transition, with many options for near-term actions. To continue the work of finding alternative business models for the company, the City and PGW are actively investigating the design and implementation of a pilot program that PGW can launch, informed by the findings of this report.

The consulting team has engaged in several conversations with the City and PGW to outline the contours of a potential pilot program resulting from the analysis in this report. Throughout these conversations, several objectives of the pilot program were defined:

- The pilot needs to result in GHG reductions;
- The pilot needs to have the potential to grow revenue or retain workforce on the long-term;
- The pilot needs to be able to launch within approximately six months;
- The pilot needs to test a new energy application or innovative business model;
- The pilot potentially needs to provide benefits to low-income customers.

Based on these criteria, the study team established an overview of the business models presented in Chapter 5 and assessed the feasibility of a potential pilot program for each of these options. The results of this analysis are shown in Table 6.

Table 6. Evaluation of pilot program options

Business model option	Potential pilot program	Criteria (program has the potential to…)					Note / key regulatory considerations
		Result in carbon reductions	Grow revenue or retain workforce	Launch within six months	Test new energy application or model	Benefit low income customers	
RNG blending	Landfill gas program working with other City Departments	Yes	Potentially	Potentially	Yes	No	Option requires investigation into current PUC regulation and gas quality standards
Weatherization with utility-led financing	Weatherization program for all customer types with on/off bill financing	Yes	Yes	Potentially	Yes	Yes	Short term launch requires investigation into Management Agreement, Pennsylvania law and PUC regulation
Networked geothermal	Feasibility study into	Yes (if piloted)	Yes	Yes (as feasibili	Yes	Potentially (depending	A feasibility study rather than pilot program is recommended

Business model option	Potential pilot program	Criteria (program has the potential to…)					Note / key regulatory considerations
		Result in carbon reductions	Grow revenue or retain workforce	Launch within six months	Test new energy application or model	Benefit low income customers	
(district heating)	Networked Geothermal systems			ty study)		on cost allocation, location and design)	due to novelty/uncertainty of concept
LNG & CNG Supply	Expanding LNG operations	No	No	Yes	No	No	Does not directly lead to carbon reductions; already existing application
Strategic Electrificati on	Assist small customer group in adopting and installing (hybrid) heat pumps	Yes	Potenti ally	No	Yes	Potentially	Not feasible in short term under Management Agreement, Pennsylvania law and PUC regulation
Heat as a Service	Small customer program aimed at selling heat rather than gas	Potenti ally	Yes	No	Yes	Yes	Not feasible in short term under Management Agreement and PUC regulations; only reduces emissions combined EE measures
Microgrids	Working together with campus or hospital to test microgrid opportunities	Potenti ally	Yes	Potenti ally	Yes	No	Requires more research into benefits and role of PGW
Community solar	Engage in installation & procurement of pilot solar program	Yes	Yes	No	Yes	Potentially	Currently not feasible under Pennsylvania law

Based on the assessment presented in the table above, as well as feedback from stakeholders, the study team recommends that the City and PGW further investigate the following pilot program opportunities:

- ***A weatherization program with novel financing opportunities*** (on/off-bill financing), where PGW supports low- and medium-income customers in the upfront financing or direct utility investment in the implementation of weatherization applications such as home insulation. This option directly increases home comfort for customers, reduces carbon emissions, benefits low-income customers, and could likely be launched on a pilot basis relatively quickly to provide an opportunity for PGW to test new types of services and revenue opportunities. On-bill financing options can be tied to the gas meter, rather than the customer, making these options available to renters and landlords, as well as homeowners. Furthermore, by offsetting the cost of the weatherization retrofits with energy bill savings, on-bill financing options can be designed to be accessible to PGW customers regardless of their credit score, ensuring equitable access to these services.

- ***A feasibility study for networked geothermal district heating***, where PGW would investigate the technical and geological potential of block-level networked geothermal district systems, as well as the utility financial model for such a system. Given the uncertainties related to this concept and the importance of local geological conditions determining the feasibility, the study team recommends the City and PGW start investigating this option through a feasibility study rather than a pilot option. This concept received many recommendations from stakeholders, as noted in Appendix A.
- ***A local decarbonized gas program***, where PGW would potentially work together with other City departments, such as Streets and the Water Department, to investigate opportunities to convert city waste into biomethane. This option would make use of local resources without stressing the environment, reduce carbon emissions for the City and provide an opportunity for PGW to test the technical opportunities for blending other types of gas into the existing pipeline and establish standards for gas quality. Many cities across the U.S., including in Pennsylvania, have already implemented landfill gas programs,[67] based on the understanding that even though biomethane supplies are limited, there is still a benefit to using the "low-hanging fruit" from landfill gas facilities to displace combustion of fossil gas. This option provides an opportunity for PGW to diversify its business in the short term, making use of existing assets and expertise. Furthermore, even if many residents in Philadelphia switch to electric end uses, there is expected to be some remaining gas demand in Philadelphia through at least 2050, so displacing this gas use with biomethane will be necessary to meeting the City's climate goals. Although this pilot would not directly benefit low-income customers, a green tariff program could be designed to allow customers to opt-in to pay for the biomethane, avoiding placing any cost burden on low-income customers.

6.2. Additional recommendations

In addition to the short-term pilot options outlined above, the consulting team makes the following additional recommendations to the City and PGW to move towards developing and implementing a concrete, long-term plan for PGW and the City's buildings:

[67] See: https://www.epa.gov/lmop/landfill-gas-energy-project-data

- ***The City should work together with PGW to define mid-term (i.e., 2025 and 2030) GHG reduction targets for PGW that are consistent with achieving the City's carbon neutrality target by mid-century.*** PGW should provide the City with regular progress updates on the status of its pilot program(s) to diversify its business and reduce GHG emissions as well as regular updates on PGW's current and projected GHG emissions.
- ***The City should work together with PGW's regulatory bodies (the Philadelphia Gas Commission and the Pennsylvania Public Utilities Commission) to consider options to better align the legal and regulatory constraints, and cost-recovery mechanisms, of PGW with achieving the City's climate neutrality and air quality objectives.*** A key challenge, highlighted by this Study, is that there is not currently a clear legal or regulatory path forward for PGW to pursue many of the diversification and decarbonization strategies discussed in this report. Regulatory considerations might include efforts to reduce costs of the gas system, changes in how gas system costs are recovered and allocated, and programs to protect low- and moderate-income customers from rising costs.
- ***The City, together with PGW, should collaborate on a Greenhouse Gas Reduction Implementation Strategy for Philadelphia's buildings.*** Expanding on the Philadelphia Climate Action Playbook (2021) and as a follow-up to this Business Diversification Study, the consulting team recommends that the City develop a GHG Reduction Implementation Strategy for Philadelphia's buildings that outlines concrete plans, commitments, and programs for achieving GHG reductions in buildings, while prioritizing equity, affordability, environmental justice, and air quality consistent with the City's goals. In addition, the development of the implementation strategy should consider potential impacts to PGW's revenue, workforce, and PGW's customers. The implementation strategy should include plans for new construction buildings as well as existing residential and commercial buildings.
- ***The City should work closely together with PGW to conduct a PGW Workforce Impact Study.*** Such a study would consider the impact of different decarbonization pathways on PGW's existing workforce over the coming decades as well as strategies to mitigate potential negative impacts to PGW's existing workforce, including opportunities for workforce training and pension protection.

7. Appendix

Appendix A: synthesis of stakeholder input

Community Conversations

Since Philadelphia is one of the most energy burdened cities in the U.S., with a median energy burden 86% higher than the national average, the Office of Sustainability (OOS) made it a priority at the outset of the Study to hear from community members in areas of the City where energy burden is highest. During Fall 2020, OOS held a series of focus group-style community conversations about energy burden in six of the City's most energy-burdened communities (three focus groups per community). Organized in partnership with the Philadelphia Association of Community Development Corporations (PACDC), the American Cities Climate Challenge, Greenlink Analytics, and six community-based organizations,[68] these discussions provided a forum to hear from local community members, discuss their relationship with energy services, and learn from their lived experiences. Some key findings included:

- Most participants (54%) who are PGW customers consider their monthly heating bills too expensive for them to afford.
- All participants agreed that energy assistance programs are too exclusive. Many who are not eligible for programs are still in need of assistance. Others mentioned challenges navigating PGW billing processes, program applications, and customer service.
- There is interest in home building repairs, including weatherization and other energy efficiency improvements that will reduce energy utility costs, in addition to whole building repairs.
- Safety of natural gas equipment is not a concern for most participants, and most feel comfortable with having PGW employees or contractors into their homes to implement energy measures.
- There is also interest in learning about natural gas alternatives; for most, the understanding of these alternatives is limited. Where there is a greater understanding of them, interest in electrification is higher.
- Participants are interested in solutions that reduce/stabilize bills, improve health, and put people in their communities to work, but they are skeptical that new policies and

[68] Achievability, HACE Community Development Corporation, Hunting Park Community Revitalization Corporation, Philly Thrive, SEAMAAC, Strawberry Mansion Community Development Corporation

programs will provide them with real benefits as they have been disappointed by previous claims.

To illustrate the energy burden in Philadelphia, OOS partnered with Greenlink Group to develop and publish the report *6 Years of Energy Burden Impacts: Philadelphia in Focus*. This report was published in February 2021 and can be accessed here.

Stakeholder Workshop

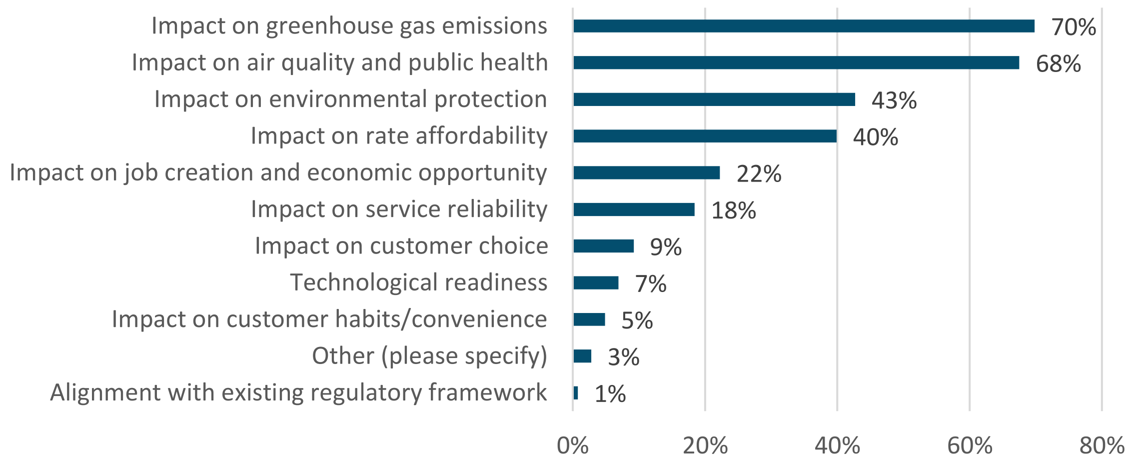
In March 2021, OOS held a virtual workshop with 43 stakeholders representing a range of organizations across the Philadelphia region, most of which had an energy, environmental, economic, or equity focus. The workshop included a presentation, live polling, and breakout group discussions. Questions for participants focused on the criteria for assessing the different diversification options, new energy directions and business models for PGW (including trade-offs and risks), short-term actions or pilot projects, and other longer-term next steps they would like to see happen after the Study.

+ During the live polling, participants cited GHG emission reduction as the most important criteria, both for them as individuals and for PGW. Other criteria important to participants were public health and environment, rate affordability, and job creation. When polled about new energy directions or business models, participants were generally more interested in electrification options than decarbonized gas options, particularly ground source heat pumps, air-source heat pumps, energy efficiency and weatherization, districting heating, and “Heat as a Service.”
+ During the small group discussions, there was strong interest in electrification, weatherization, and geothermal district heating (e.g., Networked Geothermal). The need to account for workforce considerations (retention, retraining, and job creation) and equity in any scenario was also a point of emphasis, with a general sentiment that any new actions or projects that follow this Study should incorporate workforce development and be piloted in low-income neighborhoods. Another key consideration for pilot projects is the benefit of bundling several pilots together that complement one another so that they can be tested as a portfolio.

Online Survey

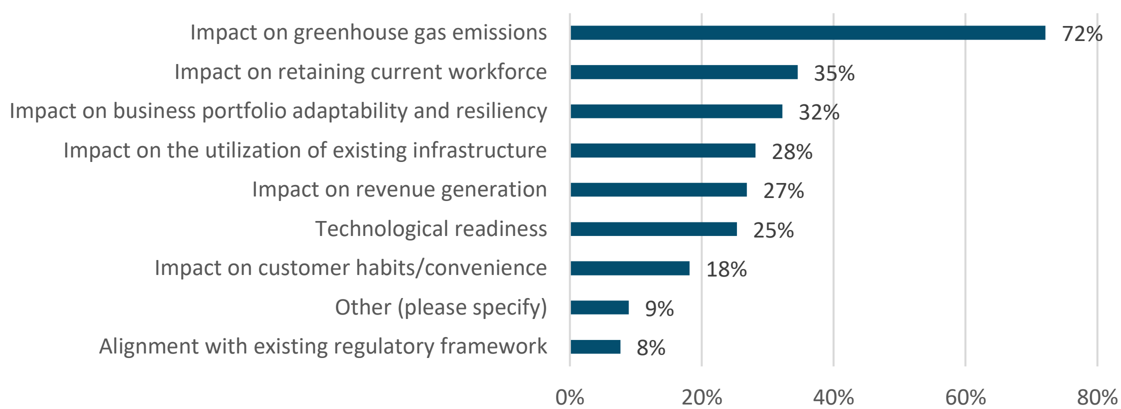
An online survey was developed and made available to the public from late-March to mid-April 2021, generating 391 responses. The feedback from the survey was used to develop the draft materials posted for public comment two weeks prior to the Gas Commission Virtual Town Hall on May 11, 2021. The results of the survey are summarized below (multiple-choice in charts; open-ended in text):

Which evaluation criteria are most important to you? (Select up to 3)



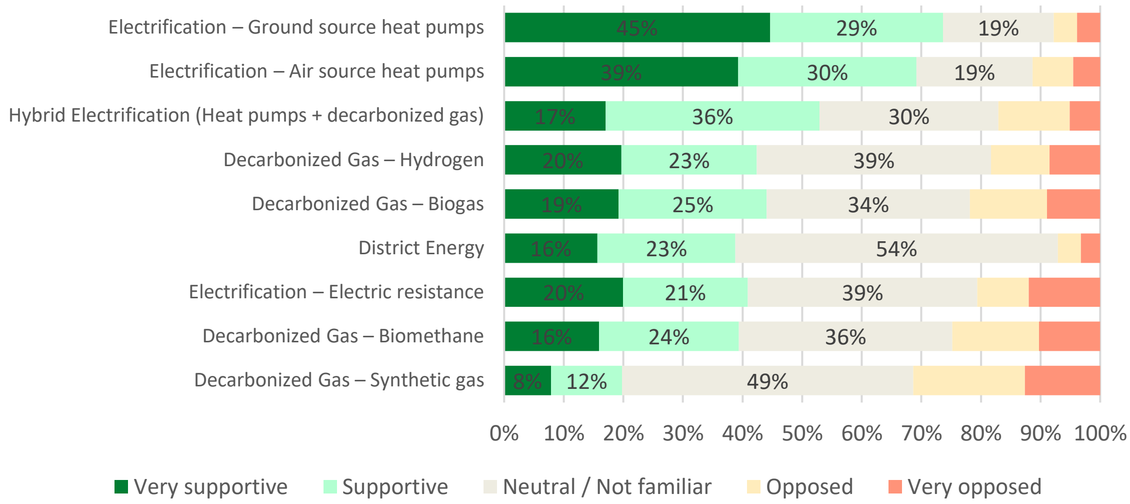
n = 391 respondents (1,492 total responses)

Which evaluation criteria do you feel are most important to PGW's future? (Select up to 3)

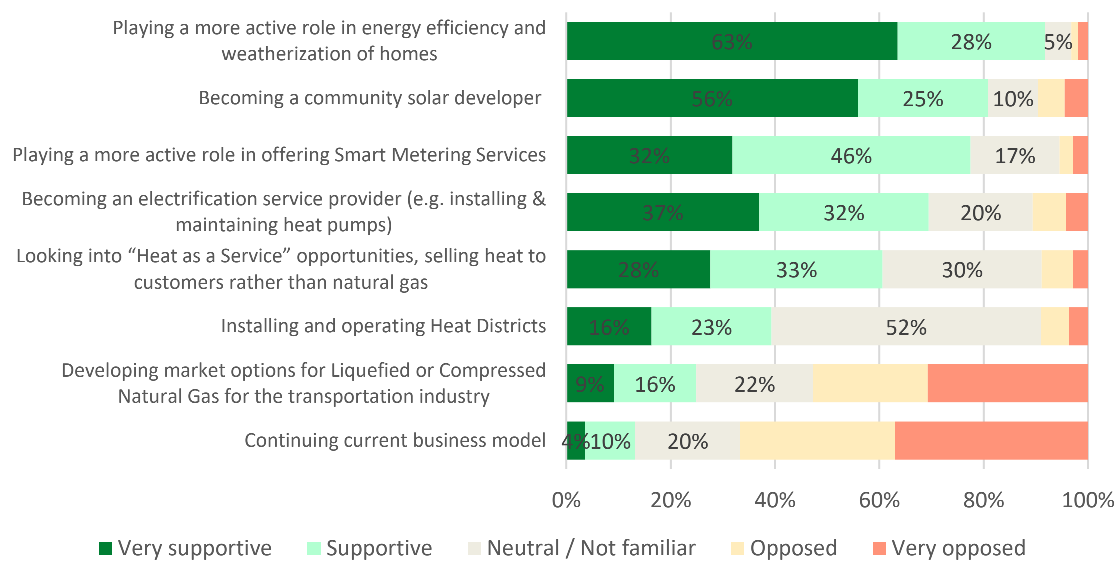


n = 391 respondents (1,319 responses)

Which of the following potential energy directions for PGW do you support? (n = 324)



Which options for diversifying its business operations do you support? (n = 324)



What challenges do you see related to Business Diversification Options for PGW? How can these challenges be addressed? (Optional)

This question was open-ended and generated 286 responses. Among the most common challenges cited were: resistance to change (from politicians, PGW, and/or customers); ensuring that an energy transition be equitable, especially related to impacts on rate affordability for low-income customers; the costs of new infrastructure and technologies and funding sources needed; the need for a just workforce transition, to retain and retrain existing workers and to create new jobs of the future; competition from the private sector (such as with PECO in the Electrification scenario); time and resources; communicating and educating the public about energy transition; technological readiness and compatibility with PGW's existing infrastructure; including diverse voices and perspectives in the planning process; maintaining service reliability; political will; and the regulatory changes that are needed to test and implement new business practices.

As an optional follow-up question, respondents were asked how these challenges could be addressed. Among 167 responses, the most cited ways to address these challenges were: funding; community outreach and involvement; public communications and education; workforce training; and partnerships/collaboration with other agencies and the private sector.

What kind of short-term actions or pilot projects from PGW would you like to see?

This question was open-ended and generated 286 responses, many of which included multiple answers. The most commonly cited short-term actions or pilot projects, each cited by about 15% to 20% of respondents, related to: energy efficiency or building weatherization (often combined with electrification); electrification, including ground and air-source heat pumps (often combined with efficiency/weatherization, geothermal, solar, or district energy); geothermal energy, often in reference to a networked district-based system (e.g., the GeoMicroDistrict); and solar energy, such as becoming a community-based rooftop solar provider. About 10% cited renewable natural gas (RNG) projects, most commonly biogas and hydrogen. Other actions/projects cited included: workforce trainings; customer incentives; district energy; public engagement and education; wind energy; CHP; microgrids; alternative uses for natural gas, such as for the transportation sector; electric vehicles; and further studies or plans (including regulatory analysis). In addition, there were several themes that cut across different categories. These included: the need to implement any pilot project through an equity lens (e.g., a building weatherization or geothermal district heating pilot in a low-income neighborhood); the need to include workforce training as part of any pilot; and the need to bundle several pilots together in a complementary fashion (e.g., weatherization + electrification + rooftop solar, or district heating + geothermal energy).

What other next steps would you like to see happen after the Diversification Study?

This question was open-ended and generated 286 responses. Most responses were related to creating more opportunities for public and stakeholder involvement, educating customers about decarbonization (and the different options they have for decarbonizing their homes), implementing more pilot projects, and creating an implementable master plan for the future of PGW.

Public Comments on Draft Study Presentation

On April 30, 2021, draft materials for the Study were posted on the OOS website and members of the public were encouraged to provide comments. The draft materials posted to the OOS website for public comment can be accessed here.

The public comment period remained open following the Gas Commission Town Hall, and closed on May 28, 2021, to give OOS and the consulting team time to review the comments and integrate them into the final report. In total, 75 comments were received, with some members of the public also submitting supportive reference materials. Some common themes included: 1) questions about how the cost projections for the Electrification scenarios factor in savings due to strategic decommissioning of PGW's gas distribution network; 2) questions about how the cost projections for the Electrification scenarios factor in additional revenues generated from new business models supporting electrification; 3) questions about how the cost projections of the Hybrid scenario factor in current and projected advancements in heat pump technology that would reduce the need for a backup gas furnace; 4) questions about the cost-effectiveness of the Hybrid scenario compared to the Electrification scenario; 5) skepticism about the benefits of decarbonized gas beyond a supplemental or transitionary role, including its technological readiness to adopt at scale, its impacts on air quality and climate change, and the costs associated with the need to maintain the entire PGW gas distribution network; 6) interest in networked geothermal systems (i.e., Networked Geothermal) and building weatherization/electrification retrofits as pilot projects, focusing on low-income communities; 7) the need to create incentives and policies that protect low-income/energy-burdened customers during transition; 8) the need for new business models to provide good-paying union jobs that include workforce development/skills training for PGW's existing workforce; and 9) concerns about potential PGW conflicts of interests.

In addition to informing the final Study, stakeholder comments will be retained and used for reference by OOS and PGW in planning efforts that build on the Study following publication, including the development of potential pilot project(s) for which certain comments may provide specific, relevant details.

Gas Commission Virtual Town Hall

On May 11, 2021, the Philadelphia Gas Commission hosted a virtual Town Hall (conducted via Zoom), during which the Study team gave a presentation on draft materials of the Study, and members of the public provided live testimony on the presentation and draft materials. During the session, 27 people testified, allotted two minutes each (if needed, further elaboration was encouraged to be submitted in writing). Some common themes included: interest in networked geothermal, especially as a pilot project; interest in building electrification and weatherization; an emphasis on equity, especially rate affordability for low-income households; an emphasis on workforce retention, retraining, and job creation; concerns about PGW conflicts of interests with the natural gas industry; and questions about certain assumptions made in the Study methodology related to costs and projections.

A video of the Town Hall can be accessed here, and the transcript can be accessed here.

Appendix B: PGW's Regulatory Structure

PGW is a collection of assets, real and personal, owned by the City of Philadelphia. This collection of assets is managed by a non-profit corporation, the Philadelphia Facilities Management Corporation ("PFMC"), through the terms and conditions of a management agreement ("The Management Agreement") between the City and PFMC. The Management Agreement is essentially a blueprint of how PFMC operates PGW as a gas utility. Changes to the Management Agreement require an ordinance passed by City Council.

Pursuant to the Home Rule Charter and the terms of the Management Agreement, PGW is overseen by a City commission: the Philadelphia Gas Commission ("PGC"). Per the terms of the Management Agreement, the PGC approves (and/or recommends to City Council) PGW's budgets, real estate transactions, gas purchases and procurement standards. Action by the Gas Commission is done at a public meeting by Commissioner vote. In addition to the PGC, Philadelphia's City Council specifically approves PGW's capital budget, real estate transactions, gas purchases, and pension changes.

PGW is also subject to the jurisdiction and regulation of the Pennsylvania Public Utility Commission (the "PUC"), which operates under the authority of the state Public Utility Code and associated regulations. The PUC regulates PGW's rates/tariffs, safety, and customer service issues and programs, as well as other aspects common to other utilities in Pennsylvania. Changes to the Public Utility Code must be effectuated by the PA General Assembly; however, the PUC has some leeway to independently make changes through regulations approved by the PUC itself at public meetings via vote of the Commissioners.

For most purposes under law, PGW is considered an instrumentality of the City. Laws and regulations that apply to political subdivisions therefore typically apply to PGW, including laws that govern permissible business activities. Federal and state laws can be changed by Congress and the PA General Assembly, respectively. In certain cases, local laws applicable to the City and/or "quasi-city agencies" also apply to PGW (e.g., the Philadelphia Home Rule Charter and Philadelphia Code provisions). Charter changes must be approved by the voters of Philadelphia. Philadelphia Code changes are effectuated by ordinance.

PGW's revenue bonds are pursuant to the First Class City Revenue Bond Act. The City, and PGW, must comply with the terms of the Act, debt instruments, and the IRS code, with respect to the treatment of the debt and revenues ("Bond Covenants").

Appendix C: Modeling approach and assumptions

Overall modeling approach

For the purpose of this project, E3 established a model to forecast PGW's future revenues under different energy scenarios and business models. This model is based on PGW's cash flow accounting model and was developed using input on short-term cost forecasts from PGW, as well as long-term analysis developed by E3. PGW's Base Rate Filings (2020) and Comprehensive Annual Financial Report (2020) were used to gather existing costs of the system, PGW's assets and depreciation schedules, existing bond schedules and the allocation of costs of the system to customer classes. Based on this data, E3 established a long-term Revenue Requirement forecast that was used to analyze customer delivery rates on a $/MCF basis. Overall, it is important to note that the model used to forecast PGW's revenues and customer rates represents a simplification of PGW's financials. Yet, the model offers a useful platform to allow for "what-if" scenarios that explore the impacts of decarbonization scenarios on PGW's revenues.

Baseline energy demands for this report are based on a variety of sources. E3 used weather-normalized historical average consumption reported by PGW for the last 10-year period for residential, commercial, and industrial customers to establish a baseline consumption level per customer. For residential customers, this average consumption level (of 73 mcf/year) was then scaled to the Philadelphia building stock using U.S. Census Data and EIA's Residential Energy Consumption Survey (RECS) to provide average consumption levels for single family versus multifamily homes. The RECS was also used to provide a breakdown of annual gas consumption into space heating, water heating, cooking, and clothes drying.

Building electricity and gas demands in the scenarios evaluated change over time based on a stock rollover model. As building appliances are long-lived, their replacement with efficient or electric devices is assumed to only occur at their natural retirement (end of useful life). This means that as soon as an appliance reaches the end of its lifetime, the customer faces a decision to transition to electric appliances. As end of lifetime occurrences happen on a household-to-household level, this method assumes that the gas system needs to be maintained in an entire neighborhood, even if parts of that neighborhood have already electrified. The purpose of this project, and the model used by E3, was to explore diversification options for PGW and additional sources of revenue that could help retain PGW's workforce in the long-term. As such, this project did not evaluate potential cost reductions related to the gas system in different decarbonization scenarios. Within the scope of this project and based on a stock rollover model, the consulting team assumed that the gas system would need to be maintained on a longer term. More research into the strategic decommissioning of gas systems could help mitigate the costs of the system, and therefore the cost borne by customers, in the long run.

In addition to the stock rollover model impacting long-term gas demands, there are several other factors influencing how building energy demands change over time that were captured in this analysis:

- **Growth in building stock:** The residential building stock in Philadelphia is expected to grow by 10% through 2050, based on the Delaware Valley Regional Planning Commission.[69]
- **Gas device efficiencies:** Device efficiencies are expected to increase over time based on EIA NEMS data (reference efficiency for gas furnace: 80%, efficient device efficiency for gas furnace: 90%).
- **Building shell upgrades:** Building shell upgrades reduce demand for space heating. All scenarios assume 80% of residential homes have received a building shell upgrade by 2050, resulting in an average demand reduction of 20% per building.
- **Climate change:** The impact of climate change is assumed to gradually reduce the demand for space heating; E3 assumed a 0.3%/year reduction in space heating demand based on EIA AEO 2020 data.
- **Scenario-specific adjustments:** For example, the growth of Networked Geothermal Systems will reduce gas demand as homes are added to new infrastructure.

Fuel costing approach and assumptions

In addition to an assessment of long-term customer delivery rates that reflect the costs of PGW's distribution system, E3 developed a forecast of gas commodity costs to assess the long-term costs of gas. First, E3 established an overview of long-term natural gas costs based on the EIA Annual Energy Outlook. In addition, E3 developed a cost forecast for the cost of decarbonized gases. As these costs forecasts are highly uncertain, both an optimistic and conservative cost bookend are provided.

Decarbonized gas supply assumptions are developed from E3's biofuels optimization module, which determines the most cost-effective way to convert biomass into biofuels across all sectors. Biomethane costs are based on the following assumptions:

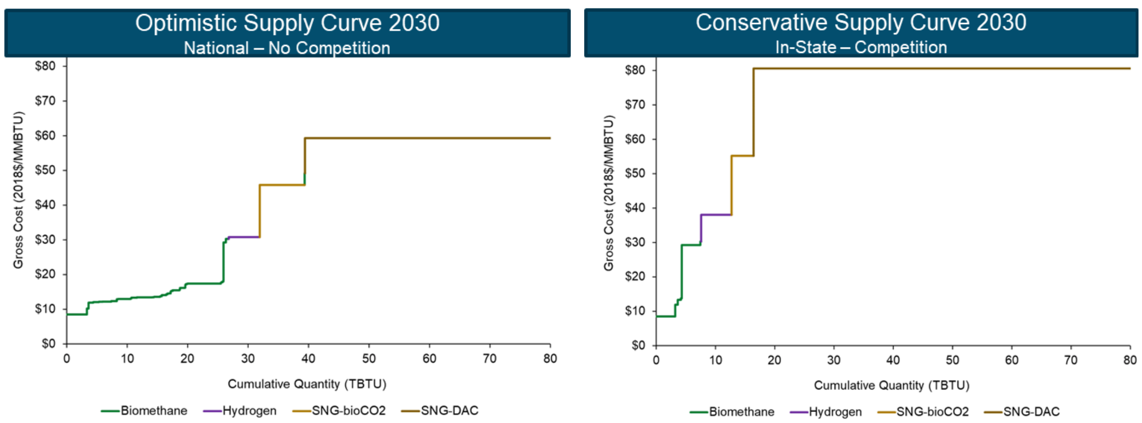
- Optimistic scenario (low-cost bookend): PGW has access to a national biofuels market without competition from other markets (i.e., gasoline, diesel, and jet fuel industries). PGW's access to available gas is downscaled based on its customers as share of the national population. Optimistic cost trajectories are assumed for electrolyzer technology and technology efficiency (at installed costs of $300 $/kW by 2040 at 76% efficiency).
- Conservative (high-cost bookend): PGW only has access to in-state biofuel volumes with assumed competition from other markets. PGW's access to available gas is downscaled based on its customers as share of the national population. Conservative cost trajectories

[69] See: https://www.dvrpc.org/Reports/ADR022.pdf

are assumed for electrolyzer technology and technology efficiency (at installed costs of $1,000 $/kW by 2040 at 73% efficiency).

Figure 21 shows the decarbonized gas Supply Curves assumed for this Study. E3's biofuels optimization model is based on a supply ranking method that ranks available supply from the cheapest resource to the most expensive one, as outlined on the chart. This means that all cheapest resources are used first, up to their available amount. In the Conservative scenario, up to around 6 TBtu of biomethane is supplied before more expensive sources are needed. SNG-DAC[70] is viewed as a non-limited source as opposed to biomethane, and hydrogen is assumed to only blend in at 7% of energy (20% of volume).

Figure 21. Decarbonized Gas supply curves assumed for this Study (based on E3 biofuels optimization model)



Electricity rate approach and assumptions

It was not within the scope of this Study to perform an in-depth Revenue Requirement analysis of PECO's electricity sector. However, E3 developed a high-level approach to forecast electricity rates for the next 30-year period.

The electricity price forecast developed includes both a "baseline" forecast (assuming no building electrification) and the additional capacity and reliability required to support the electrification assumed in for this analysis:

- Baseline Energy, Capacity and T&D costs are based on PECO's existing Revenue Requirement. To establish this Revenue Requirement analysis, E3 derived annual baseline revenues and sales for PECO for residential, commercial, and industrial customers from S&P Global and the allocation of costs by component from Carnegie

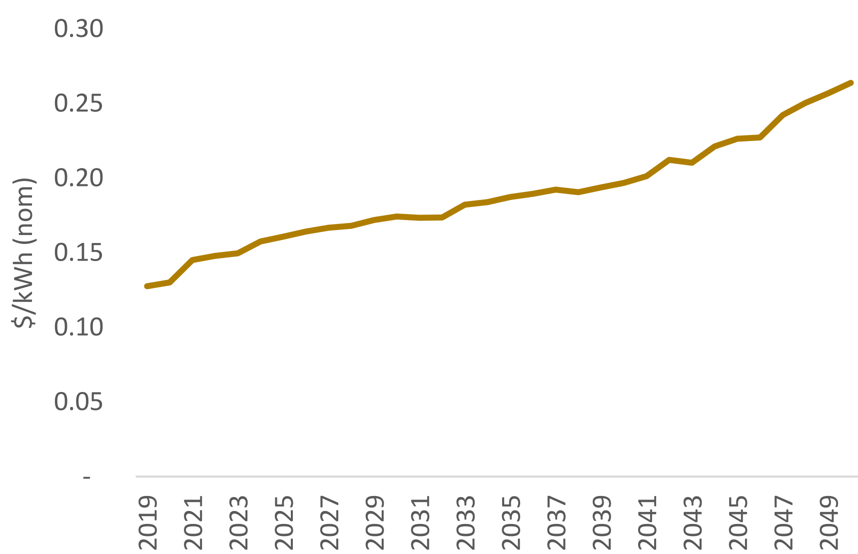
[70] SNG-DAC refers to Synthetic Natural Gas (SNG) based on CO2 from Direct Air Capture (DAC). SNG-bioCO2 refers to SNG based on CO2 from bio-sources.

Mellon (2019)[71] Baseload electricity load is forecasted to increase by 0.1%/yr, taken from PJM's 2020 Load Report.

- The baseline forecast is scaled using EIA forecasts for energy, distribution and transmission for the PJM East region, with a cost premium for zero carbon generation from E3 RESOLVE data.[72]
- Incremental Capacity, Transmission & Distribution costs as a result of electrification are based on PJM's Cost of New Entry Study (2018) and the Cost Effectiveness Screening Tool for Energy Efficiency Program Administrators (Synapse, 2015). As such, the capacity costs required to build a new combustion turbine to meet reliability requirements are assumed at 106.4 $/kW-yr, based. Additional T&D costs needed to serve higher electrification load amount to $53.06 $/kW-yr in 2020. However, since PECO has a higher summer peak than winter peak, there is headroom available that avoids the direct need of building new capacity (since heat pump peaks occur in winter). Additional peak capacity is estimated based on annual to peak ratios of 0.1% for air-source heat pumps.

Figure 22 provides an overview of the residential electricity price assumed for this Study based on the assumptions described above.

Figure 22. Residential forecasted electricity price assumed in this Study (shown for the High Electrification scenario)



[71] Carnegie Mellon (2019): The Value of Solar for PECO and its ratepayers

[72] In a separate recent study, E3 performed a reliability and cost-effective analysis to assess decarbonization and reduction emission goals in the PJM Interconnection, the regional grid that Philadelphia relies upon for power. That study included a "100% CES by 2050" scenario (CES = Clean Energy Standard, meaning 100% of retail sales is met by clean electricity). E3 used results from the "100% CES by 2050" scenario as the basis for our electricity costs and emissions in this Study. See: *E3 Report: Least-Cost Carbon Reduction Policies in PJM States – EPSA*.

Additional assumptions

The following table provides additional key assumptions that were used in this analysis.

Category	Assumption	Source
Electrification parameters		
Annual average COP of Air-Source Heat Pumps	3	E3 modeling results for similar climate zones
Annual average COP of Air-Source Heat Pumps with Gas Backup	3.5	
Annual average COP of Electric Water Heaters	3	
Annual average COP of Networked Geothermal Heat Pumps	5	HEET & BuroHappold (2019). GeoMicroDistrict Feasibility Study
PECO Summer Peak	8,145 MW	PJM Load Report 2020
PECO Winter Peak	6,778 MW	PJM Load Report 2020
Gas Consumption parameters		
Baseline annual average gas consumption of Single Family (attached) home in Philadelphia	81.8 mcf/yr	PGW data, EIA RECS, US Census Bureau
Baseline annual average gas consumption of Multi Family home in Philadelphia	48.8 mcf/yr	PGW data, EIA RECS, US Census Bureau
Baseline annual average gas consumption of commercial buildings in Philadelphia	477 mcf/yr	PGW data, EIA CBECS, Philadelphia Large Building Energy Benchmark Data
Assumed annual gas demand supplied by Gas Back Up in Hybrid Electrification scenario	25% of annual space heating demand	E3 modeling results for similar climate zones
Emission parameters		
Natural gas emission coefficient	53.06 kgCO2/MMBtu	EPA
GWP (100 year)	28	IPCC 5th Assessment (Table 8A.1)
PGW Methane Leakage factor (baseline)	0.7% (2018 reporting year)	EPA Flight Tool
PGW Methane emission reductions	74% by 2050 from 2018 levels	Provided by PGW
2019 electricity sector emissions rate	380.66 kgCO2/MWh	PJM (2020). 2015 – 2019 CO2, SO2 and NOX Emission Rates
Other parameters		
Networked Geothermal installation costs	13,000 $/ton	HEET & BuroHappold (2019). GeoMicroDistrict Feasibility Study
Installed capital costs assumed for household appliances in Figure 17 (Single Family home)	• Gas Furnace with AC: $7,450 • Air-Source Heat Pump: $14,200 • Air-Source Heat Pump with Gas Back Up: $11,350	Heat pump costs are based on E3 analysis using data from the Energy Trust of Oregon. Other appliance

	• Electric Water Heater: $3,225 • Gas Water Heater: $1,070 • Gas/electric stove: $350 • Gas Dryer: $760 • Electric Dryer: $838	costs are based on HomeAdvisor and EIA NEMS data. Note that, as described in this report, household appliance costs are highly dependent on building characteristics.
PGW % of cast iron mains	45%	2018 Philadelphia Institutional Investor Conference (We Work for Philly)