A report from the Health Impact Project | Aug 2017

10 Policies to Prevent and Respond to Childhood Lead Exposure

An assessment of the risks communities face and key federal, state, and local solutions

Contents

Figures and tables

The Pew Charitable Trusts

Susan K. Urahn, *executive vice president*
Allan Coukell, *senior director*

Robert Wood Johnson Foundation

Giridhar Mallya, *senior policy officer*
Pamela Russo, *senior program officer*

Health Impact Project

Rebecca Morley, *director*
Amber Lenhart, *senior associate*
Gabriela Illa, *associate*
Mary Jean Brown, *consultant*

Study partners

Child Trends

Vanessa Sacks, *research scientist*
Kristin Moore, *senior scholar and youth development director*
Fadumo Abdi, *research analyst*

Altarum Institute

George Miller, *fellow*
Paul Hughes-Cromwick, *co-director, Center for Sustainable Health Spending*
Corwin Rhyan, *health care research analyst*

Urban Institute

Steven Martin, *senior research associate*
Gregory Acs, *director, Income and Benefits Policy Center*

Trust for America's Health

Rich Hamburg, *executive vice president and chief operating officer*
Albert Lang, *senior communications officer*

National Center for Healthy Housing

David Jacobs, *chief scientist*

External experts and reviewers

This report was reviewed by Morri E. Markowitz, M.D., the Children's Hospital at Montefiore, and professor of pediatrics, Albert Einstein College of Medicine; and Steven Teutsch, M.D., M.P.H., senior fellow, Leonard D. Schaeffer Center for Health Policy and Economics, University of Southern California, senior fellow, Public Health Institute, and adjunct professor, UCLA Fielding School of Public Health. Although they found the approach and methodology to be sound, neither they nor their organizations necessarily endorse the report's findings or conclusions.

Acknowledgments

The team thanks the following people for their contributions to this report as partners, subject matter experts, and case study reviewers: Christine Stanik, Altarum Institute; Jonathan Schwabish, Urban Institute; Jonathan Wilson and Amanda Reddy, National Center for Healthy Housing; Jonathan Cuppett, Water Research Foundation; Maida Galvez, M.D., Mount Sinai; Todd Grindal, Ed.D., Abt Associates; Cheryl Johnson, People for Community Recovery; Linda Kite, Healthy Homes Collaborative; Patrick MacRoy, M.A., Environmental Health Strategy Center; Howard Mielke, Ph.D., Tulane University School of Medicine; Deborah Nagin, M.P.H., New York City Department of Health and Mental Hygiene; Tom Neltner, J.D., and Ananya Roy, Sc.D., Environmental Defense Fund; Rick Nevin, ICF International; Ruth Ann Norton and G. Wesley Stewart, Green & Healthy Homes Initiative; Janet Phoenix, M.D., The George Washington University; Lisa Ragain, Metro Washington Council of Governments; Jay Schneider, Ph.D., Thomas Jefferson University; Lynn Thorp, Clean Water Action/Clean Water Fund; Steven Via, American Water Works Association; Kamillah Wood, M.D., Stewards of Affordable Housing for the Future; Laura Brion, Childhood Lead Action Project; Valerie Charlton, M.D., Lauren Rice, and Rick Kreutzer, M.D., California Department of Public Health; Julia Robey Christian and Lisa A. Gilmore, Government of the District of Columbia; Dale Clarkson, Peoria City/County Health Department; Kara Eastman, M.S.W., Omaha Healthy Kids Alliance; Angie Goodman, Lansing Board of Water and Light; Gary Kirkmire, City of Rochester Inspection and Compliance Services; Elisabeth Long, Washington State Department of Health; Lisa Smestad, City of Minneapolis; Amber A. Sturdivant, District of Columbia Department of Energy and Environment; Claire Barnett, M.B.A., Healthy Schools Network; Don Farquhar, J.D., National Conference of State Legislatures; Perry Gottesfeld, M.P.H., Occupational Knowledge International; Paul Haan, Healthy Homes Coalition of West Michigan; and Christina Hecht, Ph.D., Nutrition Policy Institute at the University of California.

Many thanks also to the concerned citizens, parents, community-based organizations, community health professionals, landlords, and federal, state, and local agency staff who served as key sources of information for this project.

Finally, the team thanks current and former Pew colleagues Dan Benderly, Gaby Bonilla, Stefanie Carignan, Erika Compart, Jennifer V. Doctors, Richard Friend, Tami Holzman, Carol Hutchinson, Bronwen Latimer, Mary Markley, Bernard Ohanian, Jennifer Peltak, and Peter Wu, as well as our fact check team, for their assistance in preparing this document for publication.

Advisory Group

This report benefited from the guidance of a formal advisory group with diverse perspectives and expertise. Although the research team gave substantial weight to the committee's input and advice, it retained final authority over and responsibility for the process, findings, and recommendations. Additionally, although the committee members found the approach and methodology to be sound, neither they nor their organizations necessarily endorse the findings or conclusions.

Committee members

Nancy Andrews, M.S., president and chief executive officer, Low Income Investment Fund

John Bartlett, executive director, Metropolitan Tenants Organization

Jeanne Brooks-Gunn, Ph.D., M.Ed., Virginia and Leonard Marx Professor of Child Development, Columbia University

Mona Hanna-Attisha, M.D., M.P.H., director, Pediatric Residency Program, Hurley Medical Center, Michigan State University

Mark Hayward, Ph.D., professor of sociology, The University of Texas at Austin

Ruth Katz, J.D., M.P.H., executive director, the Aspen Institute

Bruce Lanphear, M.D., M.P.H., professor, Simon Fraser University

Marie Lynn Miranda, Ph.D., M.A., provost, Rice University

Brenda Music, co-director, Iowa Parents Against Lead

Damon Music, co-director, Iowa Parents Against Lead

Michèle Prévost, Ph.D., professor, Department of Civil, Geological and Mining Engineering, Polytechnique Montréal

Queen Zakia Shabazz, director, United Parents Against Lead

Steve Shabazz, parent advocate, United Parents Against Lead

Sara Rosenbaum, J.D., professor, George Washington University

Joshua Sharfstein, M.D., associate dean, Johns Hopkins University

Deborah Cory-Slechta, Ph.D., M.A., professor, Department of Environmental Medicine, University of Rochester

Lauren Smith, M.D., M.P.H., managing director, Foundation Strategy Group

Alan Woolf, M.D., M.P.H., professor of pediatrics, Harvard Medical School

Overview

The ongoing lead contamination crises in Flint, Michigan, and East Chicago, Indiana, as well as the surge of news reports about lead risks in communities across the country have shone a national spotlight on the problem of childhood lead exposure. The increased public awareness and scientific evidence that lead poisoning is completely preventable make this a critical moment for action to protect the nation's children, enhance their opportunities to succeed, and reduce costs to taxpayers.

With that background, the Health Impact Project convened a team of researchers to assess the implications of childhood lead exposure and perform a cost-benefit analysis of various policies to prevent and respond to the problem. The study team conducted a literature review, case studies, interviews, national listening sessions, focus groups, and quantitative analyses using models developed by Altarum Institute and by the Brookings Institution, Child Trends, and Urban Institute. The team included staff from Altarum, Child Trends, Urban Institute, Trust for America's Health, the National Center for Healthy Housing, and the Health Impact Project, a collaboration of the Robert Wood Johnson Foundation and The Pew Charitable Trusts.

Lead's adverse health impacts have been recognized since at least the second century B.C. Since then, thousands of studies have concluded that lead has wide-ranging effects on the health of young children and significant costs to taxpayers. Even at very low levels, lead exposure affects the brain's ability to control impulses and process information. Lead-poisoned children are more likely to struggle in school, drop out, get into trouble with the law, underperform in the workplace, and earn less throughout their lives, independent of other social and economic factors. The financial consequences of these outcomes include billions of dollars in public spending on special education, juvenile justice, and other social services.

Despite the evidence, the U.S. lagged many European nations by nearly 50 years in reducing the sources of exposure to lead. The delay resulted in greater quantities of lead in the environment, higher rates of childhood lead poisoning, and the need for more resources for remediation. Various federal agencies have imposed restrictions on lead during the past 40 years, yet lead persists in many places, mainly in drinking water and in existing paint in older homes and the dust and soil contamination it generates. Many states and communities have implemented laws to address lead exposure, but those efforts have been fragmented and underfunded. As a result, lead continues to adversely affect millions of children, particularly those in low-income communities and those of color because of their disproportionate risk of exposure to sources of lead in older homes and under-resourced neighborhoods.

The study team analyzed existing policies for their impacts on public health and health equity—the concept that every person should have the same opportunity to be healthy. The effort was guided by a diverse group of advisers and experts from fields including environmental and public health, child development, economics, housing, health care, environmental and social justice, and drinking water engineering. In addition, input from stakeholders, including families whose children have suffered the toxic effects of lead, provided valuable insights.

Where economic benefits are estimated, they are referred to as "future benefits"—meaning they are discounted at a rate of 3 percent per year to account for changes in the value of money over time. The cost-benefit analyses are based on the lifelong impacts of interventions for a single cohort of U.S. children, those who will be born in 2018. Where appropriate, the analysis includes benefits that would accrue for additional children born into the same households within 10 years. In some cases, costs were unavailable so a cost-benefit ratio is not provided.

Key findings include:

- **Removing leaded drinking water service lines from the homes of children born in 2018 would protect more than 350,000 children and yield $2.7 billion in future benefits, or about $1.33 per dollar invested.** Of those benefits, about $2.2 billion in higher lifetime earnings, better health, and other gains would accrue to 272,000 children born in the 2018 cohort, and $550 million would come from protecting the roughly 80,000 other children born into those homes over the next 10 years. The total includes $480 million for the federal government and $250 million for states and municipalities from health and education savings and increased tax revenue associated with higher earnings among the cohort. Replacing these lead pipes would cost an estimated $2 billion.
- **Eradicating lead paint hazards from older homes of children from low-income families would provide $3.5 billion in future benefits, or approximately $1.39 per dollar invested, and protect more than 311,000 children.** About $2.8 billion of those benefits would accrue to roughly 244,000 of the 4 million children in the 2018 cohort. The other $670 million in benefits would accrue from protecting approximately 67,000 additional children born into those homes over the next 10 years. The total benefits include $630 million in federal and $320 million in state and local health and education savings and increased revenue. Controlling lead paint hazards would cost $2.5 billion for the 2018 cohort.
- **Ensuring that contractors comply with the Environmental Protection Agency's rule that requires lead-safe renovation, repair, and painting practices would protect about 211,000 children born in 2018 and provide future benefits of $4.5 billion, or about $3.10 per dollar spent.** This includes $990 million in federal and $500 million in state and local health and education savings and increased revenue. The effort would cost about $1.4 billion.
- **Eliminating lead from airplane fuel would protect more than 226,000 children born in 2018 who live near airports, generate $262 million in future benefits, and remove roughly 450 tons of lead from the environment every year.**
- **Providing targeted evidence-based academic and behavioral interventions to the roughly 1.8 million children with a history of lead exposure could increase their lifetime family incomes and likelihood of graduating from high school and college and decrease their potential for teen parenthood and criminal conviction.** No studies have specifically assessed the effectiveness of such programs for lead-exposed children. However, research shows that for children at similar developmental risk from trauma, poverty, and other adverse experiences, certain high-quality interventions can increase the likelihood of earning a high school diploma and a four-year college degree and reduce the chance of becoming teen parents. The estimated benefits presume comparable impacts on lead-exposed children.

The costs and benefits outlined in the bullets above are based on a targeted approach to implementing the interventions, such as focusing on older homes with the highest probability of having lead hazards, and on populations at greatest risk, including low-income families. These economic calculations do not include emotional distress or other potentially large costs to families, such as time away from work.

Preventing childhood lead exposure will require significant policy and regulatory action, coordination across levels of government, and public and private investments, but it has the potential to generate substantial economic and public health gains in the short and long terms. The maximum potential future benefits of preventing all lead exposure for the 2018 birth cohort, such that those children's blood lead levels could be kept from rising above zero, could reach $84 billion, not including the costs to achieve such total prevention. This figure includes nearly $18.5 billion for the federal government and $9.6 billion for states in the form of increased revenue and savings to the health care, education, and criminal justice systems. Calculating the cost of such hypothetical total prevention was beyond the scope of this study, but as shown above, the models for the individual interventions, which together could address a significant share of children's exposure risk, do include cost estimates.

No recent conclusive epidemiologic evidence exists on the relative contribution of different sources to children's blood lead levels,[1] so based on the results of its research, the study team has prioritized policies that the research literature strongly indicated could have the greatest positive population-wide effect on blood lead levels and could protect the most children. Secondarily, the team proposes focusing on other sources that contribute to the overall amount of lead, including nonessential uses of lead, which may cause individual acute cases of lead poisoning, but account for a smaller proportion of lead in children's blood overall. Concurrent with efforts to prevent exposure, the team also encourages the adoption of policies for intervening with children already poisoned by lead and for improving the data available to policymakers and the public.

The study team recommends:

Priority sources

- **Reduce lead in drinking water in homes built before 1986 and other places children frequent.** States and municipalities, with support from federal agencies, should fully replace lead service lines, from street to structure, that provide drinking water to homes built before the EPA banned their use. The EPA should strengthen its requirements to reduce the corrosivity of drinking water, improve water sampling protocols, and create a science-based household water lead action level—the amount that requires intervention—to help families and communities assess their risks. States and localities should investigate and mitigate drinking water hazards in schools and child care facilities.
- **Remove lead paint hazards from low-income housing built before 1960 and other places children spend time.** According to the Department of Housing and Urban Development, about 3.6 million homes nationwide that house young children have lead hazards such as peeling paint, contaminated dust, or toxic soil. HUD, the EPA, and the Centers for Disease Control and Prevention should work with states and local governments to support replacement of windows coated with lead paint, fix peeling paint, clean up contaminated dust, and treat toxic soil in and around those homes. States should require school districts and child care facilities to identify and remediate lead paint hazards.
- **Increase enforcement of the federal renovation, repair, and painting rule.** The EPA and its state agency partners should conduct more investigations to ensure that contractors are in compliance with federal regulations requiring training and certification to minimize dust and debris when working with lead-based paint. The EPA and states should emphasize enforcement for work done at child care facilities and in housing built before 1960.

Additional sources

- **Reduce lead in food and consumer products.** The federal government, through participation in the international Codex Alimentarius Commission—a cooperative effort of the United Nations and World Health Organization—should encourage expedited reduction of international limits on lead in foods, particularly those that young children and babies are likely to consume. Further, where local data indicate that children are being exposed to lead from sources such as candy, health remedies, or cosmetics, state and local agencies should target education and outreach to at-risk neighborhoods; support cultural awareness among physicians; and increase investigation and enforcement of small retailers.

- **Reduce air lead emissions.** The EPA and other federal agencies should collaborate to curtail new discharges by reducing concentrations of lead into the environment, such as from aviation gas and lead smelting and battery recycling facilities.
- **Clean up contaminated soil.** The EPA should collaborate with business to remediate dangerous conditions at and near facilities that extract lead from batteries and other electronics.

Poisoning response

- **Improve blood lead testing among children at high risk of exposure and find and remediate the sources of their exposure.** Federal and state health agencies should work with parents of lead-poisoned children, providers, Medicaid, and the Children's Health Insurance Program to remove barriers to blood lead testing and reporting, and to reduce sources of lead in children's home environments.
- **Ensure access to developmental and neuropsychological assessments and appropriate high-quality programs for children with elevated blood lead levels.** The U.S. Departments of Health and Human Services and Education and state and local health and education agencies should invest in education and care programs, and the federal Centers for Medicare & Medicaid Services should increase children's access to developmental assessments and neuropsychological testing so that the services provided address each child's individual needs.

Data and research

- **Improve public access to local data.** Federal, state, and local authorities should work together to make lead-risk data available to families, policymakers, and other stakeholders who need information about sources of exposure, such as property-specific information on leaded drinking water pipes and lead in the water, dust, paint, and soil at or near homes, schools, and child care facilities.
- **Fill gaps in research to better target state and local prevention and response efforts.** Federal, state, and local agencies and philanthropic organizations should support new studies and conduct their own research to identify sources of lead exposure and populations at greatest risk.

Policy initiatives such as these, while ambitious, are not without precedent, and this report includes illustrative case studies from states and municipalities that have tackled significant lead-exposure problems.

The report begins with a brief history of lead in the U.S. and the policies enacted to address it, a discussion of the impact of lead on children's brains and the disproportionate risks to low-income children and children of color, and a description of the study methods and limitations. It then examines policies to prevent exposure, including interventions focused on lead in drinking water, paint, dust, air emissions, and soil, as well as research gaps revealed during the study of those policy options. Later sections look at strategies for improving blood lead testing in children and at nutritional, educational, and behavioral programs to help mitigate the effects of lead in children already exposed. Each policy discussion includes literature review findings; case studies; input from stakeholders; potential challenges; and, when possible, costs, benefits, and simulated effects on children's lifetime outcomes. The study concludes with a detailed list of actions federal, state, and local policymakers can take to implement the above recommendations. (See Page 79.)

The history of lead in the United States

By the 20th century, lead had permeated every aspect of American life, from air in cities to windows and plumbing of homes across the country. In 1900, "more than 70 percent of [the nation's] cities with populations greater than 30,000 used lead water lines."[2] Then in 1923, leaded automobile gasoline entered the public market and quickly surpassed other fuels, becoming one of the most important sources of lead exposure.[3] Further, between 1900 and 1950, paint containing high concentrations of lead pigments replaced wallpaper as the primary wall covering in homes.[4]

Lead's harmful effects on children were first documented in Australia during the 1890s, and by the 1920s, several European nations had adopted laws limiting lead in paint.[5] For example, France, Belgium, and Austria banned white-lead interior paint in 1909. Then, in 1921, the International Labour Organisation adopted a proposal to prohibit the use of lead-based paint in all member countries, but the U.S. declined to adopt the rule.[6] During this same period, public concern led some American towns and cities to prohibit the use of leaded drinking water lines.[7] In the 1930s, the FDA recognized the need to control potential lead exposure from food and limited the use of lead-containing substances, such as pesticides.[8]

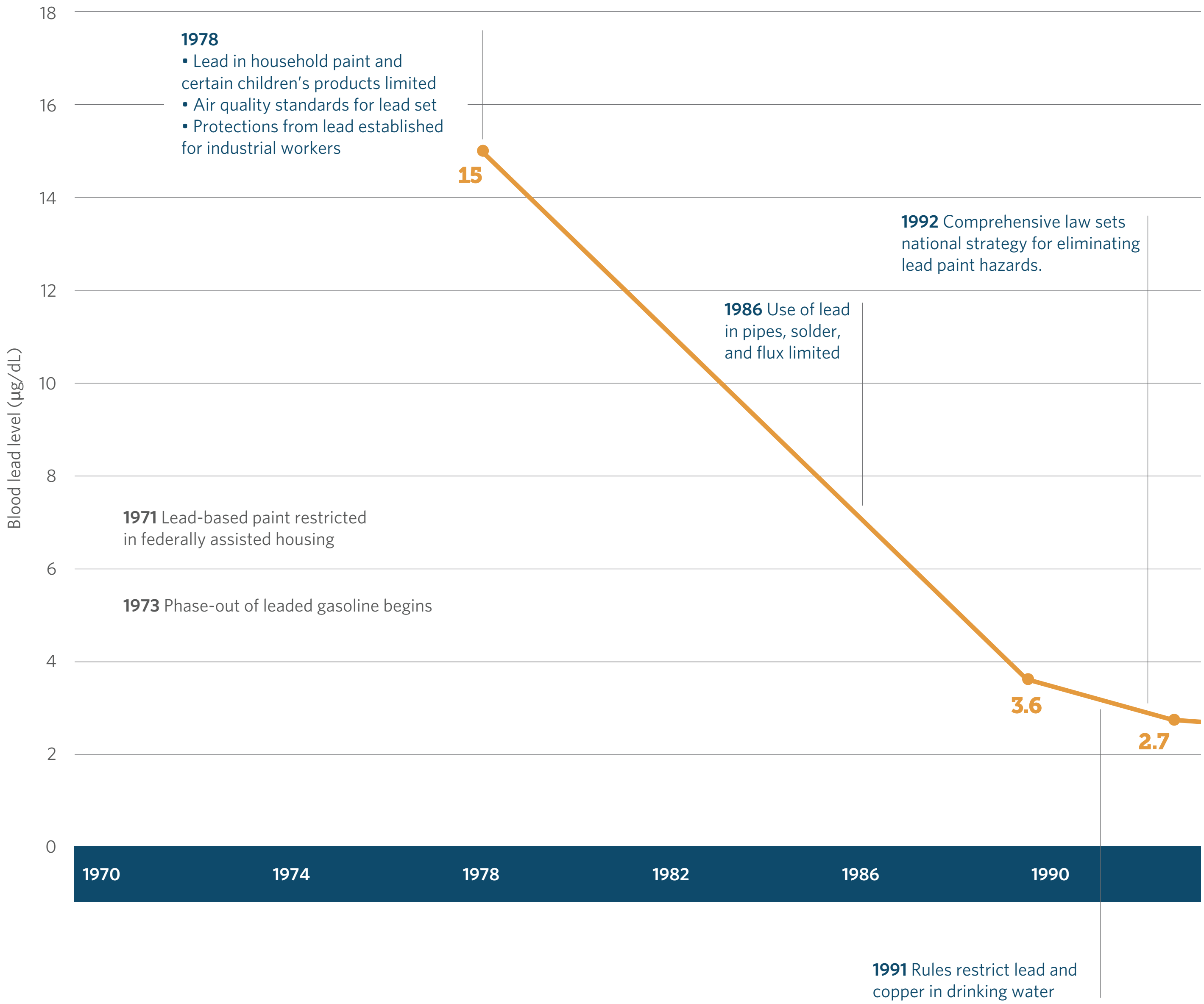
But despite the growing evidence of lead's toxic effects on children, during the 20th century the Lead Industries Association aggressively promoted lead as a superior product while downplaying public health risks and undercutting larger-scale regulatory efforts.[9] Notably, the industry developed model building codes for lead in plumbing and paint and successfully lobbied for their adoption by federal, state, and municipal governments.[10]

Additional federal action lagged until the Clean Air Act of 1970, which regulated air pollution and required that all cars manufactured in the U.S. after 1975 be built with catalytic converters—emission control devices that turned out to be incompatible with leaded gas.[11] The 1971 Lead-Based Paint Poisoning Prevention Act, which prohibited the use of lead paint in government-funded housing, was largely driven by the determined efforts of the scientific community, whose work would help to shape the next 40 years of federal guidelines and policies to protect children.[12] In 1973, the EPA announced a phase-out of lead in gasoline, although the process took more than 20 years.[13] Thanks to key policy actions, including the elimination of leaded gasoline, reductions in industrial emissions, limits placed on lead in residential paint in 1978, the 1974 Safe Drinking Water Act, the 1986 prohibition against use of lead pipes and plumbing, and a shift in the 1990s to welded (nonsoldered) food cans, average blood lead levels among U.S. children have declined by about 94 percent from 15 micrograms per deciliter (μg/dL) in 1976 to 0.86 μg/dL today.[14] (See Figure 1.) In the early 1970s, the U.S. Centers for Disease Control and Prevention (CDC) called for public health action at a blood lead level of 40 μg/dL. Since that time the agency has incrementally lowered the threshold for action. In October 2012, the CDC established a reference value—the level at which a child's blood lead level is much higher than most children's and public health interventions are recommended—of 5 μg/dL and declared, "No safe blood lead level in children has been identified."[15] The CDC's scientific advisers recommended lowering the reference level to 3.5 μg/dL, and agency officials were considering the change as of the writing of this report.[16]

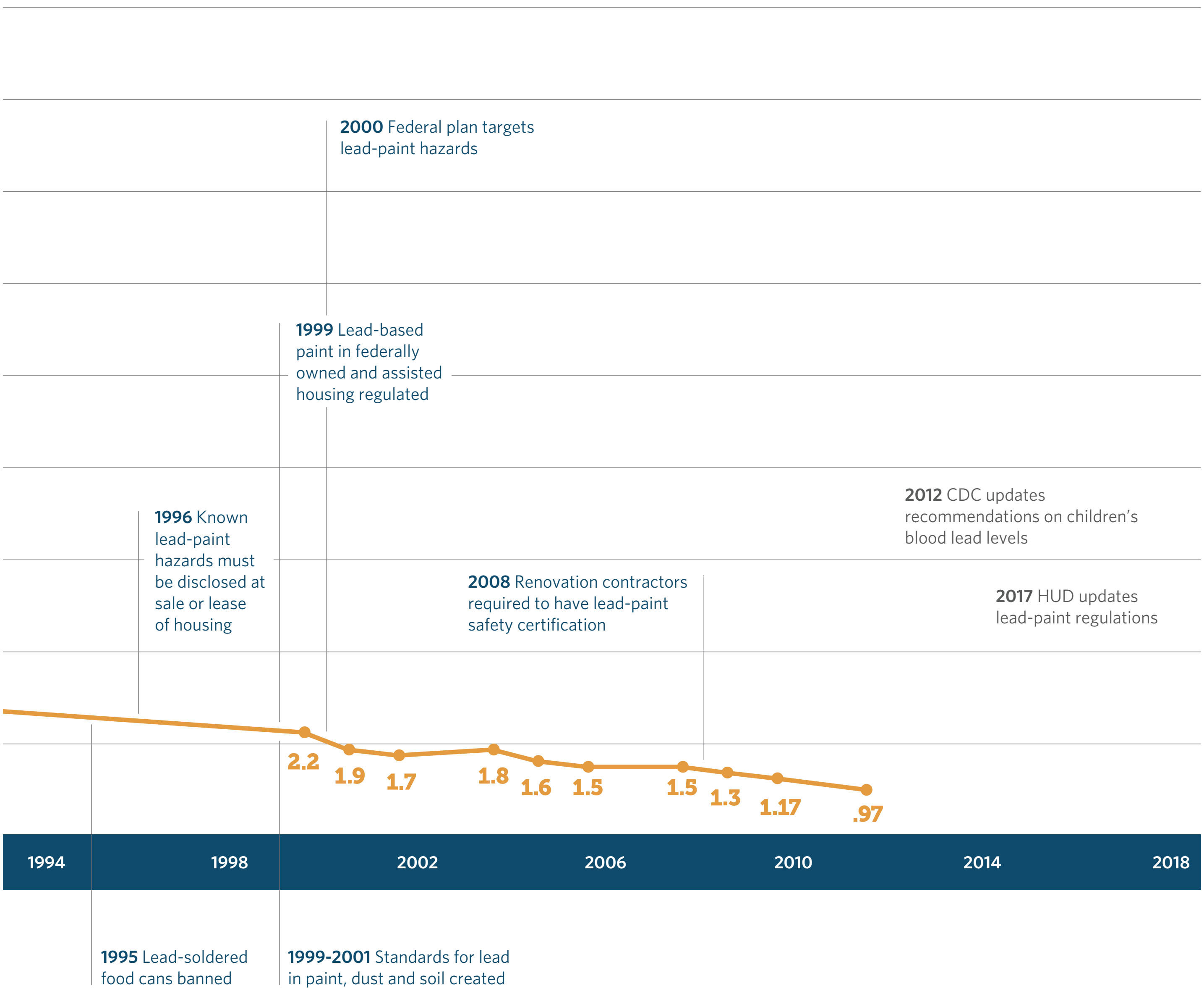
Figure 1

Exposure Prevention Effectively Lowers Children's Lead Levels

Average blood lead levels in children 1 to 5 and federal policies



Sources: Reproduced and modified from Mary Jean Brown & H. Falk, "Toolkit for Establishing Laws to Control the Use of Lead Paint. Module C.iii. Conducting Blood Lead Prevalence Studies," Global Alliance to Eliminate Lead Paint (2016); President's Task Force on Environmental Health Risks and Safety Risks to Children, "Key Federal Programs to Reduce Childhood Lead Exposures and Eliminate Associated Health Impacts" (November 2016), https://ptfceh.niehs.nih.gov/features/assets/files/key_federal_programs_to_reduce_childhood_lead_exposures_and_eliminate_associated_health_impactspresidents_508.pdf


2000 Federal plan targets lead-paint hazards
1999 Lead-based paint in federally owned and assisted housing regulated
1996 Known lead-paint hazards must be disclosed at sale or lease of housing
2012 CDC updates recommendations on children's blood lead levels
2008 Renovation contractors required to have lead-paint safety certification
2017 HUD updates lead-paint regulations
2.2
1.9
1.7
1.8
1.6
1.5
1.5
1.3
1.17
.97
1994
1998
2002
2006
2010
2014
2018
1995 Lead-soldered food cans banned
1999-2001 Standards for lead in paint, dust and soil created

An advertisement for leaded paint from 1866.
Photo: Library of Congress

Despite this progress, U.S. children remain at risk from lead exposure. The CDC found in 2016 that approximately 500,000 children ages 1-5 tested at or above the reference value.[17] Additionally, many federal limits on lead in the environment have not been updated to reflect new evidence about the effects of low-level exposure, and most agencies have not set standards to protect unborn babies and pregnant women.[18] For example, in 2016, during the most recent such review, the EPA opted not to update the 2008 air standards for lead. Standards for paint, dust, soil, water, and occupational hazards are 15 to 40 years old, despite calls to modernize them, such as from the EPA's Science Advisory Board.[19] For example, the EPA's soil lead standard is 400 parts per million (ppm) for areas where children play, while, by comparison, California's guideline is 80 ppm.

Lead and the brain

Very high doses of lead, which are rarely seen in the U.S. today, can cause seizures, coma, and death.[20] However, even much lower levels, between 3 and 5 μg/dL, can lead to neurologic damage, including impaired memory and executive function,[21] which is the ability to plan, remember instructions, and juggle multiple tasks. Such levels can lead to decreased IQ and academic performance and can also cause behavioral problems, such as impulsivity, hyperactivity, and attention disorders.[22] Some studies suggest that lead exposure may also cause conduct disorders, depression, anxiety, and withdrawn behavior[23]—the tendency to avoid the unfamiliar, either people, places, or situations.

The mechanisms by which lead causes harm are complex and not completely understood, but one important way it is known to affect children's brains is by mimicking or competing with other metals such as calcium, zinc, iron, and copper. Young children, particularly from birth to age 6, require large amounts of these essential metals for growth and development, especially to build brain cells and send signals throughout the nervous system. The passage of these metals from the blood into the brain is regulated by the blood-brain barrier—a cellular membrane that selectively allows some substances, such as oxygen, immune cells, and nutrients, to pass between the bloodstream and the brain.[24] Lead can masquerade as these essential metals, moving across the barrier, taking the place of important metals in the brain and interfering with the growth of brain cells, which can lead to changes in the way those cells communicate.[25]

Disproportionate Risks and Related Health Disparities

Any child can be affected by lead, but exposure in the United States is unequal across populations. (See Figure 2.) Race and ethnicity are particularly strongly associated with children's risk. A national survey found that African-American children's average blood lead levels were well above those of non-Hispanic white and Mexican-American children.[*] Although the survey did not control for social and economic factors, other studies have shown that race and ethnicity are associated with elevated blood lead levels in children regardless of family income. One study of more than 1 million blood tests from Chicago collected between 1995 and 2013 found that, after controlling for socioeconomic factors, children from predominantly black, and to a lesser extent Hispanic, neighborhoods had higher rates of lead poisoning than their white counterparts, even as blood lead levels fell dramatically citywide. (See the Glossary for the definition of lead poisoning used throughout this report.) Another study of children from Rochester, New York, found that, after adjusting for environmental exposures, behaviors, socioeconomic status, and dietary intake, black children were at higher risk of elevated blood lead than their peers of other races.[†]

These findings reflect the disparate risk that minority communities face from older housing with lead paint hazards, a condition that has its origins in unfair lending practices and social policies, such as redlining—in which even well-qualified black applicants were treated as too risky for federally backed mortgages—and racial covenants, which prohibited people of color from moving into white neighborhoods.[‡] These practices contributed to the isolation of impoverished communities and people of color in areas with poorer-quality housing, infrastructure, and air.[§] One national survey found that the extent of serious lead paint hazards in U.S. housing differed significantly by race and income: Twenty-eight percent of African-American households and 29 percent of poorer households faced housing-related exposure risks, compared with 20 percent of white and 18 percent of more affluent families, respectively.[||]

Continued on next page

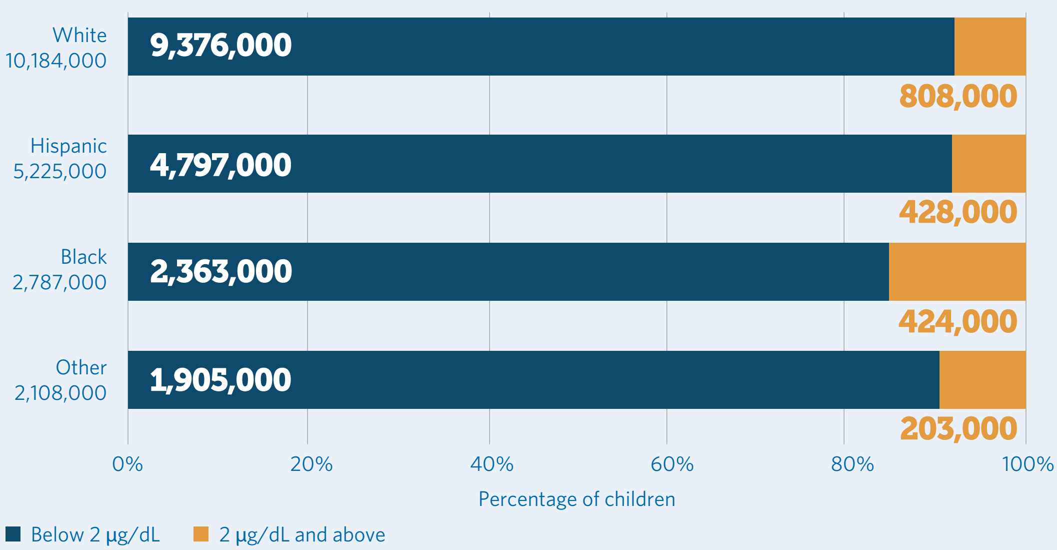
Further, American Indian and Alaska Native children are far more likely than other children to be exposed to potentially lead-contaminated runoff and other effects of former mining sites, and in a 2008 study from New York City, foreign-born children were five times as likely as their U.S.-born counterparts to have elevated blood lead levels.[#]

Certain ethnic groups also experience disproportionate risk from lead associated with health remedies and consumer products. Lead and other heavy metals are sometimes added to traditional medicines used to treat ailments such as arthritis, infertility, upset stomach, menstrual cramps, teething, and colic. Lead has been found in some candies and spices, such as chili powder and tamarind. In addition, traditional eye cosmetics are still made with ingredients, such as kohl, that are high in lead, and the FDA does not allow importation or marketing of these products in the U.S., though they are sometimes brought in by individual travelers.[**]

Figure 2

All Children Face Some Exposure Risk, but Racial and Ethnic Disparities Persist

Share and number of 1-5-year-olds with blood lead levels below and above 2 μg/dL by race and ethnicity, 2011-14



Note: All numbers are rounded.

Sources: Altarum analysis of National Center for Health Statistics, "National Health and Nutrition Examination Survey 2011-2012," accessed May 26, 2017, https://wwwn.cdc.gov/nchs/nhanes/continuousnhanes/default.aspx?BeginYear=2011; and National Center for Health Statistics, "National Health and Nutrition Examination Survey 2013-2014," accessed May 26, 2017, https://wwwn.cdc.gov/nchs/nhanes/continuousnhanes/default.aspx?BeginYear=2013

Continued on next page

Income also influences rates of lead exposure. According to the CDC, children living in poverty had significantly higher average blood lead levels than their more affluent peers.[††] This is in part because low-income families tend to rent rather than own their homes, and renters are more likely than owners to face issues associated with inadequate housing, such as lack of complete plumbing facilities in the unit, have more serious constraints on funding for improvements, and depend on landlords to make their homes lead-safe.[‡‡]

In addition, some evidence suggests that rural communities may be exposed to contaminated soil resulting from past use of lead in pesticides applied to orchards and other crops; however published research on these risks is limited.[§§]

* William Wheeler and Mary Jean Brown, "Blood Lead Levels in Children Aged 1-5 Years—United States, 1999—2010," *Morbidity and Mortality Weekly Report* 62, no. 13 (2013): 245–48, https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6213a3.htm.

† Robert J. Sampson and Alix Winter, "The Racial Ecology of Lead Poisoning: Toxic Inequality in Chicago Neighborhoods, 1995-2013," *Du Bois Review: Social Science Research on Race* 13, no. 2 (2016): 261–83, http://dx.doi.org/10.1017/S1742058X16000151; Bruce Lanphear et al., "Environmental Lead Exposure During Early Childhood," *Journal of Pediatrics* 140, no. 1 (2002): 40–47, https://dx.doi.org/10.1067/mpd.2002.120513.

‡ Kirwan Institute for the Study of Race & Ethnicity, "History Matters: Understanding the Role of Policy, Race, and Real Estate in Today's Geography of Health Equity and Opportunity in Cuyahoga County" (February 2015), http://kirwaninstitute.osu.edu/wp-content/uploads/2015/02/history-of-race-real-estate.pdf.

§ Ibid.; Alex F. Schwartz, "Housing Policy in the United States: An Introduction" (Routledge, Taylor and Francis Group, 2006): 217–18; Russ P. Lopez, "Public Health, the APHA, and Urban Renewal," *American Journal of Public Health* 99, no. 9 (2009): 1605, http://dx.doi.org/10.2105/AJPH.2008.150136.

|| U.S. Department of Housing and Urban Development, "American Healthy Homes Survey: Lead and Arsenic Findings" (2011), http://portal.hud.gov/hudportal/documents/huddoc?id=AHHS_Report.pdf.

\# Lacey McCormick, "Honoring the River: How Hardrock Mining Impacts Tribal Communities," National Wildlife Foundation, news release, April 25, 2013, http://www.nwf.org/News-and-Magazines/Media-Center/News-by-Topic/Wildlife/2013/04-25-13-Honoring-the-River-Press-Release.aspx; Parisa Tehranifar et al., "Immigration and Risk of Childhood Lead Poisoning: Findings From a Case-Control Study of New York City Children," *American Journal of Public Health* 98, no. 1 (2008): 92–97, http://dx.doi.org/10.2105/AJPH.2006.093229.

** U.S. Food and Drug Administration, "Kohl, Kajal, Al-Kahal, Surma, Tiro, Tozali, or Kwalli: By Any Name, Beware of Lead Poisoning," accessed March 6, 2017, https://www.fda.gov/Cosmetics/ProductsIngredients/Products/ucm137250.htm.

†† Wheeler and Brown, "Blood Lead Levels in Children Aged 1-5 Years—United States, 1999–2010."

‡‡ Joint Center for Housing Studies of Harvard University, "The State of the Nation's Housing 2016" (Cambridge, MA: Harvard University, 2016): 5, 25, http://www.jchs.harvard.edu/sites/jchs.harvard.edu/files/jchs_2016_state_of_the_nations_housing_lowres.pdf.

§§ Carol L. Hanchette, "The Political Ecology of Lead Poisoning in Eastern North Carolina," *Health and Place* 14, no. 2 (2008): 214, http://dx.doi.org/10.1016/j.healthplace.2007.06.003; C. Marjorie Aelion et al., "Associations Between Soil Lead Concentrations and Populations by Race/Ethnicity and Income-to-Poverty Ratio in Urban and Rural Areas," *Environmental Geochemistry and Health* 35, no. 1 (2013): 10, http://dx.doi.org/10.1007/s10653-012-9472-0.

Recent news reports provide stark reminders that lead continues to affect American communities. In September 2015, Dr. Mona Hanna-Attisha found significant blood lead increases among children in Flint, Michigan, which elevated the city's drinking water crisis to a national public health issue. Nearly a year later, roughly 270 families in East Chicago, Indiana, were displaced from a public housing development built near a former smelter and lead refinery, which is now a federally designated Superfund site.[26] Soil at the housing complex had lead levels significantly above the EPA's action level—the concentration of lead above which regulatory or remedial intervention is needed.[27]

Methods

The research team developed a list of more than 100 policies for analysis based on documents from a range of organizations and agencies, including the 2000 President's Task Force on Environmental Health Risks and Safety Risks to Children, the U.S. Centers for Disease Control and Prevention, Earthjustice, the American Academy of Pediatrics, the National Center for Healthy Housing, the National Safe and Healthy Housing Coalition, the Green & Healthy Homes Initiative, the Healthy Schools Network, and the Lead Service Line Replacement Collaborative.[28]

The research team selected policies for analysis based on interviews; focus groups; and a series of meetings with experts, advocates, and community members. The team asked these stakeholders to identify policies for inclusion in the study based on their public health and health equity value and, noting the urgency of action, their potential to be implemented within 18-36 months. Additionally, the team chose policies with the strongest evidence base.

Priority was placed on those that related most directly to preventing children from coming into contact with lead and enabling those who have already been exposed to access services to help improve their lifelong outcomes.[29]

The analysis included qualitative and quantitative research organized according to a modified Sequential Explanatory approach, to develop an understanding of the relevant social, economic, and cultural contexts for lead exposure in children.[30] Studies that use both qualitative and quantitative methods are strengthened by the combination because they are able to present information from multiple perspectives. Qualitative data collection, including focus groups, listening sessions, and interviews, was conducted first, followed by quantitative analyses of costs and benefits.

See the appendix for an in-depth discussion of the methodology used for this report.

Quantitative models

Child Trends, a nonprofit research center focused on child development, led the quantitative work, in partnership with Altarum Institute, a nonprofit health systems research organization, and the Urban Institute, a nonprofit economic and policy research organization.

The study team quantitatively modeled only those prevention interventions for which data on the scope of exposure and the effectiveness of the policy were readily available. For example, data exist on the extent of lead paint, lead service lines, and contaminated dust in homes, as well as on the effectiveness of interventions to address these hazards. However, similarly comprehensive information for these threats and policies to mitigate them in schools and child care facilities was not available. Exposure from sources not tied to a specific structure, such as consumer products and food, was also difficult to estimate, and data regarding the effectiveness of interventions targeted at those sources were lacking. Despite these data constraints, in recognition of the reality that many sources of lead contribute to childhood lead exposure, the team studied those hazards for which quantitative data were not available using the qualitative methods described later in this chapter. The team selected the inputs for the models from a literature search that identified 176 peer-reviewed articles related to the policies analyzed. The team used the most rigorous literature available as the basis for the quantitative models.

Child Trends and the Urban Institute used the Social Genome Model (SGM), which examines how actions at developmentally significant life stages reverberate through a person's life, to predict the effects of policies to prevent harmful blood lead levels and of interventions for lead-exposed children.[31] The SGM simulated the effects of the prevention and response policies on educational attainment, grade point average, teen parenthood, criminal convictions, and lifetime family income. Using a data set of 8,056 children, the SGM tracks lifelong development starting at birth and employs statistical techniques to assess the relationships between children's early life circumstances and later outcomes. The studied effects build on one another over a child's life: Circumstances at birth influence early childhood, which in turn affects middle childhood circumstances, which translate into a child's situation in adolescence, and so on well into adulthood. For example, robust research shows that, after controlling for other factors, children with lower blood lead levels have better early reading scores than those with higher levels.[32] The SGM calculates how this better reading contributes to greater educational attainment and higher income later in life.

The SGM does not include information on children's blood lead levels, so the team used data from the two most recent editions (2011-14) of the National Health and Nutrition Examination Survey (NHANES), a national population-based survey, to assign blood lead levels to children based on their social and demographic characteristics.

The modeling team used data from the literature to determine the change in children's blood lead that could be expected as a result of the policy interventions and how it would affect reading, math, and behavior. The team then ran the SGM to estimate how those effects would, in turn, impact later life outcomes, such as graduation rates, criminal convictions, and teen pregnancy. The SGM was used to examine five interventions for which effect size estimates were available: lead service line replacement; lead paint hazard control; renovation, repair, and painting rule enforcement; removal of lead from aviation gas; and programs for children with a history of lead exposure. The SGM outputs for this final intervention are presented in the body of the report, while for brevity, the findings from the first four analyses may be found in the appendix.

The analysis also employed Altarum Institute's Value of Prevention (VP) tool, a spreadsheet-based application, which synthesizes research findings and national data sets to quantify the financial and health impacts of various preventive investments. The tool has been applied to investigating the value of smoking and obesity prevention, and of early childhood education. For this study, the team synthesized four types of data to estimate the costs and benefits of the four prevention policies. The tool integrated published findings on the effect of an intervention on blood lead levels and information on the health and social impacts of lead exposure to infer later-life health status, health care costs, and incarceration rates; and data on the effect of lead on IQ and on the relationship between IQ and income to predict lifetime earnings.

The research team modeled the benefits for the cohort of children born in 2018, the next full year that most closely approximates the blood lead level data from the 2011-14 NHANES. According to those data, the mean blood lead level for the population of children 1-5 was 1.1 µg/dL.

These analyses provided an estimate of the benefits of each policy to society and to the federal and state and local governments. These are referred to in the report as "future benefits" and are discounted at a rate of 3 percent per year to account for the changing value of money over time.

To better understand and describe any uncertainty within the findings, the modeling team conducted two additional analyses. First, it modeled the effects of preventing blood lead levels from rising above 0 μg/dL as a bounding exercise to provide an upper limit on the potential impacts of the intervention policies. Second, to address uncertainties that could not be tested by that method, the team performed quantitative sensitivity analyses to clarify how changes in the assumptions, coefficients, and data points could affect the overall results. (See the appendix for details.)

Qualitative methods

Through qualitative approaches, researchers can identify stakeholder concerns, explain why and how phenomena occur, and gauge the range of effects. These methods also provide context for quantifiable information and enable an examination of processes and experiences along with outcomes.

In addition to the research literature gathered for the quantitative models, the study team identified and reviewed other studies across a range of methods and topics that could help with screening policies and formulating recommendations. Across the two literature searches, the team identified roughly 700 peer-reviewed articles.

Through 16 focus groups held in Baltimore; Chicago; Flint; Indianapolis; Los Angeles; New Orleans; Philadelphia; and Warren, Arkansas, the team collected feedback from at least 129 community members, including landlords (16 participants), parents of children with high blood lead levels, and other concerned citizens (113 participants). The team gathered basic demographic information from participants in the parents and concerned citizens groups using a brief survey. (See Table A.3 for complete results.) The team also held two conference calls with eight parents of lead-poisoned children to capture their experiences navigating the medical and education systems.

The research team developed a list of themes from the discussion guides for the focus groups. The team analyzed the field notes and transcriptions from each focus group to identify additional common themes and keywords to add to the list and then summarized the findings and linked those to the quantitative results to provide context for the economic information. Perhaps more importantly, the qualitative analysis allowed the team to identify barriers to implementing the recommendations as well as steps to mitigate those challenges and support effective remediation of lead exposure risks.

In addition, the research team gathered more insight into the effects of childhood lead exposure and potential policy interventions through five national online listening sessions. (See the appendix for details on participants and methodologies for these events.) Unstructured conversations with experts provided additional input for the report.

Finally, the Trust for America's Health and the National Center for Healthy Housing developed case studies to highlight examples of policies in action and lessons learned from across the country. The team selected the case studies based on their relevance to the policies analyzed and their applicability to other jurisdictions. (See the "Policy in Action" listings in the Table of Contents.)

Study limitations

Qualitative data limitations

Obtaining input from all stakeholder groups that could be affected by the recommendations was beyond the scope of the study. Efforts were made to broadly advertise the national listening sessions to ensure that the study included diverse stakeholder perspectives, but in general, school administrators, the aviation industry, and owners of secondary smelters did not respond and so are not as well represented as the public health community. Further, although the team solicited feedback through the advisory committee and focus groups from several representatives of water utilities, property management firms, renovation contractors, child care operators, and rental property owners, fewer of these groups' perspectives were included than of public health professionals and community-based organizations. Finally, the focus group locations and project advisers were subject to selection bias, because existing relationships and networks were leveraged during the selection process. When possible, the team controlled for this by seeking input from a broad array of partners.

Quantitative model limitations

Blood lead data for the 2018 birth cohort

The team relied on the two most recent NHANES surveys (2011-14) to establish children's baseline blood lead, which, based on historical trends, may be higher than what will be seen among the 2018 birth cohort. However, data from the CDC lead surveillance program indicate a leveling-off between 2009 and 2015 of the number of children with blood lead levels above 10 μg/dL,[33] suggesting that using the NHANES data is appropriate to predict 2018 blood lead levels.

Current exposure levels

Recent epidemiologic data on the relative contribution to blood lead levels of different environmental sources are scarce. Therefore, the study team could not determine whether the proportion of exposure coming from different sources has changed or what adjustments would be necessary to reflect such shifts.

Data on the impact of interventions

In light of today's lower blood lead levels and the decreased amount of lead in the environment, the team took several precautions to avoid overestimating the benefits of exposure prevention, including using multistep processes to estimate the relationship between lead in the environment and in blood and the most recent data available on the effectiveness of the interventions, relying on studies of children with lower mean blood lead levels, and modeling different baseline levels of lead in the environment.

For the lead paint hazard control and drinking water interventions, instead of relying on older epidemiologic studies of environmental and blood lead levels, the team used a two-part process to establish first the relationship between the interventions and levels of lead in the environment and, second, the association between those environmental levels and the amount of lead in a child's blood. The team used an estimate from a large national evaluation of the effect of lead paint hazard control on dust lead levels in the home and then used corresponding blood lead level reductions from a 2009 study. In addition, the team modeled the benefits of the intervention based on two starting levels of lead in dust on floors; 20 and 10 μg/sq ft.

The team used a similar process for determining the relationship between removing lead drinking water lines, levels of lead in water, and lead in a child's blood. The team also modeled two baseline water lead level scenarios, 11.4 ppb and 5 ppb, to show a range of effects of replacing lead service lines depending on baseline water lead levels.

For renovation, repair, and painting, the team relied on a 2008 EPA model that estimated the effects of preventing acute exposure from unsafe practices.

For aviation gas, the team relied on a study of Michigan children from 2001 to 2009 with a relatively low mean blood lead level of 2.98 μg/dL.

The relationship between current blood lead levels and cognitive and behavioral outcomes

The models rely on estimates of the relationship between blood lead levels and outcomes such as IQ, cognition, and behavior from older studies that were conducted when mean blood lead levels were higher. Although few studies capture the relationship between IQ and blood lead levels below 2 μg/dL, several have found a relationship at mean levels of 3 to 5 μg/dL.[34] Not only do low blood lead levels result in IQ changes, but evidence suggests that IQ losses from lead exposure may be greater at lower blood levels.[35] An increase in blood lead from less than 1 to 10 μg/dL is associated with a loss of 6 IQ points, compared with 2 points lost from a rise from 10 μg/dL to 20.[36] (See appendix for further discussion of the impacts of low-level lead exposure on IQ.)

To avoid potentially overstating the blood lead-to-IQ impact for today's population of children, the team modeled different effect sizes depending on the predicted blood lead level of a child. For the lowest blood lead category of less than 5 μg/dL, the team relied only on studies with a mean level below 5 μg/dL. Although limited data exist on the relative effect sizes on IQ of blood levels below 2 μg/dL, the team assumed that the linear relationship established in the literature for levels between 5 and 2 μg/dL continued below 2 μg/dL. These strategies—using studies with the closest possible mean to today's blood lead levels and assuming a linear trend down to 0 μg/dL—are identical to those used by the EPA for its 2008 clean air regulations.[37]

Similarly, the team considered 14 estimates of the relationship between blood lead and reading and math scores, all but two of which were based on samples of children with mean blood lead levels of 5 μg/dL or lower.[38] Among the studies, two found that the rate of decline in reading scores increased at lower blood lead levels, while the others found a linear relationship, even in children with low blood lead levels. The team also reviewed eight estimates of the effect size of blood lead on behavioral outcomes: five from study samples with mean blood levels below 6 μg/dL, and three based on samples with higher mean levels.[39]

Other limitations

Data for the numbers of children at risk from leaded aviation gas and living in homes with leaded drinking water pipes as well as for those children's blood lead levels were incomplete. The benefits only account for the child residing in a treated home; they exclude children who might visit, except where otherwise noted. Further, the NHANES, which was used to establish the baseline blood lead levels for children in the quantitative models, estimates levels nationally rather than by smaller geographic areas such as neighborhoods, and the SGM is based on a population with fewer immigrants than the current U.S. population. These differences may mean that predictions in this study may understate or overstate effects for certain communities.

In addition, the cost-benefit ratios exclude the cost of government administration for the studied interventions because they could be operated by many levels of government or the private sector at widely varying costs. Where available, information about program administration expenses is included in the discussion of each intervention.

Further, outcome predictions assume complete implementation of each intervention, but, in reality, a portion of targeted homes would probably not receive a given remediation because of refusal, financial barriers, or other factors. As a result, total benefits, total costs, and net benefits would be lower, while cost-benefit ratios and per-child benefits would remain the same.


Kev Klopper/Getty Images

Total prevention of lead poisoning

> "I guess there must have been some public health campaigning at one point where they said paint chips are it! Because everybody got that message. It was like Smokey the Bear. But they don't understand that it's so much broader than that. … It's in the soil. It's [in] the air. It's in your pipes."
>
> —New Orleans resident

The team, with guidance from advisers and key stakeholders, selected policies for analysis that promised the greatest public health and equity benefits and that could be adopted, though not necessarily fully implemented, in 18 to 36 months, given the urgent need for action.

Lead is ubiquitous; past and present uses challenge eradication efforts

Many sources and pathways add to the amount of lead in a child's blood, including releases from previous exposure stored in a child's bones. In addition, individual children's exposures vary based on several factors, including location, age, intake of food and water, mouthing behavior, and nutritional status. Evidence also suggests that for children with blood lead levels below 10 µg/dL, "no single exposure source predominates,"[40] underscoring the need for a comprehensive response.

Lead in Everyday Items

To the surprise of many people, lead continues to be used in a variety of everyday consumer and commercial goods. Although the team found no data to characterize the extent to which these sources present a population-level health risk, dozens of case studies have documented acute instances of child lead poisoning and even death from a range of products, including candies, health remedies, cosmetics, and spices.[*] For example, one national survey found that imported candy contributed 10 percent of dietary lead for 2- to 6-year-old children.[†] In addition, Greta, a health remedy used in some Hispanic cultures to treat upset stomach, contains high levels of lead and has accounted for several cases of lead poisoning;[‡] Tiro, an African eye cosmetic, has been found to contain 82 percent lead and has sickened at least one child in the U.S.;[§] and Litargirio (also known as litharge or lead monoxide), a Central American antiperspirant and deodorant, poisoned two siblings in Rhode Island in 2003. Further, between 2010 and 2014, six poisoning cases were attributed to lead-contaminated spices, including turmeric.[||]

Lead compounds, such as lead oxide, also are sometimes used in pottery glazes because they allow for a broader range of firing temperatures. However, when fired at inadequate or uncontrolled temperatures, the lead may not be not fully incorporated into the glaze and can leach into food.[#] Also, many commercially available food products contain small amounts of lead, including some marketed for infants and toddlers.[**] The allowable amount of lead for many foods is based on consultation with other countries and on what is achievable for members of an international committee called the Codex Alimentarius General Standard for Contaminants and Toxins in Food and Feed.[††]

In focus groups, participants worried about lead contamination of food, including imported spices, breast milk, toys, jewelry, and other products, wanted improved labeling, and expressed concerns for refugees and a desire to ban lead from health remedies. They also identified a need for culturally and linguistically appropriate education efforts to reach recent immigrants and refugee families with information about sources of lead in consumer goods. According to one Spanish-speaking participant from Flint, Michigan, "There isn't any information about lead in Spanish here." In general, participants wanted increased testing and labeling of food products containing lead and improved health communication about related risks.

California has led U.S. efforts to ban lead from a range of products beginning with a 1986 law, known as Proposition 65, which requires manufacturers, retailers, and other businesses to notify consumers when they are being exposed to toxic chemicals, including lead. More recently, the state has enacted additional policies:

- The 2006 Lead-Containing Jewelry Law requires jewelry and components, such as dyes and crystal, that is sold, shipped, or manufactured for sale in California to meet limits set by the state under a 2004 consent judgment that applied to a number of manufacturers, retailers, and distributors.[‡‡]

Continued on next page

- A 2010 law restricted the use of heavy metals including lead in motor vehicle brake pads to no more than 0.1 percent by weight. In January 2015, brake manufacturers agreed that all brake pads sold in the United States will meet California standards.[§§]
- The 2003 Toxics in Packaging Prevention Act, which limited harmful substances in packaging, originally exempted lead in paint or applied ceramic decoration on glass bottles, but a 2008 amendment banned such uses in excess of 600 ppm.[|| ||]
- To protect wildlife, a 2013 law required that only lead-free ammunition be used for hunting with a firearm.[##]

* Centers for Disease Control and Prevention, "Childhood Lead Poisoning Associated With Tamarind Candy and Folk Remedies—California, 1999–2000"; Whitney Cowell et al., "Ground Turmeric as a Source of Lead Exposure in the United States," *Public Health Reports* 132, no. 3 (2017): 289–93, http://dx.doi.org/10.1177/0033354917700109.

† S.K. Egan et al., "U.S. Food and Drug Administration's Total Diet Study: Intake of Nutritional and Toxic Elements," *Food Additives and Contaminants* 19, no. 2 (2002): 103–25.

‡ Centers for Disease Control and Prevention, "Lead Poisoning Associated With Ayurvedic Medications—Five States, 2000–2003."

§ Centers for Disease Control and Prevention, "Infant Lead Poisoning Associated With Use of Tiro, an Eye Cosmetic From Nigeria—Boston, Massachusetts, 2011," Aug. 3, 2012, https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6130a3.htm.

|| Centers for Disease Control and Prevention, "Lead Poisoning Associated With Use of Litargirio—Rhode Island, 2003," *Morbidity and Mortality Weekly Report*, March 11, 2005, https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5409a5.htm; Whitney Cowell et al., "Ground Turmeric as a Source of Lead Exposure in the United States."

U.S. Food and Drug Administration, "Guidance for Industry: The Safety of Imported Traditional Pottery Intended for Use With Food and the Use of the Term 'Lead Free' in the Labeling of Pottery; and Proper Identification of Ornamental and Decorative Ceramicware," accessed Feb. 6, 2017, http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/ucm214740.htm.

** U.S. Food and Drug Administration, "Total Diet Study, Elements Results Statistics, Market Baskets 2006 through 2011" (College Park, MD: U.S. Food and Drug Administration, 2014), https://www.fda.gov/downloads/food...totaldietstudy/ucm184301.pdf.

†† Codex Alimentarius Commission, "Report of the Ninth Session of the Codex Committee on Contaminants in Foods" (New Delhi, India, March 16–20, 2015), ftp://ftp.fao.org/codex/reports/reports_2015/REP15_CFe.pdf.

‡‡ California Department of Toxic Substances Control, "History of the Law," accessed Jan. 12, 2017, http://www.dtsc.ca.gov/PollutionPrevention/ToxicsInProducts/upload/History-of-the-Law1.pdf.

§§ California Department of Toxic Substances Control, "Brake Pad Legislation," accessed Jan. 12, 2017, http://www.dtsc.ca.gov/SCP/BrakePadLegislation.cfm; U.S. Environmental Protection Agency, "Copper Mitigation in Watersheds and Waterways," accessed Jan. 12, 2017, https://www.epa.gov/sites/production/files/2015-11/documents/copper_brakepads_mou.pdf.

|| || California Department of Toxic Substances Control, "Senate Bill (SB) 774 and Changes to the Toxics in Packaging Prevention Act," accessed Jan. 12, 2017, https://www.dtsc.ca.gov/ToxicsInPackaging/upload/TIP_FS_SB-774_Changes.pdf.

California Fish and Game Commission, "Prohibition on the Use of Lead Projectiles and Ammunition Using Lead Projectiles for the Take of Wildlife," accessed Jan. 12, 2017, http://www.fgc.ca.gov/regulations/current/mammalregs.aspx#250_1.

Modeling total prevention

The research team modeled interventions to prevent children's blood lead levels from exceeding zero. Notably, given the diverse sources of lead in the environment and the widely varied exposure risks across populations, a zero blood lead level is aspirational. However, the team chose to model a zero level to establish the maximum possible benefits that could be realized under a total prevention scenario. Using the VP Tool, the team determined that the discounted future societal benefits of such hypothetical total prevention would be $84 billion for the 2018 birth cohort. (See Table 1.)

Table 1

Keeping Blood Lead Levels of Children Born in 2018 at Zero Would Generate $84 Billion in Benefits

Future savings and increased earnings by source and recipient

Benefit	Value (in billions)
Increased lifetime earnings for entire 2018 cohort	$77.2
Health savings	$1.7
Education savings	$1.9
Quality-adjusted life years benefits	$3.1
Total future benefits	**$84.0**
Share to the federal government	**$18.5**
Share to state and local governments	**$9.6**
Share to households, private sector, and other nongovernmental entities	**$55.9**

Notes: Analysis is based on the 2018 birth cohort, estimated at approximately 4 million children. Future benefits are discounted at 3 percent per year to account for the changing value of money over time. Quality-adjusted life years is the number of additional healthy years of life resulting from an intervention, which the research team conservatively valued at $50,000 for each additional year of healthy life. Total future benefits include small changes in incarceration costs, which are not itemized in the table.

Source: Altarum Institute Value of Prevention Tool calculation. See the appendix for details on the model methodology and underlying data sources.

The benefits include earnings associated with greater employment and higher-paying jobs and lower public spending on short- and long-term health care costs, such as for testing and treating lead-exposed children, doctor visits, and hypertension and cardiovascular disease later in life. The benefits also include savings to the education system, specifically, reduced spending on special education and grade repetition. The calculations also capture benefits from quality-adjusted life years (QALYs)—the number of additional healthy years of life resulting from an intervention—which the research team conservatively valued at $50,000 each.[41] Finally, the estimated future benefits also include $13 million in savings from decreased incarceration based on a longitudinal study that linked blood lead levels to arrest rates.[42] However, that study only documented effects for blood lead above 6 µg/dL, a level that few children experience today, so the predicted benefits associated with reduced criminal involvement are relatively small. The model did not account for other potential cost reductions associated with crime and criminal justice, such as from fewer arrests, so the benefit estimates may be conservative.

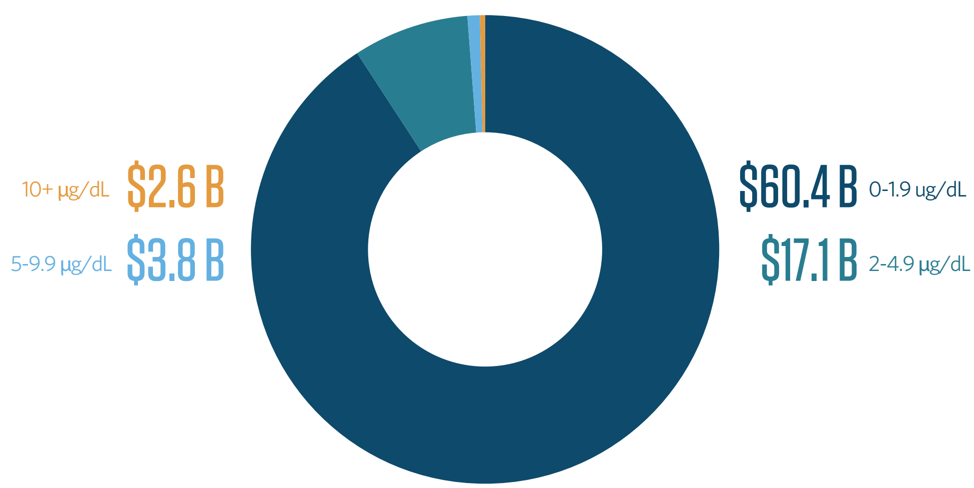
Of the $84 billion in future benefits for the 2018 birth cohort, about $77 billion comes from increased earnings, most of which accrues to families and the private sector, with a portion also going to federal, state, and local governments as increased tax revenue. Of the $19 billion federal share, nearly $15 billion is in the form of increased tax collections, with the remaining $4 billion coming from reduced spending on education, health care, and social support programs. The $10 billion for state and local governments includes about $4 billion from increased tax revenue and roughly $6 billion in decreases in government expenditures. This analysis predicts that increased employment and wages would reduce demand for government assistance, leading to lower spending on social support programs, which is counted as a benefit for federal, state, and local governments. However, because the savings result in a loss to the citizens who would receive payments, the reduced government spending is not included in the $84 billion benefit total.

Further, assuming no changes to current programs and policies, NHANES data predict that without the intervention, from ages 1-5, 90.8 percent of the cohort would have blood lead levels below 2 µg/dL; 8.0 percent would be between 2 and 5; 0.9 percent between 5 and 10; and 0.3 percent above 10. (See Figure 3.)

Figure 3

Most Benefits of Exposure Prevention Accrue for Children Whose Blood Lead Would Otherwise Be Below 2 µg/dL

Economic gains by avoided blood lead levels and number of children



Notes: Without intervention, the blood lead level distribution at ages 1-5 for the 2018 birth cohort would be 14,000 children with blood lead levels greater than 10 µg/dL, 34,000 between 5 and 9.9 µg/dL, 318,000 between 2 and 4.9, and 3,612,000 between 0 and 1.9.

Source: Altarum Institute Value of Prevention Tool calculation

If federal investment of $80 billion was sufficient to prevent the 2018 cohort's blood lead from exceeding zero, estimated societal benefits would be $1.05 per $1 invested; if the necessary investment proved smaller, the cost-benefit ratio would be greater. Additionally, permanent removal of lead hazards would affect future cohorts, and those benefits would be in addition to the estimates provided in this analysis.

Additionally, the research team used the SGM to explore the effects of full prevention on children's educational attainment and likelihood of risky behaviors, such as criminal activity. The model indicated that holding blood lead levels at zero would improve high school and college graduation rates, and decrease rates of teen parenthood and criminal conviction. (See Table 2.)

Table 2

Keeping Blood Lead Levels at Zero Among Children Born in 2018 Would Improve Educational and Social Outcomes

Effects on education, teen parenthood, and crime

Outcome		All children born in 2018			Children born in 2018 whose blood lead levels would be expected to rise above 2 µg/dL in early childhood		
		Baseline conditions	Total prevention	Children benefiting	Baseline conditions	Total prevention	Children benefiting
Average high school GPA		2.93	2.94	N/A	2.74	2.78	N/A
Percentage and number of children	Earn high school diplomas	83.7%	84.0%	14,600	74.4%	75.6%	4,500
	Become teen parents	13.5%	13.3%	6,000	20.1%	19.6%	1,900
	Be convicted of crimes	17.2%	16.9%	15,500	22.0%	20.7%	4,700
	Complete 4-year college degrees	26.7%	27.1%	15,200	17.0%	18.3%	4,700

Notes: Analysis is based on the SGM's sample of about 8,000 children, drawn from the Children of the National Longitudinal Survey of Youth dataset. To arrive at the number of children positively affected, the research team applied the percentage point differences between baseline conditions and total prevention to the roughly 4 million children expected to be born in 2018 and to the roughly 365,000 of them whose blood lead levels would probably exceed 2 µg/dL. See the appendix for information on the model and methodology.

Source: Social Genome Model analysis by Child Trends and the Urban Institute

The modeling team examined the impact of the total prevention scenario on the IQs of children born between 2018 and 2023 using a similar methodology to that presented by Gilbert and Weiss and found that, on average, preventing exposure would avoid the loss of 1.27 IQ points per child.[43] A 1.27-point difference would be difficult to discern between two children, but preventing lead exposure would reduce the number of intellectually challenged children, those with IQs below 70, by about 101,000 or 18.5 percent and would increase the number of children in the gifted category, above 130 IQ points, by about 119,000 or 22 percent across six birth cohorts. Findings from a recent study suggest that the impact of childhood lead exposure on IQ persists into adulthood, which lends support to the findings of these models that preventing exposure and mitigating the effects of lead for young children would improve their outcomes later in life.[44]

Drinking water

> [Before the Flint, Michigan, case], I never thought we could get lead poisoning from water. I was totally ignorant about that."
>
> —Flint focus group participant

Sources of contamination in drinking water include corrosion of lead service lines (LSLs), brass plumbing fixtures, and lead solder installed before Congress limited the use of lead in plumbing and pipes in 1986.[45] Although indoor plumbing fixtures and lead solder can also contribute to elevated lead levels in water, the research indicates that LSLs account for the largest share of lead in water.[46] Importantly, observational studies show that U.S. residences with LSLs are at even greater risk if the techniques used to manage the corrosivity of water are not effective.

A robust body of academic literature from the U.S. and Canada links lead in drinking water to increases in blood lead levels.[47] For example, one cross-sectional study[48] of 183 children randomly selected from urban areas found that an increase in water lead concentrations from background levels to 15 ppb was associated with a nearly 14 percent jump in the share of children with estimated blood lead over 10 µg/dL.[49] Participants in all 16 focus groups said lead in drinking water at homes, schools, and child care facilities was a primary concern, and several parents of lead-exposed children said water was the source of their children's exposure.

Lead in Water and Infant Health

Infants can ingest lead through breast milk and water used to reconstitute powdered formula. Lead stored in bones can release into a mother's blood, and a fraction (up to 3 percent) of that lead can transfer to breast milk.[*] Breastfeeding provides infants and mothers with many health benefits, and weighing those against the adverse effects of lead exposure, the CDC recommends mothers with blood lead levels below 40 µg/dL continue to breastfeed.[†] In situations where breast milk is supplemented with or replaced by formula, caregivers should take steps to avoid using water contaminated by lead to reconstitute formula, such as flushing the tap or using bottled or filtered water, and never using water from the hot tap.[‡]

* Centers for Disease Control and Prevention, "Guidelines for the Identification and Management of Lead Exposure in Pregnant and Lactating Women" (Atlanta: U.S. Department of Health and Human Services, 2010), https://www.cdc.gov/nceh/lead/publications/leadandpregnancy2010.pdf.

† Ibid.

‡ Ibid.

The EPA began requiring water utilities to manage lead under its 1991 Lead and Copper Rule.[50] The rule set forth "corrosion control" as the primary method for reducing lead in water in the United States. This technique involves treating water with chemicals, such as orthophosphates, that create a barrier between the pipes and the water in them or adjusting the pH or hardness of water. Since the rule's inception, corrosion control has dramatically decreased water lead levels in the U.S., but the various methods can differ substantially in effectiveness, so the EPA requires utilities to monitor selected water quality parameters, such as pH.[51]

The rule also mandated that water utilities periodically test lead concentrations across a sample of customer taps that are deemed more likely to have elevated levels based on the presence of LSLs, other lead pipes, or any pipes with lead solder and to report the results to consumers. However, the rule does not require that all customer taps be tested. Instead, systems are only obligated to sample 10 percent of their taps. The crisis in Flint shed light on the shortcomings of the current approach to managing lead in water. The EPA acknowledged challenges in a document concerning possible revisions to the Lead and Copper Rule, which cited issues including complexity, sampling protocols, a lack of attention to specific areas such as schools, and too much flexibility regarding corrosion control implementation and monitoring.[52]

Water fountains in many public schools have not been tested for lead risks.

Drinking Water in Schools and Child Care Facilities

Millions of children spend significant time in school and child care facilities each day, making these places important potential sources of exposure.

- About 50.4 million children attend public school and nearly 4.3 million children under 5 are served annually by center- and home-based child care providers.*
- Case studies of school drinking water have found dramatic variation: A 2015 study of 3,100 taps across 63 Seattle schools found lead levels from less than 1 ppb to 1,600 ppb; an analysis of first-draw samples—those taken after water sat in the pipes overnight—from the Los Angeles Unified School District revealed a range of 0.2 to 13,000 ppb; a 2004 study of Philadelphia schools found that about 57 percent of buildings had water lead above the EPA action level of 20 ppb, and 29 percent had water with mean levels over 50 ppb; and a report determined that a third of Chicago schools tested (30 percent of taps) had at least one sample above 15 ppb.†
- The average age of U.S. public schools is 44 years, but many have undergone major renovations, putting their “functional” age closer to 19 years on average. Despite the upgrades, the American Society of Civil Engineers in 2017 rated school infrastructure and drinking water quality as poor.‡

Continued on next page

- About 10 percent (roughly 8,000) of the nation's schools and child care facilities maintain their own water supplies and are regulated under the Lead and Copper Rule, but because the rule only requires a sampling of taps across the community, many schools may never have been tested. Approximately 98,000 public schools and 500,000 child care facilities are excluded from the federal Safe Drinking Water Act,[§] but in its 3Ts (training, testing, telling) guidance, the EPA recommends testing and a standard of 20 ppb.[‖]
- The CDC School Health Policies and Practices Survey's 2014 data show that nationwide, fewer than half (46 percent) of schools test their drinking water for lead and other contaminants.[#]

In the absence of an overarching law or regulation governing drinking water in public schools and licensed child care facilities, the 2010 Healthy, Hunger-Free Kids Act provides a possible avenue to address lead risks. The act requires schools and child care programs that participate in the National School Lunch (NSLP) and Child and Adult Care Food (CACFP) programs, respectively, to provide children with free potable water.[**] The NSLP operates in more than 100,000 public and nonprofit private schools and residential child care institutions, and in 2012, it provided low- or no-cost lunches to more than 31 million children each school day. CACFP supplied meals and snacks for more than 4.1 million children in child care settings each day in 2015.[††]

The U.S. Department of Agriculture (USDA), which oversees both programs, provides guidance related to drinking water and has encouraged schools and child care facilities to follow the EPA's testing recommendations, but it has not defined the term "potable" to include safety from the risks of lead above the EPA's guidance of 20 ppb.[‡‡] The American Academy of Pediatrics recommends a standard of 1 ppb lead in water from school drinking fountains, and in March 2017, Health Canada published for public comment a maximum allowable concentration of lead in water for schools and child care providers of 5 ppb,[§§] either of which could serve as an updated standard for the U.S.

Providing drinking water that meets such a health-based action level could help protect low-income children served by these programs who are at increased risk of lead exposure.

Many focus group participants raised concerns that school drinking fountains were a potential source of lead, but they also cited drawbacks to efforts to provide alternative sources of drinking water, such as bottled water. For example, schools may need to provide cups, and in some cases parents had to shoulder additional costs. Participants suggested adding filters to fountains or installing filtered-water stations that allow students to refill personal water bottles.

Continued on next page

Concern over contaminated water in schools led to the introduction of 82 bills in 12 states and the District of Columbia in 2016,[‖‖] and several school districts began testing tap water and replacing or shutting down fountains with high lead levels:

- At least nine states and the district took action to test school drinking water at the tap, including the Oregon Health Authority, which posted its results online.[##]
- Governor Jerry Brown (D) of California issued an executive order requiring all public water systems to offer free testing to schools in their service areas and included $9.5 million for remediation in the state budget.
- Massachusetts appropriated $2 million for voluntary school testing.
- Illinois is developing rules for mandatory testing, notification, and mitigation in all licensed child care homes and centers.
- New York, which requires testing and remediation of taps in schools and school-based child care, has included funds for the effort in its state budget, and posts results online.
- Rhode Island's General Assembly passed the Lead and Copper Drinking Water Protection Act in June 2016, requiring schools, day care providers, public playgrounds, shelters and foster homes with children under 6, and other state facilities to certify that drinking water conduits are lead-safe. The act also directs state inspectors to conduct annual lead and copper tests at these locations.[***]

* National Center for Education Statistics, "Digest of Education Statistics" (2016), Table 105.20, https://nces.ed.gov/programs/digest/d15/tables/dt15_105.20.asp?current=yes; U.S. Census Bureau, "Who's Minding the Kids? Child Care Arrangements: Spring 2011" (April 2013), https://www.census.gov/prod/2013pubs/p70-135.pdf.

† U.S. Environmental Protection Agency, "Seattle, WA: Arsenic in Public Schools" (Washington: U.S. Environmental Protection Agency, September 2015), https://www.epa.gov/sites/production/files/2015-09/documents/casestudy_seattle.pdf; Joel Grover and Matt Goldberg, "School Water Investigation—Part 2," NBC Los Angeles, Oct. 30, 2008, http://www.nbclosangeles.com/news/School_Water_Investigation_-_Part_2.html; S. Bryant, "Lead-Contaminated Drinking Waters in the Public Schools of Philadelphia," *Journal of Toxicology: Clinical Toxicology* 42, no. 3 (2004): 287–94; Juan Perez Jr., "CPS Is Testing Schools for High Lead Levels in Water: What You Should Know" *Chicago Tribune*, June 19, 2016, http://www.chicagotribune.com/news/local/breaking/ct-chicago-schools-lead-explainer-met-20160619-story.html.

‡ Debbie Alexander and Laurie Lewis, "Condition of America's Public School Facilities: 2012-2013 (NCES 2014-0222)," U.S. Department of Education (Washington: National Center for Education Statistics, 2014), https://nces.ed.gov/pubs2014/2014022.pdf; American Society of Civil Engineers, "2017 Infrastructure Report Card," accessed May 19, 2017, https://www.infrastructurereportcard.org/americas-grades.

§ U.S. Environmental Protection Agency, "Controlling for Lead in Schools: A Summary of State Programs" (Washington: EPA, Office of Water, 2004), EPA-810-R-04-00, accessed Jan. 22, 2017, https://www.epa.gov/sites/production/files/2015-09/documents/report_lcmr_schoolssummary.pdf; U.S. Environmental Protection Agency, "Lead in Drinking Water in Schools and Childcare Facilities," accessed June 5, 2017, https://www.epa.gov/dwreginfo/lead-drinking-water-schools-and-childcare-facilities.

Continued on next page

|| U.S. Environmental Protection Agency, "3Ts for Reducing Lead in Drinking Water in Schools" (Washington: EPA, 2006), https://www.epa.gov/sites/production/files/2015-09/documents/toolkit_leadschools_guide_3ts_leadschools.pdf.

Centers for Disease Control and Prevention, "School Health Policies and Practice Study: Results From the School Health Policies and Practices Study, 2014" (Atlanta: Centers for Disease Control and Prevention, 2015): 119, http://www.cdc.gov/healthyyouth/data/shpps/pdf/shpps-508-final_101315.pdf.

** Healthy, Hunger-Free Kids Act of 2010, Pub. L. No. 111-296, 124 Stat. 3183 (2010), Section 221 (u) 2.

†† U.S. Department of Agriculture, "Program Information Report (Key Data)" (Washington: USDA, 2016), http://www.fns.usda.gov/sites/default/files/datastatistics/keydata-january-2016.pdf; U.S. Department of Agriculture, "Child and Adult Care Food Program: Why CACFP Is Important," accessed Feb. 4, 2017, http://www.fns.usda.gov/cacfp/why-cacfp-important.

‡‡ U.S. Department of Agriculture, "Resources for Making Potable Water Available in Schools and Child Care Facilities," Memo Code SP 49—2016, CACFP 18—2016 (Alexandria, VA: USDA, Food and Nutrition Service, July 20, 2016), http://media.wix.com/ugd/9c073b_31708a4607294627a28777bc30668936.pdf.

§§ Health Canada, "Lead in Drinking Water" (October 2016), http://www.healthycanadians.gc.ca/health-system-systeme-sante/consultations/lead-drinking-water-plomb-eau-potable/alt/lead-drinking-water-plomb-eau-potable-03-01-2017-eng.pdf.

|| || National Conference of State Legislatures, "State Legislation on Lead, Lead in Water, Lead in Schools 2016-2017," February 2017.

"Drinking Water Test Results: Oregon Schools," Oregon Health Authority (2016), http://geo.maps.arcgis.com/apps/MapSeries/index.html?appid=6a4f2b6001bd474ca7d0a7f0c2552f57.

*** State of Rhode Island, "An Act Relating to Waters and Navigation—Lead and Copper Drinking Water Protection Act," accessed Jan. 13, 2017; State of Rhode Island General Assembly, "Assembly Passes Rep. Naughton Bill to Test Public Drinking Water for Lead, Copper Contamination," accessed Jan. 13, 2017, http://webserver.rilin.state.ri.us/BillText16/HouseText16/H8127.pdf.

Residential lead service line replacement

Under the Lead and Copper Rule, when testing finds lead concentrations that exceed the 15 ppb action level in more than 10 percent of the samples, the utility must evaluate its corrosion control practices, conduct public education, and initiate LSL replacement. Water systems removing LSLs must offer property owners the opportunity to replace their portion of the line at the same time. But because owners cannot be compelled to pay for replacement of their lines, the public portion is often all that gets updated.

However, research showing that lead concentrations increase during and after such partial remediation has raised concerns about safety.[53] For example, one analysis based on an event in Washington, DC, found that children living in homes with lead in at least some part of their service lines were twice as likely as those living in homes without LSLs to have blood lead of 5 to 9 µg/dL and three times as likely to have levels at or above 10 µg/dL. The same study did not find a statistically significant difference between blood lead levels of children from homes with partial versus full LSLs,[54] indicating that partial replacements—in which only one portion of a line is updated—are inadequate to protect children from exposure.

In 2011, an expert panel advising the EPA reviewed pilot studies and anecdotal reports from utilities and concluded that partial LSL replacement does not reliably reduce water lead levels, at least in the short term, and may result in more harm than benefit.[55] A recent field study monitoring partial replacement over 18 months found a short-term increase immediately following replacement and then slightly lower water lead thereafter.[56] A Canadian study also showed a short-term (less than one month) increase but found no improvement compared with no replacement after six months. These analyses confirm the limited benefits of partial replacement for reducing water lead levels and conclude that full replacement is preferable.

The number of LSLs in use across the country is unknown, but estimates suggest that between 5.5 and 10 million LSLs provide water to an estimated 15 to 22 million people. Similarly, no national data characterize the levels of lead in U.S. drinking water, so as communities work to more clearly identify the number of LSLs in operation, the estimates could prove low.[57]

Policy in Action: Strategies to Promote Lead Service Line Replacement

Milwaukee requires full replacement of lead service lines with copper pipe if a leak or failure is discovered or if the utility-owned portion is replaced on a planned or emergency basis. The city is using $2.6 million in state grants to replace lines at 300 day care centers and 300 residences as well as $3.6 million of its own funds to cover replacement of the city-owned portion of 600 other residential lines. The city's total $3.9 million budget for the program also includes funds to help pay for replacement of privately owned LSLs at the same time that the city updates the public portions and to provide water filters and bottled water to property owners during the work. Under the program, property owners are responsible for no more than one-third of the cost of replacement up to $1,600 if the work is done by a city contractor, and they can pay their share over 10 years. Previously, a property owner was responsible for the full cost, which could be as much as $7,000.

Milwaukee Water Works will use customer water payments to cover the balance of the cost to replace the city-owned portions, and property taxes will cover the difference for the private portion. The program is expected to take several decades to complete, reaching about 600 properties a year until all 68,300 known residential LSL are replaced.[*]

In 1986, **Woonsocket, Rhode Island**, adopted a policy requiring builders to replace the entire lead service line when a structure is sold, demolished, or replaced.[†] The property owner is responsible for the cost of the private side, and the city pays for its part at the same time, if it has not already been replaced.

In November 2016, the Centers for Medicare & Medicaid Services (CMS) authorized an amendment to allow **Michigan**'s Children's Health Insurance Program (CHIP) to pay for the replacement of water pipes and fixtures from the homes of low-income families with children, marking the first such approval.

Continued on next page

The amendment was developed under a provision that allows a state to access special federal CHIP matching funds for certain noncoverage-related expenditures that have a value of no more than 10 percent of the state's total amount paid for program benefits. Eligible activities include initiatives targeted at improving the health of children, outreach, translation or interpretation services, payments for other child health assistance such as specialty care not included in the benefit package, and other reasonable administrative costs.[‡]

Properties in Flint with contaminated water receive first priority, and any property in the state with a resident under 19 who qualifies for Medicaid or CHIP is eligible. Under the initiative, Michigan will spend $333,000 on the effort in fiscal year 2017, which will be matched by $23.5 million in federal funds. Over five years, the state plans to spend $119 million. Lead paint hazard control for eligible statewide residences is also an allowable expense under the initiative.[§]

* Don Behm, "Milwaukee Aldermen Approve Lead Pipe Replacement Plan," *Milwaukee Journal Sentinel*, Dec. 13, 2016, http://www.jsonline.com/story/news/local/milwaukee/2016/12/13/milwaukee-aldermen-approve-lead-pipe-replacement-plan/95342526.

† Lead Service Line Replacement Collaborative, "State and Local Examples," *Requiring LSL Replacement When Opportunities Arise*, accessed May 25, 2017, http://www.lslr-collaborative.org/requiring-lsl-replacement.html.

‡ Cindy Mann, Kinda Serafi, and Arielle Traub, "Leveraging CHIP to Protect Low-Income Children From Lead" (January 2017), https://www.manatt.com/getattachment/235604fe-5700-4ec1-a25e-7d51c4e347af/attachment.aspx; U.S. Centers for Medicare & Medicaid Services, "Michigan Health Services Initiative," *2016 Fact Sheets*, Nov. 14, 2016, https://www.cms.gov/newsroom/mediareleasedatabase/fact-sheets/2016-fact-sheets-items/2016-11-14-3.html.

§ David Eggert for Associated Press, "Michigan Gets Federal OK to Spend $119 Million on Lead Abatement," *Crain's Detroit Business*, Nov. 14, 2016, http://www.crainsdetroit.com/article/20161114/NEWS01/161119887/michigan-gets-federal-ok-to-spend-119-million-on-lead-abatement; Kaiser Family Foundation, "Michigan's Medicaid Section 1115 Waiver to Address Effects of Lead Exposure in Flint," accessed Jan. 26, 2017, http://kff.org/medicaid/fact-sheet/michigans-medicaid-section-1115-waiver-to-address-effects-of-lead-exposure-in-flint.

Stakeholder input

Participants in the focus groups recognized that lead in water from fixtures, solder, and pipes is a potential source of childhood exposure. Many community residents knew about steps they could take to reduce the risk, such as flushing taps and using bottled or filtered water, but some expressed concerns that bottled water could also be contaminated with lead or other chemicals. A few participants across multiple groups did indicate some misperceptions about lead in drinking water, primarily that it would be visible as a brown tint or particulate matter. A few believed that boiling water could protect against lead when, in fact, it can actually increase the concentration.[58]

Focus group participants in Flint emphasized the burden the city's crisis has placed on small-business owners and residents. For example, a woman who prepared and sold tamales from her home was forced to terminate her business because of water contamination. Others described stress and strain on social relationships resulting from worry and embarrassment over the quality of water in homes and said fear of unsafe water even led a church to discontinue baptisms. One nursing mother explained that she had asked to have her blood tested for lead to ensure that she could safely breastfeed her child. The discussions also highlighted the importance of tailoring LSL replacement policies to local contexts; for example, a policy to replace pipes in Lansing, Michigan, may not be successfully replicated in Flint because as participants explained, Flint's water pipes are intricately bent rather than straight as in Lansing. Community members also noted that Flint's water system is underused due to significant population declines after the closure of General Motors' manufacturing plants.

Participants identified potential unintended effects of LSL removal, including traffic issues and closed streets. Others expressed concern about the cost of replacing private lines. Some also worried that the expense associated with replacing public lines would present a barrier to decision-makers in their communities. One Flint focus group participant said he "simply didn't trust the water and couldn't bear to drink it" despite having received LSL replacement and filters.

Participants in the national listening sessions said policies aimed at eliminating lead in water should address the risks of partial LSL replacement, consider the need for better sample collection and testing and reporting methods, include remediation as part of federal infrastructure investments, and ensure that grant assistance is available if abatement becomes a requirement of real estate transactions. They also pointed out that most federal, state, and local laws regarding lead hazards in housing do not address drinking water. For example, replacement of leaded pipes or plumbing is not an eligible expense under HUD's lead paint hazard control grant program because the relevant statute specified only paint, dust, and soil hazards.

These participants and expert advisers also expressed concern that consumers incorrectly interpret the EPA's action level of 15 ppb as addressing their individual tap, rather than the water system as a whole. Stakeholders recommended that the EPA issue a separate tap action level to help customers know when they should take steps to reduce the amount of lead in their water. The experts also pointed to a recent assessment by Health Canada that proposed a maximum allowable concentration of 5 ppb, and they suggested the same level could serve as an interim standard toward the goal of getting to 1 ppb over time.

Experts further expressed concern about the water sampling protocol used by utilities, specifically that too few samples are drawn within each home and that the samples are not consistently taken after the water has sat in the pipe (stagnated), so they may underestimate the risk to consumers. Many factors, including the materials used to collect samples, water flow rates, and components at the tap also influence results, so typical testing may not always be reliable. However, identifying a revised sampling protocol was beyond the scope of this study.

Experts recommended that the EPA develop a new protocol and partner with state agencies to assure that utilities inform homeowners about appropriate test procedures. They also thought that the EPA should require more widespread monitoring of lead in customers' tap water rather than the current practice of sampling only a percentage of taps.

Proposed solution

Full lead service line replacement (from street to structure) in the U.S. could take 20 to 30 years to complete, and a large number of homes still have lead plumbing fixtures. The research suggests a multipronged approach is the best option for reducing children's exposure to lead in drinking water. First, the EPA should improve corrosion control efforts by strengthening its Lead and Copper Rule to increase compliance monitoring, the use of corrosion control, and the adoption of optimized corrosion control, a practice that can involve adjusting the pH of water and adding chemicals to inhibit corrosion. Second, rather than treating LSL replacement as a last resort, municipalities should proactively replace lead service lines. Finally, in light of the evidence of public health risks associated with partial replacement, municipalities should replace the entire line during routine repairs that disturb LSLs.

Although corrosion control will remain an important component of lead management, particularly for addressing risks associated with leaded plumbing fixtures and solder, because of concerns about the consistent effectiveness of corrosion control practices, and to permanently remediate a key source of exposure, the research team modeled the costs and benefits of removing LSLs from homes built before 1986 where children in the 2018 birth cohort would reside.

Although the benefit of the intervention is broad—affecting hundreds of thousands of children, as discussed earlier—children residing in low-income communities and localities with aging infrastructure would reap the greatest benefits from the replacement of lead service lines.

Literature summary

Evidentiary support: Scientifically supported. Strategies have been tested in multiple robust studies with consistently favorable results.[59]

Population affected: Regional or national.[60]

Modeling assumptions

- The number of LSLs used in this analysis relied in part on self-reported survey data collected from water utilities and on input from industry representatives.[61] No data source was found to document how many children are served by LSLs or their blood lead levels, so the team used a national survey of water systems to first estimate that 6.84 percent of the U.S. population is served by a lead service line and then applied that percentage to the roughly 4 million children estimated by the Current Population Survey to be in the 2018 cohort.[62] This calculation determined that the number of children born in 2018 who would be served by a lead service line is 272,285.[63]
- In the absence of national data to characterize the level of lead in drinking water in homes served by LSLs, the research team used two water lead levels for reference. A mean concentration of 11.4 ppb was derived from unpublished profiling samples from five Midwest utilities that were compliant with the Lead and Copper Rule but were not considered to have optimized corrosion control, and a lower level of 5 ppb was taken from profiling samples of an eastern U.S. utility viewed as using optimized corrosion control and from unpublished data from the city of Ottawa.[64] These levels were selected to be indicative of systems in compliance with the Lead and Copper Rule and to reflect the likely mean concentration of lead in water after stagnation. The team, in consultation with members of the advisory committee, assumed that LSL replacement could reduce drinking water lead levels to 2 ppb, rather than zero, because of remaining lead plumbing fixtures and solder in homes.
- To estimate baseline levels for children living in homes built before 1986 (the year the EPA banned lead in drinking water pipes), the team used NHANES blood lead level data for children residing in homes built before 1990—the closest available year.
- Although two well-designed studies from the literature review provided an effect size for the relationship between lead in water and children's blood lead levels, both had limitations that made them inappropriate for use in this study. Therefore the research team used the EPA's Integrated Exposure Uptake and Biokinetic (IEUBK) model estimates of 0.042 μg/dL change in blood lead per 1 ppb difference water lead.[65] Applying this estimate to the expected water lead changes, the team estimated that full residential LSL replacement would

prevent a 0.40 μg/dL and a 0.13 μg/dL increase in blood lead, for the 11.4 ppb and 5 ppb baseline water lead levels, respectively, and then applied these estimates to children's starting blood lead levels from NHANES. (See the appendix for more details.)

- In the absence of national pricing data for full LSL replacement, the research team estimated a per-unit cost of $6,000. A 2008 national survey of utilities found that typical replacement costs ranged widely from $250 for the utility portion and $600 for the customer portion to $3,000 and $4,000, respectively.[66] A recent informal survey of all systems known to be pursuing full LSL replacement suggested average costs of roughly $7,500.[67] Given the cost variations across localities, the research team combined these estimates to calculate the per-unit cost.
- The benefits include one child per home from the 2018 birth cohort as well as 80,000 additional children born into the remediated homes in the subsequent 10 years. They do not account for children who visit but do not reside in those homes.

Findings

The analysis, including the calculations of blood lead, cost, and children affected as well as the modeling, found that full LSL replacement across all homes built before 1986 with resident children would:

- Protect 352,000 children, including 272,000 born in 2018 and 80,000 born into the same homes over the next 10 years.
- Cost an estimated $2.0 billion for the 2018 cohort.

For homes with baseline water lead levels around 11.4 ppb, the intervention would:

- Prevent an increase of 0.40 μg/dL lead in the blood of children in the 2018 birth cohort.
- Produce total future benefits of $2.7 billion, including $480 million for the federal government and $250 million for states and municipalities.
- Generate roughly $1.33 per $1.00 invested.

If, alternatively, baseline water lead levels were 5 ppb, replacing LSLs would:

- Prevent an increase of 0.13 μg/dl lead in the blood of children in the 2018 birth cohort.
- Yield future benefits of $860 million, including $150 million for the federal government and $80 million for states and municipalities.
- Result in $0.42 in benefits for each $1 invested. (See Table 3.)

Table 3

Every Dollar Invested in Full Lead Service Line Replacement Would Generate $.42 to $1.33 in Benefits

Cost-benefit analysis, for two initial water lead levels

Baseline estimates	Number and percentage of children born in 2018 into homes built before 1986 (1 child per unit)		2,352,000 (59%)	
	Percentage of those children in homes with potential lead service lines (LSLs)		6.84%	
	Average blood lead level for children without intervention		1.19 µg/dL	
	Starting level of lead in water (ppb)		11.4	5
Predicted impacts	Homes receiving lead service line replacement		272,000	
	Children affected (including future cohorts)		352,000	
	Expected decrease in water lead (ppb)		**9.4**	**3**
	Prevented blood lead level increase per child (µg/dL)		**0.40**	**0.13**
Gross future benefits	Initial cohort	Earnings	$2.0 billion	$640 million
		Health savings	$40 million	$10 million
		Education savings	$50 million	$20 million
		Quality-adjusted life years benefits	$80 million	$30 million
	Future cohorts (through year 10)		$550 million	$170 million
	Total gross future benefits		**$2.7 billion**	**$860 million**
	Share to federal government		**$480 million**	**$150 million**
	Share to state and local governments		**$250 million**	**$80 million**
	Share to households, the private sector, and other nongovernmental entities		**$2.0 billion**	**$630 million**

Continued on next page

Costs	Testing cost per potential lead service line	$175	
	Total testing cost	$410 million	
	Full lead service line replacement cost per home	$6,000	
	Full lead service line replacement cost for all homes	$1.6 billion	
	Total costs	**$2.0 billion**	
Net	Net future benefits	$680 million	-$1.2 billion
	Cost-benefit ratio	1.33	0.42

Notes: Analysis is based on the 2018 birth cohort, estimated at approximately 4 million children. Analysis includes benefits for future cohorts. Total future benefits include small changes in incarceration costs not itemized in the table. Values may not add up to totals because of rounding.

Source: Altarum Institute Value of Prevention Tool calculation

Policy in Action: Replacing Lead Service Lines

From 2004 through 2016, **Lansing, Michigan**, replaced 12,150 LSLs with copper lines at a cost of $44.5 million through a program of the Lansing Board of Water and Light (BWL), a municipally owned utility.[*] In 2004, then-Michigan State Senator Virg Bernero encouraged local officials to advocate with BWL Commissioners to accelerate the removal of Lansing's LSLs. The BWL funded the program as an infrastructure investment and utility customers shared the cost through an increase in water rates.[†] BWL prioritized lines serving schools and licensed day care centers, areas where testing showed that children had high blood lead levels, households with pregnant women or children under 6, and other places with large concentrations of LSLs.[‡]

BWL has developed a faster, more efficient method for replacing pipes: What had been a nearly eight-hour, $9,000 job requiring a trench to be dug from the main to the foundation of the house was streamlined to four hours and $3,600. Now, rather than trenching, BWL digs a hole in the street and another at the shut-off valve and pulls a new pipe in behind the old one.[§] Where possible, the program has followed planned street, sewer, and other infrastructure projects to minimize street closures and reduce street reconstruction costs.[||]

BWL water quality reports indicate a decrease in lead levels in the water over 10 years, with 90 percent of homes falling from 11.3 ppb in 2005 to no more than 7.8 in 2015.[#] Although BWL has completed its LSL replacement program, it plans to continue corrosion control processes.

* Lansing Board of Water and Light, "Lead Service Advisory Information," accessed Jan. 12, 2017, https://lbwl.com/Community-Impact/Water-Quality/Lead-Service-Information; Lansing Board of Water and Light, "BWL 2015 Annual Water Quality Report," accessed Jan. 12, 2017, http://lbwl.com/WaterQualityReport; Lorna Benson, "In Battle to Keep Lead From Water, St. Paul Digs Deep," MPR News, May 25, 2016, https://www.mprnews.org/story/2016/05/25/water-stpaul-lead-pipes.

† Trent Gillies, "Flint Crisis Can Be Fixed With $55M in New Pipes: Lansing Mayor," CNBC, April 24, 2016, http://www.cnbc.com/2016/04/22/flints-crisis-can-be-fixed-with-55m-in-new-pipes-lansing-mayor.html.

‡ Lansing Board of Water and Light, "Lead Service Advisory Information."

§ Faith Miller, "Lansing BWL Helping Flint Figure Out How to Replace Lead Pipes," WILX 10, Feb. 9, 2016, http://www.wilx.com/home/headlines/Lansing-BWL--368260751.html.

|| Lansing Board of Water and Light, "Lead Service Advisory Information."

Lansing Board of Water and Light, "BWL 2015 Annual Water Quality Report"; Lorna Benson, "In Battle to Keep Lead From Water, St. Paul Digs Deep."

Lansing Board of Water and Light employees replace the last lead service line with copper pipes in Lansing, Michigan, on Dec. 14, 2016.

Potential challenges

Although specifics vary across communities, service lines are typically jointly owned: The utility generally owns the portion running from the water main at the street to the property line, while the section from the property line into the home, as well as the household plumbing, belongs to the property owner. Also, some cities assess substantial permitting fees; for example, Chicago reportedly charges $3,500 for city permits to perform the work.[68]

The concerns discussed above about partial LSL replacement risks have prompted some municipalities, such as Lansing, Madison, and Milwaukee, to prohibit the practice and have driven others to authorize public water utilities to replace the privately owned lines.[69] Promptly replacing LSLs would improve children's health and produce economic benefits, but it also would be costly and has the potential for unintended consequences. In particular, avoiding excessive costs to taxpayers, utilities, and ratepayers; proactively planning for the safe disposal of removed leaded lines; and minimizing traffic issues, street closures, and disruption to residents would all require significant planning, budgeting, and organizational capacity. In addition, investing in LSL removal could constrain resources and limit expenditures for other drinking water-related priorities.

The EPA's Drinking Water State Revolving Loan Fund (DWSRF) offers one potential means of offsetting these expenses. The fund was created in 1996 as an amendment of the Safe Drinking Water Act and is appropriated annually by Congress.[70] The program provides infrastructure grants to the states, the District of Columbia, and Puerto Rico for eligible projects, such as facility upgrades to improve drinking water quality and installation of water storage tanks. Grant awards are based on the most recent Drinking Water Infrastructure Needs Survey and Assessment, and states must provide 20 percent in matching funds. As water systems repay loans, the principal and interest are directed back into the fund. In total, the DWSRF has provided over $32 billion to water systems through nearly 13,000 grants.

Lead paint hazards

> I didn't think about it. … We had repainted every surface of the house. It looked clean. It looked neat. It looked ready. But there was still lead."
>
> —Baltimore resident

Lead-based paint and the contaminated dust it generates in homes and soil represent one of the most dangerous and widespread sources of exposure afflicting children.[71] The relationship between lead paint and blood lead has been extensively studied.[72] More than half of homes built before 1978 have some lead-based paint, and the share increases to 76 percent and 86 percent for homes built before 1960 and 1940, respectively.[73] The 2006 American Healthy Homes Survey found that more than a third of the nation's housing stock (an estimated 37 million residences) contain lead paint, and more than 1 in 5 homes (roughly 23 million) have deteriorating lead paint or dust or soil lead levels that exceed federal standards. Approximately 3.6 million homes with lead paint hazards house young children, including those from roughly 1.1 million low-income households.[74]

Residential remediation

Reducing lead paint hazards in homes involves testing paint, dust, and soil to determine whether levels are above federal standards. Once a lead paint problem is identified, property owners typically choose from one of two methods for dealing with it: Long-term "abatement" can last at least 20 years and involves either permanently covering or removing lead paint,[75] while shorter-term "interim controls" include repairing flaking and peeling paint and covering contaminated soil with mulch or grass. Windows have the highest levels of lead paint and dust compared with other building components, and replacing windows with lead paint has been shown to deliver large, sustained reductions in dust lead levels, including on floors that children are likely to contact more frequently.[76] One barrier to replacing old windows coated with lead paint is provisions of the National Historic Preservation Act, which along with state and local rules restricts replacement of features such as windows in historic homes.[77]

The preponderance of research evidence, including from multiple randomized-control trials and systematic reviews, demonstrates the effectiveness of lead paint hazard control,[78] but a small body of research has contradicted those findings. A few studies from the late 1980s and early 1990s found increased blood lead levels after abatement, but those discordant findings were the result of unsafe practices such as using high heat to remove paint, which created dangerous fumes and dust,[79] and which the federal government banned more than 20 years ago. In addition, some systematic reviews have found limited evidence to support lead paint abatement. However, those studies focused on the efficacy of treatment measures in reducing elevated blood lead levels in children,[80] which is an imperfect metric because blood lead can remain elevated for months or years after exposure as lead is exchanged between blood and bone.[81] In children, bone lead represents about 70 percent of total body lead,[82] so blood levels of lead-exposed children would not be expected to be statistically different one year after their homes were treated. Therefore, not only do those findings not suggest that the intervention is ineffective, they in fact underscore the importance of actions, such as abatement, that can prevent exposure.

The primary federal law concerning lead paint hazards in housing is the Residential Lead-Based Paint Hazard Reduction Act, also called Title X, to reflect the section of the Housing and Community Development Act of 1992 in which it was enacted.[83] Key features of the act include:

- **Authorizing the HUD lead hazard control grant program**, which is the federal government's primary means of assisting homeowners with control efforts. The program makes up less than 0.3 percent of the department's budget.
- **Creating a certification system for individuals and businesses** performing lead control activities.
- **Requiring either interim controls or lead abatement for federally owned and assisted housing**, such as public and military housing.
- **Establishing the federal lead disclosure rule**, which requires property owners to reveal any known lead paint hazards to prospective buyers or tenants before a property is sold or rented.
- **Defining existing lead-based paint in housing as containing 5,000 ppm of lead** or 1 mg/cm^2.
- **Requiring EPA to publish standards** for lead in dust and bare soil at residential properties.

Title X led to a significant reduction in the number of homes with lead paint hazards. Specifically, more than 190,000 homes have been made lead-safe with HUD lead hazard control grants since the program's inception in 1993. The program has a budget of about $90 million that supports lead-hazard reduction in roughly 7,000 units each year, but the funding amount falls far short of the $230 million recommended by a federal lead poisoning prevention task force in 2000.[84] About 12,000 low-income homes undergo lead paint hazard control annually under HUD regulations authorized by Title X that apply to federally assisted housing. Additionally, HUD, the EPA, and the Department of Justice enforce the federal lead disclosure rule which to date has yielded $31 million in settlement funds from property owners, and under landlords' agreements with HUD, the remediation of lead paint hazards in more than 188,000 homes of low-income families.

Rental housing built before 1960 that is in poor condition and is occupied by low-income families carries the greatest lead risks. States and local agencies can use available data to identify the neighborhoods and even blocks or streets that have these characteristics and target resources to those areas.[85] One study found that children from low-income families residing in federally assisted rental properties had lower blood lead levels than comparable children living in housing without federal subsidies.[86] These results suggest that the former group's rental units may be in better condition because of federal requirements and that unsubsidized low-income housing should be the primary focus for action in many states and localities. However, in communities that have strong policies in place to prevent children from being exposed to lead in rental housing, low-income owner-occupied homes, such as those handed down through generations, pose the more serious threat. Such variation in risk profiles within and across communities underscores the need for neighborhood-level data to support decision-making.

Forty-four states have adopted laws addressing lead paint hazards, and 38 require certification for contractors that conduct lead inspections and abatement. EPA handles such licensing for the remaining states.[87] Several municipalities also have taken action to address lead hazards in housing through code enforcement or public health laws. Such local government action has the advantage of being targeted to communities' immediate situations. For example, the city of Rochester, New York, used neighborhood-level blood lead data to prioritize enforcement of its local law. Municipal laws also are often more easily amendable than federal or state laws.[88]

Frequently, a small number of rental units is responsible for poisoning many children in a given community. For example, in Chicago, 67 high-risk buildings contributed to 994 cases of high lead levels, and in Jefferson County, Kentucky (home to Louisville), 79 houses were home to 35 percent of the children with blood lead levels at or above 20 µg/dl.[89] This is largely because most state and local laws permit property owners to re-rent units where a child has been exposed to lead even if the hazards persist. Laws requiring inspection and treatment of units with identified lead hazards can prevent multiple cases of lead poisoning at the same address. A study found that Massachusetts and Ohio, which mandate inspection and treatment of units with hazards, were 79 percent less likely than Mississippi, which lacks such a requirement, to have residential addresses that repeatedly contributed to high lead levels in children.[90]

Policy in Action: Local Lead Paint Laws

In **Rochester, New York**, 87 percent of homes were built before 1950, and 60 percent of housing is tenant-occupied.[*] In December 2005, the City Council passed an ordinance requiring regular inspections of most pre-1978 rental housing for lead paint hazards as part of the city's certificate of occupancy process for rental properties.[†]

Housing inspections may be triggered by a new certificate of occupancy, renewal of an existing certificate, a neighborhood survey, a referral by an outside agency, or a complaint. Single-family and duplex rental units are inspected every six years with some exceptions, and buildings with three or more units as well as mixed-use properties are inspected every three years.

To receive a certificate, property owners must correct identified lead hazard violations. The city maintains an online database of all lead-safe units and properties granted a certificate.[‡]

Experts describe Rochester's law as one of the smartest in the nation.[§] In the decade since the ordinance's passage, the city has inspected more than 141,000 homes and the number and proportion of children with high blood lead levels has decreased countywide. In 2004, 900 children tested for lead in Monroe County had levels above the CDC's action level at the time of 10 µg/dL compared with 206 children in 2015.[||] Between 1997 and 2011, the number of children with blood lead over 10 µg/dL decreased roughly twice as fast in Monroe County as it did in New York state as a whole and nationwide.[#] Despite this significant progress in 2015, 988 of 14,283 children tested—enough to fill more than 40 kindergarten classrooms—had blood lead levels at or above CDC's current reference value of 5 µg/dL, indicating that additional efforts are needed in Rochester.[**]

The District of Columbia's Lead Hazard Prevention and Elimination Act of 2008, amended in 2011, prohibits the presence of lead-based paint hazards in dwelling units, common areas of multifamily properties, and day care and prekindergarten facilities constructed before 1978.[††] Before a purchaser or tenant is obligated under contract to buy or lease a unit, the property owner must prove no lead-based paint hazards were present within the previous 12 months.[‡‡]

Continued on next page

A related provision extends this requirement to units occupied or visited by a child or pregnant woman. In addition, if owners discover lead-based paint in their properties, they must disclose it to their tenants within 10 days.

* National Institutes of Health, "Rochester's Lead Law: Evaluation of a Local Environmental Health Policy Innovation," accessed Jan. 13, 2017, http://www.cityofrochester.gov/article.aspx?id=8589936091.

† City of Rochester, "Article III: Lead-Based Paint Poisoning Prevention," accessed Jan. 13, 2017, http://ecode360.com/8677707; City of Rochester, "Lead Paint—Get Prepared," accessed Jan. 13, 2017, http://www.cityofrochester.gov/article.aspx?id=8589936091.

‡ Dan Telvock, "Rochester Leads on Lead While Buffalo Dallies," *Investigative Post*, accessed June 9, 2017, http://www.investigativepost.org/2014/11/12/buffalo-lacks-leadership-lead-poisoning-problem.

§ Rachel Dissell and Brie Zeltner, "How Rochester Responded to Its Lead Poisoning Problem: Toxic Neglect," *Cleveland Plain Dealer*, Oct. 23, 2015, http://www.cleveland.com/healthfit/index.ssf/2015/10/how_rochester_stopped_using_ch.html.

|| Meaghan M. McDermott, "Lead Levels on the Rise in Monroe County," *Democrat & Chronicle*, June 28, 2016, http://www.democratandchronicle.com/story/news/2016/06/28/children-lead-levels-monroe-county/86471002.

Byron Kennedy et al., "Declines in Elevated Blood Lead Levels Among Children, 1997-2011," *American Journal of Preventive Medicine* 46, no. 3 (2014): 259–64, http://dx.doi.org/10.1016/j.amepre.2013.11.007.

** McDermott, "Lead Levels on the Rise."

†† D.C. Official Code § 8-231.01 et seq.

‡‡ D.C. Municipal Regulations and D.C. Register, "Regulation of Lead-Based Paint Activities."

Stakeholder input

Regardless of race, ethnicity, and socioeconomic status, focus group participants worried about children coming into contact with lead paint at home. Nearly all parents said they wished they had more information about lead hazards in their homes before their children were exposed. Many also said that lead disclosure forms did not sufficiently communicate the dangers, and that they would prefer to have access to property inspection documents. Two homeowners admitted disregarding the lead disclosure information when they purchased their homes to avoid seeming fussy or losing the sale. Renters suggested that fear of eviction might prevent them from raising concerns about lead hazards with their landlords. Similarly, concerns about property devaluation keep many property owners from testing for lead.

Community residents largely agreed that fining noncompliant landlords is inadequate because it does not necessarily compel property owners to address the lead hazards. Families that moved to avoid continued exposure worried that future renters could be in danger because of the landlord's failure to comply or inability to afford abatement or remodeling. Landlords, in turn, worried about lawsuits, even when the rental unit was not confirmed as the primary source of exposure.

Not surprisingly, residents and landlords had different views on requiring inspections to identify lead hazards. Some renters had experienced conflicts with landlords over lead hazards, while property owners worried that the costs of addressing lead could cause financial strain and difficulty selling homes that still required abatement. Funding for abatement could mitigate some of these unintended harms. The cost of remediation and restrictions on the type of modifications allowed to historic properties, such as window replacements, could make it difficult for landlords meet lead requirements.

To reduce these burdens, some participants proposed prioritizing inspections for homes with young children or units rented using housing vouchers, but targeting units with young children could mean lead paint hazards in the homes of grandparents or other caregivers go undetected and could discourage landlords from renting to families. Another suggestion was offsetting the cost of window replacement and lead abatement through tax credits and financing to minimize burdens and encourage landlords and homeowners to have properties inspected. Some participants, however, identified citizenship requirements to receive financing and credits as a barrier for some property owners to access such funding.

In interviews, stakeholders recommended that jobs generated to address lead paint hazards in housing, such as inspectors and lead paint hazard control workers, be offered first to community members in lead-affected areas.

Policy in Action: State Lead Paint Hazard Control Laws

Maryland's Reduction of Lead Risk in Housing Act, enacted in 1994 and amended in 2012, requires owners of rental residences built before 1978 to annually register their properties with the Maryland Department of the Environment indicating that they are free of chipping, peeling paint, and lead-contaminated dust. To qualify for registration, owners must hire a certified contractor to address any defective paint and have an accredited inspector verify compliance before any change in occupancy. The department files between 500 and 800 violation notices annually, and a team from the state's attorney general's office is responsible for enforcing actions against noncompliant owners. Since the law's enactment, the rate of high blood lead levels in Maryland children has declined by 98 percent: In 1993, 14,546 (23.9 percent) of the 60,912 children under 6 tested had blood lead levels of 10 µg/dl or higher, and by 2015, that figure had declined to 377 children of 110,217 (0.3 percent).[*]

Since 1993, **New York state** regulations have included a Notice and Demand component that requires property owners to address lead hazards to prevent exposure. After inspecting a unit for lead paint hazards, including deteriorated paint and contaminated dust and bare soil, the local health department can issue a written notice, which outlines the hazards present and requires owners to submit a corrective work plan within a fixed number of days.[†]

Continued on next page

* Maryland Department of the Environment, "Lead Poisoning Cases Drop in Baltimore and in Maryland, Department of the Environment Moves to Reduce Potential Exposures in More Homes," accessed Jan.12, 2017, http://news.maryland.gov/mde/2015/09/03/lead-poisoning-cases-drop-in-baltimore-and-in-maryland-department-of-the-environment-moves-to-reduce-potential-exposures-in-more-homes; Maryland Department of the Environment, "Childhood Blood Lead Surveillance, Statewide 1993-2014," accessed June 14, 2017, http://www.mde.state.md.us/programs/PressRoom/Documents/Childhood_Lead_Surveillance_Statewide_1993-2014.pdf; Maryland Department of the Environment Lead Poisoning Prevention Program, "Childhood Blood Lead Surveillance in Maryland: Annual Report 2015," accessed May 25, 2017, http://www.mde.state.md.us/programs/land/documents/leadreports/leadreportsannualchildhoodleadregistry/leadreportclr2015.pdf.

† New York State Department of Health, "NYS Regulations for Lead Poisoning Prevention and Control—NYCRR Title X, Part 67," accessed Jan. 13, 2017, https://www.health.ny.gov/regulations/nycrr/title_10/part_67/#sec67-2-6.

Proposed solution

According to HUD, roughly 23 million residences have lead hazards such as peeling paint, contaminated dust, or toxic soil, and 3.6 million of these are home to young children.[91] Substantial evidence including from randomized control trials indicates that remediating lead paint hazards reduces blood lead levels, and many states and localities have undertaken successful lead hazard control efforts.[92] Given this diverse body of evidence, the research team chose to analyze the impacts of testing and treating paint, dust, and soil, and replacing old windows.

Literature summary

Evidentiary support: Scientifically supported. Strategies have been tested in multiple robust studies with consistently favorable results.[93]

Population affected: Regional or national.[94]

Modeling assumptions

- Using published literature on the effects of lead paint hazard control on dust lead levels and studies of the relationship between lead in dust and in blood, the team undertook a two-step process to estimate that removing lead paint hazards from homes before those children are born would prevent a 40 percent increase in their blood lead.

  To establish the reduction in dust lead levels resulting from lead paint hazard control, the team used data from a long-term follow-up of interventions in 189 nonrandomly selected homes from multiple regions of the country that found an 89 percent decline in dust lead 12 years after treatment.[95] The study did not include a control group for ethical reasons, but it is, nevertheless, the largest and longest national evaluation of lead hazard control efforts, and its findings align with many smaller studies of lead paint hazard control effects.[96] Second, the team used a national cross-sectional survey conducted from 1999 through 2004 to predict the effect of decreased dust lead on child blood lead levels.[97] The data indicated that the above-referenced 89 percent reduction in dust lead would prevent a 39.5 percent increase in children's blood lead levels.

- The study team used the American Healthy Homes Survey to estimate that about 75 percent of pre-1960 homes and 50 percent of pre-1978 homes have lead-based paint and would require remediation.[98]
- The per unit cost of remediation is estimated based on data from HUD's Lead Hazard Control program which includes costs for replacing some windows, treating deteriorated paint, remediating toxic soil, and repairing other high-risk areas, such as doors. In addition, the cost estimates include $1,000 for testing of paint, dust, and soil to identify hazards before work is initiated and to ensure the safety of the home before residents return. The costs do not include expenses necessary to administer lead-hazard control programs, for which HUD spends about $2.7 million. HUD also caps administrative costs for grantee states and municipalities at 10 percent, typically less than $300,000 for a three-year program.
- The benefits include one child per home from the 2018 birth cohort as well as 67,000 additional children likely to be born into the remediated homes in the subsequent 10 years.[99] They do not account for children who visit but do not reside in those homes.[100]

The team modeled the implementation of lead paint hazard control under four scenarios. Specifically, the models examined impacts for those living in homes built before 1978, the year that the CPSC restricted the use of lead-based paint for residential use, and those built before 1960, because data suggest that the use of lead paint tapered off after that date. Additionally, the team examined the effects of lead paint hazard control for the entire population of children and for the population from families with incomes at or below 120 percent of the federal poverty threshold. (See Table 4.)

Findings

The analysis determined that comprehensive lead paint hazard remediation for the children born in 2018, would, on average:

- Protect 311,000 low-income children who live in homes built before 1960.[101] This includes 244,000 children born in the initial 2018 cohort, with an additional 67,000 births estimated born into the same homes in the following 10 years.
- Cost approximately $2.5 billion.

For homes with floor dust lead levels around 20 µg/sq. ft., the intervention would:

- Yield $3.5 billion in total discounted future benefits, including:
    - $630 million for the federal government.
    - $320 million for state and local governments.
- Generate $1.39 per $1 invested.

If, alternatively, baseline floor dust lead levels are 10 µg/sq. ft., the intervention would:

- Yield $2.8 billion in total discounted future benefits, including:
    - $490 million for the federal government.
    - $250 million for state and local governments.
- Produce $1.09 for every $1 invested. (See Table 4.)

The research found that targeting this intervention only to more at-risk populations—pre-1960 homes, and low-income residents—generates a greater return and higher net benefits.

Table 4

Targeting Lead Paint Hazard Control to Older Low-Income Housing Offers the Greatest Per-Dollar Benefits

Cost-benefit analysis by income, age of housing, and floor dust lead level

			Pre-1960 homes				Pre-1978 homes			
			All		Low-income		All		Low-income	
Baseline estimates	Number and percentage of children expected to live in older housing (1 child per unit)		1,068,000 (26.8%)		321,000 (8.1%)		1,934,000 (48.6%)		600,000 (15.1%)	
	Percentage of those children whose homes need lead hazard control (LHC)		75.8%				52.4%			
	Average blood lead level for children if no intervention (µg/dL)		1.34		1.63		1.25		1.53	
	Starting level of lead in floor dust (µg/sq. ft.)		10	20	10	20	10	20	10	20
Predicted impacts	Homes remediated		809,000		244,000		1,014,000		315,000	
	Children affected (including future cohorts)		1,033,000		311,000		1,295,000		402,000	
	Expected decrease in levels of lead in house dust		76%	89%	76%	89%	76%	89%	76%	89%
	Prevented increase in blood lead levels per child		32%	40%	32%	40%	32%	40%	32%	40%
Gross future benefits	Initial cohort	Earnings	$6.1 billion	$7.7 billion	$2.0 billion	$2.6 billion	$7.2 billion	$9.0 billion	$2.5 billion	$3.2 billion
		Health savings	$140 million	$170 million	$50 million	$60 million	$160 million	$200 million	$60 million	$80 million
		Education savings	$140 million	$170 million	$50 million	$60 million	$170 million	$210 million	$60 million	$70 million
		Quality-adjusted life years benefits	$250 million	$310 million	$90 million	$110 million	$290 million	$360 million	$110 million	$140 million
	Future cohorts (through year 10)		$1.6 billion	$2.0 billion	$530 million	$670 million	$1.8 billion	$2.3 billion	$650 million	$830 million
	Total gross future benefits		**$8.2 billion**	**$10.3 billion**	**$2.8 billion**	**$3.5 billion**	**$9.6 billion**	**$12.1 billion**	**$3.4 billion**	**$4.3 billion**
	Share to the federal government		**$1.5 billion**	**$1.8 billion**	**$490 million**	**$630 million**	**$1.7 billion**	**$2.2 billion**	**$600 million**	**$770 million**
	Share to state and local governments		**$740 million**	**$940 million**	**$250 million**	**$320 million**	**$880 million**	**$1.1 billion**	**$310 million**	**$390 million**
	Share to households, the private sector, and other nongovernmental entities		**$6.0 billion**	**$7.5 billion**	**$2.0 billion**	**$2.6 billion**	**$7.0 billion**	**$8.9 billion**	**$2.5 billion**	**$3.2 billion**

Continued on next page

		Pre-1960 homes				Pre-1978 homes			
		All		Low-income		All		Low-income	
Costs	Cost of inspection per home	$1,000							
	Total inspection costs	$1.1 billion		$320 million		$1.9 billion		$600 million	
	Cost of LHC per home	$9,043				$8,269			
	Total LHC costs	$7.3 billion		$2.2 billion		$8.4 billion		$2.6 billion	
	Total costs	$8.4 billion		$2.5 billion		$10.3 billion		$3.2 billion	
Net*	Net future benefits	-$210 million	$1.9 billion	$230 million	$990 million	-$690 million	$1.8 billion	$200 million	$1.1 billion
	Cost-benefit ratio	0.97	1.23	1.09	1.39	0.93	1.17	1.06	1.35

* Results are based on dust lead levels of 10 or 20 as shown on the previous page.

Notes: Analysis is based on the 2018 birth cohort, estimated at approximately 4 million children, and includes benefits for future cohorts. Total future benefits include small changes in incarceration costs not itemized in the table. Values may not add up to totals because of rounding.

Source: Altarum Institute Value of Prevention Tool calculation

Policy in Action: Financing Lead Paint Hazard Control

Massachusetts' lead law, enacted in 1971, is one of the oldest in the country and requires that any property built before 1978 and occupied by a child under 6 be "deleaded" by removing or covering lead paint hazards.[*] The state also prohibits property owners from discriminating against families with young children when renting or selling. To help homeowners pay for abating lead hazards, including replacement of windows, Massachusetts offers income tax credits of $500 and $1,500, depending on a property's needs, and administers a series of loan programs to support compliance with the law.[†]

Massachusetts imposes surcharges of $25 to $100 on the annual fees of certain professional licenses, including for real estate brokers, property and casualty insurance agents, mortgage brokers and lenders, small loan agencies, and individuals who perform lead inspections.[‡] The collected revenue, roughly $2.5 million annually, is deposited into the Lead Paint Education and Training Trust Account for use by the state's Department of Public Health.[§] In 2016, testing found that of more than 175,000 Massachusetts children tested, just 686 under age 6 had blood lead levels of 10 μg/dL or greater, compared with 3,095 of about 194,000 children tested in 2001, the earliest date for which data are available online.[||]

Continued on next page

* “What Does the Massachusetts Lead Law Require,” Massachusetts Executive Office of Health and Human Services, accessed Jan. 13, 2017, http://www.mass.gov/eohhs/gov/departments/dph/programs/environmental-health/exposure-topics/lead/lead/massachusetts-lead-law-requirement.html.

† Ibid.

‡ National Center for Healthy Housing, “Lead Education Trust Fund,” 2017, accessed June 14, 2017, http://www.nchh.org/Portals/0/Contents/Alternative-Financing-Mechanism_Massachusetts_LETF.pdf.

§ National Center for Healthy Housing, “Lead Education Trust Fund”; Centers for Disease Control and Prevention, “Building Blocks for Primary Prevention,” accessed Feb. 14, 2017, https://www.cdc.gov/nceh/lead/publications/building_blocks_for_primary_prevention.pdf.

|| Massachusetts Department of Public Health Bureau of Environmental Health, Environmental Public Health Tracking, accessed May 24, 2017, http://www.mass.gov/eohhs/docs/dph/environmental/lead/stats/screening-and-prevalence-statistics-by-community-cy-2016.pdf; Massachusetts Department of Public Health Bureau of Environmental Health, “Prevalence of Males and Females With Confirmed Elevated BLLs >= 10 µg/dL, Screened in 2001 That Were Between 0 - <72 Months of Age,” *Environmental Public Health Tracking*, accessed June 6, 2017, table generated from https://matracking.ehs.state.ma.us/Health-Data/Childhood_Blood_Lead_Levels.html.

Potential challenges

Stakeholders pointed to cost as the single biggest barrier to widespread implementation of lead paint hazard control and suggested several financing options, many of which are included in the recommendations. (See Page 79.) At nearly $10,000 per unit, lead paint hazard control is unaffordable for many low- and middle-income Americans. Higher housing costs can have severe consequences for low-income residents if the cost of replacement or abatement is passed on to them. Typical lower-income households spend 40 percent of their income on housing,[102] suggesting many people are vulnerable to even small increases in rents or mortgages. Unaffordable housing can lead to evictions, foreclosures, and homelessness, which can have devastating effects on the health of the family.

Stakeholders also highlighted many missed opportunities to inform renters and owners about potential risks. The federal lead disclosure rule requires only that owners document known hazards before selling or renting a home, not that they determine if lead is in fact present, and lead in water is not covered by the law. However, because most homes in the country have not been inspected, most owners have nothing to disclose. States can expand upon this federal law by requiring inspections during real estate transactions.

Remediating more than a million older low-income homes with children in the country will take time. Meanwhile, preventive housing inspections can help identify hazards and compel action before a child becomes sick. Although prevention is the most urgent and effective policy approach, when a child has already been poisoned, environmental inspections are vital to identify the source and compel property owners to promptly fix hazards. States could prevent the proliferation of repeat-offender units by requiring landlords to fix lead hazards before re-renting a unit and could mandate inspections for all units in a building where one is found to have lead hazards. This requirement would also create jobs because of increased demand for inspection and abatement, and those jobs could be prioritized for low-income residents of the high-risk communities. According to one estimate, addressing lead hazards in the highest-risk homes would create 50,000 to 75,000 jobs.[103]

Luis Benitez (left) and Jose Diaz remove lead paint in a contaminated building in Providence, Rhode Island, in 2006.

Stakeholders highlighted the lack of incentives and policies to encourage replacement of old windows as another missed opportunity. For example, federal programs such as the Department of Energy's (DOE) Weatherization Assistance Program (WAP) uses a "savings to investment ratio" to prioritize possible upgrades, but guidance regarding the calculation of this ratio does not typically rank window replacement high among WAP priorities. States and the DOE could adjust their approaches to this ratio to promote lead paint hazard controls within the WAP.

Another potential barrier to hazard-reduction efforts is that lead-based paint is not part of property value calculations for mortgage and appraisal purposes. For example, the Federal Housing Administration (FHA) states that, for single-family properties it insures, the "[m]ortgagee must confirm that the Property is free of lead paint hazards."[104] However, this determination is typically made based on a visual inspection, not a determination by a licensed lead professional. Without mandatory inspections for lead paint and dust in pre-1978 units, appraisers cannot adjust the market price, provide buyers with important information, or encourage owners to correct hazards, but state and federal home financing programs could update their requirements to include lead inspections.

Lead Paint Hazards and Contaminated Soil at Schools and Child Care Facilities

The most common sources of lead exposure in and around schools and child care settings are lead-based paint, dust, and contaminated soil. (See "Air emissions and soil contamination" on Page 57 for additional information about lead in soil.) This is a particular concern for young children, because of their frequent and extensive contact with soil outside and with floors, carpets, windows, and other indoor areas where dust gathers, as well as their frequent hand-to-mouth activity.[*]

- Approximately 65 percent of school facilities were constructed before 1980.[†] A 2014 national survey of schools and classrooms found that only about a third (34 percent) had been inspected for lead in cracked or peeling paint in the preceding 12 months, and another 29 percent had already been identified as having lead paint hazards and remediated.[‡]
- Further, a 2003 study based on data from a nationally representative sample of licensed U.S. child care facilities showed that 14 percent have one or more lead-based paint hazards, including 26 percent of those located in buildings built before 1960 compared with 4 percent in newer buildings.[§]
- Painted metal or wood playground equipment may also contain high levels of lead, which becomes a risk as it ages.[||] A 1996 Consumer Product Safety Commission (CPSC) investigation of 26 older playgrounds in 13 cities across 11 states found that 20 had equipment with lead paint levels above 600 ppm, the CPSC's standard at the time. In addition, nine states and 19 cities tested 223 additional playgrounds and reported that 125 exceeded the CPSC standard.[#] Many of these playgrounds have probably been replaced in the intervening 30 years, so these data should be interpreted with caution.
- One cross-sectional study of four inner-city child care facilities in New Orleans, which involved testing the hands of 40 children before and after they played outside, found that greater outdoor lead dust levels were correlated with higher levels on the children's hands.[**]

Remediating lead hazards in schools and child care facilities is subject to barriers similar to those identified for home environments. Older buildings tend to have more problems and to be in poorer communities with fewer resources; public schools in these places often have many competing priorities for limited dollars. Without new funding, the cost of removing lead paint, dust, and soil hazards may be a hardship for some school districts, as well as state and local governments.[††] Grants for capital improvements and maintenance, particularly for schools in high-risk communities and that serve low-income children, could help offset this burden and improve health equity for these disadvantaged populations.

Continued on next page

One possible model for addressing lead hazards in schools would be the USDA's Equipment Assistance Grants program, which provides federal funds to state child nutrition agencies that then competitively award grants to individual schools for the purchase of kitchen equipment necessary to meet National School Lunch Program (NSLP) nutrition standards.[‡‡] The program also prioritizes high-need schools where at least half of enrolled students are eligible for free or reduced-price meals.[§§]

In addition, the 2014 reauthorization of the Child Care and Development Block Grant Act included several changes to improve the health and safety of children in early care and education settings that could provide a springboard for action on lead hazards. Specifically it requires states to have health and safety regulations in place for providers serving children funded by the grant and to include "building and physical premises safety" in provider training.[‖‖]

Focus group participants cited lead paint in child care facilities, especially those in historic buildings, as a concern, reported difficulty in finding information about lead risks in these facilities, and recommended increased testing. In addition to citing cost as a potential burden for child care providers, stakeholders pointed out that some people care for multiple children but don't have a license and so might not feel safe seeking help with identifying and abating lead hazards.

According to a participant who worked at a child care center in a church, unlicensed providers and facilities operated by religious institutions may also not be covered under existing regulations, which could allow lead hazards to go unaddressed. Such unlicensed and "family and friends" child care accounts for about half of all care provided to children under 5.[##]

Stakeholders in the national listening sessions suggested using local data to target information to parents in high-risk areas. Schools also could be a good forum for reaching parents, including expectant parents. Because of the legacy of lead paint, stakeholders also suggested engaging a lead professional during the planning phase of school renovations.

* U.S. Environmental Protection Agency, "America's Children and the Environment, Third Edition," EPA 240-R-13-001 (Washington: U.S. Environmental Protection Agency, January 2013): 289, https://www.epa.gov/sites/production/files/2015-06/documents/ace3_2013.pdf; Ronnie Levin et al., "Lead Exposures in U.S. Children, 2008: Implications for Prevention," *Environmental Health Perspectives* 116, no. 10 (2008): 1285–93, https://dx.doi.org/10.1289%2Fehp.11241; Howard W. Mielke et al., "The Urban Environment and Children's Health: Soils as an Integrator of Lead, Zinc, and Cadmium in New Orleans Louisiana, USA," *Environmental Research* 81, no. 2 (1999): 117–29, https://doi.org/10.1006/enrs.1999.3966.

Continued on next page

† National Center for Education Statistics, "Public-Use Data Files and Documentation (FRSS 105): Condition of Public School Facilities: 2012-13," accessed April 6, 2017, https://nces.ed.gov/surveys/frss/downloads.asp.

‡ Centers for Disease Control and Prevention, "School Health Policies and Practice Study: Physical School Environment," accessed June 6, 2017, https://www.cdc.gov/healthyyouth/data/shpps/pdf/2014factsheets/phy_sch_env_shpps2014.pdf.

§ David Marker et al., "First National Environmental Health Survey of Child Care Centers: Final Report" (Rockville, MD: Westat Inc., 2003), http://www.nmic.org/nyccelp/documents/HUD_NEHSCCC.pdf.

|| "Protect Your Family from Exposures to Lead," U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, accessed June 6, 2017, https://www.epa.gov/lead/protect-your-family-exposures-lead.

Consumer Product Safety Commission, "CPSC Staff Recommendations for Identifying and Controlling Lead Paint on Public Playground Equipment" (Washington: U.S. Consumer Product Safety Commission, October 1996), http://www.state.nj.us/dca/divisions/dhcr/rec/pdf/recleadpaint.pdf.

** Latonia Viverette et al., "Environmental Health in Minority and Other Underserved Populations: Benign Methods for Identifying Lead Hazards at Day Care Centres of New Orleans," *Environmental Geochemistry and Health* 18 no. 1 (1996): 41–45, https://dx.doi.org/10.1007/BF01757218; Howard W. Mielke et al., "The Urban Environment and Children's Health: Soils as an Integrator of Lead, Zinc, and Cadmium in New Orleans Louisiana, USA."

†† Rafael Guerrero, "Local Schools Have Mixed Reactions to Bill That Would Require Lead Testing," Chicago Tribune, Jan. 13, 2017, http://www.chicagotribune.com/suburbs/elgin-courier-news/news/ct-ecn-schools-lead-testing-st-0115-20170113-story.html.

‡‡ The Pew Charitable Trusts, "U.S. Department of Agriculture Equipment Grants Improve School Kitchens," Kids' Safe and Healthful Foods Project (June 2016), http://www.pewtrusts.org/en/multimedia/data-visualizations/2016/usda-school-kitchen-equipment-grants.

§§ U.S. Department of Agriculture, "2016 NSLP Equipment Assistance Grants," Food and Nutrition Service (February 2016), https://www.fns.usda.gov/2016-nslp-equipment-assistance-grants.

|| || President's Task Force on Environmental Health Risks and Safety Risks to Children, "Key Federal Programs to Reduce Childhood Lead Exposures and Eliminate Associated Health Impacts" (November 2016), https://ptfceh.niehs.nih.gov/features/assets/files/key_federal_programs_to_reduce_childhood_lead_exposures_and_eliminate_associated_health_impactspresidents_508.pdf.

U.S. Census Bureau, "Who's Minding the Kids? Child Care Arrangements: Spring 2011" (2013), http://www.census.gov/prod/2013pubs/p70-135.pdf.

Safe renovation, repair, and painting enforcement

> We bought the house in March of this year, and after buying the house we found out that it had been painted last year, and when the house was painted they took no precautions when they were scraping off the lead paint."
>
> —Indianapolis resident

As discussed above, residential remediation is the primary strategy for preventing chronic exposure to lead dust. However, renovation, repair, and painting activities in older homes are also a major source of lead exposure. The use of safe work practices is critical for avoiding acute exposures from highly toxic dust, debris, and fumes that can be created when homes undergo routine maintenance and repair, including dry scraping, power sanding, and the use of torches and heat guns to remove paint, which in older homes is often lead-based.[105] Children can be exposed to these hazards if the family is not relocated during the work, if dust hazards remain when the family returns to the home, and if a parent is a contractor who brings home dust-contaminated clothes or shoes.

Unsafe and unregulated remodeling and renovation of older housing that contains lead-based paint pose significant hazards that can increase children's blood lead levels by as much as 69 percent.[106] In a 2013 study, 276 children ranging in age from 6 months to 2 years whose housing underwent interior renovation had mean blood lead levels at 2 years of age that were 12 percent higher than children whose homes were not renovated. The study also found that the higher the lead paint content in the home, the more elevated the blood lead.[107] Studies have found that work done by parents and other do-it-yourselfers has been a factor in children's high blood lead levels.[108] For example, in 2006-07, a review of case records of children in New York state revealed that 14 percent of children with blood lead levels at or above 20 μg/dL lived in homes that had undergone recent renovations. Notably, residents performed 66 percent of these renovations, suggesting that while preventing unsafe work by contractors is important, educating homeowners and renters about proper renovation practices is also vital.[109]

Although the 1992 Title X law directed EPA to require safe work practices similar to those for lead paint abatement the agency did not finalize its rule for renovation activities until 2008.[110] The updated regulation went into effect in April 2010 and set training requirements, standards, and enforcement mechanisms for renovations that disturb paint in pre-1978 buildings.

The EPA supervises compliance with the rule through its 10 regional offices. The EPA is responsible for enforcement in 36 states and has delegated this responsibility to 14 states. However, federal oversight is severely underfunded. In its regulatory impact assessment, the EPA estimated that 11.4 million projects in pre-1978 homes and child care facilities would potentially fall under the scope of the rule each year, with about 4.4 million required to follow its safe practices after subtracting minor maintenance projects and structures found not to have lead.[111]

Unfortunately, model codes which serve as the basis for many state and local housing regulations only require any peeling paint in housing to be repaired. However, the codes do not explain how to perform the repairs safely, nor do they reference the EPA's requirements. Multiple efforts to fix the codes have been rejected by the governing International Code Council because of unfunded mandates and concerns about code officials being responsible for enforcement that the EPA should handle. Several state and local governments have found ways to encourage compliance:

- **New York City** has a system to identify potentially unsafe renovations and intervene to prevent lead exposure. Health department inspectors who observe uncontained paint dust or debris must take samples and stop the work. Owners or contractors must then post a "conspicuous" sign with a phone number to access additional information, including inspection results, until they have completed cleanup and undergone additional inspections to confirm that the source of potential lead exposure has been addressed.[112] When contractors resume work, they must follow safe work practices that contain and minimize dust.[113]
- In the **District of Columbia**, where an estimated 75 percent of housing was built before 1978, contractors seeking permits for renovation must show proof of EPA-required training.[114]
- **Rhode Island** requires contractors working in homes and child care facilities built before 1978 to hold a Lead-Safe Remodeler/Renovator or higher certification.[115] To ensure compliance, the cities of **Providence** and **Pawtucket** will not issue permits for construction work at properties covered by the law without proof of such licensure.[116]

Stakeholder input

In stakeholder conversations, parents of children with a history of lead exposure frequently cited renovation as the culprit. One mother explained that she rented a historic home after the owners completed a do-it-yourself remodel. Flaking paint on the windows and doors contributed to her child's high lead levels. A few other parents related similar stories of their children coming into contact with lead during home remodeling, including renovations completed by the parents themselves as well as contractors who lacked proper certification.

One landlord pointed out that property owners who inherit buildings from family members may not know about renovation, repair, and painting requirements and might attempt renovations without taking required precautions, although most participants knew that they should seek out certified contractors. In some cases, tenants distrusted the contractors hired by their landlords or felt that landlords hired the lowest bidder without confirming proper certification. Residents and landlords alike suggested offering free certification classes for contractors and encouraging the hiring of local builders. Landlords recommended providing and encouraging training for property managers and smaller renovators on lead-safe practices and requirements.

Proposed solution

According to the EPA, an estimated 4.4 million older homes need repairs and updates that could generate lead-contaminated dust, debris, and fumes of the sort that many robust studies show could cause sharp spikes in children's blood lead levels.[117] Several localities have successfully implemented programs and policies to increase the use of these safe practices. Yet focus group participants identified home repairs as an ongoing concern.

Drawing upon findings from the literature, expert input, the experience of community members, and state and local examples, the research team modeled enforcement of the EPA's policy requiring that renovations, repair, and painting in homes with children and child care facilities built before 1978 use lead-safe work practices.

Literature summary

Evidentiary support: Scientifically supported. Strategies have been tested in multiple robust studies with consistently favorable results.[118]

Population affected: Regional or national.[119]

Modeling assumptions

- Using an EPA model which suggests that following lead-safe renovation practices would prevent a 1.08 μg/dL increase in blood lead levels of children, the team modeled the effect of compliance with the renovation rule enforcement on a single birth cohort, in terms of lifetime earnings, health and education expenditures, and QALYs.[120] (See Table 5.)
- The costs and the number of renovation events are based on the EPA's regulatory impact analysis for the rule. The impact analysis included the costs of testing, increased training and education for renovators, government certification and enforcement, and additional necessary supplies, such as plastic sheeting.[121] The study team added costs associated with conducting full dust clearance testing after a renovation to ensure a home is completely safe. The EPA analysis suggested that approximately 1.27 million children age 6 and younger would be protected by the rule and assumed an achievable compliance rate of 75 percent.[122]

The research team assumed, therefore, that a cohort of children born in the same year would be equal to that figure divided by six, or approximately 211,000. The cost calculations also include clearance dust testing following renovations, which the EPA does not require, because evidence indicates that it is necessary to confirm the safety of a structure.[123] The team included the annual cost of compliance for all homes and child care facilities built before 1978, but only counted benefits for children from the 2018 cohort living in those homes or visiting those facilities. The calculations exclude benefits for children who may visit during a renovation activity or may move into a remediated house in the future.

The federal estimates, and thus the models used in this study, exclude do-it-yourself renovations, which are not regulated by the EPA. However, one analysis found that these projects accounted for most renovation-related lead poisoning.[124]

Findings

The analysis found that, for children born in 2018, rigorous enforcement of the EPA's rule would:

- Protect 211,000 children from lead exposure in those settings.
- Cost about $1.4 billion.
- Provide positive net benefits of approximately $3 billion, including:
  - $990 million for the federal government.
  - $500 million for state and local governments.
- Return $3.10 for every dollar invested. (See Table 5.)

Table 5

Lead-Safe Renovation Could Yield $3.10 Per $1 Invested

Benefits of EPA rule enforcement

Baseline estimates	Average blood lead level for children if no intervention	1.25 µg/dL
	Number of children in homes with covered events	211,000
	Total number of renovation events	11.4 million
	Number of renovations requiring safe work practices	4.4 million
Predicted impacts	Prevented increase in blood lead per child	1.08 µg/dL
Gross future benefits	Earnings	$4.1 billion
	Health savings	$90 million
	Education savings	$90 million
	Quality-adjusted life years benefits	$160 million
	Total gross future benefits	**$4.5 billion**
	Share to the federal government	**$990 million**
	Share to state and local governments	**$500 million**
	Share to households, the private sector, and other nongovernmental entities	**$3.0 billion**
Costs	Testing cost per renovation event	$10
	Total testing cost	$110 million
	Lead-safe work practices per renovation event	$302
	Total lead-safe work practices	$1.3 billion
	Total costs	**$1.4 billion**
Net	Net future benefits	$3.0 billion
	Cost-benefit ratio	3.10

Notes: Analysis is based on the 2018 birth cohort, estimated at approximately 4 million children. Total future benefits include small changes in incarceration costs not itemized in the table. Values may not add up to totals because of rounding.

Source: Altarum Institute Value of Prevention Tool calculation

Jana Curtis and her children walk past a construction site next to their Philadelphia neighborhood park in April 2017. Curtis's 3-year-old daughter was poisoned by lead in the soil in their backyard and from construction dust in the neighborhood.

Potential challenges

The modeled policy is unique among those studied in its simplicity and low cost, which is a primary driver of its high cost-benefit ratio. Training for renovators in the EPA's required protocol is widely available. However, the lack of enforcement undercuts the rule's protectiveness because contractors can avoid compliance without penalty. Based on stakeholder feedback, consumer knowledge of the rule remains low. State and local governments have the opportunity to codify EPA's requirements or adopt their own laws and to conduct aggressive public outreach about lead-safe renovation practices, but only a few have done so. Although all 4.4 million renovation events undertaken each year in the U.S. probably do not require direct EPA or state oversight and supervising every jobsite would be impractical, the large number of renovations that go unchecked are a missed opportunity for protecting children. The EPA has only authorized 14 states to enforce the rule, but it could encourage more states to apply for delegated authority. Additionally, the EPA could increase high-profile enforcement to promote contractors' awareness of the rule and adherence to its requirements.

Air emissions and soil contamination

> "I grew up in the country digging in the dirt and gardening and stuff, and that's not a reality for my kid."
>
> —Baltimore resident

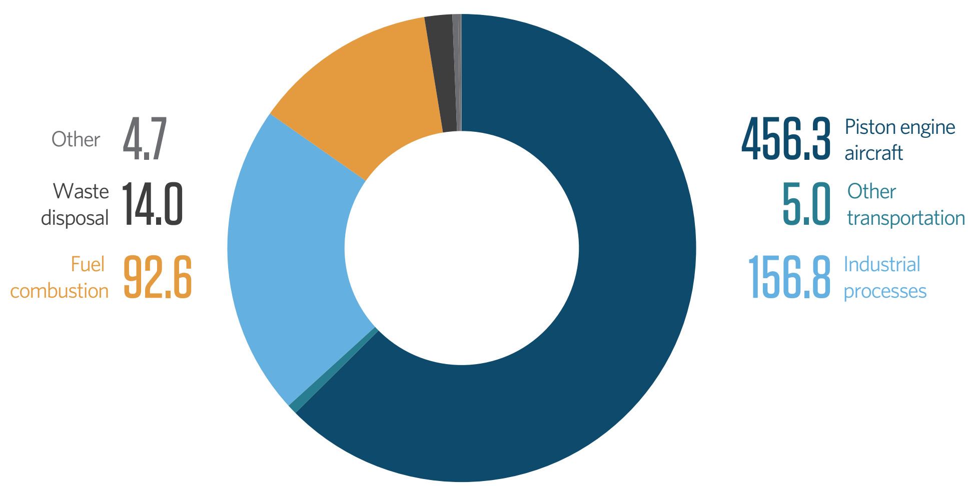
Even as the nation struggles to address the legacy of lead in homes, yards, and drinking water, more lead is being introduced into the environment every day. Most emissions result from mobile sources such as the use of leaded fuels in smaller piston-engine aircraft, followed by mining and smelting, factories that use lead, and electric power plants that burn coal and other contaminated fuels.[125] (See Figure 4.)

In 2008, the EPA decreased the acceptable level of lead concentration in air—the primary National Ambient Air Quality Standard (NAAQS)—from 1.5 to 0.15 $\mu g/m^3$ to better protect children and other at-risk populations. The Children's Health Protection Advisory Committee recommended a more significant reduction to 0.02 $\mu g/m^3$ because of the unique effects on children, particularly children of color.[126] Under current regulation, state and environmental agencies that track lead in the air must place monitors at non-airport facilities that reported lead emissions of a half-ton or more per year and at airports with documented emissions of 1 ton or more per year.[127]

Figure 4

Piston Engine Aircraft and Industrial Processes Make Up the Majority of Lead Emissions

Lead emissions by source in tons, 2014



Notes: Other transportation includes locomotives, commercial marine vessels, diesel heavy-duty vehicles. Industrial processes include activities involving ferrous (iron-containing) and nonferrous metals, mining, oil and gas production, pulp and paper production, cement manufacturing, and petroleum refining. Fuel combustion includes electricity generation, the use of industrial boilers/internal combustion engines, and the burning of residential oil, commercial natural gas, and coal. Waste disposal includes livestock waste and field burning. Other includes dust, agriculture, gas stations, and solvents, comprising industrial surface coatings and degreasing agents.

Source: EPA, "2014 National Emissions Inventory Data" (2014), https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data

Lead in the air eventually makes its way into the top layer of soil, which children may ingest directly or be exposed to if it contaminates toys or is tracked into homes.[128] The most recent nationally representative survey of residential yards documented a mean soil lead level of 169 ppm, which is less than the EPA's standard of 400 ppm for areas where children play, but this average can obscure significant site-specific contamination. For example, a property near the East Chicago public housing development had levels of 54,900 ppm.[129]

Importantly, the risks of lead in soil are not equally distributed. Two observational studies from New Orleans suggest that children exposed to higher levels of lead in soil are more likely to be black, have low socioeconomic status, and live in inner cities without safe outdoor play areas that are free from harmful lead.[130]

The relationship between soil lead and children's blood lead has been the subject of several analyses with findings showing increases in blood lead of 0.12 to 1.4 μg/dL per 100 ppm lead in soil.[131] One study found that at lower levels of lead in soil (i.e., below 100 ppm) the relationship between lead in soil and in blood is steeper than at higher levels (i.e., above 300 ppm).[132]

Despite the need for a cost-effective approach to soil lead remediation, the peer-reviewed studies evaluating soil interventions are limited.[133] One randomized control trial study published in 1993 evaluated the difference in children's blood lead levels before remediation and again 11 months after and found that among the group whose homes received treatment, average blood lead was 1.28 μg/dL lower than the comparison group. The blood lead decline associated with soil remediation ranged from 0.8 to 1.6 μg/dL after adjusting for other factors.[134] Conversely, one study found no reduction in blood lead after soil remediation, despite an average reduction in soil lead from 501 to 34 ppm.[135]

More recently, a case study review article assessed changes in blood lead and identified 13 relevant studies.[136] Twelve of those demonstrated decreases in blood lead or in the proportion of children with high levels after treatment. The authors found that most soil remediation efforts have focused on Superfund sites or individual neighborhoods with lead smelters that have affected nearby residences. They noted that low-cost solutions are needed in cases where no "responsible party" is available to pay for cleanup, such as large residential communities contaminated by past industry or gasoline emissions. Some options proposed by the authors include the use of biosolid and compost-based soil products to build raised bed gardens; the use of biochar—charcoal produced from plant or animal waste matter—which immobilizes lead in soil; and watering of lawns to prevent soil resuspension in warm, dry months.[137]

Lead smelting and battery recycling facilities

The production of lead, from mining and primary smelting—a process that uses high temperatures and chemical oxidation to produce lead from ore—as well as from recycling of lead-containing products, such as car batteries and electronic devices, referred to as secondary smelting, can cause widespread contamination of air and soil in surrounding communities. According to the EPA, more than 80,000 people experienced elevated health threats from 15 secondary lead smelters located in 10 states and Puerto Rico.[138] These communities typically have a higher proportion of people of color (41 percent nonwhite) and more Latino and Hispanic residents (52 percent) than the population as a whole (25 percent and 14 percent, respectively).[139] More recently, Exide plants in Vernon, California (described later in this report); Frisco, Texas; and Baton Rouge, Louisiana, permanently closed, and one was constructed in Florence, South Carolina, bringing the total number of active facilities at the time of this report to 13.[140]

Secondary smelting has increased as the value of lead has risen on international markets,[141] and no complete account of current and historical secondary lead smelting sites in the U.S. exists. A 2001 study found that the EPA's centralized index of regulated facilities listed only 32 percent of existing sites.[142] Research indicates that many are located in or near residential areas, suggesting that they have produced or are causing widespread contamination of nearby neighborhood soil.[143] For example, between 2001 and 2009, 22 lead-emitting facilities operated in Detroit.[144] These data highlight the need to monitor secondary smelter sites and identify and measure lead concentrations in residential soils close to legacy sites.

A sign warns residents of the West Calumet Housing Complex in East Chicago, Indiana, to avoid playing in the dirt where high levels of lead and arsenic were discovered in 2016.

Superfund sites

In 1992, the Agency for Toxic Substances and Disease Registry (ATSDR) ranked lead as the number one priority hazardous substance at sites included on the EPA's national priorities list (NPL), an inventory of the most contaminated places in the country, known as Superfund sites. The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), which is the Superfund law, typically requires identification of a "principal responsible party" (e.g., smelter, mine, manufacturing plant, or other facility) that caused the contamination and outlines steps to reduce hazards such as excavating and replacing contaminated soil, cleaning up interior dust, and, in limited circumstances, stabilizing exterior paint to preserve soil treatment.

The EPA has documented lead contamination at 66 percent of the 1,300 Superfund sites across the country. CERCLA does not apply to the many other facilities and communities with lead contaminated soil that do not appear on the NPL, including more than 450 EPA-identified sites where lead was produced or used.[145] Lead dust from industrial facilities can contaminate surrounding soil, creating a hidden source of exposure for communities.

In 2016, the EPA found that 800,000 children under 18 reside within roughly one mile of active Superfund sites.[146] A small but consistent set of local studies demonstrates an association between elevated blood lead in children and residing near a Superfund site. One study of shuttered industrial facilities and the long-term risks they pose determined that children living near one such abandoned factory in Philadelphia were more than four times as likely as the general population to have elevated blood lead levels, but the investigators were not able to verify that the facility was the source of the lead from the tested homes.[147]

Similarly, children living near the Bunker Hill Superfund Site in northern Idaho were exposed to high levels of lead in the mid-1970s; in 1974 more than 95 percent of children within 3 miles of the smelter had blood lead levels over 40 μg/dL.[148] The Bunker Hill cleanup strategy included remediating nearby homes and soil. In 2001, only 3 percent of children in neighboring residential areas had blood lead levels over 10 μg/dL.[149]

A 1999 observational study of four Superfund sites examined whether soil lead could be a predictor of blood lead in children. Researchers evaluated blood lead measurements and environmental samples from soil, house dust, interior paint, and tap water collected for the 1,015 children in the ATSDR's multisite lead and cadmium study. After adjusting for income, education of the parents, presence of a smoker in the household, gender, and dust lead, the authors found a statistically significant association between lead in soil and in blood independent of home dust lead levels; however, the model also had high levels of uncertainty and variability.[150]

Policy in Action: Superfund Cleanup

In 1998, the **Omaha, Nebraska**, City Council requested assistance from the EPA after blood tests conducted by the Douglas County Health Department revealed that nearly 10 percent of tested children in the county had blood lead levels higher than 10 μg/dL.[*] The EPA began investigating contamination from historic smelting and refining operations under its Superfund authority, and in 2003, approximately 14 square miles of property in East Omaha was deemed at high risk and added to the national priorities list.[†]

Cleanup included soil testing at child care facilities, schools, playgrounds, parks, and homes; removal and replacement of contaminated soil; and planting of new sod and grass seed. The EPA funded an interior dust program to provide residents who had their soil remediated with education and a free vacuum.[‡] To date, the EPA has tested nearly 40,000 properties, cleaned up more than 12,000 that were polluted, and awarded $40 million to the city of Omaha through a cooperative agreement to address the final phases of the work, including continued attempts to collect soil samples and clean up remaining contaminated properties.[§]

A lead-acid battery recycling plant in **Vernon, California**, which opened in 1922, contributed to air pollution in the nearby Los Angeles neighborhood of Boyle Heights, for more than 90 years. The plant logged at least 88 violations of emissions standards between 1996 and 2015.[||] The facility, which was purchased by Exide Technologies in 2000, ran seven days a week, processing 25,000 batteries a day and emitting lead, arsenic, and other pollutants into the air.[#]

Continued on next page

In 2013, after the South Coast Air Quality Management District found the plant "posed a higher cancer risk to more people than any of 450 operations the agency has regulated in the last 25 years," the state temporarily shut it down.[**] Exide was able to get the closure overturned quickly, driving advocates to take further action. In 2014, the EPA found that Exide had violated the Clean Air Act emissions standards more than 30 times and was subject to fines of up to $37,500 a day for each violation. The ruling resulted in the plant's second temporary closure.[††]

At the same time, Exide was under criminal investigation and entered into an agreement with the U.S. attorney's office to avoid prosecution in exchange for permanently closing the plant and paying $50 million to tear it down and clean the site, including $9 million for removing lead from nearby homes[‡‡] In April 2016, California appropriated an additional $177 million to clean up about a 2-mile radius surrounding the plant and intends to seek reimbursement from the company.[§§]

* Agency for Toxic Substances and Disease Registry , "ATSDR Releases Public Health Assessment Concerning Lead for the Omaha Lead Site, Omaha, Neb.," accessed Jan. 13, 2017, https://www.atsdr.cdc.gov/news/displaynews.asp?PRid=1979.

† United States Environmental Protection Agency, "Site Information for Omaha Lead," accessed Jan.13, 2017, https://archive.epa.gov/region07/cleanup/npl-archive/web/pdf/record_of_decision.pdf.

‡ Environmental Protection Agency, "Site Information for Omaha Lead."

§ The Chicago Tribune, "Violent Crime Part of Lead's Toxic Legacy," *Omaha World-Herald*, June 14, 2016, http://www.omaha.com/eedition/sunrise/articles/violent-crime-part-of-lead-s-toxic-legacy/article_b4865302-fa82-5e76-84a6-c1fe9b80e154.html; Brandon McDermott, "Where Does Omaha Stand After 15 Years of EPA Cleanup?," KNVO News, May 16, 2014, http://www.kvnonews.com/2014/05/omaha-stand-15-years-epa-cleanup; Steve Kemp, "Going Home to Manage the Final Steps of Omaha's Historic Lead Cleanup," *The EPA Blog*, May 25, 2016, http://blog.epa.gov/blog/2016/05/going-home-to-manage-the-final-steps-of-omahas-historic-lead-cleanup.

|| Molly Peterson, "State Toxic Regulators Give Exide 30 Days to Correct Permit Problems," Southern California Public Radio, June 17, 2014, http://www.scpr.org/news/2014/06/17/44788/state-toxics-regulators-give-exide-30-days-to-corr/; Tony Barboza, "Exide's Troubled History: Years of Pollution Violations but Few Penalties," *Los Angeles Times*, March 14, 2015, http://graphics.latimes.com/exide-battery-plant.

Tony Barboza, "How a Battery Recycler Contaminated L.A.-Area Homes for Decades," *Los Angeles Times*, Dec. 21, 2015, http://www.latimes.com/local/lanow/la-me-exide-cleanup-story-so-far-20151121-story.html.

** Jessica Garrison and Kim Christensen, "Vernon Plant Closed Over Toxics," *Los Angeles Times*, April 25, 2013, http://articles.latimes.com/2013/apr/25/local/la-me-exide-arsenic-20130425.

†† Ibid.; Tony Barboza, "How a Battery Recycler Contaminated L.A.-Area Homes for Decades."

‡‡ Haley Branson-Potts, "Vernon Battery Recycler Cited by EPA for Excessive Lead Emissions," *Los Angeles Times*, May 23, 2014, http://www.latimes.com/local/la-me-0524-epa-exide-20140524-story.html; Environmental Protection Agency, "Annual Air Quality Monitoring Network Plan," July 2015, https://www3.epa.gov/ttn/amtic/files/networkplans/CASCAQMDPlan2015.pdf.

§§ "$177 Million for Exide Cleanup Signed Into Law," Southern California Public Radio, April 20, 2016, http://www.scpr.org/news/2016/04/20/59806/177-million-for-exide-cleanup-signed-into-law.

Increasing the number of sites placed on the NPL and financing cleanup when no responsible industry party can be identified are critical needs for scaling cleanup efforts. CERCLA initially gave the EPA authority to tax crude oil, imported petroleum products, and hazardous chemicals and to use those funds for Superfund-related activities. However, that provision of the law expired in 1996, severely reducing the resources available for cleaning up contaminated sites.

Policy in Action: Imposing a Fee on Emitters to Fund Public Lead Remediation Programs

In the mid-1980s, the **California** Legislature declared childhood lead poisoning to be the state's most significant environmental health problem and subsequently established a prevention program within the Department of Public Health.* To help pay for the program, in 1993, California adopted an annual fee on manufacturers and other entities involved with the production or sale of lead and lead-based products collected from businesses in the petroleum and architectural coatings industries and from facilities reporting releases of lead into the air. The department employs a "historical market share attributions" concept to estimate each payer's long-term contribution to environmental lead contamination and allocate fees. It then deploys collected funds to support health care referrals, assessments of homes for hazards, and educational activities. The fee generated $20.6 million in fiscal 2015.†

* Californians for a Healthy and Green Economy, "California: The Leader in Lead Regulation," accessed Jan. 12, 2017, http://www.changecalifornia.org/2010/08/lead.html.

† California State Board of Equalization, "Supporting Our Communities: Funding a Better Quality of Life," accessed Jan. 12, 2017, http://www.boe.ca.gov/pdf/pub306.pdf.

Stakeholder input

Several focus group participants identified lead in soil as a concern, and a few parents said it was the source of exposure for their children's elevated blood lead. Los Angeles focus group participants expressed concerns about children in a community near a smelter coming into contact with lead through soil at bus stops or while playing in sprinklers. Community members in Baltimore said they kept their children from playing outside in the dirt, digging, planting, climbing trees, or picking up worms. Other focus group participants reported gardening in raised beds to avoid exposing their children to produce contaminated by lead, and in Chicago, one person described a program where farmers brought fruits and vegetables to a school to give residents access to local produce grown in safe soil.

Many participants wanted more transparency and better communications about lead hazards in their neighborhoods. Residents in Philadelphia related how when the EPA came to their community to test soil and children's blood lead levels many people distrusted the researchers and didn't answer their doors or participate in the tests, suggesting a need for improved communication in the future. Others worried that residents who participated in inspections would be unintentionally penalized and experience financial strain or difficulty selling their homes because of disclosure requirements. Participants also were concerned about lingering contamination in their neighborhoods even after industrial sites had been cleaned up, and some called for safer handling of industrial lead waste and disclosure of information about its location. A few individuals also worried about exposure resulting from parents' unintentionally carrying home lead from their workplaces on their clothing or shoes. Participants discussed job loss as a potential disadvantage to increasing regulations on industry.

Proposed solution

Several policy interventions are available that could address industry-related lead soil contamination, such as reducing emissions from secondary lead smelters, increasing public funding, and prioritization of cleanup, particularly at sites where no responsible industry party exists to finance the work. To protect against lead risks for food grown at home, the EPA has recommended practices for gardeners working in soil containing more than 100 ppm lead (soil lead levels can be tested by private or university labs[151]), including building raised beds, planting in containers, wearing gloves, using tools, restricting gardening by and for children, and selecting plants with shallow roots.[152] Quantitatively modeling these strategies on a national basis was both beyond the scope of this study and deemed by the team to present a significant chance of inaccuracy because soil exposure is highly dependent on community context.

Lead levels in the ground and in the air can be higher near airports that serve piston engine aircraft, such as this one.

Literature summary

Evidentiary support: Some evidence. Strategies with this rating are likely to work, but further research is needed to confirm effects. These strategies have been tested more than once and results trend favorable overall.[153]

Population affected: Community.[154]

Leaded aviation gas

Leaded fuel used by piston engine aircraft is the nation's largest source of lead emissions into the air, with approximately 167,000 aircraft emitting about 450 tons a year.[155] These planes constitute 71 percent of the U.S. air fleet, and many of them require high-octane gasoline to avoid dangerous engine knocking. Lead is one of the best known ingredients for raising octane, and eliminating its use would require modifications to a significant share of existing planes.[156] However, research suggests that most planes could safely make the transition to unleaded fuel at little cost if airports provided appropriate alternatives to leaded gas, and most new aircraft are certified to run on ethanol-free automobile gasoline.[157]

In 2010, the EPA estimated that about half of lead emissions from aircraft remains in the vicinity of the airport, and that approximately 16 million people live near the roughly 20,000 U.S. airports that serve aircraft running on leaded fuel and 3 million children attend school near these airports.[158] Most of these are small, general aviation facilities serving civilian, noncommercial flights, such as private or corporate planes, flying schools, and sightseeing tours.[159] In one study, children who lived within 0.6 miles of an airport were found to have blood lead levels that are 5.7 percent higher than those of children residing more than 2.5 miles from airports.[160]

Stakeholder input

Community members in Los Angeles mentioned lead in aviation gas as a concern, and experts identified it as an important contributor to air emissions. Additionally, the experts suggested that removing lead from the fuel would decrease pilots' and aircraft fuelers' contact with lead, potentially reducing take-home exposure.

Proposed solution

The team modeled the effect on blood lead in children residing within about 0.6 mile of airports serving piston engine aircraft of prohibiting the use of lead in aircraft fuel.

Literature summary

Evidentiary support: Some evidence. These strategies have been tested more than once and results trend favorable overall.[161]

Population affected: Community.[162]

Assumptions

- The team used data from a cross-sectional study to determine that children living closer than 0.6 miles from airports using leaded gas have blood lead levels that are 5.7 percent higher than those of children living farther away.[163]
- EPA data show that about 5.7 percent of the U.S. population resides within 0.6 miles of an airport that serves piston engine aircraft, so the study team applied this percentage to the 2018 birth cohort to predict that 226,000 children would live within that radius of such airports.[164]
- Baseline blood lead levels for children living in close proximity to airports serving piston engine aircraft were based on NHANES 2011-14 data and mirror the national average.

Findings

Removing lead from aviation gas would:

- Prevent an increase in blood lead levels of 5.7 percent.
- Protect 226,000 children born in 2018.
- Provide positive benefits of approximately $262 million, including:
    - $60 million for the federal government.
    - $30 million for state and local governments. (See Table 6.)

In the absence of cost data, the team did not compute a cost-benefit ratio for this intervention.

Table 6

Removing Lead From Aviation Fuel Could Prevent a 5.7% Increase in Children's Blood Lead

Benefits, assuming about 230,000 children

Baseline estimates	Number and percentage of children expected to live within 0.6 miles of airports serving piston engine aircraft	226,000 (5.7%)
	Average blood lead levels for children if no intervention	1.11 µg/dL
Predicted impacts	Prevented increases in blood lead levels per child	5.7%
	Children affected	226,000
Gross future benefits	Earnings	$240 million
	Health savings	$6 million
	Education savings	$6 million
	Quality-adjusted life years benefits	$10 million
	Total gross future benefits	**$262 million**
	Share to the federal government	**$60 million**
	Share to state and local governments	**$30 million**
	Share to households, the private sector, and other nongovernmental entities	**$170 million**

Notes: Analysis is based on the 2018 birth cohort, estimated at approximately 4 million children total. Total future benefits include small changes in incarceration costs not itemized in the table. Values may not add up to totals because of rounding.

Source: Altarum Institute Value of Prevention Tool calculation

Potential challenges

In 2012, the FAA estimated that phasing out leaded fuel would take 11 years.[165] According to a recent federal task force report, the FAA is working to identify unleaded alternative fuels for most piston engine aircraft by 2018, and under section 231 of the Clean Air Act, the EPA is evaluating whether lead emissions from aviation fuel "cause or contribute to air pollution that may reasonably be anticipated to endanger public health or welfare."[166] Based on the results of its investigation, the EPA could help to expedite the elimination of lead in aviation fuel by using its authority under the act to issue an "endangerment finding," indicating that leaded aircraft fuel emissions are polluting and harmful to public health. Such a ruling would trigger the FAA to issue standards.

Given the protracted timelines for federal action, however, states may wish to take steps to address the problem by, for example, requiring all general aviation airports to provide unleaded gas or establishing fees or taxes on airports serving piston engine aircraft to support the cleanup of the soil in parks and near homes, schools, and child care facilities.

Policy in Action: Safe Soil for Schools and Child Care

In **New Orleans**, the use of leaded gasoline contributed significantly to elevated soil lead levels, particularly in transit-heavy areas downtown. Research estimates that vehicles deposited more than 10,000 metric tons of lead dust in New Orleans soil between 1950 and 1985.[*]

In 2004, more than 40 percent of New Orleans soils exceeded the EPA's cleanup standard.[†] But a year later, storm surges and flooding from Hurricane Katrina deposited cleaner, less hazardous surface soil over the high-lead topsoil, which, combined with citywide cleanup and remediation efforts, reduced lead dust in homes and surrounding soil.[‡] Lead assessments conducted in Katrina's immediate aftermath found a 46 percent reduction in median soil lead levels.[§] And the declines continued. Before the storm, 15 of the city's 46 census tract neighborhoods exceeded the EPA's regulatory soil lead standards; by 2010, only six neighborhoods exceeded standards.[||]

Inspired by the city's unique natural experiment, researchers used a similar approach to clean up soil at 10 child care centers in New Orleans, covering lead-contaminated surface soils with a water-permeable barrier and 6-inch layer of low-lead soil.[#] Since 2005, nine of 10 federal public housing projects in the city also were rebuilt using this process.[**] New Orleans expanded this practice to all public parks and playgrounds that tested high for lead.[††] These efforts, combined with the potential reduction of lead in soil from fresh topsoil deposited by the storm surge during Hurricane Katrina, led to a decrease in the percentage of children from high-lead, largely inner-city areas with blood lead of at least 5 µg/dL from 64 percent in 2005 to 19 percent in 2015.[‡‡]

* Howard W.Mielke et al., "Environmental and Health Disparities in Residential Communities of New Orleans: The Need for Soil Lead Intervention to Advance Primary Prevention," *Environment International* 51 (2013): 73-81, https://doi.org/10.1016/j.envint.2012.10.013.

† Janet Pelley, "Lead a Hazard in Post-Katrina Sludge," *Environmental Science & Technology* 40, no. 2 (2006): 414–15, https://www.ncbi.nlm.nih.gov/pubmed/16468382.

‡ Howard W. Mielke et al., "Spatiotemporal Dynamic Transformations of Soil Lead and Children's Blood Lead Ten Years After Hurricane Katrina: New Grounds for Primary Prevention," *Environment International* 94 (2016): 567–75, https://doi.org/10.1016/j.envint.2016.06.017.

§ Sammy Zahran et al., "New Orleans Before and After Hurricanes Katrina/Rita: A Quasi-Experiment of the Association Between Soil Lead and Children's Blood Lead," *Environmental Science & Technology* 44, no. 12 (2010): 4433–40, https://doi.org/10.1021/es100572s.

|| Ibid.

Howard Mielke et al., "Soil Intervention as a Strategy for Lead Exposure Prevention: the New Orleans Lead-Safe Childcare Playground Project," *Environmental Pollution* 159 (2011): 2071–77, https://doi.org/10.1016/j.envpol.2010.11.008.

** Mielke et al., "Spatiotemporal Dynamic Transformations of Soil Lead and Children's Blood Lead Ten Years After Hurricane Katrina."

†† Ibid.

‡‡ Ibid.

Addressing data gaps

> We need some data. We need to get children tested. Once we have that data, we will have a game plan. If 80 percent of our kids have lead, then we have an epidemic. We can raise our voices and perhaps get something done."
>
> —New Orleans resident

Data play an important role in the nation's ability to prevent and respond to childhood lead exposure by helping to identify high-risk locations, assessing testing rates among high-risk groups, evaluating the impact of remediation efforts, and detecting housing units responsible for multiple exposures over time. However, inadequate investment in state and local technology and limited capacity for timely data collection, processing, and sharing impede the ability of agencies at all levels of government to provide the public with transparent data on the highest-risk areas and to protect privacy.

But even if these data were collected, no federal agency curates or integrates national blood lead and environmental information into a single database. For example, the National Health and Nutrition Examination Survey provides the best available blood lead data, and the American Healthy Housing Survey is the best estimate of lead paint hazards, but because these are two separate databases, research on the issue is needlessly complicated. Further, data are rarely available at a census tract level or finer, and county-level data obscure neighborhood risks because exposure can vary block by block depending, for example, on the location of industrial sources or the age of buildings and water infrastructure.

In addition to the need for better community-level information about lead, the research team identified several significant research gaps during the course of this study. The questions include epidemiologic research to establish the dose-response relationships between levels of lead in the environment and lower blood lead levels; research on the effectiveness of prevention and response interventions; data on the geographic location of certain lead risks and any populations that are at high risk of exposure; and information about valid testing methods.

Community members and landlords wanted more sharing of information about issues affecting their neighborhoods. Spanish-speaking residents in Flint, for example, explained that the Latino community didn't learn about the water crisis until Univision reported on the issue four months after the story first broke. This oversight speaks to the importance of cultural competency, that is the "ability to address [people's] diverse values, beliefs and behaviors," in response programs to ensure that they promote equity by meeting the needs of the populations at risk.[167]

Some parents noted that messages about lead dangers tend to focus on specific populations, for example, Medicaid-eligible children, at the risk of overlooking others, such as children from middle-income families exposed to lead through home renovations.

Many community members expressed distrust in industries, inspectors, and the agencies that they feel should be tracking information and protecting citizens. In Los Angeles, participants suspected that industry-hired researchers manipulated data about blood lead levels in children from different neighborhoods to make the case that a nearby battery facility hadn't exposed children to harmful levels of lead.

Focus group participants suggested making neighborhood-level data publicly available to help community members, policymakers, and the medical community detect possible sources of exposure and address high lead levels in children. They felt that sharing these data by census tract or ZIP code could help pediatricians and obstetricians identify patients at a high risk of lead exposure in their homes or yards. Participants also supported community-based science and research, in which community members could be trained to collect samples from their homes and neighborhoods and help with sharing data.

Some state laws may make it difficult to share data publicly or between responding agencies such as schools and public health departments. Further, although cooperative agreements require states and cities to submit blood lead surveillance data to the CDC, many states do not receive CDC funding and so are under no obligation to submit data. Similarly, states and localities do not categorize lead as a reportable disease, which means that laboratories across the country do not consistently convey all results of blood lead tests to health departments, and even when those data are shared, considerable time typically elapses before the public is made aware of neighborhood or other trends.

Future research could address the most pressing knowledge gaps, such as:

Water: Several municipalities, including Cincinnati, the District of Columbia, and Boston, have inventoried their LSLs and made the information publicly available, and California and Ohio have passed laws requiring the creation of such records.[168] However, no recent and rigorous national surveys have estimated the number of LSLs in operation nationwide. Similarly, information on the extent of lead-leaching internal plumbing in homes across the country is scarce. Finally, protocols for sampling water from homes and schools should be updated and validated.

Housing: The evaluation of HUD's lead hazard control program is the largest study of strategies to address lead paint hazards in housing. Limitations of the study include that the units were not randomly selected, the omission of a control or comparison group for ethical reasons, and that it was conducted when blood lead levels and the amount of lead in the environment were higher. As a result, new assessments of this program are needed, as are other studies to rigorously investigate the extent of lead paint hazards and resultant child exposures.

Epidemiology of blood and environmental lead levels: Declining blood lead levels and the technology to detect lower amounts of lead in the environment create new research opportunities. New studies should include epidemiologic research on the relationship between lead exposure and various sources such as food, water, soil, air, dust, and paint, as well as better national and community-level data on risks by geography and population. Future studies could examine the effect of blood lead levels below 2 μg/dL on IQ. Additionally, a longitudinal study tracking IQ and lead exposure through childhood and adulthood could strengthen the evidence of the link between lead exposure and lifetime earnings.

Educational interventions: No studies have measured the effectiveness of educational, social, or behavioral interventions for children with a history of lead poisoning. Research is needed to identify practices and pedagogies that can help children with elevated blood lead levels avoid or overcome cognitive and behavioral challenges.

Supporting children with a history of lead exposure

> Children affected by lead who can't focus in class get separated from the other students and labeled a trouble child."
>
> —Los Angeles resident

Prevention is the most critical and first approach to addressing childhood lead exposure, but those efforts have come too late for many children. Children exposed to lead may demonstrate delays in development of language skills, problems focusing, poor impulse control, and disruptive behavior. They are more likely to be diagnosed with a learning disability, to struggle to pass achievement tests, and to have lower IQs and worse academic achievement than other children.[169] Recent research has found that among young adults exposed to lead as children, the areas of the brain important for language can reorganize to facilitate language; however this reorganization does not necessarily compensate for the effects of lead on language function.[170] Research suggests that exposure to lead has particularly detrimental effects on children's executive functioning, such as working memory, mental flexibility, and self-control. These skills help children retain and manipulate information over short periods; sustain or shift attention in response to different demands; set priorities; and resist impulsive actions, responses, or judgments.[171] If children do not receive appropriate early interventions, lead-related deficits can ripple through their lives. For example, attention deficit hyperactivity disorder, which is common among lead-poisoned children, is a strong predictor of social isolation, which in turn can decrease school success and increase risky behaviors.[172] All of these problems become risk factors for delinquency, criminal behavior, substance use, and pregnancy in adolescence and young adulthood.[173]

Fortunately, cognitive and behavioral developmental skills are malleable and can be built through high-quality interventions, staffed by engaged and skilled personnel who are supported by practice-based professional development and provided in a safe setting with small child-to-adult ratios.[174] Research consistently finds that strategic investments in children's development can yield benefits for children and families.[175] However, the ability to intervene early and effectively with at-risk children before problems compound begins with testing to ascertain the extent of the exposure and then, through neuropsychological and developmental assessments, to determine if developmental delay or cognitive or functional deficits have resulted.

Blood lead testing

A necessary precursor to getting children the interventions and care they need is determining the level of lead in their bodies. Some state health departments encourage health care providers to use risk factor screening questionnaires to identify children at a high risk of lead exposure based on housing and other conditions, but one study found that many of these questionnaires do a poor job of predicting risk.[176] Providers often incorrectly assume that if patients do not live in a poor neighborhood or a community of color then they are not at risk, and clinicians are not always up to date on the latest CDC guidelines regarding harmful levels of lead in blood. For example, some providers and laboratories still tell parents that blood lead test results are normal if levels are below 10 μg/dL. Further, low blood lead levels can have lasting effects without any visible symptoms. For all of these reasons, a blood test is the preferred way to determine if a child has been exposed to lead.

The CMS requires states to comply with the Early Periodic Screening Diagnostic and Testing (EPSDT) program, a comprehensive preventive child health initiative that emphasizes early assessment of children's health care needs and requires that all children receiving Medicaid be tested for various health indicators, including receiving a blood lead test, at 12 and 24 months of age, unless the state has been granted a waiver by the CMS. However, despite these and other long-standing requirements, about 40 percent of Medicaid-enrolled children do not receive tests.[177]

State guidelines for children not covered by Medicaid range from universal testing to screening only high-risk children.[178] Ten states plus the District of Columbia require testing of all children, eight mandate targeted testing, and the rest either provide only recommendations or have no policy. Most of the states with universal testing require it at ages 1 and 2 or at 3 years of age if no previous test was conducted, but even in these states, not all children actually receive tests.[179]

The CDC's 2009 report on testing of Medicaid-eligible children recommends offering blood lead testing at sites operated by the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) to increase the percentage of children tested.[180] The report notes that collaboration with WIC has been effective for blood lead testing of Native American children. Additionally, the CDC created lead poisoning prevention recommendations for newly arrived refugee children, including testing within 90 days of entry to the U.S. for children ages 6 months to 16 years, and six months after resettlement for children 6 years of age and younger.[181]

Under EPSDT, Medicaid agencies are also required to cover diagnostic services and treatment to correct and ameliorate defects, physical and mental illnesses, and other conditions for individuals up to age 21. To qualify for coverage, school-based health programs must be primarily medical rather than educational in nature, medically necessary for the child, and delivered by a qualified Medicaid provider to income-eligible families. Services can include diagnosis and treatment of acute uncomplicated problems, monitoring and treatment of chronic medical conditions, and provision of medical services to children with disabilities that are required by the Individuals with Disabilities Education Act (IDEA). States and schools have flexibility in how they implement these services. (See Special Education below.)

Academic and behavioral interventions

Many lead-poisoned children's developmental and learning deficits are similar to those in children affected by trauma and poverty. Within that broader population of at-risk children, certain high-quality, evidence-based programs have demonstrated positive effects, for example on executive functioning.[182] In fact, research studies consistently find that investments in high-quality child development interventions reap positive benefits for children, families, and society.[183] Although no formal evaluations have measured the effectiveness of academic and behavioral interventions for children with a history of lead exposure, robust evidence nevertheless shows that various childhood interventions reduce deficits in the very same skills and behaviors most commonly affected by lead exposure through injuries it causes to the brain. Further, although no high-quality programs were designed or implemented specifically for children exposed to lead, they generally focus on children at similar developmental risks from trauma, poverty, stress, and other adverse childhood experiences and therefore may provide benefits for children affected by lead.

One such intervention is the federal Head Start and Early Head Start program for which the Administration for Children and Families provides grants to states and communities to deliver high-quality early learning opportunities to low-income infants, toddlers, and young children. Recipients then use the funding to provide services for children from low-income families. Given the federal support and focus on high-risk populations, Head Start could be a valuable entry point for reaching children who have been exposed to lead and could have positive impacts on their academic and behavioral outcomes and executive functioning.

Early Head Start provides a range of comprehensive services for parents, including family support and coaching offered in and outside the home. Such parent-focused interventions can build on the positive impacts of early childhood education programs if they include regular, voluntary in-home family support and coaching—commonly known as home visiting—to provide parents with opportunities to practice responsive interactions and other activities that offer their children age-appropriate encouragement. A recent analysis of parent education programs found that combining monthly in-home family support and coaching visits with parent education resulted in the highest improvements in children's cognitive and pre-academic skills, such as vocabulary development, task persistence, reading, and counting.[184] If regularly provided, intensive, and focused on improving the quality of interactions with young children, these programs might also represent a promising intervention for lead-exposed children.

Still further, high-quality targeted academic and behavioral school-based, community-based, and caregiver and parent training programs can provide children in elementary and middle school with opportunities and tools to manage anger, aggression, and negative thoughts, which in turn can improve social and academic performance. Some programs rely on cognitive therapy approaches, a type of talk therapy that builds awareness of negative thinking and helps manage stress.[185] Behavioral interventions can engage parents to promote healthy emotional management, improve attention, and reduce impulsiveness through meditation and computer trainings.

Rigorous research has demonstrated the positive effects of many high-quality early and middle childhood interventions for children with some of the same deficits faced by lead-exposed children. For example:

- **Nurse-Family Partnership** (NFP) connects young, low-income, first-time expectant mothers with a public health nurse, who meets with the woman in her home, starting during pregnancy and continuing until the baby turns 2. The model has been shown to have a 54 percent return to the federal government on its investment, lower enrollment in Medicaid, a 9 percent reduction in Medicaid costs, a decrease in emergency room visits for poisonings, and fewer behavior and intellectual problems among children. A 2012 study found long-term benefits of the program of almost $23,000 per participant.[186] At age 12, children who had received nurse visits in early childhood out-performed their counterparts on standardized reading and math tests and were 70 percent less likely than children who did not participate to have used harmful substances, including cigarettes and alcohol.[187] By age 15, participating children were half as likely to have behavioral problems and had half as many arrests as those without visits.[188]
- **The Incredible Years** training program consists of a range of activities that promote positive parenting and teaching practices, interpersonal skills, academic competence, and general social skills and has been shown, overall, to decrease harsh discipline practices, improve proactive parenting skills and the parent-child relationship, enhance children's academic and social competence, and decrease aggression.[189] In a randomized controlled trial, researchers found reductions in antisocial behavior of up to 59 percent among children who received training or whose parents or teachers were trained.[190]

- **Promoting Alternative Thinking Strategies** (PATHS) fosters emotional and social competencies through the development and strengthening of skills in emotional literacy, positive peer relations, and problem solving and was found in an evaluation involving children in grades one to three to improve cognitive concentration and reduce aggressive and antisocial behavior.[191] PATHS has also been found to improve academic skills. In a 2015 randomized evaluation of children from 24 elementary schools, those who participated in PATHS were 1.7 and 1.6 times more likely to attain proficiency in reading and math, respectively.[192]
- **Steps to Respect** is a school-based bullying-prevention program that focuses on prosocial beliefs and social-emotional learning. Students participate in a 12- to 14-week-long curriculum that uses literature-based lessons, and parents receive information and updates about the program. Participating students demonstrated fewer antisocial characteristics, such as aggression and bossiness, and by the end of the intervention, schools saw a nearly 25 percent reduction in bullying behavior.[193]

Only rigorously tested, culturally competent high-quality interventions have the potential to deliver benefits for any children, including those exposed to lead. Policymakers and other stakeholders will need to investigate the options with the needs of their communities in mind. The programs described above are illustrative of the many high-quality interventions available. The resources below provide detailed descriptions of and information on supporting research and evidence for these and many other interventions and can provide a starting point for policymakers' exploratory efforts:

- Blueprints for Healthy Youth Development, available at http://www.blueprintsprograms.com.
- Child Trends—What Works, available at https://www.childtrends.org/what-works.
- Home Visiting Evidence of Effectiveness, available at https://homvee.acf.hhs.gov.
- The Institute of Education Sciences' What Works Clearinghouse, available at https://ies.ed.gov/ncee/WWC.
- The National Institute of Justice's Crime Solutions, available at https://www.crimesolutions.gov/default.aspx.
- Pew-MacArthur Results First Clearinghouse Database, available at http://www.pewtrusts.org/en/multimedia/data-visualizations/2015/results-first-clearinghouse-database.

Special education

The deficits associated with lead often do not become apparent until a child is older, such as in first grade when children begin to acquire basic academic skills, and in sixth or seventh grade when executive functions such as planning and organization skills are needed. For this reason, it is best not to wait until the effects of lead exposure become a problem for the child, but rather begin intervention as early as possible once a child is identified as having an elevated blood lead level.

The IDEA ensures that all children with disabilities receive a free appropriate public education. Part C of the law serves infants and toddlers through age 2 with developmental delays or physical or mental conditions likely to result in delays. Part B provides grants to states to partially fund special education and related services for children and youth ages 3-21. Only eight states specify lead exposure as a condition that qualifies for IDEA, 12 others mention blood lead levels ranging from more than 10 to over 45 µg/dL as a criterion for eligibility, and 13 reference "toxic" exposures generally.[194] IDEA requires states to identify children with disabilities, determine their eligibility, and make referrals to services via the comprehensive Child Find system.[195]

All states participate in IDEA, but state and local implementation and quality varies, resulting in some differences in policies, services, processes, and outcomes. One promising, but not yet rigorously evaluated, strategy to accomplish this is Universal Design for Learning, an educational framework based on scientific insight for improving teaching and learning for all students.

Policy in Action: Serving Children With a History of Lead Exposure

Connecticut has a unique approach to providing educational interventions for lead-exposed children. Under the Child Find program, the State Department of Education collaborates with local school districts and the Connecticut Parent Advocacy Center to identify children with a history of lead exposure or blood lead levels of 5 µg/dL or above, then notify the parent, refer the family to medical providers and housing assistance, and obtain a health history from the school nurse.[*] Based on a subsequent assessment, children then receive one of three interventions:

- *If the child has no noted or suspected developmental delays or other risk factors*, the school team develops a monitoring plan with annual review and refers the family to Head Start or a school readiness or other enrichment program.[†]
- *If the child has a suspected or actual developmental delay or disability*, the team determines IDEA eligibility, conducts an evaluation, develops an individualized education program identifying necessary services and supports, and places the child in district pre-kindergarten or another enrichment program. For children with disabilities who do not qualify for IDEA, the team completes evaluations as appropriate and investigates eligibility under Section 504 of the federal Rehabilitation Act of 1973, which requires schools to meet the needs of such children.[‡]
- *If the child has other risk factors (e.g., poor housing condition, anemia, lack of enrichment) but no noted or suspected delay*, the team still assesses for services under Section 504 and, if the child is eligible, develops an accommodation and monitoring plan and considers placement in district or other enrichment programs in accordance with the federal provision. If the child is not eligible, the team proceeds with an annual monitoring plan and referral to Head Start, school readiness, or other enrichment programs. If the child does not qualify for Section 504, the team proceeds with an annual monitoring plan and referral to Head Start or a school readiness or other enrichment program.

* Connecticut Parent Advocacy Center, "Child Find," accessed March 9, 2017, http://www.cpacinc.org/hot-topics/child-find; U.S. Centers for Disease Control and Prevention, "Educational Interventions for Children Affected by Lead" (Atlanta: U.S. Department of Health and Human Services, 2015), https://www.cdc.gov/nceh/lead/publications/educational_interventions_children_affected_by_lead.pdf.

† U.S. Centers for Disease Control and Prevention, "Educational Interventions for Children Affected by Lead."

‡ Ibid.

Nutrition

Nutritional measures have not yet been proven to have a clinically important impact on the blood lead levels of children who have already been exposed.[196] However, nutritional interventions can support children's development in areas that lead exposure is known to cause impairment—particularly reading, math, and social-emotional skills—and so may serve as a buffer against lead's deleterious effects. Multiple studies, including randomized control trials, have found that healthy diets high in iron may improve children's developmental outcomes, including motor control, social interaction, and IQ later in life.[197]

In a recent experiment in North Carolina, children with high blood lead levels received various health- and nutrition-related services, such as WIC, and their parents were given advice about reducing lead in the home.[198] Children in the treated group had improved educational achievement and reduced adolescent antisocial behavior, compared with the control group, which included children who did not have high blood lead levels and did not receive interventions. The researchers observed and controlled for some differences between the two groups, such as children in the control group had more days absent from school and were suspended more than the intervention group.

The USDA's food programs, such as the Supplemental Nutrition Assistance Program (SNAP, previously known as food stamps) and the National School Lunch Program (NSLP), must meet strong nutrition standards, including providing meals that are high in iron, calcium, and other vital nutrients, but the research team did not find any studies of the impact of these programs on children with elevated blood lead levels.[199] A few small studies, however, have explored how these programs affect outcomes such as reading, math, and social-emotional skills, which are areas that lead exposure tends to undermine. Specifically, these analyses found slight but not statistically significant increases in reading and math scores and social-emotional outcomes among children participating in WIC, while another study identified a positive relationship between participation in SNAP and reading and math scores among elementary grade girls.[200]

Policy in Action: Healthy Diets for Better Long-Term Outcomes

Michigan State University (MSU) and Hurley Children's Hospital created the Pediatric Public Health Initiative in January 2016 in response to Flint's lead crisis. As part of the initiative, university and hospital staff provide nutrition education.[*] Additionally, the Fair Food Network, an organization committed to connecting families with healthy food, expanded its "Double-Up Food Bucks" program to increase participants' access to fruits and vegetables. This initiative matches the value of federal food assistance that enrollees spend on produce at participating farmers markets and grocery stores. For example, residents who buy $10 worth of fruit and vegetables get another $10 in produce. Similarly, WIC beneficiaries can receive coupons to buy locally grown fruit and vegetables through a program called WIC Project Fresh.[†]

* Michigan State University, "About MSU-Hurley Children's Hospital Pediatric Public Health Initiative," accessed Jan. 25, 2017, http://humanmedicine.msu.edu/pphi/About.htm.

† Michigan State University, "Fight Lead With Nutrition," accessed Feb. 18, 2017, http://msue.anr.msu.edu/uploads/resources/pdfs/MSUE_Fight_Lead_With_Nutrition_WEB-4-22-16.pdf.

Stakeholder input

Parents of children with a history of exposure or who may be at risk strongly and consistently urged universal blood lead testing.[201] Further, they advocated for blood tests to start early (e.g., 9 months) and be conducted often, with some recommending annual tests. Parents of lead-exposed children thought having this information sooner could have enabled them to seek appropriate follow-up treatment.

Some focus group participants explained that their children had blood lead tests as part of regular pediatric checkups, but others said they had to ask their pediatricians for the tests. Participants in Flint noted that parents without health insurance, especially immigrant families, might not have access to blood tests. Many participants supported universal testing, though some said that positive tests set off a chain of negative events, including visits from the health department, home inspections, doctor appointments, and requirements to abate or remediate lead. Some participants reported receiving threats that Child Protective Services would remove their children if they did not comply with health department requirements to remediate hazards.

Community members and parents emphasized the importance of prevention and improved awareness among adult caregivers before children come into contact with lead, but many also commended the early interventions their children received. Recommendations to improve these programs included professional development for teachers, specialized curricula, and extension of certain services to older children.

Participants recommended employing community health and social workers to implement parent-focused interventions and reinforced the need for neuropsychological assessments to ensure that interventions address each child's specific challenges. Other concerns included the cost of assessments and insurance coverage of related expenses.

A small number of focus group participants mentioned healthy, nutritious food as a way to help protect children from the effects of lead exposure. In Baltimore, a parent attributed her son's decreasing lead levels to the diet high in vegetables and fruits he received at school. Other participants in the same group referred to a connection between diets rich in iron and low blood lead levels. In Chicago, a focus group participant explained that the farm-to-school program described earlier in this report expanded to accept SNAP benefits, which allowed more children to take advantage of the health benefits of fresh fruits and vegetables. In Indiana, the NAACP started produce giveaways at two churches.

Experts from the national listening sessions and the advisory committee recommended including nutrition as a policy to combat the effects of lead exposure. Listening session participants also considered whether special education eligibility regulations should cite specific blood lead levels and inquired whether the Health Insurance Portability and Accountability Act prohibits health care providers and health agencies from disclosing children's blood lead levels to schools; it does not in most cases.[202]

Proposed solution

Although all children benefit from healthy diets, nutritional interventions cannot completely prevent the harms associated with lead exposure.[203] However, based on the literature, expanding the services and outreach provided by programs such as WIC, SNAP, Child and Adult Care Food Program (CACFP), and the NSLP helps improve children's academic and social outcomes.

Additionally, a vast and robust body of literature demonstrates positive outcomes for children with deficits similar to those that result from lead exposure who receive high-quality educational interventions. Experts in pediatrics and project advisers agreed that providing access to developmental assessments and culturally appropriate evidence-based programs is critical to responding to lead poisoning in children. Parents of lead-poisoned children who participated in focus groups universally agreed that their children benefited from educational supports.

Giving children with elevated blood lead the best opportunity for success begins with ensuring that clinicians follow blood lead testing guidelines; recommendations to improve blood lead testing for high-risk children are included later in this report. Once a child is identified as having elevated levels of lead in his or her blood, any ongoing source of exposure must be removed and neuropsychological assessments should be conducted to identify the specific parts of the brain that have been affected. From there, caregivers need help navigating the complicated system of potential educational and care interventions. Child Find is one program that can help parents identify and enroll their children in appropriate programs. These are the ideal steps for children who have been exposed to lead, but they are not in place in most communities in the U.S.

In the absence of this protocol, children with a history of elevated blood lead levels should be offered entry into early and middle childhood development programs that are available in their communities. To quantify the potential of doing so, the study team modeled the benefits of providing high-quality, culturally appropriate early and middle childhood education and care programs for children known to have been exposed to lead.

Assumptions

- The team modeled the effect of high-quality interventions on later-life outcomes for children with blood lead levels above 2 μg/dL. This blood lead level was selected because too few children in NHANES had blood lead levels above other potential cut-points such as 3.5 or 5 μg/dl, which would lead to instability in the modeling, and because, given that any lead in blood is harmful, it is the lowest practical level for which remediation might be offered.
- The team drew effect sizes from a review of experimental evaluations and meta-analyses of programs for children in early and middle childhood and then took the median effect size across the studies for each outcome.
- Child Trends identified evidence-based interventions and determined their effect sizes for children with other disadvantages, such as poverty and trauma. The relevant outcomes in the SGM include improved reading and math scores and reduced antisocial behavior and hyperactivity, which are all areas of potential deficit in lead-exposed children. To be included, interventions must have been rigorously evaluated, served children in early or middle childhood, and reported on one or more of the outcome categories in the SGM: academic, behavioral, or both. Assuming comparable benefits for children with lead-related deficits, those effect sizes were used to predict impacts on children's educational attainment, rates of teen parenthood and criminal convictions, and family income later in life.

Findings

The Social Genome Model found possible benefits of high-quality early and middle education programs for children with blood lead levels above 2 μg/dL (see Table 7), compared with having no such intervention, including:

- Increases of roughly 4 and 3 percentage points, respectively, in the likelihood of earning a high school diploma and a four-year college degree. Among the 2018 birth cohort, this would result in more than 13,000 additional high school graduates.

- Decreases of 1.1 and 1.7 percentage points, respectively, in the likelihood of becoming a teen parent or being convicted of a crime. This translates into 4,300 fewer teen parents and 6,200 fewer convictions among the 2018 birth cohort alone.
- Increased estimated lifetime family earnings of:
  - $33,000 for children who receive only early interventions.
  - $69,000 for children enrolled only in middle childhood interventions.
  - $102,000 for children who receive both.

Table 7

Providing Both Early and Middle Childhood Interventions Could Yield the Greatest Benefits

Effects on education, crime, and income

Outcome		Baseline	Early childhood programs		Middle childhood programs		Both	
			With intervention	Children affected	With intervention	Children affected	With intervention	Children affected
At age 19								
Average high school GPA		2.74	2.77	N/A	2.79	N/A	2.82	N/A
Percentage of children	Earn a high school diploma	74.4%	75.6%	4,100	76.9%	9,200	78.0%	13,300
	Become a teen parent	20.1%	19.9%	900	19.2%	3,500	19.0%	4,300
	Be convicted of a crime	22.0%	21.4%	2,500	21.0%	3,700	20.3%	6,200
At age 29								
Earn a 4-year college degree		17.0%	18.1%	3,800	18.9%	6,800	19.9%	10,700
Income (in 2015 constant dollars)								
Mean family at age 40		$62,300	$65,500	N/A	$68,800	N/A	$72,000	N/A
Estimated lifetime family		$753,500	$786,700	N/A	$822,000	N/A	$855,300	N/A

Notes: Analysis is based on the SGM's sample of about 8,000 children drawn from the Children of the National Longitudinal Survey of Youth dataset. To arrive at the number of children positively affected, the research team applied the percentage point differences between baseline conditions and total prevention to the roughly 365,000 children in the 2018 birth cohort whose blood lead levels would probably exceed 2 μg/dL.

Source: Social Genome Model analysis by Child Trends and the Urban Institute

Potential challenges

Differences in guidelines for and implementation of blood lead testing and parents' concerns about safety and cost may pose barriers to identifying children exposed to lead. Requiring universal testing in communities at high risk would push local clinicians to recognize the urgency of blood lead tests and ensure that lead-exposed children receive needed follow-up services. Increasing environmental testing and public disclosure of results could help parents make more informed choices about having their children tested.

The lack of studies investigating the effectiveness of educational interventions for children with a history of elevated blood lead levels may present an obstacle to increasing availability of these programs. The unique biological mechanisms by which lead contributes to behavior and attention deficits in children may mean that interventions that support non-exposed children with similar deficits will not yield comparable benefits for lead-exposed children. More research is needed to determine which specific types of interventions, if any, could effectively help to mitigate the various impacts of lead on children's brains.

Further, the cost of neuropsychological and developmental assessments may be a barrier to children being evaluated and receiving needed services. States and the CMS could improve access by providing adequate reimbursement for comprehensive follow-up services for children affected by lead, such as inspection and reduction of hazards, family support and coaching programs, and remediation and developmental assessments.

In addition, school systems may not be in compliance with legal requirements to provide services such as special education to children with a history of elevated blood lead levels because they have not allocated enough funding or for other reasons. Without additional financial resources to increase access for these children, schools may shift funding from one child in need to another. Similarly, schools and districts also may not have the capacity for needed training and staffing, and programs that require complete fidelity to a specific model may not be flexible enough to adapt to local circumstances.

Finally, stakeholders worried about stigma associated with labeling children as having a disability, so care would need to be taken to address the potential unintended harms of increasing enrollment in these programs. Specifically, trauma-informed care, an approach now being used in schools that involves understanding, recognizing, and responding to the effects of trauma, could be a useful model for lead-exposed children to minimize stigma and enhance understanding among providers, caregivers, and children. To address stakeholders' concerns about lack of support after children age out of programs, mental health and other services should be made available to young people over the age of 18 with a history of childhood exposure to help reduce interactions with the criminal justice system, difficulties with job performance, and risky behaviors.

Recommendations

Children poisoned by lead may suffer from impaired brain development and behavior problems, making them more likely to struggle and drop out of school, get into trouble with the law, and underperform in the workplace. It is not possible to quantify the emotional and psychological trauma these children and their families experience.

Eliminating lead exposure would avoid health and financial harms to families and future generations and could yield $84 billion in discounted future benefits per birth cohort. The federal government would realize about $19 billion, and states would gain approximately $10 billion, in the form of increased tax collections and lower health care, education, and safety net expenditures for the children born in 2018 alone. In the absence of lead, these children will have higher GPAs, a better chance of earning their high school diplomas and of graduating from college, and they will be less likely to become teen parents or be convicted of a crime. Among children for whom prevention efforts have come too late, comprehensive academic and behavioral interventions may help overcome the challenges they will encounter and could help prevent the toxic effects of lead from diminishing their lifelong health and potential for achievement.

Federal, state, and local organizations should coordinate to effectively align and target resources. In light of the overwhelming evidence about the effects of lead at very low levels and the urgency of sending our next generation of children to school ready and able to learn, the team developed the following 10 policy recommendations and implementation tactics for various sources of lead exposure, such as housing and water.

At the national level, the success of these strategies depends on a comprehensive approach, rather than focusing discretely on individual sources of lead, and demands collaboration across agencies and levels of government to achieve full implementation within the next 36 months. At the state and local levels, data on community risk factors can inform prioritization of the recommendations.

Priority sources

Based on the quantitative and qualitative findings the study team recommends prioritizing policies that address sources of lead with which children are most likely to come into contact and in the places that they spend most of their time.

Reduce lead in drinking water in homes built before 1986 and other places children frequent

- By 2019, the EPA and states should require water utilities to submit plans for full lead service line replacement across their systems, including specific efforts by utilities to reduce the financial burden on low-income customers. The plans should include strategies for ensuring customer safety following LSL replacement, such as flushing, monitoring, and provision of water filters. For example, Lansing, Michigan; St. Paul, Minnesota; and Madison, Wisconsin, have nearly completed replacement of their LSLs. (See Policy in Action on Page 36.)
- State or local governments should require all properties to be inspected for drinking water lead risks before sale or lease.
- The EPA should develop an action level for lead in a home's drinking water. Health Canada's proposed maximum allowable concentration of 5 ppb could serve as an interim level with the goal of getting to 1 ppb over time.[204]

- The EPA should increase the number of household drinking water taps that are tested for lead under its Lead and Copper Rule requirements.
- HUD and the EPA should require drinking water sampling as part of lead risk assessment procedures.
- The EPA and HUD should coordinate funding for addressing lead in low-income housing so it includes the replacement of LSLs and plumbing as well as removal of paint hazards.
- Municipalities should require developers to conduct full LSL replacement when a structure is sold, demolished, or rebuilt. Woonsocket, Rhode Island, has pursued this policy. (See Policy in Action on Page 29.)
- The EPA and states should require utilities to take immediate protective steps when partial LSL replacements occur, including optimized corrosion control, flushing, monitoring, sampling, and clear and timely communication to affected residents.
- The EPA should provide funding to train water system personnel to improve the consistency and effectiveness of corrosion control across systems of different sizes and water chemistries.
- State Medicaid agencies should seek approval from the CMS to use CHIP funding for testing and remediation of lead in water in children's homes and child care facilities. (See Policy in Action on Page 30.)
- The USDA should provide supplemental benefits for SNAP and WIC participants whose home tap water contains harmful levels of lead to purchase bottled water.
- The USDA should work with the EPA to define water quality for the National School Lunch Program (NSLP) and the Child and Adult Care Food Program (CACFP).
- For schools and child care sites participating in NSLP and CACFP, respectively, the USDA should establish a fund for testing and remediation costs. Such a program could be modeled after the NSLP Equipment Assistance Grants program.
- The USDA should ensure that schools and child care facilities meet water quality standards through its NSLP Administrative Reviews and CACFP Monitoring.
- Schools and licensed child care facilities should implement the EPA's 3Ts recommendation to test water for lead.
- States should require that schools and licensed child care providers test for lead in drinking water and release the results publicly. California, New York, and Rhode Island already require testing at the tap in these facilities. (See Policy in Action on Page 27.)
- To increase the number of water samples drawn from places where vulnerable children spend time, the EPA's Lead and Copper Rule should require utilities to collect and test water from schools and licensed child care facilities in their service districts.

Remove lead paint hazards from low-income housing built before 1960 and other places children spend time

- HUD should increase funding for replacement of windows coated with lead paint, fix peeling paint, clean up contaminated dust, and treat toxic soil outside homes of low-income families built before 1960, while ensuring that the homes remain affordable.

- The U.S. Department of Energy and states should encourage the replacement of lead-painted windows with new energy-efficient ones by including the benefits of preventing lead exposure and government dollars spent in the savings-to-investment ratio used to determine the cost effectiveness of energy upgrades.
- State and local governments should make lead paint hazard control financially accessible for property owners by offering low-interest loans, tax credits and other incentives.
- States or localities should require housing inspections and remediation of lead paint hazards, including peeling or chipped paint and contaminated soil and dust, before a home is sold, rented, or financed. Agencies should seek to reduce costs for compliant rental property owners by, for example, requiring recertification only at intervals that are demonstrated to protect health. Rental registries, such as those in Maryland and Rhode Island, and systematic code enforcement, as in Rochester, New York, demonstrate various ways this can be accomplished. (See Policy in Action on Page 40.)
- States and localities should prevent displacement of tenants in homes with lead hazards by freezing any eviction proceeding initiated without just cause and within six months of a finding of a high blood lead level or lead hazard in the home and should prohibit landlords from re-renting units that poisoned a child or where lead has been found until hazards are addressed.
- States should mandate inspections of all apartments in buildings where one unit is found with hazards to prevent other children from coming into contact with lead paint hazards. New York state's notice and demand authority provides a model for this approach. (See Policy in Action on Page 42.)
- State Medicaid agencies should pay for state and local health department testing of homes in high-risk neighborhoods for environmental hazards, and states should establish additional permanent sources of funding, other than Medicaid, for such investigations when affected children do not qualify for other state or federal funds.
- The CMS and Title V Maternal and Child Health Services Block Grant Program should provide training to enable home health care workers and other home-based aides to identify potential lead hazards in homes with children.
- The EPA should update its standards for lead dust, soil, and paint based on evidence, and states should adopt standards for lead in dust and on porches that are comparable to those covering HUD lead hazard control grantees.
- The EPA and state and local governments should offer funding to schools and child care providers to support lead paint hazard identification and mitigation.

Increase enforcement of the EPA's renovation, repair, and painting rule

- The EPA should develop and implement a strategy for ensuring compliance with its renovation, repair, and painting rule with an emphasis on older homes with children and child care facilities.
- Local governments should require proof of appropriate EPA-compliant lead-remediation training before issuing a permit for work that is likely to disturb paint in housing built before 1978 and more broadly disseminate information about the rule's requirements. Providence, Rhode Island, and the District of Columbia and have enacted such policies. (See Page 53.)
- The EPA should provide state and local agencies with funding to support compliance with the rule, including educating businesses and consumers about the hazards of unsafe renovation and federal requirements.
- The EPA should require that contractors perform dust testing after completing renovation, repair, and painting work to ensure that the home is safe for reoccupancy.

- The Occupational Safety and Health Administration should protect construction and renovation workers and their children by updating its standards for occupational lead exposure to reduce both on-the-job risks and the likelihood of dust and other hazards transferring from the jobsite to workers' homes.

Additional sources

Although the top policy priority should be addressing sources of lead with which children are most likely to come into contact, achieving total prevention also requires focusing on other sources that contribute to the overall amount of lead in the environment and may cause individual serious cases of lead poisoning but account for a smaller proportion of lead in children's blood overall.

Reduce lead in food and consumer products

- The federal government, through participation in the Codex committee, should encourage expedited reduction of international limits on lead in foods, particularly those that young children and babies are likely to consume. Where local surveillance data indicate that children are being exposed to lead from sources such as candy, health remedies, or cosmetics, state and local agencies should target education and outreach to at-risk neighborhoods; support cultural awareness among physicians; and increase investigation and enforcement of small retailers.

Reduce air lead emissions

- The EPA should implement the Children's Health Protection Advisory Committee's recommendation to reduce the National Ambient Air Quality Standard for lead to 0.02 $\mu g/m^3$ and prioritize regulation of concentrations around lead smelting and battery recycling facilities.
- The FAA should eliminate lead from aviation gas and identify alternative formulas that can minimize the cost to airport and plane operators, and the EPA should issue an endangerment finding that lead emissions from aircraft threaten public health and promulgate emissions limits, which would then require the FAA to adopt regulations to ensure compliance with those standards.
- State and local governments should impose fees on airports serving piston engine aircraft that rely on leaded gas and use the revenue to finance the cleanup of soil in surrounding residential neighborhoods, parks, and school districts. California levies a fee on paint and petroleum. (See Policy in Action on Page 62.)

Clean up contaminated soil

- Congress should provide adequate funding for Superfund cleanup at lead-contaminated sites.
- The EPA and states should investigate lead levels in neighborhoods near former lead smelter sites and other industrial and hazardous waste facilities and convey the information resulting from those studies in a culturally competent manner and in partnership with organizations trusted by local communities.
- The EPA and HUD should coordinate Superfund efforts and lead hazard control activities so that when a residence is treated for contaminated soil, the interior and exterior of homes are also made lead-safe. The Omaha Superfund site provides an example of this approach. (See Policy in Action on Page 60.)
- State agencies should develop and fund a coordinated cleanup effort for contaminated neighborhoods.
- The EPA should adopt a health-based standard for lead in dust and soil and eliminate the distinction between areas where children do and do not play in the soil.

Poisoning response

Prevention is the most critical and first approach to addressing childhood lead exposure, but those efforts have come too late for many children. Policymakers should take concrete steps to ensure that children with elevated blood lead levels are identified and receive the supportive services they need to minimize negative outcomes and succeed later in life. Although no studies have specifically assessed the effect of education and care interventions among children exposed to lead, high-quality programs have shown benefits for children at similar developmental risk and might improve certain cognitive and behavioral outcomes among lead-exposed children.

Improve blood lead testing among children at high risk of exposure and find and remediate the sources of their exposure

- The CDC should collaborate with the American Academy of Pediatrics and other professional organizations, with input from concerned parents, to determine the factors that contribute to the persistent lack of appropriate testing of high-risk children and should develop and implement strategies to address identified barriers.
- HHS and the CDC should provide funding to upgrade and improve blood lead surveillance at the state and local levels and to ensure that health agencies have the necessary resources to provide follow-up care for children with elevated blood lead, including for finding the sources of exposures and connecting families to remediation services and developmental and neuropsychological assessments.
- The CMS should work with state Medicaid agencies to increase the number of states that include blood lead testing of Medicaid-enrolled children as one of its performance measures and should make publicly available its annual estimates of Medicaid-enrolled children tested for lead by age 2, broken out by state and health provider.
- State and local health departments should offer blood lead testing at clinics and schools and through mobile health units to improve access for at-risk families; these sites can use simple, portable devices to check blood lead levels at the point of care.[205] The results from blood lead tests should be shared with children's pediatricians and state agencies responsible for surveillance.
- The USDA should develop mechanisms to reimburse blood lead testing conducted at WIC sites in concert with hemoglobin testing.
- State Medicaid agencies should only allow health care providers to receive an increased reimbursement rate for Early and Periodic Screening, Diagnostic and Treatment services if required blood lead testing is also conducted.
- State Medicaid agencies should use CHIP funding to increase inspections of the homes of lead-exposed children and to remediate identified paint, dust, soil, and water hazards.

Ensure access to developmental and neuropsychological assessments and appropriate high-quality programs for lead-exposed children

- The U.S. Departments of Health and Human Services and Education and state and local health and education agencies should invest in high-quality early and middle childhood education programs for children with a history of elevated blood lead levels.
- State education departments, through their Child Find programs, should collaborate with local health departments to identify children with elevated blood lead levels and ensure that they receive needed supports and services. Connecticut provides a model approach. (See Policy in Action on Page 73.)

- The CMS should provide adequate reimbursement for comprehensive follow-up services for children affected by lead, including lead hazard remediation and developmental and neuropsychological assessments.
- State education agencies should modify their IDEA Part C programs so neurocognitive and developmental deficits of lead exposure qualify for services and should presume that children with elevated blood lead levels are eligible for services. States also should modify IDEA Part B programs to help local education agencies identify and provide interventions and accommodations for children affected by lead.
- The USDA should increase funding for programs such as WIC and SNAP to expand their ability to improve children's nutrition.

Data and research

Decades of research have documented the extent of lead exposure and its impacts on children, but as policy actions have helped curb exposures, research has not kept pace. As a result, more study of the effectiveness of interventions on today's lower blood lead and exposure levels is needed. In addition, local data, which play an important role in helping public health officials and community organizations identify and target treatment and response efforts, are often not readily available to the agencies and groups that need them.

Improve public access to local data

- The CDC should, in partnership with community-based organizations, local health agencies, and private philanthropy, collect census tract level data on blood lead level results; the presence of leaded drinking water pipes; and lead in the water, dust, paint, and soil of homes, schools, child care facilities, and other places children spend time.
- The CDC should use gathered data to produce culturally competent and accessible community lead reports and broadly disseminate them to health care providers, school administrators, and child care operators. New York City's Environment & Health Data Portal is a good example.
- States should require laboratories to electronically submit all blood lead test results to local and state health departments within a week of the result so the information can be aggregated to assist with prevention and response efforts.
- States should be required to report blood lead surveillance data to the CDC.
- States should, in partnership with local health agencies and their municipalities, make property-specific information on leaded drinking water pipes and lead in water, dust, paint, and soil of homes, schools, child care facilities, and other places where children spend time easily available to the public.

Fill gaps in research to better target state and local prevention and response efforts

- The federal government should support an integrated national survey of children's blood lead levels and multiple sources of exposure, including food, water, soil, paint, house dust, and consumer products.
- HUD and the EPA should design and implement a study of water from a representative sample of U.S. housing to collect data that can be used to estimate how much lead different sections of the house plumbing system add to water. Samples should be drawn over time during cold and warm weather, from different parts of the service lines, and under varying corrosion control and water source conditions. The study design should produce exposure estimates for susceptible populations such as formula-fed babies and expectant mothers.
- The EPA should develop and validate a standardized method for sampling water for homes, schools, and child care facilities that can be implemented in the field by environmental health professionals.

- The EPA should support an evaluation of the efficacy and efficiency of water pipe liners and point-of-entry water filters for prevention of lead leaching.
- The EPA should identify barriers to optimal corrosion control and methods to overcome them, including widespread education of the public and water utilities.
- The EPA should develop field tools to identify LSLs.
- The EPA should evaluate the effectiveness of different periods of flushing in reducing dissolved and particulate lead concentrations at household taps.
- HUD should research the effectiveness of various lead hazard control treatments in preventing blood lead level increases.
- HUD and the EPA should undertake large-scale studies to test the effect of soil treatments over time to inform cleanup programs.
- Federal, state, and local agencies and philanthropy should conduct small-area population-based studies to identify relative risks among communities and subpopulations compared with the general population.
- The National Institute for Environmental Health Sciences should fund studies on the impacts of prenatal and early childhood lead on high-prevalence adult conditions such as hypertension, cardiac disease, and stroke.
- The EPA and other agencies should conduct studies to understand the primary sources of children's lead intake, including dietary, residential, and neighborhood sources among the general population and newly arrived immigrant groups.

Conclusion

Childhood lead poisoning is preventable. U.S. children's blood lead levels have declined dramatically over the past few decades as a result of successful policy interventions that have removed large amounts of lead from the environment and reduced potential sources of exposure. However, current crises in Flint, East Chicago, and other communities across the country demonstrate the need for continued attention and action to protect children from the harmful effects of lead.

Eliminating lead hazards from the places where children live, learn, and play will pay dividends in terms of social and educational outcomes, and this analysis found that it also could yield $84 billion in long-term benefits per birth cohort. The federal government would reap about $19 billion, and states would gain approximately $10 billion for children born in 2018 alone. In the absence of lead, hundreds of thousands of children would be more likely to realize their full potential thanks to higher GPAs, a better chance of earning high school diplomas and graduating from college, and a reduced likelihood of becoming teen parents or being convicted of crimes.

Children spend dozens of hours each week in school and child care facilities, and dozens of case reports show elevated levels of lead in the tap water of these facilities. Yet only scarce national data are available to indicate how much lead children are coming into contact with in classrooms, from drinking fountains, or on playgrounds. Uncovering and remediating the current sources of childhood exposure to lead both nationally and at the community level, given the importance of contextual factors, should be a high priority.

And while prevention is the priority, addressing sources of lead does little to meet the needs of children once they have been exposed. Children with a history of lead exposure can suffer from impaired brain development and behavior problems, making them more likely to struggle and drop out of school, get into trouble with the law, and underperform in the workplace. And recent research confirms that the effects of early childhood exposure to lead persist, undermining cognition and socioeconomic status well into adulthood.[206]

Giving these children the best opportunity for success begins with ensuring that clinicians follow blood lead testing guidelines. Although no studies have evaluated the effectiveness of childhood interventions for lead-exposed children, the absence of these data should not prevent children from receiving evidence-based, high-quality childhood interventions shown to reduce the same cognitive and behavioral deficits common among lead-exposed children.

By taking steps to both address sources of lead affecting children and implement interventions to help lead-exposed kids overcome the obstacles they face, federal, state, and local governments together with business leaders can save billions of taxpayer dollars, generate thousands of good jobs, and improve the quality of life for children and families across the nation.

Glossary

Abatement: Measures to permanently control (i.e., 20 years or more) lead-based paint or paint hazards, including contaminated soil, dust, and deteriorated lead-based paint. EPA regulations exclude from the definition "renovation, remodeling, landscaping or other activities, when such activities are not designed to permanently eliminate lead-based paint hazards, but instead are designed to repair, restore, or remodel a given structure or dwelling, even though these activities may incidentally result in a reduction or elimination of lead-based paint hazards."[207]

Action level: Measurements used to express a health or physical hazard. They indicate the level of a harmful or toxic substance or activity requiring medical surveillance, increased industrial hygiene monitoring, or biological monitoring.

Blood lead test: Any draw of blood (capillary, venous, or unknown sample type) from a child that produces a quantifiable lead level result and is analyzed by a certified facility or an approved portable device. A blood lead test may be collected for use in screening, confirmation, or follow-up.

Community Development Block Grant (CDBG) program: A HUD program that issues grants to local government and state entities to promote community development. Lead-based paint activities are an eligible expense under the program.

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA): A federal law enacted in 1980, also known as Superfund, that granted federal agencies the authority to respond to public health and environmental threats posed by the release of hazardous substances and levied a tax on the chemical and petroleum industries to fund cleanup of waste sites. The funding provision has since expired, and the program is now funded through regular appropriations.

Corrosion control: Treatment to minimize the dissolution of lead and/or copper in drinking water.

Cultural competency: The ability to address people's diverse values, beliefs, and behaviors in public programs to ensure they promote equity by meeting the particular needs of the population being served.

Early Periodic Screening Diagnostic and Testing (EPSDT) program: A comprehensive preventive child health initiative that emphasizes early assessment of children's health care needs and requires that all children receiving Medicaid be tested for various health indicators, including blood lead at 12 and 24 months of age, unless the state has been granted a waiver by the CMS.

Effect size: A quantitative measure of the magnitude of a difference between or within groups over time. Effect size is particularly useful in comparing the effects of interventions.

Elevated blood lead level (EBL): The CDC uses this term to refer to a blood lead level greater than or equal to 5 µg/dL, which it defines as high and requiring public health intervention. (See also "reference value" and "lead poisoning.")

FIND: Filming Interactions to Nurture Development.

Healthy, Hunger-Free Kids Act (HHFKA): An update to the Child Nutrition Act passed in 2010 to improve child nutrition through oversight of the USDA's child nutrition programs, including the National School Lunch Program, the School Breakfast Program, the Special Supplemental Nutrition Program for Women, Infants and Children (WIC), the Summer Food Service Program, and the Child and Adult Care Food Program.

Integrated Exposure Uptake and Biokinetic model (IEUBK): Estimates lead in children using four interrelated modules (exposure, uptake, biokinetic, and probability distribution) for children exposed to lead from water, food, dust and soil, and through inhalation. The model allows the user to estimate, for a hypothetical child or population of children at different ages, a distribution of blood lead concentrations based on information about different sources of exposure to lead.

Individuals with Disabilities Education Act (IDEA): A law that was first enacted in 1975 to protect the rights of children with disabilities to receive free appropriate education.

Interim controls: Set of measures to temporarily control lead-based paint hazards. Interim control methods must be completed by qualified workers using safe work practices and followed by clearance testing. Follow-up monitoring is needed.

Lead and Copper Rule (LCR): A regulation introduced by the EPA in 1991 to control lead and copper in the drinking water distribution system. The EPA is currently considering new modifications to the rule, which has been revised several times.

Lead-based paint: Defined by HUD and the EPA as existing paint or other surface coatings that contain lead equal to or exceeding 5,000 parts ppm. In 1978, the CPSC banned residential use of new lead-based paint that contained greater than or equal to 600 ppm of lead, which was later reduced by Congress to 90 ppm.

Lead-based paint hazards: Any condition that causes exposure to lead from dust-lead hazards, soil-lead hazards, or lead-based paint that is deteriorated or present in chewable surfaces, friction surfaces, or impact surfaces, and that would result in adverse human health effects.

Lead-Based Paint Hazard Control Grant Program (LBPHC): A HUD-administered program that assists elements of local government in establishing programs to address lead-based paint hazards in privately owned residences.

Lead exposure: In toxicology, exposure is defined as any detectable level in blood; thus, lead exposure in this document means any detectable level of lead in blood.

Lead poisoning: For the purposes of this report, a child is considered to have been poisoned by lead if he or she has a single blood lead test (capillary or venous) at or above the Centers for Disease Control and Prevention's 2012 reference value of 5 μg/dL even though some experts use the term to refer to a child who is at risk of a blood lead concentration greater than 5 μg/dL.

Lead service line (LSL): The pipe that connects a home or other structure to the water main. Use of lead pipes in all drinking water plumbing, including service lines, was banned by Congress effective 1986.

Microgram (μg): 1/1000th of a milligram (or 1 millionth of a gram). To put this unit into perspective, a penny weighs 2 grams, so a microgram would be one of 2 million equal pieces of that penny.

National Health and Nutrition Examination Survey (NHANES): A set of representative national surveys that measures the health and nutrition of adults and children in the United States using interviews, physical examinations, and blood specimens. NHANES is the main government data source for estimating mean blood lead levels for the U.S. population and the number of children with high blood lead levels.

National Ambient Air Quality Standards (NAAQS): EPA rules for concentrations of various pollutants in outdoor air intended to minimize human health risks.

National Priorities List (NPL): The EPA's list of locations with hazardous wastes eligible for cleanup under CERCLA.

Parts per billion (ppb): Equivalent to μg/kilogram by weight, a part per billion is equal to the value of one penny compared with $10 million. This unit is used to measure lead in water.

Parts per million (ppm): Equivalent to μg/gram (10,000 ppm = 1 percent) by weight, this unit is used to measure lead in paint and soil.

Quality-adjusted life year (QALY): A generic measure of disease burden, including the quality and the quantity of life lived that is used in economic evaluations to assess the monetary value of medical interventions. One QALY is equal to one year of perfect health.

Reference value/level: A value used to identify children with blood lead levels that indicate an elevated source of exposure in their environment. The value is based on the 97.5th percentile of blood lead concentrations from the National Health and Nutrition Examination Survey. In 2011 this value was 5 μg/dL, and the CDC recommended implementing interventions for individual children at this or higher blood lead concentrations. The CDC has not made a recommendation for blood lead levels at the 2014 reference value of 3.5 μg/dL. The reference value is calculated every four years based on the two latest years of NHANES data.

Risk assessment: A comprehensive evaluation, conducted by a certified assessor, to identify lead-based paint hazards using paint testing, dust and soil sampling, and visual examination, and to recommend appropriate reduction methods.

Savings to investment ratio (SIR): A measure that expresses the ratio of savings to costs.

Smelter: An industrial facility that extracts metals from ore (usually mixed with purifying and/or heat-generating substances such as limestone and coke) at high temperature in an enclosed furnace. The process results in lighter ore components (impurities called slag or tailing) rising to the top and floating on the molten metal.

Social Genome Model (SGM): A quantitative tool that combines two national longitudinal datasets to simulate the effects of childhood interventions on outcomes at five life stages, from birth to age 40.

Soil remediation: The purification, covering, or removal of contaminated soil.

Value of Prevention (VP) Tool: A quantitative modeling system that synthesizes data from literature and national datasets to characterize the financial and health impacts of investment in prevention from the perspectives of different stakeholders.

Appendix: Methodology

Study methods included policy screening, literature review, case studies, interviews, national listening sessions, focus groups, and quantitative modeling. (See Table A.1.) The models required several inputs, including the number of children likely to be affected by a proposed policy, their baseline blood lead levels, and the expected change in those levels as a result of each policy intervention.

To determine the number of children affected by a policy, the researchers sought information about the scope of sources of exposure. For example, to determine the effect of replacing lead service lines, researchers needed to know how many children live in homes with those lines, the level of lead in the water of their homes, their current blood lead levels, and what the evidence suggests would happen to their blood lead levels with the replacement of the lead lines. In the case of policy proposals for which those data were lacking, the team did not attempt quantitative modeling and instead relied on qualitative research. Similarly, the team conducted cost-benefit analyses only for policy solutions for which cost information was available. Details of the various methods are included below.

Table A.1

Summary of Research Methods

Method	Purpose	Source
Policy screening	• Narrow the list of policies to be included in the assessment	
Literature review	• Identify potential policy interventions • Document the relationship between blood lead levels and parameters in the quantitative models including IQ, earnings, and math and reading scores • Identify the effect sizes of potential policy interventions on environmental lead levels, blood lead levels, and educational and behavioral outcomes for use in quantitative modeling • Determine the populations affected by the prospective policies • Document known sources of exposure for affected populations and vulnerable subpopulations	Articles in medical, public health, education, and child development publications, including original papers, meta-analyses, syntheses, and literature reviews
Case studies	• Illustrate if and how recommended policies have been implemented at the state and local levels to provide pragmatic information	
Informant interviews	• Capture the perspectives of stakeholders, such as parents of children with a history of lead exposure, businesses that could be affected by the policies, and environmental health and early childhood experts and advocates	

Continued on next page

Method	Purpose	Source
National listening sessions	• Identify possible unintended benefits and consequences of policy interventions • Prioritize recommendations	Federal, state, and local officials, industry representatives, academics, and advocacy organizations
Focus groups	• Prioritize recommendations • Document community concerns and priorities • Identify possible unintended benefits and consequences of policy interventions	Landlords and property managers Parents of children with a history of lead exposure People at high risk of exposure, and other concerned community members
Quantitative models	• Quantify potential effects of policy interventions on early childhood and adult outcomes, including cognitive and social/emotional development, academic achievement, and earnings • Predict policies' long-term economic impacts in terms of potential cost and future savings	Social Genome Model and Value of Prevention Tool

Policy screening process

The Health Impact Project conducted policy screening between August and December 2016 using the following criteria:

- Will Congress or a federal, state, or municipal agency likely consider the policy within the next 18-36 months?
- Does an authoritative document (i.e., a produced by a multidisciplinary task force, advisory committee, professional organization, or government body) cite the policy as a recommendation?
- Is the policy a high priority for affected populations?
- What is the expected result of the policy intervention in terms of the number of children affected and effect size of the intervention?

The timeframe criteria reflect the team's desire to identify policies that can reasonably be advanced in time to protect the next generation of children. The 18-36 month window assumes policy adoption, but not full implementation. The team relied on authoritative documents to identify recommendations that addressed stakeholder priorities and that experts and advocates had previously vetted. To avoid potential conflicts between recommendations promoted by agencies and experts and those endorsed by community members, the team specifically sought input from affected populations during the policy screening process.

The screening process began with an Aug. 5 meeting of advocates and experts from the fields of water, housing, soil, consumer products, and early childhood to identify "best policy bets." The research team used the findings from the meeting, combined with recommendations developed by a wide range of organizations and agencies, to generate a list of more than 100 policy options for consideration. (The full list is available upon request.)

The team then refined the list to include policies that would result in either reduced environmental sources of lead (prevention) or the provision of a service for children at risk or with a history of exposure (response). This screening led the team to initially exclude financing strategies, operational policies (e.g., task forces, job training), and approaches to blood lead testing.

After the initial screening, about 50 policies remained for consideration. In October 2016, subject matter experts helped the team further narrow the list to 28 for potential study. The experts subsequently identified several underrepresented policy areas on the list, including schools, plumbing fixtures, wells, lead paint hazards created through demolition, exposures associated with Superfund sites, lead in ambient air, occupational hazards, blood lead testing, state and municipal policies, and early interventions for children exposed to lead. The team conducted informant interviews and additional literature reviews to fill many of these gaps. For example, at the recommendation of stakeholders, the team included several financing policies deemed critical to implementing the prevention policies, as well as options related to blood lead testing, Superfund, early interventions, and schools and child care facilities. In total, the team studied 10 high-level policy options and analyzed 70 tactics for implementing those 10.

In November 2016, the Health Impact Project conducted a series of national virtual conversations to collect stakeholder feedback on the interventions and tactics. Between December 2016 and January 2017, the team held focus groups to document the concerns of communities across the country. Feedback from these events also helped refine the list of policies considered for analysis.

Literature review

Researchers from Pew, with support from Child Trends and other experts, led the literature search to answer a set of research questions on the effects of lead on young children and interventions to prevent and respond to exposure. The initial research questions were:

1. To what extent do blood lead levels above 5 µg/dL affect cognition and academic achievement (i.e., IQ, reading scores, math scores, high school drop-out/graduation rates, cognition, attention disorder, memory impairment)?
2. To what extent do elevated blood lead levels affect lifetime earnings (i.e., lifetime earnings, employment, income)?
3. To what extent do elevated blood lead levels affect criminal behavior (i.e., delinquency, violent crime)?
4. To what extent do elevated blood lead levels affect health (i.e., hypertension, cardiovascular health, immunological health, endocrine health, child growth rates, hearing)?
5. To what extent does the replacement of lead service lines decrease or prevent elevated blood lead levels?
6. To what extent does lead hazard control prevent elevated blood lead levels?
7. How do nutritional interventions impact cognition and educational achievement for children exposed to lead (i.e., IQ, reading scores, math scores, high school drop-out/graduation rates, cognition, attention disorder, memory impairment)?
8. How do nutritional interventions impact cognition and educational achievement for children with blood lead levels less than 5 µg/dL (i.e., IQ, reading scores, math scores, high school drop-out/graduation rates, cognition, attention disorder, memory impairment)?
9. How do early childhood education interventions impact cognition and educational achievement for children with blood lead levels greater than 5 µg/dL (i.e., IQ, reading scores, math scores, high school drop-out/graduation rates, cognition, attention disorder, memory impairment)?
10. How do early childhood interventions impact cognition and educational achievement for children with blood lead levels less than 5 µg/dL (i.e., IQ, reading scores, math scores, high school drop-out/graduation rates, cognition, attention disorder, memory impairment)?

11. To what extent do detectable levels of lead in a pregnant woman's blood affect her newborn's health?
12. To what extent do the impacts of lead poisoning increase societal or taxpayer costs?

Pew searched PubMed, Cochrane, Campbell, ERIC, EBSCO, Google Scholar, and Google databases for systematic reviews, experimental studies, and quasi-experimental studies conducted over the past 30 years. For searches that yielded a large number of results, the team screened a minimum of 50 abstracts to determine relevance to the research questions, and for those that produced fewer than five articles, the team employed a "snowball" method to identify relevant peer-reviewed studies and gray literature from citations and bibliographies. The search excluded articles published in languages other than English or that studied populations outside the United States, except when no U.S. studies addressed a particular research question, in which cases the team expanded the search to international articles published in English. For each study, the team documented the target population, source name, article title, year of publication, authors, source type (e.g., peer-reviewed or gray literature), analysis type (i.e., systematic review, experimental study, quasi-experimental), data sources and measures, and key findings. The initial search included 100 articles in medical, public health, education, and child development publications, including original papers, meta-analyses, syntheses, and literature reviews.

Concurrent with the literature search, the Health Impact Project commissioned five sector-specific white papers to summarize the literature related to the prospective policies. Experts prepared papers on housing, water, consumer products, early interventions, and schools and child care facilities and contributed additional references to be included in the Pew literature review. Child Trends reviewed the sector-specific white papers to compare the studies cited in those with other identified articles to ensure that no major research was omitted. Experts recommended several international studies to fill gaps where U.S. data were lacking and the team eventually included those in the search results. Pew, with assistance from Child Trends, the Urban Institute, and Altarum Institute, conducted additional literature searches throughout the project based on input from key informants, subject matter experts, and advisory committee members. The team ultimately reviewed well over 700 articles.

Of those, Child Trends reviewed 176 studies that provided information necessary to inform the inputs in the two quantitative models. Child Trends, the Urban Institute, and Altarum Institute performed a third-party review of these selected studies to establish effect sizes for interventions that would be included in the models. Using a five category scale, Child Trends evaluated the strength of each study used to estimate effect sizes based on design, sample size, attrition rate, intent-to-treat analysis, clarity of variable definitions, and whether or not the studies adjusted for socio-economic status. (See Table A.2.)

Table A.2

Strength of Evidence Criteria for Literature Review Used in Quantitative Models

Study type	Lower quality	Higher quality
Level 1: Meta-analysis		
Design	Quasi Experimental Designs (QEDs) or mix of randomized control trials and QEDs	Randomized control trials
Number of included studies	Fewer than 10	10 or more
Inclusion/exclusion criteria	Unclearly defined, or inconsistently applied across studies	Clearly defined, and consistently applied across studies
Attrition	Attrition rate of included studies is 50% or more and/or varies between treatment and control group	Attrition rate of included studies is 49% or lower
Control variables	Included studies don't control for socioeconomic status	Included studies that control for at least one measure of socioeconomic status, such as mother's education or free and reduced-price meal eligibility
Intent-to-treat analysis	Not used by included studies	Used by included studies
Outcome measures	Unclearly defined, not valid and reliable, or inconsistently applied across study participants	Clearly defined, valid, reliable, and implemented consistently across study participants
Level 2: Randomized controlled trial		
Sample size	No power analysis conducted, or, sample size insufficient to conduct all analyses as required	Sample size is sufficient to conduct all analyses as required. If sufficiency of sample size is not clear, then a power analysis was conducted
Attrition	Attrition rate is 50% or more, and/or attrition rate varies between treatment and control group	Attrition rate is 49% or lower
Control variables	Doesn't include SES	Includes at least one measure of SES such as mother's education or free and reduced price meal eligibility
Intent-to-treat analysis	Not used	Used
Outcome measures	Unclearly defined, or not valid and reliable, or inconsistently applied across study participants	Clearly defined, valid, reliable, and implemented consistently across all study participants
Level 3: Controlled trial without randomization (Quasi-experimental design)		
Sample size	No power analysis conducted, or, sample size insufficient to conduct all analyses as required	Sample size is sufficient to conduct all analyses as required. If sufficiency of sample size is not clear, then a power analysis was conducted
Attrition	Attrition rate is 50% or more, and/or attrition rate varies between treatment and control group	Attrition rate is 49% or lower
Control variables	Doesn't include SES	Includes at least one measure of SES such as mother's education or free and reduced price meal eligibility
Intent-to-treat analysis	ITT analyses not used	ITT analyses used
Outcome measures	Unclearly defined, or not valid and reliable, or inconsistently applied across study participants	Clearly defined, valid, reliable, and implemented consistently across all study participants

Continued on next page

Study type	Lower quality	Higher quality
Level 4: Cohort study or case-control study		
Sample size	Insufficient to conduct all analyses as intended	Sufficient to conduct all analyses as intended
Control variables	Doesn't include SES	Includes at least one measure of SES such as mother's education or free and reduced price meal eligibility
Outcome measures	Unclearly defined, or not valid and reliable, or inconsistently applied across study participants	Clearly defined, valid, reliable, and implemented consistently across all study participants
Additional criteria for prospective cohort studies only		
Attrition	Attrition rate is 50% or more	Attrition rate is 49% or lower
Additional criteria for retrospective cohort studies and case control studies		
Potential for recall bias	Data subject to bias (e.g., subjects asked to recall)	Data from administrative source or recorded prior to start of study
Missing data	33% or more of cases are missing data	Less than 33% of cases are missing data
Additional criteria for case control studies only		
Sample selection	Convenience sample	Sample selection method accounts for bias (e.g., matching, two or more control groups, random sampling of cases and controls)
Level 5: Cross sectional study		
Representativeness	Representative at state or local level; not representative; representativeness unknown; or, nationally representative but response rate below 80%	Nationally representative, with a response rate of 80% or higher
Sample size	Insufficient to conduct all analyses as intended	Sufficient to conduct all analyses as intended
Control variables	Doesn't include a measure of SES	Includes at least one measure of SES such as mother's education or free and reduced price meal eligibility
Outcome measures	Unclearly defined, or not valid and reliable, or inconsistently applied across study participants	Clearly defined, valid, reliable, and implemented consistently across all study participants

Case studies

Trust for America's Health (TFAH) and the National Center for Healthy Housing (NCHH) received grants from the Health Impact Project to create case studies (see the "Policy in Action" listings in the Table of Contents) detailing successful prevention and response strategies at the state and local levels. To select the case study subjects, NCHH reviewed literature and developed three criteria for policies and programs under consideration: diversity of lead hazard exposures addressed (water, housing, consumer products, etc.), geographic diversity, and impact (based on published evaluations or summaries of the policies and programs). NCHH contacted members of the National Safe and Healthy Housing Coalition, a broad voluntary coalition of over 300 organizations, for recommendations on possible case study locations. Based on the literature review and the responses from coalition members, NCHH recommended 20 communities as models to include in the case studies. The Health Impact Project made additions to the list using the same criteria. Ultimately, TFAH developed 22 case studies, and the study team selected 15 for inclusion in the final report based on the above criteria and a determination of relevance to the policies analyzed.

Listening sessions

The Health Impact Project held five national listening webinars to collect additional stakeholder feedback. The topics of the web-based conversations included housing, schools and childcare, early childhood development, and consumer products; one general session was also held. In total, more than 200 people registered for the listening sessions and approximately 195 attended, including individuals from federal, state, and local environmental, health, housing, water, and utilities agencies and tribal health departments as well as nonprofit and advocacy organizations who work with policymakers. Stakeholders unable to participate through the webinars had the opportunity to provide feedback through an online form. The team collected and stored under password protection registrants' names, email addresses, and organizations and summarized all feedback provided in the session thematically.

Parent conversations

The Health Impact Project led two conference calls with a total of eight parents of lead-poisoned children and guided the participants in open-ended discussions. The conversations focused primarily on interventions for children with a history of lead exposure and parents' experiences with various programs. The team summarized parent feedback thematically and identified relevant quotes for inclusion in the report. The Health Impact Project collected and stored under password protection participants' names, cities and states of residence, and email addresses.

Focus groups

The Health Impact Project held a total of 16 focus groups between December 2016 and January 2017 in Baltimore; Chicago; Flint, Michigan; Indianapolis; Los Angeles; New Orleans; Philadelphia; and Warren, Arkansas, with a diverse group of participants, including property owners and landlords, residents of communities affected by lead exposure, parents of lead exposed children, and representatives from organizations supporting these populations. (See Table A.3.) The team led the semi-structured, open-ended discussions to identify which lead sources raised the greatest concern, obtain feedback on potential policies to prevent and respond to lead exposure, and provide stakeholders with an opportunity to inform the policy development process.

The team sought Institutional Review Board (IRB) approval for the focus group methodology and the Chesapeake board deemed the project exempt from IRB oversight on Dec. 7. Two to 15 individuals attended each focus group, and participation was entirely voluntary. Focus group settings included a library, a church, and several facilities operated by community organizations. Host site contacts chose the locations based on their convenience and accessibility. Focus group participants received prepaid Visas in the amount of $25 as thank-you gifts. The team recorded each participant's city and state of residence. No other identifying information was collected. The team summarized the findings, and identified key themes.

Table A.3

Focus Group Participant Demographics and Other Characteristics

Participant demographics	n	%
Race and ethnicity		
American Indian and Alaska Native	7	7%
Asian and Pacific Islander	2	2%
Black, non-Hispanic	44	42%
Hispanic, any race	17	16%
White, non-Hispanic	25	24%
Other, including two or more races	7	7%
No response	2	2%
Educational attainment		
Some high school	8	8%
High school/GED	25	24%
Associate's degree	4	4%
Some college, no degree	16	15%
College graduate or above	47	45%
Other	2	2%
No response	2	2%
Annual household income		
$19,999 or less	24	23%
$20,000 to $24,999	11	11%
$25,000 to $34,999	14	13%
$35,000 to $44,999	18	17%
$45,000 to $54,999	7	7%
$55,000 to $64,999	4	4%
$65,000 to $74,999	4	4%
$75,000 and over	16	15%
No response	6	6%

Housing characteristics	n	%
Type		
Single-family	65	63%
Duplex	10	10%
Multiunit	17	16%
No response	12	12%
Age		
Built before 1940	22	21%
Built between 1940 and 1959	20	19%
Built between 1960 and 1978	17	16%
Built after 1978	10	10%
Don't know	23	22%
No response	12	12%
Ownership		
Own	59	57%
Rent	33	32%
No response	12	12%
History of lead testing		
Paint/dust	13	13%
Water	15	14%
Paint/dust and water	18	17%
Neither	40	38%
Don't know	7	7%
No response	11	11%

Quantitative methods

Social Genome Model

The Social Genome Model (SGM) is a lifecycle microsimulation model starting at birth and moving through five subsequent life stages—early childhood, middle childhood, adolescence, transition to adulthood, adulthood—through age 40. The version of the SGM used for this research (the SGM79) is constructed using two data sets from the Bureau of Labor Statistics' National Longitudinal Surveys: the Children of the National Longitudinal Survey of Youth (CNLSY) and the National Longitudinal Survey of Youth 1979 (NLSY79). The CNLSY follows from birth through age 19 a sample of children born to the women of the National Longitudinal Survey of Youth 1979 (NLSY79). Most of the children in the CNLSY were born in the 1980s or early 1990s. The second survey is the NLSY79 itself, which follows a sample of people in the United States born between 1957 and 1964 from their first interview (ages 14-22 in 1979) into mid-adulthood. Data are available for 25 rounds of data collection, through 2012 when respondents were 47-55 years of age.

To combine the two sources of information, SGM uses information about the children in the CNLSY from birth through age 19 and then statistically matches them to comparable individuals in the NLSY79 sample based on variables measuring circumstances at birth and adolescence common in the two data sets. The NLSY79 data are then used to estimate outcomes at age 29 and age 40 for the children in the CNLSY. The overall model is based on data on 8,056 children. Lifetime income estimates are based on data from the 1998-2015 Current Population Survey, which is the primary source of labor force statistics for the population of the United States.[208]

The SGM uses CNLSY and NLSY data to track children's development from birth onward and employs regression models to assess the relationships between children's early life circumstances and subsequent outcomes such as educational attainment, grade point average, teen parenthood, criminal conviction, and lifetime family income. The model enables researchers to assess how actions at developmentally significant life stages reverberate through a person's life. For example, circumstances at birth influence early childhood outcomes, which in turn affect middle childhood. Those middle and early childhood conditions influence adolescent outcomes, and so on through middle age. Using data on children to assess these effects over time allows the SGM to explore how early changes may ripple through outcomes later in life. Thus, if lead reduction improves a child's reading ability in early childhood, the SGM can be used to see how that improvement in reading leads, for instance, to greater educational attainment and higher income later in life.

Because lead is not a variable included in the surveys that underpin the model's dataset, the Urban Institute and Child Trends had to estimate the blood lead levels for the children in the sample by using blood lead data from the 2011-12 and 2013-14 NHANES to predict the age 1-5 blood lead level of each child. In other words, they created in the dataset a cohort of children with blood lead levels consistent with those of the national child population based on regression models of the logarithm of blood lead as a function of race, ethnicity, gender, family income, maternal education, and maternal marital status, using children age 1-5 in the combined NHANES samples. The average blood lead level in the combined two surveys for children ages 1-5 was 1.1 μg/dL, which may be higher than what will be seen among the 2018 birth cohort. One option to address this possibility was to extrapolate the trend line from earlier years to predict 2018 levels, but this strategy would underestimate 2018 levels if the rate of decline is slower between 2014 and 2018. Data from the CDC lead surveillance program indicate that the number of children with blood lead above 10 μg/dL leveled off between 2009 and 2015.[209] The potential for similar settling at lower levels in subsequent years makes the 2011-14 NHANES data the most accurate approach to predicting 2018 blood lead levels.

The modeling team assigned a blood lead value to every person in the SGM cohort to identify whether that person was part of the target population for a policy intervention. This blood lead variable was not used in the SGM regression equations to predict later life outcomes, so the results cannot be biased by misclassifying a person's blood lead level. The team modeled the policy effects by directly altering the values of the early and middle childhood outcome scores (reading, math, and behavior) to the degree that the literature suggests given the change in blood lead levels resulting from a given policy intervention. For example, if a child in the SGM has a blood lead level of 1.5 μg/dL and is in the target population to receive a policy intervention that prevents a 50 percent increase in blood lead, his or her blood lead should be 0.75 μg/dL lower than without the intervention. Using the expected reading score effect size, estimated from the literature, of a 0.0405 standard deviation increase in reading score for every 1 μg/dL decrease in blood lead, this child's reading score would improve by 0.0304 (i.e., 0.75 x 0.0405) standard deviations. This change in reading score, in turn, affects the person's later outcomes, such as high school graduation and family income at age 40.

The modeling team identified the effect of blood lead levels on variables in the model's dataset that the literature review indicated are affected by blood lead levels. The model contains the following outcomes for which Child Trends and the Urban Institute gathered effect sizes for children ages 5 and 11 from the literature:

- Peabody Individual Achievement Test (PIAT) reading scores.
- PIAT math scores.
- Behavior Problems Index (BPI) hyperactivity subscale.
- BPI antisocial behavior subscale.

No studies estimated an association between blood lead levels and the specific variables in the SGM, so the modeling team relied on estimates from other similar standardized reading and math assessments and on indices of antisocial and hyperactive behavior. For reading and math scores, Child Trends used the median effect size for all the included studies. For hyperactivity and antisocial behavior, most studies included multiple measures of behavior, so the team first calculated a mean effect size for each study, then used the median value of the study means. For example, if a study examined parent and teacher reports of hyperactivity on one scale, Child Trends took the mean of those two measures and then used the median of those means across all the studies. Significant and insignificant effect sizes were included in the calculations. A summary of the basis for the effect size calculations is available upon request and includes a list of the research used as well as effect sizes and average blood lead levels reported in each study.

Table A.4 provides the results of the SGM modeling of the prevention interventions: lead service line replacements, lead paint hazard control, lead-safe renovation practices, and the elimination of leaded aviation fuel. Although the differences in outcomes for children with and without interventions appear small, it is important to bear in mind that these are the changes for the entire population of children targeted for an intervention (for example, all those who live in a house built before 1960), not just those who are at greatest risk or have the highest blood lead levels. The effects for subpopulations with higher blood lead levels would be larger. Additionally, improving outcomes such as high school graduation and the attainment of a college degree are difficult to achieve with any one intervention since many factors play a role. Finally, the fact that blood lead levels have declined rapidly as a result of the reduction of lead in the environment is evidence that policy interventions make a difference for the population—and the fact that disparities in exposure have shrunk over the last two decades suggests that policies have been appropriately targeted. Intervening on lower levels of lead in blood result in more modest improvements in later-in-life outcomes than in the recent past when blood lead levels were much higher. But even modest outcomes when applied across a population of newborn children are meaningful, both for individual children and for the entire cohort of school aged children.

Table A.4

Summary of Effects of Selected Lead-Exposure Prevention Policies

Impacts on education, income, teen parenthood, and crime

	Children living in pre-1978 homes who experience a renovation, repair, and painting (RRP) event (N=211,167)			Lead paint hazard control (LHC) for children living in pre-1960 low-income housing (N=321,182)		
	Unsafe RRP	Safe RRP	Children benefiting	Without LHC	With LHC	Children benefiting
Outcomes at age 19						
Average high school GPAs	2.86	2.87	N/A	2.79	2.80	N/A
Earn high school diplomas	81.6%	82.0%	900	72.1%	72.4%	1,000
Become teen parents	15.4%	15.2%	500	28.0%	28.0%	100
Be convicted of crimes	18.0%	17.7%	700	23.8%	23.6%	600
Outcomes at age 29						
Complete 4-year degrees	23.5%	23.8%	800	15.0%	15.1%	400
Income						
Mean family income at age 40 (2015$)	$69,100	$70,000	N/A	$58,300	$58,900	N/A
Estimated lifetime family income (2015$)	$838,300	$848,700	N/A	$701,300	$707,200	N/A

Notes: Analysis is based on the SGM's sample of about 8,000 children drawn from the Children of the National Longitudinal Survey of Youth dataset. To arrive at the number of children positively affected, the research team applied the percentage point differences between the baseline conditions and total prevention to the estimated number of children in the 2018 birth cohort who would receive the intervention.

Source: Social Genome Model analysis by Child Trends and the Urban Institute

Full lead service line (LSL) replacement for children living in homes built before 1986 with baseline water lead levels of 11.4 ppb (N=272,285)			Full lead service line replacement for children living in homes built before 1986 with baseline water lead levels of 5 ppb (N=272,285)			Children ages 1-5 living within 0.6 miles of an airport serving planes using leaded aviation gas (N=226,530)		
With an LSL	Without an LSL	Children benefiting	With an LSL	Without an LSL	Children benefiting	Without removing lead from aviation gas	Removing lead from aviation gas	Children benefiting
2.90	2.90	N/A	2.90	2.90	N/A	2.83	2.83	N/A
82.8%	82.9%	300	82.8%	82.9%	0	80.8%	80.9%	0
14.0%	13.9%	200	14.0%	13.9%	100	15.9%	15.9%	0
17.7%	17.6%	100	17.7%	17.7%	100	17.8%	17.8%	0
24.6%	24.8%	600	24.7%	24.8%	200	23.0%	23.0%	100
$70,700	$71,100	N/A	$70,700	$70,800	N/A	$67,500	$67,600	N/A
$855,400	$859,500	N/A	$855,400	$857,000	N/A	$823,700	$824,400	N/A

Value of Prevention Tool

Using data from the literature and national datasets, the Value of Prevention Tool predicts the financial and health effects of investments in social determinants of health, such as access to early education. The tool can assess the potential cost and future savings associated with various policies that would accrue to the federal government, states, and society at large based on the intervention's predicted impact on mortality, morbidity, future earnings and health care and incarceration costs, and noneconomic impacts such as educational attainment.

The tool tracks impacts on the federal government, specifically those related to spending on Medicaid, CHIP, Medicare, and other medical costs, such as exchange subsidies and care for veterans and military families; safety net expenditures; Social Security spending; incarceration costs; and tax revenue. State effects may include Medicaid and other medical spending, safety net expenditures, and incarceration costs. The tool also tracks impacts on the federal, state, and local governments in the form of changes in tax receipts resulting from differences in lifetime earnings.

The tool provides an assessment of the QALYs that could be gained by the affected population as well as the predicted impact of each intervention on health-adjusted life expectancy, both of which account for the amount of time lived in less than perfect health. QALYs are the number of additional healthy years of life resulting from an intervention measured on a scale of 0 to 1, where 0 and 1 correspond to the worst and best possible health outcomes.

For this project, Altarum used the tool to estimate the benefits of policies that reduce exposure to lead for an annual cohort of children (about four million births) over their lifetimes. These benefits consist of increased lifetime earnings, reduced health expenditures, decreased education spending, and a lower risk of mortality; are measured in 2015 constant dollars; and are discounted at 3 percent. When cost estimates of a policy were available, the tool reported the cost-benefit ratio of an investment.

Reductions in incarceration costs were estimated but not depicted in the tables because they were very small compared with the other outcomes measured. The benefits of decreased incarceration are based on a longitudinal study that linked blood lead levels to arrest rates. However, that study only documented effects for blood lead above 6 μg/dL,[210] a level that few children experience today, so the predicted benefits associated with reduced criminal involvement are relatively small. The Value of Prevention Tool is designed to measure incarceration costs so the team converted arrests to incarceration using FBI data to predict both the probability and length of incarceration given an arrest for a nonviolent and violent crime. The model did not account for other potential criminal justice-related cost reductions, such as those associated with arrests.

Importantly, the costs and benefits Altarum calculated are for a single annual cohort of children. Many of these policies could and probably would be implemented over a longer period, but the results are reported only for a single cohort to ensure consistency across policies and so readers can compare these simulations to previous work.[211] Further, estimating benefits beyond the first cohort introduces greater uncertainty because it requires the prediction of cohorts' blood lead levels and other characteristics further into the future. The tool models lifetime earnings benefits by estimating changes in IQ from lead exposure and their downstream impact on earnings potential, health savings by approximating lead exposure's short-term health costs (testing, office and emergency room visits) and long-term impacts (increased risk of cardiovascular disease, hypertension, and associated costs), and education savings by estimating the decreased need for special education and repeated grades associated with avoided IQ losses.

The QALY benefits are estimated through reductions in mortality risk associated with lifetime cardiovascular disease, which puts a dollar value on increased healthy years of life and is included in many regulatory analyses of environmental hazards. In this report the value of a gained QALY unit is $50,000, a conservative estimate when compared with similar analyses.[212] The team's estimates were restricted to benefits associated with reduced cardiovascular disease because it is the only increased risk of mortality shown to occur down to blood lead levels of zero, an important consideration given the lower levels of lead in children's blood today.

The tool modeled the impacts of lead paint hazard control and lead service line replacement in homes for the estimated 3,978,038 children who will be born in 2018. However, lead paint hazard control has been shown to make changes in home dust lead levels that persist for at least 12 years, and lead service line replacement should make permanent improvements to home water lead levels. Therefore, future children born into remediated homes would see benefits. The modeling team approximated the number of such children using data on the housing stock and the size of future birth cohorts from the American Community Survey. This analysis showed that in the next 10 years, about 0.25 future children on average will be born into an already remediated home.

When possible, conservative assumptions were used and only some benefits were included as quantifiable in the Value of Prevention Tool results. Therefore, interventions with a positive cost-benefit ratio have a beneficial impact, but may have even greater positive effects not included in the results.

The tool tracks and distinguishes among benefits that accrue to different stakeholders, including the federal government, state and local governments, and the remainder of society, including households and businesses. Therefore, the future benefits reported are societal and include discounted benefits to all entities, not a particular stakeholder or investor. When possible, Altarum breaks out individual benefits by the level of government to which they would accrue. Many of these benefits occur far in the future, so the results are highly sensitive to the 3 percent discount rate and 1 percent real-earnings growth assumptions.[213]

Altarum models evaluated changes in health care costs in two pieces. The first is short-term costs associated with increased use of medical services, such as lead testing, office visits, environmental investigations, and chelation therapies. The medical procedures recommended for various blood lead levels were taken from the American Academy of Pediatrics recommendations for children above the 5 μg/dL cutoff,[214] which, in turn, were revised from the previous guidance which recommended care beginning at 10 μg/dL.[215] Cost estimates for medical procedures were derived from Gould's 2009 study and inflated to 2015 dollars using Altarum's health care prices index.[216]

The second piece of health outcomes are long-term risks associated with lead exposure, which has a large research base. In addition to the cognitive impacts discussed above, evidence has found harmful effects of lead exposure on hypertension; cardiovascular, immunological, and endocrine health; child growth rates; and hearing. However, much of this research has been done in children and adults at blood lead levels much higher than 5 μg/dL, and the strongest evidence of impacts on individuals with levels at or below 5 μg/dL is for hypertension and cardiovascular disease. The model, therefore, included only increased mortality risk and long-term health care expenditures associated with cardiovascular disease and hypertension.

Further, to simplify the process of estimating long-term health impacts of childhood exposure and avoid the need for engineering models to approximate changes in blood and bone lead over time, the analysis assumes that children's blood lead levels persist throughout their lives. This approach is reasonable because, although blood lead levels are likely to fluctuate during a lifetime as a result of changing exposures, childhood levels are one of the best predictors of lifetime average blood lead levels, particularly given the relationships between blood lead and lead stored in bones.

The first long-term health outcome measured was increased mortality risk through likelihood of fatal cardiovascular disease. Initial, nonexposed mortality risks were drawn from the Underlying Cause of Death data from the CDC.[217] The model then used research on hazard ratios to represent the increased mortality risk.[218] To calculate increased mortality rates, the team identified cardiovascular and noncardiovascular mortality from the CDC Underlying Cause of Death data and then used a linearized hazard ratio to find the increased annual risk of cardiovascular mortality associated with a 1 μg/dL increase in blood lead.[219]

Additionally, for hypertension the model uses American Heart Association data from 2015 on hypertension risks for baseline nonexposed risks,[220] and then other published data to calculate the increased risk of hypertension associated with a 1 μg/dL increase in blood lead.[221] The higher prevalence of hypertension is then used as a predictor for increased cardiovascular and health care costs through published data showing that people with hypertension spend $5,755 in 2007 dollars more on average each year for medical expenditures.[222] Altarum then inflated these costs to 2015 dollars using its health care prices index and aggregated to produce the cohort-level estimates.

IQ

The effect size of early childhood blood lead levels on IQ has been well studied, although researchers have produced a wide range of estimates. The emphasis for this analysis was on the IQ impacts for young children with blood lead levels less than 10 μg/dL because this is the range for most U.S. children. Strong evidence in the recent literature suggests that the relative impacts of blood lead on IQ are much larger at lower levels.[223] Therefore, the team estimated the impact of lead on IQ for three separate categories: children in the <5 μg/dL range, the 5-9.9 μg/dL range, and the 10+ μg/dL range.

The team identified four distinct studies of IQ in U.S.-based cohorts of young children with blood lead levels in the <5μg/dL range[224] and standardized their estimated impacts to a 1 μg/dL increase in blood lead, measured in IQ points.

When studies produced multiple estimates from subsamples of different blood lead level ranges, the research team included all those estimates. The IQ estimates for the <5 μg/dL group ranged from a 0.19 to 2.53 decrease in IQ points per 1 μg/dL increase in blood lead depending on study and methodology. Of the five estimates included, the median result for the <5 μg/dL category was 0.77 IQ points lost per 1 μg/dL of additional blood lead and the mean was 1.15 points. Altarum used the mean result of -1.15 in IQ per 1 μg/dL increase in blood level for the <5 μg/dL analysis. The estimate is slightly more conservative than the effect size used by the EPA in its 2008 NAAQS final rule, which was based on four studies with a median result of -1.75,[225] but is slightly more aggressive than the -0.83 estimate found by the European Food Safety Authority in its literature review.[226] For the 5-10 μg/dL category, the mean result was 0.51 IQ points lost, and for the 10+ μg/dL category, the mean result was 0.18 points. A summary of the basis for the effect size calculations is available upon request and includes a list of the research used as well as effect sizes and average blood lead levels reported in each study.

Lifetime earnings

The team used a similar methodology to determine the effect of IQ changes on lifetime earnings. The team performed a literature search of relevant studies and supplemented the results using a survey article[227] because the universe of available data on lifetime earnings is smaller than the data on IQ and blood lead levels. The team found no literature directly connecting blood lead levels to lifetime earnings and therefore employed a two-step approach commonly used in the field, first linking blood lead levels to IQ as described above and then linking IQ to earnings.

Altarum further restricted the estimates of IQ effects on earnings to studies that analyzed males and females together because the evidence suggests that IQ impacts on earnings for women are larger than those for men, so studies that only report the effect size for males would underestimate the total. Additionally, Altarum focused on studies that included in lifetime earnings not only hourly or annual wages but also likelihood of labor force participation, because studies that consider just wage effects underestimate the impact of IQ on lifetime earnings.

In addition, the team excluded studies that analyzed the impacts of IQ on lifetime earnings while controlling for educational attainment because increased education is a probable pathway through which higher IQ increases earnings, and controlling for education creates a "blocking variable" that results in an underestimate of the impact of IQ on earnings.[228] Further, some studies attempted to approximate the lifetime value of blood lead reduction through willingness-to-pay analyses for certain lead remediation and treatment,[229] but Altarum deemed them inappropriate and excluded them because of the probable information asymmetries related to the effectiveness of lead-related treatment.

The result of the above work is three estimates. Two focus on the NLSY79 cohort and a third incorporates some evidence from literature that drew on the NLSY's 1997 cohort, a nationally representative sample of approximately 9,000 youths who were 12 to 16 years old as of Dec. 31, 1996. One finds an overall impact of a single IQ point on lifetime earnings of 1.43 percent in the NLSY79 sample and similar effects in the NLSY97 data. The second estimates an earnings impact of 2.56 percent, and the third estimates a 2.82 percent effect.[230] Taking the mean of these three estimates, Altarum used an effect size of a 2.27 percent increase in earnings per IQ point for this analysis.

Some researchers in this field view these estimates of IQ impacts on earnings as aggressive because of the inability to control for other noncognitive variables, such as self-control and conscientiousness.[231] Others suppose that 1.1 percent may be more appropriate, but the team found only one study that included noncognitive controls in a lifetime earnings regression analysis.[232] Furthermore, because the Value of Prevention Tool does not include noncognitive effects, the estimated effect size of 2.27 percent best aligns with the data incorporated into the tool.

Economic benefits

The quantifiable benefits of reducing child lead exposure are dominated by the expected increases in future lifetime incomes as a result of improved cognitive and noncognitive ability, increased educational attainment, and greater labor force participation. However, the Value of Prevention Tool also includes benefits associated with reductions in special education and lifetime health spending and increases in expected lifespans as a result of lower blood lead levels. Although the Value of Prevention and Social Genome models are structured differently and draw on different types of information, when considering a common outcome, such as the discounted present value of lifetime income, they would reach conclusions within the same order of magnitude.

Education

Education impacts are estimated through expected changes in IQ as described above. Previous lead modeling literature approximated the additional educational costs associated with children with blood lead levels above 20 μg/dL. One study estimated that 20 percent of those children would require an additional three years of special education.[233] Altarum instead modeled possible increases in special education spending for all children exposed to lead. This was done by approximating the number of children whose IQs would decline below the 70 point threshold as a result of lead exposure and assuming that all those children would require special education interventions. The analysis also assumed a standard normal IQ distribution and used the IQ-to-blood lead level effect sizes described above to estimate the number of children affected. For example, children in the 5 to 10 μg/dL blood lead category were predicted to lose 6.2 IQ pts as a result of their full lead exposure, so the model estimated that any child within this blood lead level range and the post-intervention distribution between 76 and 70 IQ points (3.6 percent of children) would fall below the 70 point threshold absent elimination of blood lead and would require additional special education. The analysis then assumed that special education spending for these children would persist throughout their primary school years.

The expected additional cost of a year of special education was estimated for the 1999-2000 school year to be $8,040 per student.[234] This number was inflated using the CPI to 2015 dollars. Total educational spending was estimated by multiplying the number of affected children by the per-year per-student cost and then by the number of primary education years.

Assumptions for modeled policies

Lead service line replacement

- Because of a lack of data for most of the inputs, the models had to rely on a range of available information sources. For the number of LSLs in the country, this analysis relied in part on self-reported survey data collected from water utilities and on input from industry representatives.[235] No data source was found that could document how many children are served by those lines or their blood lead levels. The team used a 2016 study to estimate that 6.84 percent of the population is served by a lead service line and then applied that percentage to the roughly 4 million children in the 2018 cohort to determine the number of children who would be served by a lead service line (272,285).[236]
- Limited data connect lead levels in water to blood lead levels in children so the research team assumed that replacing an LSL prevents a 0.40 μg/dL increase in blood lead. This estimate is derived from proposed IEUBK model coefficients.[237] An alternative to the IEUBK estimate would have been to use findings from one study that found a 20 percent reduction in blood lead levels for children exposed to less than 5 ppb of lead in water compared with those exposed to greater than 5 ppb.[238] However, that report used data from a 2005 pooled analysis, which drew water samples in such a way that they may not have accurately depicted the exposure risk. Alternatively, a Canadian study showed a 35 percent decrease in blood lead for every 1 ppb decline in water lead levels.[239] Assuming that LSL replacement reduces water lead levels from 11.4 to 2.0 ppb, the Canadian findings suggest a resulting 98 percent decrease in blood lead levels, which seems implausible given that children are also at risk from other sources of exposure. Ultimately, the research team used recently proposed parameters for the IEUBK model that suggest a 0.5 μg/dL change in mean blood lead level is caused by a 11.8 ppb increase in water lead. The team converted this to a 0.04 μg/dL increase in blood lead for every 1 ppb increase in water lead.[240]
- In the absence of national data to characterize the level of lead in drinking water in homes served by LSLs, the research team used two water lead levels for reference: 11.4 ppb lead based on unpublished sampling data from five utilities in the Midwest and 5 ppb from unpublished Canadian data.[241] These levels were selected to represent a system in compliance with the Lead and Copper Rule, and to reflect the upper bound amount of lead in water for a system using optimized corrosion control, respectively.
- About 59 percent of the U.S. population lives in pre-1986 homes according to the American Community Survey, so this analysis assumed the same percentage for the approximately 4 million children in the 2018 birth cohort to arrive at 2,351,498 children residing in homes built before 1986.

- The team assumed that children served by LSLs would have starting blood lead levels similar to the average across children living in all homes built before 1990, specifically 1.16 μg/dL, with 9.2 percent of the cohort having levels of at least 2 μg/dL.
- The team assumed that replacing the LSL in one home would affect one child in the initial cohort (i.e., that one child, rather than multiple children, per cohort will be born into each home).
- The number of children born into homes with replaced LSLs in the next 10 years was estimated separately from the initial cohort. First the percent of the housing stock that each intervention would remediate was calculated by dividing the number of remediated homes by the total housing stock using data from the American Community Survey.[242] This percentage was then used as the likelihood a future child will be born into a remediated home. For example, in the LSL replacement intervention for pre-1986 housing, an estimated 0.3 percent of the housing stock would be remediated. Therefore each future child has a 0.3 percent chance of living in a remediated home. This is likely a conservative estimate because it assumes births are evenly distributed across the housing stock and ignores that children cluster in families and certain styles of homes. The team also conservatively assumed that the impacts would persist for only the next 10 birth cohorts.
- In the absence of national pricing data for full LSL replacement, the research team estimated a per-unit cost of $6,000. A 2008 national survey of utilities found that typical replacement costs ranged widely from $250 for the utility portion and $600 for the customer portion to $3,000 and $4,000, respectively.[243] A recent informal survey of all systems known to be pursuing full LSL replacement suggested that current costs averaged roughly $7,500. The real cost varies greatly across regions, states, and even local providers and by the length of the line, so the research team combined these estimates to calculate a rough $6,000 per unit cost.[244]

Lead paint hazard control

- Using published literature on the effects of lead paint hazard control on dust lead levels and studies of the relationship between levels in dust and those in blood, the team assumed that removing lead paint hazards from homes before children are born would cut their expected blood lead levels by 39.5 percent. This involved a two-step process. First, the team used data from a long-term follow up of lead hazard control interventions, which found an 89 percent decline in dust lead levels 12 years after treatment.[245] The study was conducted in 189 nonrandomly selected homes from multiple regions of the country and did not include a control group for ethical reasons. It is, nevertheless, the largest national evaluation of lead hazard control efforts and its findings align with many smaller studies of lead paint hazard control effects.[246]
- Second, the team used a an analysis of a national cross-sectional survey to predict the effect of decreased dust lead on child blood lead levels.[247] The study was based on blood lead levels from 1999 to 2004. (See "Uncertainty in modeling lead impacts and remediation policies" below.) The data indicated that the above-referenced 89 percent reduction in dust lead would prevent a 39.5 percent increase in children's blood lead levels.
- The team provided an alternative baseline of 10 μg/sq. ft. to illustrate the benefits of the intervention at lower floor dust lead levels.
- The analysis used the American Healthy Homes Survey to estimate that about 75 percent of pre-1960 homes and 50 percent of pre-1978 homes have lead-based paint and would require remediation.[248]
- The team calculated children's baseline blood lead levels based on NHANES data from 2011-14.

- The benefits include one child per home from the 2018 birth cohort as well as additional children likely to be born into the remediated homes in the subsequent 10 years. To calculate the number of children born into a remediated home the team used the same methodology described under "Lead service line replacement" above.

Renovation, repair, and painting

- The team consulted an EPA study which used the Leggett model to determine that following lead-safe renovation practices would prevent a 1.08 µg/dL increase in blood lead levels of children and then used that estimate to model the impact of compliance with the renovation rule enforcement on a single birth cohort, in terms of lifetime earnings, health and education expenditures, and QALYs.[249] The Leggett model enables estimates of blood lead levels and the probability of a child's concentration exceeding levels of concern based on different exposure scenarios.
- Although the EPA does not require clearance dust testing following renovations, these tests were included in this study's cost calculations because they are necessary to confirm the safety of a home or child care facility before children are allowed to re-enter.
- The team included the annual cost of compliance for all homes and child care facilities built before 1978 so that it could use cost information from the EPA's regulatory impact assessment. However, to be consistent with all of the interventions modeled in this report, the team only counted benefits for children from the 2018 cohort living in those homes or visiting those facilities. As discussed, some limited benefits would also accrue to homes without children, but those impacts were excluded from the modeling.

Aviation gas

- The team used published research to determine that children living closer than 0.6 miles from airports using leaded gas have blood lead levels that are 5.7 percent higher than those living further away.[250]
- The team used EPA's estimated number of people living within 0.6 miles from airports serving piston engine aircraft and assumed based on the NHANES 2011-14 blood lead distribution that the children living within that proximity had baseline blood lead levels similar to the national average.
- Other researchers have found larger benefits than those shown in this report or studied the effects of aviation emissions to the population of children living farther (up to 2.5 miles) from an airport serving piston engine aircraft.[251] However, the research team found no published data on the number of such children nationwide and so only modeled the distance for which data were available: 0.6 miles.

Early and middle childhood education and care

To estimate the potential impact of early and middle childhood care and education interventions on children who have high blood lead levels, Child Trends identified evidence-based interventions and determined their effect size on outcomes for children with other disadvantages, such as poverty and trauma, in the SGM, specifically, reading and math scores, antisocial behavior, and hyperactivity, which are all areas of potential deficit in lead-exposed children. Child Trends evaluated the early childhood literature to identify specific programs that have been rigorously evaluated and demonstrated to improve outcomes for children at risk for or displaying cognitive and behavioral deficits. Programs selected for the modeling effort have been the subject of previous meta-analyses (reviews that compared multiple studies to determine typical effects), randomized controlled trials, and quasi-experimental evaluations. In addition, research shows that addressing such disadvantages has strong economic benefits, which are not included in this analysis.[252]

To develop the list of programs to be considered, Child Trends reviewed high-quality interventions recommended by subject matter experts, meta-analyses, and the following additional resources:

- Blueprints for Healthy Youth Development's compendium of evidence-based program evaluations of interventions for children and youth.[253]
- *The Nurture Effect: How the Science of Human Behavior Can Improve Our Lives and Our World.* Oakland, CA: New Harbinger.[254]
- Child Trends' LINKS Compendium of random assignment intent-to-treat evaluations of social interventions for children. [255]
- *Early Childhood Roots of Bullying: Early Childhood Investigations Webinar.* Child Trends.[256]

To be included, interventions must have been subject to a randomized evaluation and an intent-to-treat analysis. In addition, the program had to have served children in either early or middle childhood and reported on one or more outcome categories included in the SGM, academic, behavioral, or both.

To determine the effect size of the interventions on academic and behavioral outcomes, Child Trends initially categorized programs into either early childhood (0-5 years old) or middle childhood (6-11 years old). Because some were implemented over a period of time, which resulted in data being collected in waves, Child Trends only included the final outcome measures for those interventions. In cases when a program evaluation measured multiple aspects of a behavioral or academic outcome, Child Trends calculated the mean effect size for each outcome in that evaluation. Finally, to determine the overall effect size of early childhood and middle childhood interventions, the research team used the median value across all of the program evaluations for reading, math, and behavior, including significant and insignificant findings. A summary of the basis for the effect size calculations is available upon request and includes a list of the research used as well as effect sizes and average blood lead levels reported in each study.

Uncertainty in modeling lead impacts and remediation policies

Modeling the long-term impacts, costs, and benefits of early childhood focused lead remediation and prevention policies is complex and involves high levels of uncertainty. Given available data, an analysis cannot generate wholly accurate estimates of the effects of specific policies in reducing future blood lead levels in children and mitigating the various effects of lead exposure, but rather is most useful to provide more insight into which policies would most likely be effective and cost-beneficial and how policies might best be structured to help ensure their usefulness. The long-term nature of the harms resulting from lead exposure and data limitations in quantifying these harms necessitates a multistage modeling process that can compound the effects of uncertainties from different sources.

Strong evidence indicates that early childhood lead exposure is statistically correlated with intermediate outcomes, such as IQ, reading, math, and behavior, and that they, in turn, are statistically related to lifetime outcomes, particularly earnings and educational attainment.

However, the modeling team has found neither data that directly links primary prevention interventions or blood lead exposure to lifetime earnings outcomes nor studies designed to prove causality in an early childhood lead exposure and earnings relationship. Therefore, for this project the modeling team used studies that measured the impact of lead exposure on IQ (Value of Prevention Tool) and reading scores, math scores, and behavioral outcomes (Social Genome Model) as intermediate outcomes to predict lifetime outcomes. As a result, defining traditional statistical levels of uncertainty or "confidence intervals" in the results is not possible. Statistical measurements of uncertainty are driven by standard errors and are designed to measure the relationship of multiple variables taken from data analyzing a single sample of participants.

As a substitute, the modeling team performed three separate analyses to address concerns about the uncertainty of the estimates of the lifetime benefits of reducing childhood lead exposure via policy interventions. The first was a qualitative exploration and the second was a set of “bounding exercises” to frame possible upper and lower limits on the impact of certain model results. Assuming appropriate data were used in other modeling steps, these exercises show the maximum possible benefit (the prevention of any lead exposure, and therefore the complete elimination of lead in children’s blood) that might be achieved through various policy interventions. Finally, the modeling team used the VP Tool to perform sensitivity analyses on key areas of uncertainty.

Sensitivity analyses do not estimate statistical uncertainty, but they do provide descriptive, quantitative evidence on how the dependent outcomes of a modeling process change depending on the inputs. The analyses chosen to run were prioritized because either the parameter values were believed to be particularly uncertain (e.g., there are a wide range of values in the literature) or parameter values for which even small changes in input values result in large changes in the final results.

Qualitative description of uncertainty

The estimation of lifetime benefits of lead abatement policies is a multistage process, with uncertainties at each step. To address these, the team developed a brief qualitative description of the modeling details relevant to each step and of how each effect size might be larger or smaller in the real world.

Step 1: Impact of a policy intervention on lead in the environment and in children’s blood

The ability to quantify the magnitude of the effect of intervention policies on environmental and childhood blood lead levels varies depending on the data available for each intervention. Whenever possible, the modeling team used real-world risk and effect-size data from controlled evaluations of lead interventions; other types of studies were also employed as needed. In some cases, no one clear effect size was evident, and the modeling team relied on subject matter experts’ guidance to select an input for the model.

For example, for the first intervention examined, the replacement of residential LSLs, as discussed previously, because of a lack of data the modeling team estimated water lead levels before and after a lead service line replacement intervention. To address the uncertainty, the team modeled two starting water levels: 11.4 μg/dL and 5 μg/dL.

The second intervention, residential lead hazard control, has been more extensively studied, and the data have shown robust effects over long periods. The study used in this analysis to generate the effect size for lead paint hazard control was conducted between 2008 and 2009.[257] If lead hazard control abatement and interim control techniques and standards have improved since then, the data may underestimate the impact of lead hazard control implemented today. Whether dust lead levels are higher or lower than those in the underlying study is unknown, and as pre-1960 housing continues to age, dust lead levels attributed to deteriorated paint may increase. The modeling team presented two baseline floor dust lead scenarios to examine the impact of varying dust lead levels on the predicted benefits.

Modeling lead paint hazard control required a second step of predicting the effect of lower dust lead levels on childhood blood lead. The modeling team considered a mix of evidence for this effect size. Although the range was much tighter than the lead service line effect sizes, the team similarly relied on bounding assumptions that the intervention could prevent some but not all lead exposure. However, whether the assumed effect size accurately states, overstates, or understates the impact is unclear.

As with lead service line replacement, the third intervention, improved renovation and repair standards, has a limited evidence base regarding impact. Some previous work explored the effect of a renovation on raising child blood lead levels when compared to no renovation, but the modeling team could not find any analyses that specifically compared the effects of safe versus unsafe practices on blood lead levels. However, one study looked at the impact of following the EPA rule requirements on dust lead levels,[258] and strong anecdotal evidence and expert opinion indicate that renovations pose some of the most acute risks because they disturb and spread lead dust.

As a result, the modeling team relied heavily on previous work by the EPA for this intervention. Because this model is looking at the prevention of a spike in blood lead levels, it is not as well bounded as the previous interventions. Additionally, renovation activities are likely to cause short-term spikes in blood lead rather than prolonged exposure as from lead in soil or water, and because the comparative effects of short- vs. long-term exposure are not well studied, the model may overstate the impacts of the improved standards.

The final intervention, removal of lead from aviation gas, was modeled differently. No data are available on the prohibition of leaded aviation fuel because it has not been done. So the modeling team attempted to estimate the effect of childhood exposure to aviation gas through the differential of blood lead between children living near airports (within 0.6 miles) compared with those living farther away (more than 2.5 miles). Then, using that figure, the modeling team was able to predict the amount of blood lead that might be prevented by eliminating leaded aviation gas. This approach may understate the impacts because it assumes that children living more than 2.5 miles from an airport are not exposed to lead from aviation emissions, which is probably untrue and leads to a conservative estimate.

Step 2: Impact of childhood blood lead levels on intermediate outcomes

After predicting the impact on childhood blood lead levels of the four policy interventions, the modeling team used a more comprehensive set of literature to estimate the impact on intermediate childhood outcomes. These analyses primarily rely on regression modeling, which derives the relationship between blood lead levels and childhood IQ, reading, math, and behavioral outcomes from data for a sample of children. These regression-based approaches bring specific uncertainties into the modeling process. First, they are not designed to demonstrate causal links between exposure and outcomes—that is, they are not random-assignment studies—which could result in effect sizes that overstate the relationship. Because these are not random-assignment studies, they instead must use control variables to account for other characteristics, such as socioeconomic status, related to lead exposure and outcomes. These models could be missing key variables, which could also result in overstated effect sizes. Alternatively, these models might over-control for certain variables and therefore understate the relationship between lead and later outcomes.

Extrapolating results from this literature also includes some level of uncertainty. These studies may include sampling errors, although many, such as those that explore the relationship between blood lead and reading and math scores, have large sample sizes and probably low error levels. Nevertheless, sampling errors could understate or overstate the true impacts. More concerning is the ability to apply the findings to children with very low blood lead levels because most of these studies do not address that population and instead looked at children with levels between 2 and 10 μg/dL. However, the majority of children today in the U.S. fall well below these levels. The modeling team therefore extrapolated results for blood lead levels greater than 2 μg/dL to children below that level and assumed linear relationships, which may over- or understate the effect sizes at lower levels. If lead exposure below a certain threshold does no biological harm, then the linear extrapolations would overstate the true relationship, but if, as suggested by some experts, a supralinear relationship continues at very low levels, this analysis could be understating the effect. (Note that the VP tool used different effect sizes for blood lead levels below 5 μg/dl, 5-10 μg/dl, and above 10 μg/dl to reflect the nonlinear relationship found in the literature). Finally, uncertainty persists about the cumulative impacts of lead exposure, and the studies used for this analysis, which look only at point-in-time relationships, may understate the true relationship between blood lead and IQ, reading, math, and behavioral outcomes.

Step 3: Effect of intermediate outcomes on lifetime outcomes

Similar to the above steps connecting blood lead levels to intermediate outcomes, the relationships between those intermediate outcomes and lifetime earnings and educational attainment are based on previous regression models and literature. The SGM's and VP Tool's approaches to estimating earnings diverge somewhat in this step, with the former relying on its well-tested and established microsimulation model, and the latter using previous literature on the relationship between IQ and lifetime earnings.

The SGM is a regression-based model which raises concerns similar to those outlined in Step 2 above, in that it might overstate the relationship if it misses important control variables or because it cannot show a causal link between the regression-generated results. Additionally, the SGM process does not produce a direct calculation of standard errors; hence, it does not provide a range around the estimated effects into which the true effect will fall. Nevertheless, the effects shown represent the model's best estimates.

The final uncertainty concern in the SGM results from the use of data on past children to predict effects for future children. The cohorts from which the samples were drawn entered adulthood as long ago as the early 1980s and grew up with much higher levels of childhood lead exposure than exist today, which could be reflected in their outcome measures. Therefore, applying their childhood and adult experiences to children born in 2018 and later could cause the modeling to understate or overstate the relationship between intermediate and lifetime outcomes, but given the increasing importance of cognitive skills for life success, they are more likely to understate the effect sizes.

In contrast, the VP Tool uses academic literature to connect intermediate childhood IQ to lifetime earnings. The greatest amount of uncertainty in this relationship involves IQ measurements collected at different points in time. In particular, the IQ that is connected to childhood blood lead comes from tests of children at younger ages (5-10), but the IQ measurements used to estimate impacts on lifetime earnings are from older children (around age 18). If childhood IQ is not perfectly predictive of adolescent IQ, this process may understate or overstate the effect of childhood blood lead on lifetime earnings. Further, these relationships are estimated through regression models, which are subject to the same concerns listed above regarding the use of regression in the SGM process, except for those related to older samples and to direct standard error calculations.

Bounding exercises to measure uncertainty in effect sizes

A useful process to measure and constrain uncertainty in the estimation of effect sizes is to run the models assuming a complete elimination of blood lead. Although this process still contains uncertainty surrounding the blood lead-to-lifetime outcome effect sizes described in Steps 2 and 3 above, it provides a useful upper bound on the potential impacts of a given policy. In this analysis, the modeling teams ran the models measuring the impacts of preventing blood lead levels from rising above 0 μg/dL. Although this is an impossible real-life scenario, it represents a maximum bound on achievable benefits for all policies.

The results of the bounding runs are available in Tables 1 and 2 of the report.

Quantitative sensitivity analyses

To address uncertainties that could not be tested in the bounding exercises, particularly those described in Steps 2 and 3 above, the modeling team performed quantitative sensitivity analyses using the VP Tool on the "Prevent all Lead Exposure" hypothetical modeling scenario. (See Table 1.) These analyses help to better understand and describe the sensitivity of the findings to changes in the input assumptions, coefficients, and data points.

Inputs and coefficients were selected for sensitivity analyses based on their likelihood of having substantial impacts on the final results or if the published values in the literature varied substantially. Alternative values for each coefficient were chosen through literature reviews and typically had been used in previous analyses by other authors. Details on how each alternative value was selected can be found below in the detailed discussion of each result.

Although the sensitivity analyses were run on the hypothetical "total prevention" scenario, the results are relevant to all four interventions modeled in the report. In general, the relative change in benefits would be similar in the other modeling results. For example, an alternative input that reduced the total benefits in this sensitivity analysis by 50 percent would probably have close to the same effect on any of the four policy cost-benefit analyses. (See Table A.5.)

Table A.5

Value of Prevention Tool Sensitivity Analysis Results

			Total discounted benefits	Benefit per child
Results using original inputs			$84 billion	$21,000
Input tested	Original value	Alternative value	Alternative total discounted benefits	Alternative benefit per child
Blood lead level (BLL) to IQ effect size (<5 µg/dL)	1.15	2.53	$174 billion	$44,000
BLL to IQ effect size (<5 µg/dL)	1.15	0.51	$42 billion	$11,000
IQ to lifetime earnings effect size	2.27%	1.10%	$45 billion	$11,000
Population BLL distribution	1.11	0.95	$74 billion	$16,000
Real wage growth	1%	0%	$57 billion	$14,000
Gross domestic product multiplier	1.00	1.92	$155 billion	$39,000
Valuation of QALYs	$50k	$0k	$81 billion	$20,000
Discount rates	3%	1%	$208 billion	$52,000
		5%	$38 billion	$9,000
		7%	$19 billion	$5,000

Blood lead level-to-IQ effect size

The modeling team reviewed the available research to ensure that its estimates of the effect size on IQ of lead in blood were appropriate. The literature included several prospective and cross-sectional epidemiologic studies conducted in diverse populations with adjustment for socioeconomic variables as well as parental intelligence, education, and caregiving quality and stimulation. The studies provide strong support of the loss of neurocognition among young children with blood lead concentrations.[259] The research literature also included a pooled analysis of children ages 4.8-10 who participated in seven prospective studies conducted in Boston, Cincinnati, Cleveland, and Rochester, New York, in the U.S. as well as Mexico City; Port Pirie, Australia; and Kosovo, Yugoslavia, which found associations between blood lead levels and deficits in full-scale intelligence quotient (FSIQ), infant mental development, memory, learning, and executive function in children ages 2-17 with mean blood levels (measured at various life stages and time periods) of 5 to 10 μg/dL. As discussed above, when using this pooled analysis only study estimates of children with the lowest peak blood lead (<7.5 μg/dL and <10 μg/dL) were included for the <5μg/dL effect size. The range of concurrent blood lead levels from these categories was 0.9 to 7.4 μg/dL and 0.1 to 9.8 μg/dL.

The team was particularly interested in whether the relationship between blood lead and IQ persisted at blood levels less than 5 μg/dL. Although few studies extend this relationship below 2 μg/dL, several found IQ deficits in children ages 2-10 with lower mean blood lead levels of 3 to 5 μg/dL.[260] Specifically, in analyses of the Boston and Rochester cohorts and of data pooled across all seven cohorts but restricted to children in the lower blood lead range (e.g., up to 10 μg/dL), associations were observed in children with mean levels of 3 to 4 μg/dL.[261] The mean blood lead levels in these subsets of children were 3.3 μg/dL (Rochester) and 3.8 μg/dL (Boston), which are closer to those of current U.S. children compared with other prospective studies. Further, the Rochester cohort study considered the effects of several variables, including gender, family income, maternal education, race, prenatal maternal smoking, birth weight, and maternal IQ.[262]

The modeling team, with input from members of the advisory committee, made separate estimates for the blood lead-to-IQ effect size depending on starting blood level (<5 μg/dL, 5-10 μg/dL, and 10+ μg/dL), as described above. The estimate for levels below 5 μg/dL had by far the greatest impact on the final results because based on data from NHANES 2011-14, more than 90 percent of children in the U.S. fall into this group.

For the <5 μg/dL category, five estimates from the literature produced an average effect size of 1.15 IQ points per 1 μg/dL blood lead, which was used in the original analyses for this report. This result is somewhat smaller than previous EPA estimates used in regulatory studies (1.75 in the NAAQS final rule and 2.94 in the 2015 cost-benefit analysis on the Steam Electric Power Standards) but somewhat larger than the 0.51 coefficient used in previous research.[263] The 2.94 and 0.51 values are both based on a 2005 pooled analysis, which also was among the studies used to derive the original assumptions for this report.[264] The 2.94 is based on the linear relationship of children below 7.5 μg/dL, and the 0.51 is from the log-linear relationship of children between 2.4 and 10 μg/dL.

The team performed two sensitivity analyses on the blood lead-to-IQ effect size using alternate estimates of 2.53 and 0.51. The team selected these values because 2.53 is corrected from a re-analysis of the 2005 study's <7.5 μg/dL subsample (previously 2.94) and 0.51 is commonly used in other lead remediation studies.[265] As seen in Table A.5, both alternate values had a substantial impact on the final results, changing the total discounted benefits from $84 billion to $174 billion and $42 billion, respectively.

Lifetime earnings-to-IQ effect size

As previously discussed, the modeling team used an average of studies on the relationship between IQ and earnings, while excluding studies that over-controlled for educational attainment or failed to calculate effect sizes for both males and females. The 2.27 percent increase in earnings per IQ point was calculated from the mean of three studies. Some additional literature, which the team excluded for the reasons stated above, favors a value closer to 1.1 percent.[266] The team therefore selected 1.1 percent for the sensitivity analysis, and similar to the IQ-to-blood lead effect size, this change had a large impact on the results, reducing total discounted benefits to $45 billion.

Starting blood lead levels

The modeling team defined population blood lead levels using the two most recent samples from NHANES data (2011-12 and 2013-14), as explained above. The team used a combined sample to provide demographic breakouts of lead exposure as well as a larger dataset, which reduces uncertainty. However, given the persistent downward trend in child blood lead levels since the start of NHANES data collection, the mixture of the two samples could overestimate population blood lead concentrations. To account for this possibility, the team ran a sensitivity analysis using only the 2013-14 distribution, which has a slightly lower mean (0.95 µg/dL vs. 1.1 µg/dL) and a smaller percentage of children above important thresholds (2 µg/dL and 5 µg/dL). The sensitivity analysis revealed relatively small impacts of the alternate data set on the results.

Real wage growth

The benefit calculations were particularly sensitive to assumptions about the labor market and future earnings. Real wage growth was estimated to be 1 percent, which has been used in previous work on childhood lead exposure and is similar to estimates used in other economic projections.[267] An alternative assumption of 0 percent real wage growth had a significant impact on the results, reducing the benefits from $84 billion to $57 billion.

Gross domestic product

The team did not include in the original model gross domestic product (GDP) multiplier effects of the increased income resulting from reduced childhood lead exposure. Some previous work in this area does include such impacts, which result from the assumption that an individual who gains $1 in income will spend some of that dollar, increasing GDP by more than $1.[268] This concept is debated among economists, though most generally agree that the real-world multiplier is greater than 1.0 and that the effect is larger when the economy is not at full employment. The modeling team made a conservative assumption by not including a multiplier effect for this work. Not using a GDP multiplier makes the results more consistent with previous work that also did not include this effect.[269]

An alternative multiplier value of 1.92 was derived using data from the Bureau of Economic Analysis and the ratio of GDP to earned income,[270] which have been relatively consistent over the past 10 years, ranging from about 1.86 to 1.92. Altering this assumption to 1.92 had a significant impact on the results, increasing the total benefits from $84 to $155 billion.

Valuation of QALYs

Another impact of reducing childhood lead exposure is greater longevity resulting from reduced risk of disease, the benefits of which are captured in the model in multiple ways: reductions in health spending, increases in lifetime earnings, and QALYs, a calculation of the "implicit value" of added years of life. QALYs is a somewhat intangible benefit but one that is commonly included in regulatory analyses.[271] The modeling team used a conservative valuation of $50,000 per QALY, and a sensitivity analysis to omit this variable (e.g., valuing a QALY at zero) produced a very similar final result of $81 billion.

Discount rate

In an economic analysis, the rate at which the value of future benefits decreases relative to present-day dollars has a substantial impact on the results. Because many of the benefits from reducing childhood lead exposure come from earnings many years in the future, the discount rate has a very large impact on the findings in this study. A discount rate of 3 percent has become relatively standard in regulatory analyses, though, in the past, the Office of Management and Budget and the Congressional Budget Office have advocated for using both 7 percent and 3 percent. To address this variation in the field, the modeling team conducted a sensitivity analysis at the 7 percent discount rate. The results were a substantially smaller present value, $19 billion rather than $84 billion.

Although government cost-benefit analyses tend to use 3 percent and 7 percent, some economists suggest that discount rates over longer time horizons should be much lower. In particular, they have argued that when analyzing intergenerational transfers (interventions paid for today that benefit future generations), discount rates closer to zero percent are more appropriate.[272] Conducting the sensitivity analysis using a smaller discount rate of 1 percent yielded far greater total discounted benefits of $208 billion.

Endnotes

1 Ronnie Levin et al., "Lead Exposures in U.S. Children, 2008: Implications for Prevention," *Environmental Health Perspectives* 116, no. 10 (2008): 1285–93, http://dx.doi.org/10.1289/ehp.11241; Susan M. Bernard and Michael A. McGeehin, "Prevalence of Blood Lead Levels >5 µg/dL Among U.S. Children 1 to 5 Years of Age and Socioeconomic and Demographic Factors Associated With Blood of Lead Levels 5 to 10 µg/dL, Third National Health and Nutrition Examination Survey, 1988–1994," *Pediatrics* 112, no. 6 (2003): 1308–13, http://pediatrics.aappublications.org/content/112/6/1308.

2 Richard Rabin, "The Lead Industry and Lead Water Pipes: A Modest Campaign," *American Journal of Public Health* 98, no. 9 (2008): 1584–92, http://dx.doi.org/10.2105/AJPH.2007.113555.

3 U.S. Environmental Protection Agency, "Phasing Down Lead in Gasoline," *Environmental Protection Agency Journal* 11, no. 4 (1985), https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=93000E80.txt.

4 Gerald Markowitz and David Rosner, *Lead Wars: The Politics of Science and the Fate of America's Children*, 2013 (Berkeley, CA: University of California Press, 2013).

5 National Research Council Committee on Measuring Lead in Critical Populations, *Measuring Lead Exposure in Infants, Children, and Other Sensitive Populations*; International Labour Organisation, "White (Painting) Convention," 1921 (No. 13), accessed March 20, 2017, http://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_INSTRUMENT_ID:312158.

6 International Labour Organisation, "White (Painting) Convention"; David E. Jacobs, "Lead Poisoning: Focusing on the Fix," *Journal of Public Health Management & Practice* 22, no. 4 (2016): 326, http://dx.doi.org/10.1097/PHH.0000000000000430; Gerald E. Markowitz and David Rosner, *Deceit and Denial: The Deadly Politics of Industrial Pollution* (Berkeley: University of California Press, 2002).

7 David E. Jacobs, "Lead Poisoning: Focusing on the Fix"; Richard Rabin, "The Lead Industry and Lead Water Pipes: A Modest Campaign."

8 Lead-Soldered Food Cans, 60 Fed. Reg. 33106 (June 27, 1995), https://www.gpo.gov/fdsys/granule/FR-1995-06-27/95-15593.

9 David E. Jacobs, "Lead Poisoning: Focusing on the Fix"; Gerald E. Markowitz and David Rosner, *Deceit and Denial.*

10 David E. Jacobs, "Lead Poisoning: Focusing on the Fix"; Gerald E. Markowitz and David Rosner, *Deceit and Denial*, 58.

11 U.S. Environmental Protection Agency, "Phasing Down Lead in Gasoline."

12 U.S. Food and Drug Administration, "Lead-Based Paint Poisoning Prevention Act," accessed April 14, 2017, https://www.fda.gov/RegulatoryInformation/LawsEnforcedbyFDA/ucm148755.htm; Randolph K. Byers and Elizabeth E. Lord, "Late Effects of Lead Poisoning on Mental Development," *American Journal of Diseases of Children* 66, no. 5 (1943): 471–94, http://rachel.org/files/document/Late_Effects_of_Lead_Poisoning_on_Mental_devel.pdf; Gerald E. Markowitz and David Rosner, *Deceit and Denial*, 58.

13 U.S. Environmental Protection Agency, "EPA History: Lead," accessed April 12, 2017, https://www.epa.gov/history/epa-history-lead; U.S. Energy Information Administration, "Gasoline Explained: Gasoline and the Environment," accessed Feb. 7, 2017, http://www.eia.gov/energyexplained/?page=gasoline_environment.

14 Man-Fung Tsoi et al., "Continual Decrease in Blood Lead Level in Americans: United States National Health Nutrition and Examination Survey 1999-2014," *American Journal of Medicine* 129, no. 11 (2016): 1213–18, http://dx.doi.org/10.1016/j.amjmed.2016.05.042; William Wheeler and Mary Jean Brown, "Blood Lead Levels in Children Aged 1-5 Years—United States, 1999-2010," *Morbidity and Mortality Weekly Report* 62, no. 13 (2013): 245–48, https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6213a3.htm.

15 Centers for Disease Control and Prevention, "What Do Parents Need to Know to Protect Their Children?" accessed Jan. 27, 2017, https://www.cdc.gov/nceh/lead/acclpp/blood_lead_levels.htm.

16 National Center for Environmental Health/Agency for Toxic Substances and Disease Registry (meeting of the Lead Poisoning Prevention Subcommittee of the NCEH/ATSDR Board of Scientific Advisors, record of the proceedings, Atlanta, Sept. 19, 2016), https://www.atsdr.cdc.gov/science/lpp/docs/lead_subcommittee_minutes_9_19_2016_508.pdf.

17 Ibid.

18 Centers for Disease Control and Prevention, "Guidelines for the Identification and Management of Lead Exposure in Pregnant and Lactating Women" (Atlanta: U.S. Department of Health and Human Services, Nov. 2010), https://www.cdc.gov/nceh/lead/publications/leadandpregnancy2010.pdf. During pregnancy and lactation, lead stored in bones can release into a mother's blood.

19 U.S. Environmental Protection Agency, "Review of the National Ambient Air Quality Standards for Lead," Fed. Reg. 81, no. 201, Oct. 18, 2016, https://www.gpo.gov/fdsys/pkg/FR-2016-10-18/pdf/2016-23153.pdf; U.S. Environmental Protection Agency, "Lead; Identification of Dangerous Levels of Lead; Final Rule," 40 CFR Part 745, Fed. Reg. 66, no. 4 (2001): 1206–40, https://www.gpo.gov/fdsys/pkg/FR-2001-01-05/pdf/01-84.pdf; Code of Federal Regulations, Protection of Environment, Title 40, Part 141 (1991), http://www.ecfr.gov/cgi-bin/text-idx?SID=531617f923c3de2cbf5d12ae4663f56d&mc=true&node=sp40.23.141.i&rgn=div6; Department of Health and Human Services, National Institute for Occupational Safety and Health, "Occupational Safety and Health Guideline for Inorganic Lead," accessed April 17, 2017, https://www.cdc.gov/niosh/docs/81-123/pdfs/0368.pdf; "Citizen Petition to EPA Regarding the Paint and Dust Lead Standards" (Aug. 10, 2009): http://www.nchh.org/Portals/0/Contents/EPA_Lead_Standards_Petition_Final.pdf.

20 U.S. Environmental Protection Agency, "What Are the Health Effects of Lead?" *Learn About Lead* (March 2017), https://www.epa.gov/lead/learn-about-lead#effects.

21 Ibid.; Bruce Lanphear et al., "Low Level Environmental Lead Exposure and Children's Intellectual Function: An International Pooled Analysis," *Environmental Health Perspectives* 113, no. 7 (2005): 894–99, https://dx.doi.org/10.1289/ehp.7688; email from David Bellinger, Harvard Medical School, to Jee-Young Kim, EPA (2008)—subject: request for additional information on Bellinger and Needleman (2003) (EPA-HQ-OAR-2006-0735-5156), U.S. Environmental Protection Agency, http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2006-0735-5156; email from Dr. Richard Canfield, Cornell University, to Jee-Young Kim, USEPA (2008)—subject: request for additional information on Canfield et al. (2003) (EPA-HQ-OAR-2006-0735- 5811), U.S. Environmental Protection Agency, http://www.regulations.gov/#!documentDetail;D=EPAHQ-OAR-2006-0735-5811; email from Richard Hornung, Cincinnati Children's Hospital Medical Center (CCHMC), to Jee-Young Kim, USEPA (2008)—subject: request for additional information on Lanphear et al. (2005) (EPA-HQ-OAR-2006-0735-5814), U.S. Environmental Protection Agency, http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2006-0735-5814; email from Martha Tellez-Rojo, Center of Investigation in Evaluation and Polls, National institute of Public Health, to Jee-Young Kim, USEPA (2008)—subject: questions on the Tellez-Rojo et al. (2006) paper (EPAHQ-OAR-2006-0735-5123).

22 U.S. Environmental Protection Agency, "Integrated Science Assessment for Lead" (2013), https://www.epa.gov/isa/integrated-science-assessment-isa-lead.

23 U.S. Environmental Protection Agency, "Integrated Science Assessment for Lead."

24 Atmaram Yarlagadda et al., "Blood-Brain Barrier: The Role of Calcium Homeostasis," *Psychiatry (Edgmont)* 4, no. 12 (2007): 55–59, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2861516; Elizabeth Prado and Kathryn Dewey, "Nutrition and Brain Development in Early Life," *Nutrition Reviews* 72, no. 4 (2014): 267–84, https://doi.org/10.1111/nure.12102.

25 U.S. Environmental Protection Agency, "Air Quality Criteria for Lead—Volume I" (October 2006), http://ofmpub.epa.gov/eims/eimscomm.getfile?p_download_id=459555; Talia Sanders et al., "Neurotoxic Effects and Biomarkers of Lead Exposure: A Review," *Environmental Health* 24, no. 1 (2009): 14, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2858639/pdf/nihms190515.pdf.

26 U.S. Environmental Protection Agency, "West Calumet Housing Complex—East Chicago, Ind.," accessed Jan. 27, 2017, https://www.epa.gov/uss-lead-superfund-site/west-calumet-housing-complex-east-chicago-ind; Agency for Toxic Substances and Disease Registry, "Public Health Assessment for U.S. Smelter and Lead Refinery Inc. (USS Lead) East Chicago, Indiana" accessed Feb. 14, 2017, https://www.atsdr.cdc.gov/HAC/pha/USSmelterandLeadRefinery/USSLeadPHABlue01272011.pdf.

27 U.S. Environmental Protection Agency, "West Calumet Housing Complex—East Chicago, Ind."

28 Council on Environmental Health, "Prevention of Childhood Lead Toxicity," *Pediatrics* 138, no. 1 (2016), http://dx.doi.org/10.1542/peds.2016-1493; National Center for Healthy Housing, "Find It, Fix It, Fund It: A Lead Elimination Action Drive," accessed Jan. 27, 2017, http://www.nchh.org/Portals/0/Contents/Find-It-Fix-It-Fund-It.pdf; Ruth Ann Norton, "Strategic Plan to End Childhood Lead Poisoning," Green & Healthy Homes Initiative Blog, accessed Jan. 27, 2017, http://www.greenandhealthyhomes.org/StrategicPlanforEndingLeadPoisoning; Earthjustice, "Health, Environment & Children's Groups Call for National Strategy to End Lead Poisoning and Lead Exposure," Oct. 24, 2016, http://earthjustice.org/news/press/2016/health-environment-children-s-groups-call-for-national-strategy-to-end-lead-poisoning-and-lead-exposure; President's Task Force, "Federal Strategy"; Centers for Disease Control and Prevention, "Preventing Lead Poisoning in Young Children" (August 2005), https://www.cdc.gov/nceh/lead/publications/prevleadpoisoning.pdf; Nick Farr and Cushing N. Dolbeare, "Childhood Lead Poisoning: Solving a Health and Housing Problem" *Cityscape* 2, no. 3 (1996): 167–81, https://www.huduser.gov/periodicals/cityscpe/vol2num3/farr.pdf; Centers for Disease Control and Prevention, "Preventing Lead Exposure in Young Children: A Housing-Based Approach to Primary Prevention of Lead Poisoning" (Atlanta: CDC, 2004), https://www.cdc.gov/nceh/lead/publications/primarypreventiondocument.pdf; U.S. Environmental Protection Agency, "Report of the Lead and Copper Rule Working Group to the National Drinking Water Advisory Council" (2015), https://www.epa.gov/sites/production/files/2016-01/documents/ndwaclcrwgfinalreportaug2015.pdf; Educational Services for Children Affected by Lead Expert Panel, "Educational Interventions for Children Affected by Lead" (2015), https://www.cdc.gov/nceh/lead/publications/educational_interventions_children_affected_by_lead.pdf; Centers for Disease Control and Prevention, "Guidelines for the Identification and Management of Lead Exposure in Pregnant and Lactating Women" (Atlanta: U.S. Department of Health and Human Services, November 2010), https://www.cdc.gov/nceh/lead/publications/leadandpregnancy2010.pdf.

29 The models include impacts for the 2018 birth cohort up to age 100 and estimate the number of children alive at each age using CDC Underlying Cause of Death data. A decreasing percentage of the cohort is predicted to be alive and receiving the benefits of lead reduction at older ages. For example, at age 100 approximately 4 percent of individuals are projected to still be alive.

30 A.C. Klassen et al., "Best Practices for Mixed Methods for Quality of Life Research," *Quality of Life Research* 21, no. 3 (2012): 377–80, https://doi.org/10.1007/s11136-012-0122-x; Sachiko Ozawa and Krit Pongpirul, "10 Best Resources on … Mixed Methods Research in Health Systems," *Health Policy and Planning* 29 (2014): 323–27, https://doi.org/10.1093/heapol/czt019.

31 Isabel V. Sawhill and Richard V. Reeves, "Modeling Equal Opportunity," *The Russell Sage Foundation Journal of the Social Sciences* 2, no. 2 (2016): 60–97; Gregory Acs et al., "The Social Genome Model: Estimating How Policies Affect Outcomes, Mobility and Inequality Across the Life Course," *Journal of Social Issues* 72 (2016): 656–75, http://dx.doi.org/10.1111/josi.12188.

32 Lisa Chiodo et al., "Blood Lead Levels and Specific Attention Effects in Young Children," *Neurotoxicology and Teratology* 29, no. 5 (2007): 538–46, https://doi.org/10.1016/j.ntt.2007.04.001; Marie Lynn Miranda et al., "The Relationship Between Early Childhood Blood Lead Levels and Performance on End-of-Grade Tests," *Environmental Health Perspectives* 115, no. 8 (2007): 1242–47, https://doi.org/10.1289/ehp.9994; Michael J. Blackowicz et al., "The Impact of Low-Level Lead Toxicity on School Performance Among Hispanic Subgroups in the Chicago Public Schools," *International Journal of Environmental Research and Public Health* 13, no. 8 (2016): 774, https://dx.doi.org/10.3390%2Fijerph13080774; Anne Evens et al., "The Impact of Low-Level Lead Toxicity on School Performance Among Children in the Chicago Public Schools: A Population-Based Retrospective Cohort Study," *Environmental Health* 14, no. 24 (2015): 21, https://doi.org/10.1186/s12940-015-0008-9; Katarzyna Kordas et al., "Deficits in Cognitive Function and Achievement in Mexican First-Graders With Low Blood Lead Concentrations," *Environmental Research* 110, no. 3 (2006): 371–86, https://doi.org/10.1016/j.envres.2005.07.007; Bruce Lanphear et al., "Cognitive Deficits Associated With Blood Lead Concentrations <10 microg/dL in U.S. Children and Adolescents," *Public Health Reports* 115, no. 6 (2000): 521–29, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1308622; David Bellinger, Karen Stiles, and Herbert Needleman, "Low-Level Lead Exposure, Intelligence and Academic Achievement: A Long-Term Follow-Up Study," *Pediatrics* 90, no. 6 (1992): 855–61, https://www.ncbi.nlm.nih.gov/pubmed/1437425.

33 U.S. Centers for Disease Control and Prevention, National Center for Environmental Health, Division of Emergency and Environmental Health Services, "National Surveillance Data (1997–2015)," last updated Oct. 28, 2016, https://www.cdc.gov/nceh/lead/data/national.htm.

34 Bruce Lanphear et al., "Low Level Environmental Lead Exposure and Children's Intellectual Function: An International Pooled Analysis," *Environmental Health Perspectives* 113, no. 7 (2005): 894–99, https://dx.doi.org/10.1289/ehp.7688; email from David Bellinger, Harvard Medical School, to Jee-Young Kim, EPA (2008)—subject: request for additional information on Bellinger and Needleman (2003) (EPA-HQ-OAR-2006-0735-5156), U.S. Environmental Protection Agency, http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2006-0735-5156; email from Dr. Richard Canfield, Cornell University, to Jee-Young Kim, USEPA (2008)—subject: request for additional information on Canfield et al. (2003) (EPA-HQ-OAR-2006-0735-5811), U.S. Environmental Protection Agency, http://www.regulations.gov/#!documentDetail;D=EPAHQ-OAR-2006-0735-5811; email from Richard Hornung, Cincinnati Children's Hospital Medical Center (CCHMC), to Jee-Young Kim, USEPA (2008)—subject: request for additional information on Lanphear et al. (2005) (EPA-HQ-OAR-2006-0735-5814), U.S. Environmental Protection Agency, http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2006-0735-5814; email from Martha Tellez-Rojo, Center of Investigation in Evaluation and Polls, National Institute of Public Health, to Jee-Young Kim, USEPA (2008)—subject: questions on the Tellez-Rojo et al. (2006) paper (EPAHQ-OAR-2006-0735-5123).

35 Bruce Lanphear et al., "Cognitive Deficits"; Lisa Chiodo et al., "Blood Lead Levels and Specific Attention Effects in Young Children," *Neurotoxicology and Teratology* 29, no. 5 (2007): 538–46, https://doi.org/10.1016/j.ntt.2007.04.001; Pamela Surkan et al., "Neuropsychological Function in Children With Blood Lead Levels < 10μg/dL," *Neurotoxicology* 28, no. 6 (2007): 1170–77, https://dx.doi.org/10.1016/j.neuro.2007.07.007; Meeyoung Min et al., "Cognitive Development and Low-Level Lead Exposure in Poly-Drug Exposed Children," *Neurotoxicology and Teratology* 31 no. 4 (2009): 225–31, https://dx.doi.org/10.1016/j.ntt.2009.03.002.

36 Richard L. Canfield et al., "Intellectual Impairment in Children With Blood Lead Concentrations Below 10 μg per Deciliter," *New England Journal of Medicine* 348 (2003): 1517–26, http:/dx.doi.org/10.1056/NEJMoa022848.

37 U.S. Environmental Protection Agency, "Benefit and Cost Analysis for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category" (October 2015), https://www.epa.gov/sites/production/files/2015-10/documents/steam-electric_benefit-cost-analysis_09-29-2015.pdf.

38 Marie Lynn Miranda et al., “The Relationship Between Early Childhood Blood Lead Levels and Performance on End-of-Grade Tests," *Environmental Health Perspectives* 115 (2007): 1242–47, http://www.jstor.org/stable/4626860?seq=1#page_scan_tab_contents; Michael J. Blackowicz et al., “The Impact of Low-Level Lead Toxicity on School Performance Among Hispanic Subgroups in the Chicago Public Schools,” *International Journal of Environmental Research and Public Health* 13, no. 8 (2016): 774, doi: 10.3390/ijerph13080774; Chiodo et al., "Blood Lead Levels and Specific Attention Effects in Young Children," *Neurotoxicology and Teratology* 29, no. 5 (2007): 538–46, https://doi.org/10.1016/j.ntt.2007.04.001; David C. Bellinger, Karen M. Stiles, and Herbert L. Needleman, "Low-Level Lead Exposure, Intelligence and Academic Achievement: a Long-Term Follow-Up Study," *Pediatrics* 90, no. 6 (1992): 855–61, http://pediatrics.aappublications.org/content/90/6/855.short; Evans et al., “The Impact of Low-Level Lead Toxicity on School Performance Among Children in the Chicago Public Schools: a Population-Based Retrospective Cohort Study,” *Environmental Health* 14, no. 21 (2015), https://doi.org/10.1186/s12940-015-0008-9; Kordas et al., “Deficits in Cognitive Function and Achievement in Mexican First-Graders With Low Blood Lead Concentrations,” *Environmental Research* 100, no. 3 (2006): 371–86, https://doi.org/10.1016/j.envres.2005.07.007; Lanphear et al., "Cognitive Deficits Associated With Blood Lead Concentrations< 10 microg/dL in U.S. Children and Adolescents,” *Public Health Reports* 115, no. 6 (2000): 521–29, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1308622.

39 J.M. Burns et al., “Lifetime Low-Level Exposure to Environmental Lead and Children's Emotional and Behavioral Development at Ages 11-13 Years: The Port Pirie Cohort Study,” *American Journal of Epidemiology* 149, no. 8 (1999): 740–49, https://www.academia.edu/25223826/Lifetime_Low-Level_Exposure_to_Environmental_Lead_and_Childrens_Emotional_and_Behavioral_Development_at_Ages_11-13_Years_The_Port_Pirie_Cohort_Study; Aimin Chen et al., “Lead Exposure, IQ, and Behavior in Urban 5- to 7-Year-Olds: Does Lead Affect Behavior Only by Lowering IQ?” *Pediatrics* 119, no. 3 (2007): e650–58, http://pediatrics.aappublications.org/content/119/3/e650.short; Lisa M. Chiodo, Sandra W. Jacobson, and Joseph L. Jacobson, “Neurodevelopmental Effects of Postnatal Lead Exposure at Very Low Levels,” *Neurotoxicology and Teratology* 26, no. 3 (2004): 359–71, doi: 10.1016/j.ntt.2004.01.010; Lisa M. Chiodo et al., "Blood Lead Levels and Specific Attention Effects in Young Children," *Neurotoxicology and Teratology* 29, no. 5 (2007): 538–46, doi: 10.1016/j.ntt.2007.04.001; Joel T. Nigg et al., “Low Blood Levels Associated With Clinically Diagnosed Attention-Deficit/Hyperactivity Disorder and Mediated by Weak Cognitive Control,” *Biological Psychiatry* 63, no. 3 (2008): 325–31, doi: 10.1016/j.biopsych.2007.07.013.

40 S.M. Bernard and M.A. McGeehin, “Prevalence of Blood Lead Levels ≥5 μg/dL Among U.S. Children 1 to 5 Years of Age and Socioeconomic and Demographic Factors Associated With Blood Lead Level 5 to 10 μg/dL, Third National Health and Nutrition Examination Survey, 1988–1994,” *Pediatrics* 112, no. 6 (2003): 1308–13.

41 Peter J. Neumann, Joshua T. Cohen, and Milton C. Weinstein, “Updating Cost-Effectiveness—The Curious Resilience of the $50,000-per-QALY Threshold,” *New England Journal of Medicine* 371, no. 9 (2014): 796–97, http://dx.doi.org/10.1056/NEJMp1405158.

42 John Paul Wright et al., “Association of Prenatal and Childhood Blood Lead Concentrations With Criminal Arrests in Early Adulthood,” *PLoS Medicine* 5, no. 5 (2008): e101, https://doi.org/10.1371/journal.pmed.0050101.

43 Steven G. Gilbert and Bernard Weiss, “A Rationale for Lowering the Blood Lead Action Level from 10 to 2 μg/dL,” *Neurotoxicology* 27, no. 5 (2006): 693–701, https://dx.doi.org/10.1016%2Fj.neuro.2006.06.008; Tanya E. Froelich et al., “Association of Tobacco and Lead Exposures With Attention-Deficit/Hyperactivity Disorder,” *Pediatrics* 124, no. 6 (2009): e1054–63, https://doi.org/10.1542/peds.2009-0738.

44 Aaron Reuben et al., “Association of Childhood Blood Lead Levels With Cognitive Function and Socioeconomic Status at Age 38 Years and With IQ Change and Socioeconomic Mobility Between Childhood and Adulthood,” *The Journal of the American Medical Association* 317, no. 12 (2017): 1244–51, http://dx.doi.org/10.1001/jama.2017.1712.

45 U.S. Environmental Protection Agency, “Basic Information About Lead in Drinking Water,” accessed Dec. 12, 2016, https://www.epa.gov/ground-water-and-drinking-water/basic-information-about-lead-drinking-water; “Safety of Public Water Systems,” The Public Health and Welfare, U.S. Code 42 § 300f, accessed May 24, 2017, https://www.gpo.gov/fdsys/pkg/USCODE-2010-title42/pdf/USCODE-2010-title42-chap6A-subchapXII.pdf. A later amendment to the SDWA that went into effect in 2014 banned lead plumbing fixtures in homes and redefined the term “lead free.”

46 Anne Sandvig et al., “Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues” (Denver: AWWA and EPA, 2008), https://archive.epa.gov/region03/dclead/web/pdf/91229.pdf.

47 Simoni Triantafyllidou and Marc Edwards, “Lead (Pb) in Tap Water and in Blood: Implications for Lead Exposure in the United States,” *Critical Reviews in Environmental Science and Technology* 42, no. 13 (2012): 1297–1352, http://dx.doi.org/10.1080/10643389.2011.556556; Mary Jean Brown and Stephen Margolis, “Lead in Drinking Water and Human Blood Lead Levels in the United States,” *Morbidity and Mortality Weekly Report* 61 (2012), https://www.cdc.gov/mmwr/pdf/other/su6104.pdf; Marc Edwards, Simoni Triantafyllidou, and Dana Best, “Elevated Blood Lead in Young Children Due to Lead-Contaminated Drinking Water,” *Environmental Science and Technology* 43, no. 5 (2009), http://dx.doi.org/10.1021/es802789w; G. Ngueta et al., “Use of a Cumulative Exposure Index to Estimate the Impact of Tap Water Lead Concentration on Blood Lead Levels in 1- to 5-Year-Old Children (Montreal, Canada),” *Environmental Health Perspectives* 124 (2016): 388–95; http://dx.doi.org/10.1289/ehp.1409144.

48 A cross-sectional study is an analysis of observed data collected from a population at a specific point in time.

49 Bruce P. Lanphear et al., “Environmental Exposures to Lead and Urban Children’s Blood Lead Levels,” *Environmental Research* 76, no. 2 (1998): 120–30, https://doi.org/10.1006/enrs.1997.3801.

50 "National Primary Drinking Water Regulations," Code of Federal Regulations, title 40, part 141 (June 7, 1991), http://www.ecfr.gov/cgi-bin/text-idx?SID=531617f923c3de2cbf5d12ae4663f56d&mc=true&node=sp40.23.141.i&rgn=div6.

51 U.S. Environmental Protection Agency, "Lead and Copper Rule Revisions White Paper" (Washington: U.S. Environmental Protection Agency, 2016), https://www.epa.gov/sites/production/files/2016-10/documents/508_lcr_revisions_white_paper_final_10.26.16.pdf.

52 Ibid.

53 An observational study is an analysis in which individuals are monitored or certain outcomes are measured. No attempt is made to affect the outcome (for example, no treatment is given). Well-designed observational studies have been shown to provide results similar to randomized controlled trials. Cohort and case-control studies are two primary types of observational studies that aid in evaluating associations between diseases and exposures.

54 Mary Jean Brown et al., "Association Between Children's Blood Lead Levels, Lead Service Lines, and Water Disinfection, Washington, DC, 1998–2006," *Environmental Research* 111 (2011): 67–74, https://doi.org/10.1016/j.envres.2010.10.003.

55 U.S. Environmental Protection Agency, "SAB Evaluation of the Effectiveness of Partial Lead Service Line Replacements" (2011), https://www.epa.gov/sites/production/files/201509/documents/sab_evaluation_partial_lead_service_lines_epa-sab-11-015.pdf.

56 Élise Deshommes et al., "Monitoring-Based Framework to Detect and Manage Lead Water Service Lines," *Journal of the American Waterworks Association* 108, no. 11 (2016): 555–70, http://dx.doi.org/10.5942/jawwa.2016.108.0167.

57 David A. Cornwell, Richard A. Brown, and Steve H. Via, "National Survey of Lead Service Line Occurrence," *Journal of the American Water Works Association* 108, no. 4 (2016): E187–92, http://dx.doi.org/10.5942/jawwa.2016.108.0086; U.S. Environmental Protection Agency, "Drinking Water Action Plan" (Washington: U.S. Environmental Protection Agency, November 2016), https://www.epa.gov/sites/production/files/2016-11/documents/508.final_.usepa_.drinking.water_.action.plan_11.30.16.v0.pdf.

58 Michael W. Shannon and John W. Graef, "Lead Intoxication in Infancy," *Pediatrics* 89, no. 1 (1992): 87–90, http://pediatrics.aappublications.org/content/89/1/87?sso=1&sso_redirect_count=1&nfstatus=401&nftoken=00000000-0000-0000-0000-000000000000&nfstatusdescription=ERROR%3a+No+local+token.

59 County Health Rankings, "Our Ratings," accessed May 5, 2017, http://www.countyhealthrankings.org/roadmaps/what-works-for-health/our-ratings. Scientifically supported is defined by County Health Rankings as interventions for which there are 1 or more systematic review(s), or at least three experimental studies, or three quasi-experimental studies with matched concurrent comparisons. Studies have strong designs and statistically significant favorable findings, see http://www.countyhealthrankings.org/roadmaps/what-works-for-health/our-methods.

60 Alaska Department of Health and Social Services, "Technical Guidance for Health Impact Assessment In Alaska," accessed May 12, 2017, http://dhss.alaska.gov/dph/Epi/hia/Documents/AlaskaHIAToolkit.pdf.

61 Cornwell et al., "National Survey of Lead Service Line Occurrence."

62 U.S. Census Bureau, Population Division, "Annual Estimates of the Resident Population by Single Year of Age and Sex for the United States: April 1, 2010 to July 1, 2015" (Washington: U.S. Census Bureau, June 2016), https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk.

63 Ibid.

64 Michèle Prévost and Élise Deshommes. "Calculation of Reference Water Levels for Lead Service Line Replacement Intervention," http://altarum.org/our-work/lead-exposure-mitigation; S. Triantafyllidou et al., "Low Contribution of Pb02-Coated Lead Service Lines to Water Lead Contamination at the Tap," *Environmental Science & Technology* 49, no. 6 (2015): 3746–54, doi: 10.1021/es505886h.

65 U.S. Environmental Protection Agency, "Proposed Modeling Approaches for a Health-Based Benchmark for Lead in Drinking Water" (Washington: U.S. Environmental Protection Agency, 2017), https://www.epa.gov/sites/production/files/2017-01/documents/report_proposed_modeling_approaches_for_a_health_based_benchmark_for_lead_in_drinking_water_final_0.pdf; U.S. Environmental Protection Agency, Integrated Exposure Uptake Biokinetic Model for Lead in Children, EPA 9285.7-42540-K-01-005, IEUBK win 32Lead Model Version 1.1 Build 11 (May 2007) https://www.epa.gov/superfund/lead-superfund-sites-software-and-users-manuals. IEUBK uses site-specific data and biokinetic modeling.

66 Anne Sandvig et al., "Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues" (Denver: AWWA and EPA, 2008), https://archive.epa.gov/region03/dclead/web/pdf/91229.pdf.

67 Personal communication with Steve Via, "Informal Survey of Estimated Lead Service Line Replacement Costs," unpublished dataset, cited with permission, March 2017.

68 Pam Zekman, "2 Investigators: Cost of Replacing Lead Service Lines Is on Chicago Home Owners," CBS Chicago, Dec. 8, 2016, http://chicago.cbslocal.com/2016/12/08/2-investigators-cost-of-replacing-lead-service-lines-is-on-chicago-home-owners.

69 Michael Hawthorne and Peter Matuszak, "As Other Cities Dig Up Pipes Made of Toxic Lead, Chicago Resists," *Chicago Tribune*, Sept. 21, 2016, http://www.chicagotribune.com/news/watchdog/ct-lead-water-pipes-funding-20160921-story.html; Environmental Protection Agency Science Advisory Board, "SAB Evaluation of the Effectiveness of Partial Lead Service Line Replacements."

70 U.S. Environmental Protection Agency, "How the Drinking Water State Revolving Fund Works," accessed March 21, 2017, https://www.epa.gov/drinkingwatersrf/how-drinking-water-state-revolving-fund-works.

71 Ronnie Levin et al., "Lead Exposures in U.S. Children, 2008: Implications for Prevention."

72 David E. Jacobs, "Lead-Based Paint as a Major Source of Childhood Lead Poisoning: A Review of the Evidence," in *Lead in Paint, Soil and Dust: Health Risks, Exposure Studies, Control Measures and Quality Assurance*, ed. Michael E. Beard and S.D. Allen Iske (Philadelphia: American Society for Testing and Materials, 1995), 175–87.

73 U.S. Department of Housing and Urban Development, "American Healthy Homes Survey: Lead and Arsenic Findings" (2011), http://portal.hud.gov/hudportal/documents/huddoc?id=AHHS_Report.pdf.

74 Ibid.

75 40 CFR 745.223.

76 HUD, "American Healthy Homes Survey" (2011); David E. Jacobs et al., "Replacing Windows Reduces Childhood Lead Exposure: Results From a State-Funded Program," *Journal of Public Health Management and Practice* 22, no. 5 (2016): 482–91, https://doi.org/10.1097/PHH.0000000000000389.

77 Caroline Alderson, "Technical Preservation Guidelines: Upgrading Historic Building Windows" (Washington: U.S. General Services Administration, April 2009), https://www.gsa.gov/graphics/pbs/Windows.pdf; Advisory Council on Historic Preservation, "The National Historic Preservation Program: Overview," accessed Feb. 17, 2017, http://www.achp.gov/overview.html.

78 David E. Jacobs, "Lead-Based Paint as a Major Source of Childhood Lead Poisoning"; Sherry Dixon et al., "Window Replacement and Residential Lead Paint Hazard Control 12 Years Later," *Environmental Research* 113 (2012): 14–20, https://doi.org/10.1016/j.envres.2012.01.005; David E. Jacobs et al., "Replacing Windows Reduces Childhood Lead Exposure"; Rick Nevin et al., "Monetary Benefits of Preventing Childhood Lead Poisoning With Lead-Safe Window Replacement," *Environmental Research* 106, no. 3 (2008): 410–19, http://doi.org/10.1016/j.envres.2007.09.003; Lead Safe Illinois, "CLEAR-WIN Comprehensive Lead Elimination and Reduction—Through Window Replacement" (2010), http://www.leadsafeillinois.org/uploads/documents/CLEARWINfactsheet62010.pdf; Illinois Department of Public Health, "Clear-Win Program: Pilot Phase Evaluation" (December 2014), http://www.dph.illinois.gov/sites/default/files/publications/publications-ohp-clear-winreport-042016.pdf.

79 Yona Amitai et al., "Residential Deleading: Effects on the Blood Lead Levels of Lead-Poisoned Children," *Pediatrics* 88, no. 5 (1991): 893–97, http://pediatrics.aappublications.org/content/88/5/893.

80 Walter J. Rogan et al., "The Effect of Chelation Therapy With Succimer on Neuropsychological Development in Children Exposed to Lead," *The New England Journal of Medicine* 344 (2001): 1421–26, http://dx.doi.org/10.1056/NEJM200105103441902; Hilary Thomson et al., "Housing Improvements for Health and Associated Socio-Economic Outcomes," *Cochrane Database of Systematic Reviews* 2 (Feb. 28, 2013), https://doi.org/10.1002/14651858.CD008657.pub2; Barbara Nussbaumer-Streit et al., "Household Interventions for Preventing Domestic Lead Exposure in Children (Review)," *Cochrane Database of Systematic Reviews* 10 (2016): 2–3, http://dx.doi.org/10.1002/14651858.CD006047.pub5.

81 Roberto Gwiazda, Carla Campbell, and Donald Smith, "A Noninvasive Isotopic Approach to Estimate the Bone Lead Contribution to Blood in Children: Implications for Assessing the Efficacy of Lead Abatement," *Environmental Health Perspectives* 113, no. 1 (2005): 104–10, http://www.jstor.org/stable/3435755.

82 P.S. Barry, "A Comparison of Concentrations of Lead in Human Tissues," *British Journal of Industrial Medicine* 32, no. 2 (1975): 119–39, https://www.ncbi.nlm.nih.gov/pubmed/1131339; Michael B. Rabinowitz, "Toxicokinetics of Bone Lead," *Environmental Health Perspectives* 91 (1991): 33–37, http://dx.doi.org/10.2307/3430979; Howard Hu et al., "The Epidemiology of Lead Toxicity in Adults: Measuring Dose and Consideration of Other Methodologic Issues," *Environmental Health Perspectives* 115, no. 3 (2007): 455–62, https://dx.doi.org/10.1289%2Fehp.9783; Pam Factor-Litvak et al., "The Yugoslavia Prospective Study of Environmental Lead Exposure," *Environmental Health Perspectives* 107, no. 1 (1999): 9–15, http://dx.doi.org/10.2307/3434284; Mary Jean Brown et al., "Determinants of Bone and Blood Lead Concentrations in the Early Postpartum Period," *Occupational and Environmental Medicine* 57, no. 8 (2000): 535–41, https://dx.doi.org/10.1136%2Foem.57.8.535; Hung-Yi Chuang et al., "Interrelations of Lead Levels in Bone, Venous Blood, and Umbilical Cord Blood With Exogenous Lead Exposure Through Maternal Plasma Lead in Peripartum Women," *Environmental Health Perspectives* 109, no. 5 (2001): 527–32, http://dx.doi.org/10.2307/3454713; P.S. Barry, "Concentrations of Lead in the Tissues of Children," *British Journal of Industrial Medicine* 38, no. 1 (1981): 61–71, http://www.jstor.org/stable/27723491.

83 Residential Lead-Based Paint Hazard Reduction Act of 1992, Pub. L. No. 102-550 (as amended through April 21, 2005), https://www.hud.gov/offices/lead/library/lead/Title_X.pdf.

84 President's Task Force on Environmental Health Risks and Safety Risks to Children, "Key Federal Programs to Reduce Childhood Lead Exposures and Eliminate Associated Health Impacts" (November 2016), https://ptfceh.niehs.nih.gov/features/assets/files/key_federal_programs_to_reduce_childhood_lead_exposures_and_eliminate_associated_health_impactspresidents_508.pdf.

85 U.S. Department of Housing and Urban Development, "American Healthy Homes Survey: Lead and Arsenic Findings."

86 Katherine A. Ahrens et al., "Housing Assistance and Blood Lead Levels: Children in the United States, 2005–2012," *American Journal of Public Health* 106, no. 11 (2016): 2049–56, http://dx.doi.org/10.2105/AJPH.2016.303432.

87 National Conference of State Legislatures, "Lead Hazards Project" (Washington: NCSL, Aug. 3, 2016), http://www.ncsl.org/research/environment-and-natural-resources/lead-hazards-project.aspx.

88 Katrina S. Korfmacher and Michael L. Hanley, "Are Local Laws the Key to Ending Childhood Lead Poisoning?" *Journal of Health Politics, Policy and Law* 38, no. 4 (2013): 757–813, http://dx.doi.org/10.1215/03616878-2208603.

89 Nimia L. Reyes et al., "Identifying Housing That Poisons: A Critical Step in Eliminating Childhood Lead Poisoning," *Journal of Public Health Management and Practice* 12, no. 6 (2006): 563–69, http://journals.lww.com/jphmp/Abstract/2006/11000/Identifying_Housing_That_Poisons__A_Critical_Step.10.aspx; Dori B. Reissman et al., "Use of Geographic Information System Technology to Aid Health Department Decision Making About Childhood Lead Poisoning Prevention Activities," *Environmental Health Perspectives* 109, no. 1 (2001): 89–94, http://dx.doi.org/10.2307/3434926.

90 Chinaro Kennedy et al., "Primary Prevention of Lead Poisoning in Children: A Cross-Sectional Study to Evaluate State Specific Lead-Based Paint Risk Reduction Laws in Preventing Lead Poisoning in Children," *Environmental Health* 13 (2014): 93. http://dx.doi.org/10.1186/1476-069X-13-93.

91 U.S. Department of Housing and Urban Development, "American Healthy Homes Survey: Lead and Arsenic Findings" (2011), http://portal.hud.gov/hudportal/documents/huddoc?id=AHHS_Report.pdf.

92 David E. Jacobs, "Lead-Based Paint as a Major Source of Childhood Lead Poisoning"; Sherry Dixon et al., "Window Replacement and Residential Lead Paint Hazard Control 12 Years Later," *Environmental Research* 113 (2012): 14–20, https://doi.org/10.1016/j.envres.2012.01.005; David E. Jacobs et al., "Replacing Windows Reduces Childhood Lead Exposure: Results From a State-Funded Program," *Journal of Public Health Management and Practice* 22, no. 5 (2016): 482–91, https://doi.org/10.1097/PHH.0000000000000389; Rick Nevin et al., "Monetary Benefits of Preventing Childhood Lead Poisoning With Lead-Safe Window Replacement," *Environmental Research* 106, no. 3 (2008): 410–19, http://doi.org/10.1016/j.envres.2007.09.003; Lead Safe Illinois, "CLEAR-WIN Comprehensive Lead Elimination and Reduction—Through Window Replacement" (2010), http://www.leadsafeillinois.org/uploads/documents/CLEARWINfactsheet62010.pdf; Illinois Department of Public Health, "Clear-Win Program: Pilot Phase Evaluation" (December 2014), http://www.dph.illinois.gov/sites/default/files/publications/publications-ohp-clear-winreport-042016.pdf.

93 County Health Rankings, "Our Ratings." Scientifically supported is defined by County Health Rankings as interventions for which there are one or more systematic review(s), or at least three experimental studies, or three quasi-experimental studies with matched concurrent comparisons. Studies have strong designs and statistically significant favorable findings.

94 Alaska Department of Health and Social Services, "Technical Guidance for Health Impact Assessment in Alaska."

95 Sherry Dixon et al., "Window Replacement and Residential Lead Paint Hazard Control 12 Years Later," *Environmental Research* 113 (2012): 14–20, https://doi.org/10.1016/j.envres.2012.01.005.

96 Mark Farfel et al., "An Extended Study of Interim Lead Hazard Reduction Measures Employed in the Baltimore Clinical Center of the Treatment of Lead-Exposed Children (TLC)—Clinical Trial" (Washington: U.S. Department of Housing and Urban Development, April 2000), http://www.nmic.org/nyccelp/medical-studies/Farfel-extended-study-interim-controls-4-00.pdf; Farfel et al. 1997, "Lead Based Paint Abatement and Repair and Maintenance Study" (Washington: U.S. Environmental Protection Agency, December 1997), EPA-747-R-97-005, https://www.epa.gov/sites/production/files/documents/24folup. pdf. Several variables would affect the applicability of this study to the prevention scenario. Techniques and standards may have improved since the study was conducted in 2008 and 2009, so its data may underestimate the impact of lead hazard control undertaken today. Because the prevalence of contaminated dust in older homes may have changed since these data were collected the team modeled two different baseline dust lead levels, 20 and 10 μg/sq. ft.

97 Sherry L. Dixon et al., "Exposure of U.S. Children to Residential Dust Lead, 1999–2004: II. The Contribution of Lead-Contaminated Dust to Children's Blood Lead Levels," *Environmental Health Perspectives* 117, no. 3 (2009): 468–74, https://dx.doi.org/10.1289/ehp.11918.

98 U.S. Department of Housing and Urban Development, "American Healthy Homes Survey: Lead and Arsenic Findings" (April 2011), http://portal.hud.gov/hudportal/documents/huddoc?id=AHHS_Report.pdf.

99 To determine the number of children born into a remediated home in the next 10 years, the team first calculated the percent of the housing stock that would receive the intervention by dividing the number of remediated homes by the total number of homes in the U.S. as shown in the American Community Survey. The team then used this percentage as the likelihood that a future child would be born into a remediated home. For example, for the pre-1960, lead hazard control intervention, the team estimated that 2.1 percent of the housing stock would receive the intervention and therefore each future child would have a 2.1 percent chance of living in a remediated home. The team then assumed conservatively that these effects would persist for the next 10 birth cohorts.

100 Mark Farfel et al., "An Extended Study of Interim Lead Hazard Reduction Measures Employed in the Baltimore Clinical Center of the Treatment of Lead-Exposed Children (TLC)—Clinical Trial" (Washington: U.S. Department of Housing and Urban Development, April 2000), http://www.nmic.org/nyccelp/medical-studies/Farfel-extended-study-interim-controls-4-00.pdf; Mark Farfel et al., "Lead Based Paint Abatement and Repair and Maintenance Study in Baltimore: Findings Based on Two Years of Follow-Up" (Washington: U.S. Environmental Protection Agency, December 1997), https://www.epa.gov/sites/production/files/documents/24folup.pdf.

101 The maximum number children born in 2018 from low-income families expected to reside in pre-1960 housing is 321,000. A subset of these children—311,000—are expected to reside in homes with lead-based paint.

102 The Pew Charitable Trusts, "Household Expenditures and Income: Balancing Family Finances in Today's Economy" (March 2016), http://www.pewtrusts.org/en/research-and-analysis/issue-briefs/2016/03/household-expenditures-and-income.

103 National Center for Healthy Housing, "Find It, Fix It, Fund It."

104 Federal Housing Administration, "FHA Single Family Housing Policy Handbook" (Washington: U.S. Department of Housing and Urban Development, Aug. 27, 2014), https://portal.hud.gov/hudportal/documents/huddoc?id=sfh_poli_appr_prop.pdf.

105 U.S. Environmental Protection Agency, Economic Analysis for the TSCA Lead Renovation, Repair, and Painting Program Final Rule for Target Housing and Child-Occupied Facilities, §402(c) (2008): 3 39–41, http://www.nchh.org/Portals/0/Contents/EPA-HQ-OPPT-2005-0049-0916_Final_Economic_Analysis_3-08.pdf.

106 Michael Rabinowitz, Alan Leviton, and David Bellinger, "Home Refinishing, Lead Paint and Infant Blood Lead Levels," *American Journal of Public Health* 75, no. 4 (1985): 403–04, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1646251/pdf/amjph00280-0093.pdf.

107 Adam J. Spanier et al., "The Contribution of Housing Renovation to Children's Blood Lead Levels: A Cohort Study," *Environmental Health* 12, no. 1 (2013): 72, http://dx.doi.org/10.1186/1476-069X-12-72.

108 E.M. Franko et al., "Children With Elevated Blood Lead Levels Related to Home Renovation, Repair, and Painting Activities—New York State, 2006-2007," *Morbidity and Mortality Weekly Report* 58, no. 3 (2009): 55–58, https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5803a3.htm; Rabinowitz, Leviton, and Bellinger, "Home Refinishing, Lead Paint and Infant Blood Lead Levels."

109 E.M. Franko et al., "Children With Elevated Blood Lead Levels."

110 U.S. Environmental Protection Agency, Lead Renovation, Repair and Painting Rule, 40 CFR 745, Federal Register 73, no. 78 (2008): 21691–769, https://www.gpo.gov/fdsys/pkg/FR-2008-04-22/html/E8-8141.htm.

111 U.S. Environmental Protection Agency, Economic Analysis for the TSCA Lead Renovation, Repair, and Painting Program Final Rule for Target Housing and Child-Occupied Facilities, 3 39–41.

112 National Center for Healthy Housing, "New York's Childhood Lead Poisoning Primary Prevention Program: Year 8 Grantee Impact Summaries (Draft)," accessed Feb. 3, 2017, http://www.nchh.org/Portals/0/Contents/NYSDOH_Yr8_Appendix_Final.pdf; City of New York, "Health Department Launches New Lead Dust Notification Procedures," accessed Feb. 3, 2017, https://www1.nyc.gov/site/doh/about/press/pr2015/pr021-15.page.

113 National Center for Healthy Housing, "New York's Childhood Lead Poisoning Primary Prevention Program: Year 8 Grantee Impact Summaries (draft)," accessed Feb. 3, 2017, http://www.nchh.org/Portals/0/Contents/NYSDOH_Yr8_Appendix_Final.pdf.

114 District of Columbia Department of Energy and Environment, "All About Lead," accessed Jan. 13, 2017, http://doee.dc.gov/lead.

115 Rhode Island Department of Health, "Lead Safe Renovation, Repair, and Painting," accessed Jan. 13, 2017, http://www.health.ri.gov/healthrisks/poisoning/lead/about/renovationrepairandpainting.

116 Lead Safe Kids, "Working Lead-Safe in Providence: What Does This Mean for Me?" accessed Jan. 13, 2017, http://www.leadsafekids.org/en/news/77-providence-rrp.

117 U.S. EPA, Economic Analysis for the TSCA Lead Renovation, Repair, and Painting Program, 3-39–41; Spanier et al., "The Contribution of Housing Renovation to Children's Blood Lead Levels: A Cohort Study"; Rabinowitz, Leviton and Bellinger, "Home Refinishing, Lead Paint and Infant Blood Lead Levels"; Franko et al., "Children With Elevated Blood Lead Levels."

118 County Health Rankings, "Our Ratings." Scientifically supported is defined by County Health Rankings as interventions for which there are one or more systematic review(s), or at least three experimental studies, or three quasi-experimental studies with matched concurrent comparisons. Studies have strong designs and statistically significant favorable findings.

119 Alaska Department of Health and Social Services, "Technical Guidance for Health Impact Assessment In Alaska."

120 U.S. Environmental Protection Agency, "The Approach Used for Estimating Changes in Children's IQ From Lead Dust Generated During Renovation, Repair and Painting in Residences and Child-Occupied Facilities" (Washington: EPA, March 28, 2008), https://www.regulations.gov/document?D=EPA-HQ-OPPT-2005-0049-0930; Richard W. Leggett, "An Age-Specific Kinetic Model of Lead Metabolism in Humans," *Environmental Health Perspectives* 101, no. 7 (1993): 598–616, http://dx.doi.org/10.1289/ehp.93101598; U.S. Environmental Protection Agency, "Revised Final Report on Characterization of Dust Lead Levels After Renovation, Repair, and Painting Activities" (Washington: U.S. Environmental Protection Agency, Nov. 13, 2016), https://www.regulations.gov/document?D=EPA-HQ-OPPT-2005-0049-0857.

121 U.S. EPA, Economic Analysis for the TSCA Lead Renovation, Repair, and Painting Program, ES-4.

122 U.S. EPA, Economic Analysis for the TSCA Lead Renovation, Repair, and Painting Program.

123 In its economic analysis, the EPA identified the cost of spot test kits as approximately $0.50 each, and assumed that testing four samples would require about 15 minutes of a certified renovator's time. Therefore, the estimated cost of using the kits would be $10 per renovation event.

124 Franko et al., "Children With Elevated Blood Lead Levels."

125 Environmental Protection Agency, "2014 National Emissions Inventory Data" (2014), https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data.

126 Children's Health Protection Advisory Committee, "National Ambient Air Quality Standards for Lead" (Jan. 8, 2015), https://www.epa.gov/sites/production/files/2015-01/documents/naaqs_for_lead_letter.pdf.

127 Environmental Protection Agency, "Review of the National Ambient Air Quality Standards for Lead."

128 Howard W. Mielke et al., "Environmental and Health Disparities in Residential Communities of New Orleans: The Need for Soil Lead Intervention to Advance Primary Prevention," *Environment International* 51 (2013) 73–81, http://dx.doi.org/10.1016/j.envint.2012.10.013; U.S. Environmental Protection Agency, "America's Children and the Environment, Third Edition," EPA 240-R-13-001 (Washington: U.S. Environmental Protection Agency, January 2013): 61, https://www.epa.gov/sites/production/files/2015-06/documents/ace3_2013.pdf.

129 Environmental Protection Agency, "Results of Lead and Arsenic Testing at West Calumet Housing Complex (Excel spreadsheet)," accessed May 10, 2017, https://www.epa.gov/sites/production/files/2016-08/uss-lead-zone-1-action-data-redacted.xlsx.

130 Michael D. Lewin, Sara Sarasua, and Paul A. Jones, "A Multivariate Linear Regression Model for Predicting Children's Blood Lead Levels Based on Soil Lead Levels: A Study at Four Superfund Sites," *Environmental Research* 81, no. 1 (1999): 52–61, https://dx.doi.org/10.1006/enrs.1998.3952; Sammy Zahran et al., "Linking Source and Effect: Resuspended Soil Lead, Air Lead, and Children's Blood Lead Levels in Detroit, Michigan," *Environmental Science and Technology* 47, no. 6 (2013), http://pubs.acs.org/doi/abs/10.1021/es303854c; Howard W. Mielke et al., "The Urban Environment and Children's Health: Soils as an Integrator of Lead, Zinc, and Cadmium in New Orleans, Louisiana, USA," *Environmental Research* 81, no. 2 (1999): 117–19, https://dx.doi.org/10.1006/enrs.1999.3966; Mielke et al., "Environmental and Health Disparities in Residential Communities of New Orleans."

131 Howard Mielke et al., "Nonlinear Association Between Soil Lead and Blood Lead of Children in Metropolitan New Orleans, Louisiana: 2000-2005," *Science of the Total Environment* 388, no. 1–3 (2007): 43–53, http://dx.doi.org/10.1016/j.scitotenv.2007.08.012; Jeffrey Shire and John Villanacci, "Analysis of Risk Factors for Childhood Blood Lead Levels El Paso, Texas, 1997–2002," prepared by the Texas Department of Health for the Agency for Toxic Substances and Disease Registry (April 20, 2004), https://www.dshs.texas.gov/epitox/consults/elppasblpbgisfinal4_23.pdf.

132 Howard Mielke et al., "Nonlinear Association Between Soil Lead and Blood Lead of Children in Metropolitan New Orleans, Louisiana: 2000–2005," *Science of the Total Environment* 388, no. 1–3 (2007): 43–53, http://dx.doi.org/10.1016/j.scitotenv.2007.08.012.

133 Mark Laidlaw et al., "Case Studies and Evidence-Based Approaches to Addressing Urban Soil Lead Contamination," *Applied Geochemistry* (2017), http://dx.doi.org/10.1016/j.apgeochem.2017.02.015.

134 Mielke et al., "Environmental and Health Disparities in New Orleans"; Michael Weitzman et al., "Lead-Contaminated Soil Abatement and Urban Children's Blood Lead Levels," *JAMA* 263, no. 13 (1993): 1647–54.

135 Katherine Farrell et al., "Soil Lead Abatement and Children's Blood Lead Levels in an Urban Setting," *American Journal of Public Health* 88, no. 12 (1998): 1837–39, http://dx.doi.org/10.2105/AJPH.88.12.1837.

136 Mark Laidlaw et al., "Case Studies and Evidence-Based Approaches to Addressing Urban Soil Lead Contamination."

137 Ibid.

138 U.S. Environmental Protection Agency, National Emissions Standards for Hazardous Air Pollutants From Secondary Lead Smelting, 77 Fed. Reg. 3 (Jan. 5, 2012), https://www.gpo.gov/fdsys/pkg/FR-2012-01-05/pdf/2011-32933.pdf#page=2.

139 EC/R Inc., memo prepared for EPA Office of Air Quality Planning and Standards, "Risk and Technology Review—Final Analysis of Socio-Economic Factors for Populations Living Near Secondary Lead Smelting Facilities," December 2011, http://earthjustice.org/sites/default/files/Leadsmeltersocioeconomicanalysis.pdf.

140 U.S. Environmental Protection Agency, National Emissions Standards for Hazardous Air Pollutants From Secondary Lead Smelting, 77 Fed. Reg. 3; Jessica Garrison and Kim Christensen, "Vernon Plant Closed Over Toxins," *Los Angeles Times*, April 25, 2013, http://articles.latimes.com/2013/apr/25/local/la-me-exide-arsenic-20130425; Texas Commission on Environmental Quality, "Exide Frisco Batter Recycling Center" (October 2014), https://www.tceq.texas.gov/remediation/sites/exide/exide; Amy Wold, "New Plan to Close Former Exide Site Expected to Be Complete in Early 2016," *The Advocate,* Jan. 5, 2016, http://www.theadvocate.com/baton_rouge/news/article_e0375310-ed91-578d-9f77-aa3019a2efdd.html.

141 U.S. Geological Survey, "Historical Statistics for Mineral and Material Commodities in the United States" (2011), https://minerals.usgs.gov/minerals/pubs/historical-statistics; International Lead Association, "Lead Industry Profile," accessed March 28, 2017, http://www.ila-lead.org/UserFiles/File/factbook/chapter4.pdf.

142 William P. Eckel, Michael B. Rabinowitz and Gregory D. Foster, "Discovering Unrecognized Lead-Smelting Sites by Historical Methods," *American Journal of Public Health* 91, no. 4 (2001), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1446633/pdf/11291377.pdf.

143 Ibid.

144 Sammy Zahran et al., "Linking Source and Effect: Resuspended Soil Lead, Air Lead, and Children's Blood Lead Levels in Detroit, Michigan," *Environmental Science and Technology* 47, no. 6 (2013): 2839–45, http://dx.doi.org/10.1021/es303854c .

145 United States Environmental Protection Agency, Office of Inspector General, "EPA Has Made Progress in Assessing Historical Lead Smelter Sites but Needs to Strengthen Procedures" (June 2014), https://www.epa.gov/sites/production/files/2015-09/documents/20140617-14-p-0302.pdf.

146 Environmental Protection Agency, "Superfund Remedial Annual Accomplishments: Fiscal Year 2016 Superfund Remedial Program Accomplishments Report," accessed May 10, 2017, https://www.epa.gov/superfund/superfund-remedial-annual-accomplishments#metrics.

147 Agency for Toxic Substances and Disease Registry, "John T. Lewis Community Childhood Blood Lead Study: Findings," accessed March 24, 2017, https://www.atsdr.cdc.gov/sites/jtlewis/findings.html.

148 Ian von Lindern et al., "Estimating Children's Soil/Dust Ingestion Rates Through Retrospective Analyses of Blood Lead Biomonitoring From the Bunker Hill Superfund Site in Idaho," *Environmental Health Perspectives* 124, no. 9 (2016): 1462–70, http://dx.doi.org/10.1289/ehp.1510144.

149 Ian von Lindern et al., "Assessing Remedial Effectiveness Through the Blood Lead: Soil/Dust Lead Relationship at the Bunker Hill Superfund Site in the Silver Valley of Idaho," *Science of the Total Environment* 303 no. 1–2 (2003): 139–70, http://doi.org/10.1016/S0048-9697(02)00352-2.

150 Michael D. Lewin, Sara Sarasua, and Paul A. Jones, "A Multivariate Linear Regression Model for Predicting Children's Blood Lead Levels Based on Soil Lead Levels."

151 University of Maryland, "Lead in Garden Soils," accessed June 7, 2017, https://extension.umd.edu/hgic/lead-garden-soils.

152 U.S. Environmental Protection Agency, "Technical Review Workgroup Recommendations Regarding Gardening and Reducing Exposure to Lead-Contaminated Soils" (Washington: U.S. Environmental Protection Agency, 2014), http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100JJS3.TXT.

153 County Health Rankings, "Our Ratings." Some evidence is defined by County Health Rankings and Roadmaps as: one or more systematic review(s), or at least two experimental studies, or two quasi-experimental studies with matched concurrent comparisons, or three studies with unmatched comparisons or pre-post measures. Studies have statistically significant favorable findings. Compared with "Scientifically Supported," studies have less rigorous designs or limited effect(s). Although the removal of lead from aviation fuel has not been tested, multiple studies have documented an association between blood lead levels and residence near an airport serving aircraft using leaded fuel.

154 Alaska Department of Health and Social Services, "Technical Guidance for Health Impact Assessment in Alaska."

155 Unleaded AVGAS Transition Aviation Rulemaking Committee, "FAA UAT ARC Final Report Part I: Unleaded AVGAS Findings & Recommendations" (Washington: Federal Aviation Administration, U.S. Department of Transportation, Feb. 17, 2012), https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/Avgas.ARC.RR.2.17.12.pdf; Control of Air Pollution from Aircraft and Aircraft Engines, Code of Federal Regulations, title 40, part 87 (2013); Advance Notice of Proposed Rulemaking on Lead Emissions From Piston-Engine Aircraft Using Leaded Aviation Gasoline 75 Fed. Reg. 81 (April 28, 2010): 22439–68, https://www.federalregister.gov/documents/2010/04/28/2010-9603/advance-notice-of-proposed-rulemaking-on-lead-emissions-from-piston-engine-aircraft-using-leaded.

156 Sammy Zahran et al., "The Effect of Leaded Aviation Gasoline on Blood Lead in Children," *Journal of the Association of Environmental and Resource Economists* 4, no. 2 (2017): 575–610, http://dx.doi.org/10.1086/691686; "U.S. Product Supplied of Aviation Gasoline," U.S. Energy Information Administration, accessed Jan. 29, 2017, http://www.eia.gov/dnav/pet/hist/Leafhandler.ashx?n=PET&s=MGAUPUS1&f=A.

157 Ibid.

158 Proposed Rulemaking on Lead Emissions From Piston-Engine Aircraft, 75 Fed. Reg. 81 (April 28, 2010), https://www.gpo.gov/fdsys/pkg/FR-2010-04-28/pdf/2010-9603.pdf.

159 Rebecca Kessler, "Sunset for Leaded Aviation Gasoline?" *Environmental Health Perspectives* 121, no. 2 (2013): 54–57, http://dx.doi.org/10.1289/ehp.121-a54; Marie Lynn Miranda, Rebecca Anthopolos and Douglas Hastings, "A Geospatial Analysis of the Effects of Aviation Gasoline on Childhood Blood Lead Levels," *Environmental Health Perspectives* 119, no. 10 (2011): 1513–16, https://dx.doi.org/10.1289%2Fehp.1003231; Zahran et al., "The Effect of Leaded Aviation Gasoline."

160 Zahran et al., "The Effect of Leaded Aviation Gasoline."

161 County Health Rankings, "Our Ratings." Some evidence is defined by County Health Rankings and Roadmaps as: one or more systematic review(s), or at least two experimental studies, or two quasi-experimental studies with matched concurrent comparisons, or three studies with unmatched comparisons or pre-post measures. Studies have statistically significant favorable findings. Compared to "Scientifically Supported," studies have less rigorous designs or limited effect(s). Although the removal of lead from aviation fuel has not been tested, multiple studies have documented an association between blood lead levels and residence near an airport serving aircraft using leaded fuel.

162 Alaska Department of Health and Social Services, "Technical Guidance for Health Impact Assessment in Alaska," accessed May 12, 2017, http://dhss.alaska.gov/dph/Epi/hia/Documents/AlaskaHIAToolkit.pdf.

163 Alaska Department of Health and Social Services, "Technical Guidance for Health Impact Assessment in Alaska," accessed May 12, 2017, http://dhss.alaska.gov/dph/Epi/hia/Documents/AlaskaHIAToolkit.pdf.

164 Proposed Rulemaking on Lead Emissions From Piston-Engine Aircraft, 75 Fed. Reg. 81; Advance notice of proposed rulemaking on lead emissions from piston-engine aircraft using leaded aviation gasoline, 75 Fed. Reg. 22440: 22440–68 (April 28, 2010).

165 Unleaded AVGAS Transition Aviation Rulemaking Committee, "FAA UAT ARC Final Report Part I" (February 2012).

166 President's Task Force on Environmental Health Risks and Safety Risks to Children, "Key Federal Programs to Reduce Childhood Lead Exposures and Eliminate Associated Health Impacts," https://ptfceh.niehs.nih.gov/features/assets/files/key_federal_programs_to_reduce_childhood_lead_exposures_and_eliminate_associated_health_impactspresidents_508.pdf.

167 Substance Abuse and Mental Health Services Administration, "Cultural Competence," accessed April 20, 2017, https://www.samhsa.gov/capt/applying-strategic-prevention/cultural-competence

168 Greater Cincinnati Water Works, "Lead Awareness" (2007), http://cincinnati-oh.gov/water/lead-information/; DC Water, "Service Map, Lead" (2017), https://www.dcwater.com/servicemap; Boston Water and Sewer Commission, "Lead Service Map" (2017), http://www.bwsc.org/COMMUNITY/lead/leadmaps.asp#TOP_PAGE; Lead Materials, California Health and Safety Code 104 Part 12, Ch. 5 Art 4, http://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=HSC&division=104.&title=&part=12.&chapter=5.&article=4.; Ohio House of Representatives Bill 512, 131st General Assembly (Sept. 9, 2016), http://search-prod.lis.state.oh.us/solarapi/v1/general_assembly_131/bills/hb512/EN/05?format=pdf.

169 U.S. Centers for Disease Control and Prevention, "Educational Interventions for Children Affected by Lead" (Atlanta: U.S. Department of Health and Human Services, 2015), https://www.cdc.gov/nceh/lead/publications/educational_interventions_children_affected_by_lead.pdf.

170 Weihong Yuan et al., "The Impact of Early Childhood Lead Exposure on Brain Organization: A Functional Magnetic Resonance Imaging Study of Language Function," *Pediatrics* 118, no. 3 (2006): 971–77, https://doi.org/10.1542/peds.2006-0467.

171 Center on the Developing Child at Harvard University, "Building the Brain's 'Air Traffic Control' System: How Early Experiences Shape the Development of Executive Function," Working Paper No. 11 (2011), http://developingchild.harvard.edu/resources/building-the-brains-air-traffic-control-system-how-early-experiences-shape-the-development-of-executive-function.

172 T. Matthews et al., "Social Isolation and Mental Health at Primary and Secondary School Entry: A Longitudinal Cohort Study," *Journal of the American Academy of Child and Adolescent Psychiatry* 54, no. 3 (2015): 225–32, http://doi.org/10.1016/j.jaac.2014.12.008.

173 Jessica Wolpaw Reyes, "Lead Exposure and Behavior: Effects on Antisocial and Risky Behavior Among Children and Adolescents," *Economic Inquiry* 53, no. 3 (2015): 1580–1605, http://dx.doi.org/10.1111/ecin.12202.

174 Adele Diamond and Kathleen Lee, "Interventions Shown to Aid Executive Function Development in Children 4 to 12 Years Old," *Science* 333, no. 6045 (2011): 959–64, https://dx.doi.org/10.1126%2Fscience.1204529.

175 Hirokazu Yoshikawa et al., “Investing in Our Future: The Evidence Base on Preschool Education” (Ann Arbor, MI: Society for Research in Child Development, 2013), http://www.srcd.org/sites/default/files/documents/washington/mb_2013_10_16_investing_in_children.pdf.

176 Eric M. Ossiander, “A Systematic Review of Screening Questionnaires for Childhood Lead Poisoning,” *Journal of Public Health Management Practice* 19, no. 1 (2013): E21–29, http://dx.doi.org/10.1097/PHH.0b013e3182249523. This report uses the term “screening” to refer to questionnaires only, while “testing” includes any sampling of blood. Methods for analyzing blood tests range in price, accuracy, sample size, difficulty of use, and amount of time required to provide results. In the U.S., most laboratories cannot detect blood lead levels below 3 μg/dL. Factors such as the person performing the analysis and the care taken to ensure that the sample is not contaminated after collection can also affect the results.

177 The Centers for Medicare & Medicaid Services, “Early and Periodic Screening, Diagnostic, and Treatment,” accessed June 7, 2017, https://www.medicaid.gov/medicaid/benefits/epsdt/index.html; Joshua Schneyer and M. B. Pell, “Unsafe At Any Level,” *Reuters*, June 9, 2016, http://www.reuters.com/investigates/special-report/lead-poisoning-testing-gaps.

178 Anne M. Wengrovitz and Mary Jean Brown, “Recommendations for Blood Lead Screening of Medicaid-Eligible Children Aged 1-5 Years: An Updated Approach to Targeting a Group at High Risk,” *Morbidity and Mortality Weekly Report* 58, no. RR-9 (2009): 1–11, https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5809a1.htm.

179 Jennifer Dickman, “Children at Risk: Gaps in State Lead Screening Policies” (Washington: Safer Chemicals, Healthy Families, January 2017), http://saferchemicals.org/sc/wp-content/uploads/2017/01/saferchemicals.org_children-at-risk-report.pdf.

180 Wengrovitz and Brown, “Recommendations for Blood Lead Screening of Medicaid-Eligible Children.”

181 Centers for Disease Control and Prevention, “CDC Recommendations for Lead Poisoning Prevention in Newly Arrived Refugee Children,” accessed Feb. 22, 2017, https://www.cdc.gov/nceh/lead/publications/refugeetoolkit/pdfs/cdcrecommendations.pdf

182 Diamond and Lee, “Interventions Shown to Aid Executive Function Development in Children 4 to 12 Years Old.”

183 Hirokazu Yoshikawa et al., “Investing in Our Future: The Evidence Base on Preschool Education” (Ann Arbor, MI: Society for Research in Child Development, 2013), http://www.srcd.org/sites/default/files/documents/washington/mb_2013_10_16_investing_in_children.pdf.

184 Todd Grindal et al., "The Added Impact of Parenting Education in Early Childhood Education Programs: A Meta-Analysis," *Children and Youth Services Review* 70 (2016): 238–49, https://doi.org/10.1016/j.childyouth.2016.09.018.

185 Mayo Clinic, “Cognitive Behavioral Therapy,” accessed March 9, 2017, http://www.mayoclinic.org/tests-procedures/cognitive-behavioral-therapy/home/ovc-20186868.

186 Nurse-Family Partnership, “A Rigorously Tested Program with Measureable Benefits,” accessed Feb. 23, 2017, http://www.nursefamilypartnership.org/assets/PDF/Fact-sheets/NFP_Benefit_Cost.aspx.

187 Harriet J. Kitzman et al., “Enduring Effects of Prenatal and Infancy Home Visiting by Nurses on Children,” *Archive Pediatric Adolescent Medicine* 164, no. 5 (2010): 412–18, https://dx.doi.org/10.1001/archpediatrics.2010.76.

188 David Olds et al., “Long-Term Effects of Nurse Home Visitation on Children’s Criminal and Antisocial Behavior: 15-Year Follow-Up of a Randomized Controlled Trial,” *Journal of American Medicine Associatio*n 280, no. 14 (1996): 1238–44, https://dx.doi.org/ 10.1001/jama.280.14.1238.

189 Child Trends, “Incredible Years Series,” accessed December 2016, https://www.childtrends.org/programs/incredible-years-series.

190 M. Jamila Reid, Carolyn Webster-Stratton, and Mary Hammond, “Follow-Up of Children Who Received the Incredible Years Intervention for Oppositional-Defiant Disorder: Maintenance and Prediction of 2-Year Outcome,” *Behavior Therapy* 34 (2003): 471–91, https://dx.doi.org/ 10.1016/S0005-7894(03)80031-X.

191 Hugh F. Crean and Deborah B. Johnson, “Promoting Alternative Thinking Strategies (PATHS) and Elementary School Aged Children's Aggression: Results From a Cluster Randomized Trial,” *American Journal of Community Psychology* 52, no. 1–2 (2013): 56–72, https://dx.doi.org/10.1007/s10464-013-9576-4.

192 David J. Schonfeld et al., “Cluster-Randomized Trial Demonstrating Impact on Academic Achievement of Elementary Social-Emotional Learning,” *School Psychology Quarterly* 30, no. 3 (2015): 406–20, http://dx.doi.org/10.1037/spq0000099.

193 Karin S. Frey et al., “Reducing Playground Bullying and Supporting Beliefs: An Experimental Trial of the Steps to Respect Program,” *Developmental Psychology* 41, no. 3 (2005): 479–90, https://dx.doi.org/10.1037/0012-1649.41.3.479.

194 U.S. Centers for Disease Control and Prevention, “Educational Interventions for Children Affected by Lead,” 34.

195 Assistance to States for the Education of Children With Disabilities, “§ 300.111 Child Find,” Cornell University Law School, accessed April 20, 2017, https://www.law.cornell.edu/cfr/text/34/300.111.

196 U.S. Centers for Disease Control and Prevention, "Managing Elevated Blood Lead Levels Among Young Children: Recommendations From the Advisory Committee on Childhood Lead Poisoning Prevention," accessed May 1, 2017, https://www.cdc.gov/nceh/lead/casemanagement/managingEBLLs.pdf.

197 Betsy Lozoff, "Iron Deficiency and Child Development," *Food and Nutrition Bulletin* 28 (2007): S560–71, http://journals.sagepub.com/doi/pdf/10.1177/15648265070284S409.

198 Stephen Billings and Kevin Schnepel, "Life Unleaded: Effects of Early Interventions for Children Exposed to Lead" (Working Paper No. 2015-18, Life Course Centre, Australian Research Council, August 2015), http://www.lifecoursecentre.org.au/wp-content/uploads/2015/08/2015-18-LCC-Working-Paper-Billings-and-Schnepel2.pdf.

199 U.S. Department of Agriculture Food and Nutrition Service, "Women, Infants and Children (WIC): WIC Food Package Regulatory Requirements," accessed April 18, 2017, https://www.fns.usda.gov/wic/wic-food-package-regulatory-requirements.

200 Margot I. Jackson, "Early Childhood WIC Participation, Cognitive Development and Academic Achievement," *Social Science & Medicine* 126 (2015): 145–53, https://dx.doi.org/10.1016/j.socscimed.2014.12.018; Abigail Arons et al., "Participation in the Special Supplemental Nutrition Program for Women, Infants, and Children Is Not Associated With Early Childhood Socioemotional Development: Results From a Longitudinal Cohort Study," *Preventive Medicine Reports* 4 (2016): 507–11, https://dx.doi.org/10.1016/j.pmedr.2016.09.004; Edward A. Frongillo, Diana F. Jyoti, and Sonya J. Jones, "Food Stamp Program Participation Is Associated With Better Academic Learning Among School Children," *The Journal of Nutrition* 136, no. 4 (2006): 1077–80, http://jn.nutrition.org/content/136/4/1077.full.pdf+html.

201 U.S. Preventive Services Task Force, "Final Recommendation Statement: Lead Levels in Childhood and Pregnancy: Screening" (2006), https://www.uspreventiveservicestaskforce.org/Page/Document/RecommendationStatementFinal/lead-levels-in-childhood-and-pregnancy-screening. In 2006, the U.S. Preventive Services Task Force recommended against universal blood lead testing for children at average risk of exposure. This guidance was designed to avoid potential harms, including false-positive results, anxiety, inconvenience, absenteeism from work and school, and financial costs of repeated testing. However, the recommendations did not address testing for high-risk children.

202 Anne Guthrie Wengrovitz et al., "Overcoming Barriers to Data-Sharing Related to the HIPAA Privacy Rule" (Washington: Alliance for Healthy Homes, June 2004), https://www.cdc.gov/nceh/lead/policy/HIPAADoc.pdf.

203 Katarzyna Kordas, "The 'Lead Diet': Can Dietary Approaches Prevent or Treat Lead Exposure?" *Journal of Pediatrics*, in print (2017), http://dx.doi.org/10.1016/j.jpeds.2017.01.069.

204 Health Canada, "Lead in Drinking Water" (Health Canada, the Federal-Provincial-Territorial Committee on Drinking Water, October 2016), http://www.healthycanadians.gc.ca/health-system-systeme-sante/consultations/lead-drinking-water-plomb-eau-potable/alt/lead-drinking-water-plomb-eau-potable-03-01-2017-eng.pdf.

205 Dr. Pascal Haefliger, "Brief Guide to Analytical Methods for Measuring Lead in Blood," World Health Organization (2011), http://www.who.int/ipcs/assessment/public_health/lead_blood.pdf; The U.S. Centers for Disease Control and Prevention defines a blood lead test as "any blood lead draw (capillary, venous or unknown sample type) on a child that produces a quantifiable result and is analyzed by a Clinical Laboratory Improvement Amendments (CLIA)-certified facility or an approved portable device. A blood lead test may be collected for screening, confirmation, or follow-up."

206 Reuben et al., "Association of Childhood Blood Lead Levels With Cognitive Function and Socioeconomic Status at Age 38 Years and With IQ Change and Socioeconomic Mobility Between Childhood and Adulthood."

207 40 CFR 745.223.

208 Miriam King, Steven Ruggles, J. Trent Alexander, Sarah Flood, Katie Genadek, Matthew B. Schroeder, Brandon Trampe, and Rebecca Vick. Integrated Public Use Microdata Series, Current Population Survey: Version 3.0. [Machine-readable database]. Minneapolis, MN: Minnesota Population Center [producer and distributor], 2010.

209 U.S. Centers for Disease Control and Prevention, National Center for Environmental Health, "National Surveillance Data (1997–2015)" (Atlanta: U.S. Department of Health and Human Services, 2016), https://www.cdc.gov/nceh/lead/data/national.htm.

210 John Paul Wright et al., "Association of Prenatal and Childhood Blood Lead Concentrations With Criminal Arrests in Early Adulthood," *PLoS Medicine* 5, no. 5 (2008): e101, https://doi.org/10.1371/journal.pmed.0050101.

211 Leonardo Trasande and Yinghua Liu, "Reducing the Staggering Costs of Environmental Disease in Children, Estimated at $76.6 Billion in 2008," *Health Affairs* 30, no. 5 (2011): 863–70, http://content.healthaffairs.org/content/30/5/863.short.

212 P.J. Neumann, J.T. Cohen, and M.C. Weinstein, "Updating Cost-Effectiveness—The Curious Resilience of the $50,000-per-QALY Threshold," *New England Journal of Medicine* 371, no. 9 (2014): 796–97.

213 G.D. Sanders et al., "Recommendations for Conduct, Methodological Practices, and Reporting of Cost-Effectiveness Analyses," *JAMA* 316, no. 10 (2016): 1093–1103; W. Max, "Present Value of Lifetime Earnings, 2007," unpublished tables, Institute for Health and Aging, University of California, San Francisco (2010).

214 Council on Environmental Health, "Prevention of Childhood Lead Toxicity," *Pediatrics* (2016), http://dx.doi.org/10.1542/peds.2016-1493.

215 Elise Gould, "Childhood Lead Poisoning: Conservative Estimates of the Social and Economic Benefits of Lead Hazard Control," *Environmental Health Perspectives* 117, no. 7 (2009): 1162–67, http://dx.doi.org/10.1289/ehp.0800408.

216 Ibid.; Altarum Institute, "Health Sector Economic Indicators—Price Briefs," available at http://altarum.org/our-work/cshs-health-sector-economic-indicators-briefs.

217 U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics, Underlying Cause of Death 1999-2015 on CDC WONDER Online Database, released 2016. Data are compiled from the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program, accessed at http://wonder.cdc.gov/ucd-icd10.html. Data for 2015 are compiled from the Multiple Cause of Death File 2015, Series 20, No. 2U, 2016.

218 Yutaka Aoki et al., "Blood Lead and Other Metal Biomarkers as Risk Factors for Cardiovascular Disease Mortality," *Medicine* 95, no. 1 (2016): e2223, http://dx.doi.org/10.1097/MD.0000000000002223.

219 Ibid.

220 Dariush Mozaffarian et al., "Heart Disease and Stroke Statistics—2015 Update: A Report From the American Heart Association," *Circulation* 131 (2015): e29–322, http://dx.doi.org/10.1161/CIR.0000000000000152.

221 Martin et al., "Association of Blood Lead and Tibia Lead With Blood Pressure and Hypertension in a Community Sample of Older Adults," *American Journal of Epidemiology* 163, no. 5 (2006): 467–78, https://doi.org/10.1093/aje/kwj060.

222 Guijing Wang et al., "Hypertension-Associated Expenditures for Medication Among U.S. Adults," *American Journal of Hypertension* 26, no. 11 (2013): 1295–1302, https://doi.org/10.1093/ajh/hpt079.

223 Bruce Lanphear et al., "Low-Level Environmental Lead Exposure and Children's Intellectual Function: an International Pooled Analysis," *Environmental Health Perspectives* 113, no. 7 (2005): 894–99, https://dx.doi.org/10.1056/NEJM200307313490515; Todd Jusko et al., "Blood Lead Concentrations < 10 µg/dL and Child Intelligence at 6 Years of Age," *Environmental Health Perspectives* 166 (2008): 243–48.

224 Jusko et al., "Blood Lead Concentrations"; Richard L. Canfield et al., "Intellectual Impairment in Children With Blood Lead Concentrations below 10 µg per Deciliter," *New England Journal of Medicine* 348 (2003): 1517–26, http:/dx.doi.org/10.1056/NEJMoa022848; David Bellinger and Herbert Needleman, "Intellectual Impairment And Blood Lead Levels," *New England Journal of Medicine* 349 (2003): 500–02, https://dx.doi.org/10.1056/NEJM200307313490515; Bruce Lanphear et al., "Low-Level Environmental Lead Exposure And Children's Intellectual Function: An International Pooled Analysis," *Environmental Health Perspectives* 113, no. 7 (2005): 894–99, https://dx.doi.org/10.1289%2Fehp.7688.

225 National Ambient Air Quality Standards for Lead, 73 Fed. Reg. 219 (Nov. 12, 2008): 66964.

226 European Food Safety Authority, "Scientific Opinion on Lead in Food: EFSA Panel on Contaminants in the Food Chain (CONTAM)," *EFSA Journal* 8, no. 4 (2010): 1570, http://dx.doi.org/10.2903/j.efsa.2010.1570.

227 David S. Salkever, "Assessing the IQ-Earnings Link in Environmental Lead Impacts on Children: Have Hazard Effects Been Overstated?," *Environmental Research* 131 (2014): 219–30, http://dx.doi.org/10.1016/j.envres.2014.03.018.

228 Ibid.

229 Randall Lutter, "Valuing Children's Health: A Reassessment of the Benefits of Lower Lead Levels," Working Paper 00-02 (AEI-Brookings Joint Center for Regulatory Studies, 2000), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=243537.

230 Dajun Lin, Randall Lutter, and Christopher J. Ruhm, "Cognitive Performance and Labor Market Outcomes," Working Paper 22470 (NBER, 2016), http://www.nber.org/papers/w22470; David Salkever, "Updated Estimates of Earnings Benefits From Reduced Exposure of Children to Environmental Lead," *Environmental Research* 70, no. 1 (1995): 1–6, https://dx.doi.org/10.1006/enrs.1995.1038; Derek A. Neal and William R. Johnson, "The Role of Premarket Factors in Black-White Wage Differences," *Journal of Political Economy* 104, no. 5 (1996): 869–95, http://dx.doi.org/10.1086/262045.

231 Scott Grosse, "How Much Does IQ Raise Earnings? Implications for Regulatory Impact Analyses," Research Letter, Association of Environmental and Resource Economics, 27, no. 2 (2007). http://www.umsl.edu/~kosnikl/AERE%20Essay.pdf.

232 Ted Gayer and Robert W. Hahn, "Designing Environmental Policy: Lessons From the Regulation of Mercury Emissions," *Journal of Regulatory Economics* 30 (2006): 291–315, http://dx.doi.org/10.1007/s11149-006-9005-9; Lin, Lutter and Ruhm, "Cognitive Performance."

233 J. Schwartz, "Societal Benefits of Reducing Lead Exposure," *Environmental Research* 66 (1994): 105–24, https://dx.doi.org/10.1006/enrs.1994.1048.

234 Jay G. Chambers, Thomas B. Parish, and Jenifer J. Harr, "What Are We Spending on Special Education Services in the United States, 1999-2000?" (Washington: American Institutes for Research, 2004), http://www.csef-air.org/publications/seep/national/advrpt1.pdf.

235 David A. Cornwell, “National Survey of Lead Service Line Occurrence,” *American Water Works Association* 108, no. 4 (2016), http://dx.doi.org/10.5942/jawwa.2016.108.0086.

236 David A. Cornwell, Richard A. Brown and Steven Via, “National Survey of Lead Service Line Occurrence,” *Journal of the American Water Works Association* 13 (2016): E187–92, http://dx.doi.org/10.5942/jawwa.2016.108.0086.

237 U.S. Environmental Protection Agency, “Proposed Modeling Approaches for a Health-Based Benchmark for Lead in Drinking Water” (2017), https://www.epa.gov/sites/production/files/2017-01/documents/report_proposed_modeling_approaches_for_a_health_based_benchmark_for_lead_in_drinking_water_final_0.pdf.

238 Bruce P. Lanphear et al., “Environmental Exposures to Lead and Urban Children’s Blood Lead Levels,” *Environmental Research* 76 no. 2 (1998): 120–30, https://dx.doi.org/10.1006/enrs.1997.3801; Bruce P. Lanphear et al., “Environmental Lead Exposure During Early Childhood,” *Journal of Pediatrics* 140, no. 1 (2002): 40–47, http://dx.doi.org/10.1067/mpd.2002.120513; Bruce P. Lanphear et al., “Low-Level Environmental Lead Exposure And Children’s Intellectual Function: An International Pooled Analysis.”

239 Gerard Ngueta et al., “Use of a Cumulative Exposure Index to Estimate the Impact of Tap Water Lead Concentration on Blood Lead Levels in 1- to 5-Year-Old Children (Montreal, Canada),” *Environmental Health Perspectives* 124 (2016): 388–95; http://dx.doi.org/10.1289/ehp.1409144.

240 U.S. Environmental Protection Agency, “Proposed Modeling Approaches for a Health-Based Benchmark for Lead in Drinking Water.”

241 Michèle Prévost and Élise Deshommes. “Calculation of Reference Water Levels for Lead Service Line Replacement Intervention”; S. Triantafyllidou et al., "Low Contribution of Pb02-Coated Lead Service Lines to Water Lead Contamination at the Tap."

242 U.S. Census Bureau, “American Community Survey,” U.S. Census Bureau’s American Community Survey Office (2006), http://factfinder2.census.gov.

243 Anne Sandvig et al., “Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues” (Denver: AWWA and EPA, 2008), https://archive.epa.gov/region03/dclead/web/pdf/91229.pdf.

244 Personal communication with Steve Via, “Informal Survey of Estimated Lead Service Line Replacement Costs,” unpublished dataset, cited with permission, March 2017.

245 Sherry Dixon et al., “Window Replacement and Residential Lead Paint Hazard Control 12 Years Later,” *Environmental Research* 113 (2012): 14–20, https://doi.org/10.1016/j.envres.2012.01.005.

246 Mark Farfel et al., “An Extended Study of Interim Lead Hazard Reduction Measures Employed in the Baltimore Clinical Center of the Treatment of Lead-Exposed Children (TLC)—Clinical Trial” (Washington: U.S. Department of Housing and Urban Development, April 2000), http://www.nmic.org/nyccelp/medical-studies/Farfel-extended-study-interim-controls-4-00.pdf; Farfel et al. 1997, “Lead Based Paint Abatement and Repair and Maintenance Study” (Washington: U.S. Environmental Protection Agency, December 1997) EPA-747-R-97-005, https://www.epa.gov/sites/production/files/documents/24folup.pdf.

247 Sherry L. Dixon et al., “Exposure of U.S. Children to Residential Dust Lead, 1999–2004: II. The Contribution of Lead-Contaminated Dust to Children’s Blood Lead Levels,” *Environmental Health Perspectives* 117, no. 3 (2009):468–74, https://dx.doi.org/10.1289/ehp.11918.

248 U.S. Department of Housing and Urban Development, “American Healthy Homes Survey: Lead and Arsenic Findings” (Washington: HUD, 2011), http://portal.hud.gov/hudportal/documents/huddoc?id=AHHS_Report.pdf; An alternative to this approach would have been to use the percent of homes with lead-based paint hazards, defined as significantly deteriorated lead-based paint, or dust or soil lead levels in excess of EPA standards, which is a subset of those with lead-based paint: The AHHS estimates that 52.5 percent of pre-1960 homes and 33.7 percent of pre-1978 homes have hazards. The study team chose to lead-based paint rather than hazards for several reasons. First, homes with lead paint could develop hazards at any time if the paint deteriorates or is damaged. Second, the AHHS definition of a lead-based paint hazard would exclude many units that by today’s standards would be considered dangerous. For example, a home with a floor dust lead level under 40 μg/sq ft would not constitute a hazard under the survey, but would far exceed HUD’s recently adopted floor dust standard of 10 μg/sq ft for grantees of the department’s lead paint hazard control program. This variation in standards could result in an underestimation of high-risk units if only homes with hazards were considered. Finally, by focusing on low-income older housing, which evidence suggests is in poorer condition than other homes, the models and recommendations probably already isolated the units with the greatest likelihood of risk.

249 U.S. Environmental Protection Agency, “The Approach Used for Estimating Changes in Children’s IQ From Lead Dust Generated During Renovation, Repair and Painting in Residences and Child-Occupied Facilities” (Washington: EPA, March 28, 2008), https://www.regulations.gov/document?D=EPA-HQ-OPPT-2005-0049-0930; Richard W. Leggett, “An Age-Specific Kinetic Model of Lead Metabolism in Humans,” *Environmental Health Perspectives* 101, no. 7 (1993): 598–616, http://dx.doi.org/10.1289/ehp.93101598; U.S. Environmental Protection Agency, “Revised Final Report on Characterization of Dust Lead Levels After Renovation, Repair, and Painting Activities” (Washington: U.S. Environmental Protection Agency, Nov. 13, 2016), https://www.regulations.gov/document?D=EPA-HQ-OPPT-2005-0049-0857.

250 Sammy Zahran et al., "The Effect of Leaded Aviation Gasoline on Blood Lead in Children," *Journal of the Association of Environmental and Resource Economists* (In press).

251 Philip J. Wolfe et al., "Costs of IQ Loss From Leaded Aviation Gasoline Emissions," *Environmental Science and Technology* 50 (2016): 9026–33, http://dx.doi.org/10.1021/acs.est.6b02910; Sammy Zahran et al., "The Effect of Leaded Aviation Gasoline on Blood Lead in Children."

252 Lynn A. Karolyn, M. Rebecca Kilburn, and Jill Cannon, "Early Childhood Interventions: Proven Results, Future Promise" (Santa Monica, CA: RAND Corp., 2005), http://www.rand.org/content/dam/rand/pubs/monographs/2005/RAND_MG341.pdf.

253 Blueprints for Healthy Youth Development, "Blueprints Programs," accessed November 2016, http://www.blueprintsprograms.com/programs.

254 A. Biglan, *The Nurture Effect: How the Science of Human Behavior Can Improve Our Lives & Our World* (Oakland, CA: New Harbinger Publications, 2015).

255 ChildTrends, *Youth Development Outcomes Compendium* (2001), https://www.childtrends.org/publications/youth-development-outcomes-compendium.

256 Kristen E. Darling-Churchill, Laura Lippman, "Early Childhood Social and Emotional Development: Advancing the Field of Measurement," *Journal of Applied Developmental Psychology* 45 (2016): 1–7, http://dx.doi.org/10.1016/j.appdev.2016.02.002.

257 Sherry Dixon et al., "Window Replacement and Residential Lead Paint Hazard Control 12 Years Later," *Environmental Research* 113 (2012): 14–20, https://doi.org/10.1016/j.envres.2012.01.005.

258 U.S. Environmental Protection Agency, "Revised Final Report on Characterization of Dust Lead Levels After Renovation, Repair, and Painting Activities" (Washington: U.S. Environmental Protection Agency, Nov. 13, 2016), https://www.regulations.gov/document?D=EPA-HQ-OPPT-2005-0049-0857.

259 U.S. Environmental Protection Agency, "Air Quality Criteria for Lead: Volume I of II [EPA Report, EPA/600/R-05/144aF]" (2006), http://cfpub.epa.gov/ncea/CFM/recordisplay.cfm?deid=158823.

260 Bruce Lanphear et al., "Low Level Environmental Lead Exposure and Children's Intellectual Function: an International Pooled Analysis," *Environmental Health Perspectives* 113, no. 7 (2005): 894–99, https://dx.doi.org/10.1289/ehp.7688; David Bellinger, email to Jee-Young Kim, Feb. 13, 2008; Richard Canfield, email to Jee-Young Kim, Aug. 12, 2008; Richard Hornung, email to Jee-Young Kim, Aug. 19, 2008; Martha Tellez-Rojo, email to Jee-Young Kim, Feb. 11, 2008.

261 David Bellinger, email to Jee-Young Kim, Feb. 13, 2008.

262 Ibid.; Richard Hornung, email to Jee-Young Kim, Aug. 19, 2008; Richard Canfield et al., "Intellectual Impairment in Children With Blood Lead Concentrations Below 10 µg per Deciliter," *The New England Journal of Medicine* 348 (2003): 1517–26, http://dx.doi.org/10.1056/NEJMoa022848.

263 National Ambient Air Quality Standards for Lead, 73 Fed. Reg. 219 (Nov. 12, 2008): 66964; U.S. Environmental Protection Agency, "Benefit and Cost Analysis for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category" (2015), https://www.epa.gov/sites/production/files/2015-10/documents/steam-electric_benefit-cost-analysis_09-29-2015.pdf; Elise Gould, "Childhood Lead Poisoning: Conservative Estimates of the Social and Economic Benefits of Lead Hazard Control," *Environmental Health Perspectives* 117, no. 7 (2009): 1162–67, http://dx.doi.org/10.1289/ehp.0800408; Leonardo Trasande and Yinghua Liu, "Reducing the Staggering Costs of Environmental Disease in Children, Estimated at $76.6 Billion in 2008," *Health Affairs* 30, no. 5 (2011): 863–70, http://content.healthaffairs.org/content/30/5/863.short.

264 Bruce Lanphear et al., "Low-Level Environmental Lead Exposure and Children's Intellectual Function: an International Pooled Analysis," *Environmental Health Perspectives* 113, no. 7 (2005): 894–99, https://dx.doi.org/10.1056/NEJM200307313490515.

265 K.S. Crump et al., "A Statistical Reevaluation of the Data Used in the Lanphear et al. (2005) Pooled Analysis That Related Low Levels of Blood Lead to Intellectual Deficits In Children," *Critical Reviews in Toxicology* 43 (2013): 785–99.

266 Scott Grosse, "How Much Does IQ Raise Earnings? Implications for Regulatory Impact Analyses," Research Letter, *Association of Environmental and Resource Economics* 27, no. 2 (2007), http://www.umsl.edu/~kosnikl/AERE%20Essay.pdf; Ted Gayer and Robert W. Hahn, "Designing Environmental Policy: Lessons From the Regulation of Mercury Emissions," *Journal of Regulatory Economics* 30 (2006): 291–315, http://dx.doi.org/10.1007/s11149-006-9005-9; Lin, Lutter and Ruhm, "Cognitive Performance."

267 Leonardo Trasande and Yinghua Liu, "Reducing the Staggering Costs of Environmental Disease in Children, Estimated at $76.6 Billion in 2008," *Health Affairs* 30, no. 5 (2011): 863–70, http://content.healthaffairs.org/content/30/5/863.short; See economic assumptions and methods in Social Security Administration, "The 2016 Annual Report of the Board of Trustees of The Federal Old-Age and Survivors Insurance and Federal Disability Insurance Trust Funds" (2016), https://www.ssa.gov/OACT/TR/2016/tr2016.pdf.

268 Philip J. Wolfe et al., "Costs of IQ Loss From Leaded Aviation Gasoline Emissions," *Environmental Science and Technology* 50 (2016): 9026–33, http://dx.doi.org/10.1021/acs.est.6b02910.

269 Elise Gould, "Childhood Lead Poisoning: Conservative Estimates of the Social and Economic Benefits of Lead Hazard Control," *Environmental Health Perspectives* 117, no. 7 (2009): 1162–67, http://dx.doi.org/10.1289/ehp.0800408; Leonardo Trasande and Yinghua Liu, "Reducing the Staggering Costs of Environmental Disease in Children, Estimated at $76.6 Billion in 2008," *Health Affairs* 30, no. 5 (2011): 863–70, http://content.healthaffairs.org/content/30/5/863.short.

270 U.S. Bureau of Economic Analysis, "Table 1.10. Gross Domestic Income by Type of Income," accessed April 13, 2017, https://www.bea.gov/iTable/iTable.cfm?ReqID=9&step=1#reqid=9&step=3&isuri=1&903=51.

271 U.S. Environmental Protection Agency, "Mortality Risk Valuation," https://www.epa.gov/environmental-economics/mortality-risk-valuation.

272 See, for example, the discussion of discount rates in N.H. Stern & Great Britain, *The Economics of Climate Change: The Stern Review* (Cambridge, UK: Cambridge University Press, 2007).

For further information, please visit:
healthimpactproject.org

Contact: Tami Holzman, officer, communications
Phone: 202-552-2122
Email: tholzman@pewtrusts.org

The Health Impact Project, a collaboration of the Robert Wood Johnson Foundation and The Pew Charitable Trusts, is a national initiative designed to reduce health inequities and improve the health of all people by ensuring that health is a valued and routine consideration in decisions affecting them.

This report was funded by Robert Wood Johnson and Pew, with additional support from the Charles Stewart Mott Foundation. Any opinions and conclusions expressed herein do not necessarily represent the views of the contributing individuals, organizations, advisory committee members, or funders of the Health Impact Project.