Perspective
Expert insights on a timely policy issue

Informing Pittsburgh's Options to Address Lead in Water

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On April 11, 2017, a "Not Another Flint" town hall held in the Larimer neighborhood of Pittsburgh drew a standing-room-only crowd of over 100 residents concerned about high levels of lead in Pittsburgh's water supply (Reid, 2017b). The public outcry came amid a flurry of news reports describing deepening management, financial, and infrastructure problems faced by the Pittsburgh Water and Sewer Authority (PWSA). Concerns with lead in the water have been part of the conversation about Pittsburgh's infrastructure challenges for decades, but how did the city end up here?

In this Perspective, we review the history and recent developments related to the use of lead in Pittsburgh's infrastructure. Lead in the city's water system is of particular concern in 2017, given new regulatory requirements with which PWSA must comply, rising public concern, and recent actions to address lead in water. Consequently, this Perspective summarizes the policy options for water supply lead remediation currently being weighed by local decisionmakers. We review the costs, regulatory barriers, and feasibility of the various options under consideration, including the City of Pittsburgh's new Safe Water Program and multiple pipe replacement options. Case studies from peer cities (including Madison, Wisconsin, and Flint, Michigan) support the analysis and its assumptions. We conclude with recommended next steps for local decisionmakers, including PWSA, the City of Pittsburgh, and the newly formed Allegheny County lead task force. These include promoting home filter use and ensuring optimal pipe corrosion control in the near term, while pursuing innovations from other cities to reduce the public and private costs of a long-term solution that entails full lead service line (LSL) replacement.

A Brief History of Lead in Pittsburgh

Much of Pittsburgh's infrastructure was constructed during the city's industrial boom of the early 20th century. Around this time, LSLs were pervasive in most of the country's large cities: 70 percent of all cities with populations over 30,000 in 1900 at least partially relied on lead-based water delivery systems (Rabin, 2008). Due to lead's pliability, durability, and resistance to corrosion, it was very common in service lines and in residential plumbing and fixtures (Rabin, 2008). Service lines, which connect street water mains to individual buildings or residences, were either made completely of lead or lined with lead. Residential plumbing also used lead pipes or, more recently, lead solder to connect copper piping (Holmberg, 2016; Holsopple, 2016).

Lead enters the water supply when pipes and plumbing components corrode under acidic conditions, or when minerals like magnesium and calcium are present in insufficient concentrations to form a protective coating in pipes (in "soft water" conditions) (Rabin, 2008). Lead in the water is dangerous for anyone who drinks tap water, and no known level of lead exposure is safe. People who have exposure to lead may experience anemia, weakness, and kidney and brain damage. They are also at risk for high blood pressure, heart disease, kidney disease, and reduced fertility. Lead exposure for children can cause intellectual disability and behavioral disorders, including lower IQ, attention deficit hyperactivity disorder, and antisocial behavior. The neurological and behavioral effects of lead are believed to be irreversible (World Health Organization, 2016).

Regulation of Lead in Water Systems

Scholars have long been aware of the potential health threats from lead, and the toxicity of lead in public water began receiving attention from health experts in the late 19th century (Aub et al., 1926; Troesken, 2006). Lobbying and research sponsored by the Lead Industries Association kept lead in use in the Pittsburgh region until 1969, when Allegheny County banned the use of lead pipes (Holmberg, 2016; Rabin, 2008). Local action on lead pipes in municipal areas across the country prompted federal and state legislation limiting its use in any plumbing capacity in 1986 and 1991, respectively (Pennsylvania Department of Environmental Protection [PADEP], 2015; U.S. Environmental Protection Agency [EPA], 2017c).

The EPA's "Lead and Copper Rule" (LCR), established as part of the Safe Drinking Water Act, requires that local water utilities conduct regular lead testing according to a standard procedure (EPA, 2017b; Ganim, 2016). If lead levels above 15 parts per billion (ppb) are detected in more than 10 percent of tests of homes with LSLs, the utility must undertake a number of additional actions, including steps to control corrosion, providing public education about lead concentrations, and steps to limit exposure (EPA, 2017b). Water systems that exceed benchmark lead levels may also be required to begin replacement of LSLs at a rate of 7 percent annually (EPA, 2017b). PADEP, which has primary enforcement authority for drinking water quality in the state, established a similar lead and copper rule in 1997 (PADEP, 1997; PWSA, 2017b).

Like water utilities in other cities, PWSA uses anticorrosive agents to prevent lead from leaching into the water supply. Under the Safe Drinking Water Act, water utilities are legally obligated to notify PADEP and receive authorization to make any changes to the anticorrosives.

Pittsburgh's Legacy of Lead

Although lead pipes are banned in new construction, over 88 percent of the houses in Pittsburgh were built before 1970. Estimates suggest that about 25 percent of PWSA's 80,500 customers (about 20,000 customers) still get their water through pipes containing lead, although the true number of customers with either LSLs or lead within residential plumbing is currently unknown (Hopey, 2017a; U.S. Census Bureau, 2015). For comparison, research by the University of Michigan indicates that 50 percent of Flint, Michigan, residents may get their water from lead pipes (Carmody and Brush, 2016). In Washington, D.C., the first city to systematically map its lead pipes, about 10 percent of the city's 125,390 service lines (about 12,300 lines) were found to be made from lead (District of Columbia Water and Sewer Authority, 2016; Frostenson, 2016).

Lead in the water supply is not the only source of lead exposure in Pittsburgh. With old housing stock also comes a risk of exposure to lead through paint. Lead was commonly used in residential paint in the early part of the 20th century due to its durability and quick-drying properties. Lead paint was not banned until 1978, after the majority of homes in Pittsburgh were constructed (Holsopple, 2017; U.S. Census Bureau, 2015). Lead paint on walls, windowsills, and in household dust could be present in over 25 percent of homes built before the ban, although the number of houses with lead paint is also difficult to determine and the number in Pittsburgh is suspected to be higher, given the age of its housing stock (EPA, 2017d; Holsopple, 2017).

Lead may also be found in soil in yards, parks, and vacant land. Lead is naturally occurring in the soil in some areas, and soils can also become contaminated with lead paint or old leaded gasoline. Former industrial sites, common in the Pittsburgh region, are also more likely to leave behind lead in the soil that children could play in and possibly ingest (EPA, 2017d).

Public policy efforts to reduce lead exposure are complicated by a multiplicity of sources and a lack of information. Although past efforts in Pittsburgh have focused primarily on lead paint, there is still substantial uncertainty about the extent to which various vectors contribute to lead exposure. Paint, dust, and soil may contribute 80 to 90 percent of a child's total lead intake, for instance, while infants fed with formula may experience 40 to 60 percent of their exposure from water (Rabin, 2008).

Why Has Lead in Water Re-Emerged as an Urgent Policy Concern?

Local health officials have been aware of issues associated with lead paint and pipes in Pittsburgh homes for decades, but lead re-entered the public consciousness in 2013 when lead levels in the city's water were found to be just below the federal action levels after climbing steadily since 2007 (Frazier, 2016; Khan and Caruso, 2017). The 2015 water crisis in Flint—coupled with the revelation that PWSA had switched to cheaper caustic soda instead of soda ash as an anticorrosive agent between April 2014 and January 2016 without notifying PADEP, which is prohibited—elevated lead to an urgent concern for Pittsburgh residents and city government alike and triggered an administrative order from PADEP (PADEP, 2016).

Since these revelations surfaced, PWSA has conducted two rounds of testing for levels of lead in tap water, focused on homes known or suspected to have LSLs as required by EPA. Test results from July 2016 showed 17 of 100 residences tested above the 15 ppb action level; additional tests in December 2016 counted 30 out of 149 residences (20 percent) over 15 ppb (PWSA, 2017c). EPA requires action when a city's 90th-percentile lead level in homes with LSLs is over 15 ppb. The second round of tests pushed Pittsburgh's level to 18 ppb (EPA, 2017b).[1] As a result, federal and state regulators required PWSA to address lead in its drinking water and, *The continued threat of lead in Pittsburgh's water, paint, and soil has made it an urgent public health issue, which also has important implications for public capital spending.*

as of 2016, PWSA has begun to take steps to comply with EPA and PADEP requirements (PADEP, 2016; PWSA, 2016c).

PWSA also began providing residents with free water sampling kits in February 2016 (PWSA, 2017c). Of the 3,110 free samples returned and tested as of January 2017, 348 (11.2 percent) had water lead levels above the federal action level (PWSA, 2017c). As of May 2017, PWSA is the second-largest U.S. water system (after Portland, Oregon), with over 10 percent of households exceeding federal lead levels, and is one of 1,200 water systems nationwide exhibiting elevated lead levels (EPA, 2017a). However, long wait times for testing kits and results, a lack of systematic testing, and concerns about the validity of tap water lead sample results have left open questions about true lead levels in Pittsburgh households' water supplies (Conway, 2017; Reid, 2017a).

The public health implications of Pittsburgh's recent lead exceedances are also unclear. Clinical testing for blood lead levels (BLL) in the region is sporadic, despite calls from experts over the past decade to increase BLL testing and test data sharing (Keyser et al., 2006). According to the Pennsylvania State Department of Health's most recent *Childhood Lead Surveillance Annual Report*, 39 percent of Pittsburgh's children were tested for lead, and 8.32 percent of those children had BLL greater than or equal to 5 µg/dL, which is the Centers for Disease Control and Prevention (CDC)'s reference value for elevated BLL (Pennsylvania Department of Health, 2014). The number of children in Pittsburgh with elevated BLL was comparable to statewide values (8.54 percent), but was much higher than national values (3.77 percent) in 2014 (CDC, 2016).[2] New action by the Allegheny County Board of Health and County Council has paved the way for universal testing in children to begin in early 2018, which the CDC recommends in communities where 27 percent or more of housing was built before 1950 (Hopey, 2017b; Rischitelli et al., 2006). Lead testing does not reveal the source of lead contamination (e.g., water, paint, soil), but can help to direct mitigation efforts via targeted assessments in residences of children with high BLL and prioritizing lead remediation resources for those households.

The continued threat of lead in Pittsburgh's water, paint, and soil has made it an urgent public health issue, which also has important implications for public capital spending. But to date, little policy analysis has been conducted to systematically assess and compare the various options to address lead in drinking water. Uncertainty about the primary contributors to lead exposure in the region, ongoing regulatory requirements, significant public concern, and current actions under way to address lead in Pittsburgh's water all highlight the local significance of this policy challenge. This policy Perspective summarizes the current policy options for addressing the issue and highlights the key trade-offs that local decisionmakers will need to consider.

Public and Private Responsibility for Lead Mitigation

Current public concern about lead contamination in Pittsburgh's water is leading to demands for public investment in pipe replacement to help mitigate the problem. However, replacing LSLs is not only expensive, it is complicated by several factors related to ownership of service lines and affordability for Pittsburgh residents.

Public Agencies

PWSA is responsible for treating and distributing drinking water for most customers in the City of Pittsburgh.[3] But PWSA, as an authority of the City of Pittsburgh, has limited responsibility for the city's lead pipe infrastructure (Blackhurst, 2017). Under current interpretations of Pennsylvania's Municipal Authorities Act, PWSA is prohibited from replacing service lines on private property. PWSA is legally able to replace only the portions of service lines on public property—up to the curb for most residences—although some local leaders contend that changes to or clarification of the law could enable PWSA to replace the full LSL (Reid, 2017c; Zhorov, 2016). PWSA's challenge is further complicated by the fact that the location and true number of LSLs are as yet unknown (Blackhurst, 2017). Pittsburgh's City Council introduced legislation in June 2017 to allow PWSA to pay to replace the private portion of LSLs, and, at the time of this writing, changes to state law are moving through the Pennsylvania legislature to grant PWSA the authority to actually perform the replacement (Bauder, 2017; Smeltz, 2017d, 2017e).

Private Home- and Building Owners

Under Pennsylvania's Municipal Authorities Act, property owners are currently responsible for replacing service lines that fall within property lines, which can often cost thousands of dollars (Zhorov, 2016). Property owners are also fully responsible for any lead pipes, solder, or fixtures that may be present in older buildings. Additionally, owners would be responsible for removing any lead paint and soil vectors found on their property. Thus, many important lead remediation activities are entirely at the discretion of residents and building owners, although capital and investment from public or other outside sources can help to support or incentivize these actions (Blackhurst, 2017).

Current Actions in Response to Lead in Drinking Water

The City of Pittsburgh has initiated various lead remediation activities, but there is ongoing debate about whether current actions are sufficient to protect residents, which actions are proving most effective, and what new measures should be considered. The current response to the lead water challenge includes the following initiatives:

- The **Pittsburgh Safe Water Program,** announced on March 8, 2017, allocated $1 million to provide water filters and free lead testing kits to all homeowners, prioritizing residents that are low-income, have BLL over 10 ppb, or are in neighborhoods where PWSA began partially replacing LSLs (City of Pittsburgh, 2017b; Smeltz, 2017b). The Safe Water Program is part of a public-private partnership, with a contribution of $500,000 by People's Gas and the remainder split between the City of Pittsburgh and PWSA (Smeltz, 2017b).
- The Blue Ribbon Panel, assembled on March 10, 2017, is tasked with overseeing the **reorganization of PWSA,** including creating long-term strategies to improve PWSA's operations, customer service, and value (Krauss, 2017b). As part of this process, PWSA is conducting a "pipe-loop study" to

determine the optimal level and type of anticorrosives for water treatment (PWSA, 2016d).

- PWSA is providing ongoing **public education** through community outreach meetings, informational materials, and social media to describe the risk of lead exposure from water and methods for minimizing exposure (e.g., flushing water lines before use, using NSF International–certified filters)[4] (PWSA, 2016a).
- PWSA has been mandated to begin **partial service line replacement** for about 1,400 residences per year, until lead levels fall below the 15 ppb federal action level. The first step is to locate LSLs, and PWSA has begun reviewing and digitizing historical service line records and conducting curb box inspections (PWSA, 2016d). At the time of this writing, partial service line replacement has been temporarily halted, but may continue after consultation with regulators (Reid, 2017c).
- The Urban Redevelopment Authority of Pittsburgh initiated the **Replace Old Lead Lines (ROLL) loan program** in April 2017 to incentivize homeowners to initiate full service line replacement. Under ROLL, homeowners who make less than 150 percent of the area median income are eligible for loans of up to $10,000, with a 3-percent interest rate and ten-year repayment period (Urban Redevelopment Authority of Pittsburgh, 2017).
- At the time of this writing, the Allegheny County Board of Health and County Council have approved **universal childhood blood lead testing,** and testing will begin in January 2018 if approved by the County Executive. This would require children in Allegheny County to undergo mandatory blood testing for lead at 9 to 12 months of age and again at two years old (Hopey, 2017b).
- Allegheny County announced the formation of a **lead task force** in May 2017 to be chaired by Allegheny County Health Department (ACHD) Director Karen Hacker. This task force will be asked to produce a report to guide policy and strategy on the region's lead issues (*Pittsburgh Post-Gazette*, 2017).

Exploring Possible Policy Options

While the city and other key players have already begun to tackle Pittsburgh's lead problem, many of the initiatives to date have been short-term and uncoordinated. A more comprehensive strategy may be necessary to fully protect Pittsburgh's residents from lead exposure, a responsibility tasked to the county's new lead task force. Below, we review the landscape of policy options available to deal with lead in the water supply to help inform the task force's recommendations. We compare options proposed for Pittsburgh with approaches taken by other cities, including Madison and Milwaukee, Wisconsin, along with Flint and Lansing, Michigan. We also note that these efforts should be coordinated with those to remediate lead paint and remove contaminated soil, including the recently announced Allegheny Lead Safe Homes program (Allegheny County, undated).

To put these options into perspective, we have developed first-order calculations to demonstrate how the relative cost burden of each policy option might be shared between public and private entities. Where possible, cost estimates are specific to the Pittsburgh region, but note that these should be treated as rough estimates due to the lack of detailed cost data available. Cost estimates for the options described in this Perspective are summarized in

Table 1. Relative Share of Estimated Cost Burden, by Policy Option

Policy Option	Estimated Total Cost	Estimated Cost Per Residence	Share of Per-Residence Cost	
			Private Entities	Public Entities
Status quo[a]	\$0.52–\$0.86 million per year; \$5.2–\$8.6 million over ten years	\$26–\$43 per year; \$260–\$430 over ten years	\$26–\$43 per year	
Filters	\$1.5–\$25.9 million in the first year; \$11.7–\$48 million over ten years	\$80–\$1,290 in the first year; \$580–\$2,400 over ten years	People's Gas: \$25[b] Households in the first year: Pitcher filters: \$50–\$90 Point-of-use filters: \$50–\$330 Point-of-entry filters: \$400–\$1,250	City: \$12.50 PWSA: \$12.50
Optimal corrosion control[c]	\$15,000	–	–	–
Partial replacement of service lines by PWSA[d]	\$22.5–\$254.4 million	\$1,125–\$12,720 one-time cost	Households via fee or rate increase: \$30–\$250 per year over ten years Households, private portion replacement cost: \$1,300–\$7,500 one-time cost	PWSA: \$1,125–\$12,720 one-time cost
Full replacement of service lines by PWSA[e]	\$48.5–\$413 million	\$2,425–\$20,650 one-time cost	Households via fee or rate increase: \$60–\$520 per year over ten years	PWSA: \$2,425–\$20,650 one-time cost

[a] All cost estimates assume 20,000 LSLs in Pittsburgh. Flushing cost range is based on flushing LSLs twice daily for three to five minutes, at a value of \$11.80 per 1,000 gallons (Katner et al., 2017; PWSA, 2017a).

[b] Safe Water Program: People's Gas contributed \$500,000 and the City of Pittsburgh and PWSA together contributed \$500,000 (Smeltz, 2017b). This covers 20,000 residents for three to four months, and residents are responsible for covering the cost of flushing and replacement filters. Cost ranges for filtering systems are \$50–\$1,250 (pitchers, point-of-use, and point-of-entry options included) in the first year.

[c] The estimated cost of corrosion control oversight is based on a one-time fee of \$5,000 per academic reviewer; estimates are based on a three-reviewer committee. Oversight costs could vary based on the reviewers' experience, roles, and expected deliverables, but would be minimal if costs were distributed across all ratepayers, and is therefore not included in the table (Katner, 2017).

[d] 2017 rates increased by \$82.80, but PWSA estimated partial replacement could cost ratepayers \$200 million over ten years (\$250 per household per year, much more than would be raised at current water rates) (Peduto, 2017). Based on a range of data from a city report and from other cities, we estimate a partial replacement cost of \$1,125–\$12,720 (Corley, 2016; Peduto, 2017). PWSA's cost breakdown attributed \$6,600 to replacement of the public section, and included additional costs of \$920 for lead pipe locating, \$2,300 for design and planning, and 30 percent (\$2,900) for contingency. Using these estimates, ratepayers could pay as little as \$30 per year to fund partial replacement costs. Replacing the private section was estimated to cost the homeowner an additional \$7,500, considering a \$4,500 base cost, and an additional \$3,000 in planning and contingency costs (Peduto, 2017). Note that our cost estimates for LSL replacement do not specifically account for additional financing costs or associated timelines for loan repayment.

[e] Based on data from a city report and data from other cities, we estimate a full replacement one-time cost of \$2,425–\$20,650 per residence, with local estimates on the high end of that range (Corley, 2016; Peduto, 2017). The range of total costs is wide, from \$48.5–\$413 million (Corley, 2016; Peduto, 2017). Distributed over all PWSA ratepayers, the range of costs per ratepayer per year is \$60–\$520 for full pipe replacement.

Table 1. The table presents the total cost (if investments were made for all suspected LSLs in Pittsburgh), cost per residence, and the share of the per-residence cost borne by private or public entities for each option. For pipe replacement options, cost burden columns indicate the public *or* private costs, depending on which entity is responsible for costs. Methods and assumptions used to estimate cost ranges for each option are included as table notes.

Status Quo: Public Education and Pipe Flushing

While decisions are being made to direct capital spending, PWSA is currently required to provide public education around the importance of flushing water in households suspected to have LSLs. Residents are able to request free lead testing kits from PWSA to determine lead levels in their own water supply (PWSA, 2016a). Boiling water does not remove lead contamination, and using water from the hot water tap for drinking or cooking may increase lead exposure. Most experts recommend that residents flush their water for about three to five minutes before drinking (or before using a shower, dishwasher, or washing machine) after roughly six hours of non-use (Katner et al., 2017; PWSA, 2016a). For most households, this means flushing their taps twice per day. Based on these assumptions and current PWSA water rates, households would pay an extra $26–$43 per year on flushing.[5] This option limits city or PWSA action to public education around the dangers of lead and the importance of flushing. Even without further public expenditure, some residents may also choose to purchase filters in addition to flushing their lines, as discussed in the next section.

Provide Residential Water Filters: Pitchers, Point-of-Use, or Point-of-Entry

NSF International–certified water filters come in various forms and price points, from a basic pitcher water filter ($20–$40); to faucet attachments or under-sink (point-of-use) filters ($30–$280); to whole-house (point-of-entry) filters ($360–$1,170) (Amazon.com, undated[b], undated[d], undated[e]; Aquasana, undated[b]; ZeroWater, undated[a]). From pitchers to point-of-entry filtration systems, lead protection coverage increases, as do cost and level of effort to install. Regardless of which option is chosen, filters require regular upkeep, cleaning, or replacement. Filter replacement depends on usage, but on average, these filters should last about three to six months, with replacements costing between $30 and $80 per year depending on the filtering method chosen (Amazon.com, undated[a], undated[c], undated[f]; Aquasana, undated[a]; ZeroWater, undated[c]). Appropriate use and replacement of water filters can reduce lead exposure, but NSF International standards do not ensure that all lead is removed from filtered water (NSF International, 2017). We estimate the range of filtering costs to be $80–$1,290 per residence in the first year ($580–$2,400 over ten years), some of which can be subsidized by public and private investment.

The Pittsburgh Safe Water Program, a public-private partnership, seeks to provide certified pitcher water filters and lead testing kits to all city residents (City of Pittsburgh, 2017b). The program's current funding level is limited to $1 million, which will likely not cover every affected residence in the city. This iteration of the program has been described as "Phase 1," so one possible option is to provide additional or renewal phases to maintain coverage of residences susceptible to lead-contaminated water supply. However, the program is considered a stopgap measure, and continuing the program would depend on additional funding, including support from the private sector or other nongovernment sources.

People's Natural Gas has contributed $500,000, while the city and PWSA have contributed $250,000 each. There are an expected 20,000 residences affected by LSLs, and distributing program funds across all of those residents would allocate $50 per residence. While some of this cost will go to program oversight and distribution, the program has committed to using the funding to provide NSF-certified half-gallon pitcher water filters. The program funding covers the cost of a pitcher and filter for three to six months of use for 20,000 households, with future filter replacement costs falling to residents (ZeroWater, undated[b]). Additionally, residents would need to be advised to continue flushing their water lines.

Establish Improved Oversight to Ensure Optimal Corrosion Control

Corrosion control on pipes works to prevent lead from leaching into the water supply. While the appropriate use of anticorrosives is effective at reducing lead levels below the federal action level, they cannot completely protect water that is flowing through lead pipes, such as in unexpected soft water situations or when the water supply suddenly becomes more acidic (EPA, 2016). However, appropriate use will depend on improved management and operational oversight from PWSA. The current high lead levels detected in households are suspected to be related to PWSA's unlawful substitution of caustic soda for soda ash for corrosion control (Smeltz, 2017a).[6]

Oversight and transparency measures were enacted in Flint as a key part of the city's emergency response. One response was to establish an EPA expert task force to provide technical assistance for implementing appropriate corrosion control treatment. In addition, EPA began posting results of preliminary water quality data on an interactive map that residents could access (Acosta, 2016). The Michigan Department of Environmental Quality also promised to work toward "instilling a new culture of collaboration that will take into consideration community and expert level insight" (Fonger, 2016). While PWSA is currently conducting an internal study to determine the optimal use of anticorrosives, adopting a broader range of actions with stakeholder input could provide additional mechanisms of oversight. We estimate the cost of corrosion control oversight to be approximately $15,000 for one-time payments to academic researchers to participate in an oversight committee (Katner, 2017).

Partial Replacement of LSLs by PWSA

Under EPA requirements, PWSA is required to replace 7 percent of the system's LSLs per year (about 1,400), but only until testing shows the 90th percentile of lead levels falls below 15 ppb (EPA, 2017a). Under current interpretations of the Municipal Authorities Act, however, PWSA may only replace public portions of service lines, with the private home- or building owner responsible for replacing the remaining portion of the LSL. PWSA may choose to continue partial replacement of LSLs regardless of testing results.

However, research suggests the disruption caused by partial replacement of LSLs can cause an even greater amount of lead to leach into the water supply in both the short and long terms, such that EPA is evaluating the provisions of the LCR that require partial replacement of service lines (Blackhurst, 2017; Edwards, Triantafyllidou, and Best, 2009; EPA, 2011). Following suit with other cities, PWSA has recently halted efforts to replace public portions of LSLs while deliberations with PADEP proceed (Reid, 2017c). Given the dangers of increased lead levels, if partial replacement were to continue, the risks to homeowners opting out of replacing the private portion remain high. To mitigate this, PWSA has encouraged homeowners to coordinate simultaneous replacement of public and private sections of their service lines. Under these conditions, homeowners bear a high cost burden and renters would not have control over the LSLs entering their homes, two factors that disproportionately impact lower-income households and leave them potentially more susceptible to lead exposure (LSLR Collaborative, 2017a).

As an incentive, pilot programs have attempted to reduce the burden of replacement costs for homeowners for the private portion of the service line. Thus far, however, results have not been promising. A pilot in Pittsburgh's Lawrenceville neighborhood in May 2016 alerted homeowners when work on public lines would be ongoing so that they could replace their private lines at the same time, saving them money based on economies of scale. However, only one homeowner ultimately opted to conduct a full replacement, and more-intensive public education around risk misperceptions and the negative impacts of partial service line replacement are likely necessary to increase homeowner buy-in in the future (Krauss, 2017a).

The ROLL loan program is another pilot intended to support service line replacement. It remains to be seen, however, if these favorable loan terms will be sufficient incentive for low-income homeowners to take action. In addition, total program funding is currently $500,000. With an estimated average loan of $6,000, there are only enough resources to provide loans to about 83 residents (Marusic and Caruso, 2017). Reports in June 2017 indicated that uptake to date has been low (Reid, 2017c).

If partial replacements were to continue, PWSA would bear the full cost of partial replacement of LSLs, although some of this cost is passed on to residents in the form of rate increases. PWSA has committed $60 million to infrastructure investment in 2017, but lead water testing and service line replacement is only one of five projects the investment will fund (PWSA, 2016b). Recent local estimates suggest that replacement of an estimated 20,000 public LSLs could cost ratepayers up to $200 million over ten years, at a rate of $12,720 per line (Marusic and Caruso, 2017). We calculate that this would translate to about $250 per household ratepayer per year over that period.[7]

It is important to note that the cost estimates of public service line replacement being considered in Pittsburgh are much higher than those seen in other areas. For example, in Madison, replacement costs averaged about $1,125, roughly 10 percent of the estimated cost in Pittsburgh, and replacement costs in Flint currently average $7,500 per line (Corley, 2016; Dolan, 2016). We presented this range of costs in Table 1, both in total and per residence.

Full Replacement of LSLs by PWSA

Full replacement—when both public and private portions of service lines are replaced at the same time by the utility—is becoming the industry standard in other cities.[8] However, to provide full line replacement in Pittsburgh, homeowners need to opt in to allow PWSA to manage the full replacement, and legal barriers must be overcome before PWSA can be granted the authority to do so. At the time of this writing, local advocacy and legislative action has begun for changes to or clarification of state law that would allow PWSA to do work on the privately owned portions of service lines, and city leadership is likely to continue to push for changes to the law at the state level in order to proceed with systemwide replacement (Hopey and Smeltz, 2017; Smeltz, 2017e). While PWSA contends that the Municipal Authorities Act prohibits authorities from replacing private lines, some local leaders assert that the law is not explicit and are looking to establish clear responsibility for PWSA (Clift, 2017; Smeltz, 2017c). In the interim, homeowners can either initiate a stand-alone replacement or coordinate replacement of the private portion with PWSA's preplanned construction to reduce costs.

Recent estimates suggest that the all-in cost of replacing the private section of service lines, including planning, design, and contingency, would be about $7,500 on top of the public cost, bringing the total to $20,320 per line (Peduto, 2017). Again, this is on the upper end of estimates from other metropolitan regions, and a wide range of per-household costs is still possible (ranging from $2,425 to $20,650).[9]

Trenchless pipe replacement is a new and innovative method that involves minimal excavation and can usually be accomplished in one day. Pipe replacement using existing routes is done using a cone-shaped tool that attaches to one end of the service pipe. A cable passes through the pipe, attaches to the cone, pulls it and the attached pipe from the ground, and simultaneously pulls the replacement pipe in behind the cone (Roost, 2016). There is also an option to install a new pipe along a new route without digging a trench, leaving the existing LSL in the ground (LSLR Collaborative, 2017b). Trenchless methods save labor costs and could reduce

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an $8,000 to $9,000 replacement to between $1,250 and $3,700 (Costin, 2016; Dougherty, 2017; Marusic and Caruso, 2017).[10] However, the feasibility of trenchless replacement depends on the soil around pipes, structure of pipes, and location of other utilities, so this option still needs a more-complete feasibility evaluation for Pittsburgh (Roost, 2016).

Social and Economic Benefits of Lead Remediation

Lead poisoning incurs important social and economic costs, which include increased health service and medication expenditures, increased need for special education resources, decreased IQ and lifetime earnings, decreased tax base, and increased crime and violence costs. Using data from the CDC, Hamblin (2016) estimated a lifetime cost of $50,000 and 0.2 years of life lost for each low-level exposure to lead.

However, the wide-ranging social and economic impacts of lead poisoning mean that benefits of lead mitigation are equally large. A comprehensive cost-benefit study in 2009 calculated conservative estimates of reducing childhood lead poisoning at the national level, and found that each dollar invested in lead paint remediation resulted in a return of between $17 and $221, or a national net savings of $181–$269 billion (Gould, 2009). A 2016 return-on-investment analysis in Michigan found a $600 million investment in lead remediation could reduce lead poisoning in children by 70 percent, while paying for itself in three years and returning taxpayer investment in seven to eight years (Swinburn, 2016).

Opportunities for Public-Private Partnerships

Many of the policy options described in this Perspective will require coordination between the public and private sectors in not only strategic operations, but also financing. The most obvious source of private capital comes from ratepayers and residents: increasing user fees or water rates to fund fixes to public infrastructure, and requiring homeowners to finance repairs to the privately owned portions. This approach could be particularly challenging for PWSA customers, given that rates are already perceived as high and are presently increasing.[11] However, other cities, such as Madison and Lansing, have had success with mandates for homeowners in combination with generous public subsidies to offset the cost of repairs (Marusic and Caruso, 2017; Schmidt, 2016). Madison did so using fees from cellular antennas on water towers, and cities in Massachusetts and Wisconsin have also been able to leverage state funds made available to support LSL replacement in low-income communities (LSLR Collaborative, 2017a). Pending legislation allowing PWSA to pay for full-service LSL replacement, city officials hope to obtain a low-interest loan from the Pennsylvania Infrastructure Investment Authority to fund the replacement costs (Bauder, 2017). Congress also recently approved $300 million in loans from EPA to low-income households to replace residential portions of LSLs, although Congress has yet to appropriate the funds and Pittsburgh's participation remains in question (Neltner, 2017).

Incentives or subsidies for lead remediation could also be funded with private or philanthropic donations. Currently, private investment from People's Natural Gas is funding half of the $1 million going to provide PWSA customers with water filters through the city's Safe Water Program. The Hillman Foundation has provided a $300,000 grant to the ACHD to support lead reduction efforts, including blood testing and public education (*Tribune-Review*, 2017). Philanthropic donations like these may be sought to encourage additional lead mitigation efforts (People's Natural Gas, 2017). Other cities, like Chicago and Milwaukee, have successfully partnered with private banks and other lenders to create pool funds or grant matches for loans to contractors, landlords, and homeowners to do lead remediation. However, demand for these programs was shown to be low without corresponding mandates for property owners to take action (Delta Institute and EPA, 2017).

Another role the private sector can play is advocacy or in-kind support. Local community organizations or law firms could provide *pro bono* advocacy or legal advice in support of changing or clarifying the Municipal Authorities Act. In Flint, the trade association Plumbing Manufacturers International and the union United Association of Journeymen and Apprentices of the Plumbing and Pipe Fitting Industry issued a joint call to action to their members. This resulted in the donation of hundreds of faucets, plumbing supplies, and the labor of a team of 300 plumbers to work in houses and apartment buildings in areas most affected by the water crisis. The state of Michigan took advantage of this event and provided free water filters to be distributed to the affected areas (Roy, 2016).

However, Pittsburgh residents may have reservations about any private-sector involvement in the city's water system. A private company, Veolia, was responsible for managing some aspects of

PWSA operations when the unlawful switch in anticorrosives was made, an action that is suspected to have contributed to some of the city's lead issues (Aupperlee, 2016; Cohen, 2017). One of the tasks of the PWSA reorganization effort is to evaluate the potential role of the private sector in PWSA moving forward. This array of issues—related to public perception, as well as technical, financial, and regulatory feasibility—highlights the need for analysis of Pittsburgh's policy options and trade-offs.

Understanding the Trade-Offs

Costs are only one factor in policy decisionmaking, albeit an important one. Table 2 summarizes the policy options for lead mitigation in Pittsburgh's drinking water, along with criteria that can help inform next steps. The table summarizes each option in terms of a rough, qualitative estimate of lead remediation benefit; cost per residence; technical feasibility; legal or regulatory barriers; and time frame. This table is presented as a "stoplight chart" using red, yellow, and green shading to allow for visual comparison across criteria and options. Colors roughly correspond to the performance of an option for a given criterion.

The costs of citywide lead remediation strategies are high, and most of the current debate is on the portion of the cost that will fall to the public sector. However, Table 1 demonstrates that regardless of the option chosen, residents and businesses will also bear a large portion of the cost, although it may not be as readily apparent. If the city decides to maintain the status quo, or even to continue to fund the Safe Water Program, the burden of responsibility will fall to residents. Not only will this responsibility be financial, it will also require that residents engage in appropriate health and safety behaviors to protect themselves from the risk of lead poisoning. Likewise, appropriate use of corrosion control will decrease the risk of lead exposure. However, while corrosion control can bring lead levels under the federal action level, they do not fall to zero. And as recent years have shown, better management and oversight is necessary to maintain the appropriate protection of residents.

As Table 2 indicates, there are no policy options currently on the table that fully and permanently address the risk of lead in the water other than full pipe replacement. Our analysis suggests that corrosion control, coupled with a publicly supported filter distribution program, is an acceptable short-term option to reduce lead risk as the city wrestles with more-permanent solutions—a "no regrets" option that can achieve positive impacts while long-term strategies are developed. Thus, improving management and oversight of corrosion control strategies ought to be a key aspect of the ongoing PWSA reorganization efforts. Our analysis of the current science and industry standards also indicates that the strategy of partial pipe replacement is not only costly, it is ineffective and likely counterproductive for reducing lead in Pittsburgh's water over time.

In the long term, full pipe replacement will permanently address the lead issue in the city and has been adopted as a best practice in other cities. However, innovations to reduce the cost of full pipe replacement on a large scale are needed, given the high cost estimates currently being discussed. As case studies from other cities indicate, there are options like trenchless replacement that—with economies of scale—could reduce total costs substantially if proven feasible given local conditions. Full replacement also presents a prime opportunity for foundations and businesses to engage through advocacy; providing support for residents; or working to change, repeal, or clarify the Municipal Authorities Act in addi-

Table 2. Summary of the Options for Lead Mitigation and Decision Criteria

Policy Option	Impact on Lead Remediation	Cost Per Residence	Technical Feasibility	Legal or Regulatory Barriers	Time Frame
Status quo	Continued risk of lead exposure to residents	$26–$43 per year; $260–$430 over ten years	No technical requirements, but requires residents to consistently comply with flushing instructions	None	Immediate
Filters	Provides short-term protection from lead in water, but only for those who sign up for the Safe Water Program or procure their own filters	$80–$1,290 in the first year; $580–$2,400 over ten years	Procuring and distributing water filters is feasible, but filters must be maintained and replaced regularly	None	Safe Water Program rolled out quickly, but will only last three to six months
Optimal corrosion control	If administered correctly, should protect water from lead pipes, but it is an ongoing operations strategy rather than a permanent fix	–	Study currently under way to determine most effective anticorrosive; Blue Ribbon Panel assessing management changes	Legal challenges ongoing over unlawful change	Dependent on the amount of time the study will take; will need ongoing oversight and regulation
Partial replacement of service lines by PWSA	Has been shown to increase amount of lead leaching into the water supply. Only effective in coordination with property owners to replace private portions of lines.	$1,125–$12,720 one-time cost	Labor- and resource-intensive, but new technologies exist	PWSA must replace 7 percent of lines per year, but only until 90th percentile drops below 15 ppb; from curb to house, service lines are private—must generate resident buy-in	Will take PWSA about ten years to replace all LSLs
Full replacement of LSLs by PWSA	Permanently removes key source of water-based lead exposure in safe manner	$2,425–$20,650 one-time cost	Labor- and resource-intensive, but new technologies exist	Municipal Authority Act being contested to allow for PWSA to replace private portion of LSLs	Very time-intensive; estimates of 14 years for widespread replacement

Performance Key	High	Medium-high	Medium-low	Low

tion to supporting legislation paving the way for public financing proposed at the local level.

Next Steps for Decisionmakers

So what does this mean for decisionmakers, including PWSA, the City of Pittsburgh, and the county's new lead task force? Lead exposure is a problem with multiple sources, and engages many stakeholders with different perspectives and priorities. While possible remedies exist, there is no obvious path forward to full resolution because of legal impediments, cost, and current trade-offs. In addition, decisionmakers must balance lead exposure with other priorities that demand attention, such as inequities in housing, education, and employment. However, as this Perspective has demonstrated, lead poisoning is a cross-cutting problem that affects citizens' well-being through health status, educational attainment, lifetime earnings, and local crime rates. Furthermore, responding to the lead problem in a piecemeal fashion has proven ineffective.

The city recently released its first resilience strategy, *OnePGH*, which comprehensively lays out the risks facing Pittsburgh's aging infrastructure and residents, and proposes a systems approach to address high-priority issues and resolve multiple risks at once (City of Pittsburgh, 2017a). Using a multiphased systems approach, including near-term "no regrets" options, could involve the steps we describe in the text boxes.

PWSA Infrastructure and Water-Management Decisions

1. Capitalize on public-private partnerships to incentivize the adoption and use of water filters.
2. As PWSA reorganization proceeds, ensure optimal corrosion control to mitigate lead risk in the short term.
3. Remove legal barriers to full replacement of LSLs, either through clarification of the Municipal Authorities Act or by explicit changes to the law at the state level.
4. Pursue options to fund full LSL replacement and decrease public and private costs, including through obtaining additional public or private funding and conducting feasibility studies of trenchless pipe replacement or other cost-reducing innovations.
5. Develop a strategy to identify and conduct full replacements of all LSLs.

This Perspective has explored the available options for lead in water, provided rough estimates to illustrate the costs for key players, and laid out the trade-offs for decisionmakers. The steps identified here could help put Pittsburgh on a path to a permanent solution to the lead-in-water challenge and protect the city's future generations. However, without a long-term strategy and committed collaboration across key stakeholders (including city and county officials, PWSA, private companies, community organizations, and residents) the health, social, and economic costs of lead exposure will persist.

Research, Outreach, and Education Activities to Support Near- and Long-Term Solutions

1. Invest in evidence-based public education about the dangers of lead from all sources, possible solutions, and the importance of flushing and filtering to address the near-term risks of lead in water.

2. Collect systematic data to determine true risks of lead exposure and poisoning in the city, including BLL testing among children.

3. Build a culture of public-private partnership by engaging both public- and private-sector players in the task force's work, including homeowners, private funders, local businesses, and community organizations. This team should be tasked with coordinating responses across sectors and generating the necessary regulatory or legal support to do so.

4. Conduct a full cost analysis and calculate return on investment for various lead remediation efforts, spanning paint, soil, and water exposure, to demonstrate the collective nature of both costs and benefits. This would provide a platform to garner buy-in and financial support from both public and private entities.

Notes

[1] By comparison, one study of the lead levels during the Flint water crisis revealed that its 90th percentile value was 25 ppb, with some samples exceeding 100 ppb. However, the homes sampled for this study were randomly sampled and did not all have LSLs, so the true 90th percentile value for homes with LSLs is suspected to have been higher (Roy, 2015).

[2] Note that the CDC is considering lowering its reference value to 3.5 µg/dL, and continues to assert that there is no safe BLL for children, underlining the importance of addressing even low-level contributors to lead exposure (Robbins, 2017).

[3] Other water service providers, primarily Pennsylvania American Water in the South Hills suburbs of Pittsburgh, operate water systems supplying water treated at PWSA facilities.

[4] NSF International began as the National Sanitary Foundation in 1944.

[5] This flushing cost range is based on flushing twice daily for three to five minutes, at a value of $11.80 per 1,000 gallons (Katner et al., 2017; PWSA, 2017a).

[6] While soda ash may cost less per kilo than caustic soda, it is generally considered to be more expensive due to higher equivalent alkalinity costs (i.e., more soda ash than caustic soda is required to treat the same volume of water), larger capital investment, and higher handling costs (Prout and Moorhouse, 2012).

[7] Available cost estimates of service line replacement are highly variable, and depend on unique contextual parameters (e.g., length of the service line, presence of driveways or trees). In March 2017, PWSA estimated partial service line replacement to cost about $12,720. The cost breakdown attributed $6,600 to replacement of the public section and included additional costs of $920 for lead pipe locating, $2,300 for design and planning, and 30 percent ($2,900) for contingency. Replacing the private section was estimated to cost the homeowner $4,500 and the utility an additional $3,000 in planning and contingency costs (Peduto, 2017). Cost comparisons for partial replacement are sparse, but in Madison replacement costs averaged about $1,125 for the utility portion and $1,300 for the private portion when the city replaced all of its lead pipes (Corley, 2016).

Service line replacement in Flint was initially projected to cost about $3,670 per line, but a recent review of 30 replacements shows the average cost to be closer to $7,500. The report cited issues such as extensive contractor delays and made several recommendations, which included investigating pipe composition before beginning construction, and conducting replacements in clumps by neighborhood rather than by individual households (Dolan, 2016). Thus, management of the replacement process will be important for keeping costs down.

[8] Washington, D.C., abandoned partial line replacements in 2008 when it found that the replacements caused higher levels of lead in the water supply for several months (Renner, 2010). In 2015, the National Drinking Water Advisory Council released a report commissioned by EPA, which stated, "the driving proactive principle to improve public health protection is removing full lead service lines from contact with drinking water to the greatest degree possible" (Donas, 2015). In Philadelphia, the Water Department (which, as a city department rather than an authority, is not subject to the Municipal Authorities Act) is taking a proactive

approach, replacing private service lines at no cost if they are discovered during replacement of the public section and if they receive consent from the homeowner, or by offering zero-interest loans to homeowners (Marusic and Caruso, 2017).

[9] Milwaukee, Wisconsin, is estimating future replacement to cost between $7,300 and $10,800 per service line (Schmidt, 2016). However, the American Water Works Association conducted a national survey in 2004 and estimated an average replacement cost, adjusted to 2017 dollars, of $4,130 (range: $970–$20,650) (Rabin, 2008). The City of Madison Water Utility was the first utility to replace both public and private portions of all lead service lines—about 8,000 lines over more than a decade (Schmidt, 2016). The full replacement process was mandated and homeowners with LSLs received an average bill of $1,300 (Corley, 2016). However, the city also covered half of the homeowners' portion, up to $1,000, which was financed from charging cell phone companies to place antennas on utility water towers. Average cost per replacement was about $2,425 (Roelofs, 2016).

[10] In the City of Lansing, which owns all service lines even under private land, use of the trenchless method decreased the average replacement cost from $3,100 to $2,000. As such, Lansing was able to replace 12,000 LSLs over 12 years with minimal cost to ratepayers. Total costs of the replacement endeavor, including management and planning, cost an average of $3,700 per line (Marusic and Caruso, 2017). In York, Pennsylvania, the use of trenchless replacement has driven the average cost down to $1,250 per line—though its water system is much smaller (Dougherty, 2017).

[11] Beginning on January 1, 2017, PWSA rates increased by 13 percent, meaning the typical PWSA residential customer experienced a rate increase of 23 cents per day, or $6.90 per month, over the previous year (PWSA, 2017a).

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About This Perspective

This Perspective reviews the use of lead in Pittsburgh's water system and the policy options for remediation currently being weighed by local decisionmakers. We review the costs, regulatory barriers, and feasibility of the various options under consideration, including the city's new Safe Water Program and multiple pipe replacement options. We conclude with recommendations to reduce the public and private costs of full line replacement.

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