COMMENTS SUBMITTED TO U.S. ENVIRONMENTAL PROTECTION AGENCY

In Support of Proposed Finding that Lead Emissions from Aircraft Engines that Operate on Leaded Fuel Cause or Contribute to Air Pollution that May Reasonably Be Anticipated to Endanger Public Health and Welfare
Docket EPA–HQ–OAR–2022–0389

Submitted by County of Santa Clara, CA; Bay Area Air Quality Management District; City of Oakland, CA; City and County of San Francisco, CA; City of Santa Monica, CA; Boulder County, CO; City of South Bend, IN; City of Northampton, MA; County of Travis, TX; Town of Middleton, WI; Washtenaw County Prosecutor's Office, WI

January 17, 2023

The undersigned local and regional government agencies hereby submit this public comment in support of the U.S. Environmental Protection Agency's ("EPA") proposed finding that lead emissions from aircraft engines that operate on leaded fuel cause or contribute to air pollution that may reasonably be anticipated to endanger public health and welfare. As agencies charged with protecting the public health, safety, and welfare, we share a serious concern over the continuing and irreversible damage that lead air pollution from leaded aviation gasoline ("avgas") inflicts on our constituents – particularly to the health and development of exposed children, the safety of airport workers, and the welfare of already overburdened airport-adjacent communities. Leaded avgas exposure also burdens public agencies responsible for administering public health, safety, and social safety net services that serve exposed populations, while compromising the safe operation of the many publicly owned airports. Eliminating lead air pollution from avgas nationwide lies within the purview of the EPA and should be treated as an urgent public health and environmental justice priority of this Administration. We commend the EPA on taking this necessary and long overdue step toward regulating lead emissions from piston-engine aircraft and urge it to finalize its proposed endangerment finding with haste.

In its proposed finding, the EPA provides overwhelming evidence that leaded avgas meets the legal requirements for regulation under section 231 of the Clean Air Act: (1) lead air pollution has been known for decades to endanger the public health and welfare, and (2) emissions from leaded avgas, which account for 70% of airborne lead, incontrovertibly cause or contribute to this pollution. These burdens are not evenly distributed. As the EPA documents in its proposed finding, airport-adjacent communities are disproportionately low-income and/or communities of color, and many are already overburdened with other sources of lead exposure. Airports operating in or nearby our jurisdictions illustrate this environmental injustice.

Given the severe and avoidable harm from the continued use of leaded avgas, we also urge the EPA to proceed swiftly to the second phase of this rulemaking and finalize emissions standards that eliminate lead from aviation fuel on a timeline that matches the urgency of the public health crisis. A rapid phaseout of lead from avgas is technologically feasible and can be done safely, without undue cost: The Federal Aviation Administration ("FAA") has already certified a fully unleaded fuel that is safe for use by the entire piston-engine fleet. Urgent action is further compelled by the Biden-Harris Administration's and the EPA's own commitments to advancing environmental justice, including the EPA's recent strategy to reduce lead exposures in communities overburdened by pollution. Moreover, rapidly banning leaded avgas is ethically necessary. In the decades that this endangerment finding has been pending, millions of children nationwide have suffered irreversible harm from unregulated leaded avgas. We ask that the EPA finalize its proposed findings and fulfill its mandate by quickly eliminating this pollutant.

BACKGROUND

The instant rulemaking proceeding has been decades in the making. The environmental advocacy organization Friends of the Earth first formally petitioned the EPA to make an endangerment finding for leaded avgas under section 231(a)(2)(A) of the Clean Air Act in 2006, following an initial request in 2003.[1] The EPA issued an Advance Notice of Proposed Rulemaking in 2010 describing and requesting comment on information to inform a subsequent endangerment finding proposal.[2] In this Notice, the EPA estimated that "up to 16 million people reside and three million children attend school in close proximity to airport facilities servicing piston-engine aircraft that are operating on leaded avgas" and acknowledged its "concern[s] about the potential for health and welfare effects from exposure to lead emission from aircraft engines using gas."[3] Nevertheless, the EPA did not formally respond to the 2006 petition until 2012, after Friends of the Earth filed a lawsuit challenging the EPA's unreasonable delay.[4] In 2015, the EPA announced its plans to issue a proposed endangerment finding for public comment in 2017 and a final endangerment finding in 2018.[5] These deadlines came and went.

In fall 2021, two of the undersigned governmental organizations – the County of Santa Clara, California and the Town of Middleton, Wisconsin – joined a nationwide coalition in petitioning the EPA to follow through on its commitments to make an endangerment finding for

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[1] Friends of the Earth, Pet. for Rulemaking & Collateral Relief (Oct. 3, 2006), https://www.epa.gov/sites/production/files/2016-09/documents/foe-20060929.pdf.
[2] U.S. EPA, Advance Notice of Proposed Rulemaking on Lead Emissions from Piston-Engine Aircraft Using Leaded Aviation Gasoline, 75 Fed. Reg. 22440 (Apr. 28, 2010).
[3] *Id.* at 22442.
[4] *See* Letter and Memorandum from Gina McCarthy, Assistant Administrator, EPA, to Deborah Behles & Helen Kang, Env't L. & Just. Clinic; & Marianna Engelman Lado et al., Earthjustice (July 18, 2012), https://19january2021snapshot.epa.gov/sites/static/files/2016-09/documents/ltr-response-av-ld-petition.pdf.
[5] Letter from Gina McCarthy, Administrator, EPA, to Deborah Behles, Env't L. & Just. Clinic; & Marianna Engelman Lado, Earthjustice (Jan. 23, 2015), https://www.epa.gov/sites/default/files/2016-09/documents/ltr-response-av-ld-foe-psr-oaw-2015-1-23.pdf.

leaded avgas.[6] On January 12, 2022, the EPA wrote to petitioners to inform them that it intended to issue a proposed endangerment finding in 2022, followed by a final endangerment finding in 2023.[7] In March 2022, the County, the Town of Middleton, and seven of the undersigned agencies filed a letter urging the EPA to act swiftly on this rulemaking and documenting the investment of local governmental agencies in expeditious national phaseout of leaded avgas.[8]

As explained in those filings, the nationwide problem of leaded avgas exposure requires an effective nationwide solution. Federal law limits the authority of state and local governments to directly regulate aviation fuel additives: Congress vested the authority and responsibility to set emission standards for air pollution from aircraft and engines in the EPA[9] and the authority to prescribe fuel composition standards to control these emissions in the FAA.[10]

A patchwork of efforts by committed local agencies cannot stand in for federal action. Public airport proprietors that have taken or proposed aggressive action to prevent exposures – such as the County of Santa Clara in banning the sale of leaded avgas at its airports, or the City of Santa Monica in preparing to remove fixed base operators from its airports and take over fueling operations – have been subject to investigation by the FAA or other obstacles. Other public airport proprietors have found it challenging to eliminate lead fuel sales on their own due to difficulties in sourcing unleaded fuels, capital costs for additional fueling infrastructure, and challenges in helping pilots obtain type certifications for fuel switching, among other things.[11] And even if public airport proprietors do eliminate leaded avgas sales at their airports, such action does not prevent airplanes from fueling up with leaded avgas elsewhere and transiting through their airports.

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[6] Alaska Cmty. Action on Toxics et al., Pet. for Rulemaking (Aug. 24, 2021) (updated Oct. 12, 2021), https://www.epa.gov/system/files/documents/2022-01/aviation-leaded-avgas-petition-exhibits-final-2021-10-12.pdf.

[7] Letter and Memorandum from Michael Regan, Administrator, EPA to Jonathan Smith, Earthjustice; Michael Lawton, Boardman & Clark; Deborah Sivas et al., Env't L. Clinic; James Williams & Jerett Yan, Cty. of Santa Clara (Jan. 12, 2022), https://www.epa.gov/system/files/documents/2022-01/ltr-response-aircraft-lead-petitions-aug-oct-2022-01-12.pdf.

[8] Letter of Support for Pet. for Rulemaking from Bay Area Air Quality Mgmt. Dist., City and Cty. of San Francisco, Cal., City of Oakland, Cal., City of Santa Monica, Cal., Cty. of Santa Clara, Cal., Dane Cty. Towns Ass'n, Wis., & Town of Middleton, Wis. to Michael Regan, Administrator, EPA (Mar. 21, 2022), available at https://www.sfcityattorney.org/wp-content/uploads/2022/03/2022-03-21-Section-231-Rulemaking-Public-Agency-Letter-of-Support.pdf.

[9] *See* 42 U.S.C. § 7571.

[10] *See* 49 U.S.C. § 44714.

[11] *See, e.g.*, Transp. Rsch. Bd. et al., *Options for Reducing Lead Emissions from Piston-Engine Aircraft* 3 (Nat'l Acads. of Scis., 2021) [hereinafter "NAS Report"] (explaining that so long as they must also provide a higher-octane leaded fuel, "thousands of small airports would need to invest more than $100,000 in a second avgas storage and dispensing system" to dispense 94 octane unleaded avgas), *id.* at 19 ("[A]ircraft owners interested in switching to unleaded fuels may find this recertification option prohibitively expensive, except in cases where a supplemental [type certificate] is already available at moderate cost."); *id.* at 102 (explaining that "the costs for airports to add storage and distribution facilities for a second fuel could be significant and potentially prohibitive, especially for small airports").

Agencies without proprietary control over general aviation airports have even fewer options, regardless of whether the impacts of lead emissions occur primarily within their jurisdictions. The Town of Middleton, for example, is invested in addressing lead emissions from a general aviation airport operated by the neighboring city, which exposes Town residents to ongoing lead air pollution. Dane County, Wisconsin, where the Town of Middleton is located, has the second highest amount of lead aircraft emissions of the 72 counties in Wisconsin. Thirty-two percent of all airborne lead emissions annually in Dane County are from operation of City of Middleton Municipal Airport – Morey Field ("Morey Airport" or "C29").[12] Due to prevailing westerly winds, at least 70% of aircraft departures from Morey Airport occur over the Town of Middleton and the adjacent Town of Springfield.[13] But the Towns have no authority to limit leaded avgas sales or provide unleaded avgas fueling at the neighboring City airport. And although Swift Fuels has been producing a fully unleaded avgas (94-octane "UL94") since 2015, this unleaded fuel alternative usable by two-thirds of the piston-engine fleet[14] is not sold at Morey Airport. To the contrary, use of UL94 has contracted in Wisconsin in recent years, highlighting the challenges of reducing lead emissions without regulatory standards. According to the Wisconsin Bureau of Aeronautics, "In 2020, UL94 was available at five Wisconsin airports. By the end of 2021, it was only available at two airports each with less than $4,000 gallons [*sic*] sold."[15]

Ultimately, the only way to keep general aviation airports safely operating is through the promulgation of uniform national regulatory standards that quickly eliminate use of leaded avgas.

DISCUSSION

I. The EPA is Correct to Conclude that Leaded Avgas Endangers Public Health and Welfare

The evidence overwhelmingly demonstrates that leaded avgas meets the legal requirements for an endangerment finding. Section 231(a)(2)(A) of the Clean Air Act requires the EPA to issue emission standards to control the emission of any air pollutant from aircraft engines if the EPA determines that the pollutant "causes, or contributes to, air pollution which

[12] Trinity Consultants, *Measurement of Ambient Lead Concentrations Around the Middleton Wisconsin Municipal Airport – Morey Field (C29)* 2-7 (Sept. 15, 2022), available at https://town.middleton.wi.us/vertical/Sites/%7B97A50AAB-3824-4833-ACEA-EF2B9A14C856%7D/uploads/C29_Airport_Lead_Report_091522-3_email.pdf [hereinafter "Morey Airport Lead Study"].
[13] *See* Mead & Hunt, *Middleton Municipal Airport Morey Field (C29) Master Plan* 4-20 to -21 (June 2022), https://www.cityofmiddleton.us/DocumentCenter/View/10416/C29-Master-Plan-Report-without-appendices-2022-07-21?bidId= [hereinafter "C29 Master Plan"] (discussing utilization of Morey Airport's Runway 28).
[14] *See* Swift Fuels, *Frequently Asked Questions*, https://www.swiftfuelsavgas.com/faq (last visited Dec. 28, 2022) (answering "What is UL94 Unleaded Avgas?"); *see also* Section II.A *infra*.
[15] Wis. Bureau of Aeronautics, *2021 Wisconsin Airports Rates and Changes Survey* 10 (June 2022), https://wisconsindot.gov/Documents/doing-bus/aeronautics/resources/rates-chgs.pdf.

may reasonably be anticipated to endanger public health or welfare."[16] This threshold determination – commonly referred to as an "endangerment finding" – requires two showings: (1) that lead air pollution as a whole may reasonably be anticipated to endanger public health or welfare, and (2) that emissions from use of leaded avgas in piston-engine aircraft cause or contribute to this pollution. The EPA provides more than enough evidentiary support for both prongs, and even this understates the evidence for a positive endangerment finding.

A. There is no question that lead air pollution endangers public health and welfare.

Public Health

The EPA has known for decades that lead air pollution and its impacts on communities constitute a public health crisis. Nearly fifty years ago, the EPA recognized lead as a "known toxic substance for which no beneficial biological role" exists and found that airborne lead was contributing to an "epidemic" of "[e]xcessive lead exposures among children."[17] According to the U.S. Centers for Disease Control and Prevention, lead exposure can harm the nervous, cardiovascular, immune, and reproductive systems, damage the kidneys, and cause anemia and increased blood pressure.[18] Moreover, lead avgas emissions are a particularly pernicious source of exposure: Because the lead particles released in aircraft exhaust tend to be significantly smaller in size than those from other sources, they have the "potential of rapidly penetrating the lung defenses" and "gain[ing] direct access to the brain," increasing the potential for neurological and cognitive damage.[19]

Children are particularly vulnerable to lead, both as a result of behaviors that make them more susceptible to exposure and their greater sensitivity to lead toxicity.[20] Even at the lowest detectable levels, childhood exposure to lead may cause cognitive and intellectual impairment, harm academic performance, and increase risk for attention and behavioral disorders.[21] Indeed,

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[16] 42 U.S.C. § 7571(a)(2)(A).
[17] U.S. EPA, *EPA's Position on the Health Effects of Airborne Lead* at VII, VII-4 (Nov. 29, 1972), available at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9100EYMW.TXT; *see also*, *e.g.*, Prohibition on Gasoline Containing Lead or Lead Additives for Highway Use, 61 Fed. Reg. 3832, 3833 (Feb. 2, 1996) (recognizing that leaded fuel poses "a significant risk of harm to the health of urban populations, especially children").
[18] Agency for Toxic Substances and Disease Registry, *Lead – ToxFAQs* (2020), available at https://www.atsdr.cdc.gov/toxfaqs/tfacts13.pdf.
[19] NAS Report, *supra* note 11, at 56; *see also* Ex. A, Decl. of Bruce Lanphear [hereinafter "Lanphear Decl."] ¶ 14 (attesting that "small particles of lead" from aircraft emissions "are readily absorbed and may be transported directly to the brain via the olfactory nerve").
[20] *See, e.g.*, NAS Report, *supra* note 11, at 49.
[21] Mountain Data Grp., *Leaded Aviation Gasoline Exposure Risk at Reid-Hillview Airport in Santa Clara County, California* 1 (2021), available at https://news.sccgov.org/sites/g/files/exjcpb956/files/documents/RHV-Airborne-Lead-Study-Report.pdf [hereinafter "RHV Lead Exposure Report"]; Lanphear Decl. ¶ 7 (attesting that "[d]ozens of studies show that exceedingly low levels of lead adversely impact children's cognitive abilities and neurodevelopment"); *id.* ¶ 9 (attesting that "[l]ead also increases the risk of children developing attention and behavior disorders such as ADHD").

decline in cognitive ability is steepest at lower blood lead levels.[22] The EPA's 2013 Integrated Science Assessment for Lead unambiguously finds "no evidence of a threshold below which there are no harmful effects on cognition from lead exposure."[23]

Many of the harms caused by childhood lead exposure are irreversible. Childhood lead exposure, for instance, has been linked to measurable reductions in IQ and cognitive and behavioral impairments persisting into adulthood, as well as adult-onset physical health problems.[24] As the EPA notes, when a large share of a population is exposed – as is the case for airport-adjacent communities exposed to lead emissions from piston-engine aircraft – even small shifts in IQ are associated with significant public health harm.[25]

Lead also threatens maternal health and birth outcomes.[26] Lead is a risk factor for preeclampsia, a disorder of severe hypertension in pregnant women.[27] Lead exposure also increases the likelihood of preterm births[28] and fetuses that are small for their gestational age.[29] Additionally, exceedingly low levels of lead can diminish male fertility and delay conception.[30]

Lead is also a risk to the cardiovascular health of exposed adults. Cardiovascular effects such as hypertension and elevated blood pressure can occur at relatively low levels of lead exposure, causing great public health concern.[31] Additionally, lead is a causal risk factor for coronary heart disease – the number one cause of death worldwide.[32] A national study identified

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[22] RHV Lead Exposure Report, *supra* note 21, at 2-3; *see id.* at 1 (explaining that "estimated marginal effects with respect to negative cognitive and behavioral outcomes in lead-exposed children are higher at lower [blood lead levels]"); Lanphear, *Childhood Lead Poisoning Preventing: Too Little, Too Late*, 293 J. of the Am. Med. Ass'n 2274 (2005).
[23] U.S. EPA, *Integrated Science Assessment for Lead* lxxxvii-lxxxviii (2013) [hereinafter "ISA for Lead"].
[24] *See*, *e.g.*, RHV Lead Exposure Report, *supra* note 21, at 2; Reuben et. al., *Association of Childhood Blood Lead Levels with Cognitive Function and Socioeconomic Status at Age 38 Years and With IQ Change and Socioeconomic Mobility Between Childhood and Adulthood*, 317(12) J. of the Am. Med. Ass'n 1244 (2017); McFarland et al., *Half of US Population Exposed to Adverse Lead Levels in Early Childhood*, 119(11) Proceedings of the Nat'l Acad. Of Scis. 1 (2022) (concluding that average lead-linked loss in cognitive ability was 2.6 IQ points per person as of 2015 as a result of early childhood lead exposure); Lanphear Decl. ¶ 8.
[25] ISA for Lead, *supra* note 23, at xciii.
[26] Lanphear Decl. ¶¶ 10-11.
[27] *See* Poropat et al., *Blood lead and preeclampsia: A meta-analysis and review of implications*, 160 Env't Rsch. 12 (2018).
[28] *See* Taylor et al., *Adverse effects of maternal lead levels on birth outcomes in the ALSPAC study: A prospective birth cohort study*, British J. of Obstetrics and Gynecology 322 (2014); Li et al., *Maternal serum lead level during pregnancy is positively correlated with risk of preterm birth in a Chinese population*, 227 Env't Pollution 227 484 (2017); Vigeh et al., *Blood lead at currently acceptable levels may cause preterm labour*, 68 Occupational & Env't Med. 231 (2011).
[29] *See* Bui et al., *Does short-term, airborne lead exposure during pregnancy affect birth outcomes? Quasi-experimental evidence from NASCAR's deleading policy*, 166 Env't Int'l 1 (2022).
[30] *See* Buck Louis et al., *Heavy metals and couple fecundity: The LIFE Study*, 87 Chemosphere 1201 (2012).
[31] ISA for Lead, *supra* note 23, at xciii.
[32] *Id.* at 1-68.

lead as *the* leading risk factor for deaths from coronary heart disease, accounting for 185,000 deaths every year.[33]

In addition to the well-documented health impacts of lead exposure to airport-adjacent communities, leaded avgas also puts airport workers at risk.[34] Though relatively little research has been done on the impacts of leaded avgas on airport workers, the proximity and duration of these workers to aircraft during takeoff – when nearly half of lead emissions from piston-engine aircraft occur[35] – suggest they face heightened risks of exposure. A peer-reviewed study of aircraft maintenance workers in Korea found that workers had significantly higher blood lead levels at air bases where leaded avgas was used compared to those where jet fuel was used. Workers' blood lead levels also increased with time spent near runways where leaded avgas was used.[36]

Public Welfare

Though the EPA presents leaded avgas primarily as a danger to public health, the societal costs of this lead exposure also do profound harm to the public welfare. Clean Air Act section 302(h) defines "welfare" to include "effects on economic values and on personal comfort and well-being, whether caused by transformation, conversion, or combination with other air pollutants."[37] The economic costs of lead exposure are immense. Researchers have conservatively estimated that exposure to lead from all sources among children aged six and younger results in total nationwide costs of $192-270 billion for each cohort of lead poisoned children, divided between lost lifetime earnings ($165-233 billion) and related lost tax revenue ($25-35 billion), direct medical treatment costs for lead poisoning ($11-53 billion), special education costs ($30-146 million), costs of lead-linked ADHD cases ($267 million annually), and direct costs of lead-linked criminal activity ($1.7 billion).[38] In 2012, Oakland's Office of Planning, Building & Neighborhood Preservation estimated that medical services, special education, disabilities, and lost wages due to lead poisoning cost city residents upwards of $150 million each year.[39]

The actual economic and non-economic damage to public welfare far exceeds these costs. These conservative estimates exclude the costs of treatment of secondary health harms caused by

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[33] Lanphear Decl. ¶ 13; Lanphear et al., *Low-level lead exposure and mortality in US adults: a population-based cohort study*, 3 Lancet Public Health e177, e181 (2018).
[34] NAS Report, *supra* note 11, at 60.
[35] *See* Endangerment Finding, 87 Fed. Reg. at 62761.
[36] Park et al., *Blood Lead Level and Types of Aviation Fuel in Aircraft Maintenance Crew*, 84 Aviation, Space, & Env't. Med. 1087, 1088-89 (2013).
[37] 42 U.S.C. § 7602(h).
[38] Gould, *Childhood Lead Poisoning: Conservative Estimates of the Social and Economic Benefits of Lead Hazard Control*, 117 Env't Health Perspectives 1162, 1162 (July 2009).
[39] Tobias, *Racial Equity Impact Analysis: Eliminating Lead Paint Hazards in Oakland & Alameda County* 11 (2021), available at https://cao-94612.s3.amazonaws.com/documents/Lead-Paint-REIA_9-23-21_FINAL.pdf.

lead, neonatal mortality, loss in property value, and other indirect costs.[40] They also underestimate total societal costs by excluding impacts of lead exposure on older children and adults and by omitting consideration of indirect impacts of exposure on those who care for, are cared for by, or live or work alongside lead-exposed individuals or are otherwise indirectly affected through the diversion of resources.[41] Other significant sources of non-economic harms – including the emotional and psychological harms of lead exposure – need to be accounted for as well.

Lead exposure from piston-engine aircraft contributes to these immense societal costs. Studies have conservatively estimated costs of $1 billion nationwide each year, accounting only for lost lifetime earnings due to IQ decreases resulting from leaded avgas exposures to young children.[42] Adding in healthcare costs, special education costs, behavior and crime control costs, costs associated with adult and worker exposures, and other direct and indirect costs would significantly increase this estimate.[43]

While these societal costs are borne most heavily by affected communities, they also impair the ability of public agencies to fulfill our core duties of protecting the health, welfare, and safety of our constituents. The societal costs of lead air pollution ripple through social safety net systems administered by public agencies, burdening our services and forcing us to divert resources from other efforts. The most directly impacted public systems include public health systems and government-run hospitals. State and local governments are at the frontline of public health protection, operating 19% of the nation's community hospitals[44] and performing the bulk of public health activities nationwide. These public health and hospital systems expend resources to screen children for elevated blood lead levels, identify and prevent sources of exposure, and manage cases when children are identified as having elevated blood lead levels. In addition to direct treatment of lead-poisoned individuals, screening and treatment for the many secondary harms that lead poses – including harms to cardiovascular health, immune system and kidney function, reproductive system function, and cognition – consume staffing attention and resources.

Lead exposure also imposes costs on school systems, special education services, policing, and crime control infrastructure while reducing the tax revenue available to support these systems. In particular, public agencies operate childcare and public school systems, where

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[40] Gould, *supra* note 38, at 1166.
[41] *See, e.g.*, Gazze et al., *The Long-Run Spillover Effects of Pollution: How Exposure to Lead Affects Everyone in the Classroom*, Nat'l. Bureau of Econ. Rsch. Working Paper No. 28782 (May 2021) (finding that having more lead-exposed peers is associated with reduced academic outcomes).
[42] Zahran et. al., *The Effect of Leaded Aviation Gasoline on Blood Lead in Children*, 4(2) J. of the Ass'n of Env't & Res. Economists 575, 605 n.17 (2017); Wolfe et. al., *Costs of IQ Loss from Leaded Aviation Gasoline Emissions*, 50(17) Env't Sci. & Tech. 9026 (2016).
[43] Zahran et al., *supra* note 42, at 604; Wolfe et al., *supra* note 42, at 9031; RHV Lead Exposure Report, *supra* note 21, at 7.
[44] Am. Hosp. Ass'n, *Fast Facts on U.S. Hospitals* (2022), https://www.aha.org/statistics/fast-facts-us-hospitals.

behavioral and learning challenges resulting from lead exposures necessitate increased investment in special education services and divert resources from other needs.[45] Behavioral effects of lead exposure also have consequences for crime levels, which in turn tax public safety systems.[46] For instance, empirical analysis suggests that the reduction in childhood lead exposure caused by the removal of lead from gasoline in the 1970s was the most significant driver of the drop in violent crime during the 1990s.[47] Meanwhile, reduction in lifetime earnings attributable to lead exposures results in lost tax revenues for state and local governments.[48] While the specific contribution of avgas to these socialized costs may be incremental, it stands out as particularly egregious given the complete absence of federal regulation of this major ongoing source of lead pollution.

Lead air pollution from avgas even compromises the ability of public agencies to operate their general aviation airports and the services those airports provide. In addition to hosting commercial and private flights and pilot trainings, many general aviation airports provide critical functions such as emergency medical transport and wildfire response. These services cannot be provided without putting airport workers, their families, and airport adjacent communities at undue risk while leaded fuel continues to be used.[49] In addition to compromising the ability of airports to safely provide these services, exposures to airport workers may result in healthcare costs, workers' compensation costs, and other benefits payouts.[50]

B. Leaded avgas more than contributes to harmful lead air pollution.

Under section 231 of the Clean Air Act, a pollution source need not be a "major" source of dangerous air pollution nor even make a "significant" contribution to it to satisfy the cause or contribute prong of the endangerment determination.[51] As the single largest source of lead air pollution in recent years, leaded avgas far exceeds this threshold. Leaded avgas is used by between 170,000[52] and 220,000[53] piston-engine aircraft operating out of 20,000 airports spread across the country. The percentage of the U.S. lead air pollution inventory coming from piston-engine aircraft emissions has grown steadily, increasing from 59% in 2008 to a staggering 70%

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[45] *See* Gould, *supra* note 38, at 1164-65.
[46] *Id.* at 1165.
[47] *See* Wolpaw Reyes, *Environmental Policy as Social Policy? The Impact of Childhood Lead Exposure on Crime*, Nat'l. Bureau of Econ. Rsch. Working Paper No. 13097 (May 2007).
[48] Gould, *supra* note 38, at 1164.
[49] *See* NAS Report, *supra* note 11, at 60, 63-67 (explaining that airport workers may be directly exposed to dispensed or spilled fuels and may take it home to their households on their clothes).
[50] *See* Levin, *The Attributable Annual Health Costs of U.S. Occupational Lead Poisoning*, 22 Int'l J. of Occupational & Env't Health 107 (2016).
[51] Endangerment Finding, 87 Fed. Reg. at 62774 (citing 81 Fed. Reg. at 54438 (Aug. 15, 2016)).
[52] *Id.* at 62759.
[53] Eliminate Aviation Gasoline Lead Emissions (EAGLE), *What do I need to know about EPA's Proposed Endangerment Finding for Lead Emissions from Piston Aircraft?*, FAA at 1 (Oct. 13, 2022).

of all lead air emissions in the nation in 2017, when piston-engine aircraft emitted approximately 470 tons of lead.[54]

The EPA itself has repeatedly recognized the significant contribution of avgas to harmful levels of lead air pollution. In its 2020 study of airborne lead concentrations at U.S. airports, the EPA concluded that general aviation airport operations increase lead air concentrations, particularly in downwind areas.[55] The EPA's study also identified a subset of airports where the lead emissions might potentially be violating national ambient air quality standards.[56]

Data from our own communities bolster this conclusion. A report commissioned by the Town of Middleton, Wisconsin confirms that the use of leaded avgas by piston-engine aircraft spreads breathable airborne lead particles over nearby communities.[57] The Town of Middleton is located next to Morey Airport (C29), operated by the neighboring City of Middleton. Areas around and in the immediate vicinity of Morey Airport are highly developed with residences, schools, playgrounds, and athletic fields. The report found elevated lead levels around Morey Airport attributable to local aircraft operations, with the highest concentrations of lead in downwind areas and near the part of the runway where engine runup generally occurs.[58] The area just east of the airport, which is subject to the heaviest airborne lead pollution due to prevailing winds, is home to multi-unit housing, including a significant amount of the City of Middleton's affordable housing – raising environmental justice concerns.

The Town of Middleton also recently commissioned a government water quality sampling study of areas near Morey Airport due to concerns about potential drinking water contamination, as all residential areas in the Town rely on the use of private wells for drinking water. Two of six residential private drinking water wells sampled in this study tested positive for the isotopic fingerprint for Morey Airport leaded avgas.[59] In 2022, the City of Middleton

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[54] Endangerment Finding, 87 Fed. Reg. at 62761.
[55] *See* U.S. EPA, *Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports* 3 (Feb. 2020), available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YG52.pdf. The EPA also acknowledged that, by considering only airborne lead, its model was scoped conservatively. To reflect the full range of exposures to leaded avgas among populations near airports, the analysis would need to account for potential exposures to emitted lead particles that settle in nearby water and soil. *Id.* at 5.
[56] *Id.* at 3, 53 (Table 6).
[57] Morey Airport Lead Study, *supra* note 12. Trinity Consultants conducted ambient air sampling to measure actual ambient lead concentrations at selected locations around Morey Airport. This report builds off a previous study commissioned by the Town of Middleton, in which Trinity Consultants and Oak Leaf Environmental modeled ambient air quality using EPA's AERMOD model to evaluate ambient concentrations of lead in the air around Morey Airport based on assumptions regarding the lead content of the fuel being used, flight patterns and airport activity.
[58] Morey Airport Lead Study, *supra* note 12, at 2-4.
[59] U.S. Geological Survey Presentation, Town of Middleton Board Meeting Agenda Item #5, *Concentrations of Perchlorate, Metals, GRO, Hydrocarbons, and BTEX Compounds in Surface Water, Groundwater, and Soil Near Morey Airport* (Dec. 19, 2022), available at https://middleton.civicweb.net/Portal/MeetingInformation.aspx?Org=Cal&Id=467.

adopted an Airport Master Plan for significant expansion of the airport, amplifying concerns about potential contamination. [60]

In a recent published study of Reid-Hillview Airport in East San José, a community in Santa Clara County, California,[61] researchers found that children residing within a half-mile of the airport have higher blood lead levels compared to statistically similar children more distant from the airport.[62] The effects compound when accounting for intensity of aircraft traffic and wind patterns. For instance, an increase in piston-engine aircraft traffic from minimum levels to maximum levels caused blood lead levels of children proximate to RHV to increase by 0.92 µg/dL in children living within a half-mile of the airport – more than double the increase in blood lead levels at the peak of the Flint Water Crisis.[63] On the whole, children living downwind (east) of the airport were at the greatest risk, with blood lead levels that were, on average, 0.237 µg/dL higher than blood lead levels of sampled children living north of the airport.[64] Indeed, children living downwind of the airport were, all else held equal, 2.18 times more likely than children residing upwind of the airport to have a blood lead level equal to or greater than 4.5 µg/dL – the threshold for action used by the California Department of Public Health in assessing elevated blood lead.[65] Even commuting toward Reid-Hillview Airport for school was found to put children at significant risk.[66] Accounting only for impacts of elevated blood lead levels on IQ, these exposures translate to a net lifetime earnings loss of $11-24.9 million for the cohort of children residing within 1.5 miles of the airport.[67]

Moreover, the EPA cited multiple studies specifically linking lead emissions from piston-engine aircraft to severe health effects: two finding elevated blood lead levels in children

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[60] *See* C29 Master Plan, *supra* note 13.

[61] Ex. C, Zahran et al., *Leaded Aviation Gasoline Exposure Risk and Child Blood Lead Levels*, 2 PNAS Nexus 1 (2022) [hereinafter "RHV Lead Study Publication"]. The full August 3, 2021 report by Mountain Data Group, *Leaded Aviation Gasoline Exposure Risk at Reid-Hillview Airport in Santa Clara County, California*, was peer-reviewed by two external experts: Dr. Rebecca Anthopolos, an Assistant Professor in the Division of Biostatistics within the Department of Population Health at New York University Grossman School of Medicine, who has published on the risk of early childhood lead exposure in relation to aviation gasoline, and Dr. Mark Cullen, a retired professor of Medicine, Epidemiology, and Biomedical Data Sciences at Stanford University, where he served as the Founding Director of the Center for Population Health Sciences and as Senior Associate Dean for Research for the School of Medicine. *See* RHV Lead Exposure Report, *supra* note 21.

[62] RHV Lead Study Publication, *supra* note 61, at 3 (finding that children within 0.5 miles of the airport have blood lead levels that are about 0.2 µg/dL higher than statistically similar children more distant from the airport); *id.* (reporting that "no matter the measurement of transformation . . . child BLLs decrease statistically significantly with residential distance from RHV"); *see also* RHV Lead Exposure Report, *supra* note 21, at 37.

[63] RHV Lead Study Publication, *supra* note 61, at 4; *see also id.* at 3 (reporting that "[a]t the height of the [Flint Water Crisis], child BLLs surged by an estimated 0.35 to 0.45 µg/dL over baseline levels").

[64] *Id.* at 3.

[65] *Id.* at 3, 5.

[66] RHV Lead Exposure Report, *supra* note 21, at xvii, 65-72 (finding that children who commute to school by traveling one mile towards Reid-Hillview Airport from their place of residence have predicted blood lead levels 0.65 µg/dL higher than children who commute one mile away from the airport).

[67] *Id.* at xviii, 79.

residing or attending school in close proximity to general aviation airports,[68] and one finding higher cardiovascular mortality rates in adults 65 and older living near single-runway airports in years with more piston-engine air traffic.[69]

This harm is avoidable. Researchers also found that blood lead levels in children residing near Reid-Hillview Airport tracked the contraction in piston-engine aircraft activity during the period of heightened COVID-19 restrictions. During the period from February to July 2020 when piston-engine aircraft traffic declined by 34 to 44%, children residing near the airport presented with blood lead levels that were about 0.23 µg/dL lower than among children sampled outside this contraction window.[70] Eliminating lead from avgas would immediately remove a significant and ongoing source of lead exposures for this uniquely vulnerable subpopulation.[71] Indeed, the authors of the published RHV lead study determined that the results "support[] the [EPA's] conclusion that emissions from [piston-engine aircraft] traffic independently contribute to child [blood lead levels], potentially endangering the health and welfare of populations residing near over 21,000 general aviation airports that service avgas-consuming aircraft."[72]

Evidence of the public health and welfare risks of lead air pollution were sufficient to merit regulation 50 years ago, when the EPA issued the first lead reduction standards for automobile fuel. Finding otherwise here – in the face of evidence directly linking leaded avgas to lead air pollution and elevated blood lead levels – would defy logic. With approximately 5.2 million people living within 500 meters of an airport runway, 363,000 of whom are children aged five and under,[73] there can be no reasonable dispute that this harmful pollutant endangers public health and welfare.

C. Children, people of color, and low-income communities bear the brunt of lead air pollution from leaded avgas.

Eliminating lead exposures from leaded avgas should be an environmental justice and children's health priority of this Administration. The EPA defines environmental justice as the "fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies."[74] Fair treatment means that "no group of people

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[68] *See* Miranda et al., *A Geospatial Analysis of the Effects of Aviation Gasoline on Childhood Blood Lead Levels*, Env't Health Perspectives 1513 (2011); Zahran et al., *supra* note 42.
[69] *See* Klemick et al., *Cardiovascular Mortality and Leaded Aviation Fuel: Evidence from Piston-Engine Air Traffic in North Carolina*, Int'l J. of Env't Rsch. and Pub. Health (2022).
[70] RHV Lead Study Publication, *supra* note 61, at 4.
[71] *See* Finding That Greenhouse Gas Emissions From Aircraft Cause or Contribute to Air Pollution That May Reasonably Be Anticipated To Endanger Public Health and Welfare, 74 Fed. Reg. 66495, 66506 ("If vulnerable subpopulations are especially at risk, the [EPA] Administrator is entitled to take that point into account in deciding the question of endangerment.").
[72] RHV Lead Study Publication, *supra* note 61, at 2.
[73] Endangerment Finding, 87 Fed. Reg. at 62768.
[74] *Id.* at 62756.

should bear a disproportionate burden of environmental harms and risks, including those resulting from the negative environmental consequences of industrial, governmental and commercial operations or programs and policies."[75] For over thirty years, executive policy has directed federal agencies including the EPA to make achieving environmental justice part of their mission to the greatest extent possible by addressing disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on people of color and low-income communities.[76] The Biden-Harris Administration reaffirmed this commitment and made securing environmental justice for disadvantaged communities that have been historically marginalized and overburdened by pollution a policy priority.[77] Executive policy also directs agencies to identify and address health and safety risks that disproportionately affect children.[78]

The EPA has recently affirmed that reducing exposures to lead nationwide, and in high-risk communities in particular, is key to fulfilling these policy commitments. In October 2022, the EPA released its *Strategy to Reduce Lead Exposures and Disparities in U.S. Communities* ("Lead Strategy"),[79] building on the 2018 *Federal Action Plan to Reduce Childhood Lead Exposures and Associated Health Impacts*.[80] The Lead Strategy recognizes that low-income communities and communities of color suffer the most from lead exposure and identifies the EPA's work to reduce exposure inequities as responsive to the Biden-Harris Administration's day-one commitment to advancing environmental justice and equity.[81] The EPA specifically identified addressing lead emissions from use of leaded avgas as an important component of its Lead Strategy.[82]

The proposed endangerment finding recognizes the environmental justice and children's health dimensions of lead exposure from leaded avgas, providing evidence that children, communities of color, and low-income communities are disproportionately at risk. The EPA analyzed the demographic makeup of airport-adjacent communities within one kilometer of a general aviation airport compared to that of non-adjacent communities one to five kilometers from that airport. The EPA chose the one-kilometer area because of the likelihood of elevated lead levels from combustion of leaded avgas within this radius.[83] The results are striking. Of the 2,022 airports included in the EPA's analysis, 25% had a greater prevalence of children under

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[75] *Id.* at 62756 n.11.
[76] *See* Exec. Order No. 12898, *Federal Action to Address Environmental Justice in Minority Populations and Low-Income Populations*, 59 FR 7629 (Feb. 16, 1994).
[77] *See* Exec. Order No. 14008, *Tackling the Climate Crisis at Home and Abroad*, 86 FR 7619 (Feb. 1, 2021).
[78] *See* Exec. Order No. 13045, *Protection of Children from Environmental Health Risks and Safety Risks*, 62 FR 19885 (Apr. 23, 1997).
[79] U.S. EPA, *Strategy to Reduce Lead Exposures and Disparities in U.S. Communities* (Oct. 2022) [hereinafter "EPA Lead Strategy"].
[80] President's Task Force on Environmental Health Risks and Safety Risks to Children, *Federal Action Plan to Reduce Childhood Lead Exposures and Associated Health Impacts* (Dec. 2018).
[81] EPA Lead Strategy, *supra* note 79, at 3.
[82] *Id.* at 37-38.
[83] Endangerment Finding, 87 Fed. Reg. at 62768.

five in the airport-adjacent community compared to the non-adjacent community, 33% had a greater prevalence of people of color in the airport-adjacent community, and 38% had a greater prevalence of people with incomes below two-times the Federal Poverty Level in the airport-adjacent community.[84] The magnitude of racial and socioeconomic disparities between airport-adjacent and non-adjacent communities was large for many of these airports. Of the 666 airports with racial and ethnic disparities, 123 had disparities of 10-20% and 40 had disparities of 20%+, with the highest percent difference in the people of color population between airport-adjacent and nearby communities ranging up to 45%. Likewise, of the 761 airports with socioeconomic disparities, 180 had disparities of 10-20% and 51 had disparities of 20%+, with the highest percent difference in the low-income population between airport-adjacent and non-adjacent communities ranging up to 42%.[85]

If anything, the EPA's analysis understates the environmental justice implications of leaded avgas exposure. The airports raising the most serious public health and welfare concerns are those that are high lead-emitting and those located in densely populated areas. The racial and socioeconomic disparities in these highly exposed communities are especially pronounced. The Stanford Regulation, Evaluation, and Governance Lab analyzed the demographics of all communities living within one kilometer of 2,809 general aviation airports in the U.S. using the latest available Census data.[86] In all, at least 2.4 million people (7 out of every 1,000 Americans) live within one kilometer of these general aviation airports.[87] Communities adjacent to airports in the top quartile by lead emission and population density have 5.0 to 7.4 percentage points more residents of color than the country as a whole.[88]

Disparities are particularly apparent for airports that account for an outsized proportion of total airport lead emissions and/or at-risk residents. The top 350 lead-emitting airports generate more than half of all general aviation airport lead emissions.[89] For the population living within one kilometer of these high-emitting airports, 52.9% of residents are persons of color compared to 42.2% of the national population.[90] Compared to the nation at large, the 700,000 people living within one kilometer of these highest lead-emitting airports are 1.3 times more likely to be people of color, 1.5 times more likely to be Hispanic or Latino, 1.6 times more likely to be Asian, and 2.5 times more likely to be Native Hawaiian and Pacific Islander.[91] Likewise, only 121 airports account for half of all persons living within one kilometer of an airport with general aviation activities; 52.3% of residents living within one kilometer of these high-density airports are persons of color.[92] For the 35 airports that are in the top 5% by lead emission and by density

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[84] *Id.* at 62770.
[85] *Id.*
[86] *See* Ex. B, Decl. of Derek Ouyang [hereinafter "Ouyang Decl."].
[87] *Id.* ¶ 17.
[88] *Id.* ¶ 28.
[89] *Id.* ¶ 13.
[90] *Id.* ¶ 29.
[91] *Id.* ¶ 24.
[92] *Id.* ¶ 24 (Table 8).

of adjacent communities, 67.7% of residents living within one kilometer are persons of color, making residents of these airport-adjacent populations 1.6 times more likely to be persons of color than in the rest of the country.[93] Further, 65.7% of these highest-emitting and highest-density airports have disproportionately more residents of color in their vicinity compared to their surrounding county, and 71.4% have disproportionately more lower-income households in their vicinity compared to their surrounding county.[94]

In addition, roughly 60% of households in communities adjacent to airports in the top quartile by lead emissions and population density are more likely than their surrounding county to have incomes below the national median.[95] These airports are generally located in counties that have a higher income than the U.S. as a whole.[96] The effect of this disparity is that these lower-income residents in wealthier counties living near general aviation airports are less able to escape the risks of lead exposure because their income levels make other housing options unavailable.

Airports in and around our jurisdictions reflect these disparities. Reid-Hillview Airport is again illustrative. The 35th highest lead-emitting airport in the nation, Reid-Hillview's ratio of lead emissions per person living within a one-mile radius is the third-highest ratio in the nation, and is over ten times the median.[97] Over 52,000 people reside within 1.5 miles of Reid-Hillview Airport,[98] including nearly 13,000 children.[99] There are also 21 schools and childcare centers in this radius.[100] Located in the densely populated urban core of East San José, in the heart of Silicon Valley, the airport is situated in one of the most nonwhite and lowest-income locations in the region. In an American Community Survey, 93% of respondents living within 1.5 miles of the airport identified as Latino/Hispanic or Asian; in the neighborhoods immediately abutting the airport, 99.3% of residents identified as a race other than white.[101] Nearly 80% speak a primary language other than English at home. In the four zip codes closest to the airport, 27% of residents live below 200% of the Federal Poverty Line compared to 16% for the remainder of the county.[102] Residents in these zip codes experience higher rates of diseases like cancer, Alzheimer's, stroke, and diabetes than elsewhere in the county.[103] They also face a

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[93] *Id.*
[94] *Id.* ¶ 25.
[95] *Id.* ¶ 27.
[96] *Id.*
[97] Analysis based on data from EPA's National Emissions Inventory and EJScreen.
[98] County of Santa Clara, Report of the County Executive to Board of Supervisors, Report No. 107018 at 14 (approved as amended Aug. 17, 2021), http://sccgov.iqm2.com/Citizens/Detail_LegiFile.aspx?Frame=&MeetingID=13226&MediaPosition=&ID=107018&CssClass= [hereinafter "SCC Report No. 107018"].
[99] *See* RHV Lead Exposure Report, *supra* note 21, at 79 (Table 12, Column A cohort of potentially affected children).
[100] SCC Report No. 107108, *supra* note 98, at 1.
[101] *Id.* at 9-10.
[102] *Id.* at 11.
[103] *Id.* at 13.

disproportionate burden of other sources of lead hazards, such as lead risk from housing.[104] As discussed above, elevated blood lead levels from leaded avgas exacerbate these burdens.[105]

The compounding nature of environmental health burdens borne by airport-adjacent communities is not unique to Reid-Hillview. As the EPA recognized, environmental hazards such as air pollution disproportionately burden communities of color and low-income communities, including those located near transportation sources.[106] Airports themselves are a source of a range of air pollutants, including from aircraft exhaust, airport ground-service equipment, and other airport operations.[107]

For many airport-adjacent communities, the harms from leaded avgas exposure also layer on top of an outsized share of exposures to other sources of lead. For instance, a study of 448 airports in Michigan reported that the percentage of homes presumed by their age to contain lead-based paint was almost twice as high in neighborhoods proximate to airports compared to neighborhoods more distant from airports.[108] In other words, those children most at risk of leaded avgas exposure are also among those at highest risk of lead-based paint exposure.

Many airport-adjacent communities are particularly vulnerable to impacts from these cumulative exposures due to poverty, health characteristics, housing burden, linguistic isolation, age, and other factors. A published study documented that children living near general aviation airports across the state of Michigan were disproportionately likely to live in households receiving public assistance.[109] In the City of Oakland, the neighborhood surrounding the Oakland International Airport suffers from a variety of environmental hazards, such as poor air or water quality, as well as socioeconomic limitations, such as lack of access to healthcare or linguistic isolation.[110] Over 80% of the residents of this neighborhood are Black or Latinx.[111] In this way, the health impacts of lead exposure from avgas compound risks from other sources of air pollution, lead hazards, and socioeconomic vulnerabilities.

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[104] *See* CalEnviroScreen 4.0: Children's Lead Risk from Housing, available at https://oehha.maps.arcgis.com/apps/instant/sidebar/index.html?appid=6c2ec624cea84b66a95412117da4977a.
[105] *See generally*, RHV Lead Study Publication, *supra* note 61.
[106] Endangerment Finding, 87 Fed. Reg. at 62767.
[107] *See* Masiol & Harrison, *Aircraft Engine Exhaust Emissions and Other Airport-Related Contribution to Ambient Air Pollution: A Review*, 95 Atmospheric Env't 409 (2014); *cf.* Bendtsen, *A Review of Health Effects Associated with Exposure to Jet Engine Emissions in and Around Airports*, 20 Env't Health 10 (2021) (concluding proximity of residential areas to airports with jet engine traffic was associated with increased risk of disease, increased hospital admission, and self-reported lung symptoms).
[108] Zahran et al., *supra* note 42, at 576.
[109] Lanphear Decl. ¶ 16.
[110] Tobias, *supra* note 39, at 52-54.
[111] *Id.* at 57.

D. The EPA should finalize this endangerment finding early in 2023

This status quo of public health crises and environmental injustices posed by leaded avgas will persist and worsen without federal action. The EPA acknowledges that, without controls, lead emissions from piston-engine aircraft are likely to continue to be an important source of lead air pollution.[112] Indeed, the EPA's projections of piston-engine aircraft activities out to 2045 predict that the number of airports with lead emissions ≥ 0.1 tons will *increase* from 638 to 656.[113] Air lead concentrations may approach or potentially exceed the current National Ambient Air Quality Standards for lead ("lead NAAQS") at these levels.[114] While air lead concentrations exceeding the NAAQS are a particular concern, airport lead emissions are detrimental regardless of whether they cause exceedances of the lead NAAQS. The lead NAAQS have been criticized for being insufficiently protective of human health and may miss a significant channel of airborne lead exposure from the 20% of leaded avgas exhaust emitted in the readily inhalable vapor phase.[115] Moreover, lead pollution is unsafe and can cause significant and irreversible damage to human health at any level of exposure, with incremental harms to cognition most severe at lower exposure levels.

To stave off a worsening crisis, the EPA must finalize this endangerment finding in accordance with promised timelines and take expedient action to eliminate this harmful source of lead air pollution. The EPA has announced plans to issue any final endangerment finding in 2023. The Agency should adhere to this timeline and finalize the leaded avgas endangerment finding as early in 2023 as possible. Previous regulatory timelines indicate that a finalized finding in the first half of 2023 is more than feasible, and it should certainly be so in this case given the irrefutable and extensive evidence establishing each of the endangerment finding factors. When the EPA undertook an endangerment finding rulemaking for greenhouse gases, it issued the final finding just over six months after the end of the 60-day comment period – during which over 380,000 public comments were submitted.[116] This rulemaking is very unlikely to receive comparable public participation, given the highly charged nature of greenhouse gas emissions regulation in the wake of the Supreme Court's decision in *Massachusetts v. EPA*, 549 U.S. 497 (2007). There is no reason that the EPA should not significantly outpace that timeline and finalize the endangerment finding months earlier than July 2023.

II. Bold Federal Action is Needed to Solve the Leaded Avgas Problem

While finalizing the leaded avgas endangerment finding is a necessary step toward regulating this last remaining leaded transportation fuel, harmful lead exposures will continue

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[112] Endangerment Finding, 87 Fed. Reg. at 62780.
[113] *Id.* at 62760.
[114] *Id.* at 62764.
[115] *See* Lanphear Decl. ¶ 14.
[116] U.S. EPA, *Timeline of EPA's Endangerment Finding*, U.S. Env't Protection Agency, available at https://www.epa.gov/climate-change/greenhouse-gas-endangerment-finding-timeline.

until the EPA issues and implements emissions standards banning lead from avgas. A positive endangerment finding in and of itself does not require any changes to the operation of covered aircraft or engines. However, once an affirmative finding is made, the EPA will be required under section 231(a)(2)(A) of the Clean Air Act to issue piston-engine aircraft emissions standards for lead air pollution. A positive endangerment finding will also trigger the FAA's duties under 49 U.S.C. section 44714 to prescribe fuel standards that control or eliminate lead pollution from avgas and under section 232 of the Clean Air Act to prescribe regulations to ensure compliance with EPA emissions standards.

If seized, this moment provides the EPA a rare opportunity to quickly eliminate the single greatest source of lead air pollution in the country. Though innovation in the fuel industry has already begun to shift the general aviation fleet to unleaded avgas, federal regulation is necessary to ensure a timely and universal transition. The undersigned organizations submit the following comments about appropriate regulatory timelines for emissions standards and additional federal action needed in this moment, based on our expertise as governmental organizations working to address exposures from lead in our communities.

A. The EPA should quickly eliminate lead emissions from avgas to prevent ongoing harm.

Regulation of leaded avgas is already sorely overdue. The EPA began phasing lead out of automobile gasoline 50 years ago under an analogous statutory provision,[117] and evidence has been clear for decades that lead emissions from aviation gasoline similarly contribute to damaging pollution. Since 2003, organizations have been calling on the EPA to issue an endangerment finding for leaded avgas.[118] As detailed above, the EPA's delay in doing so has resulted in avoidable and ongoing harm to a generation of exposed individuals and billions of dollars in societal costs – impacts that are disproportionately borne by vulnerable communities including people of color, low-income populations, and young children.

Despite the public health and environmental justice imperatives of addressing this crisis rapidly, the FAA is advancing a prolonged timeline that will subject airport-adjacent communities, airport workers, and children to dangerous lead exposure for another seven years. In February 2022, the FAA and aviation and petroleum industry leaders announced an initiative to Eliminate Aviation Gasoline Lead Emissions (the "EAGLE Initiative") by 2030. The 2030 elimination date has remained unchanged even after the EPA proposed this endangerment finding, despite the EPA's recognition of significant health and welfare effects of leaded avgas and its creation of regulatory incentives to expedite unleaded alternatives. The EAGLE

[117] *See* 38 Fed. Reg. 33734 (Dec. 6, 1973) (issuing regulations designed to gradually reduce the content of lead in leaded automobile gasoline, because the EPA found that lead emissions presented a significant risk of harm to the health of urban populations, especially children).
[118] *See* Endangerment Finding, 87 Fed. Reg. at 62772 (discussing the 2003 letter to the EPA submitted by Friends of the Earth that initially raised the issue of an endangerment finding for leaded avgas).

Initiative's updated timeline incorporating this rulemaking maintains a five-year gap between the projected issuance of standards and the ultimate elimination of lead from avgas in 2030.[119]

The EAGLE Initiative timeline lays out a multi-phased regulatory process. Once the endangerment finding is finalized in 2023, the EPA and FAA would concurrently undertake two-year rulemakings to issue emissions and fuel standards, respectively. These standards, which would be issued in 2025 under this timeline, would not be enforced for multiple years, as the FAA undertakes another multi-year rulemaking to issue certification standards under section 232 of the Clean Air Act. Even then, the EAGLE Initiative does not anticipate swift elimination of leaded avgas: "The publication of [the FAA's] final rule does not in and of itself implement an immediate ban on the use of lead in aviation gasoline; however, it does signal its inevitable and eventual prohibition."[120]

Instead of accepting the EAGLE Initiative's prolonged regulatory timelines, the EPA, in coordination with the FAA, should move as swiftly as possible to address this public health and environmental justice crisis, starting by issuing lead emissions standards during this Administration. The Agency need not wait until the endangerment finding is finalized to propose emissions standards. In fact, as the EPA noted in the proposed finding, past endangerment findings have been proposed concurrently with standards under section 231 of the Clean Air Act.[121] Further, the content of appropriate emission standards is already clear: They must fully ban use of leaded avgas and lead fuel additives. The EPA should not delay on developing and proposing emissions standards and initiating the rulemaking process to ensure that emissions standards are issued by the end of 2024 under this Administration. Doing so would mark an important achievement in realizing the Biden-Harris Administration's and the EPA's own commitments to environmental justice, including the EPA's recent strategy to reduce disparities in lead exposures.

Nor should the EAGLE Initiative's unambitious 2030 target, which industry leaders acknowledge represents a worst-case scenario,[122] guide or constrain the EPA's timeline for zero lead emissions. Nationwide transition to unleaded avgas will be possible years earlier, even without regulatory incentives. Already, an unleaded fuel option – 94-octane unleaded fuel

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[119] *See* EAGLE, *What do I need to know about EPA's Proposed Endangerment Finding for Lead Emissions from Piston Aircraft?* at 4.

[120] *See id.*

[121] Endangerment Finding, 87 Fed. Reg. at 62773.

[122] *See* Baker, *Unleaded Fuel: You've Got Questions*, Aircraft Owners and Pilots Association ("AOPA") (Oct. 1, 2022), https://www.aopa.org/news-and-media/all-news/2022/october/pilot/presidents-position-unleaded-fuel; *see also* National Air Transportation Association ("NATA"), Public Comment on Proposed Finding that Lead Emissions from Aircraft Engines that Operate on Leaded Fuel Cause or Contribute to Air Pollution that May Reasonably Be Anticipated to Endanger Public Health and Welfare at 2 (Nov. 7, 2022), available at https://www.regulations.gov/search/comment?filter=EPA-HQ-OAR-2022-0389 ("Even though 2030 is the target to achieve a fleet authorization, lead-free alternative to 100LL, we hope to obtain that goal much sooner with industry and government working together.").

("UL94") manufactured by Swift Fuels – is approved for use by two-thirds of covered aircraft.[123] More significantly,[124] multiple unleaded 100-octane fuels that could be safely used by the entire piston-engine fleet are anticipated to be ready at scale in the next few years. In September 2022, the FAA formally approved a 100-octane unleaded fuel ("G100UL") invented by General Aviation Modifications, Inc. ("GAMI") for use in the entire existing fleet of spark-ignition piston-powered engines and each of the aircraft that use those engines .[125] The FAA's review and approval process leading up to this effective fleetwide authorization included over 10 years of testing.[126] GAMI expects to deliver the first shipments of G100UL to a small number of airports, including those operated by the County of Santa Clara, in the second quarter of 2023, and anticipates expanding availability to fill nationwide in the next four to five years (in 2026-2027).[127]

Other fully unleaded fuel options are likely to be available for use by the entire piston-engine fleet within the next several years. Swift Fuels expects that its 100-octane unleaded fuel ("100R") will be ready for fleetwide approval in 2023 and available for use fleetwide within three years (by the end of 2025).[128] Additional unleaded fuel candidates are or will be going through the FAA's Piston Aviation Fuel Initiative ("PAFI") testing and evaluation process.[129] With fleetwide availability of both G100UL and 100R fuels expected in 2025-2027, combined with the existing supply of UL94 and the prospect of additional fuels gaining FAA approval through PAFI during this period, there is no justification for allowing leaded avgas to remain in use until 2030.

To expedite the transition, the EPA can and should attach an aggressive effective date to the standards' elimination of lead emissions for the entire piston-engine fleet, with a full ban effective well before 2030. Section 231 of the Clean Air Act provides the EPA broad discretion to issue emissions standards, including standards with technology-forcing results.[130] The only limitations on EPA's exercise of this discretion are that the standards not significantly increase noise or adversely affect safety under section 231(a)(2)(B), and that their effective date provide

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[123] *See* NAS Report, *supra* note 11, at 93.
[124] The development of unleaded 100-octane fuels is particularly significant because uptake of 94UL has faced significant barriers, including lack of secondary fueling infrastructure at many general aviation airports and steep costs of adding more fuel tanks. Moreover, the portion of the piston-engine aircraft fleet that requires 100-octane fuel accounts for a greater proportional share of fuel burn and flight hours. Thus, even with optimal adoption of 94UL, switching the lower-performance fleet to UL94 would only reduce the amount of lead consumed by about 30%. *See id.* at 80, 106.
[125] *See* General Aviation News Staff, *GAMI unleaded fuel approved for all general aviation aircraft*, General Aviation News (Sept. 3, 2022), https://generalaviationnews.com/2022/09/03/gami-unleaded-fuel-approved-for-all-general-aviation-aircraft/.
[126] Interview with George Braly, CEO, General Aviation Modifications, Inc. ("GAMI") (Nov. 14, 2022).
[127] *Id.*
[128] *See* Baker, *supra* note 122.
[129] *See* FAA, *White Paper: Piston Aviation Fuel Initiative ("PAFI")*, https://www.faa.gov/about/initiatives/avgas/media/media/pafi_white_paper.pdf.
[130] *See* Control of Air Pollution from Aircraft Engines: Emission Standards and Test Procedures, 87 Fed. Reg. 225 at 72316 (Nov. 23, 2022).

sufficient time for the development and application of the requisite technology and give appropriate consideration to compliance costs under section 231(b).[131] The EPA should exercise this discretion to adopt emissions standards that make a ban on lead emissions from piston-engine aircraft effective by the end of 2025. A 2025 effective date, which aligns with the earlier estimates of when the fuel industry anticipates that it could produce enough fuel to supply the current general aviation fleet under the current market conditions, will incentivize further investment by the fuel industry, airport proprietors, and aircraft owners to ensure that they are able to implement a timely transition to unleaded avgas. The EPA could structure some degree of regulatory flexibility into these rules, allowing for reasonable delay in fully effecting a zero-emissions standard to not later than 2027 if the unleaded fuel supply is insufficient at the time the ban would take effect. Bold emissions standards like those suggested here easily meet the requirements for technological feasibility and safety without imposing unreasonable costs.

First, given the significant recent advances in unleaded fuels, emissions standards that eliminate lead emissions from avgas in 2025 are technologically feasible and appropriate. As discussed above, even without regulatory incentives, UL94 is already on the market, at least one unleaded 100-octane fuel is expected to be available fleetwide in 2025, and additional unleaded 100-octane fuels are anticipated fleetwide by 2027. The EPA also has authority, and clear reason, to accelerate timelines for fuel transition by taking a technology-forcing approach to its emissions standards. But even if the EPA were to adopt standards that merely follow the available technology, there is no reason for emissions standards to allow lead air pollution from avgas to continue beyond 2027 given currently available unleaded fuel technology.

Second, far from impairing airport safety, removing lead from avgas is a safety imperative: Airports cannot be safely operated so long as leaded avgas remains in widespread use. As discussed above, the continued use of leaded avgas threatens the safety of airport workers who spend time in close proximity to aircraft during takeoff, and who are thereby at high risk of lead exposure. The continued use of leaded avgas also threatens the safety of airport-adjacent communities, who live with daily risks from lead air pollution caused by aircraft running on leaded avgas. Meanwhile, there is no evidence indicating that banning leaded avgas and replacing it with unleaded avgas presents a safety concern.

Finally, a rapid transition to unleaded fuels would not impose unreasonable costs on airport operators. Once 100-octane unleaded fuel is available, airports are not expected to need any new infrastructure to begin providing unleaded fuel. Both GAMI and Swift's unleaded 100-octane fuels can be stored in the same airport fuel tanks as the 100-octane low lead fuel ("100LL") that is universally used in general aviation operations.[132] Additionally, airports with

[131] 42 U.S.C. § 7571(a)-(b).
[132] GAMI, *Questions about G100UL avgas and Answers* at 2, https://gami.com/g100ul/GAMI_Q_and_A.pdf [hereinafter "GAMI Q&A"] ("After extensive testing, no compatibility issues have been identified in any aircraft, engines, storage tanks or transportation systems. G100UL is a drop-in fuel, fully fungible with 100LL and other

multiple fuel tanks can take immediate action to reduce lead exposure by procuring and providing UL94 for qualifying aircraft in existing secondary fueling infrastructure without additional infrastructure costs. The County of Santa Clara serves as a model for how airport proprietors with secondary fueling infrastructure can safely transition to unleaded fuels: The County has exclusively sold UL94 since January 1, 2022 when the County's Board of Supervisors banned the sale of leaded avgas at its airports after researchers documented alarming blood lead levels caused by leaded avgas in communities near Reid-Hillview Airport,[133] while maintaining protocols for accessing leaded avgas supplies in case of emergency.

Nor will the transition to unleaded avgas impose more than minimal costs on pilots. Few to no pilots will be required to modify their engines before transitioning to unleaded 100-octane fuel: G100UL is a drop-in fuel requiring no modifications,[134] and Swift Fuels expects 100R will be drop-in-ready for 85% of the piston-engine aircraft fleet.[135] Additionally, as with airport fuel tanks, both fuels can be safely commingled with 100LL at any ratio in aircraft fuel tanks.[136] Pilots' primary cost for transitioning to unleaded fuel would be purchasing from the fuel manufacturer any necessary supplemental type certificate ("STC") to modify the operating limits of their aircraft to provide for use of that fuel. Adding STCs is not an atypical expense for pilots; the FAA's database of STCs contains over 47,000 entries.[137] Currently, Swift Fuels' STC is a one-time cost of $100 covering all the manufacturer's unleaded fuels, including UL94 and 100R,[138] and GAMI indicates that its STC will be priced in a similar manner to other fuel STCs.[139] No STC is needed for fuels approved through the FAA's PAFI fleetwide authorization process.[140]

Additionally, the price of fueling up with unleaded avgas will not unreasonably increase over that of 100LL: UL94 is priced competitively with 100LL and the same will be true for

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aviation gasolines, and ready to be used within the industry's existing infrastructure."); Swift Fuels, *Frequently Asked Questions*, https://www.swiftfuelsavgas.com/faq [hereinafter "Swift FAQ"] ("Our 100-octane unleaded avgas will be fully commingable [sic] with 100LL. This means that it can be stored in the same airport tank as 100LL. . . ."); *see also* NAS Report at 90-91 (discussing convergence to 100LL avgas).

[133] *See* Office of Communications and Public Affairs, *Sale of Leaded Aviation Fuel Ends at Reid-Hillview and San Martin Airports*, County of Santa Clara (Jan. 6, 2022), https://news.sccgov.org/news-release/sale-leaded-aviation-fuel-ends-reid-hillview-and-san-martin-airports.

[134] GAMI Q&A, *supra* note 132, at 1 ("Other than placards, no [engine] modifications are required [to use G100UL avgas].").

[135] Swift FAQ, *supra* note 132 (answering "Is Swift Fuels' 100-octane Avgas 'Drop-In Ready'?").

[136] GAMI Q&A, *supra* note 132, at 2 (answering "Are there any known material compatibility issues in aircraft, engines, storage tanks or transportation systems?"); Swift FAQ, *supra* note 132 (answering "Will I need a separate tank at my airport for your 100-octane avgas to fully replace 100LL?").

[137] *See* FAA, *Dynamic Regulatory System*, https://drs.faa.gov/browse/doctypeDetails (as of Dec. 4, 2022) [filtering by Supplemental Type Certificates (STC)].

[138] Swift FAQ, *supra* note 132 (answering "How much does a FOREVER Avgas STC certificate cost?").

[139] GAMI Q&A, *supra* note 132, at 5 ("The STC pricing will be based on engines and horse-power, in a manner similar to the pricing for other fuel STCs that have been available for low octane gasolines.").

[140] *See* FAA, *Programs & Initiatives: Avgas*, https://www.faa.gov/about/initiatives/avgas/ (describing PAFI's fleet-wide Authorization Qualification Test Program, with the STC process as an alternative)

100R.[141] In large batch volume production, G100UL is expected to be only $0.85-1.00/gallon more expensive than existing 100LL.[142] As discussed below, federal resources supporting the transition to unleaded fuels as part of the Biden-Harris Administration's commitment to environmental justice could further reduce marginal costs. Moreover, any transition costs are dwarfed by the steep societal costs of continued lead exposure from leaded avgas.

B. A whole of government approach can facilitate the transition to unleaded avgas and minimize exposures while a complete phaseout is pending.

The EPA's recent *Strategy to Reduce Lead Exposures and Disparities in U.S. Communities* recognizes the need for coordinated federal action to solve the leaded avgas problem, alongside the long-overdue emissions regulation that will result from this rulemaking process. Consistent with the Biden-Harris Administration's government-wide approach to the climate crisis and environmental injustice,[143] the Lead Strategy commits to addressing leaded avgas through a "whole of government" approach in coordination with the FAA and other agencies now, while fuel replacement programs and regulatory actions are pending.[144] This inter-agency work includes implementing National Academy of Sciences recommendations regarding options for reducing lead emissions from piston-engine aircraft.[145]

Putting this whole of government approach into action, the EPA together with the FAA should use resources to facilitate the transition to unleaded avgas and to mitigate exposures while the transition is underway. Particularly relevant to undersigned airport proprietors, the National Academy of Sciences recommends exploring public policy options that will enable greater use of available unleaded avgas, including providing airports with incentives and means to supply unleaded fuel.[146] These incentives could take various forms, ranging from funding airports to purchase unleaded fuel STCs for pilots, to providing financial assistance to airports with only one fuel tank to install secondary fueling infrastructure so they can offer UL94 before unleaded 100-octane fuel is widely available. Additional mitigations that would benefit from federal assistance include changes in airport operations and practices to reduce aviation lead exposure, including educating airport personnel and the pilot community about the risks of lead exposure from leaded avgas and ways to minimize those risks,[147] and moving high-emitting run-up areas that are adjacent to communities or centers of human activity to other areas within the airport boundary.[148] The EPA could work with the FAA to administer these incentives by identifying

[141] Interview with Chris D'Acosta, CEO, Swift Fuels (Nov. 8, 2022).
[142] Interview with George Braly, *supra* note 126.
[143] *See* Exec. Order No. 14008, 86 Fed. Reg. at 7622.
[144] EPA Lead Strategy, *supra* note 79, at 37.
[145] *Id.*
[146] NAS Report, *supra* note 11, at 103 (Recommendation 5.2).
[147] *Id.* at 84 (Recommendation 4.2).
[148] *Id.* at 85 (Recommendation 4.3).

and prioritizing high lead-emitting airports in densely populated areas to maximize public health and environmental justice benefits.

CONCLUSION

The Biden-Harris Administration's commitment to environmental justice is shared by local governments across the country. Elimination of the last remaining leaded transportation fuel is central to fulfilling these promises. Federal action to regulate leaded avgas nationwide is urgently needed to protect communities from exposures over which they have no control, to allow aeronautical services to be provided safely, and to allow healing to occur at the community level. Further, while federal regulatory action is pending, local governments and airport proprietors require the coordinated assistance and support of federal agencies in efforts to mitigate ongoing exposures to lead from avgas in the most impacted communities.

For the reasons set forth above, the undersigned therefore urge the EPA to finalize the proposed positive endangerment finding for leaded avgas on the promised timelines and to expedite issuance of emission standards that will quickly ban the use of this damaging fuel additive. As with the many other sources of lead exposure that EPA has banned, removing the largest lead air pollution source is essential to achieving an environmentally just outcome. It must be accomplished without further delay.

Respectfully submitted,

Sydney Speizman, Certified Law Student
Stephanie L. Safdi, Supervising Attorney
Environmental Law Clinic
Mills Legal Clinic at Stanford Law School
559 Nathan Abbott Way
Stanford, California 94305
(650) 723-0325
ssafdi@stanford.edu
speizman@stanford.edu

Attorneys for County of Santa Clara, California

COUNTY OF SANTA CLARA, CALIFORNIA

DocuSigned by:
Jerett Yan
163B7BB7398A4B8...

James R. Williams, County Counsel
Jerett T. Yan, Deputy County Counsel
70 West Hedding Street, East Wing, 9th Floor
San Jose, California 95110-1770
(408) 299-5900
county.counsel@cco.sccgov.org

BAY AREA AIR QUALITY MANAGEMENT DISTRICT

Sharon L. Landers

Sharon L. Landers, Interim Executive Officer/APCO
375 Beale Street, Suite 600 | San Francisco, CA 94105
415.749.5000
sharon@baaqmd.gov

CITY OF OAKLAND, CALIFORNIA

/s/ Barbara J. Parker
Barbara J. Parker, State Bar #69722
City Attorney
OAKLAND CITY ATTORNEY'S OFFICE
Oakland City Hall
1 Frank H. Ogawa Plaza
Oakland, CA 94612
Telephone: (510) 238-3601
Email: BParker@oaklandcityattorney.org
Attorney for the Oakland City Attorney's Office

CITY AND COUNTY OF SAN FRANCISCO, CALIFORNIA

/s/ David Chiu
David Chiu, San Francisco City Attorney
City Hall, Room 234
1 Dr. Carlton B. Goodlett Pl.
San Francisco, CA 94102-4602
(415) 554-4748
cityattorney@sfcityatty.org

CITY OF SANTA MONICA, CALIFORNIA

/s/ Ivan O. Campbell
Douglas Sloan, City Attorney
Ivan O. Campbell, Deputy City Attorney
Santa Monica City Attorney's Office
1685 Main Street, Third Floor
Santa Monica, CA 90401
(310) 458-8336
ivan.campbell@santamonica.gov

Attorneys for the City of Santa Monica

BOULDER COUNTY, COLORADO

/s/ Olivia Lucas
Olivia Lucas
Senior Assistant County Attorney
P.O. Box 471
Boulder, CO 80306-0471
Telephone (303) 441-3190
olucas@bouldercounty.org

CITY OF SOUTH BEND, INDIANA

Sandra L. Kennedy, Corporation Counsel
1200 S. County-City Building
227 W. Jefferson Blvd.
South Bend, Indiana 46601
(574) 235-9241
skennedy@southbendin.gov

CITY OF NORTHAMPTON, MASSACHUSETTS

/s/ Alan Seewald

Alan Seewald
Northampton City Solicitor
One Roundhouse Plaza
Suite 304
Northampton, MA 01060
Attorney for the City of Northampton, Massachusetts

COUNTY OF TRAVIS, TEXAS

/s/ Delia Garza
Delia Garza
Travis County Attorney
P.O. Box 1748
Austin, Texas 78701

Attorneys for the County of Travis, Texas

TOWN BOARD, TOWN OF MIDDLETON, WISCONSIN

Cynthia Richson, Town Board, Chair
7555 W. Old Sauk Road
Verona, Wisconsin 53593
(608) 833-5887
townchair@town.middleton.wi.us

Approved by the Town Board of the Town of Middleton authorizing the Town Chair to sign on behalf of the Town Board on January 3, 2023.

WASHTENAW COUNTY PROSECUTOR'S OFFICE, WISCONSIN

Eli Savit
WASHTENAW COUNTY
PROSECUTOR'S OFFICE
P.O. Box 8645
Ann Arbor, Michigan 48107
(734) 222-6620
savite@washtenaw.org

Prosecuting Attorney
Washtenaw County, MI

EXHIBIT A

I, Bruce P. Lanphear, MD, MPH, declare as follows:

Background

1. I submit this declaration in support of the proposed finding by the U.S. Environmental Protection Agency ("EPA") that lead emissions from aircraft engines contribute to air pollution that endangers public health or welfare (the "endangerment finding"). I also submit this declaration in support of the public comment by County of Santa Clara, California and other local and regional public agencies urging the EPA to finalize its proposed endangerment finding. The matters stated herein are based upon my research and personal knowledge and, if called to testify, I could and would testify competently to them.

2. I am a physician with board certification in Public Health and Preventive Medicine from the American Board of Preventive Medicine. I also received post-doctoral training in community pediatric research at the University of Rochester School of Medicine and Dentistry in Rochester, New York.

3. For over 25 years, I have studied the sources of lead exposure and the health impacts of lead poisoning. I have conducted studies or served as an advisor on how to reduce lead contamination in Chicago, Illinois; Detroit, Michigan; St. Louis, Missouri; Herculaneum, Missouri; Rochester, New York; Los Angeles, California; Santa Clara County, California; and many other communities across the United States. I have served on advisory committees of the EPA, the Centers for Disease Control and Prevention ("CDC"), the National Toxicology Program of the National Institutes of Health, and the American Academy of Pediatrics. For instance, I was a member of the recent work group that advised the CDC to reduce the blood lead reference value, used to identify children with elevated blood lead levels, to 3.5 µg/dL. I am currently a member of the EPA's science advisory panel for the national air lead standard.

4. Lead exposure from piston-engine aircraft has been a significant focus of my work for the past two years. At the request of County of Santa Clara Administration, I reviewed the airborne lead study of Reid-Hillview Airport conducted by Mountain Data Group, and I provided an expert presentation at the August 17, 2021 County Board of Supervisors public meeting to inform the Board's consideration of recommendations relating to the airborne lead study, described below. I

also served as a witness at the House Committee on Oversight and Reform's July 29, 2022 subcommittee hearing on phaseout of leaded aviation fuel.

5. Based on this expertise, I can say without a doubt that the EPA's proposed endangerment finding for leaded avgas is supported by overwhelming evidence that (1) airborne lead endangers public health, and (2) lead emissions from piston-engine aircraft cause or contribute to harmful lead air pollution.

Lead Endangers Public Health

6. Lead exposure threatens human health in myriad ways. Among the most consequential are enduring cognitive deficits and behavioral disorders from childhood exposure, threats to pregnancies and maternal health, and fatal coronary heart disease.

7. Dozens of studies show that exceedingly low levels of lead adversely impact children's cognitive abilities and neurodevelopment.[1] In a study of 58,000 Chicago school children, my colleagues and I found that a 5 µg/dL increase in blood lead concentration was associated with a 32% increased risk of reading failure on standardized tests in 3rd grade children.[2] We estimated that 13% of reading failures in Chicago school children were attributable to blood lead concentrations of 5 to 9 µg/dL. Lead-induced cognitive effects are especially harmful for children who are already struggling with reading. In a study of over 1,000 Milwaukee children, Sherly Magzamen and her team found that lead exposure led to an 18-point decrease in reading scores for children with poorer reading abilities, compared to an average 13.7-point decrease for all exposed children.[3] In a national

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[1] *See, e.g.*, Canfield RL, Henderson CR, Cory-Slechta DA, Cox C, Jusko TA, Lanphear BP, *Intellectual Impairment in Children with Blood Lead Concentrations Below 10 µg per Decileter*, 348 New England J. of Medicine 1517-26 (2003); Lanphear BP, et al., *Low-Level Environmental Lead Exposure and Children's Intellectual Function: An International Pooled Analysis*, 113 Env't Health Perspect. 894-99 (2005); Desrochers-Couture M., et al., *Prenatal, Concurrent, and Sex-Specific Associations Between Blood Lead Concentrations and IQ in Preschool Canadian Children*, 121 Env't Int'l 1234-42 (2018).

[2] Evens A, Hryhorczuk D, Lanphear BP, et al., *The Impact of Low-Level Lead Toxicity on School Performance Among Children in the Chicago Public Schools: A Population-Based Retrospective Cohort Study*, 14(21) Env't Health 1 (2015).

[3] Magzamen S, Amato M, Imm P, et al., *Quantile Regression in Environmental Health: Early Life Lead Exposure and End-of-Grade Exams*, 137 Env't Rsch. 108-19 (2015).

study of over 9,000 U.S. children (the National Institutes of Health-funded Adolescent Brain Cognitive Development Study cohort), my colleagues and I found that low-income children living in neighborhoods at high-risk for lead poisoning had diminished brain volume.[4]

8. Cognitive deficits resulting from childhood lead exposure are enduring. Aaron Reuben et al. found that children with higher blood lead concentrations at 11-years of age had further decrements in intellectual abilities by 38-years of age. After adjusting for childhood IQ score, mothers' IQ score, and socioeconomic background, each 5 μg/dL increase in childhood blood lead concentration was associated with an additional 1.6-point reduction in IQ score.[5] Reuben also found that children with higher blood lead concentrations were less likely to attain the same social standing as their parents.[6]

9. Lead also increases the risk of children developing attention and behavior disorders such as ADHD.[7] In a national study of 8- to 15-year-old children, my colleagues and I found that the fraction of children with ADHD increased from 5% to 13% as blood lead concentrations increased from < 0.7 μg/dL to > 1.3 μg/dL. We also estimated that one in five cases of ADHD nationwide – representing 600,000 children – was attributable to lead exposure.[8]

10. Maternal exposure to lead also creates significant risks for fetuses. Multiple studies have identified lead as a risk factor for preterm birth.[9] In a pregnancy and birth cohort study in Bristol,

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[4] Marshall AT, Betts S, Kan EC, McConnell R, Lanphear BP, Sowell ER, *Association of Lead-Exposure Risk and Family Income with Childhood Brain Outcomes*, 26 Nat. Med. 91-97 (2020).

[5] Reuben A, Caspi A, Belsky DW, et al., *Association of Childhood Blood Lead Levels with Cognitive Function and Socioeconomic Status at Age 38 Years and with IQ Change and Socioeconomic Mobility Between Childhood and Adulthood*, 317 JAMA 1244-51 (2017).

[6] *Id.*

[7] Nigg JT, Knotternerus GM, Martell MM, et al., *Low Blood Lead Levels Associated with Clinical Diagnosed Attention-Deficit/Hyperactivity Disorder and Mediated by Weak Cognitive Control*, 63 Biol. Psychiatry 325-31 (2008); Froehlich T, Lanphear BP, Auinger P, Hornung R, Epstein JN, Braun J, Kahn RS, *The Association of Tobacco and Lead Exposure with Attention-Deficit/Hyperactivity Disorder in a National Sample of US Children*, 124 Pediatrics 1054-63 (2009).

[8] Froehlich, et al., *The Association of Tobacco and Lead Exposure with Attention-Deficit/Hyperactivity Disorder in a National Sample of US Children*, supra n.7.

[9] *See, e.g.*, Taylor CM, Golding J, Emond AM, *Adverse Effects of Maternal Lead Levels on Birth Outcomes in the ALSPAC Study: A Prospective Birth Cohort Study*, 122(3) British J. of Obstetrics &

England, pregnant women with a blood lead level > 5 µg/dL were 1.9-fold more likely to give birth preterm.[10] In the China-Anhui Birth Cohort Study of women with a mean blood lead concentration of 1.5 µg/dL, researchers found that the risk of preterm birth was elevated in those with moderate (1.18-1.79 µg/dL) and high (≥ 1.61 µg/dL) lead concentrations compared with women who had lower exposure (<1.18 µg/dL).[11] In an Iranian cohort of 348 pregnant women with a mean blood lead level of 3.5 µg/dL, researchers found that higher blood lead concentrations measured during early pregnancy were associated with a higher risk of preterm birth.[12] Likewise, risks to fetuses lessen as lead exposure declines. After NASCAR decided to eliminate leaded gasoline in its automobile races, Dr. Linda Bui and her team studied birth outcomes in 147,000 women and found that the probability of preterm births declined by 2.7%, and newborns small for gestational age declined by 4.1%.[13] The authors concluded that the EPA's National Ambient Air Quality Lead Standard, which is based on a 3-month moving average, failed to protect against risks from short-term exposures.

11. Lead also affects maternal health and fertility. Lead exposure during pregnancy is linked to preeclampsia, a disorder of severe hypertension in pregnant women. In a meta-analysis of all high-quality studies, researchers found that for every 1 µg/dL increase in blood lead in pregnant women, the risk of preeclampsia rose by 1.6%. Additionally, exceedingly small amounts of lead can delay conception. In a study of 501 couples, researchers found that women who had male partners

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Gynaecology 322-28 (2014); Li J., et al., *Maternal Serum Lead Level During Pregnancy is Positively Correlated with Risk of Preterm Birth in a Chinese Population*, 227 Env't Pollution 484-89 (2017); Vigeh M, Saito H, Sawada S, *Lead Exposure in Female Workers Who Are Pregnant or of Childbearing Age*, 49 Ind. Health 255-61 (2011).

[10] Taylor, et al., *Adverse Effects of Maternal Lead Levels on Birth Outcomes in the ALSPAC Study: A Prospective Birth Cohort Study*, supra n.9.

[11] Li, et al., *Maternal Serum Lead Level During Pregnancy is Positively Correlated with Risk of Preterm Birth in a Chinese Population,* supra n.9.

[12] Vigeh, et al., *Lead Exposure in Female Workers Who Are Pregnant or of Childbearing Age*, supra n.9.

[13] Bui LTM, Shadbegian R, Marquez A, Klemick H, Guignet D, *Does Short-Term, Airborne Lead Exposure During Pregnancy Affect Birth Outcomes? Quasi-Experimental Evidence From NASCAR's Deleading Policy*, 166 Env't Int'l 1-9 (2022).

with higher blood lead levels took 15% longer to conceive.[14] The difference in blood lead concentrations among men with diminished fertility was only 0.24 µg/dl.[15]

12. Adult lead exposure is a causal risk factor for coronary heart disease.[16] Using NASCAR's elimination of leaded gasoline as a natural experiment, researchers found that lead emissions have an immediate effect on elderly mortality. After racing fuel was de-leaded, overall elderly mortality rates dropped by 91 deaths per 100,000 in counties where races took place, and the rates of elderly deaths caused by cardiovascular mortality, ischemic heart disease, and respiratory mortality all declined.[17]

13. Cardiovascular effects of adult lead exposure are of great concern. Fifteen prospective cohort studies conducted in Europe and the United States examining blood lead concentrations and cardiovascular mortality all found that lead was a risk factor for cardiovascular disease mortality.[18] In 2013, the EPA concluded that lead is a causal risk factor for coronary heart disease – the leading cause of death worldwide.[19] Studies published over the past decade confirm this conclusion.[20] In a

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[14] Buck Louis GM, Sundaram R, Schisterman EF, et al., *Heavy Metals and Couple Fecundity: The LIFE Study*, 87 Chemosphere 1201-07 (2012).

[15] *Id.*

[16] U.S. Env't Protection Agency, *Integrated Science Assessment for Lead* 1-29, 4-412 to -414 (June 2013).

[17] Hollingsworth A, Rudik I, *The Effect of Leaded Gasoline on Elderly Mortality: Evidence from Regulatory Exemptions*, 13 Am. Econ. J.: Econ. Policy 345-73 (2021).

[18] Navas-Acien A, *Lead and Cardiovascular Mortality: Evidence Supports Lead as an Independent Cardiovascular Risk Factor*, Working Paper, U.S. EPA Nat'l Ctr. for Env't Econ. ("NCEE") 21-03 (May 2021).

[19] U.S. Env't Protection Agency, *Integrated Science Assessment for Lead*, supra n.16.

[20] *See, e.g.*, McElvenny DM, Miller BG, MacCalman LA, Sleeuwenhoek A, van Tongeren M, Shepherd K, Darnton AJ, Cherrie JW, *Mortality of a Cohort of Workers in Great Britain with Blood Lead Measurements*, 72 Occup. Env't Med. 625-32 (Sept. 2015); Aoki Y, Brody DJ, Flegal KM, Fakhouri THI, Axelrad DA, Parker JD, *Blood Lead and Other Metal Biomarkers as Risk Factors for Cardiovascular Disease Mortality*, 95 Medicine 1-8 (2016); Chowdhury R, Ramond A, O'Keeffe LM, et al., *Environmental Toxic Metal Contaminants and Risk of Cardiovascular Disease: Systematic Review and Meta-Analysis*, 362 British Med. J. 1-13 (2018); Lanphear BP, Rauch S, Auinger P, Allen RW, Hornung RW, *Low-Level Lead Exposure and Mortality in US Adults: A Population-Based Cohort Study*, 3 Lancet Public Health E177-E84 (2018); Wang G, DiBari J, Bind E, Steffens AM, Mukherjee J, Azuine RE, Singh GK, Hong X, Ji Y, Ji H, Pearson C, Zuckerman BS, Cheng TL, Wang X, *Association Between Maternal Exposure to Lead, Maternal Folate Status, and*

meta-analysis of eight studies encompassing over 90,000 people, researchers found that blood lead concentration was a risk factor for coronary heart disease.[21] This risk exists even at low levels of exposure; no apparent threshold exists for lead-induced coronary heart disease.[22] In a national study of the United States, I found that lead was *the* leading risk factor for deaths from coronary heart disease, accounting for 185,000 deaths every year.[23]

14. The health risks from lead exposure may be greater when leaded avgas is the source of the exposure. Lead particles found in aircraft emissions are significantly smaller than those from other sources, including automobile emissions.[24] These small particles of lead are readily absorbed and may be transported directly to the brain via the olfactory nerve.[25] Moreover, up to 20% of lead in aircraft emissions is in the vapor phase (also known as alkyl or organic lead) that can be readily inhaled, and transported directly to the brain, or dermally absorbed.[26] Because the EPA's current NAAQS standard relies on measures of lead in total suspended particles, it may underestimate the toxic effects of lead from vapor-phase aircraft emissions.

Leaded Avgas Causes or Contributes to Harmful Lead Air Pollution

15. The major sources of airborne lead in the United States are piston-engine aircraft, lead battery recycling operations, and incinerators. Of these, aircraft emissions contribute the greatest share of lead air pollution: the EPA estimated that over 450 tons of lead were emitted by piston-

Intergenerational Risk of Childhood Overweight and Obesity, 2 JAMA Network Open 1-14 (2019).

[21] Chowdhury, et al., *Environmental Toxic Metal Contaminants and Risk of Cardiovascular Disease: Systematic Review and Meta-Analysis*, supra n.20.

[22] *See* Navas-Acien, *Lead and Cardiovascular Mortality: Evidence Supports Lead as an Independent Cardiovascular Risk Factor*, supra n.18; Lanphear, et al., *Low-Level Lead Exposure and Mortality in US Adults*, supra n.20.

[23] Lanphear, et al., *Low-Level Lead Exposure and Mortality in US Adults*, supra n.20.

[24] *See* Griffith JD, *Electron Microscopic Characterization of Exhaust Particles Containing Lead Dibromide Beads Expelled from Aircraft Burning Leaded Gasoline*, 11 Atmospheric Pollution Rsch. 1481-86 (2021).

[25] *See* Thompson K, et al., *Olfactory Uptake of Manganese Requires DMT1 and Is Enhanced by Anemia*, 21 J. of the Fed'n of Am. Soc'ys for Experimental Biology 223-30 (2007).

[26] U.S. Env't Protection Agency, *Integrated Science Assessment for Lead*, supra n.16.

engine aircraft every year, totaling 70% of all lead emissions to the air nationwide.[27]

16. The burden of lead exposure from leaded aviation fuel falls particularly heavily on people located near airports.[28] Two studies conducted by Dr. Sammy Zahran demonstrate the uneven distribution of lead exposure. In a study of 448 airports and over 1 million children in Michigan, Zahran found that children who lived near a general aviation airport had significantly higher blood lead levels after accounting for age of housing stock and industrial sources. Compared with children who resided > 4 km from an airport, children who lived < 1 km, 1–2 km, and 2–3 km were 25.2%, 16.5%, and 9.1% more likely to have a blood lead > 5 µg/dL, respectively.[29] The increase in blood lead concentration was larger for children who lived downwind from the airport, especially toddlers. The heightened risk to airport-adjacent communities in Michigan has environmental justice implications. Children who lived near airports were more likely to live in households receiving public assistance.[30]

17. In 2021, Zahran was invited to conduct a study of childhood lead exposure at Reid-Hillview airport in Santa Clara County, California. Using blood lead tests of 17,000 children collected by the California Department of Public Health from January 1, 2011 to December 31, 2020, Zahran and his team identified significant differences in blood lead concentration based on distance from the airport. Zahran found that 2% of toddlers who lived more than half a mile from the airport had a blood lead > 3.5 µg/dL. In contrast, 5.7% of toddlers who lived within half a mile of the airport had a blood lead > 3.5 µg/dL, and 10.5% of toddlers who lived within 0.5 miles of the

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[27] U.S. Env't Protection Agency, *National Emissions Inventory (NEI) Data* (2017), https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data.

[28] *See* Miranda ML, Anthopolos R, Hastings D, *A Geospatial Analysis of the Effects of Aviation Gasoline on Childhood Blood Lead Levels*, 119 Env't Health Perspectives 1513-16 (2007); Zahran S, Iverson T, McElmurry SP, Weiler S, *The Effect of Leaded Aviation Gasoline on Blood Lead in Children*, 4 J. of the Ass'n of Env't and Res. Econ. 575-610 (2017); Zahran S, Keyes C, Lanphear BP, *Leaded Aviation Gasoline Exposure Risk and Child Blood Lead Levels*, 2 PNAS Nexus 1-11 (2022).

[29] Zahran et al., *The Effect of Leaded Aviation Gasoline on Blood Lead in Children*, supra n.28.

[30] *Id.*

airport and were downwind of the airport had a blood lead > 3.5 µg/dL during heavy traffic.[31]

18. Collectively, these studies indicate that low-level lead exposure is a major risk factor for cognitive deficits, ADHD, preterm birth, preeclampsia, and coronary heart disease, and that lead emissions from piston-engine aircraft are a major source of lead exposure for nearby communities. The EPA estimated that sixteen million Americans – including three million children – live within a kilometer of a general airport. With dangerous exposure to lead particles from aircraft emissions occurring on this scale, it is undeniable that leaded avgas endangers public health. It is high time that the EPA act to solve it.

I declare, under penalty of perjury, that the foregoing is true and correct to the best of my knowledge and recollection. I executed this declaration on January 10th, 2023 in Vancouver, British Columbia, Canada.

Bruce P. Lanphear, MD, MPH

[31] Zahran et al., *Leaded Aviation Gasoline Exposure Risk and Child Blood Lead Levels*, supra n.28.

EXHIBIT B

I, Derek Ouyang, declare as follows:

Background

1. I submit this declaration in support of the proposed finding by the U.S. Environmental Protection Agency ("EPA") that lead emissions from aircraft engines that operate on leaded fuel contribute to air pollution that endangers public health or welfare (the "endangerment finding"). I also submit this declaration in support of the public comment by County of Santa Clara, California and other local and regional public agencies urging the EPA to finalize its proposed endangerment finding. The matters stated herein are stated upon my personal knowledge and, if called to testify, I could and would testify competently to them.

2. I am a researcher and practitioner with nearly a decade of experience working with government agencies to promote better governance on public health and environmental challenges. Since 2022, I have been Research Manager at the Stanford Regulation, Evaluation, and Governance Lab ("RegLab"). The RegLab partners with government agencies to design and evaluate programs, policies, and technologies that modernize government. We are an interdisciplinary team of legal experts, data scientists, social scientists, and engineers who leverage state-of-the-art advances in machine learning, artificial intelligence, and causal inference to build a bridge between government agencies and academic frontiers in data science. The RegLab has an extensive track record working with local and national government agencies and nonprofits, including partnerships with the U.S. Environmental Protection Agency, Santa Clara County Public Health Department, and Seattle & King County Public Health Departments. Since the outbreak of the Covid-19 pandemic, I have spearheaded the RegLab's Covid-19 response collaborations with the Santa Clara County Public Health Department.

3. Prior to joining RegLab, I graduated from Stanford University in 2013 with dual Bachelor's in Civil Engineering and Architectural Design, and in 2015 with a Master's in Structural Engineering. From 2015 to 2022, I helped develop and lead the Stanford Future Bay Initiative, which focuses on climate resilience collaborations with San Francisco Bay Area government agencies and nonprofits.

4. The Stanford Environmental Law Clinic invited me to examine the environmental justice implications of aircraft lead emissions in accordance with the EPA's request for comments on this subject in its proposed endangerment finding.[1] The EPA in the proposed endangerment finding analyzed potential disparities by examining demographics of the populations living within 500 meters and one kilometer of 2,022 National Plan of Integrated Airport System ("NPIAS") airports. The EPA concluded from this examination that there is a greater prevalence of people of color and of low-income populations within 500 meters or one kilometer of some airports compared with people living more distant.[2] In my opinion, the EPA's analysis understates the environmental justice implications of lead exposure from piston-engine aircraft operations by treating all NPIAS airports as equivalent sources of exposure risk.

5. To refine the analysis of environmental justice implications of leaded avgas exposure, I binned all NPIAS airports with general aviation activities into quartiles of lead exposure and population, such that I can distinguish airports in the lowest quartile of lead exposure and lowest quartile of population density (low-emitting and low-density) from airports in the highest quartiles (high-emitting and high-density), which contribute an outsized share of lead emissions and expose an outsized number of individuals. My analysis reveals racial and socioeconomic disparities in these relatively dense and highly exposed communities that are more pronounced than disparities identified by the EPA.

Methodology

6. I conducted this analysis using the Federal Aviation Administration's ("FAA") 2023-2027 NPIAS dataset of 3,287 airports.[3] To identify airports with general aviation activities, I filtered

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[1] *See* U.S. Env't Protection Agency, *Proposed Finding that Lead Emissions from Aircraft Engines that Operate on Leaded Fuel Cause or Contribute to Air Pollution that May Reasonably be Anticipated to Endanger Public Health or Welfare*, 87 Fed. Reg. 62753, 62770 (Oct. 2022).

[2] *Id.*

[3] National Plan of Integrated Airport Systems (NPIAS) 2023–2027: Appendix A - List of NPIAS Airports, https://www.faa.gov/airports/planning_capacity/npias/current/2023_NPIAS_Appendix_A.

to airports with a Fiscal Year 2023 service level of general aviation ("G") or reliever ("R").[4] This filtering resulted in 2,809 airports. I then merged each airport via unique identifier to latitude and longitude coordinates from the FAA's Aeronautical Data Delivery Service.[5]

7. I then downloaded emissions data from the EPA's 2017 National Emissions Inventory for airport facilities.[6] I identified 16,607 facilities in the National Emissions Inventory with source type as "Airport," pollutant description as "Lead," and process description as "Aircraft /General Aviation /Piston" excluding those with "hospital" or "medical" in the facility name. There is no unique identifier to directly merge the EPA records with the FAA records, so I performed a spatial join between each general aviation airport and its nearest EPA emissions record. I verified that a random sample of 50 were 100% accurate matches to the intended airport.

8. Next, I identified census blocks comprising residents near airport communities. For each airport, I drew a one-kilometer radius around its latitude and longitude coordinates and identified all 2020 TIGER/Line census block and census block group ("CBG") shapefiles that spatially intersect with the circle. These census geographies may cross county or state lines. The latitude and longitude coordinates of an airport are typically located on the airport runway, and the one-kilometer circle mostly contains the airport itself. Since lead-emitting activities are not strictly confined to a single coordinate, a strict accounting of only population within the drawn circle is likely to underestimate the population that is actually within one kilometer of general aviation activities. At the same time, including the entire census geography's population may overestimate exposure, depending on the census geography's size and shape. I chose to calculate results using both definitions of exposure and report a range for each outcome.

[4] The FAA defines a reliever as "[a]n airport designated by the Secretary of Transportation to relieve congestion at a commercial service airport and to provide more general aviation access to the overall community (§ 47102(23))." FAA, *Airport Categories*, https://www.faa.gov/airports/planning_capacity/categories.

[5] FAA, *Airports*, https://adds-faa.opendata.arcgis.com/datasets/faa::airports-1/explore.

[6] 2017 National Emissions Inventory (NEI) Data, https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data.

9. I then identified racial and ethnic demographic data for the exposed census blocks. I downloaded 2020 Decennial Census redistricting data (P.L. 94-171), specifically the P2 table (HISPANIC OR LATINO, AND NOT HISPANIC OR LATINO BY RACE), which provides population counts of "Total population," "Hispanic or Latino" (Hispanic), "Not Hispanic or Latino, White alone" (White), "Not Hispanic or Latino, Black or African American alone" (Black), "Not Hispanic or Latino, American Indian and Alaska Native alone" (AIAN), "Not Hispanic or Latino, Asian alone" (Asian), "Not Hispanic or Latino, Native Hawaiian and Other Pacific Islander alone" (NHPI), and "Not Hispanic or Latino, Some Other Race alone" and "Not Hispanic or Latino, Population of two or more races" (Other) for each census block. For each airport, I calculated the population counts within one kilometer. For the circle-based approach, I used the assumption that population is evenly distributed across the original geometry, meaning that a census block that is 25% contained within the circle has 25% of each population category within the circle. I calculated the percentages of total population identifying as each race/ethnicity group within one kilometer as well as for the entire county or counties associated with the airport.

10. Next, I identified lower-income household data for the exposed census block groups. I downloaded 2017-2021 5-Year American Community Survey data, specifically the B19001 table (HOUSEHOLD INCOME IN THE PAST 12 MONTHS (IN 2021 INFLATION-ADJUSTED DOLLARS)), which provides counts of "Total households" and "Households with income less than $75,000" for each CBG. Similar to with race/ethnicity, I calculated the "% Households with income less than $75,000" (hereto "% lower-income") within one kilometer as well as for the entire county or counties associated with the airport. I chose $75,000 as the threshold for lower-income households because it is the closest available survey threshold to the 2017-2021 U.S. household median income of $69,021.

11. Following the EPA's approach, to avoid distortion of results from low population counts, I filtered to airports with greater than 100 people within the census blocks that are at least partially within one kilometer, resulting in 2,280 airports with general aviation activities used for the analysis. This count differs from the EPA's 2,022 because I chose to include reliever airports, which also

provide general aviation access, and due to minor differences in NPIAS and census data methodology.

12. I then identified quartiles of lead emissions and population density for these 2,280 airports, where lead emissions are from the 2017 EPA data and population density is calculated using the census blocks that are at least partially within one kilometer of each airport.

13. The fourth (highest) quartile for both lead emissions and population density covers a significantly broader range than the other three quartiles due to the fact that some airports are exceptionally high lead-emitters and some have exceptionally high population density. I thus also identified other subsets of particularly high-emitting and/or high-density airports. First, I considered demographic characteristics of communities within 1 km of the 350 airports accounting for roughly one half (50.06%) of all airport lead emissions and within 1 km of the 121 airports that account for roughly one half (50.04%) of all people within 1 km of an airport with general aviation activities. Next, I identified the subset of airports that are both in the top 5% of lead emissions and the top 5% of population density and examined in more detail the demographic characteristics of communities within 1 km of these highest-emitting and highest-density airports.

14. The code used to conduct this analysis is available at https://github.com/reglab/avgas.

Findings

15. Table 1 presents how the 2,280 airports are distributed across the 16 quartile-based categories.

Lead emissions quartiles (lbs/year)	Population density quartiles (persons/square mile): Least dense [0.0184, 2.77]	(2.77, 7.02]	(7.02, 16.9]	Most dense (16.9, 2540]
Least emitting [0, 24]	252	159	93	67
(24, 59]	179	180	149	68
(59, 139]	99	150	189	133
Most emitting (139, 1490]	40	81	139	302

Table 1. Number of airports with general aviation activities, presented in quartiles of lead emissions and population density. Total: 2,280 airports.

16. Table 2 presents how population within one kilometer of the 2,280 airports is distributed across the 16 quartile-based categories.

Lead emissions quartiles (lbs/year)	Population density quartiles (persons/square mile): Least dense [0.0184, 2.77]	(2.77, 7.02]	(7.02, 16.9]	Most dense (16.9, 2540]
Least emitting [0, 24]	32,000-66,000	49,000-93,000	62,000-110,000	360,000-480,000
(24, 59]	15,000-39,000	39,000-85,000	85,000-170,000	300,000-390,000
(59, 139]	8,400-22,000	31,000-74,000	100,000-200,000	320,000-510,000
Most emitting (139, 1490]	2,600-9,200	15,000-41,000	65,000-160,000	940,000-1,500,000

Table 2. Population within one kilometer of airports with general aviation activities, presented in quartiles of lead emissions and population density.

17. The total population within one kilometer of the 2,280 airports is 2.4 to 4.0 million people, encompassing approximately seven to twelve out of every 1,000 Americans. 302 airports fall in both the top quartile of lead emissions and the top quartile of population density. They are within one kilometer of 940,000 to 1,500,000 people, which is 39% of the national population of concern. They also account for 39% of all lead emissions from the 2,280 airports.

18. Table 3 presents the proportion of residents of color within one kilometer of the 2,280 airports, by quartiles of lead emissions and population density. The proportion of residents of color in the U.S. is 42%. While most of these airports are near populations that have proportionately fewer persons of color than the U.S. as a whole, we see three notable deviations where this not the case. First, the communities near the 252 least emitting and least dense airports are particularly more non-White, driven mostly by a concentration of AIAN populations. Second, the communities near the 67 airports in the least emitting quartile and most dense quartile are also more non-White, driven mostly by a concentration of Asian and Hispanic populations. Third, the communities near the 302 highest-emitting and highest-density airports are 5-7.4 percentage points more non-White, specifically 1.1-1.8 percentage points more Asian and 5-6.5 percentage points more Hispanic. This third group of airports is of greatest concern given that they are exposing the greatest number of people to the greatest amount of risk.

Lead emissions quartiles (lbs/year)	Population density quartiles (persons/square mile): Least dense [0.0184, 2.77]	(2.77, 7.02]	(7.02, 16.9]	Most dense (16.9, 2540]
Least emitting [0, 24]	51-56%	29-32%	32-33%	46-47%
(24, 59]	19-21%	21-22%	20-22%	38-40%
(59, 139]	25-27%	27-30%	26-29%	37-39%
Most emitting (139, 1490]	33-35%	30-31%	28-30%	47-50%

Table 3. Proportion of residents of color within one kilometer of airports with general aviation activities, presented in quartiles of lead emissions and population density.

19. Similarly, Table 4 presents the proportion of lower-income households within one kilometer of the 2,280 airports, by quartiles of lead emissions and population density. The proportion of lower-income households in the U.S. is 54%. With the exception of low-emitting but high-density airports, airports with general aviation activities tend to be close to lower-income populations at concentrations similar to or higher than the U.S. as a whole.

Lead emissions quartiles (lbs/year)	Population density quartiles (persons/square mile): Least dense [0.0184, 2.77]	(2.77, 7.02]	(7.02, 16.9]	Most dense (16.9, 2540]
Least emitting [0, 24]	65-66%	65%	65-66%	42-48%
(24, 59]	62-65%	66-68%	66-68%	44-51%
(59, 139]	61-64%	62-65%	62-64%	53-56%
Most emitting (139, 1490]	61-62%	55-56%	54-56%	52-54%

Table 4. Proportion of lower-income households within one kilometer of airports with general aviation activities, presented in quartiles of lead emissions and population density.

20. In the next two tables, instead of comparing to the U.S. as a whole, I compare each airport's neighboring population to the population of the surrounding county or counties. Then, for each quartile of lead emissions and population density, I report the proportion of airports for which an environmental justice disparity exists.

21. Table 5 presents the proportion of airports for which the nearby concentration of people of color is higher than in the surrounding county or counties. The general trends are similar to the comparison of airport communities to the U.S. as a whole. Notably, higher-density airports appear to have higher concentrations of residents of color, while higher-emitting airports appear to have lower concentrations of residents of color.

Lead emissions quartiles (lbs/year)	Population density quartiles (persons/square mile): Least dense [0.0184, 2.77]	(2.77, 7.02]	(7.02, 16.9]	Most dense (16.9, 2540]
Least emitting [0, 24]	47-50%	35-40%	42-43%	52-58%
(24, 59]	22-30%	32-38%	38-45%	46-56%
(59, 139]	26-35%	33-38%	35-44%	47-52%
Most emitting (139, 1490]	25-35%	36-46%	32-38%	46-47%

Table 5. Proportion of airports with general aviation activities in which the nearby community's concentration of residents of color is greater than the surrounding county's concentration, presented in quartiles of lead emissions and population density.

22. Similarly, Table 6 presents the proportion of airports for which the nearby concentration of lower-income households is higher than in the surrounding county or counties. The general trends are less clear, but notably, of the 302 highest-emitting and highest-density airports, 57-60% have disproportionately more lower-income households in their vicinity compared to their surrounding county.

Lead emissions quartiles (lbs/year)	Population density quartiles (persons/square mile): Least dense [0.0184, 2.77]	(2.77, 7.02]	(7.02, 16.9]	Most dense (16.9, 2540]
Least emitting [0, 24]	60-66%	54-59%	51-55%	48-60%
(24, 59]	45-49%	51-56%	56-59%	60-72%
(59, 139]	44-54%	42-46%	53-59%	56-62%
Most emitting (139, 1490]	57-62%	42-43%	45-50%	57-60%

Table 6. Proportion of airports with general aviation activities in which the nearby community's concentration of lower-income households is greater than the surrounding county's concentration, presented in quartiles of lead emissions and population density.

23. Table 7 lists the 35 airports that are in the top 5% of lead emissions and top 5% of population density. I refer to these airports as "highest-emitting/highest-density airports." They are within one kilometer of 280,000 to 420,000 people, which is 7-11% of the national population of concern. They also account for 9% of all lead emissions from the 2,280 airports.

State	City	Airport	ID	Lead (lbs/yr)	Density (persons/sq. mile)
CA	Concord	Buchanan Field	CCR	550	110
CA	Upland	Cable	CCB	510	140
CA	Chino	Chino	CNO	960	95
CA	Murrieta/Temecula	French Valley	F70	540	120
CA	San Diego/El Cajon	Gillespie Field	SEE	1100	150
CA	Hayward	Hayward Exec	HWD	600	220
CA	Hemet	Hemet-Ryan	HMT	420	90
CA	San Diego	Montgomery-Gibbs Exec	MYF	1200	200
CA	Palo Alto	Palo Alto	PAO	970	81
CA	San Jose	Reid-Hillview of Santa Clara County	RHV	740	380
CA	Riverside	Riverside Municipal	RAL	600	180
CA	Sacramento	Sacramento Exec	SAC	450	170
CA	Watsonville	Watsonville Municipal	WVI	550	100
FL	Jacksonville	Herlong Recreational	HEG	440	79
FL	Jacksonville	Jacksonville Exec at Craig	CRG	550	81
FL	Miami	Miami Exec	TMB	960	120
FL	Hollywood	North Perry	HWO	1200	240
FL	West Palm Beach	Palm Beach County Park	LNA	700	93
GA	Atlanta	Dekalb-Peachtree	PDK	680	140
GA	Lawrenceville	Gwinnett County/Briscoe Field	LZU	390	110
ID	Nampa	Nampa Municipal	MAN	410	93
NE	Omaha	Millard	MLE	390	150
NJ	Teterboro	Teterboro	TEB	550	98
NV	Las Vegas	North Las Vegas	VGT	660	180
OH	Dayton	Dayton-Wright Brothers	MGY	460	95

OH	Kent	Kent State University	1G3	390	90
OR	Portland	Portland-Hillsboro	HIO	1200	80
SC	Greenville	Greenville Downtown	GMU	400	98
TX	Dallas	Addison	ADS	510	180
TX	Arlington	Arlington Municipal	GKY	480	160
TX	Grand Prairie	Grand Prairie Municipal	GPM	480	150
TX	Houston	West Houston	IWS	570	84
UT	Salt Lake City	South Valley Regional	U42	520	110
WA	Auburn	Auburn Municipal	S50	890	140
WA	Puyallup	Pierce County - Thun Field	PLU	540	130

Table 7. The 35 airports that are in both the top 5% of lead emissions and the top 5% of population density.

24. Table 8 compares race/ethnicity of the overall U.S. population to the population within one kilometer of: (1) all 2,280 airports with general aviation activities, (2) the 350 airports accounting for half of all lead emissions (referred to herein as "high-emitting airports"), (3) the 121 airports accounting for half the population within 1 km of NPIAS general aviation activities (referred to herein as "high-density airports"), and (4) the 35 highest-emitting/highest-density airports. The population living within one kilometer of general aviation airports, compared to the nation at large, is notably 1.4-1.7 times more likely to be NHPI and 2.4 times more likely to be AIAN. The population living within one kilometer of the 350 high-emitting airports, compared the nation at large, is notably 1.3 times more likely to be people of color, 1.5 times more likely to be Hispanic, 1.6 times more likely to be Asian, and 2.5-2.7 times more likely to be NHPI. The population living within one kilometer of the 121 high-density airports, compared to the nation at large, is notably 1.2 times more likely to be people of color, 1.4 times more likely to be Hispanic, 2 times more likely to be Asian, and 2.5-2.6 times more likely to be NHPI, following largely the same patterns as high-emitting airports. The population living within one kilometer of the 35 highest-emitting/highest-density airports, compared to the nation at large, is notably 1.6 times more likely to be people of color, 2 times more likely to be Hispanic, 2.3 times more likely to be Asian, and 4.5-5 times more likely to be NHPI.

	U.S. Population	Within 1km of general aviation airports [2,280]	Within 1km of high-emitting airports [350]	Within 1km of high-density airports [121]	Within 1km of highest-emitting/highest-density airports [35]
Total Population	331,449,281	2,427,530-3,972,447	697,795-1,178,410	1,218,205-1,618,169	277,222-423,098
% Hispanic	18.7	18.4-20.0	25.6-27.3	25.8-26.3	37.3-37.9
% White	57.8	57.4-60.4	47.1-50.2	47.6-47.7	32.3-33.4
% Black	12.1	9.0-9.1	10.8	9.0-9.2	10.3-11.1
% AIAN	0.7	1.6-1.7	0.4-0.5	0.5	0.3
% Asian	5.9	6.0-7.1	8.2-9.2	11.3-11.7	12.6-13.7
% NHPI	0.2	0.3	0.4-0.5	0.5	0.8-0.9
% Other	4.6	4.2-4.5	4.4-4.6	4.6-4.7	4.4-4.5
% Non-White	42.2	39.6-42.6	49.8-52.9	52.3-52.4	66.6-67.7
% Lower-Income	53.6	52.9-57.0	50.5-52.1	47.2-45.0	48.8-51.1

Table 8. Author's analysis of 2020 Decennial Census and 2017-2021 5-Year American Community Survey data. Demographic comparison of U.S. population and population within one kilometer of all NPIAS airports with general aviation activities, NPIAS airports accounting for 50% total lead emissions, NPIAS airports accounting for 50% population living within with 1km of general aviation activities, and NPIAS airports that are in both the top 5% of lead emissions and the top 5% of population density. Brackets indicate the number of airports. AIAN: American Indian and Alaska Native; NHPI: Native Hawaiian and Other Pacific Islander.

25. Table 9 below focuses on the 35 highest-density/highest-emitting airports and the relationship between the demographic compositions of the population within one kilometer of those airports and that of the population of the surrounding county or counties. Only results using the circle-based approach of estimating population within 1 km are presented. I tally the airports where the nearby concentration of people of color and/or lower-income population is higher than in the surrounding county or counties. I also tally the size of this disparity, meaning the percent difference in population concentration between the nearby community and that of the surrounding county or counties. Of the 35 highest-emitting/highest-density airports, 65.7% (23 airports) have disproportionately more people of color in their vicinity compared to their surrounding county, and 71.4% (25 airports) have disproportionately more lower-income households in their vicinity compared to their surrounding county. Of the 23 highest-emitting/highest-density airports with a greater concentration of people of color, 12 have disparities of 10-20% and 2 have disparities of

20%+. Conversely, of the 12 highest-emitting/highest-density airports with a greater concentration of White residents, only 5 have disparities of 10-20% and none have disparities of 20%+. Of the 25 highest-emitting/highest-density airports with a greater concentration of lower-income households, 8 have disparities of 10-20% and 3 have disparities of 20%+.

	Number [%] of highest-emitting/highest-density airports in which proportion within 1km > proportion in county			
	Higher	0-10% higher	10-20% higher	20%+ higher
% Hispanic	21 [60.0%]	11 [31.4%]	5 [14.3%]	5 [14.3%]
% White	12 [34.3%]	7 [20.0%]	5 [14.3%]	0
% Black	16 [45.7%]	12 [34.3%]	2 [5.7%]	2 [5.7%]
% AIAN	16 [45.7%]	16 [45.7%]	0	0
% Asian	18 [51.4%]	16 [45.7%]	1 [2.9%]	1 [2.9%]
% NHPI	20 [57.1%]	20 [57.1%]	0	0
% Other	14 [40.0%]	14 [40.0%]	0	0
% Non-White	23 [65.7%]	9 [25.7%]	12 [34.3%]	2 [5.7%]
% Lower-Income	25 [71.4%]	14 [40.0%]	8 [22.9%]	3 [8.6%]

Table 9. Author's analysis of 2020 Decennial Census and 2017-2021 5-Year American Community Survey data. Percentage point difference between demographic compositions of the population within one kilometer of the 35 highest-emitting/highest-density airports and the population in the associated counties, presented as all positive point differences and as divided into three bins. AIAN: American Indian and Alaska Native; NHPI: Native Hawaiian and Other Pacific Islander.

Conclusions

26. Airports with general aviation activities vary widely in lead emissions and surrounding population density. From an environmental justice perspective, we should be particularly concerned about the potential existence of racial/ethnic and socioeconomic disparities in the subset of airports with higher emissions and higher density, because those communities have the greatest concentration of residents exposed to the greatest lead pollution risk.

27. While the proportion of lower-income residents in communities adjacent to general aviation airports nationwide is slightly lower than the proportion of lower-income persons in the national population, the most concerning general aviation airports are typically located in communities that are disproportionately lower-income populations relative to their surrounding counties. As presented in Table 6, 57-60% of the communities adjacent to airports in the top quartile by lead emission and density are disproportionately more lower-income than their surrounding counties. These airports are located in counties that are generally higher-income than the U.S. as a whole, which means that the specific neighborhoods in which these airports are located reflect localized income inequalities. One key reason why county level socioeconomic disparity is an environmental justice issue, controlling for race/ethnicity, is that lower-income households near airports may face regional economic pressures such as the cost of housing, transportation, essentials, and employment that limit their ability to choose alternative places to live and work. In other words, lower-income residents in wealthier counties are often less able to escape the risks of lead exposure from general aviation airports because their income levels make other housing options unavailable.

28. While the proportion of non-White residents in communities adjacent to general aviation airports nationwide is similar to the proportion of non-White persons in the national population, the communities surrounding the most hazardous airports are disproportionately non-White. As presented in Table 3, the communities adjacent to airports in the top quartile by lead emission and density are 5-7.4 percentage points more non-White than the country as a whole. This racial/ethnic disparity is mostly explained by these airports being located in counties that generally have more residents of color than the country as a whole. Nonetheless, one can argue that the appropriate federal policy should focus on mitigating racial/ethnic disparities at a national level, and it is the case that the harms associated with avgas disproportionately impact people of color in the U.S.

29. As presented in Table 8, disparities in race/ethnicity exist for airports that account for the top 50% of lead emissions, and for airports that account for the top 50% of at-risk residents (persons residing within 1 km of an NPIAS airport with general aviation activities). As shown in Table 8, 49.8-52.9% of residents living within 1 km of one of the 350 airports accounting for half of all airport lead emissions are persons of color, compared to 42.2% of the national population. This ratio

is roughly the same (52.3-52.4% residents of color) for communities within 1 km of one of the 121 airports that account for half of all persons living within 1 km of an airport with general aviation activities.

30. Disparities in airport-adjacent communities by race/ethnicity and income are even more pronounced when considering airports that are in the top 5% by lead emissions and by density. This subset of airports is relevant to consider because of the outsized public health risk that they pose by exposing the most residents to the highest levels of airborne lead. As shown in Table 8, 66.6-67.7% of residents within 1 km of the 35 highest-emitting and highest-density airports are persons of color, making residents of these airport-adjacent populations 1.6 times more likely to be persons of color than in the rest of the country. Similarly, as shown in Table 9, 65.7% of these highest-emitting and highest-density airports have disproportionately more residents of color in their vicinity compared to their surrounding county, and 71.4% have disproportionately more lower-income households in their vicinity compared to their surrounding county.

31. I intend the above analysis to supplement the EPA's with a comprehensive, systematic, and reproducible evaluation of racial/ethnic and socioeconomic disparities in the communities surrounding airports with general aviation activities. This analysis identifies the subsets of airports, as ranked by lead emissions and population density, which disproportionately harm communities of concern.

I declare, under penalty of perjury, that the foregoing is true and correct to the best of my knowledge and recollection. I executed this declaration on Jan 10, 2023, in Walnut Creek, California.

Derek Ouyang

EXHIBIT C

PNAS nexus

PNAS Nexus, 2022, **2**, 1–11
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Research Report

Leaded aviation gasoline exposure risk and child blood lead levels

Sammy Zahran[a,b,c,*], Christopher Keyes[a,c] and Bruce Lanphear[d]

[a]Department of Economics, Colorado State University, Fort Collins, CO 80523, USA
[b]Department of Epidemiology, Colorado School of Public Health, Aurora, CO 80045, USA
[c]Mountain Data Group, Fort Collins, CO 80524, USA
[d]Faculty of Health Sciences, Simon Fraser University, Burnaby, BC V5A 1S6, Canada
*To whom correspondence should be addressed: Email: szahran@colostate.edu
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Abstract

Lead-formulated aviation gasoline (avgas) is the primary source of lead emissions in the United States today, consumed by over 170,000 piston-engine aircraft (PEA). The U.S. Environmental Protection Agency (EPA) estimates that four million people reside within 500m of a PEA-servicing airport. The disposition of avgas around such airports may be an independent source of child lead exposure. We analyze over 14,000 blood lead samples of children (≤5 y of age) residing near one such airport—Reid-Hillview Airport (RHV) in Santa Clara County, California. Across an ensemble of tests, we find that the blood lead levels (BLLs) of sampled children increase in proximity to RHV, are higher among children east and predominantly downwind of the airport, and increase with the volume of PEA traffic and quantities of avgas sold at the airport. The BLLs of airport-proximate children are especially responsive to an increase in PEA traffic, increasing by about 0.72 μg/dL under periods of maximum PEA traffic. We also observe a significant reduction in child BLLs from a series of pandemic-related interventions in Santa Clara County that contracted PEA traffic at the airport. Finally, we find that children's BLLs increase with measured concentrations of atmospheric lead at the airport. In support of the scientific adjudication of the EPAs recently announced endangerment finding, this in-depth case study indicates that the deposition of avgas significantly elevates the BLLs of at-risk children.

Keywords: aviation gasoline, child blood lead, piston-engine aircraft

Significance Statement:

In the United States, hundreds of millions of gallons of tetraethyl lead-formulated gasoline are consumed by piston-engine aircraft (PEA) annually, resulting in an estimated half-million pounds of lead emitted into the environment. About four million persons reside, and about six hundred K-12th grade schools are located, within 500 meters of PEA-servicing airports. In January 2022, the US Environmental Protection Agency launched a formal evaluation of "whether emissions of lead from PEA cause or contribute to air pollution that endangers public health or welfare." In support of the EPA's draft endangerment finding and request of public comment, an ensemble of evidence is presented indicating that the deposition of leaded aviation gasoline significantly elevates the blood lead levels of at-risk children.

Introduction

Over the last four decades, the blood lead levels (BLLs) of children in the United States declined significantly, coincident with a series of policies that removed lead from paint, plumbing, food cans, and automotive gasoline. Most effective among these interventions was the phase-out of tetraethyl lead (TEL) from automotive gasoline under provisions of the Clean Air Act of 1970 and amendments in 1990.

While TEL is no longer used as an additive in automotive gasoline, it remains a constituent in aviation gasoline (avgas) used by an estimated 170,000 piston-engine aircraft (PEA) nationwide. TEL is one of the best-known additives for mitigating the risk of engine knocking or detonation, which can lead to sudden engine failure. In the United States, hundreds of millions of gallons of TEL-formulated gasoline are consumed by PEA annually, resulting in an estimated half-million pounds of lead emitted into the environment. Today, the use of lead-formulated avgas accounts for about half to two thirds of current lead emissions in the United States (1). In a recently published consensus study on options for reducing lead emissions by PEA by the National Academies of Sciences, Engineering, and Medicine, the authors note: "While the elimination of lead pollution has been a U.S. public policy goal for decades, the GA [General Aviation] sector continues to be a major source of lead emissions" (2).

Several studies have linked avgas use to elevated atmospheric lead levels in the vicinity of airports (3–8). The U.S. EPA estimates that four million persons reside, and about six hundred K-12th grade schools are located within 500 meters of PEA-servicing

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Table 1. Coefficients of residential distance, near angle, and PEA Traffic vis-à-vis Child BLLs.

BLLs (μg/dL)	(1)	(2)	(3)	(4)†
1. Distance RHV (0.5 to 1 miles)	−0.161**	−0.231***	−0.234***	−0.055***
	(0.070)	(0.082)	(0.067)	(0.018)
2. Distance RHV (1 to1.5 miles)	−0.173***	−0.233***	−0.235***	−0.058***
	(0.065)	(0.080)	(0.066)	(0.018)
3. PEA traffic volume	0.312***	0.319***	0.168**	0.073***
	(0.063)	(0.063)	(0.066)	(0.015)
4. East residence	0.148***	0.169***	0.237***	0.144***
	(0.034)	(0.037)	(0.036)	(0.009)
5. Constant	2.031***	1.893***	2.035***	0.746***
	(0.085)	(0.107)	(0.336)	(0.099)
Observations	14,804	14,804	14,804	14,804
R^2	0.064	0.076	0.176	0.290
Distance	Yes	Yes	Yes	Yes
PEA traffic	Yes	Yes	Yes	Yes
Near angle FE	Yes	Yes	Yes	Yes
Draw controls	Yes	Yes	Yes	Yes
Block FE	No	Yes	Yes	Yes
Demography	No	Yes	Yes	Yes
Other exposures	No	Yes	Yes	Yes
SES	No	No	Yes	Yes
Timing controls	No	No	Yes	Yes
Person RE	No	No	Yes	Yes

Notes: Bootstrapped SE in parentheses *** $P < 0.01$, ** $P < 0.05$, and * $P < 0.1$; In columns (1) to (3) BLL is in μg/dL; †, in column (4), we take the natural log of BLL. All models limited to children ≤5 y of age, residing <1.5 miles RHV (or 2.4 km); Distance is defined between RHV and the child's residence; Residential near angle is defined in equation [1], with east residence being downwind children; PEA traffic is average daily PEA operations at RHV, calculated over 60 days from child's date of draw and normalized. Demography includes child's age (years) and sex (1=female, 0=otherwise); Draw controls includes: draw method (1=capillary, 0=otherwise), limit of quantification (1=BLL ≤ limit of quantification, 0=otherwise), and repeated sample (0=singleton observation, 1,...,n=repeated n times); Other exposures includes: count of TRI facilities ≤2 miles from residential address, and percent of neighborhood housing stock built ≤ 1960; SES is the neighborhood socioeconomic status index; timing controls include indicators for season and year-quarter of the date of draw; inclusion of variables is denoted yes, where applicable.

airports (9). Two studies have statistically linked avgas use to BLLs of children residing in the vicinity of general aviation airports. In their groundbreaking study, Miranda et al (10) reported a striking relationship between child BLLs and airport proximity, noting that "[t]he estimated effect on BLLs exhibited a monotonically decreasing dose-response pattern" with children at 500 and 1,000 meters of an airport at greatest risk of elevated BLLs. In a study involving over 1 million children and 448 airports in Michigan, Zahran et al (11) found that child BLLs: (1) increased dose-responsively in proximity to airports; (2) declined measurably among children sampled in the months after the tragic events of 9-11, resulting from an exogenous reduction in PEA traffic; (3) increased dose-responsively in the flow of PEA traffic across a subset of airports; and (4) increased in the percent of prevailing wind days drifting in the direction of a child's residence.

On the basis of such studies and decades of research on the harm to human health caused by lead, various public interest organizations have petitioned the EPA to make an endangerment finding under Section 231 of the Clean Air Act for aviation gasoline (avgas) emissions. While the EPA recognizes that there is no known safe level of lead exposure, it has cautioned that additional scientific research is needed "to differentiate aircraft lead emissions from other sources of ambient air lead" (12) that may cause elevated BLLs in nearby children.

Subsequent to a report prepared for the County of Santa Clara showing that exposure to leaded avgas contributes to child BLLs (13), and a new petition by various nonprofit and governmental organizations, in January 2022 the EPA launched a formal evaluation of "whether emissions of lead from PEA cause or contribute to air pollution that endangers public health or welfare." In recent weeks, the EPA published its draft endangerment finding and is currently accepting public comment. In this paper, we present relevant information for the scientific adjudication of the EPA's draft endangerment finding, supporting the conclusion that emissions from PEA independently contribute to child BLLs, potentially endangering the health and welfare of populations residing near over 21,000 general aviation airports that service avgas-consuming aircraft.

Our paper analyzes the BLLs of children (≤5 y of age) over a 10-y observation period (from 2011 January 31 to 2020 December 31) who reside near one PEA-servcing airport–Reid-Hillview Airport (RHV) in Santa Clara County. Of the more than 21,000 airports appearing in the 2017 EPA National Emissions Inventory, RHV ranks 36th in terms of the quantity of emissions released. From 2011 January to 2018 December , 2.3 million gallons of avgas were sold at RHV. At about 2 grams of lead per gallon, and based on an EPA estimate that 95% of lead consumed is emitted in exhaust, over this 8-y period about five metric tons of lead was emitted at RHV.

The purpose of our analysis is to test key indicators of exposure risk, including child residential distance, residential near angle (or downwind residence), and volume of traffic from the date of the blood draw. We follow with extended analyses involving the statistical interaction of residential distance and air traffic, a natural experiment exploiting an observed contraction in PEA traffic at RHV following pandemic-related social distancing measures enacted countywide, and an analysis linking child BLLs to atmospheric lead measurements at the airport. Across all tests, we find consistent evidence that exposure to avgas increases child BLLs, adding a data-rich and in-depth case study to the nascent scientific literature on the epidemiological hazard of leaded avgas.

Results

Main analysis

We begin with analysis of our three main indicators of avgas exposure risk: (1) child residential distance, (2) child residential near angle, and (3) child exposure to PEA traffic. Table 1 reports regression coefficients on our main indicators of exposure risk. Our response variable of child BLL is measured in μg/dL units. Following others (10,11), residential distance is also divided into intervals: <0.5 miles (or <0.8 km), 0.5 to 1 mile (or 0.8 to 1.6 km), and 1 to 1.5 miles (or 1.6 to 2.4 km) from RHV (Our inner orbit of exposure risk at < 0.5 miles conforms to previous research. Miranda et al (10) find that children at 500m to 1km from a general aviation airport in North Carolina are at highest at-risk of presenting with elevated BLLs. Zahran et al (11) find that sampled children within 1km of 448 airports in Michigan are at greatest risk. The EPA (14) maintains that children within 500m of PEA-servicing airports are at highest risk of exposure to aviation-related atmospheric lead. Our inner distance of <0.5 miles sits between the consensus range of exposure risk at 500m to 1km).

With respect to distance, reported coefficients in Table 1 have the interpretation of an estimated difference in mean BLLs (in μg/dL units) for children at 0.5 to 1 mile (or 0.8 km to 1.6 km) and 1 to 1.5 miles (or 1.6 km to 2.4 km), respectively, vis-a-vis children most proximate to northwest tip of RHV (point coordinates 37.336225, −121.8230194) (Supplementary Material Table S2 reports results involving the estimation of a series of linear models with residential distance measured continuously and applying various transformations to both distance and child BLLs. Other things held equal, we find that no matter the measurement or transformation—distance measured linearly, log or square root transformed and child BLLs measured linearly or log transformed—child BLLs decrease statistically significantly with residential distance from RHV).

For residential near angle, the east parameter estimate has the interpretation of an estimated difference in mean BLLs (in μg/dL units) for sampled children residing east (and predominantly downwind), relative to sampled children north of RHV. PEA traffic exposure is measured as a rolling average of PEA operations over 60 days from the date of a child's blood draw. This quantity is converted to a percentile ranging from 0 to 1. With respect to PEA traffic, coefficients have the interpretation of the estimated change in child BLLs (in μg/dL units) associated with an increase in PEA traffic exposure from the observed minimum to the maximum.

We report coefficients from four different models that graduate in their saturation of control variables. The coefficients pertaining to our indicators of risk behave relatively consistently across models of varying saturation. Model (4) reports coefficients involving the natural log transformation of child BLL. Focusing our interpretation on models (3) including all possible control variables, we find that sampled children at 0.5 to 1 mile and 1 mile to 1.5 miles present with BLLs that are 0.234 and 0.235 μg/dL lower on average than sampled children nearest to RHV(< 0.5 miles). With respect to residential near angle, in model (3) we find that sampled children residing east (and predominately downwind) have BLLs that are 0.237 μg/dL higher than sampled children north of RHV. As shown in model (3), child BLLs are responsive to the measured volume of PEA traffic, increasing an estimated 0.168 μg/dL with an increase in PEA traffic exposure from the observed minimum to the maximum of traffic.

To contextualize the meaning of estimated differences in BLLs by distance, near angle, and traffic exposure, we compare our results to the estimated increase in BLLs of children in Flint during the much publicized Flint Water Crisis (FWC). At the height of the FWC, child BLLs surged by an estimated 0.35 to 0.45 μg/dL over baseline levels (15) (With over 21,000 time-stamped blood lead samples from children in Genesee County drawn from 2013 January 01 to 2016 July 19, (15) pursued a series of quasi-experimental tests to identify the causal effects of water-lead exposure, finding that the switch in water source in Flint caused child BLLs to increase by about 0.35 to 0.45μg/dL from a precrisis baseline of about 2.3 μg/dL). As shown in Table 1, children within 0.5 miles of RHV, children east of RHV, and children exposed to maximum traffic have BLLs that are about 0.2 μg/dL higher than statistically similar children more distant from RHV, residing north of RHV, and exposed to minimum traffic, respectively. These estimated differences are equivalent to about 50% of the estimated increase in BLLs of sampled children at the height of the FWC over baseline levels in Flint.

Next, we analyze threshold effects. Table 2 reports odds ratios for our main indicators of avgas exposure risk across three models with varying saturation of control variables. Given the ordered categorical measurement of our response variable, the reported odds ratios have the interpretation of the expected change in the odds of a child's blood lead sample exceeding 4.5 μg/dL relative to the combined odds of appearing in lower BLL categories. Focusing on saturated model (3), as compared to children <0.5 miles of RHV, sampled children residing 0.5 to 1 mile from RHV have 0.827× lower odds of superseding 4.5 μg/dL relative to the combined odds of lower BLL categories. For children at 1 to 1.5 miles, the probability of a blood lead sample exceeding 4.5 μg/dL is 21.4% lower than statistically similar children at <0.5 miles. With respect to residential near angle, children residing east of RHV are 2.18× more likely to present with BLLs ≥4.5 μg/dL than children residing north of RHV, all else held equal. On the question of PEA traffic exposure, we find that an increase from minimum to maximum exposure increases the odds of eclipsing 4.5 μg/dL relative to the combined odds of presenting with a lower BLL category by a multiplicative factor of 1.31.

Table 2. Proportional odds of residential distance, near angle, and PEA Ttraffic vis-à-vis categorical child BLLs.

	(1)	(2)	(3)
1. Distance RHV (0.5 to 1 miles)	0.847**	0.828**	0.827**
	(0.060)	(0.070)	(0.072)
2. Distance RHV (1 to 1.5 miles)	0.819***	0.804***	0.786***
	(0.055)	(0.066)	(0.068)
3. PEA traffic volume	1.989***	2.045***	1.311***
	(0.111)	(0.118)	(0.099)
4. East residence	1.749***	1.828***	2.182***
	(0.119)	(0.147)	(0.218)
Observations	14,804	14,804	14,804
Distance	Yes	Yes	Yes
PEA traffic	Yes	Yes	Yes
Near angle FE	Yes	Yes	Yes
Draw controls	Yes	Yes	Yes
Block FE	No	Yes	Yes
Demography	No	Yes	Yes
Other exposures	No	Yes	Yes
SES	No	No	Yes
Timing controls	No	No	Yes
Person RE	No	No	Yes

See Table 1 Notes.

Extended analysis

While results reported in Table 1 and Table 2 on child residential distance, residential near angle, and exposure to PEA traffic support the hypothesis that child BLLs are statistically associated with the risk of exposure to avgas, next we report results from additional analyses involving the statistical interaction of residential distance and PEA traffic, a natural experiment involving an observed contraction in PEA aircraft at RHV following social distancing measures enacted countywide, and the substitution of PEA traffic with measured atmospheric concentrations of lead at the airport.

First, we consider a statistical interaction between PEA traffic exposure and residential distance. Insofar as avgas gasoline exposure is a source of risk, we expect that the BLLs of sampled children proximate to RHV will be more responsive to the flow of PEA traffic than children more distant from the airport. As before, Table 3 presents coefficients for different models that increase successively in the saturation of control variables. Across models (1) through (4), estimated coefficients behave as theoretically expected and are distinguishable from chance. Model (4) reports coefficients involving the natural log transformation of child BLL. Concentrating interpretation on model (3), the main effect of residential distance indicates that sampled children at 0.5 to 1.5 miles (or 0.8 to 1.6 km) from RHV present with BLLs that are 0.242 μg/dL lower than children nearest to the airport. Because PEA traffic is

Table 3. Coefficients of PEA traffic × residential distance at RHV vis-à-vis child BLLs.

BLLs (μg/dL)	(1)	(2)	(3)	(4)†
1. Distance RHV (0.5 to 1 miles)	−0.175***	−0.241***	−0.242***	−0.059***
	(0.066)	(0.079)	(0.064)	(0.018)
2. PEA traffic volume	1.080***	1.034***	0.845***	0.235***
	(0.219)	(0.211)	(0.182)	(0.051)
3. Distance RHV × PEA traffic	−0.817***	−0.760***	−0.720***	−0.173***
	(0.227)	(0.220)	(0.195)	(0.051)
4. Constant	2.196***	2.063***	2.139***	0.789***
	(0.083)	(0.109)	(0.325)	(0.096)
Observations	14,804	14,804	14,804	14,804
R^2	0.065	0.077	0.177	0.291
Distance	Yes	Yes	Yes	Yes
PEA traffic	Yes	Yes	Yes	Yes
Near angle FE	Yes	Yes	Yes	Yes
Draw controls	Yes	Yes	Yes	Yes
Block FE	No	Yes	Yes	Yes
Demography	No	Yes	Yes	Yes
Other exposures	No	Yes	Yes	Yes
SES	No	No	Yes	Yes
Timing controls	No	No	Yes	Yes
Person RE	No	No	Yes	Yes

See Table 1 Notes.

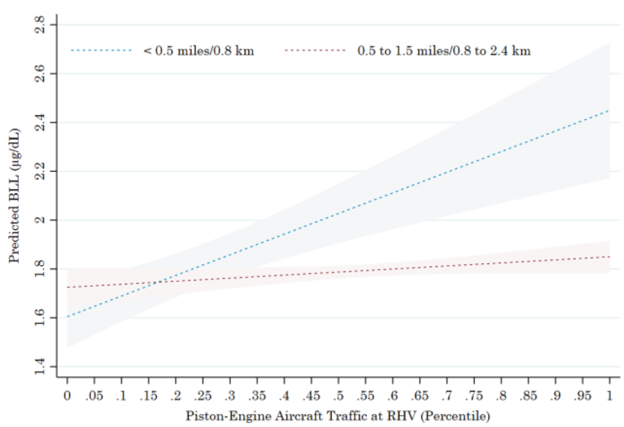

Fig. 1. Predicted child BLLs by residential distance and PEA traffic.

centered at the mean, the coefficient on PEA traffic exposure indicates that a doubling of PEA traffic from the mean is associated with a 0.845 μg/dL increase in child BLLs, all else held equal. The estimated coefficient of interaction is negative ($\widehat{\delta}$ = -0.720), implying that an increase in PEA traffic exposure affects the BLLs of sampled children more distant from RHV less than children proximate to RHV.

Figure 1 visualizes the effects reported in Table 3, showing predicted BLLs of sampled children at two distances—within 0.5 miles (0.8 km) and 0.5 to 1.5 miles from RHV—over the range of observed PEA traffic exposure. Predictions are from model (3) in Table 3, with all other model covariates set to their means. Figure 1 shows that, all else held equal, a movement from the minimum to the maximum PEA traffic exposure increases the BLLs of sampled children proximate to RHV by 0.92 μg/dL (1.57 to 2.49 μg/dL). By comparison, children more distant from RHV (0.5 to 1.5 miles) experience a more modest increase in BLLs of about 0.16 μg/dL (1.71 to 1.87 μg/dL) for an increase in PEA traffic from the minimum to the maximum.

Table 4. Coefficients of PEA traffic contraction period at Reid-Hillview vis-à-vis Child BLLs.

BLLs (μg/dL)	(1)	(2)	(3)	(4)†
1. Contraction period	−0.236***	−0.230***	−0.102*	−0.037**
	(0.032)	(0.034)	(0.061)	(0.071)
2. Constant	2.187***	2.082***	1.964***	0.721***
	(0.084)	(0.107)	(0.362)	(0.100)
Observations	14,804	14,804	14,804	14,804
R^2	0.062	0.074	0.176	0.290
Distance	Yes	Yes	Yes	Yes
PEA traffic	No	No	Yes	Yes
Near angle FE	Yes	Yes	Yes	Yes
Demography	Yes	Yes	Yes	Yes
Draw controls	Yes	Yes	Yes	Yes
Block FE	Yes	Yes	Yes	Yes
Other exposures	No	Yes	Yes	Yes
SES	No	No	Yes	Yes
Timing controls	No	No	Yes	Yes
Person RE	No	No	Yes	Yes

See Table 1 Notes.

The interaction effect of piston engine aircraft traffic exposure and residential distance persists when we restrict the sample to toddlers (age 12 to 24 months), that are especially vulnerable to place-based exposures (16). Recapitulating the results of model (3) in Table 3 and limiting to sampled children age 12 to 24 months, we observe an amplification of the distance × traffic effect. The BLLs of sampled toddlers living near RHV increase by 1.60 μg/dL (1.79 to 3.39 μg/dL) with a change from minimum to maximum exposure to PEA traffic (see Supplementry Material Figure S1). Sensitivity tests in which PEA traffic is substituted for monthly quantities of avgas sold at RHV, behave similarly. In going from 5,000 to 35,000 gallons of avgas sold, the BLLs of children who live near the airport increase by an estimated 0.54 μg/dL (see Supplementary Material Figure S2).

Next, we present results of a robustness test that leverages reductions in aircraft traffic following the outbreak of COVID-19. As the pandemic gripped the country, state and local governments enacted various restrictions on the behavior of households and firms to limit the spread of the disease. Corresponding with these efforts, PEA traffic declined measurably at RHV over the months of February to July of 2020. Compared to three baseline control periods—2011 to 2019, 2015 to 2019, and 2018 to 2019—PEA traffic declined by 34% to 44%. PEA traffic at RHV returned to pre-pandemic levels in August to December of 2020. The pandemic-caused dynamics in PEA operations at RHV present us with a natural experiment. If avgas exposure is a source of risk, then we should observe a reduction in the BLLs of children sampled in this PEA traffic contraction period, other things held equal. Table 4 presents estimated coefficients pertaining to the PEA traffic contraction period. As expected, the BLLs of sampled children during the PEA traffic contraction are significantly lower vis-à-vis children sampled before and after the contraction. Across models (1) and (2), we find that BLLs decreased by about 0.23 μg/dL, depending on the presence of control variables. The coefficient attenuates intuitively with the inclusion of measured PEA traffic exposure in model (3) and in model (4) where child BLLs are log transformed.

Last, we evaluate the relationship between child BLLs and measured atmospheric concentrations of lead at the airport with data from the Bay Area Air Quality Management District (BAAQMD). The BAAQMD data covered the period of 2012 February to 2018 March, with an atmospheric reading taken (on average) every

Table 5. Coefficients of atmospheric lead concentrations vis-à-vis child BLLs.

BLLs (μg/dL)	(1)	(2)	(3)†	(4)
1. Atmospheric lead (μg/m^3)	4.312***	4.054***	1.625***	2.102
	(1.289)	(1.300)	(0.348)	(1.372)
2. Constant	1.470***	1.238**	0.086	−0.676
	(0.403)	(0.470)	(0.164)	(0.630)
Observations	9,542	9,542	9,542	9,542
R^2	0.262	0.266	0.266	0.268
Distance	No	Yes	Yes	Yes
Near angle FE	No	Yes	Yes	Yes
PEA traffic	No	No	No	Yes
Draw controls	Yes	Yes	Yes	Yes
Block FE	Yes	Yes	Yes	Yes
Demography	Yes	Yes	Yes	Yes
Other exposures	Yes	Yes	Yes	Yes
SES	Yes	Yes	Yes	Yes
Timing controls	Yes	Yes	Yes	Yes
Person RE	Yes	Yes	Yes	Yes

Dependent variable is BLL in μg/dL; See Table 1 Notes.

6 days. The monitor was located in the aircraft run-up zone (point coordinates, 37.329841, −121.815438). Given the time-abbreviated nature of the air quality data, only 9,542 of the 14,804 blood lead samples used in our analysis could be assigned an atmospheric lead concentration coincident with the timing of blood draw. Results are reported in Table 5. Focusing attention on Model (2), an increase in atmospheric lead of 1 microgram per cubic meter (μg/m^3) increases child BLLs by 4.05 μg/dL (As noted in the methods section, this observed effect corresponds to a measurement of atmospheric lead involving a twomonth moving average (in micrograms per cubic meter) from the date of child blood draw. Restricting to 30 days before blood drawreduces the estimated coefficient to 2.45 μg/dL (95% CI:0.93, 3.96)). More substantively, an increase from the observed minimum to the observed maximum (of 0.04 to 0.12 μg/m^3) is associated with an increase of about 0.21 μg/dL, an effect size comparable to what we observe with respect to measured PEA traffic. Intuitively, in model (4), the observed atmospheric concentration effect dissipates with the inclusion of measured traffic. Following Richmond-Bryant et al (17), we also render a version Eq. (8) that takes the natural log of child BLL and atmospheric lead. Our estimated elasticity of child BLL vis-a-vis atmospheric lead of 0.123 (95% CI:0.075, 0.170) matches Richmond-Bryant et al (17) near exactly (see Supplementary Material Figure S3).

Discussion

In this study, we assessed whether the BLLs of sampled children around RHV are associated with indicators of aviation-related lead exposure, net of other lead exposure pathways.

Main analysis

Controlling for other known sources of lead exposure both explicitly and indirectly (As described in the methods section on control data, statistical models adjust for child proximity to lead-emitting toxic release inventory facilities, legacy use of lead-based paint by measurement of the age of housing stock in the census tract of residence, and include a neighborhood fixed effect to account for unobservables like soil lead accumulation that may influence BLLs that are common to sampled children within a given neighborhood but varying across neighborhoods), demographic characteristics, and neighborhood conditions, the evidence from main analyses of a statistical link between avgas exposure risk and child BLLs includes:

(1) The BLLs of the sampled children increase significantly with proximity to RHV. Children residing within 0.5 miles (0.8 km) of RHV present with significantly higher BLLs than children more distant of RHV. As shown Supplementary Material Table S2, this relationship between child BLLs and distance to RHV Airport is robust to various linear and nonlinear transformations of both input and response variables.
(2) BLLs are significantly and substantively higher among sampled children residing East (and predominantly downwind) of RHV.
(3) BLLs of sampled children increase significantly with the volume of measured PEA traffic at RHV from the date of blood draw.
(4) As evidenced in Table 2 the probability that a sampled child's BLL exceeds the CDPH-defined threshold of 4.5 μg/dL, increases significantly with proximity to RHV, is higher among children residing east of RHV, and increases with the volume of PEA traffic.

Estimated relationships between BLLs and our main indicators of avgas exposure risk are quantitatively similar to results of other studies (10,11).

Extended analysis

Again, controlling for other known sources of lead, child demographic characteristics, and neighborhood conditions, the evidence for a statistical link between child BLLs and avgas exposure from extended analyses, include:

(1) As evidenced in Table 3, the BLLs of sampled children proximate to RHV are significantly more responsive to PEA traffic and avgas sales at RHV (see Supplementary Material Figure S1) than quantitatively similar children who live more distant from the airport. Substantively, an increase from minimum to maximum PEA traffic increases the BLLs of proximate children by over 0.70 μg/dL.
(2) The interaction effect of child residential distance and volume of PEA traffic amplifies for toddlers 12 to 24 months, a particularly sensitive subpopulation to place-based exposure risk.
(3) Following efforts to stem the spread of COVID-19, PEA traffic declined significantly in the months of February to July at RHV. As evidenced in Table 4, the BLLs of children sampled in this PEA traffic contraction period declined significantly.
(4) As shown in Table 5, statistically significant results persist with the substitution of PEA for measured atmospheric concentration of lead at the airport. Our estimated elasticity of child BLL vis-a-vis atmospheric lead corroborates Richmond-Bryant et al (17) finding that child BLLs increase with exposure to airborne lead concentrations (TSP) below 0.15 μg/m^3.

While it is statistically improbable that the ensemble of evidence presented above arises by chance alone, we briefly consider a possible objection arising from child residential proximity to the San Jose Speedway (SJS). The SJS operated for many decades and was located southwest of RHV (see Supplementary Material Figure 4) (We wish to thankMichael McDonald for alerting us to the history of the SJS and for forwarding this hypothesis). Importantly, the cars racing the oval at SJS were fueled with lead-formulated gasoline. In a clever natural experiment exploiting the switch from leaded to unleaded gasoline in NASCAR and ARCA racing series in 2007, Hollingsworth and Rudik (2019) (18) found that "(i) ambient airborne lead concentrations increase immediately after a NASCAR race, (ii) counties with leaded NASCAR races have higher rates of child lead poisoning." Additionally, Bui et al (2022) (19) found that maternal exposure to airborne lead emissions from NASCAR races produced significant adverse pregnancy outcomes. Perhaps, these acute NASCAR effects have a lasting legacy, with the lead emitted from racing events depositing in the soils of neighborhoods of where children now reside. To test this possibility, we calculated the Haversine distance from a sampled child's residence to the historic location of the SJS (point coordinates 37.3293856, −121.8202305), see Supplementary Material Figure S4 for aerial photo. As we do for distance to RHV, we test the effect of distance to the SJS in both continuous and categorical terms of <0.5 miles, 0.5 to 1 mile, 1 to 1.5 miles, and >1.5 miles (see Supplementary Material Table S3).

Supplementary Material Table S3 shows results from this exercise, with distance to the speedway measured continuously and categorically, and with and without indicators of avgas exposure risk emanating from RHV. Across all models, the effect of proximity to the historic SJS on child BLLs is indistinguishable from chance. Because the historic location of the SJS is west of RHV, the null results are compatible with our finding showing that the BLLs of sampled children west (and predominately upwind) of RHV have lower BLLs than children east (and predominately downwind) of RHV.

As noted in the methods section, our point location decision at the northwest end (The northwest corner of RHV is also home to aircraft maintenance activities known to release lead in significant enough quantities to increase the risk of elevated blood lead in workers and indirectly among children in their care. Chen and Eisenberg (2013) (20) report that "The airborne lead concentration during sandblasting of spark plugs approached an occupational exposure limit for a short-term exposure, [with] small parts, tools, and metal shavings on and around workbench areas, desktops, and open shelving units pos[ing] a safety hazard.") of the airport was motivated by previous research showing that the bulk of emissions released over the landing-takeoff (LTO) cycle occur at take-off and climb out (8). Pointing to a recently published EPA report with model-extrapolated estimates of airborne lead at RHV, readers may note Section C.2.2 and accompanying figures C-3 to C-5 showing that ground-level lead concentrations appear to collect disproportionately at the Southeast corner of RHV during the run-up phase of the LTO cycle. While very important to the study of ground-level emissions, Carr et al (2011), Feinberg and Turner (2013) (21), and the EPA report itself (2020) (14) note that run-up emissions only account for about 11% of all airport lead emissions.

Still, to address possible concerns that our findings result from our point location decision, we perform a series of analyses involving various other point locations at the airport. Each new point location analyzed required separate distance and near angle calculations to a sampled child's place of residence. Supplementary Material Table S4 summarizes this statistical exercise. Across all models, the coefficients pertaining to child residential distance, near angle, and PEA traffic are robust to the point location judgment.

On the matter of avgas exposure risk to families and children proximate to general aviation airports, the National Academies of Sciences, Engineering, and Medicine maintains: "Because lead does not appear to exhibit a minimum concentration in blood below which there are no health effects, there is a compelling reason to reduce or eliminate aviation lead emissions." The ensemble evidence compiled in this study supports the "compelling" need to limit aviation lead emissions to safeguard the welfare and life chances of at-risk children.

Materials and methods

Child blood lead data

Permission to analyze blood lead was granted by agreement with the Childhood Lead Poisoning Prevention Branch (CLPPB) of the California Department of Public Health (CDPH). Databases were queried for records with: (1) an indication of residence in Santa Clara County, (2) a date of blood draw occurring within the last 10 y, (3) a date of birth for the sampled person, and (4) a reported blood lead value.

CDPH-records with indication of a residential address in Santa Clara County were independently geo-coded. We normalized each residential address by removing special characters and apartment numbers or letters. The resulting query parameter of this process was a lowercase string in the form of "number street, city, state" that was submitted to the Google Geocode API service to derive longitude and latitude point coordinates for each address record.

Responses from the API service included a confidence label indicating the level of accuracy, with the highest level of accuracy being a "rooftop" match. In all, 94.28% of address records were uniquely matched to rooftop point coordinates. Unmatched addresses were excluded from the final data set. Point coordinates corresponding to each rooftop address was then used to calculate distance and near angle variables. Restricting to children ≤5 y of age at the time of blood draw, residing < 1.5 miles (or 2.4 km) of RHV, observed from 2011 January 1 to 2020 December 31, and with a rooftop address, we arrived at 14,876 blood lead sample observations for this statistical analysis.

The main response or outcome variable of analytic interest is BLL) measured in micro-grams per deciliter of blood (μg/dL units). Restricting to children ≤5 y of age at the moment of blood sample, residing <1.5 miles of Reid-Hillview, and observed from 2011 January 1 to 2020 December 31, the unconditional mean BLL of sampled children was 1.80 μg/dL. About 1.5% of sampled children present with BLLs ≥ 4.5μg/dL, the CLPPB-defined threshold for action.

Five control variables from RASSCLE II/HL7 known to be correlated with child BLLs were collected from CDPH data, including: child gender, child age, method of blood draw, sample detection limit, and sample order. Gender is measured as 1 = female; child *age* is measured in years (ranging from 0 to 18); the method *of* blood draw = 1 if capillary, and 0 = otherwise; sample detection limit is measured as 1 = if the reported BLL is at or below the limit of quantification, and 0 = otherwise (In Supplementary Material Table S5 we render a series models where the observed BLLs is adjusted by common single imputation methods involving 1) BLL/ $\sqrt{2}$; 2) BLL×log 2; and ln(BLL/ $\sqrt{2}$)); and sample order which codes the count of blood samples (0=singleton observation, 1,...,n = repeated n times).

Avgas exposure risk data

We test three independent indicators of exposure risk to leaded avgas, including child residential distance, child residential near angle to capture whether a sampled child resides downwind of RHV, and the volume of PEA traffic from the moment of child blood draw. Child exposure risk to leaded avgas (and implied dispersion of the pollutant) is assumed to decrease linearly with distance, increases with downwind residence, and increases linearly with measured volume of PEA traffic.

Residential distance

Following others (10,11), we calculate the distance from the residential address of a sampled child to RHV. Using distance information on each child as an indicator of exposure risk, we test whether the BLLs of sampled children increase measurably with proximity to RHV.

Over the LTO cycle, studies find that the bulk of aircraft emissions are released during departure phases of run-up, takeoff, and climb-out (22–24). According to (8), total fuel consumed by piston aircraft in departure phases of the LTO cycle is estimated at 82% for twin-engine aircraft and 85% for single-engine aircraft. About 80% of lead emissions are released during departure phases of the LTO cycle (8).

Given that the bulk of lead emissions are released during departure phases of the LTO cycle, we capture child proximity by calculating the Haversine distance (The Haversine of the central angle, which is d over the r, is calculated by: $\left(\frac{d}{r}\right)$ = haversine(2 − 1) + cos(1)cos(2)haversine(λ2 − λ1), where r is the radius of earth(6,371 km), d is the distance between a child's residence and RHV, φ1, φ2 is latitude and λ1, λ2 is longitude of the child's residence and Reid-Hillview, respectively. We solve for d by the inverse sine function, getting: d = rhav−1(h) = 2rsin−1($\sqrt{}$ h)) from the child's residence at the date of blood draw to the northwest tip of RHV (point coordinates 37.3362252, -121.8230194). In addition to measuring distance continuously, residential distance is also divided into three even categories: < 0.5 miles (0.8 km), 0.5 to 1 mile (0.8 to 1.6 km), and 1 to 1.5 miles (1.6 to 2.4 km) from RHV.

Over the period of 2011 January 1 to 2020 December 31, we observe a total of 930 records at <0.5 miles, 5,564 records at 0.5 to 1 mile, and 8,382 at 1 to 1.5 miles from RHV. Insofar as avgas exposure is a source of risk, sampled children in the nearest orbit to RHV should present with higher BLLs as compared to sampled children in outer orbits. Sampled children in our inner orbit of <0.5 miles of are statistically similar to children in outer orbits (0.5 to 1.5 miles) with respect gender, residential near angle, age, PEA traffic exposure, sample order, year or timing of blood draw, and proportion of children sampled by capillary method where $P > 0.05$. We do observe statistically significant differences with respect to the percentage of neighborhood homes built prior to 1960 (24.1 vs 28.2, $P < 0.001$), the count of lead-emitting toxic release inventory facilities within 2 miles of a child's residence (2.37 vs 2.51, $P < 0.001$), and neighborhood socioeconomic status (−0.22 vs −0.27, $P = 0.007$). On variables where statistically significant differences are observed, all function to inflate the BLLs of sampled children in outer orbits. Therefore, whatever differences in estimated BLLs that may obtain between sampled children by residential distance in regression analyses we may regard these differences as possibly attenuated.

Residential near angle

The fate and transport of lead emissions depend on the direction of prevailing winds that vary in and across airport facilities. Insofar as avgas is an independent source of lead exposure, two children equidistant to the same airport face different risk of elevated blood lead depending on the child's residential near angle to the airport.

A near angle group was assigned to each address by calculating the compass bearing (degrees) between a child's residential location and RHV. We define near angle groups by the four cardinal directions: North (N), East (E), South (S), and West (W). For a BLL sample from child *i* in time *t*, with range of possible compass bearings $b_{it} \in [0, 360)$, we assign near angle group a_{it} as:

$$a_{it} = \begin{cases} E, & \text{if } b_{it} \in [45^\circ, 135^\circ), \\ S, & \text{if } b_{it} \in [135^\circ, 225^\circ), \\ W, & \text{if } b_{it} \in [225^\circ, 315^\circ), \\ N, & \text{otherwise.} \end{cases} \quad (1)$$

Because the direction of prevailing winds at RHV emanate from the West and Northwest, and insofar as exposure to avgas is a source of risk, children residing east of the airport ought to present with higher BLLs (see Supplementary Material Figure S5 for distribution of sampled children by near angle grouping).

PEA traffic and avgas sales

The volume of PEA traffic varies meaningfully between airports and within an airport in time. Therefore, two children residing in the same household but sampled at different moments in a calendar year may present with different BLLs, depending on the coincidence of PEA traffic. To capture this channel of risk, we collected data on PEA departures and arrivals from TMSC.

Daily PEA data were available for RHV. Because the half-life for lead in blood is about 30 days (25), we back-calculated a rolling average of PEA operations over 60 days from the date of a child's blood draw. In Supplementary Material Table S6 we present results with our measure PEA traffic divided into terciles, showing an apparent dose-responsivity of child BLLs vis-a-vis PEA traffic. With the date of blood draw linked to the quantity of PEA traffic, one can test whether child BLLs are dose-responsive with the volume of PEA traffic. Our measurement of PEA traffic exposure assumes that children have continuity of residence for 60 days.

Also, fuel flowage fee (FFE) data were obtained from personnel at the Roads and Airports Department of Santa Clara County. The FFE data track monthly quantities of avgas (100LL) sold to fixed-base operators at RHV from 2011 to 2019. Each child is matched to the 2-month rolling average of quantities of 100LL sold from the date of blood draw. As with PEA traffic, we test whether child BLLs are dose-responsive with avgas sales at RHV.

Control data

Lead-emitting industrial facilities are more common in the vicinity of airports (11).

Children that are proximate to airports are therefore simultaneously proximate to other point-source emitters of lead. Failing to account for this spatial coincidence can produce biased estimates of avgas exposure risk vis-à-vis BLLs in children. The U.S. EPA's TRI system tracks the industrial management of over 650 listed chemicals that pose harm to humans and the environment. We collected records on all facilities in Santa Clara County with reported on-site releases of lead between 2011 and 2020. Following (11), with the location of each facility and the year of reported release event, we counted the number of lead-emitting TRI facilities ≤2 miles (or 3.2 km) of a child's residence in the corresponding year of blood draw. All results pertaining to the assessment of statistical relationships of child BLLs and indicators of avgas exposure risk control for the presence of this alternative source of lead exposure.

Legacy use of lead-based paint remains an exposure risk to children. Exposure to lead-based paint is primarily a problem in older homes. By 1960, use of lead-based paint subsided by more than 90% from peak usage in the 1920s. Still, children in the United

States may ingest paint chips or may be exposed to dust from deteriorating or haphazardly removed lead-based paint in homes built in the era before 1960. We collected American Community Survey data on the fraction of homes in a child's neighborhood built before 1960. In the analyses that follow, each sampled child in our data is assigned a lead-based paint exposure risk according to the neighborhood of residence and year of blood draw, as captured by the percentage of homes built before 1960.

Studies show that children of low socioeconomic status are at greater risk of presenting with elevated BLLs (26,27). Socioeconomic status proxies for household resources, knowledge about the dangers of, and protective actions taken against, lead exposure (11). In addition to demographic information present in CDPH data, we measured the percentage of adults with a college degree, median home prices, and median household incomes to characterize the socioeconomic status of a child's residential neighborhood. These data were also collected from the American Community Survey. Supplementary Material Table S1 provides descriptive statistics.

Empirical methods

To assess whether the BLLs of sampled children are statistically associated with indicators of avgas exposure risk, we deploy a linear least squares estimator with census block fixed effects, accounting for heteroeskedasticity and relaxing distributional assumptions with bootstrapped SE.

The outcome of interest is child BLL, measured as a continuous variable in μg/dL (and the natural log of child BLL). For sampled child i in neighborhood block j at time t, we estimate the responsiveness of child blood lead Y_{ijt} to indicators of avgas exposure risk with the following linear model

$$\begin{aligned} Y_{ijt} &= \beta_0 + \beta_1 D^n_{it} + \beta_2 D^f_{it} + \beta_3 T_{it} + \beta_4 W^e_{it} + \beta_5 W^s_{it} + \beta_6 W^w_{it} \\ &+ \Gamma_1 G_i + \Gamma_2 A_{it} + \Gamma_3 C_{it} + \Gamma_4 S_i + \Gamma_5 Z_{it} + \Gamma_6 L_{it} \\ &+ \lambda_1 F_{it} + \lambda_2 H_{jt} + \lambda_3 I_{jt} + \lambda_4 Q_{it} + \gamma_i + \gamma_j + \varepsilon_{ijt}. \end{aligned} \quad (2)$$

Knowing that relationships of interest are possibly nonlinear, we use a flexible specification where distance D is measured as a series of dichotomous variables, where $D^n_{it} = 1$ if child i in time t resides 0.5 to 1 miles from RHV, 0 = otherwise, and $D^f_{it} = 1$ if child i in time t resides 1 to1.5 miles from RHV, and 0 otherwise. Children most proximate to RHV (<0.5 miles) constitute the reference distance. The flow of lead emitted from the aircraft traffic T_{it} is the count of PEA operations (measured in percentile terms) in the last 60 days relative to the draw date t of child i. To account for prevailing wind direction we include a series of dummy variables W for the location of child i in time t relative to the airport, with North being the reference direction, and: $W^e_{it} = 1$ if a child resides East of RHV, 0 = otherwise, $W^s_{it} = 1$ if a child resides South of RHV, 0 = otherwise, and $W^w_{it} = 1$ if a child resides West of RHV, 0 = otherwise.

A series of variables are included to control for the timing, method, quantification limit, and order of blood draw, where C_{it} is whether or not the method of blood draw is capillary, L_{it} is whether the measured BLL is at or below the limit of test detection, Z_{it} is the year and quarter of the blood draw, and S_i is the order of sample for children sampled repeatedly (For a singleton observation (nonrepeated child) i, Si = 0. Otherwise, Si = 1, ..., n for child i repeated n times over the observation period, 2011 January 1 to 2020 December 31. The date of birth, child sex, child name, and date of blood draw were used to identify sample order for each child. The majority of children (53.3%) appearing in CDPH data were sampled only once). Child demographic characteristics include the child's age A_{it} measured in years, and an indicator for whether the child is female G_i.

We include a suite of controls to account for confounding sources of lead exposure and neighborhood socioeconomic status corresponding to the residential location of a sampled child and the date of blood draw. F_{it} is the count of nearby lead-emitting toxic release inventory facilities ≤ 2 miles of a child's residence, and H_{jt} is the percent of homes built ≤ 1960 in child's neighborhood of residence, proxying for lead-based paint exposure risk. Because atmospheric concentrations of lead fluctuate seasonally—in part because of the re-suspension of lead-contaminated surface soils by turbulence (28,29)—our statistical models proxy for this phenomenon with a series of dummy variables corresponding to the season of blood draw, Q_{it}, with winter as our reference season. Also included is I_{jt}, estimating the socioeconomic status of a neighborhood by an quantitative index that incorporates measures of educational attainment, median household income, and property values (proxying for household wealth).

Importantly, γ_i is the child random effect measured as the difference between the observed BLL and the child-specific average BLL and γ_j is the neighborhood or census block fixed effect. Inclusion of γ_j accounts for nontime varying unobservable factors, which may influence BLLs that are common to sampled children within a given neighborhood but varying across neighborhoods. Fixed effects absorb omitted variables by estimating a distinct mean BLL value (or intercept) for each neighborhood. Finally, ε_{ijt} is the random error term associated to the observed Y_{ijt}.

Blood lead thresholds

We also reconstitute our response variable in ordered categorical terms, defining mutually exclusive BLL categories ranging from 0 to the exceedance of the CDPH-defined threshold of 4.5 μg/dL (For comparison, the current blood lead reference level set by the Centers for Disease Control and Prevention (CDC), adopted on 2021 May 14 is 3. μg/dL). The purpose here is to investigate threshold effects with respect to our main operations of avgas exposure risk and to relax the assumption of precisely measured BLLs, given uncertain laboratory test precision.

Under the premise that a given blood lead concentration is an imperfectly observed variable, we execute an ordered logistic regression, modeling BLL as a set of ordinal categories. Moving in increments of 1.5 μg/dL, we convert the continuous measure of blood lead concentration Y_{it} to a categorical variable B_{it}, with cutpoints defined as

$$B_{it} = \begin{cases} 1, & \text{if } Y_{it} < 1.5, \\ 2, & \text{if } 1.5 \le Y_{it} < 3, \\ 3, & \text{if } 3 \le Y_{it} < 4.5, \\ 4, & \text{if } Y_{it} \ge 4.5, \end{cases}$$

where Y_{it} is in units of μg/dL (For sampled children within 1.5 miles of Reid-Hillview, we observe 6,489 records at<1.5μg/dL, 6,806 records at 1.5 to<3μg/dL, 1,361 records at 3 to <4.5 μg/dL, and 220 records at ≥ 4.5 μg/d).Within this framework, one can estimate the proportional odds a given blood lead concentration is in exceedance of a specified blood lead category. For child i with corresponding BLL observation in time t, B_{it} takes on the ordinal values $k = 1,..., 4$, then we define the cumulative response probabilities as

$$b_{itk} = \text{Prob}(B_{it} \le k|\mathbf{X}_{it}), \qquad k = 1, ..., 4, \quad (3)$$

where $\mathbf{X}_{it}$ is a vector of explanatory values related to child i in time t. Using Eq. (3), we can represent a generalized logistic model as

$$\text{logit}\ (b_{itk}) = \ln\left(\frac{b_{itk}}{1 - b_{itk}}\right) = \theta_k + \mathbf{X}'_{it}\beta, \qquad (4)$$

where $\theta_1 \leq \theta_2 \ldots \leq \theta_k$. Taking the generalized model in Eq. (4) and the suite of covariates defined in Eq. (2), the fully specified model used to estimate the log-odds of sampled child i in neighborhood block j at time t being in BLL category B_{it} becomes

$$\begin{aligned}\text{logit}\ (b_{ijtk}) = {} & \theta_k + \beta_1 D^n_{it} + \beta_2 D^f_{it} + \beta_3 T_{it} + \beta_4 W^e_{it} + \beta_5 W^s_{it} \\ & + \beta_6 W^w_{it} + \Gamma_1 G_i + \Gamma_2 A_{it} + \Gamma_3 C_{it} + \Gamma_4 S_i + \Gamma_5 Z_{it} + \Gamma_6 L_{it} \\ & + \lambda_1 F_{it} + \lambda_2 H_{jt} + \lambda_3 I_{jt} + \lambda_4 Q_{it} + \gamma_i + \gamma_j, \qquad k = 1, \ldots, 4, \end{aligned} \qquad (5)$$

Our expectation is that the exponentiated log-odds corresponding to D^n_{it} and D^f_{it} will be <1.0 reflecting lower risk of exceeding the threshold of 4.5 μg/dL among children in outer orbits of RHV relative to children nearest to RHV. We also expect that exponentiated log-odds corresponding W^e_{it} to be >1.0, reflecting higher odds of maximum categorical blood lead for sampled children East of RHV relative to children North of RHV. Similarly, we expect the exponentiated coefficient on T_{it} to be >1.0, indicating that the risk of exceeding the CDPH-defined threshold of 4.5 μg/dL increases with exposure to PEA traffic.

PEA traffic exposure × residential distance

Next, we consider a statistical interaction between PEA traffic exposure and residential distance. Insofar as avgas exposure is a source of risk, we expect that the BLLs of sampled children proximate to RHV will be more responsive to the flow of PEA traffic than children more distant from the airport. Toward this analytic aim, we estimate the following

$$\begin{aligned} Y_{ijt} = {} & \beta_0 + \beta_1 D^{nf}_{it} + \beta_2 CT_{it} + \beta_3 W^e_{it} + \beta_4 W^s_{it} + \beta_5 W^w_{it} \\ & + \delta\left(D^{nf}_{it} \times CT_{it}\right) + \Gamma_1 G_i + \Gamma_2 A_{it} + \Gamma_3 C_{it} + \Gamma_4 S_i + \Gamma_5 Z_{it} \\ & + \Gamma_6 L_{it} + \lambda_1 F_{it} + \lambda_2 H_{jt} + \lambda_3 I_{jt} + \lambda_4 Q_{it} + \gamma_i + \gamma_j + \varepsilon_{ijt}, \end{aligned} \qquad (6)$$

where, the meaning of all terms carry from Eq. (2) with the exception of D^{nf}_{it} that now assumes a value of 1 if a sampled child resides in the outer orbit of 0.5 to 1.5 miles of RHV and 0 if a sampled child resides within 0.5 miles of RHV. Outer orbits are collapsed given insignificance of difference observed in Table 1. We expect β_1 corresponding D^{nf}_{it} to be negative, reflecting lower BLLs among distant children (0.5 to 1.5 miles) relative to proximate children (<0.5 miles). CT_{it} is the statistically centered value of PEA traffic exposure that is equal to $T_{it} - \bar{T}_{it}$ or the observed PEA traffic exposure (T_{it}) minus the mean of PEA traffic exposure($\bar{T}_{it}$). We expect the corresponding parameter β_2 to be positive, indicating that BLLs increase with the PEA traffic exposure. Finally, we expect δ corresponding to $D^{nf}_{it} \times CT_{it}$ to be negative, indicating that the BLLs of sampled children proximate to RHV (<0.5 miles) are more responsive to PEA traffic than children distant from RHV (0.5 to 1.5 miles).

PEA traffic contraction

As the COVID-19 pandemic gripped the country, state and local governments enacted various restrictions on the behavior of households and firms to limit the spread of the disease. Corresponding with these efforts, PEA traffic declined measurably at RHV over the months of February to July of 2020. As compared to three baseline control periods—2011 to 2019, 2015 to 2019, and 2018 to 2019 —PEA traffic declined by 34 to 44%. PEA traffic at RHV returned to pre-pandemic levels in August to December of 2020. The pandemic-caused dynamics in PEA operations at RHV present us with a natural experiment.

If as avgas exposure is a source of risk, then we should observe a reduction in the BLLs of children sampled in this PEA traffic contraction period, other things held equal. To test whether child blood levels behaved differently in the contraction moment, we estimate the following linear model

$$\begin{aligned} Y_{ijt} = {} & \beta_0 + \beta_1 D^n_{it} + \beta_2 D^f_{it} + \beta_3 T_{it} + \beta_4 W^e_{it} + \beta_5 W^s_{it} + \beta_6 W^w_{it} \\ & + \beta_7 COV_t + \Gamma_1 G_i + \Gamma_2 A_{it} + \Gamma_3 C_{it} + \Gamma_4 S_i + \Gamma_5 Z_{it} + \Gamma_6 L_{it} \\ & + \lambda_1 F_{it} + \lambda_2 H_{jt} + \lambda_3 I_{jt} + \lambda_4 Q_{it} + \gamma_i + \gamma_j + \varepsilon_{ijt}, \end{aligned} \qquad (7)$$

where, all terms carry from Eq. (2) with the exception COV_t that is an indicator variable equal to 1 if a child is sampled in the PEA traffic contraction moment and 0 otherwise. Other things held equal, we expect the coefficient β_7, corresponding to COV_t, to be negative, indicating that children sampled in the PEA traffic contraction moment present with lower BLLs than children not sampled in this period (A reasonable concern with this analytic exercise is that the kind of children sampled in the PEA contractionmomentmay be characteristically different than children sampled outside this moment. Comparing means onmodel variables by children sampled in versus out of the PEA traffic contraction period, we find that sampled children are statistically indistinguishable in terms of residential distance to RHV (1.02 vs 1.03 miles, P = 0.515), fraction living east of RHV (0.07 vs 0.08, P = 0.178), child age (2.19 vs 2.09, P = 0.10), the proportion children that are female (0.49 vs 0.50, P = 0.691), and sample order (0.80 vs 0.82, P = 0.702). We do observe significant differences on the proportion of samples drawn by capillary method (0.25 vs 0.19, P < 0.001), the percentage of housing stock in a child's residential neighborhood at-risk of presenting with lead-based paint (28.05 vs 24.08, P < 0.001), and neighborhood socioeconomic status (−0.28 vs 0.33, -P < 0.001). Importantly, across every variable for which we observe differences, all function to increase the BLLs of children sampled outside the contraction period relative to children sampled in the PEA traffic contraction period, likely rendering our test results conservative).

Atmospheric lead

Finally, we secured data from the Bay Area Air Quality Management District (BAAQMD) measuring atmospheric concentrations of lead at RHV. The BAAQMD data covered the period of 2012 February to 2018 March, with an atmospheric reading taken (on average) every 6 days. We merged these air quality data with our inventory blood lead samples of children ≤5 y of age and residing within 1.5 miles of RHV in the last 10 y.

Given the time-abbreviated nature of the air quality data, only 9,542 of the 14,876 blood lead samples used in our analysis could be assigned an atmospheric lead concentration coincident with the timing of blood draw. The loss of more than 1/3rd of observations warrants some caution in the use of BAAQMD data.

With this caution in mind, for a sampled child i in neighborhood block j at time t, we estimate the responsiveness of child blood lead Y_{ijt} to atmospheric lead concentration with the following linear model

$$\begin{aligned} Y_{ijt} = {} & \beta_0 + \beta_1 D^n_{it} + \beta_2 D^f_{it} + \beta_3 T_{it} + \beta_4 W^e_{it} + \beta_5 W^s_{it} + \beta_6 W^w_{it} \\ & + \beta_7 PbA_{it} \Gamma_1 G_i + \Gamma_2 A_{it} + \Gamma_3 C_{it} + \Gamma_4 S_i + \Gamma_5 Z_{it} + \Gamma_6 L_{it} \\ & + \lambda_1 F_{it} + \lambda_2 H_{jt} + \lambda_3 I_{jt} + \lambda_4 Q_{it} + \gamma_i + \gamma_j + \varepsilon_{ijt}, \end{aligned} \quad (8)$$

where, the meaning of all terms carry from Eq. (2), with the exception of PbA_{it} which captures the 2-month moving average of atmospheric lead (measured in micrograms per cubic meter) from the date of child blood draw. Insofar as exposure to atmospheric lead (measured at RHV) is a source of risk, we expect β_7 to be positive.

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Supplementary Material

Supplementary material is available at *PNAS Nexus* online.

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Data Availability

The child blood lead data supporting the analysis of this study are available from the Childhood Lead Poisoning Prevention Branch of the California Department of Public Health, were used under license for the current study, and are not publicly available.

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