



# The Long-Term Benefits of Preventing Childhood Lead Exposure

## A Simulation Using the Social Genome Model

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**This paper considers the potential benefits of reducing children’s exposure to lead. The US has made considerable progress, but some children still carry lead in their blood at elevated levels, and almost all children have detectable blood lead from one or more sources. Policies that effectively target children at risk of high blood lead levels and prevent their exposure to lead can improve children’s educational outcomes and reduce their chance of having a teen birth or criminal conviction.**

In 2016 and 2017, the Health Impact Project, a collaboration of the Robert Wood Johnson Foundation and The Pew Charitable Trusts, convened a team of researchers to assess the societal effects of childhood lead exposure and the possible benefits of policies to prevent and respond to the problem. Staff at Child Trends, the Altarum Institute, and the Urban Institute were tasked with providing quantitative assessments of the costs, benefits, and life-course consequences of these policies. The results appear in a report by [The Health Impact Project \(2017\), 10 Policies to Prevent and Respond to Childhood Lead Exposure: An Assessment of the Risks Communities Face and Key Federal, State, and Local Solutions](#).

To create these quantitative assessments, the Child Trends, Altarum Institute, and Urban Institute teams developed a multistage process.

1. The teams produced quantitative estimates of the effects of lead prevention policies on children’s lead exposure.
2. The teams then reviewed the research literature, government reports, and survey data to estimate which children would be affected by each policy under consideration, their baseline blood lead levels, and the reduction of blood lead levels each policy could achieve.

3. The teams produced quantitative assessments of childhood outcomes that would be affected by reduced blood lead levels (under each presumed lead prevention policy).
4. The teams combed the peer-reviewed research literature for high quality (generally cross-sectional and regression-controlled) studies to estimate how children’s cognitive performance and behavior vary according to their blood lead level, net of other background and economic factors.
5. The teams simulated adolescent and adult outcomes that would be affected by differences in childhood cognitive and behavior scores (corresponding to the lower blood lead levels under each presumed lead prevention policy).
6. For this stage, the Urban Institute and Child Trends used the Social Genome Model (SGM) to simulate how changes in childhood behavior and reading and mathematics scores could influence social, educational, and family outcomes. Separately, Altarum Institute employed the Value of Prevention Tool, which focused on how changes in IQ, given a reduction in blood lead levels, would affect later earnings, as described in extensive research literature on that topic.

This paper also reviews the methodology and describes the simulation results from the SGM. We refer the reader to the original report (The Health Impact Project 2017) for other analyses by the teams, including cost-benefit analyses by Altarum Institute and literature reviews by Child Trends. The appendix of the original report also contains more detailed descriptions of Urban’s methodology, along with the precise values obtained from the research literature on the effects of lead prevention policies on children’s lead exposure, blood lead levels, and relationship between children’s blood lead and their cognitive scores and behavior.

Much of the background information for this paper comes from the US Environmental Protection Agency’s cyclopedic Integrated Science Assessment for Lead ([United States Environmental Protection Agency 2013](#)). Except where we provide other citations, all information about lead exposure and lead toxicity comes from the US Environmental Protection Agency compendium.

## Background

### Effects of Childhood Lead Exposure

Lead is toxic to persons of all ages and affects many organ systems, but the greatest public health concern is its neurodevelopmental effect on children. Along with certain cardiovascular effects on adults, childhood neurological effects occur at lower blood lead levels compared to other health effects. Research has found risk for negative effects at low enough levels of exposure that no level of blood lead has been identified as safe in children.

When lead from the environment is breathed or ingested, it moves into the blood and stores itself in soft body tissues and, ultimately, bone. From bone, lead is released back into the blood and excreted slowly over time. Only about 1 percent of the lead in the body will be found in the blood, but it is via the blood that the brain and other organs are exposed to lead. Because blood is relatively easy to draw and

assay, blood tests are the most common way to measure lead in the body. A child's blood lead level is a good measure of the brain's exposure to lead under conditions where environmental exposure remains constant over time, but a current blood test will only capture a part of any sudden short-term peak of lead exposure that occurred three or fewer months before the test.

Documented effects of lead on the nervous system in children include *cognitive function decrements* that lower IQ and academic performance; *behavioral effects* that include conduct disorder and heightened risk of attention deficit, impulsivity, and hyperactivity; *psychological effects* including depression, withdrawal, and anxiety; and *decrements to sensory and motor function*.

Effects of childhood lead exposure can persist into adulthood. After early childhood, average lead exposure decreases with age, and as exposure to environmental lead is reduced, the amount of lead in the bones, tissues, and blood gradually decreases. Yet, any harm at critical stages of neurological development can have lifelong effects, including decreased educational attainment and increased rates of incarceration and unintended pregnancy.

## Sources and Levels of Lead Exposure

The history of childhood lead exposure in the US is an unfinished success story. US lead concentrations in the air and in biomarkers such as blood lead have decreased substantially since the late 1970s, following restrictions on lead in gasoline, industrial sources, household paints, and solder. However, some emission sources (such as leaded fuel for piston-engine aircrafts) remain, and many older houses contain lead paint and water pipes, disproportionately affecting children in lower-income households. These sources all contribute to children's blood lead levels, but a scarcity of epidemiological data makes it difficult to estimate the relative size of each contribution.

The Centers for Disease Control and Prevention has established a reference level of 5 micrograms per deciliter ( $\mu\text{g}/\text{dL}$ ) to identify children with blood lead levels much higher than most children. By this standard, all US children had elevated blood lead levels in the late 1970s. The National Health and Nutrition Examination (NHANES) Survey Wave 2, a nationally representative survey of health data, estimated that the mean blood level for children ages 5 and under was 16.0  $\mu\text{g}/\text{dL}$  between 1976 and 1980, with only 12.2 percent of children having blood lead levels below 10  $\mu\text{g}/\text{dL}$  (Annest et al. 1982). Much more recently, the 2011–14 NHANES recorded a mean blood lead level of 1.1  $\mu\text{g}/\text{dL}$  among children ages 5 and under, with 98.8 percent recording levels below 5  $\mu\text{g}/\text{dL}$ . Because some children still suffer from elevated blood lead, and because there is no known safe blood lead level for children, further reducing childhood blood lead levels will benefit society and individuals.

Given the many ways that children can be exposed to lead, numerous policies could target remaining sources of childhood lead exposure. In the next section, we describe our methods for simulating effects of the following proposed policies:

- an aspirational scenario for total prevention of exposure to environmental lead for all children
- an aspirational scenario for total prevention of exposure to environmental lead for all children with blood lead levels over 2.0 µg/dL
- lead hazard control (LHC) for housing where children are exposed to elevated levels of dust containing lead from paint
- replacement of lead service lines that leech lead into household water
- removing lead from aviation gas for children living near airports serving piston-engine aircrafts

## Methods

### The Social Genome Model

To assess how changes in childhood exposure to lead affect adult outcomes, researchers at Child Trends and the Urban Institute used the SGM, a statistical simulation model linking individuals' circumstances and outcomes from birth to age 40. The SGM was originally developed by researchers at the Brookings Institution and is now maintained and enhanced collaboratively by the Urban Institute and Child Trends. The data underlying the model come from a sample of 8,056 subjects in the Children of the National Longitudinal Survey of Youth 1979 cohort, linked to data in The National Longitudinal Survey of Youth 1979 cohort. The National Longitudinal Survey of Youth 1979 began with a cohort of youth ages 14 to 21. The survey collected socioeconomic information on these youth every year until the 1990s and then biennially through today. In 1986, the survey began tracking children born to women in that survey. Thus, the Children of the National Longitudinal Survey of Youth provides data on a large cohort of youth born in the United States in the 1980s and 1990s, with detailed information on their circumstances at birth, behavior, home environments, school experiences, performance on standardized tests, educational attainment, and early adult economic outcomes. The SGM uses these data to estimate multivariate statistical models linking children's outcomes or status at one stage of development with their outcomes at all subsequent stages. The SGM uses data from the original National Longitudinal Survey of Youth 1979 cohort to impute adult outcomes based on adolescent and early adult characteristics.

The SGM is a powerful tool for understanding how circumstances from birth through childhood and adolescence influence adult outcomes. It can assess the potential long-term benefits of improving conditions for children and youth. The SGM is structured around six key life stages: (1) birth, (2) early childhood, (3) middle childhood, (4) adolescence, (5) transition to adulthood, and (6) adulthood. Each stage influences all subsequent life stages. For the purposes of this analysis, we assumed the level of

lead to which a child is exposed influences her math and reading skills, along with her patterns of conduct and/or attention deficit and hyperactivity disorders, in early and middle childhood respectively. The SGM then estimates changes in subsequent life outcomes (educational attainment, teen births, criminal convictions, and lifetime family income) that would follow from a reduction in childhood lead exposure.

## Simulated Lead Exposure

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 NHANES to assign blood lead levels to children in the model based on their social and demographic characteristics. Specifically, we used the NHANES to predict the blood lead level of each child between 1 and 5 years old. In other words, we created in the SGM 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. The average blood lead level in the combined two NHANES surveys for children ages 1 to 5 was 1.1  $\mu\text{g}/\text{dL}$ .

Next, the modeling team referred to the literature to determine how much children's blood lead levels could be lowered under policies to reduce exposure to lead from dust, water, or air. The team then used separate literature to estimate how reductions in blood lead levels would affect childhood reading and math scores and behavior. Finally, the team used the SGM to estimate how differences in childhood math and reading scores and behavior would impact high school grade point average and graduation rates, college graduation rates, likelihood of criminal convictions by age 19, and likelihood of teen births. The team used the SGM to simulate the answers to the following five questions, which range from purely aspirational to more solidly grounded in specific policies.

### 1. **What would happen if we could simply prevent all childhood lead exposure?**

This is an aspirational scenario in which childhood blood lead levels for the entire US population are reduced to zero from their NHANES-imputed levels. It represents the upper theoretical bound for the aggregate social benefits of reducing lead exposure, although the benefits per child would tend to be small because many children have relatively low lead exposure.

### 2. **What would happen if we could prevent all lead exposure for the child population with blood lead above 2.0 $\mu\text{g}/\text{dL}$ ?**

The value of 2.0  $\mu\text{g}/\text{dL}$  represents 8 percent of the US child population between 2011 and 2014. The benefits per child would be relatively high because only children with higher blood lead would be subjected to this aspirational intervention. A higher threshold of 5.0  $\mu\text{g}/\text{dL}$  would align to current Centers for Disease Control standards for elevated blood lead levels but would reflect only 1.2 percent of the US population, a fraction too small for the SGM to provide stable estimates.

**3. What would happen if households with children that needed LHC had received such services?**

It is difficult to precisely estimate the number of houses with small children that have elevated lead exposure due to lead in dust and/or peeling paint. We used data from NHANES and the American Community Survey to estimate the fraction of children and their average blood lead levels living in housing built before 1960 and with a family below 120 percent of the federal poverty level. Housing age and family income are the most easily measured risk factors for living in housing that requires LHC. Full LHC would include treating chipping paint, lead-containing dust, and lead-containing soil, and replacing windows. Full details on the estimation of housing needing LHC are available in *The Health Impact Project (2017)*.

**4. What would happen if households with children that needed full lead service line replacement had received such services?**

It is also difficult to estimate the fraction of housing with children and water service lines containing lead. We based our estimates of this population on the fraction of children living in pre-1986 housing (the year the US Environmental Protection Agency required service lines be lead free)<sup>1</sup> multiplied by the fraction of pre-1986 housing that in fact has lead service lines (estimated at just under 7 percent). Full lead service line replacement replaces the entire water service line from street to structure. Full details of the estimation of children in homes with lead service lines are also available in *The Health Impact Project (2017)*.

**5. What would using unleaded fuel for piston-engine aircrafts mean for children living within one kilometer of airports that served those aircrafts?**

The team used relevant literature on the effects on blood lead levels for the estimated 5.7 percent of children living within one kilometer of such an airport. Full details of the estimation of children who would be affected by this intervention are available in *The Health Impact Project (2017)*.

For each of these research questions we used the same approach: we estimated the differences in blood lead resulting from the intervention, then estimated the differences in early and middle childhood math and reading scores resulting from that reduction in blood lead, then simulated differences in adolescent and adult outcomes resulting from those changes in scores.

The modeling team assigned a blood lead value to every person in the SGM cohort to identify whether that person was part of a policy's target population. No other variables in the SGM were changed in response to the blood lead assignments, and blood lead was not used in the SGM regression equations to predict later-life outcomes. 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 the 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 would reduce exposure and blood lead levels by 50 percent, his or her blood lead should be 0.75 µg/dL lower. Using the expected effect of blood lead on reading scores,

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 standard deviations (i.e., 0.75 x 0.0405 standard deviations). This change in reading scores, in turn, affects the person's adolescent and adult outcomes, according to the SGM's simulations. The modeling team identified the effect of blood lead levels on variables when those variables could be found in both the SGM's source data and in studies from the literature review. We focused on 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 reading scores
- Peabody Individual Achievement Test mathematics scores
- the hyperactivity subscale of the Behavior Problems Index
- the antisocial behavior subscale of the Behavior Problems Index

The adolescent and adult outcomes we report in this paper are the child's high school grade point average and whether the child goes on to complete high school by age 19, complete a 4-year college degree by age 29, have a criminal conviction by age 19, and become a teen parent (simulated for boys and girls).

## Results

### Aspirational Interventions

Table 1 shows the expected differences in adolescent and adult outcomes from preventing all lead exposure. In simulations for total prevention of lead exposure for all children, all adolescent and adult measures improved by a small but measurable amount. In simulations that focused only on the fraction of the child population with blood lead above 2.0 µg/dL, the improvements were larger, but the fraction of the child population affected is much smaller—only 8 percent of all children have blood lead levels this high. For all the outcomes, the population with high blood lead began with cognitive and behavioral scores substantially below the national average, which reflects the other family and economic disadvantages of children who are likely to experience elevated blood lead levels. Our simulations thus suggest that lead prevention could help reduce inequality in educational attainment and adult outcomes, although lead prevention alone would not be nearly enough to erase the other social and economic disparities between the high-lead child population and the overall child population.

TABLE 1

**Changes in Adult Outcomes Associated with Simulating Blood Lead Levels of Zero for All or Part of the Child Population**

	Baseline Conditions for All Children	Total Prevention for All Children	Baseline Conditions for Children with Blood Lead >2.0 µg/dL	Total Prevention for Children with Blood Lead >2.0 µg/dL
Average high school GPA	2.93	2.94	2.74	2.78
Earn high school diploma by 19	83.7%	84.0%	74.4%	75.6%
Complete 4-year degree by 29	26.7%	27.1%	17.0%	18.3%
Convicted of a crime by 19	17.2%	16.9%	22.0%	20.7%
Become a teen parent	13.5%	13.3%	20.1%	19.6%

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

Notes: GPA = grade point average. Analysis is based on the SGM's sample of 8,056 children, drawn from the Children of the National Longitudinal Survey of Youth Dataset. Additional details of the Model and methodology are available at <https://www.urban.org/research/publication/guide-social-genome-project>.

**Policy Interventions**

Table 2 shows the expected differences in adolescent and adult outcomes from three simulated policies for preventing lead exposure: LHC for children living in pre-1960 low-income housing; full lead service line replacement for children living in pre-1986 housing; and switching to unleaded aircraft fuel for children within one kilometer of an airport serving piston-engine aircrafts. In these simulations, blood lead is reduced but never eliminated, so the changes in outcomes are smaller than in the aspirational scenarios for total lead prevention. The adult scores for children affected by policies for lead hazard control remain significantly below the simulated averages for the total child population from Table 1, reflecting the fact that households that require lead hazard control tend to be older and low-income.



TABLE 2

## Changes in Adult Outcomes Associated with Policies for Preventing Lead Exposure

	LHC for Children Living in Pre-1960 Low-Income Housing		Full LSL Replacement for Children Living in Pre-1986 Housing		Switching to Unleaded Aircraft Fuel for Children within 1km of Airport	
	Without LHC	With LHC	With LSL	Without LSL	Leaded aircraft fuel	Unleaded aircraft fuel
Average high school GPA	2.79	2.80	2.90	2.90	2.83	2.83
Earn high school diploma by 19	72.1%	72.4%	82.8%	82.9%	80.8%	80.9%
Complete 4-Year degree by 29	15.0%	15.1%	24.7%	24.8%	23.0%	23.0%
Convicted of a crime by 19	23.8%	23.6%	17.7%	17.7%	17.8%	17.8%
Become a teen parent	28.0%	28.0%	14.0%	13.9%	15.9%	15.9%

**Source:** Social Genome Model Analysis by Child Trends and the Urban Institute.

**Notes:** LHC = lead hazard control. LSL = lead service line. Analysis is based on the SGM's sample of 8,056 children, drawn from the Children of the National Longitudinal Survey of Youth Dataset. Additional details of the Model and methodology are available at <https://www.urban.org/research/publication/guide-social-genome-project>.

## Conclusion

Consistent with the findings of the overall lead study, our SGM simulations indicate that policies for lead prevention would benefit children through adulthood. Among the policies considered, and as implemented in our simulations, lead hazard control in housing is likely to produce the greatest lifetime benefits. Requiring piston-engine aircrafts to use unleaded fuel was simulated to produce the smallest lifetime benefits. However, such fuel now constitutes the largest remaining source of lead emissions in the US, so there could be small but diffuse benefits of such a policy that the SGM could not measure. These small effects are consistent with the observation that children's lead levels have already fallen over 90 percent from when they were first measured nationally in the late 1970s. Our simulations suggest there are additional benefits to reducing blood lead levels for the remaining 10 percent.

Aside from the overall effects on adult outcomes, our simulations' findings for how lead policies might reduce economic and social inequality indicate that the children with the greatest burden from lead also face other obstacles to achieving positive life outcomes. Lead prevention policies are thus a tool to reduce inequality somewhat, although clearly such policies alone will not completely level the playing field for adult success.

## Note

1. Jeffrey Kempic, “Lead-Free Definition Under the Safe Drinking Water Act,” (PowerPoint presentation, Office of Water/USEPA Stakeholder Meeting, August 16, 2012), <https://www.epa.gov/sites/production/files/2015-08/documents/leadfreedefined.pdf>.

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Martin has a PhD in sociology from the University of Wisconsin–Madison. His undergraduate training was in biology at the University of California, Berkeley, with an emphasis on evolutionary biology; he also earned teaching credentials for middle and high school science and mathematics.



**Gregory Acs** is vice president for the Income and Benefits Policy Center at the Urban Institute, where his research focuses on social insurance, social welfare, and the compensation of workers. He recently completed a study of the factors contributing to persistently high unemployment in the United States and policy responses to that problem. In addition, Acs has studied the low-wage labor market, changes in welfare policies and how they have affected welfare caseloads and the well-being of low-income families, and how state and federal policies affect the incentives families face as they move from welfare to work.

Before returning to Urban, Acs was unit chief for labor and income security in the Congressional Budget Office's Health and Human Resources Division. Acs is the author and coauthor of numerous scholarly journal articles, policy papers, briefs, and reports to federal agencies. He coauthored *Leaving Welfare: Employment and Well-Being of Families That Left Welfare in the Post-Entitlement Era* with Pamela Loprest in 2004.

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