Global Lead Exposure Report

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Rethink Priorities has been piloting expanding into human-focused neartermist global priorities research. This post is one of three outputs from the pilot program. Open Philanthropy provided funding for this project and we use their general frameworks for evaluating cause areas, but they do not necessarily endorse its conclusions. We don't intend this report to be Rethink Priorities' final word on lead exposure. We hope the report galvanizes a productive conversation about lead exposure within the EA community. We are open to revising our views as more information is uncovered.

Key Takeaways

- Lead exposure is a large problem with social costs on the order of $5-10 trillion annually, most of which come through neurological damages and losses in IQ causing lost income later in life.

- Lead exposure is diverse both in terms of sources and geography, with there being many different pathways for environmental lead to enter the human body and exposure being common across nearly all low- and middle-income countries.

- Although the proportion of the lead burden attributable to different sources is unclear, important exposure pathways include informal recycling of lead acid batteries, residential use of lead-based paint, consumption of lead-adulterated foodstuffs, and cookware manufactured with scrap lead.

- Strategies for reducing lead exposure are mostly context- and source-dependent, but generally preventing new lead entering the environment seems more tractable than removing existing lead.

- We estimate that $6-10 million globally is currently spent by NGOs focused on reducing lead exposure in low- and middle-income countries.

- We are confident that existing and potential new NGOs in the area currently have the capacity to productively absorb $5-10 million annually in additional money, and it's possible though unlikely that this capacity would expand to $25 million annually over the next 5 years.

- Rough initial cost-effectiveness estimates suggest that some strategies for dealing with lead exposure could be as or more cost-effective than GiveWell top charities.

Executive Summary

We believe that the problem of lead exposure deserves more attention than it currently receives in the neartermist effective altruism community.

Exposure to lead causes many problems. High levels of lead exposure can be fatal. Even at low levels of exposure, lead exposure causes neurological damage, especially in children. Lead exposure is associated with many cognitive and behavioral problems and is a significant risk factor for cardiovascular diseases, mental disorders, and kidney disease. Worldwide, lead exposure is estimated to impose a 21.7 million DALY burden (for comparison, malaria causes a 46.4 million DALY burden) and we think the true value is likely 30-100% larger. The economic costs of lead exposure, primarily lost earnings due to reductions in IQ, are estimated to total around a trillion dollars annually but we think the true value is 30-50% of this size. If one adopts a logarithmic income utility model,[1] the utility value of this dollar burden is an order of magnitude higher, since 94% of the loss occurs in low- and middle-income countries (LMICs) which have on average 10x lower incomes than the USA.

Lead exposure is common across LMICs. Important exposure pathways include the informal recycling of lead acid batteries,[2] the residential use of lead-based paint, the consumption of lead-adulterated foodstuffs (especially spices), and the use of improperly sealed aluminum-lead alloy cookware. Unfortunately, the proportion of the lead burden attributable to these different sources is unclear. Other sources of lead exposure include metal mining and processing, cosmetics, traditional medicines, tobacco products, aviation fuel, plumbing, and electronic waste. More research on exposure pathways would be valuable.

There are many potential strategies that one could adopt to reduce lead exposure. Promising interventions include advocating for lead-based paint regulations, educating consumers about lead-adulterated products, increasing the formal recycling of lead acid batteries, cleaning toxic hotspots, and enforcing regulations related to lead in spices and pottery. Initial analysis suggests that these interventions may be competitive with GiveWell top charities, but more research is needed to evaluate the cost effectiveness of these (and other) interventions.

Lead exposure appears to be neglected relative to the size of the problem. The largest organization working on lead exposure is the non-profit Pure Earth. They operate on an annual budget of $5-6 million, of which $4-5 million is directed toward lead exposure. Summing the estimated budgets of other organizations, we believe that donors spend no more than $10 million annually on lead exposure. We are currently unsure how much

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[1] "A logarithmic utility function for income… assumes that doubling a person's income contributes the same amount to their well-being regardless of how much income they started with… [and]… implies that $1 for someone with 100x less income/consumption is worth 100x as much. This implies direct cash transfers to the extreme global poor go about 100x as far as the same money spent in the U.S., on average." [GiveWell's Top Charities Are (Increasingly) Hard to Beat](#) (Open Philanthropy, 2019)

[2] Informal recycling is typically done close to residential areas without the safety procedures and technologies necessary to limit lead fumes and stop the exposure of workers and those who live nearby. Formal recycling, on the other hand, takes place in regulated settings where emissions are controlled.

governmental funding is directed toward the problem, but the amount appears to be small enough to leave ample room for more philanthropic funding. We believe the lead exposure ecosystem could productively absorb at least an additional $5 million annually, with this amount increasing as current NGOs expand capacity and new organizations enter the space. It is unclear how quickly the cost effectiveness of additional funding would decrease.

If one were to read just two pieces about lead exposure (other than this report), we recommend (1) the 2020 UNICEF and Pure Earth report *The Toxic Truth*, which provides a nice overview of the problem of lead exposure and (2) Teresa Attina and Leonardo Trasande's 2013 paper "Economic Costs of Childhood Lead Exposure in Low- and Middle-Income Countries" because this research underpins the economic argument for working to reduce lead exposure.

If one wanted to fund direct lead exposure work this year, we would recommend two organizations: Pure Earth and the Lead Exposure Elimination Project. If one wanted to fund lead exposure research, we would recommend studies measuring blood lead levels in neglected regions, source apportionment studies (to determine the lead exposure pathways) in neglected regions, and further investigation of the relationship between lead exposure, general intelligence, and earnings potential.

Introduction to this Problem Area

Lead is a potent neurotoxin, and its effects are irreversible (WHO, 2010). Children are at increased risk because in many circumstances they are more likely to ingest lead than adults[3] and in all circumstances the ingested lead is worse for children's still-developing bodies than it is for adult's bodies. Malnourished children are at particular risk because poor nutritional status, especially calcium and iron deficiencies, increases lead absorption (Goyer, 1997). There is no safe level of lead exposure: even low-level exposure is associated with a host of health, behavioral, and cognitive problems (UNICEF, 2020).

Sources of Lead Exposure

In the 20th century, the largest source of lead exposure was leaded gasoline, responsible for 90% or more of human lead exposure (UNEP, 2020). Thankfully, this source has been almost completely eliminated. In 2002, 82 countries still allowed lead to be added to automobile fuel (UNEP, 2020). As of 2020, Algeria (population: ~43 million) is the only country in the world that has not yet banned leaded automobile gasoline.[4] Tsai & Hatfield (2011) estimate that the global elimination of leaded gasoline prevents 1.2 million premature deaths a year and saves the world economy $2.45 trillion a year.

[3] Children breathe more air, drink more water, and eat more food per unit of body weight than adults. Children also engage in hand-to-mouth behavior that results in more ingestion of contaminated substances. (WHO, 2010)
[4] Leaded aviation gasoline (avgas) is still legal in many countries, including the U.S.

Unfortunately, many sources of lead exposure remain and several new sources have appeared in the last 30 years. Major sources include lead acid batteries, spices, cookware, and paint. Other sources of lead exposure include metal mining and processing, cosmetics, traditional medicines, tobacco products, aviation fuel, plumbing, and electronic waste.

There is little research on quantitatively assessing the relative importance of exposure pathways, and it is currently unclear what proportion of the total lead burden is attributable to each of these exposure pathways. Our impression from conversations and the gray literature is that lead paint and unsafe recycling of lead acid batteries are the largest sources of exposure in LMICs. Ericson et al. (2017) suggests that out of a total of 21.2 million DALYs from lead exposure in 2013, 127,248 to 1,612,476 (0.6% to 7.6%) of them came from 10,599 to 29,241 informal lead acid battery recycling sites, but we have not vetted this study at all. A recent systematic review in *The Lancet* (Ericson et al., 2021) analyzes 478 studies of blood lead levels in low- and middle-income countries.[5] The review finds that battery manufacture or recycling was the primary source of lead exposure in more studies (118) than any other source. Somewhat surprisingly, lead-based paint is only reported as the primary source in 7 studies. However, the review only tracks primary exposure sources. It would be naive to extrapolate from the fact that 7/478 studies are from contexts where lead paint is the primary exposure source to the claim that 1.5% of the total burden is from paint because (1) paint is likely to be a non-primary but significant exposure source in many contexts, and (2) there's no reason to expect the distribution of studies across contexts to be representative since studies are more likely to take place in localities with high lead exposure. In other words, we are concerned that if you only did studies near hotspots and you only looked at primary exposure pathways, you might come to believe that a majority of the burden is attributable to (e.g.) informal battery recycling sites. If you looked instead, at the population as a whole, it might turn out that (e.g.) paint causes a higher (though more diffuse) burden.

Used Lead Acid Batteries (ULABs)

The raw materials from used lead acid batteries (ULABs) are economically valuable and easily extracted, resulting in an estimated 10,000-30,000 informal recycling enterprises worldwide, mainly in poor communities with few other economic opportunities (Ericson et al. 2017). Lead acid batteries account for about 85% of total global lead consumption, and the market is predicted to continue to grow, especially in Asia (WHO 2017). Informal ULAB recycling releases toxic dust and fumes, posing an immediate and acute danger to workers, many of whom do not wear personal protective equipment. Because informal ULAB recycling doesn't require any heavy equipment, operations can quickly change locations, making enforcement difficult even when appropriate regulations exist (WHO 2017). Informal ULAB recycling also contaminates the soil, which can continue to be a source of

[5] We have not yet been able to review the paper in full but you can see the slidedeck from a presentation of its results here. It is scheduled to be published March 11.

lead exposure for the local community long after the ULAB recycling site has ceased operation. Formal recycling facilities also have some risk of contaminating the soil as well, but our impression is that generally the risk levels are lower (Gottesfeld et al., 2018).

Spices

In some regions, particularly South Asian countries, leaded pigments are added to spices to enhance the color of the spice. Adulterated spices include turmeric, paprika, saffron, cumin, coriander, and curry powder (Hore et al. 2019). For example, in Bangladesh lead chromate pigment is added to dried turmeric root at commercial polishing mills to induce a vibrant yellow color in the spice. This practice allegedly originated over 30 years ago, driven by consumer demand for bright, colorful curries (Forsyth et al. 2019). Turmeric consumption has been linked to elevated blood lead levels in Bangladesh (Forsyth et al. 2018) and probably contributes to lead exposure in other South Asian countries. Spices also appear to be a major lead exposure pathway in Middle Eastern and North African countries (Hore et al. 2019).[6]

Cookware

The lead generated from informal recycling of lead acid batteries is often passed on to small, local manufacturers of cookware. These enterprises use the lead to create aluminum-lead alloys for a variety of cookware and cooking utensils. According to Occupational Knowledge International, inexpensive aluminum cookware from at least 20 countries has been tested and found to leach dangerous levels[7] of lead. Glazing on artisanal pottery in places like Mexico is also alleged to be a big problem, but we did not have time to investigate this issue. In conversation, Pure Earth stated that the majority of lead exposure appears to come from the kitchen (i.e., adulterated food and contaminated cookware).

Lead is also found in the glazes of certain types of pottery. Low temperature-fired kilns often use glazes made predominantly with lead dioxide to create a shiny finish. Typically wood-fired and manufactured by smaller artisans rather than large commercial enterprises, this type of glaze releases lead into food in the presence of heat or acid (e.g. tomatoes). In Mexico, artisanal pottery is considered the single largest source of lead exposure (Téllez-Rojo et al., 2019) A broad review of countries with similar practices has not been done. Pure Earth has found evidence of the same issue in South India, Guatamala, Peru, Brazil, Pakistan and elsewhere.

[6] Contaminated spices and herbal remedies have also been identified as a source of lead exposure in some communities in the United States (Angelon-Gaetz et al. 2018).

[7] "Simulated cooking leached up to 1,426 micrograms of lead per serving." The FDA recommends a maximum daily intake of 3 micrograms of lead.

Paint

When lead-based paint begins to chip or deteriorate, lead is released into the air, dust, and soil. Children get their hands coated in the dust and soil and ingest the lead through normal hand-to-mouth behavior. Additionally, young children are known to sometimes ingest paint chips (IPEN, 2021). Approximately 1.7 billion people live in countries with no regulations controlling lead in paint.[8] International Pollutants Elimination Network (IPEN), which works on regulating lead paint, has confirmed dangerously high levels[9] of lead in paint in at least 59 countries. (See their map here.) In conversation, IPEN reported that based on their data on lead in paint from 59 countries, it seems like countries without lead paint regulations are virtually guaranteed to have lead-based paint on the market. However, the opposite is not true. Countries with regulations on lead levels in paint frequently fail to enforce them. For example, despite legally binding restrictions in China, a 2017 study found that 37% of 141 sampled paints for sale contained soluble lead contents above the legal limit (IPEN, 2017). Additionally, some countries may have restrictions that are not stringent enough to eliminate dangerous levels of lead in paint.

Importance

Health Impact of Lead Exposure

Health Problems Caused by Lead Exposure

The Global Burden of Disease (GBD) includes lead exposure as a risk factor for cardiovascular diseases, mental disorders, and kidney disease.

Children are particularly vulnerable to lead exposure. This is because (1) they grow faster than adults so their bodies absorb more of a given amount of ingested lead (and this is exacerbated when they are undernourished and lacking minerals like calcium and iron which lead mimics), and (2) they tend to ingest more lead due to their normal hand-to-mouth behaviour.

Children exposed to high levels of lead poisoning can suffer severe neurological damage, intellectual difficulties, behavior disorders, and, in the worst cases, comas and death. Lower levels of exposure have less obvious symptoms but are associated with slower brain development, reduced IQ, increased antisocial behavior, anaemia, and hypertension (WHO, 2019).

[8] See this spreadsheet for details. The 1.7 billion figure is a conservative lower bound on the number of individuals living in areas with lead-based paints on the market as there are areas where there are regulations but they aren't enforced. The true figure might be twice as high.

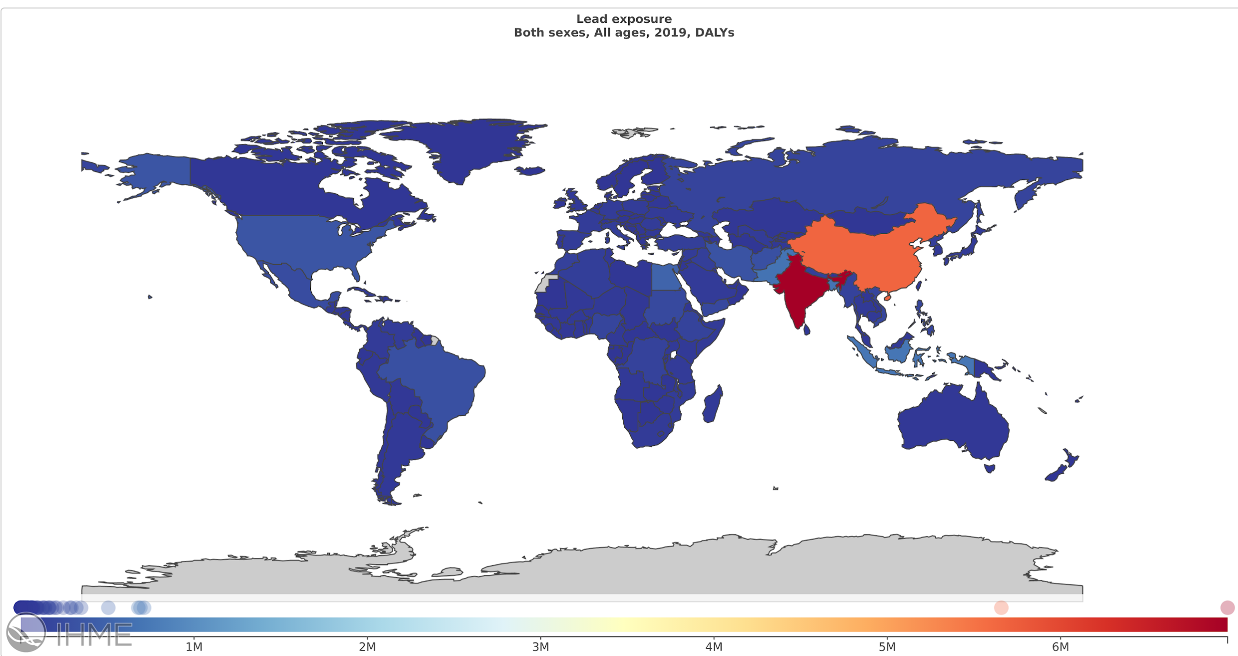
[9] "Many of these paints contained very high levels of lead above 10,000 parts per million (ppm) of the dry weight of the paint." 90 ppm is generally considered the maximum safe level.

Estimated DALY Burden

GBD estimates a global DALY burden from lead exposure of 21.7 million. 94% of the burden occurs in LMICs. In terms of the diseases lead exposure causes, GBD estimates that 82% of the DALYs are a result of cardiovascular diseases, 12% from mental disorders and 6% from kidney diseases.[10] Valuing a DALY at $50,000 puts the annual health costs from lead exposure at $1.1 trillion.

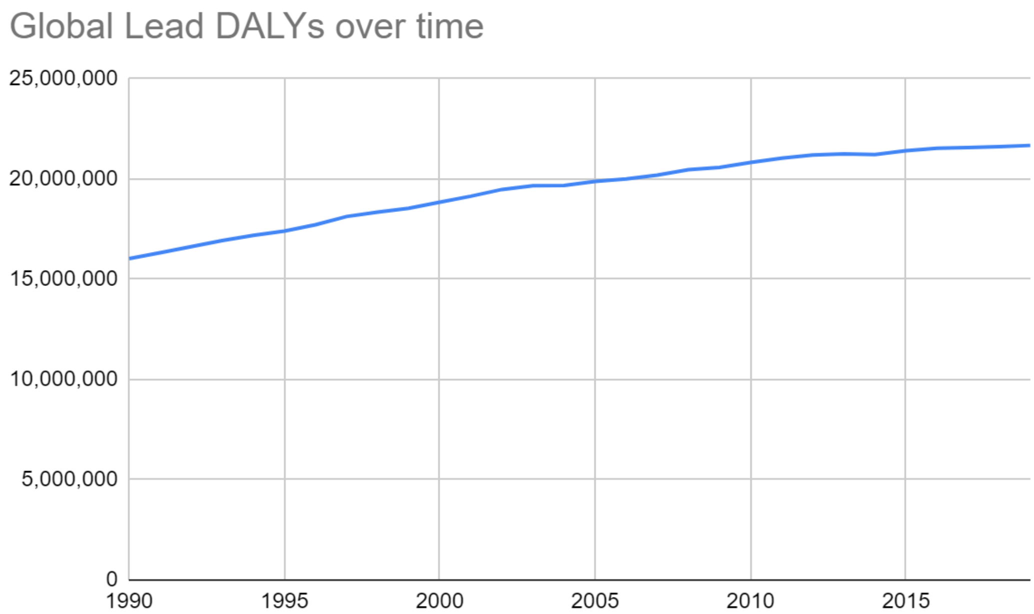
You can explore a map of the country-level estimates of the DALY burden, average blood lead level (BLL), number of children with >5 and >10 µg/dl (micrograms of lead per decilitre of blood), and premature deaths from lead exposure here. Some key takeaways include:

- There are 815 million children with BLL >5 µg/dl, around one third of all children globally (UNICEF, 2020).
- Average BLLs are 5-10x higher in Africa and Asia than in high-income countries.
- Approximately 60% of the current DALY burden occurs in India and China.
- The number of DALYs is increasing over time, but the rate of increase has slightly slowed in recent years and the DALY burden per person has decreased slightly.



Notes: 2019 Global distribution of absolute DALY burden of lead exposure from GBD

[10] See this spreadsheet for details.



Notes: Annual global DALY burden of lead exposure from GBD

Why the DALY Burden May Be an Underestimate

All DALY estimates are noisy, but DALY estimates for lead seem particularly noisy since they rely on only 88 BLL surveys across all LMICs.[11] If a country has no BLL surveys, GBD imputes the distribution using estimates from neighbouring countries and four basic covariates which we suspect gives an imprecise estimate of the actual BLL distribution (Shaffer et al., 2019).[12] Ericson et al. (2021) include data from 478 BLL surveys which should make estimates more precise but as far as we can tell, this has not yet been integrated into assessments of the health and income impacts of lead. We think that the noisy global estimate of 21.7 million DALYs is more likely to be an underestimate of the true burden than an overestimate for two main reasons.

Firstly, GBD counts IQ loss as a contribution to DALYs only if it results in an IQ below 85, classified under the cause of idiopathic developmental intellectual disability. However, lead exposure results in IQ loss across the entire distribution. We would not expect a discontinuity in disease burden or welfare loss at an IQ of 85, meaning that there is likely additional welfare loss from IQ loss not being captured.

[11] BLL surveys collect blood lead levels for a sample of individuals and report the mean BLL and other features of the distribution.

[12] The covariates are: use of leaded gasoline, numbers of two- and four-wheeled vehicles per capita, proportion of each location's population living in an urban area, and a sociodemographic index

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Secondly, GBD makes two key modelling assumptions for lead's effect on cardiovascular outcomes. The first assumption is that lead exposure affects cardiovascular outcomes solely through the pathway of increased blood pressure. The second assumption is that lead only starts affecting blood pressure after BLL exceeds 5 μg/dl (Shaffer et al., 2019).

Lanphear et al. (2018) provides weak evidence that both assumptions are false such that they result in a potentially significant underestimate of the burden. Firstly, they find that even when controlling for hypertension, lead exposure is associated with an increase in cardiovascular disease mortality, which suggests that there are pathways other than blood pressure through which lead negatively affects cardiovascular outcomes.[13] Secondly, in one analysis they also limit the sample to those with BLLs below 5 μg/dl and find that an increase from 1 to 5 μg/dl is associated with a 95% increase (95% confidence interval: 46%-160%) in cardiovascular disease mortality, suggesting that there are negative effects at low BLLs even before the GBD threshold. They attribute 400,000 out of 2.3 million annual deaths in the USA to lead exposure, which is an order of magnitude larger than the current estimate, but we are confident that the number is not that high. The study is observational, with no exogenous variation in lead exposure and many possible confounders, but we think it nonetheless provides some weak evidence that the DALY burden is higher than reported, although likely not a full order of magnitude higher given the study's limitations; our best guess is that the true DALY burden is likely 30-100% larger.

Economic Impact of Lead Exposure

The Relationship between Lead Exposure and IQ

We have not had the capacity to look into the biomedical literature, but our impression from conversations is that there is strong evidence that: lead is a neurotoxin, it causes biological damage and hinders brain development.

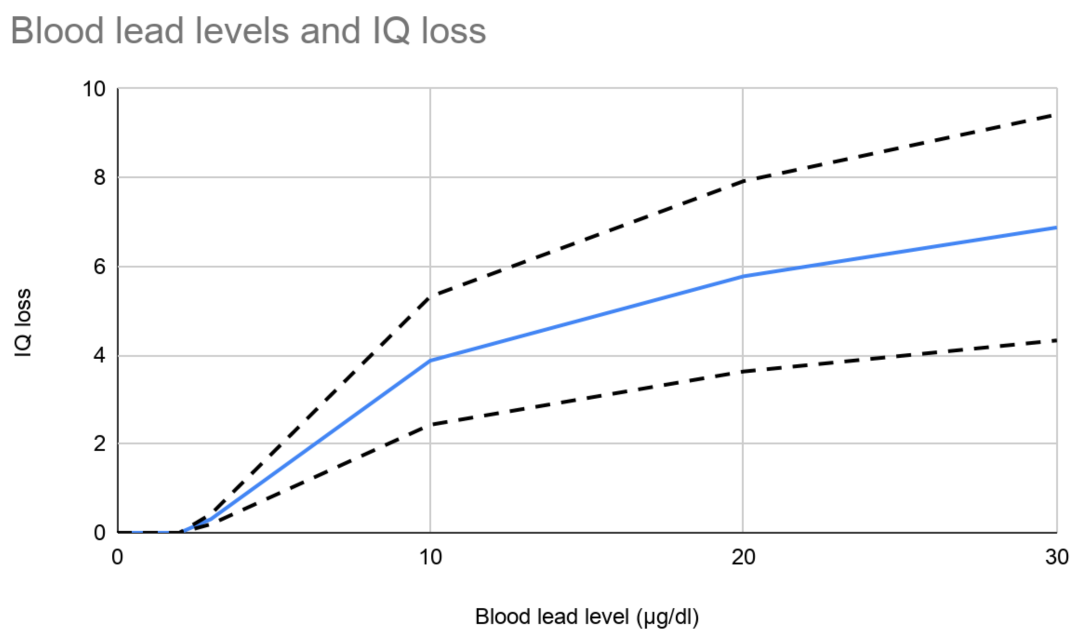
The most commonly cited paper we've seen on the blood lead level and IQ dose-response relationship is Lanphear et al. (2005). They take longitudinal data from 1,333 children in seven different sites (Boston, Cincinnati, Cleveland, Mexico, Port Pirie, Rochester, Yugoslavia) who were followed from birth to age 5-10. They regress final IQ on blood lead level and attempt to control for potential confounders. Across multiple models, they find that harm from additional lead is worse at low BLL (i.e. they find diminishing marginal harms). The model from this paper which is most commonly referenced in later literature is the spline/piecewise model, which allows for different slopes of the dose-response relationship at different ranges; we show the results from this model in the table and graph below. The causal identification here is limited, so we think the relationship is likely weaker

[13] They just control for a binary variable of whether the individual has hypertension or not. Ideally, they would more flexibly control for the continuous variable of blood pressure.

than stated, but the cost-benefit analyses in the literature (described below) that use these results take the point estimates at face value.

Blood lead level (µg/dl)	IQ loss per µg/dl [95% confidence interval]
0-2.4	No data
2.4-10	0.51 [0.32-0.70]
10-20	0.19 [0.12-0.26]
20+	0.11 [0.07-0.15]

Notes: Own calculations from the estimates in Lanphear et al. (2005). They don't provide estimates for the relationship between 0 and 2.4 µg/dl, which later modeling takes as implying there is no impact of BLL on IQ in this range.



Notes: Plot of the estimates in table above

Estimated Global GDP Reduction Due to Lead Exposure

After modelling the relationship between blood lead level and IQ, the next step of estimating the economic burden of lead exposure is to model the relationship between IQ

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and earning potential. We have not looked at the literature on the IQ-income relationship so we just report the modelling assumptions used in existing cost-benefit analyses, but we suspect that this literature does not use particularly credible causal inference methods, so general skepticism suggests we should think the relationship is weaker than reported.

The most influential paper for the economic burden of lead exposure in LMICs is Attina & Trasande (2013) who study the BLL-IQ-income pathway. Their conclusion is that across LMICs, lead exposure reduces earning potential by $977 billion annually, with their sensitivity analysis producing a range of $729-1,163 billion (actual dollars, not utils). Under a log utility model, if we value giving a dollar to a US citizen (with GDP per capita = $65k) at $1, then we should value giving a dollar to the average LMIC citizen (with GDP per capita = $5k)[14] at 65/5 = $13. If we take the estimate at face value, this would suggest that the utility value of the productivity gains from eliminating lead exposure should be valued equivalently to increasing earnings in the US by around $13 trillion, significantly higher than the health gains.

Attina & Trasande (2013) estimate the distribution of blood lead levels across all LMICs using 68 BLL surveys. For countries which don't have surveys, they predict the mean and standard deviation of the distribution using a regression where the explanatory variables are the years since leaded gasoline elimination and its square (and also include the mean BLL for predicting the standard deviation). They assume a log-normal distribution of BLL within countries. They use the BLL-IQ dose-response relationship from Lanphear et al. (2005) described above. They assume that each point of IQ loss is associated with a 2% drop in lifetime earnings, as this is what is done in Grosse et al. (2002), a study of the benefits from reduced lead exposure in the USA. In their sensitivity analysis they only drop this to 1.76%, similarly following Grosse et al. (2002).

You can view a map of the country-level estimates of the economic burden of lead in LMICs from Attina & Trasande (2013) here, where you can see that about 50% of the total dollar burden is in India and China. That map can also show the burden of lead in terms of percent of GDP (rather than the total dollar burden), which is more informative from the perspective of a log income utility model; on that metric, the burdens are higher in sub-Saharan Africa and South Asia.

We think this estimate is probably the right order of magnitude, but more likely to be an overestimate than an underestimate. We think that the strength of both the BLL-IQ and IQ-income relationships is more likely to be overestimated than underestimated. We discussed above the poor causal identification and skepticism that causes us to think the BLL-IQ link is overestimated. For IQ-income, we have similar skepticism due to limited clean causal identification. For IQ-income, there's the additional issue that previous estimates of both the BLL-IQ and IQ-income relationships have been mostly based on US

[14] https://data.worldbank.org/country/XO

data and directly extrapolated to LMICs, whereas we think it's plausible that the returns to IQ are stronger in more technologically-developed countries. That would mean that taking the IQ-income relationship from the US and exporting it to LMICs will result in an overestimate. Furthermore, GiveWell have looked more in-depth at the IQ-income relationship in LMICs and their tentative conclusion is that the returns to one point of IQ is a 0.67% increase in income[15], one third of the estimate used in Attina & Trasande (2013). Our all things considered adjustment would be to say the annual economic benefits in dollars are 30-50% of the reported value of $1 trillion and therefore under a log utility model, the economic value (through the lead-IQ-earnings pathway) of eliminating lead exposure in LMICs would be $3.9-6.5 trillion.

Finally, it's important to note that this analysis is a partial equilibrium analysis which implicitly assumes no externalities of higher IQ. It is plausible that externalities of IQ increases could substantially outweigh the direct effects and these could be positive (e.g. if having more people in the right tail significantly contributes to innovation, productivity enhancements, and economic growth) or negative (e.g. IQ shifts just change who gets a fixed set of high paying jobs). We haven't thought about which direction this might go.

Other outcomes

We think health and income gains are likely to make up the vast majority of the gains from reducing lead exposure. The main other factor included in lead cost-benefit analyses (Gould, 2009; Tsai & Hatfield, 2011) is violent crime. Rick Nevin has a series of papers where he argues that lead is a key determinant of crime levels across a number of high income countries, with a particular focus on the U.S. The descriptive statistics are compelling, but skepticism of the causal claims is justified. (See Reyes (2007), Feigenbaum & Muller (2016) and Billings & Schnepel (2018) for studies of lead and crime with modern causal inference techniques.) We haven't read these papers in detail but our initial impression is that they support the lead-crime hypothesis, however, we are very unsure about what they imply for the proportion of crime caused by lead exposure. A recent meta-analysis by Higney et al. (2021) suggests that there is publication bias in the literature and high-quality studies show an effect of lead on crime that is close to 0. They calculate that lead exposure reductions in the US are responsible for between 36% and 0% of the fall in homicides, not the majority as is often claimed. We haven't vetted this working paper.

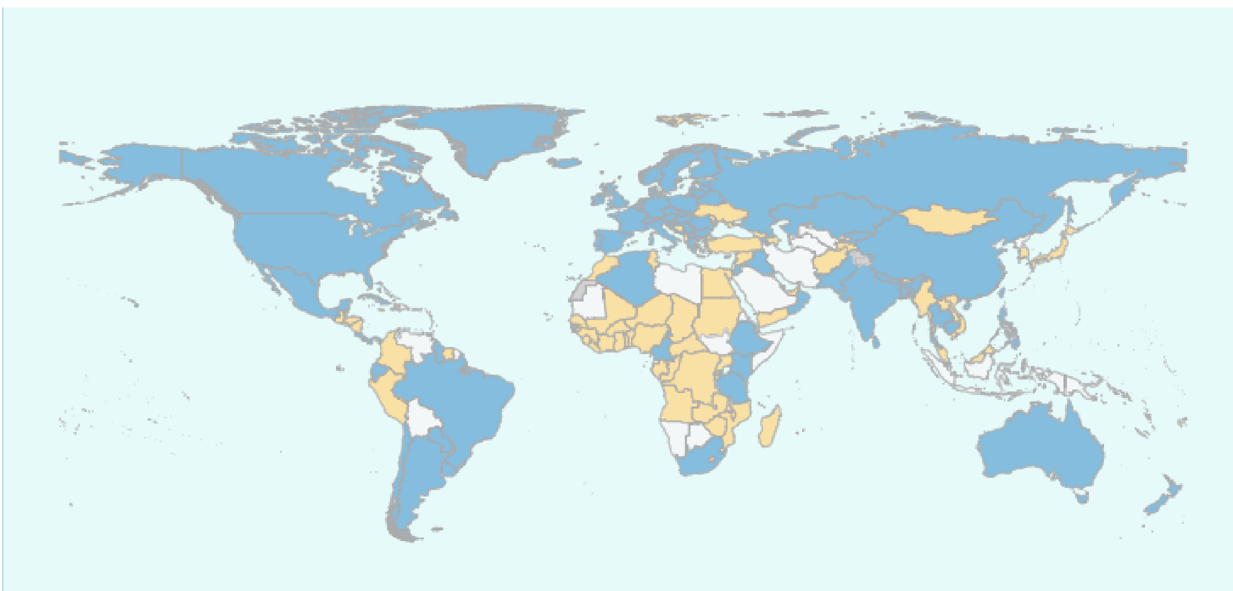
Predicted Distribution of Lead Exposure

We can think of lead exposure coming from two sources: legacy lead that already exists in the environment (e.g. houses already painted with lead paint) and new sources that are being added (e.g. houses that will be painted with lead paint).

[15] This was shared with us in private correspondence.

Our impression is that preventing new sources of lead will be more cost effective than removing legacy lead. However, there is likely a lot of heterogeneity in the costs of removing legacy lead; for instance, compare removing and replacing lead pipes with painting over lead paint with lead-encapsulating paint.

Prevention is clearly a viable strategy as one of the major sources of new environmental lead, leaded automobile gasoline, has already been eliminated via regulation across the entire world (except Algeria). Many countries have introduced regulations to limit the lead content of paint, but regulations are particularly sparse in Africa, and it is not clear how well they are enforced. Our impression is that lead in spices and pottery are likely to have regulations in place in all but the lowest-income countries, but that these are weakly enforced. Enforcement of those regulations could be expected to have a significant impact on health.



Notes: Map showing WHO Member States with legally-binding controls on lead paint (blue), Member States without legally-binding controls on lead paint (yellow), and countries for which there is no data (white), as of May 31 2020 (source)

One key factor for future exposure is population growth. Since the effects of lead are particularly harmful for young children aged less than 5, ceteris paribus we should be more concerned about lead in countries with high population growth rates, where young children will constitute a higher proportion of their population, than in countries with low growth rates.[16]

[16] See Dan Wahl's recent blog post for a more explicit model of why this matters as part of a cost-effectiveness analysis of the Lead Exposure Elimination Project

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Neglectedness

Lead exposure appears to be heavily neglected relative to its importance.

Total Funding Directed toward Lead Exposure

In conversation, IPEN estimated $2-3 million is spent annually on advocacy efforts to regulate lead paint. Much of this funding comes from the Global Environment Facility. In conversation, Pure Earth reported spending an additional $4-5 million on other exposure pathways, mainly lead acid battery recycling and spices. Much of Pure Earth's funding comes from USAID, Clarios Foundation, Oak Foundation and the World Bank. Accounting for the budget of smaller organizations, we estimate that NGOs spend $6-10 million annually to address lead exposure.

Room for More Funding

IPEN believes it would cost $15-20 million over the next decade to eliminate the sale of lead paint globally. This figure is based on their estimate of the cost to enact new regulations on lead-based paint in at least 50 additional countries, enforcement of adopted regulations, and a broader market shift to lead-free pigments within the supply chain, at which point IPEN predicts we will reach a tipping point where the remaining countries without regulations are likely to enact them without much additional pressure.[17] IPEN believes it can effectively scale up to absorb $2-3 million a year to lead such a campaign over a 10-year period.

Pure Earth believes it can absorb $50-100 million over the next decade to expand its work targeting informal lead acid battery recycling and spices adulterated with leaded pigments. They claim that even at this level of expansion, they would see little dropoff in cost-effectiveness.

LEEP's second year funding gap (beginning September 2021) is $225,000 with approximately $50,000 required per year for each additional country targeted.

Significant Organizations

The exact number of organizations actively working to reduce lead exposure is unknown. Below is a summary of the major groups of which we are aware.

[17] This thinking is based on the trajectory that the phase-out of leaded automobile gasoline followed.

Pure Earth

Formerly the Blacksmith Institute, Pure Earth runs a global lead program. They appear to be the only organization that both (a) specializes primarily in reducing lead exposure[18] and (b) takes a comprehensive approach to the issue, attempting to identify the most important exposure pathways and the most cost-effective interventions to address those exposure pathways. Pure Earth recently partnered with UNICEF and the Clarios Foundation[19] to launch the Protecting Every Child's Potential (PECP) initiative, which is working to reduce lead exposure in Mexico, Bangladesh, Georgia, Ghana, and Indonesia. Pure Earth runs the Toxic Sites Identification Program to "locate and assess contaminated sites in low- and middle-income countries and identify those that pose the greatest threat to human health." Pure Earth also helped found the Global Alliance on Health and Pollution. Pure Earth maintains a very useful collection of key publications on lead and health.

Our overall impression of Pure Earth is very positive. They seem well-attuned to the traditional EA framework for evaluating the promise of potential interventions. In our conversation with them, they emphasized the importance of measuring blood lead levels before and after an intervention to see if (and to what extent) the intervention worked. In October 2020 they underwent a strategic reorganization, dropping several programs they deemed to be less impactful and renewing their focus on reducing lead exposure.

Lead Exposure Elimination Project

The Lead Exposure Elimination Project (LEEP) is a Charity Entrepreneurship-incubated nonprofit founded in 2020. LEEP promotes regulations on lead paint and their enforcement in low-income countries. Last year LEEP conducted an on-the-ground study in Malawi, confirming dangerously high lead levels in locally marketed paint. They subsequently built relationships with key stakeholders within Malawi, including health professionals, industry representatives, and the government's Bureau of Standards and Ministry for Health. This work generated significant interest and resulted in the Malawi Bureau of Standards committing to implementing regulation banning lead in paint immediately. According to LEEP, the Bureau described LEEP's paint study as a "wake up call" and the reason for their action to implement and enforce the regulation.

Over the next year LEEP is, at the request of the Bureau of Standards, providing technical support to Malawian paint manufacturers to facilitate the switch to lead-free paint and increase compliance with regulation. LEEP then intends to repeat their paint study to evaluate whether lead levels have dropped. They have also begun paint studies in two further target countries, Botswana and Zimbabwe and will start advocacy there if high levels of lead are found. By the end of 2021 they plan to complete a paint study in

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[18] Pure Earth also runs a relatively small program focused on reducing health risks from mercury exposure.
[19] Clarios is a leading manufacturer of lead acid batteries. The Clarios Foundation promotes environmental sustainability and children's health.

Madagascar through a new partnership with the Ministry of Environment and Sustainable Development to support local lead paint advocacy efforts. Future scale-up will depend on funding availability, with approximately $50,000 required per year for each additional country targeted.

Our impression of LEEP's co-founders, Lucia Coulter and Jack Rafferty, is extremely positive. They appear competent, realistic, and aligned with effective altruism's values. LEEP's initial success in Malawi is impressive, accomplishing in roughly six months what they had estimated would take five years. It's unclear if this success can be replicated and scaled-up, but as the only explicitly EA-aligned organization working on lead, LEEP deserves consideration for any lead-related funding.

International Pollutants Elimination Network

The International Pollutants Elimination Network (IPEN) is a global coalition of more than 600 NGOs in 124 countries focused on reducing the harmful effects caused by the production, use, and disposal of toxic chemicals. The priorities and work of the network is decided by a Steering Committee where representatives of IPEN NGO members serve. Since 2009 IPEN has coordinated a program aimed at enacting regulations on lead paint in countries with no or weak restrictions. Since the program's inception, IPEN- NGOs have successfully worked through studies of lead in paint, awareness raising, collaboration with policy makers and with the national industry for new regulations in twenty countries[20] and are currently active in another eleven countries.[21] A short summary of IPEN's strategy is available here, and a full-length report on their efforts to eliminate lead paint is available here. IPEN is also advocating for leaded pigments to be included among the substances covered by the Rotterdam Convention, the international treaty that governs the importation of hazardous chemicals.

Importantly, IPEN is a network of distinct groups. That means that the member (partner) NGOs in the network work locally on the ground with support from the technical, science and communications advisors at the IPEN secretariat. The administrative support at the IPEN secretariat helps generate funding for the members of the network for their campaigns. IPEN NGOs often have a relationship with the relevant people at the government already and their local connections strengthen the long-term sustainability and effectiveness of the effort. While IPEN has partners working on lead paint in about 50 countries, this network structure limits their ability to operate in countries without reliable local partners, a gap that LEEP is well-placed to fill.

Our general impression of IPEN is positive, but they often emphasize the merits of their collaborative process over attempts to calculate the amount of good done per dollar spent.

[20] Argentina, Bangladesh, Brazil, Burundi, Cameroon, Ethiopia, India, Jordan, Kenya, Mexico, Nepal, Paraguay, Philippines, Rwanda, South Africa, Sri Lanka, Tanzania, Thailand, Uganda, and Uruguay.

[21] Colombia, Indonesia, Jamaica, Kazakhstan, Malaysia, Moldova, Nigeria, Tunisia, Ukraine, Vietnam, and Zambia.

They don't seem to place as much value on measuring the results of their interventions as we would like.[22]

Global Alliance to Eliminate Lead Paint

The Global Alliance to Eliminate Lead Paint (GAELP) is a consortium of organizations, including NGOs, governmental bodies, and trade associations, working to eliminate lead in paint. It was established in response to information on lead paint provided by IPEN. It is jointly run by the UN Environment Programme and the World Health Organization. IPEN serves on the advisory board, and LEEP is a member organization. It helps coordinate activities around the globe and promotes the phase-out of paints containing lead. GAELP is modeled in part on the Partnership for Clean Fuels and Vehicles (another UNEP program), which was a leading force in the global push to eliminate leaded automobile fuel.

Öko Institute

The Öko Institute is a large, wide-ranging German environmental think tank. The institute has done some work on lead acid battery recycling in Africa.

Vital Strategies

Vital Strategies is an international public health NGO headquartered in New Delhi. In 2018 Vital Strategies launched a childhood lead poisoning prevention campaign in Peru, emphasizing lead surveillance, public awareness, and improved regulation of lead in consumer products.

Occupational Knowledge International

Occupational Knowledge International (OK International) is an international public health nonprofit that works to reduce exposure to hazardous materials in low-income countries. OK International runs programs on lead paint, lead batteries, and contaminated cookware.

Toxics Link

Toxics Link is an Indian NGO in the IPEN network that is running a successful campaign that recently led to regulation of lead levels in Indian paint. Toxics Link is currently working on lead acid battery regulation and lead paint.

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[22] See also: "IPEN has been unable to consistently conduct follow-up studies to evaluate the effects of its national-level campaigns for lead paint regulation, except in a select few projects that received sufficient funding. Follow-up studies typically cost IPEN approximately $5,000, and when it has limited resources, it prioritizes the allocation of available funding to campaign activities—specifically in countries where no action on lead paint has yet been taken. Ideally, IPEN would like to always conduct studies of lead paint both before and after regulations have been passed" (GiveWell 2019 call notes).

Global Environment Facility

The Global Environment Facility (GEF) is a large environmental grantmaking foundation. GEF has committed $2-3 million per year to lead exposure advocacy. GEF has previously made large grants to IPEN (see, e.g., here) and Pure Earth (see, e.g, here). GEF appears to be the leading private funder of lead exposure advocacy.

International Lead Association

The International Lead Association (ILA) is the only association representing lead producers globally. ILA's main focus is lead-acid batteries. ILA provides technical assistance to battery manufacturers and battery recyclers and lobbies for favorable regulations on battery manufacture and disposal. Pure Earth believes them to be an ally on a campaign to clean up informal lead battery recycling but we have not spoken to ILA ourselves.

Counterfactual Impact

One of our biggest uncertainties is what the counterfactual impact would be of additional philanthropic investment to reduce lead exposure. Some aspects of the lead exposure problem appear to be inching toward an independent resolution. For example, pigment manufacturers appear to be moving away from the production of leaded pigments.[23] If the production of leaded pigments were phased out or severely curtailed, that could in turn lead to large reductions in lead exposure from adulterated spices and (new) lead paint. On the subject of lead paint, there appears currently to be global momentum toward restrictions on the amount of lead that can be included in residential[24] paint. According to IPEN (personal conversation), it is important to utilize this momentum now to ensure that enough countries adopt regulations to reach a point where no country wants to be among the last to regulate this toxic substance. IPEN believes that would lead to a tipping point where we see a cascade of new regulations across the remaining nations that lack regulations.[25]

On the other hand, many sources of lead exposure appear to be neglected relative to their proportion of the overall lead burden. Lead acid batteries are a good example. Pearce (2020) writes,

[23] "One notable ongoing trend is the move away from heavy-metal-based pigments (lead chromates in particular). Pigment manufacturers are actively developing environmentally friendly alternatives, including inorganic, organic, and organic/inorganic hybrid solutions, according to Howie. 'DCC LANSCO has introduced various product ranges that encompass all of these options because there are no single, one-to-one replacements for lead chromates; custom color matching to generate tailor-made solutions is required for each paint formulation, and often the result is a compromise to some degree in shade and performance,' he observes" (Challener 2018). See here for more evidence that the pigment industry is moving away from lead.

[24] Even in developed countries, leaded paint is still used for some industrial purposes, but water-based paints which do not contain lead are increasing in market share globally.

[25] The international policy community has proposed 2030 as the target for completely eliminating the sale of lead paint worldwide. UNEP and WHO had previously targeted 2020.

> "[Perry] Gottesfeld [of OK International] says UN agencies such as UNICEF and the UN Environment Programme have highlighted the issue without addressing it effectively. [Bill] Daniell [physician & epidemiologist] agrees, noting there is 'a fair amount of published research, and endless discussion, but that has not translated well to definitive action or effective policy.' [Richard] Fuller at Pure Earth says persuading policymakers will be 'a slow process.' He wants to establish a global fund to help governments provide cash for the collection of batteries by the formal sector, as a way of side-lining the backstreet operators. He highlights success in Brazil, 'which shut 80 percent of its informal sector,' mainly through economic incentives."

Tractability

When evaluating the tractability of reducing lead exposure, we can group assessments either by the source of lead (which may be addressed by multiple types of interventions) or by the type of intervention (which may address multiple sources of lead).

Tractability by Lead Source

In most cases, preventing new sources of lead exposure appears to be easier than removing existing sources of lead.[26]

Lead Paint

Preventing new sources of lead paint appears to be one of the most tractable ways to reduce lead exposure. A coalition of organizations, loosely coordinated by the Global Alliance to Eliminate Lead Paint, has worked since 2011 to achieve and enforce regulations in countries with no or few restrictions on lead levels in paint. Paint manufacturing is a high-volume, low-margin industry, which means much of the market for residential paint is supplied by local, relatively small manufacturers.[27] Many of these manufacturers appear to be either unaware that their paint contains lead or unaware of the extent of the health issues that lead exposure causes. Sometimes, when these companies are educated about the problem, they become allies in pursuit of new regulations.

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[26] Of course, we expect exceptions to this generalization. For instance, replacing window sills which have been painted with lead paint may be more tractable than enforcing regulations on the recycling of lead acid batteries.

[27] See O'Connor et al. 2018 for an overview of the role lead-based paint plays in the paint industry.

Although the exact tactics vary by country, the general strategy[28] (developed by IPEN) is for an NGO to (1) test the levels of lead in local paint to confirm the extent of the problem; (2) publicize the results to local paint manufacturers, industry representatives, and the media; (3) build a coalition of public health professionals, parents, and consumer advocates to agitate for change; (4) engage the relevant government officials and offer technical assistance for the adoption and enforcement of a regulatory framework; and (5) offer technical assistance to paint manufacturers to transition away from leaded pigments.

Two other possible strategies are worth noting. One is to attempt to hinder the trade of leaded pigments across international borders. Although most paint in low-income countries appears to be manufactured locally, some of the raw materials, including the pigments which contain lead, appear to be often sourced internationally. IPEN is working to get leaded pigments included as a controlled substance under the Rotterdam Convention, which would impose additional legal burdens on the importation of leaded pigments.

Another possibility is to apply pressure to pigment manufacturers directly. Although the global paint industry is highly dispersed, the global pigment industry appears to be relatively concentrated, largely in China and India. One could run a corporate campaign against the major pigment manufacturers compelling them to phase lead out of their pigments. We don't know of any groups who have considered this approach, and to succeed it would likely require more understanding of local context than most groups possess.

Used Lead Acid Batteries (ULABs)

The informal recycling of used lead acid batteries (ULABs) is a major source of lead exposure across the globe. There are two (complementary) approaches to informal ULAB recycling. One is cleanup and remediation. Our tentative analysis below suggests that cleanup of toxic sites in populated areas could be cost-competitive with GiveWell top charities.

An even more promising approach is prevention. Formal recycling programs exist in many of the same countries that practice informal recycling. In general, these formal recycling facilities are safer, cleaner, and more efficient[29] than their informal counterparts. The problem is that informal recyclers have lower costs than formal recycling programs, and thus are able to pay significantly more for ULABs, giving consumers a strong incentive to sell their used batteries to informal rather than formal recyclers (WEF 2020).

[28] This strategy applies both to countries without lead paint restrictions and countries that are not enforcing existing lead paint restrictions. In practice, the line between such countries can be surprisingly murky. For instance, according to WHO data, Malawi does not have restrictions on lead levels in paint. However, when LEEP began their advocacy efforts there, they discovered that there were, in fact, existing regulations that were not being enforced. Apparently, even the relevant government officials in Malawi were unaware of these regulations.

[29] In the sense that they can recover more of the useful materials from the used battery

There are several (again, complementary) approaches to resetting the economic incentives so that formal recyclers pay more than informal recyclers. A simple first step is to eliminate the goods and services tax on the formal recycling of ULABs. Another option is to place a levy or fee on the import and production of new batteries, then return that money to the industry when the battery is collected for formal recycling. Finally, governments can directly subsidize the formal collection of ULABs. According to Pure Earth, these approaches were pioneered in Brazil about 8 years ago and they reduced the market share of informal recyclers from 60-70% to less than 10%.[30] Pure Earth is now working on a similar strategy in Bangladesh and Indonesia, with hopes to expand to India, Senegal, Columbia, and the Philippines.[31]

Lead in Spices

Lead in spices can be addressed through a combination of educational campaigns and technical assistance. Turmeric is a good case study. Although turmeric adulteration is legally prohibited in many areas, the turmeric industry is dominated by small, informal enterprises that are difficult to effectively regulate. Consumer awareness campaigns are one possibility: adulterated turmeric is bright yellow whereas unadulterated turmeric is more of a dull gold. If consumers knew that artificially vibrant turmeric is toxic, they may be less likely to purchase it. Another option is to provide technical assistance to turmeric producers, explaining the dangers of lead chromate pigment and educating them about the most effective ways to dry turmeric so that natural color quality is maintained. Pure Earth has pioneered both strategies in recent years in Bangladesh. Because the lead burden from spices is so high in certain parts of Asia, and because consumer awareness and technical assistance is relatively inexpensive, Pure Earth claims that these sorts of campaigns are currently among the most cost effective approaches to reducing lead exposure.

Leaded Cookware

Weidenhamer et al. (2017) observe that prohibitions on the use of scrap metal in cookware manufacturing would be difficult to enforce. They explore coating cookware with a fluoropolymer finish to reduce corrosion (essentially sealing the lead in and reducing lead exposure by ~98%). This sort of finish is relatively inexpensive (~$0.33 per pot), but the appropriate application of the finish requires specialized equipment, making it impractical for most producers. Weidenhamer et al. note that launching this sort of intervention at scale would "require developing a new specialty business to handle a large volume of cookware from multiple artisanal producers to provide the necessary scale to reduce costs. In large cities where these producers are concentrated, it may be feasible to establish a

[30] See WEF 2020: 18-20 for additional details. Our impression is that the total volume of recycling stayed roughly constant, the assumption being that batteries were already being recycled at a very high rate, since they are so valuable. But we haven't investigated this assumption.
[31] See pp. 31-32 (37-38 of pdf) of this WHO report for more recommendations for dealing with informal recycling of lead batteries.

cooperative or central facility to apply a coating for a fixed fee to new cookware from a large number of producers" (2017: 811). Importantly, however, Weidenhamer et al. note that there are many potential health and environmental risks associated with fluoropolymer use, and they suggest anodization as another possible approach. They conclude that the problem of leaching of metals from cookware is serious enough to warrant further research.

Lead Pipes

Addressing lead exposure from currently installed lead pipes does not appear tractable due to the cost involved in replacing pipes. Individuals who receive water via lead pipes should use a lead-rated water filtration system for their drinking water. They should also consider flushing their water once a day. To prevent lead leaching into the water supply, municipalities could consider in situ electrochemical passivation, but we have not investigated that approach.

Leaded Aviation Fuel

Although leaded automobile gasoline has long been banned, across the globe about 230,000 small, piston-engine aircraft still use leaded aviation gasoline (avgas), which contains tetraethyl lead (TEL) (FAA, 2019). These aircraft are the largest single emitters of lead in the United States. According to the FAA, "TEL has not yet been banned for use in avgas, because no operationally safe alternative is currently available" (FAA, 2019). Although research is underway to identify suitable replacements, industry experts predict getting lead out of aviation fuel won't be easy or cheap and a recently released, Congressionally-mandated report concludes the same, suggesting this exposure pathway is relatively intractable.

Tractability by Intervention Type

To address the most problematic exposure pathways, a comprehensive strategy that encompasses many different intervention types will probably be needed.

New Regulations

New regulations appear to be an important tool to combat lead exposure. For instance, there are about a hundred countries with no lead paint regulations.[32] Convincing these countries to enact new regulations looks quite tractable. Since the inception of their lead paint campaign in 2009, IPEN has successfully advocated for legally binding controls on lead paint in 20 countries, with more successes expected shortly. While the country-by-country approach appears promising, regulating the international trade of lead

[32] The exact number seems to be in dispute. LEEP claims it is 113 countries. A conservative estimate is 85 countries (excluding countries for which we have no data). See WHO data here.

pigments (perhaps via the Rotterdam Convention) may also be important. It's unclear how tractable it would be to enact new international regulations.

Enforcing Existing Regulations

While enacting new regulations is important, sometimes it is sufficient to enforce pre-existing regulations. Operating on a shoestring budget and with no prior experience, LEEP was able to convince the Malawi government to actively enforce previously ignored regulations on lead paint in less than six months. (Of course, given the government's history of lax enforcement, it is unclear how durable this new commitment to enforcement will be.)

It appears much of the lead burden in low- and middle-income countries comes from activities that are, strictly speaking, illegal. For instance, in many countries there are already prohibitions on the adulteration of foodstuffs with leaded pigments or the informal recycling of lead acid batteries. The trouble is that in many areas ULAB recycling, spice production, cookware manufacturing, and e-waste disposal all seem to be dominated by a diffuse group of informal enterprises, making enforcement difficult. But ineffective enforcement can be actively counterproductive: if an informal ULAB recycling site is shut down only to reopen in another part of town, then the attempt at enforcement will have merely created an additional hotspot of contamination (WEF, 2020). Still, where possible, appropriate enforcement of existing regulations will probably prove crucial.

Monitoring

Although it is a step removed from direct impact, basic health monitoring appears to be one of the most important elements of a successful approach to lead exposure. Blood lead levels are not measured frequently enough in most communities. By monitoring BLLs more frequently in more contexts, we will better understand where the burden lies and how successful interventions are in reducing it. The most tractable remedy to this deficiency is to incorporate BLL screening into existing nutritional, demographic, or health surveys.[33]

[33] "Well-functioning biomonitoring programs are essential for tracking the trends in environmental contamination. Full-scale programs are labor-intensive and costly. The DECOMOPHES pilot collaboration in human biomonitoring among 14 European countries estimated that annual costs of a full-scale program would range €120,000–450,000 per country and €400,000–1,400,000 for central coordination, with additional costs for biobanking. This compares to $5 million/year for the U.S. NHANES and seven million Canadian Dollars/year for the Canadian Health Measures Survey [130]. However, the work of researchers at the National Institute of Public Health in Mexico demonstrates that BLL screening can be implemented into existing nutritional surveys or medical care with the use of portable lead analyzers (M.M. Téllez-Rojo, personal communication). Demographic Health Surveys (DHS), immunization campaigns, home-visiting programs for expectant mothers, or integrated young child feeding or development programs present other large-scale opportunities for the integration of BLL screening." (Kordas et al., 2018: 9-10)

Educational Campaigns

Educating individuals about the dangers of lead and their likely exposure pathways appears to be an important type of intervention. In many cases, individuals may be unaware of the long-term health impacts of informal e-waste recycling or informal ULAB recycling. (Or individuals may be aware of the general danger but unaware of the disproportionate impact on children and pregnant women.) In other cases, individuals may be unaware of their exposure to lead through adulterated spices, lead-based paint, or contaminated cookware.

Educational campaigns seem to be a common intervention to address lead exposure, but it appears their efficacy is rarely assessed rigorously.[34] We expect that educational campaigns will be a tractable and effective intervention in many circumstances. However, some health professionals caution that "educational campaigns often treat interventions as behavioral and lifestyle choices where, if individuals just had more knowledge, they would make better choices and avoid environmental exposures. This underlying logic overlooks the deep structural disparities that drive people to the margins and engagement with formal or informal sector activities with exposure risks. Educational approaches will do best when integrated with efforts to provide real and accessible alternatives that emphasize systems-level changes that span beyond the public health arena" (Kordas et al., 2018: 11).

Hotspot Cleanup

Soil can become contaminated from lead from many sources: informal ULAB recycling, informal e-waste recycling, lead mining, industrial smelting, and other industrial activities. Lead in soil has a half-life of 700 years (Semlali et al., 2004). The tractability of cleaning such sites appears to depend on details that are not entirely clear to us. Cleanup typically involves some combination of soil encapsulation, replacement, removal, enclosure, or covering. In our conversation, IPEN cautioned that clean-up must be conducted in a manner that deals safely with the waste and does not lead to further contamination. They reported that toxic cleanup can be done cheaply but poorly and that doing it well is expensive. They also warned that poor cleanup often turns into a political issue as an entity could claim they could "clean-up" lead contamination in one location, but create another lead contamination problem either during the process or through poor handling of the waste. Their view is that prevention of contamination is always the better option when possible, which is why they focus on prevention, including regulations and policies, and do not focus on applied clean-up activities.

[34] See, for example, Pascale et al. (2016) who found informal e-waste recycling to be a major source of childhood lead exposure in Montevideo, Uruguay. The authors provided educational materials to the families of 69 children, but they were only able to measure BLL changes in 10 children.

Corporate Campaigns

Leaded pigments are found not only in paints but also in spices and glazes. The pigment industry appears to be relatively concentrated and thus perhaps a good target for a corporate campaign. Another possibility is to challenge battery manufacturers (whose industry is also relatively concentrated) to pay more attention to the full lifecycle of their products.[35] The tractability of such campaigns depends on a variety of details we did not have time to investigate.

Replacing Leaded Products

Although we have not looked into the idea in any detail, directly replacing leaded products with safe alternatives may be an attractive intervention in some areas. For example, inexpensive aluminum cookware is widely used in low-income countries, and this cookware has often been found to contain and subsequently leach dangerous levels of lead (Weidenhamer et al., 2014). NGOs could offer to replace leaded cookware with non-leaded equivalents or subsidize the purchase of non-leaded equivalents. Alternatively, NGOs could work with manufacturers of cookware to ensure they are not sourcing unsafe materials. However, it seems unlikely that these methods will be the most cost-effective approaches to reducing lead exposure.

Cost-Effectiveness

In this section we discuss cost-effectiveness estimates of cleaning up informal lead acid battery sites and of regulation on lead paint, since these are the interventions for which we could find formal cost-effectiveness modeling. There are many other interventions that could be considered, and we suspect they will vary significantly in their cost effectiveness. Pure Earth suggested that public awareness and education campaigns around lead in spices could be the most cost-effective lead intervention, but we haven't seen anything backing up this claim to assess it in detail. Given the nature and degree of the uncertainty surrounding lead exposure, the most valuable use of resources might currently be additional research.

Informal lead acid battery recycling hotspots

Ericson et al. (2018a) estimate the cost effectiveness of cleaning up an informal lead acid battery recycling hotspots in the Dominican Republic. They suggest that they averted 133 to 1,096 DALYs for a cost of $392 to $3,238 (2009 USD) per DALY depending on the modeling assumptions made. They do not include the income gains from IQ gains, which we saw before were globally estimated to be roughly 10 times more valuable than the health gains. If this is the case and we naively extrapolate, we might expect a DALY equivalent to be averted for $40-$300.

[35] The industry recently launched the Responsible Battery Coalition, perhaps in anticipation of activist pressure.

Ericson et al. (2018b) look at a similar project in Vietnam but don't calculate DALY burdens. They find a BLL drop from 40.4 to 12.3 after clean-up for at least 200 children (in a village of total population 2,600) for a total cost of $118,750. In the Dominican study, there was a BLL drop of roughly half the size (20.6 to 5.3), 176 people and a total cost of $430,000, roughly 3.5 times higher. If we naively assume the benefit was twice as large for a third of the cost in Vietnam, the cost-effectiveness would be 6x larger than in the Domincan Republic. However, since (1) the BLL-IQ dose-response relationship is steepest at initial lead exposures and (2) the Dominican Republic started at a lower BLL, our rough analysis suggests that the IQ gains in the Domincan Republic and Vietnam are comparable and therefore cost-effectiveness improvements in Vietnam should be limited to the cheaper program.

Chowdhury et al. (2021) undertake a similar study in Bangladesh. They find a drop from 23 to 15 µg/dl for a cost of $40,300. However, it's not clear how many children actually benefited from this intervention since 64% of their baseline sample of 69 were not found at endline 14 months later, so the conservative assumption would be to assume only the 25 children found at the end benefitted, which would give it a similar cost-effectiveness to the Domincan Republic study.

We emphasise that we haven't carefully vetted any of these studies and our general assumption is that after further interrogation (and less naive extrapolations) these would appear less cost-effective. Furthermore, there is probably some form of publication bias with these estimates being on the more cost-effective end of the distribution.

That said, these papers all look at the cost-effectiveness of a curative approach to hotspots, cleaning them up. Typically, preventive measures are substantially more cost-effective than curative measures so approaches aimed at stopping hotspots from forming may be more cost-effective, but we haven't seen any formal analysis on preventive measures yet.[36] One preventive measure discussed below is regulating lead paint.

Lead paint regulation

The Lead Exposure Elimination Project have produced three cost-effectiveness models. Their most recent model, from April 2021, uses causal.app to produce a distribution of cost-effectiveness. Their Jan 2021 model, built upon the model Charity Entrepreneurship used in their assessment of lead paint regulation as an effective area to found a charity. This is updated from their November 2020 model with more complexity and captures some of the recent progress they have made.

[36] Possible preventive measures for informal lead acid battery recycling include regulations eliminating goods and service tax on used batteries (which currently puts the formal sector at a price disadvantage) and taxes on the manufacture and import of new batteries that are returned to the formal sector when they recycle a battery, or other policies.

The headline result of LEEP's cost-effectiveness analysis is that given their quick success in Malawi, they estimate their advocacy for lead paint regulation averts a DALY equivalent for $11 with a 90% confidence interval [$3.14-$28] (using previous GiveWell moral weights to value 2.8 years of income equally to 1 DALY, the cost-effectiveness would likely be better if DALYs were valued at $50,000 and income doublings at $60,000 as done in the importance section above). Before they started in Malawi, they assumed a 35% chance of success which resulted in an estimate of $17-$35 per DALY equivalent depending on time discounting, which they have since updated to a 80% chance of success.

From a short inspection the CEA seems fairly well done. We briefly list some factors which could potentially make LEEP an order of magnitude less cost-effective:

- They chose Malawi as a particularly effective place to start and they were unexpectedly successful there, so as they move to new countries they might face a doubly diminishing return from both a lower burden of lead and a lower probability of successful reform. The cost-effectiveness analysis is an estimate of how cost-effective they have been in the past rather than the marginal impact of additional funding.
- They discount the estimated economic burden in Malawi from Attina & Trasande (2013) by 50%, justified by their assumption of a one point drop in IQ leading to 1% less earnings, rather than the pessimistic 2%. This discount factor could be lowered further to account for the internal and external validity concerns (discussed above) around the IQ-earnings relationship and the BLL-IQ relationship, the latter of which they currently don't adjust for.
- Lead paint could make up substantially less of the lead exposure burden than 20%.
- Their cost per country in future countries could be substantially higher than $80k

Uncertainties and Open Questions

Our uncertainty can be separated into two categories: uncertainty that is particular to us and uncertainty that is general to the world. The former category includes questions that have been addressed somewhere in the literature and questions that haven't been addressed in the literature but could be reasonably answered by relevant experts. Hence, the uncertainty in this category could be resolved (or at least significantly reduced) with additional desk research. The latter category includes questions that haven't been addressed (or haven't been addressed adequately) in the literature and that cannot be reasonably answered by experts. Reducing uncertainty in this category will require fieldwork or specialized academic research. Currently, our two most important uncertainties concern source apportionment (what are the exposure pathways?) and cost effectiveness (how much of the overall lead burden can be eliminated at or below a $50/DALY-equivalent averted threshold?).

Open Questions Particular to Us

1) How much do governments spend on lead exposure?
2) How much do international development organizations spend on lead exposure?
3) Who are the big pigment producers? Where are they located? Why do they continue to put lead in their pigments?
4) How significant is lead in ceramics? What are the best interventions to address this exposure pathway?
5) How significant is lead in tobacco products? What are the best interventions to address this exposure pathway?
6) How significant is lead in electronic waste? What are the best interventions to address this exposure pathway?
7) Are there other sources of lead exposure on the horizon?

Open Questions General to the World

1) How much of the lead burden is attributable to different sources?
2) What percentage of the lead burden can be addressed cost-effectively?
3) How much will current estimates of cost-effectiveness change after further scrutiny?
4) What are the best estimates of the causal relationship between blood lead level and IQ, and IQ and income? What are the externalities of lead-related IQ gains?
5) What is the counterfactual impact of additional investment to reduce lead exposure?
6) What opportunities exist for new organizations to work on lead exposure?
7) How likely is it that, without additional investment from EA sources, leaded paint will be fully regulated by 2030? By 2040? How well enforced will these regulations be?

Grant Ideas

As we see it, there are two different categories of funding that could be valuable in the near future: funding more direct work and funding more research.

Direct Work

By our lights, there are at least two organizations addressing lead exposure in a manner that appears potentially similar in cost effectiveness to GiveWell top charities. With more research, we may be able to identify programs at other organizations that are similarly cost effective. There may also be opportunities to provide seed funding for new organizations focused on lead.

LEEP

LEEP is a small organization, so its ability to absorb new funding is currently limited. Additional funding could cover LEEP's second year funding gap of $225,000, allowing them to continue to monitor lead levels in paint in Malawi to assess the extent and durability of their initial policy success and/or allow LEEP to expand to more countries on its priority list, with an estimated cost of $50,000 per year per additional country.

LEEP focuses exclusively on lead, so fungibility is not a concern. Although LEEP's current model focuses on enacting restrictions on lead paint, if evidence emerged that other interventions were more effective at reducing lead exposure, LEEP could probably be convinced to pivot to those interventions.

Pure Earth

Pure Earth is much larger than LEEP and is thus capable of absorbing much more money. If given additional funds, Pure Earth would strengthen their current programs and expand to additional countries, with an estimated cost of $300,000 to $1 million per year per country. Pure Earth runs a small program focused on mercury exposure, but they intend lead work to absorb an increasing proportion of their resources, so fungibility between causes is not a significant concern. Fungibility between intervention types is a bigger worry. We have only evaluated Pure Earth's ULAB cleanup and remediation interventions (and are not confident in our evaluations), but these interventions appear to be surprisingly cost effective. We suspect their informal ULAB recycling preventative campaigns are even more cost effective, and they assert that their work on lead in spices is even more promising. (We haven't evaluated that claim.) Pure Earth is also working on leaded pottery glaze in Mexico, and we have no sense for the cost effectiveness of that type of work. An initial grant could fund rigorous cost-effectiveness studies on all their different intervention types. This could either be done by an external party or by Pure Earth since they seem both capable of and interested in this type of self-assessment.

More Research

Unlike many other global health problems of comparable scale (e.g., malaria), the extent of the lead problem, the pathways to lead exposure, and the potential interventions to reduce exposure are all poorly understood.

BLL Studies

Given the significance of lead poisoning, we were surprised to find a relative paucity of blood lead level (BLL) studies. BLL studies are a crucial component for both understanding the extent of the lead problem and for building political will to address the problem. Multiple individuals with whom we spoke suggested the best way to get more BLL studies done is to integrate BLL measures into existing national demographic and health surveys. The DHS Program is a natural place to attempt this integration. Because BLL studies are of such fundamental importance and because they are relatively inexpensive (especially when tacked on to a pre-existing survey), this sort of grant could have very high value of information (though we haven't attempted to calculate, even roughly, the exact value of this sort of grant).

Apportionment Studies

Knowing the blood lead levels of a particular population is important, but there is little we can do to address the problem unless we know where the lead is coming from. Systematic apportionment studies across many countries would help us pinpoint the sources of lead causing the most harm, allowing us to tailor our responses appropriately and enabling us to better prioritize future intervention research. At this time we do not know whom to fund to conduct this research.

BLL-IQ Link

Much of the scale of the lead problem hinges on the connection between lead exposure and reductions in IQ. Because this is such a crucial consideration, a shift in evidence concerning this connection could shift the way we view the lead problem. Although the existing literature on this connection is not poorly done, the literature is small and the relationship is complicated with many potential confounders. It would not surprise us if future research overturned many of the conclusions of the present literature. At this time we do not know whom to fund to conduct this research.

What We Would Do with More Time

We believe we could spend another 30-40 hours productively researching this topic and that the next 30-40 hours of research could significantly alter some of our headline conclusions. Here is a partial list of what we would do with more time:

1. Quantify our uncertainty in various important propositions, including the proportion of the lead burden attributable to different sources and the cost effectiveness of different intervention types
2. Talk to Jenna Forsyth at Stanford
3. Talk to Bret Ericson at UNEP
4. Talk Brian Wilson at ILA
5. Talk to Andreas Manhart at Öko Institute
6. Talk to Angela Bandemehr at US EPA
7. Talk to Perry Gottesfeld at OK International
8. Investigate e-waste recycling more closely
9. Investigate lead in tobacco products more closely
10. Investigate lead in ceramics more closely
11. Vet Ericson et al. 2017 more closely
12. Examine the feasibility of corporate campaigns against pigment manufacturers or battery manufacturers

13. Think more explicitly about how much we would upweight the DALY burden and downweight the income burden (or find more considerations that would change our mind on the direction)
14. Search for more burden reduction studies to use for cost-effectiveness analysis
15. Develop a better understanding of the IQ-income relationship in LMICs
16. Have a biologist scrutinize the biomedical literature on lead to confirm that lead is a significant neurotoxin

Conclusion

Although the health hazards of lead exposure have been known for millennia,[37] there is much we do not know about contemporary exposure pathways and how to reduce them. What's clear is that lead exposure is a massive problem: the health impacts and social costs of lead exposure rival other major global issues, such as malaria.[38] Despite a similar scale, lead exposure appears to be much more neglected, with donors spending at least an order of magnitude less on lead exposure than on malaria.[39] The cost effectiveness of interventions to reduce lead exposure has not been investigated as closely as the cost effectiveness of interventions to prevent malaria. However, there do appear to be interventions—such as advocating for lead paint regulations, educating consumers about lead-adulterated products, increasing the formal recycling of lead acid batteries, and cleaning toxic hotspots—that could be cost-competitive with malaria interventions. The value of information of learning more about these interventions and the problem of lead exposure in general appears to be quite high.

[37] The Greek botanist Nicander is said to have identified the toxic properties of lead in the second century BCE.

[38] Malaria's DALY burden is ~46.4 million. The DALY burden from lead exposure is ~21.7 million. Because malaria is a cause and lead exposure is a risk factor, these figures may not, strictly speaking, be comparable. However, lead exposure likely leads to much greater economic losses than malaria, primarily due to reductions in IQ from lead exposure.

[39] See Haakenstad et al. 2019 for an analysis of malaria spending. The headline figure (~$4.3 billion) is not comparable to our lead estimate ($6-10 million), but the paper suggests that a comparable figure for malaria would be in the range of $100 million to $1 billion.

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Appendix 1: How This Report Was Completed

David Rhys Bernard and Jason Schukraft jointly researched and composed this report. We spent about 90 collective hours, divided roughly evenly, on this project. Peter Hurford provided guidance and management. Thanks to Michael Aird, Sara Brosché, Lucia Coulter, Marcus A. Davis, Neil Dullaghan, Holly Elmore, Richard Fuller, Peter Wildeford, and Linchuan Zhang for helpful comments on an earlier draft. Further thanks to Björn Beeler, Sara Brosché Lucia, Coulter, Richard Fuller, Drew McCartor, Rick Nevin, Jack Rafferty, James Snowden, Carol Sumkin, and Dan Wahl for taking the time to speak with us. Open Philanthropy provided funding for this project and we use their general frameworks for evaluating cause areas, but they do not necessarily endorse its conclusions.

Individuals With Whom We Met for This Project

1. Lucia Coulter and Jack Rafferty, co-founders of LEEP
2. Dan Wahl, EA Chicago, professional engineer, and lead exposure hobbyist
3. Rick Nevin, independent economist who studies lead and crime
4. James Snowden, GiveWell
5. Sara Brosché and Björn Beeler, IPEN
6. Richard Fuller, Drew McCartor, and Carol Sumkin, Pure Earth