PHILADELPHIA'S GAS PIPE REPLACEMENT PLAN:

How much will it cost and does it make sense?

By: Dorie Seavey, PhD | March 2023

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About the Author

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Executive Summary

Philadelphia has established a carbon neutrality goal for 2050, requiring residents and businesses to significantly reduce greenhouse gas emissions, but has yet to take definitive steps to reach that goal. At the same time, the City's municipally-owned gas company, Philadelphia Gas Works (PGW), is steadily moving forward with a multi-decade plan to extend the lifetime of its natural gas distribution system by replacing leak-prone gas mains and services with new gas pipes.

The main purpose of this study is to investigate the **financial cost of PGW's gas infrastructure investment.** The study also evaluates whether PGW's current replacement plans are on track to achieve their stated goals. Finally, the study examines the scale of PGW's capital expenditures on its gas processing facilities and the company's continued investment in new pipelines to extend gas delivery service to new customers.

The main findings of this study are as follows:

- **The City is on track to spend $6 to $8 billion** in nominal dollars ($5 to $6 billion in real dollars) to replace nearly half of its aging gas distribution pipeline over the next 35 years, an unprecedented infrastructure investment for the City and an expense to be borne entirely by gas customers via their rate payments.
- **PGW's average cost of installing a mile of replacement pipeline reached $2.1 million in FY 2021.** This cost has been increasing at 8.5 percent annually since 2015.
- **PGW's current replacement plans, slated to end in 2058, are not adequate to eliminate all of the City's current inventory of leak-prone pipe.** Approximately 387 miles of leak-prone mains will likely remain by this target date.
- **Even if PGW were able to eliminate its entire current inventory of leak-prone pipe by 2058, by that time an additional 379 miles of mains installed in the 1970s and 1980s will likely be in need of replacement.**
- **PGW has been extending its gas delivery system by roughly 4.5 miles annually to bring new customers online**, adding 27 miles of mains to its distribution system over the last six years.
- **PGW is also investing significant amounts of capital in its gas processing facilities**, mainly its two LNG plants and nine gate stations, which are critical to its gas distribution system**.** For the period 2023 to 2027, PGW has received approval to spend $270.4 million to upgrade its gas processing facilities.
- **About 30 percent of PGW's residential customers qualify for federally-funded energy bill assistance payments,** meaning that they likely have difficulty affording their utility bills. Indeed**,** Philadelphia has one of the highest proportions of energy-burdened households in the country and nearly the entire city is considered an environmental justice area by the Commonwealth of Pennsylvania and the federal government.
- **During FY 2020 and FY 2021, PGW received on the order of $25 to $32 million in federal bill assistance payments credited to the customer accounts of its energy-burdened**

low-income ratepayers. These federal payments bolster PGW's revenue and keep significant numbers of low-income customers on the PGW gas system.

The report underscores that PGW's infrastructure decisions are being made in five-year planning increments that fail to create accountability for the substantial multi-decade scope of the planned aggregate spending. As a result, the impacts of this capital spending on customer energy bills and on PGW's financial viability are not subject to adequate analysis and evaluation.

The study recommends: a) regular and consistent annual reporting on the full scope of PGW's replacement activity (including actual miles of mains and number of services replaced and the associated costs), b) expansion of regulatory oversight over PGW's capital spending on its gas distribution system, including requiring a multi-decade focus and consideration of public interest concerns such as climate, equity, affordability and public health, and c) the creation of regulatory frameworks that require PGW to consider and evaluate alternatives to gas pipeline replacement.

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1. Introduction

Cities and states across the country are grappling with their plans to reduce greenhouse gas emissions in order to achieve their net-zero climate goals. At the same time, natural gas utilities are carrying out major infrastructure investments to replace significant parts of their distribution infrastructure as well as extend service to new customers. Since fugitive natural gas and combustion of natural gas generally make up a large portion of local greenhouse gas emissions, these investments are likely to directly conflict with emerging climate roadmaps and planning.

Understanding the full opportunity cost of these continued gas infrastructure investments is critical but often neglected. A comprehensive accounting of these costs is essential for two key reasons.

> **First**, these investments directly impact the financial viability of the utility at issue and raise concerns about the riskiness of the economic value of the gas-related assets on the utility's balance sheet and the prospects for adequately funding the increasing revenue requirements.
>
> **Second**, these investments affect the affordability of the energy services provided by the utility to its customers. The economics of gas is changing and some degree of electrification is inevitable.[1] To the extent that gas demand and throughput decline, and customers migrate to other thermal energy sources, then gas utility distribution spending will need to be recovered from fewer customers. Customers who don't electrify, or are unable to (such as tenants and low-income households), will be left on an increasingly costly gas system.

The subject of this study is the City of Philadelphia and its municipally-owned natural gas utility, Philadelphia Gas Works (PGW).[2] The City comprises a dense urban area consisting of 134 square miles of land. One in four households is low income and many of these households live in housing that is older and less energy efficient. As a result, Philadelphia has one of the highest proportions of energy-burdened households in the country[3] and nearly the entire city is considered an environmental justice area by the Commonwealth of Pennsylvania and the federal government.[4]

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[1] Ten years ago, it was generally less costly to heat a home with natural gas compared to alternatives such as electric heat pumps. The commodity price of gas today is about 65% higher than it was a decade ago (see Henry Hub Natural Gas Spot Price at https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm) and electrification incentives are growing (the recently enacted federal Inflation Reduction Act stands to accelerate the transition away from gas).

[2] Philadelphia Gas Works (PGW) is owned by the City of Philadelphia. Established in 1836, PGW provides for the acquisition, storage and distribution of natural gas to residents and businesses located entirely within the city's limits. PGW is the exclusive distributor of natural gas within the limits of the city. However, customers can choose an alternate gas supplier pursuant to the Natural Gas Choice and Competition Act of 1999 (the Gas Choice Act). PGW served approximately 524,000 customers in 2021 (the most recent data found). In addition, PGW operates facilities for the liquefaction, storage, and vaporization of natural gas.

[3] As of 2017, 26% of low-income households in Philadelphia had high energy burdens (defined as spending more than 6% of household income on utility bills). 13 percent of households had a "severe" energy burden (more than 10% of income spent on utility bills). Ariel Drehobl, Lauren Ross, and Roxana Ayala, *How High Are Household Energy Burdens?* (American Council for an Energy-Efficient Economy, September 2020), https://www.aceee.org/sites/default/files/pdfs/u2006.pdf and https://www.aceee.org/sites/default/files/pdfs/aceee-01_energy_burden_-_philadelphia.pdf.

[4] See the Environmental Justice Screening and Mapping Tool of the US Environmental Protection Agency available at https://ejscreen.epa.gov/mapper/index.html?wherestr=philadelphia+county%2C+PA and the EJ Areas Viewer of The Pennsylvania Department of Environmental Protection available at: https://padep-1.maps.arcgis.com/apps/webappviewer/index.html?id=f31a188de122467691cae93c3339469c. See also Sophia Schmidt, "Philadelphia is revising its environmental justice policy. Here's what's changing" (WHYY,

Over 70 percent of Philadelphians rely on natural gas as their primary fuel but the City's gas distribution system contains a high concentration of aging, leak-prone gas pipes with 60 percent of PGW mains classified as leak prone. In response, PGW has put in place pipeline infrastructure programs that aim to replace approximately 39 miles of mains and related services per year. This study explores the **likely financial cost of PGW's plans to continue replacing leak-prone mains and services in its gas distribution system.** In addition, it also analyzes two further issues: how much leak-prone pipe is likely to remain by 2058 (PGW's projected terminal date for its cast iron main replacement programs), and the scale of PGW's investment in extending its gas delivery system to new customers.

March 16, 2022), https://whyy.org/articles/pennsylvania-is-revising-its-environmental-justice-policy-heres-whats-changing/#:~:text=The%20current%20policy%20defines%20environmental,Philadelphia%2C%20in%20an%20EJ%20area.

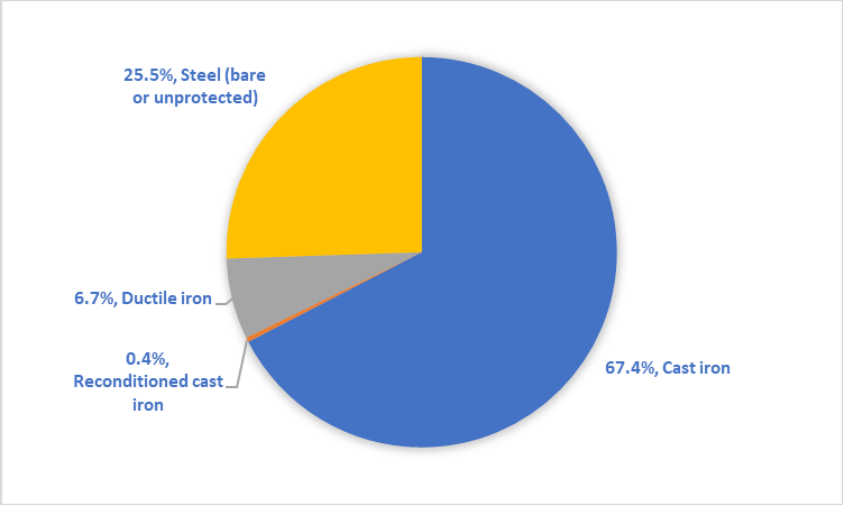
2. Background

2.1 State of PGW's pipelines

At the end of 2021, the PGW gas distribution system consisted of 3,046 miles of mains and 476,600 services.[5] Sixty percent of the company's mains are considered leak prone (1,839 miles) and 70 percent are now more than 40 years old (PGW generally considers mains to have a useful life of 54 years).[6] Over a third of the existing mains were installed in the 1940s or before.

As shown in Figure 1, 67 percent of PGW's inventory of leak-prone mains (1,239 miles) are made of cast iron—these mains are the primary focus of PGW's main replacement activity. But the company's leak-prone inventory also includes another 599 miles of pipeline made of other materials that are now considered leak prone, specifically, unprotected or bare steel, ductile iron, and reconditioned iron.

Figure 1: Philadelphia's leak-prone mains by pipe material, 2021



Source: US Department of Transportation, PHMSA, Gas Distribution Annual Data.

In addition to gas mains, PGW also has 476,600 services in place. Of these, 18 percent are considered leak prone. Virtually all of the problematic services are made of bare or unprotected steel.[7]

[5] Mains transmit natural gas from the gate station to the approximate location outside the customer's building. Sections of mains operate at different pressures, with regulators controlling the pressure. Service pipelines are smaller in diameter than mains and run from the mains to a customer meter or to the connection to a customer's piping, if there is no customer meter. For information on PGW's pipeline, see: US Department of Transportation, PHMSA, Gas Distribution Annual Data: 2010 to present (ZIP extracted for 2020), https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids.

[6] PGW, 2020 Base Rate Case (Docket R-2020-3017206), Vol. I, Report on Depreciation Accrual Rates by Black & Veatch from Nov. 2015, Table 5-1, p. 16.

[7] US Department of Transportation, PHMSA, Gas Distribution Annual Data: 2010 to present (ZIP extracted for 2020), https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids.

2.2 Replacement activity: miles and costs

Locating publicly available information about PGW's pipeline replacement activities requires accessing docketed, adjudicatory proceedings with PGW's regulators. The company is regulated by several entities: the Pennsylvania Public Utilities Commission (PUC), the City Council of Philadelphia, and the Philadelphia Gas Commission. The research team for this study thoroughly reviewed the relevant proceedings of these entities. There is no one regular annual report or filing detailing PGW's gas infrastructure replacement activity that includes a comprehensive accounting of actual quantities of pipeline replaced and actual costs incurred.[8] Therefore, this study relies on information pieced together from various reports, not all of which report the same numbers.

Infrastructure replaced. According to PGW's annual Capital Budget *Asset Inventory Information* schedule,[9] PGW replaced on average 39.25 miles of main per year from FY 2016 to FY 2021. The vast majority of these replaced mains (84 percent) were cast iron (see Table 1).

Table 1: PGW Asset Inventory Information on miles of main replaced, 2016-2021

Miles replaced	2016	2017	2018	2019	2020	2021	Total
Cast iron	31.54	33.66	33	32.56	27.65	38.7	197.11
Ductile iron	1.31	1.12	1.52	1.84	1.09	0.89	7.77
Plastic	1.25	1.19	1.1	1.69	0.76	0.75	6.74
Steel	5.01	4.08	3.77	5.01	2.61	3.38	23.86
Total	39.11	40.05	39.39	41.1	32.11	43.72	235.48

Source: PGW, "Distribution Department – Asset Inventory Information," PGW FY 2023 Capital Budget, January 3, 2022, p. 564.

The cast iron main amounts reported in PGW's Asset Inventory Information report (Table 1) are somewhat different from those reported in PGW's Annual Asset Optimization Plans (AAOP) (Table 2).[10] The AAOP is filed annually with the PUC as part of PGW's Long Term Infrastructure Improvement Program (LTIIP).[11] The mileage differences between the two reports range from 0.7 to 2.04 miles per year.[12]

[8] Any assistance locating such information would be welcomed by the author.

[9] PGW's annual proposed capital budget is submitted to the Philadelphia Gas Commission (PGC). It then must be approved first by the PGC and then by the Philadelphia City Council. The City does not provide public online access to the proposed capital budget itself. Public hearings regarding the budget can be accessed here. PGW is also subject to the jurisdiction of the Pennsylvania Public Utility Commission, which operates under the Pennsylvania State Public Utility Code and associated regulations, and is the regulator responsible for base rate cases and rate setting.

[10] Some of the mileage differences may relate to whether or not the reported pipeline length has been adjusted for fittings (which decrease the amount of pipeline used) or circumnavigating, say, sewer piping (which increases the amount of pipeline needed). Pipeline is usually purchased in 40 foot lengths.

[11] LTIIPs cover successive 5-year periods with the latest covering September 1, 2017 to August 31, 2022. To date, 9 AAOPs have been filed. The reports specify actual miles replaced in the prior fiscal year for both the basic and accelerated cast iron replacement programs but actual cost only for the accelerated program (see Section 2.3 of this report for a description of these programs). To find these reports, go to https://www.puc.pa.gov/search/document-search/, enter Document Type = Annual Optimization Plan and Utility Name.

[12] Still another set of figures on miles replaced can be found in Bureau of Investigation & Enforcement testimony and exhibits by Scott Orr as part of the 2020 base rate case (Pennsylvania Public Utility Commission, Docket R-2020-3017206, I&E Pre-Served Testimony & Exhibits, I&E Exhibit No. 3, Schedule No. 6, p. 2 of 2). Orr reports

Table 2: PGW Annual Asset Optimization Plan information on miles of main replaced, 2016-2021

Miles of cast iron replaced	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022 projected
Baseline Program	18.06	18.06	18.51	18.10	18.05	18.05	18.00
Accelerated Program	13.55	16.86	15.36	16.50	9.28	19.43	15.04
Total	31.61	34.92	33.87	34.60	27.33	37.48	33.04

Source: PGW, Annual Asset Optimization Plans for the years FY 2016 - FY 2022 (Dockets M-2016-2573637, M-2017-2631636, M-2018-3005778, M-2019-3013993, M-2020-3022689, M-2021-3029293).

The research team was unable to locate a PGW report or filing stating the number of services actually replaced over the past few years. The closest source found was the annual PGW Compliance Capital Budget reports which provide the lineal feet of services *expected* to be replaced each year. According to these reports, from FY 2019 through FY 2022 approximately 9,200 lineal feet of services were budgeted to be replaced each year.[13]

Replacement costs. The only regular reporting on actual replacement costs is partial and covers the accelerated portion of the cast iron main replacement program, as reported in the AAOPs. For example, the latest AAOP reports that PGW spent $41 million in 2021 to replace 19.43 miles under the state's accelerated replacement program, which suggests an average per-mile replacement cost of $2.1 million.[14]

PGW's annual Compliance Capital Budgets provide detailed information on *budgeted and forecasted*—but *not actual*—costs for gas distribution infrastructure replacement. According to these reports, budgeted costs for main replacement (cast iron plus other leak-prone materials) averaged $66.4 million annually from FY 2021 to FY 2023. The budgeted costs for replacing leak-prone services averaged $19.8 million per year.[15]

In PGW's 2020 base rate case, attention was given to the issue of accelerating unit costs for pipe replacement. Both PGW and the PUC Bureau of Investigation and Enforcement (BIE) concurred that unit costs had increased sharply over the prior five-year period. The key exhibit presented in this regard was a table showing cost per mile for PGW pipeline replacement from FY2015 to 2019, presumably using data obtained from PGW. That table was introduced in direct testimony by Scott Orr from BIE. Orr stated:

> PGW's capital replacement costs are increasing. In 2015, the cost was $1,204,801 per mile as compared to $1,611,987 in 2019. This is approximately a 33.8% increase in cost per mile over five years, or an average increase in cost of 6.9% per year. [16]

"pipeline replacement" of the following amounts: 32.2 miles FY 2015, 42.2 miles in FY 2016, 39.9 miles in FY 2017, 53.1 miles in 2018, and 37.9 miles in 2019. See Table 3 of this report for updated information.

[13] These reports are available at the PGW website. Visit https://www.pgworks.com/about-us/pgw-financials and scroll down to "Capital Budget Reports."

[14] Philadelphia Gas Works, Annual Asset Optimization Plan FY 2021 and FY 2022 (Projected), p. 6 (Table 2: Detailed description of facilities repaired, improved, and replaced in FY 2021), https://www.puc.pa.gov/pcdocs/1723803.pdf.

[15] PGW, Fiscal 2022 Compliance Capital Budget (April 13. 2021), pdf 17, https://www.pgworks.com/uploads/pdfs/FY_2022_Capital_Compliance_April_13.pdf and PGW, Fiscal 2023 Compliance Capital Budget, April 26, 2022, pdf 17, https://www.pgworks.com/uploads/pdfs/PGW_s_FY_23_Compliance_Capital_Budget.pdf.

[16] PUC, Docket R-2020-3017206, I&E Exhibit No.3, Schedule No. 6.

Orr's table shows annual replacement miles that are yet again different from the miles accounted for in the Asset Inventory Information Report. Furthermore, the exhibit presents total replacement costs that differ from the budgeted amounts presented in the Annual Compliance Capital Budgets.[17] According to Orr, the principal factor accounting for the increase in unit costs was rising contractor costs. The exhibit shows that contractor costs significantly increased from $822,079 per mile in 2015 to $1,219,453 per mile in 2019, a cost increase of 48 percent. (The other cost categories—labor, materials, and "other"—showed more modest or no cost increases.)

In order to obtain actual spending on pipeline replacement at PGW, the research team requested more recent PGW data under Pennsylvania's Right-To-Know Law (RTKL). Table 3 presents the information received from PGW in response to the RTKL request, covering the period FY 2015 through FY 2021. Comparing the pre-2020 information in Table 3 with the figures previously provided by Orr, while the cost figures are generally similar, the data request returned figures for the mileage of mains installed that are generally smaller. For example, Orr reported that 37.9 miles in FY 2019 were installed at a cost of $61.1 million but the RTKL information shows 33.96 miles replaced.

Table 3: PGW data on main replacement costs, FY 2015-2021

(Received via Right-To-Know Law Request, August 2022)

Fiscal year	Labor	Materials	Contractors	Other	Grand Total	Units (miles)*	Cost per mile**
2015	$5,443,656	$4,618,823	$26,470,959	$2,225,291	$38,758,729	29.42	$1,317,428
2016	$6,664,445	$6,586,625	$37,235,814	$2,964,285	$53,451,169	38.56	$1,386,182
2017	$6,149,012	$6,869,398	$41,586,160	$3,104,808	$57,709,378	34.42	$1,676,623
2018	$5,755,912	$8,010,869	$67,299,558	$3,119,446	$84,185,785	46.50	$1,810,447
2019	$5,379,833	$7,010,612	$46,217,261	$2,485,047	$61,092,754	33.96	$1,798,962
2020	$5,892,647	$6,953,349	$38,280,205	$3,506,265	$54,632,466	37.74	$1,447,601
2021	$6,773,339	$8,896,834	$51,957,631	$3,795,784	$71,423,588	34.01	$2,100,076

* Mileage of main installed for replacement projects.
**Calculation by author as Grand Total divided by Units.
Source: PGW response to author's Right-To-Know Law Request in August 2022.

The PGW data reported in Table 3 indicate that PGW's replacement costs have been increasing at an even faster rate than reported by Orr. According to the new PGW figures, **the average cost of installing a mile of replacement pipeline reached $2.1 million in FY 2021 and, since 2015, the average cost has increased 8.5 percent per year**. Since 2019, the rate of increase has been 5.6 percent per year. Contractor costs account for about three-quarters of the total cost and these per-mile contractor costs have increased 70 percent from 2015 to 2021, or by 10 percent per year.

[17] One notable outlier in the Orr table is the information for 2019: the table shows 53 miles replaced in 2018 at a cost of $84.2 million.

2.3 Pipeline replacement plans

The goals of PGW's pipeline replacement are to improve the safety and reliability of PGW operations and reduce methane emissions,[18] particularly in light of the relatively high overall leak rate of PGW's distribution infrastructure.[19]

Cast iron. Cast iron mains are considered to be the riskiest type of pipeline in the PGW distribution system. These mains are replaced under two programs: a baseline program and an accelerated program.

- The **baseline program** has historically replaced 18 miles per year and, in any given year, is paid for by gas customers under existing base rates. Rates generate some of the funding needed for capital expenditures; these funds are supplemented by the periodic issuance of long-term debt. Therefore, rates must also provide the cash flow necessary to cover debt servicing.

- The **accelerated program** began in 2013. During its first five years (FY 2013 to FY 2016), this program replaced 11.2 miles annually on average. During FY 2017 to FY 2022, annual miles replaced increased to 15.1.[20] The accelerated program is paid for by a ratepayer surcharge dedicated to funding eligible infrastructure improvements, the Distribution System Improvement Charge (DSIC). DSIC is capped at 7.5 percent of PGW's distribution revenues.[21] For FY 2023, this surcharge is budgeted at $33 million.

According to PGW, taking into account both the basic and accelerated programs, the company's "cast iron main inventory replacement is on track to be completed by 2058."[22] This trajectory assumes base rate increases of 5 percent beginning in 2026 and every five years thereafter.[23]

Non-cast iron mains. Non-cast iron mains constitute roughly a quarter of PGW's inventory of leak-prone mains, or approximately 599 miles of mains as of the end of 2021.[24] The research team could not locate a specific PGW replacement goal for the company's leak-prone non-cast iron mains. On

[18] PGW, Methane Reduction Program, June 2021, https://www.pgworks.com/uploads/pdfs/Methane_Reduction_Report_Final.pdf. According to this report, by PGW plans to reduce its methane emissions by 80% and 95% by 2050 and 2058, respectively (p. 9). The recent PGW Business Diversification Study by E3 et al. finds that a business-as-usual" approach by PGW "does not achieve City's Net-Zero goals by 2050." See Energy & Environmental Economics, Econsult Solutions Inc., Portfolio Associates, *Philadelphia Gas Works Business Diversification Study* (December 2021), Table 2, p. 44.

[19] Andrew Maykuth, "State OKs PGW gas-main replacement plan, including nearly 1,000 miles of pipes installed before WWII," *The Philadelphia Inquirer* (August 25, 2022), https://www.inquirer.com/business/philadelphia-gas-mains-replacement-pgw-cast-iron-20220825.html?query=philadelphia-gas-mains-replacement-pgw-cast-iron.

[20] The FY 2022 number in this range is expected not actual.

[21] PGW, Gas Service Tariff, Supplement 157 (issued November 30, 2022), p. 151, https://www.pgworks.com/uploads/pdfs/PGW_Gas_Service_Tariff_Through_Supplement_157.pdf. While DSIC is currently capped at 7.5%, on two prior occasions the PUC permitted DSIC to be temporarily raised, from 2016 to 2018 to 8.84%, and from 2018 to 2019 to 8.70%.

[22] PGW, Methane Reduction Program (June 2021), p. 4, https://www.pgworks.com/uploads/pdfs/Methane_Reduction_Report_Final.pdf.

[23] As a result of its 2020 base rate case, PGW received a $35 million rate increase rolled out in 3 phases: $10 million for service rendered on or after January 1, 2021, $10 million on or after July 1, 2021, and $15 million on or after January 1, 2022. Pennsylvania Utility Commission, Opinion and Order in PGW 2020 Base Rate Case, Docket No. R-2020-3017206. PGW is expected to file a new base rate case in January 2023.

[24] US Department of Transportation, PHMSA, Gas Distribution Annual Data: 2010 to present (ZIP extracted for 2020), https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids.

average, 6.4 miles of non-cast iron pipe were replaced annually from FY 2016 through FY 2021. Under the current financial structure of PGW's capital budget, this study finds that it would not be possible to completely eliminate this additional leak-prone pipe by the 2058 timeline (i.e., over the next 35 years). To do so would require adding roughly 10.5 miles annually to the current main replacement plan. (See Section 4.1 for further analysis.)

Services.[25] According to a 2021 PGW report, the utility intends to replace "all unprotected bare steel services by 2038."[26] These services are of particular concern because the PGW distribution system "has one of the shortest average service line lengths compared to other natural gas companies."[27] Shorter service lines increase the risks arising from main breaks and joint leaks because the gas has a shorter distance to migrate to reach nearby properties.[28]

2.4 Gas processing capital expenditures

PGW is primarily a gas distribution utility but it also operates facilities for the liquefaction, storage, and vaporization of natural gas, thereby supplementing the gas supply taken directly from interstate pipeline and storage companies. Specifically, PGW maintains nine City gate stations and the City's two LNG plants (the Richmond liquefaction and storage plant and the Passyunk storage facility). The LNG plants date to the 1970s and the gates are over sixty years old.

Annual gas processing capital expenditures of at least $10 million are historically common for PGW. The company's most recent five-year capital spending projections (FY 2023 to FY 2027) provide for a much higher amount, averaging $45 million per year ($270.4 million total). This significant increase is attributable to much higher proposed spending in two particular years: $30 million in 2023 for upgrades to the company's LNG plants and gate stations[29] and $170 million in 2027 to replace the liquefier at PGW's Richmond plant.[30]

[25] Service lines transport gas from a common source of supply to a customer meter or the connection to a customer's piping, whichever is further downstream, or to the connection to a customer's piping if there is no customer meter.
[26] PGW, Methane Reduction Program, June 2021, p. 5, https://www.pgworks.com/uploads/pdfs/Methane_Reduction_Report_Final.pdf. Note: PGW's use of the term "unprotected bare steel services" in its Methane Reduction Report conflates two distinct categories of services: those that are bare steel and those that are coated but not cathodically or otherwise protected. PGW should confirm that it intends to replace both types of services by 2038. According to PHMSA, as of 2021, there were 68,187 bare steel services and 18,842 unprotected coated steel services. See US Department of Transportation, PHMSA, Gas Distribution Annual Data – 2010 to present (ZIP extracted for 2020), https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids.
[27] PGW, Fiscal 2023 Capital Budget and Forecast Fiscal 2024-2028 with Fiscal 2023 Financing Plan (January 3, 2022), p. 16.
[28] PGW, Fiscal 2023 Capital Budget and Forecast Fiscal 2024-2028 with Fiscal 2023 Financing Plan (January 3, 2022), p. 16.
[29] PGW, Fiscal 2023 Capital Budget and Forecast Fiscal 2024-2028 with Fiscal 2023 Financing Plan (January 3, 2022), Exhibit 1, p. 5.
[30] PGW, Fiscal 2023 Capital Budget and Forecast Fiscal 2024-2028 with Fiscal 2023 Financing Plan (January 3, 2022), p. 67.

2.5 Cost of capital

The main emphasis of PGW's capital budget is pipeline replacement. For FY 2023, as in previous years, approximately 60 percent of PGW's capital plan is dedicated to improvements in the company's distribution system.[31] Within the distribution capital budget itself, nearly 80 percent of expenditures are allocated to main and services replacement.

Because it is municipally owned, PGW does not operate under the traditional rate-of-return regulatory framework. Its capital program is paid for by a combination of three sources: capital bond proceeds, internally generated funds from cash flow, and DSIC charges. Ratepayers provide the revenue to sustain these three funding sources through rates and special charges such as DSIC. Roughly half of the FY2023 capital plan is expected to be financed with debt.[32]

Rates and DSIC were most recently increased in 2021, following the PGW's 2020 base rate case. The rate case agreement reached in August 2020 provided PGW with a general rate increase of $35 million in annual operating revenues to be realized in three increments: $10.0 million for service rendered on or after January 1, 2021; $10.0 million for service rendered on or after July 1, 2021; and $15.0 million for service rendered on or after on January 1, 2022. PGW will be filing for its next general rate relief in January 2023.

The City's most recent "Gas Works Revenue Bonds" issue took place in 2020 in the amount of $254 million.[33] This was the sixteenth issue of such bonds and its main purpose was to finance $240 million of PGW's ongoing capital program. The proceeds are also used to pay back the principal on prior bond issues and cover the cost of issuing the bonds. This new debt has a fixed interest rate of 4 to 5 percent and is fully amortizing with final maturity in FY 2040. PGW's next debt issuance is scheduled for FY 2024 in the amount of $235 million.[34]

Part of PGW's interest expense on its long-term bonds should be attributed to PGW's pipeline infrastructure activity. PGW is clear that it has not issued any long-term debt to fund the accelerated cast iron replacement program. Instead, pipeline replacement expenditures above the cost of baseline program are on a pay-as-you-go basis funded by revenue from DSIC. At the same time, we know that about half the capital program is being financed with debt, including capital spending under the baseline pipeline replacement program.

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[31] PGW, Fiscal 2023 Capital Budget and Forecast Fiscal 2024-2028 with Fiscal 2023 Financing Plan (January 3, 2022), p. 16, Exhibit 1, p. 5. PGW's budgeted capital plan for FY 2023 totals $190,228,000. The Distribution section of the plan is budgeted for $113.6 million with main and service replacement accounting for $87.8 million of that total.

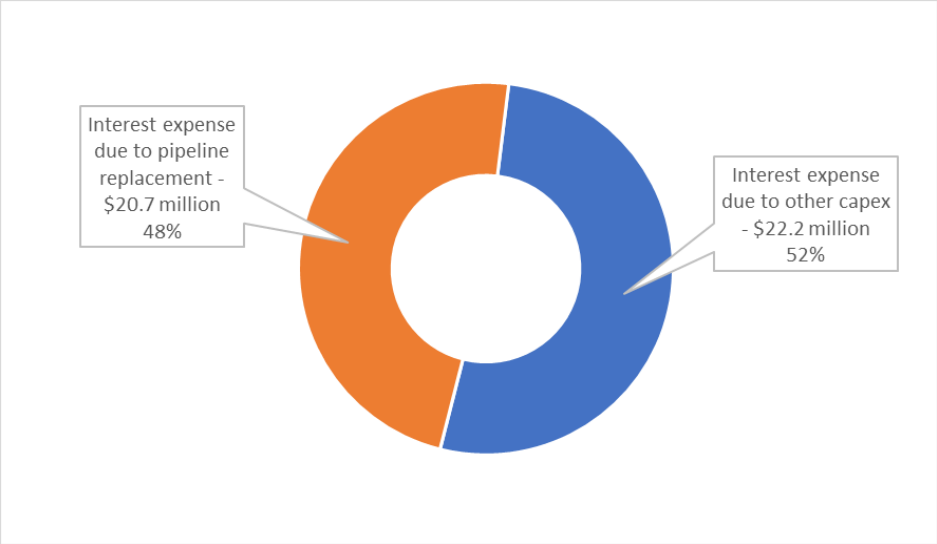
[32] Calculated from figures provided on p. 510 of PGW, Fiscal 2023 Capital Budget and Forecast Fiscal 2024-2028 with Fiscal 2023 Financing Plan (January 3, 2022). See also City of Philadelphia, Pennsylvania, Gas Works Revenue Bonds, Sixteenth Series A (October 20,2020), p. 26, https://www.phila.gov/media/20201222112611/Philadelphia-Gas-Works-Revenue-and-Refunding-Bonds-Sixteenth-Series-A-and-B.pdf.

[33] https://www.phila.gov/media/20201222112611/Philadelphia-Gas-Works-Revenue-and-Refunding-Bonds-Sixteenth-Series-A-and-B.pdf.

[34] City of Philadelphia, Pennsylvania, Gas Works Revenue Bonds, Sixteenth Series A (October 20,2020), p. 26, https://www.phila.gov/media/20201222112611/Philadelphia-Gas-Works-Revenue-and-Refunding-Bonds-Sixteenth-Series-A-and-B.pdf.

The average annual budgeted interest expense for PGW's capital program is $42.9 million for FY 2023 through FY 2027.[35] For FY 2023, the pipeline replacement budget (mains and services) is approximately $87.8 million and the total capital budget is $113.6 million. If we deduct expected DSIC revenue of $38 million from the pipeline replacement budget—to account for the fact that the accelerated cast iron replacement program is on a pay-as-you-go basis—then **the proportional amount of interest expense associated with pipeline replacement is approximately $20.7 million annually,** assuming stable interest rates and no increase in the amount of debt (see Figure 2).

Figure 2: Estimate of annual capital budget interest expense attributable to pipeline replacement vs. other capital expenditures, FY 2023-2027



Source: Calculations by author based on interest expense figures for the PGW capital budget as reported in PGW, Fiscal 2023 Capital Budget and Forecast Fiscal 2024-2028 with Fiscal 2023 Financing Plan, January 3, 2022.

[35] PGW, Fiscal 2023 Capital Budget and Forecast Fiscal 2024-2028 with Fiscal 2023 Financing Plan (January 3, 2022), p. 544.

3. Cost Projection Analysis

The main question this study seeks to answer is: **What is the likely financial cost of PGW's plan to continue replacing leak-prone mains and services in its gas distribution system?** The time frame for this analysis is the period 2022 through 2058. The 2058 end-year is the year by which PGW intends to complete the replacement of its cast iron main inventory, the riskiest pipe in its distribution system.[36]

The best way to estimate the future cost of infrastructure investments is to identify a robust average unit cost and then factor in adjustments for inflation and/or escalation in unit costs and changes in the cost of capital. Because of the uneven information available on PGW's replacement activity, **this analysis presents two sets of projections using different methodologies or approaches**. The first projects forward the current total budgeted cost for pipeline replacement while the second uses an average per-mile replacement cost figure derived from two different PGW information sources and then builds annual replacement costs based on the number of miles expected to be replaced.

3.1 Projection 1: Trending overall program costs forward

The first projection exercise takes the FY 2022 budgeted costs for the replacement of mains and services as its point of departure. The budgeted amount for main replacement of $66.4 million is trended forward for 37 years (until 2058) at the 3.5 percent escalation rate specified in the FY 2023 budget.[37] The budgeted amount for services of $19.8 million is trended forward also at 3.5 percent but only through 2038, the year by which PGW expects to replace all leak-prone services. The resulting cumulative cost of gas infrastructure replacement through 2058 is $5.3 billion.

The next step is to account for the share of PGW's annual interest expense for its capital program that should reasonably be attributed to main and service replacement. As described in the prior section, a rough estimate of the annual interest expense attributable to replacement is $20.7 million. Accounting for PGW's plan to conclude the replacement of services by 2038 and mains by 2058, the cumulative interest expense attributable to main and services replacement would be approximately $910 million, assuming constant interest rates.[38]

Projection 1 yields an estimated total cost of main and service replacement through 2058 of **$6.2 billion**. Since this method is not tied to a per-mile calculation, how much of the original leak-prone inventory would remain by 2058 is unclear although we know that, at the beginning year of this projection period, approximately 39 miles were to be replaced annually. If replacement costs, and therefore the capital budget, accelerate at more than the assumed 3.5 percent rate, then either some leak-prone pipes would be left unreplaced at the end of the period or the replacement capital budget would increase at more than the 3.5 percent rate. In the latter case, the $6.2 billion projection would be conservative.

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[36] PGW, Methane Reduction Program, June 2021, p. 4, https://www.pgworks.com/uploads/pdfs/Methane_Reduction_Report_Final.pdf.

[37] PGW, Fiscal 2023 Capital Budget and Forecast Fiscal 2024-2028 with Fiscal 2023 Financing Plan (January 3, 2002), "Capital Budget Assumption Letter" (January 3, 2022), p. 10.

[38] Assuming bond issues at intervals of every five years beginning in FY 2024, a final 30-year bond issue might be needed in FY 2059 to help fund pipeline replacement spending toward the end of that timeline plus any new spending in FY 2058. This could create additional interest expenses related to funding the replacement of mains. These possible additional financing costs are not included in this report's calculations.

3.2 Projection 2: Building a projected cost based on average per-mile replacement costs

The second projection method relies on an average per-mile main replacement cost for 2021 derived from two PGW sources: the most recent Annual Asset Optimization Plan report[39] (for FY 2021 and FY 2022) and this study's Right-To-Know Law Request (see Table 3). The unit cost figures from these two sources are $2,113,684 and $2,100,076, respectively. Since these unit costs are nearly identical, this study uses the average of these two—$2,106,880—and then escalates that cost by 3.5 percent, consistent with the escalation assumptions of PGW's FY 2023 capital budget. This calculation yields a 2022 average cost estimate of $2,180,621 per mile replaced. This cost is then escalated forward at the rate of 3.5 percent through 2058 and multiplied each year by the average number of miles replaced in the last five years (39.25 miles consisting of 32.85 miles of cast iron and 6.4 miles of non-cast iron). The replacement cost for services is trended forward at 3.5 percent until 2038. The total projected cost of this second scenario through 2058 is **$6.7 billion**. Adding this study's estimate of the interest expense attributable to pipeline replacement (see Section 2.5) increases the total cost to **$7.6 billion.**

Under this projection, a total of 1,452 miles would be replaced by 2058, or nearly half (48 percent) of the 3,046 miles of mains making up the PGW distribution system at the end of 2021. Note that the total number of miles of mains to be replaced under this scenario—even though it is based on PGW replacement goals—is less than the total number of miles considered leak-prone by PHMSA at the end of 2021 (1,839 miles).[40]

3.3 Summary of cost projections

This study uses two different approaches to estimate the likely cost of PGW's pipeline replacement activity. The resulting cost estimates are presented in Table 4. The **first approach** trends today's total pipe replacement program costs forward until 2058. The **second approach** builds a total cost based on a proxy for the average unit cost of replacing a mile of pipeline. It assumes that 39.25 miles of mains are replaced each year through 2058 (approximately 33 miles of cast iron pipe and 6 miles of steel pipe).

Both approaches share the following additional assumptions:

- 3.5 percent annual escalation rate for main replacement costs.
- Annual service replacement costs of $19.8 million beginning in 2022, escalating at 3.5 percent per year and ending in 2038.
- Annual interest expense from debt financing of $27.4 million from 2022 to 2038, declining to $22.2 million after the expected termination of services replacement in 2038 (main replacement is assumed to continue through 2058).

The resulting total cost estimates for replacing mains and services from 2022 to 2058 range from $6.2 billion to $7.6 billion in nominal dollars ($4.9 billion to $6.1 billion in real dollars).

[39] PGW, Annual Asset Optimization Plan FY 2021 and FY 2022 (Projected), p. 6 (Table 2: Detailed description of facilities repaired, improved, and replaced in FY 2021), https://www.puc.pa.gov/pcdocs/1723803.pdf. Note: Actual total cost divided by indicated mileage yields $2,113,684.

[40] See Section 2.1 of this report for citations to PHMSA data regarding PGW total distribution main miles and the amount considered leak prone.

Table 4: Cost projections for replacing leak-prone mains from 2022 to 2058 and leak-prone services from 2022 to 2038

	Projection 1	Projection 2
Cost components		
Main replacement cost		$6,287,212,490
Services replacement cost		$448,991,686
Total replacement cost	$5,324,463,929	$6,736,204,177
Interest expense cost	$909,912,400	$909,912,400
Grand total (nominal $)	**$6,234,376,329**	**$7,646,116,577**
Grand total ($2022)	**$4,947,917,722**	**$6,068,346,489**

Two conservative assumptions undergird each projection. First, the assumption that costs and/or program funding accelerate at 3.5 percent is conservative since, according to PGW data obtained via this study's data request (see Table 3), from 2015 to 2021 actual costs of main replacement increased by 8.5 percent per year, and from 2019 to 2021 by 5.6 percent. **If the most recently reported 5.6 percent rate of increase is applied, Projection 1 total costs would increase from $6.2 billion to $9.2 billion, and Projection 2 total costs from $7.6 billion to $11.6 billion.**

The second conservative assumption is that the amount of debt issuance does not increase even though annual replacement costs are assumed to increase by 3.5 percent. If costs go up by 3.5 percent annually, then gas rates will need to increase by the same amount to generate sufficient funding. This implies a 17.5 percent rate increase every five years until 2058. To the extent that gas rates do not keep up with inflation, then PGW would need to issue more debt. Greater debt issuance may in turn result in higher interest and principal payments and, all things equal, an increase in PGW's financial risk profile.

4. Additional Findings

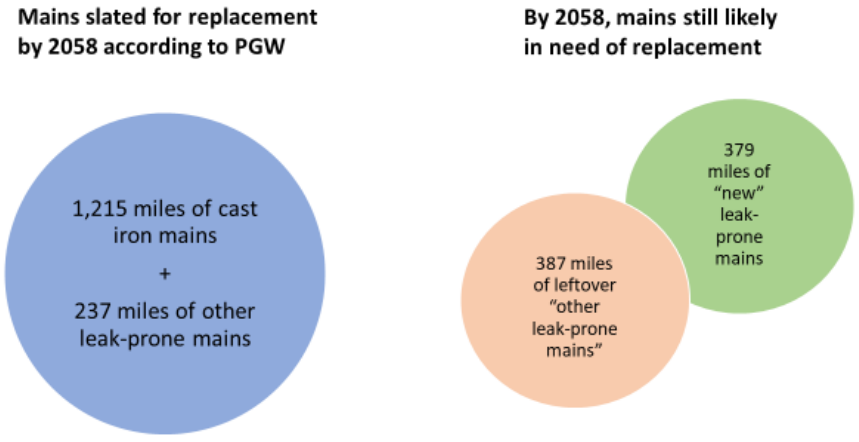
4.1 PGW's current replacement plans, slated to end in 2058, are not adequate to eliminate all of the City's current inventory of leak-prone pipe.

PGW has significantly increased the number of miles it is replacing annually but the programs and funding sources currently in place will not be sufficient to eliminate the existing inventory of leak-prone pipes by 2058. This study finds that, **by 2058, PGW will be able to eliminate its cast iron mains but a backlog of approximately 387 miles of leak-prone largely steel pipe will remain unaddressed** (see Figure 3 below). **To replace these remaining miles of pipe by 2058 would require roughly an additional $1.7 to $2 billion.** In other words, **eliminating PGW's entire current inventory of leak-prone mains (cast iron and steel) by 2058 would require total spending on the order of $7.9 to $9.6 billion.**[41]

4.2 Even if PGW were able to eliminate its entire current inventory of leak-prone pipe by 2058, by that time an additional 379 miles of mains would likely be in need of replacement.

Even if we assume that in 35 years the entire current inventory of leak-prone pipe totaling 1,839 miles (cast iron plus non-cast iron) is eliminated and replaced with new pipe, the age distribution of PGW's mains is such that, **by 2058, an additional 379 miles of mains will have aged past its useful service life and therefore be in need of replacement attention** (see Figure 3 below). This "next-up" inventory of leak-prone infrastructure will consist of mains installed in the 1970s and 1980s.[42] Were these

Figure 3: Status of leak-prone mains by 2058



Source: Author's calculations.

[41] The key financing assumptions underlying these calculations are as follows: a) unit costs increase annually by 3.5% or less, b) PGW's requests for rate relief will be granted every three to five years resulting in increased gas costs for customers, and c) new bond issues will occur as in the past with interest rates on the order of 4 to 5%.
[42] Pipes installed during these decades are likely to include Aldyl-A plastic pipe which was used from the 1960s through the early 1980s and is considered a potential hazard due to its propensity for embrittlement, cracking, and rupture.

additional mains to be replaced in 2058, **the additional replacement cost would be on the order of $2.9 billion**, assuming no debt financing and that all the replacement occurs in this final year.

4.3 In addition to replacing aging leak-prone infrastructure, each year PGW is extending its gas delivery system by roughly 4.5 miles to bring new customers online ("new load growth").

Over the last six years, PGW has added 27 miles of natural gas mains to its distribution system, or 4.5 miles per year (see Table 5).[43] For PGW, expanding its distribution system increases current and future revenue, thereby offsetting at least partially the negative revenue effects of customers leaving the gas system as they choose to electrify or fuel switch. System expansion also offsets throughput reductions tied to weatherization and other efficiency measures.[44]

Table 5: Miles of mains installed to accommodate new load growth

	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	Total
Plastic	3.45	3.99	5.48	3.89	2.72	4.08	23.61
Steel	0.24	1.47	0.92	0.05	0.58	0.19	3.45
Total	3.69	5.46	6.4	3.94	3.3	4.27	**27.06**

Source: PGW, Asset Inventory Information, FY2023 Capital Budget, January 3, 2022, p. 566.

PGW's new load growth is occurring within the context of rapidly changing economics of building heating ventilation and air conditioning (HVAC). For new residential buildings, the cost of installing electric heat pumps is now generally less than the cost of installing gas heating equipment plus central air conditioning. Retrofit calculations are more complex because they are sensitive to: the number of building retrofit measures undertaken, the degree of reduction in resident energy bills (which in turn is tied to the retrofit measures selected and the efficiency level of the new equipments), and the configuration of available rebates and incentives (which in turn impacts the payback period).[45] In any

[43] Going back even farther, since 2010 PGW has brought gas service to 8,000 new homes, according to the recent PGW Business Diversification study. Energy & Environmental Economics, Econsult Solutions Inc., Portfolio Associates, *Philadelphia Gas Works Business Diversification Study* (December 2021), p. 11, https://www.phila.gov/media/20211207134817/PGW-Business-Diversification-Study-2021-12.pdf.

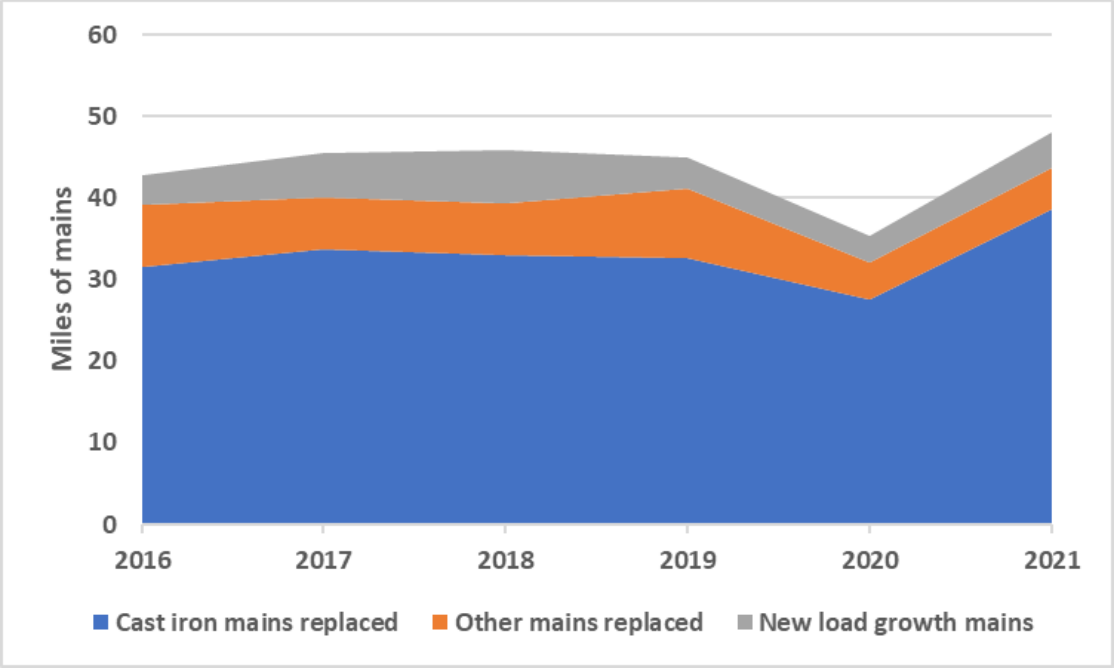
[44] The PGW Business Diversification Study states: "In past years, PGW's gas consumption per residential customer has been declining due to improved appliance efficiencies, conservation efforts, and a warming climate. These factors are likely to intensify as temperatures continue to rise and policymakers place a stronger focus on reducing the greenhouse gases (GHGs) in the atmosphere." Energy & Environmental Economics, Econsult Solutions Inc., and Portfolio Associates, *Philadelphia Gas Works Business Diversification Study* (December 2021), p. 8, https://www.phila.gov/media/20211207134817/PGW-Business-Diversification-Study-2021-12.pdf.

[45] In some areas of the country, gas equipment incentives are greater than current heat pump incentives, creating an economic barrier to electrification. For an informative analysis of new construction and retrofit electrification costs applied to one city, see Building Electrification Institute, *Washington, D.C. Customer Economics Analysis for Building Electrification* (December 2020), https://static1.squarespace.com/static/5b6a482db27e39e8fcf65bbf/t/6298044502087000c9537c03/1654129734671/BEI-DC+Customer+Economics+Analysis_Dec+2020_FINAL.pdf.

case, the ongoing utility costs and CO2 emissions of all-electric homes tend to be lower, even if gas continues to provide a significant share of electricity generation.[46]

Figure 4 provides an accounting of PGW's activity to both replace existing leak-prone mains and add new mains to accommodate new load growth. It shows that, over the past five years, the total number of mains either replaced or added has increased from 43 miles of mains in 2016 to 48 miles in 2021.

Figure 4: PGW replacement of leak-prone mains plus new load growth, 2016-2021



Source: PGW, Asset Inventory Information, FY 2023 Capital Budget, January 3, 2022.

4.4 PGW's financial model is increasingly dependent on federally-funded energy bill assistance subsidies and the company's energy assistance rate surcharge that recovers discounts provided to low-income and other energy insecure customers.

Roughly 40 percent of Philadelphia's residents are low-income—with family incomes less than 200 percent of the federal poverty level[47]—and more than 70 percent of these households rely on natural gas for space and water heating. The housing that low-income residents typically rent or own is older, less efficient, less healthy and more unsafe. As a result, the energy burdens of these households are high: the City's low-income households spend on average 12 percent of their income on their energy bills

[46] Lacey Tan, Mohammad Hassan Fathollahzadeh, and Edie Taylor, *The Economics of Electrifying Buildings: Residential New Construction* (RMI, December 2022), https://rmi.org/insight/economics-of-electrifying-residentialnew-construction.
[47] In this report, households are defined as "low income" if their family income is less than 200% of the federal poverty level. In 2022, 200% of the poverty line was $55,500. For official guidelines, see: https://aspe.hhs.gov/sites/default/files/documents/4b515876c4674466423975826ac57583/Guidelines-2022.pdf. See also Energy & Environmental Economics, Econsult Solutions Inc., and Portfolio Associates, *Philadelphia Gas Works Business Diversification Study* (December 2021), p. 27, https://www.phila.gov/media/20211207134817/PGW-Business-Diversification-Study-2021-12.pdf.

compared to 3 percent for Philadelphians as a whole.[48] In fact, Philadelphia has one of the highest proportions of energy-burdened households in the country[49] and nearly the entire city is considered an environmental justice area by the Commonwealth of Pennsylvania and the federal government.[50]

Customers having trouble affording their gas bills can apply through local energy offices for bill assistance of up to $1,000 per heating season through the federally-funded **Low Income Home Energy Assistance Program** (LIHEAP). The LIHEAP program consists of two grant components–cash grants and crisis grants–and is open to households with incomes at 150 percent or below of the federal poverty level. Cash grants assist with heating costs whereas crisis grants are offered to customers whose utility service has been disconnected or is in danger of having services terminated. Once an eligible customer is enrolled and indicates PGW as their energy provider, the grant monies are paid directly to PGW for crediting to the customer's account.

Another important source of low income assistance funding for PGW is its **Customer Responsibility Program** (CRP). CRP provides arrearage forgiveness and a reduced bill based on household size and monthly income for customers with incomes at or below 150 percent of the federal poverty level.[51] Customers can participate in CRP and LIHEAP at the same time. CRP is funded by a surcharge on ratepayer bills called the Universal Service and Energy Conservation Surcharge.

LIHEAP. In October 2021, PGW reported that "as many as 138,000 PGW customers could qualify for LIHEAP" and that "over 82,000 low-income PGW customers received LIHEAP assistance [in 2020-2021]."[52] These figures suggest that **roughly 28 percent of PGW residential customers are**

[48] Author calculations based on US Department of Energy, Office of Energy Efficiency & Renewable Energy, Low-Income Energy Affordability Data (LEAD) Tool, https://www.energy.gov/eere/slsc/maps/lead-tool.

[49] As of 2017, 26% of low-income households in Philadelphia had high energy burdens (defined as spending more than 6% of household income on utility bills). 13 percent of households had a "severe" energy burden (more than 10% of income spent on utility bills). Ariel Drehobl, Lauren Ross, and Roxana Ayala, *How High Are Household Energy Burdens?* (American Council for an Energy-Efficient Economy, September 2020), https://www.aceee.org/sites/default/files/pdfs/u2006.pdf and https://www.aceee.org/sites/default/files/pdfs/aceee-01_energy_burden_-_philadelphia.pdf.

[50] See the Environmental Justice Screening and Mapping Tool of the US Environmental Protection Agency available at https://ejscreen.epa.gov/mapper/index.html?wherestr=philadelphia+county%2C+PA and the EJ Areas Viewer of the Pennsylvania Department of Environmental Protection available at https://padep-1.maps.arcgis.com/apps/webappviewer/index.html?id=f31a188de122467691cae93c3339469c. See also Sophia Schmidt, "Philadelphia is revising its environmental justice policy. Here's what's changing" (WHYY, March 16, 2022), https://whyy.org/articles/pennsylvania-is-revising-its-environmental-justice-policy-heres-whats-changing/#:~:text=The%20current%20policy%20defines%20environmental,Philadelphia%2C%20in%20an%20EJ%20area.

[51] See https://www.pgworks.com/customer-care/crp and https://www.pgworks.com/community-impact/newsroom/pgws-customer-responsibility-program-offers-immediate-financial-relief-for-low-income-customers.

[52] For the number of PGW customers receiving/eligible for LIHEAP, see PGW, "*PGW Low-income Customers Can Now Apply For Up To $1,500 In Heating Assistance*" (October 18, 2021), https://www.pgworks.com/community-impact/newsroom/pgw-low-income-customers-can-now-apply-for-up-to-1500-in-heating-assistance#:~:text=As%20many%20as%20138%2C000%20PGW,benefit%20from%20free%20utility%20assistance.

eligible for LIHEAP.[53] In fiscal years 2020 and 2021, the average benefit received by Pennsylvania households for LIHEAP grant assistance (cash and crisis) was $387 and $371, respectively, according to the federal government.[54] Applying these amounts to the 82,000 PGW customers receiving LIHEAP grants in FY 2020 (and assuming the same number of PGW LIHEAP participants in FY 2021 as FY 2020), indicates that **PGW took into income approximately $25-$32 million in federal LIHEAP payments during fiscal years 2020 and 2021, or 14-15 percent of LIHEAP grant funds allocated by the Commonwealth.**[55]

Customer Responsibility Program (CRP). PGW reports that CRP was serving over 61,000 customers as of the end of August 2021 (a 10 percent increase in enrollment from the prior year) and that the program provided assistance totaling $27 million to low-income customers.[56] The tariff surcharge paying for this program (as well as other benefits related to vulnerable populations and low-income retrofits) was set at $0.17354 per hundred cubic feet (Ccf) beginning December 2022.[57] Assuming average residential annual consumption of 800 Ccf, this translates into an annual residential customer charge of $139. According to CRP guidelines, participants in the CRP must annually apply for and assign at least one energy assistance grant, such as a LIHEAP grant, to PGW.[58]

While LIHEAP and CRP payments to PGW customers do not address the root causes of household energy insecurity, this assistance constitutes a vital social protection that helps families meet their basic energy needs. Affordability and equity issues for PGW customers can be expected to increase as gas throughput declines due to increased energy efficiency measures and customers departing the gas system to take advantage of cleaner, more efficient heating technologies.

From PGW's standpoint, the fact that such a high proportion of PGW's customer base is low income and experiences payment difficulties arguably constitutes a significant structural financial weakness in its customer base. The PGW Business Diversification study makes clear that, no matter what energy transition path is chosen by the City, substantial changes are likely in the cost of gas sold by PGW, the volume of gas delivered, and the number of gas customers served. This implies that the low-income

[53] The 28% figure is equal to the 82,000 customers divided by the total number of residential customers (498,300). The latter figure is reported in PGW, Annual Comprehensive Financial Report for Fiscal Years Ended August 31, 2021 and 2020, p. 6, https://www.pgworks.com/uploads/pdfs/Philadelphia_Gas_Works_2021_ACFR_-_FINAL.pdf. Note: PGW reports that in FY 2021 and FY 2020, it served 524,000 customers each year. In FY 2021, its customer base consisted of 25,000 commercial accounts, 600 industrial accounts, and 498,300 residential customers.

[54] US Department of Health & Human Services, Administration for Children & Families, LIHEAP Data Warehouse, Grantee Profiles, https://liheappm.acf.hhs.gov/datawarehouse. The average statewide benefits are calculated by the author as a weighted average of benefits received by cash recipients and crisis recipients in Pennsylvania.

[55] For a detailed historical description of PGW's reliance on LIHEAP, see the depreciation study conducted for PGW's last base rate case. That study reports that, from 2007 to 2016, PGW's LIHEAP receipts ranged "from a low of $17.3 million in 2016 to a high of $41.5 million in 2010…" and its share of LIHEAP funds allocated by the Commonwealth of Pennsylvania "ranged from approximately 12 to 17 percent since 2007." Black & Veatch, FINAL REPORT ON DEPRECIATION ACCRUAL RATES, Natural Gas Utility Property of Philadelphia Gas Works (PGW 2020 Base Rate Case, Docket No. R-2020-3017206, July 2017), pdf 503, https://www.puc.pa.gov/pcdocs/1656459.pdf.

[56] PGW, Annual Comprehensive Financial Report for Fiscal Years Ended August 31, 2021 and 2020, p. iv, https://www.pgworks.com/uploads/pdfs/Philadelphia_Gas_Works_2021_ACFR_-_FINAL.pdf.

[57] PGW, Gas Service Tariff, Pa. P.U.C. No. 2, Supplement No. 157 (November 30, 2022), p. 81, https://www.pgworks.com/uploads/pdfs/PGW_Gas_Service_Tariff_Through_Supplement_157.pdf.

[58] PGW, Gas Service Tariff, Pa. P.U.C. No. 2, Supplement No. 157 (November 30, 2022), p. 59, https://www.pgworks.com/uploads/pdfs/PGW_Gas_Service_Tariff_Through_Supplement_157.pdf.

portion of PGW's customer base will increase over time and with it, the gap between the gas bills received by low-income households and what they can afford. The federal LIHEAP subsidy of PGW operations along with the company's related surcharge serve to increase cash flow, decrease accounts receivable, and sustain the company's customer base and throughput. However, even assuming greater efficiency measures, it is questionable whether these payments will be sufficient to eliminate the likely growing affordability gap for low-income customers.

5. Findings and Conclusions

5.1 Findings

Based on its review of the available information from PGW, this study offers the following findings**:**

1. **The City of Philadelphia is on track to invest on the order of $6 to $8 billion in nominal dollars ($5 to $6 billion in real dollars) to replace nearly half of its aging gas distribution system over the next 35 years,** an unprecedented infrastructure investment for the City and an expense to be borne entirely by gas customers via their rate payments.

2. **PGW's average cost of installing a mile of replacement pipeline reached $2.1 million in FY 2021.** This cost has been increasing at 8.5 percent annually since 2015.

3. **PGW's pipeline replacement programs are unlikely to achieve their stated replacement goals.** These programs are slated to end in 2058 but the expected pace of replacement work does not appear to be adequate to replace 100 percent of the City's current inventory of leak-prone pipe by that time (approximately 387 miles of leak-prone mains will remain). Furthermore, by 2058, PGW can expect an additional 379 miles of mains to have aged into "needing replacement" status. **Another two decades would be required to replace these two sets of mains at the current annual replacement rate—or until 2078.**

4. **PGW has been extending its gas delivery system by roughly 4.5 miles annually to bring new customers online**, adding 27 miles of mains to its distribution system over the last six years.

5. **PGW is also investing significant amounts of additional capital to maintain its two LNG plants and nine gate stations, facilities that are critical to the functioning of its gas distribution system.** For the period 2023 to 2027, PGW has received approval from the Philadelphia Gas Commission and the Philadelphia City Council to spend $270.4 million to upgrade these gas processing facilities, including two high-mark year investments of $30 million and $170 million in 2023 and 2027, respectively.

6. **About 30 percent of PGW's residential customers qualify for federally-funded energy bill assistance payments,** meaning that they likely have difficulty affording their utility bills. Indeed**,** Philadelphia has one of the highest proportions of energy-burdened households in the country and nearly the entire city is considered an environmental justice area by the Commonwealth of Pennsylvania and the federal government. Affordability and equity issues for the PGW gas system can be expected to increase with declining throughput due to increased energy efficiency measures and customers departing the gas system to take advantage of cleaner, more efficient heating technologies.

7. **During fiscal years 2020 and 2021, PGW received on the order of $25 to $32 million in federal bill assistance payments credited directly to the customer gas accounts of its energy-burdened low-income ratepayers.** These federal payments bolster PGW's revenue and keep significant numbers of low-income customers on the PGW gas system.

5.2 Conclusions

PGW's capital investments in its distribution and gas processing systems are creating unprecedented new fossil-fuel assets at a time when the City of Philadelphia has committed to developing energy transition plans on a scale sufficient to meet the City's net-zero goals. A **comprehensive, long-term business case for these new gas system investments has yet to be made.** Any such plan must align with the City's decarbonization goals—the City has committed to achieving carbon neutrality and 100 percent clean energy for all purposes by 2050[59]—and must be financially feasible and programmatically sound.

As underscored by the PGW Business Diversification study,[60] three structural shifts are underway that fundamentally challenge PGW's financial prospects and current business model:

- Declining throughput
- Shrinking ratepayer base leaving an increasing proportion of low-income consumers
- Relative energy prices that over the long run will favor non-emitting, renewable energy sources

As the City addresses what role the gas system is to play in meeting its climate goals, the financial impacts for PGW and its customers of a gradual shift toward high levels of electrification must be carefully modeled and evaluated. Customers are already switching to electricity from gas and this trend will accelerate as Philadelphia implements its greenhouse gas reduction goals.

Like some other gas utilities in the Northeast, PGW may be pursuing accelerated rates of pipe replacement in order to hedge the bet that, down the road, alternative gases such as biomethane, synthetic natural gas, and hydrogen will be suitable candidates for blending with natural gas and be available in sufficient quantities at affordable prices.[61] PGW's June 2021 Methane Reduction Report states that the company "is currently seeking RNG sources for gas supply, along with other RNG development opportunities."[62] The PGW Business Diversification Study, however, is not optimistic that this pathway would be a long-term solution for PGW. The study cautions that such a pathway "comes at a risk of limited available resources, high fuel costs and limited air quality improvements. If used in large

[59] Greenworks Philadelphia, Office of Sustainability, *Philadelphia Climate Action Playbook* (January 2021), https://www.phila.gov/media/20210113125627/Philadelphia-Climate-Action-Playbook.pdf. See also this press release from the Mayor's Office: City Commits to Carbon Neutrality by 2050, Releases Climate Action Playbook and Hires First Chief Resilience Officer | Office of Sustainability | City of Philadelphia; and this 2019 City Council resolution: City of Philadelphia - File #: 190728 (legistar.com).

[60] Energy & Environmental Economics, Econsult Solutions Inc., and Portfolio Associates, *Philadelphia Gas Works Business Diversification Study* (December 2021), https://www.phila.gov/media/20211207134817/PGW-Business-Diversification-Study-2021-12.pdf.

[61] In its recent report on methane reduction, PGW states that it is "currently seeking RNG [renewal natural gas] sources for gas supply, along with other RNG development opportunities." PGW, Methane Reduction Program (June 2021), p. 9, https://www.pgworks.com/uploads/pdfs/Methane_Reduction_Report_Final.pdf. In addition, PGW recently issued a "Request for Information regarding a Potential PGW Hydrogen Project" that would produce, store, and distribute hydrogen using its Passyunk LNG Plant as the facility site. See https://pgw.procureware.com/Bids/44672efb-1754-48d0-89eb-63571bb3d7eb?t=Description. It should be noted that even if cost and supply issues can be resolved over time, like natural gas, alternative gases require combustion in residential households raising the same or greater safety risks and health concerns from air pollutants.

[62] PGW, Methane Reduction Program (June 2021), p. 9, https://www.pgworks.com/uploads/pdfs/MethaneReductionReport_Final.pdf.

amounts, decarbonized gases could harm the competitiveness of PGW's services compared to alternatives like electrification."[63]

PGW's pipeline replacement programs are among the City's largest capital infrastructure projects—if not the largest—and they show a high level of annual cost escalation (8.5 percent from 2015 to 2021). Transparency and accountability would be served by regular and consistent annual reporting on the full scope of this replacement activity over time, including actual miles of main and number of services replaced and the associated costs. Current capital budget proceedings and the next base rate case create an opportunity for PGW to make publicly available detailed historical information on pipeline replacement including actual costs.

In addition, **the existing time horizon and focus of regulatory oversight is inadequate and should be reset and extended.** The main report provided by PGW on its future capital plans with respect to pipeline infrastructure is the Long Term Infrastructure Improvement Plan (LTIIP). From an oversight perspective, there are three problems with LTIIP reporting:

1. According to statute (52 Pa. Code § 121), LTIIP only has purview over accelerated pipe replacement financed by the DSIC recovery mechanism. There is no corresponding oversight of the baseline program[64] which means that the two programs are treated as effectively siloed.

2. The time horizon for LTIIP reporting is only five years even though the accelerated (and baseline) pipeline replacement programs are intended to span multiple decades, with an end date of 2058.

3. The statutory oversight responsibilities of the PUC regarding LTIIP are very limited or insufficiently specified, and PGW is only required to address a narrow set of criteria in its reporting.[65] Expanded directives are needed to incorporate public interest concerns such as climate, equity, affordability, and public health as well as a requirement that the relative cost effectiveness of alternatives to gas pipeline replacement be considered.

In light of this study's finding that PGW's pipeline replacement programs are on course to cost Philadelphians $6 to $8 billion through 2058, **it is imperative that PGW and its regulatory and oversight bodies develop mechanisms to ensure transparency and public accountability for the full aggregate impacts of PGW's investments in pipeline replacement, gas processing facilities, and new load growth**. Realistic projections that account for customers leaving the gas system and declining gas use must be provided, and the future financial ramifications for PGW and for residential customer gas rates must be modeled and vetted. Decreasing use of gas means rates must rise to capture the revenues needed to pay for infrastructure spending from fewer customers, an increasing proportion of whom are likely to be low-income ratepayers relying on public energy bill assistance payments.

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[63] Energy & Environmental Economics, Econsult Solutions Inc., and Portfolio Associates, *Philadelphia Gas Works Business Diversification Study* (December 2021), p. 4, https://www.phila.gov/media/20211207134817/PGW-Business-Diversification-Study-2021-12.pdf.

[64] In practice, the Annual Asset Optimization Plan (the annual report required by the LTIIP) typically provides some information on the related baseline replacement program.

[65] 52 Pa. Code § 121 provides that the Public Utilities Commission must assess whether the LTIIP "[c]ontains measures to ensure that the projected annual expenditures are cost-effective." LTIIP need only address a narrow set of criteria including the following: reasonable estimates of the quantity of property to be improved, projected annual expenditures and means to finance the expenditures, and how repair, improvement, or replacement will ensure and maintain adequate, efficient, safe, reliable, and reasonable service to customers.

As gas utilities and their regulators around the country confront the urgency of meeting city and state climate goals alongside the reality of rapidly rising pipeline replacement costs, **consideration of alternatives to gas pipeline replacement are being built into decision making and regulatory frameworks.**[66] These solutions—sometimes called "non-pipeline alternatives"[67]—refer to targeted activities or investments that delay, reduce, or avoid the need to build or upgrade traditional natural gas infrastructure such as pipelines, storage, and peaking resources. Many of these solutions involve transitioning the current system—where buildings are heated by fossil fuels or other combustible gases that are hazardous to health, safety, and climate—to one where buildings are heated by non-combustible, renewable sources of thermal energy via air- and ground-source heat pump technologies. Examples of alternative solutions include: thermal energy networks, synchronizing clustered electrification with strategic gas system decommissioning, and advanced leak repair and enhanced monitoring (see Appendix A for more detail and examples from around the country).

PGW regulators should adopt strong regulatory frameworks that: a) require comprehensive cost/benefit analysis of non-replacement solutions for gas pipeline infrastructure, b) take into account the total social costs of different options, including their health, safety, environmental impacts, and emissions costs, and c) evaluate the most cost effective ways of eliminating methane leaks, and enhancing safety and energy efficiency. Finally, the full opportunity costs of planned investments must be transparently presented in the public sphere so that they can be vetted and assessed.

The City of Philadelphia is at a critical juncture where strategic decisions need to be made and plans put in place to guide the City's energy future in a world of escalating climate risk. PGW has the potential to play a transformative role in fostering the City's energy future, innovating and designing new systems for a changing energy environment, protecting its most vulnerable customers, and avoiding investments that are likely to become uneconomic with too few remaining customers to support the costs. The company has important advantages: most significantly, PGW is publicly owned and, therefore, is responsible not to investor shareholders but rather to the City's residents and businesses. Compared to an investor-owned for-profit utility, PGW is more flexible and less constrained because its infrastructure spending is not tied to the need to return a profit with investor dividends. PGW has also demonstrated the discipline of paying for substantial amounts of capital investment on a pay-as-you-go basis. The substantial, multi-decade gas distribution and processing investments investigated in this report are still in their early stages, leaving room for comprehensive planning that could direct PGW's substantial capital investment resources toward energy infrastructure that best serves today's Philadelphians and future generations.

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[66] For examples see: Consolidated Edison Company of New York, Non-Pipeline Alternatives Implementation Plan (November 16, 2022), https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B6A490BBB-0E8B-41F9-9040-9342758D8AE2%7D and California Public Utilities Commission, "CPUC Creates New Framework To Advance California's Transition Away From Natural Gas" (December 1, 2022), https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-creates-new-framework-to-advance-california-transition-away-from-natural-gas.

[67] The term "non-pipeline" can be misleading. For example, networked geothermal is an alternative to the replacement of gas pipeline but involves pipelines that carry water in closed loops.

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Appendix A: Alternatives to Gas Pipeline Replacement

Alternatives to gas pipeline replacement refer to targeted activities or investments that delay, reduce, or avoid the need to build or upgrade traditional natural gas infrastructure such as pipelines, storage, and peaking resources. Many of these solutions involve transitioning the current system—where buildings are heated by fossil fuels or other combustible gases that are hazardous to health, safety, and climate—to one where buildings are heated by non-combustible, renewable sources of thermal energy via air- and ground-source heat pump technologies.

Three categories of alternatives are described below with implementation examples from around the country:

1. **Thermal energy networks.** A thermal energy network refers to an ambient temperature loop system that connects *multiple* buildings with a variety of heating and cooling loads in a shared network using geothermal, waste heat, or surface water energy connected to heat exchangers. Thermal energy networks have the potential to optimize the efficiency of shared thermal sources and they offer existing utilities and municipalities the prospect of new business lines and related or complementary workforce deployment**.**

    - **The PGW Business Diversification Study** selected large-scale adoption of networked geothermal (a thermal energy network that utilizes geothermal boreholes to access renewable, non-combustible thermal energy) as one of four decarbonization options for the City to consider. In these systems, water-filled loops are used to both heat and cool an entire street or neighborhood. The system connects buildings with different heating needs so energy is exchanged and stored in the ground until it is needed. The Business Diversification study advised that more research on the costs, feasibility and potential locations of these systems was needed[68] and in August 2022, the City approved a feasibility study for networked geothermal as part of PGW's FY 2023 operating budget.

    - In **Massachusetts**, several gas utility-sponsored networked geothermal demonstration installations are underway under the auspices of Eversource[69] and National Grid.[70]

    - In **New York**, the Public Service Commission has initiated a proceeding to implement the Utility Thermal Energy Network and Jobs Act of 2022.[71] The Act authorizes the state's utilities to own and operate thermal energy networks and calls for the Commission to require the seven largest investor-owned utilities to submit at least one and up to five proposed thermal network pilot projects for review, with at least one pilot project located in a disadvantaged community within each utility service territory.

2. **Synchronizing clustered electrification with strategic gas system decommissioning.** This involves a coordinated approach whereby portions of the gas system that are leak prone or near

[68] Energy & Environmental Economics, Econsult Solutions Inc., Portfolio Associates, *Philadelphia Gas Works Business Diversification Study* (December 2021), https://www.phila.gov/media/20211207134817/PGW-Business-Diversification-Study-2021-12.pdf.
[69] See https://www.eversource.com/content/ema-c/business/save-money-energy/clean-energy-options/geothermal-pilot-program.
[70] See https://www.nationalgridus.com/News/2022/09/National-Grid-8217-s-Massachusetts-Geothermal-Program-Implementation-Plan-Receives-Approval/.
[71] https://lpdd.org/wp-content/uploads/2022/07/New-York-2021-S09422-Introduced.pdf.

end-of-life are taken offline while the buildings they serve are fully electrified. This pruning/conversion solution is under active consideration elsewhere in the country:

- **California's Climate Energy Commission** has established a Tactical Gas Decommissioning Project that is developing a "data-driven actionable tool" to identify segments of a given gas distribution system that, if decommissioned, would result in gas system cost savings.[72] Pilots are being developed in three northern California communities.[73]
- In December 2022, a staff proposal was issued by the **California Public Utilities Commission** that suggests concepts and processes to guide gas distribution infrastructure decisions regarding what criteria should be used to determine which distribution lines should have the highest priority for proactive decommissioning.[74]
- In 2020, the **City of Palo Alto** undertook a study to assess the cost of decommissioning its gas system serving all of the City's 15,000 single-family dwellings.[75]
- In **Washington, DC**, ReWiring America has provided a blueprint for a managed decommissioning approach to the existing gas grid with corresponding clustered electrification of the city blocks, multifamily dwellings, and municipal buildings most in need.[76] More recently, a study for the District's Department of Energy & Environment creates seven neighborhood case studies comparing strategic electrification to pipe replacement from a cost and climate mitigation perspective.[77]

3. **Advanced leak repair and enhanced monitoring**: Innovations in pipe repair and leak monitoring can now help avoid intensive pipe replacement for certain types of pipe and pressure

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[72] See https://www.energy.ca.gov/event/workshop/2021-11/staff-workshop-strategic-pathways-and-analytics-tactical-decommissioning; GFO-21-504 - Development of a Data-Driven Tool to Support Strategic and Equitable Decommissioning of Gas Infrastructure (this describes a contract awarded to support the development of a data-driven tool to foster strategic, equitable, cost-effective decommissioning; deliverable due March 31, 2025).

[73] https://gridworks.org/2022/08/selecting-gas-decommissioning-pilot-locations/

[74] California Public Utilities Commission, *Staff Proposal on Gas Distribution Infrastructure Decommissioning Framework in Support of Climate Goals* (December 21, 2022), https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M500/K158/500158371.PDF.

[75] City of Palo Alto Utilities Advisory Commission, Discussion of Electrification Cost and Staffing Impacts on the City of Palo Alto's Electric and Gas Distribution Systems (Nov. 4, 2020) (ID # 11639), https://www.cityofpaloalto.org/files/assets/public/agendas-minutes-reports/agendas-minutes/utilities-advisorycommission/archived-agenda-and-minutes/agendas-and-minutes-2020/11-04-2020-special/id-11639-item-no-3.pdf. The cost of decommissioning included sealing valves to the gas mains, disconnecting gas service laterals to individual homes, and removing gas meters and risers. Costs were found to range between $1.1 million to $5.4 million per year over ten years, compared to a gas utility's capital investment budget of approximately $8 million to $10 million per year plus an additional savings of $26 million to $34 million from not having to replace gas mains and service lines. Notably, the lower estimates represent lower costs for disconnecting an entire block from gas service at once versus disconnecting one home at a time.

[76] Stephen Pantano & Sam Calisch (Rewiring America) and Daniel Munczek Edelman (Next100), *Electrification Study for the District of Columbia* (2021), https://content.rewiringamerica.org/reports/dc-electrification-report-final.pdf. This proposal comes amid growing concern in the District about fugitive emissions and the fact that, despite millions of dollars of investment to replace gas pipelines, the rate of gas leaks appears to be worsening, according to the DC Department of Energy and Environment.

[77] Bob Ackley and Nathan Phillips, *Strategic Electrification in Washington, DC: Neighborhood Case Studies of Transition from Gas to Electric-Based Building Heating* (Government of the District of Columbia, Department of Energy & Environment, in press February 2023).

settings. At much lower cost compared to pipeline replacement, these new technologies can often extend the life of a leaking or leak-prone pipe and control methane leaks.

- The interior of some pipes can be sleeved and in some cases robotic tools can be used to line the inside.[78] Technologies also exist for repairing leaking joints using cast-iron sealing robots (CISBOTs).
- Keyholing tools can be used to create a small opening in the ground to perform pipeline maintenance activities instead of the larger open-cut excavation.[79]
- The interior of some pipes can be inspected with trenchless methods of intelligent "pigging" and robotic pipe inspection using "crawlers" to search for rust, weak seams, thinning walls, and other indicators that a pipe needs repair or replacement.[80]

Above-ground enhanced monitoring of the gas system has also advanced. Mobile leak detection equipped, for example, with cavity ringdown spectrometers can be deployed multiple times a year to monitor and detect leaks in large sections of a distribution system containing high amounts of mature pipeline.[81]

A recent report on the District of Columbia compares the cost savings from two leak repairs conducted in Washington, DC compared to replacement. It describes the cost-effective role that enhanced leak monitoring and repair of the largest leaks can play in a "triage and transition" strategy wherein "an existing pipeline network is managed for retirement with resulting cost savings utilized for financing electrification equipment and/or infrastructure.[82]

[78] See descriptions of advanced pipe encapsulation technology at the US Department of Energy, Advanced Research Projects Agency-Energy (ARPA-E), https://arpa-e.energy.gov/technologies/programs/repair. See also HE Stewart et al., *Performance Testing of Field-Aged Cured-in-Place Lines (CIPL) for Cast Iron Piping* (School of Civil and Environmental Engineering, Cornell University, December 2015), https://cpb-us-w2.wpmucdn.com/sites.coecis.cornell.edu/dist/a/38/files/2014/10/151215-NYSEARCH_NGA-Final-Report-1c06yrj.pdf.

[79] "Top 10 Keyhole Uses for Smart Construction," *Underground Construction* (February 2014, 69, no. 2), https://ucononline.com/magazine/2014/february-2014-vol-69-no-2/features/top-10-keyhole-uses-for-smart-construction.

[80] Tabitha Mishra, "Understand the Differences Between Pigging and Robotic Pipe Inspection Methods," *Trenchlesspedia* (April 18, 2019), https://www.trenchlesspedia.com/understanding-the-differences-between-pigging-and-robotic-pipe-inspection-methodspipe/2/3578.

[81] Tim Keyes et al., "An enhanced procedure for urban mobile methane leak detection, *Heliyon* (October 2020, 6, no. 10), https://doi.org/10.1016/j.heliyon.2020.e04876. Independent research using precise measuring devices, such as the Picarro Cavity Ring-Down Spectrometer, typically document more gas leaks than are reported by state regulatory agencies which often rely heavily on human-reported leaks.

[82] Bob Ackley and Nathan Phillips, *Strategic Electrification in Washington, DC: Neighborhood Case Studies of Transition from Gas to Electric-Based Building Heating* (Government of the District of Columbia, Department of Energy & Environment, in press February 2023).