Earthjustice • Animal Legal Defense Fund • Boone County Farmers and Neighbors • Center for Food Safety • Conservation Law Center • Dakota Resource Council • Dakota Rural Action • Don't Waste Arizona • Endangered Habitats League • Environmental Law & Policy Center • Environmental Working Group • Flow Water Advocates • Friends of Toppenish Creek • Jefferson County Farmers & Neighbors • Michiganders for a Just Farming System • Milwaukee Riverkeeper • Missouri Coalition for the Environment • Ohio Environmental Council • Rural Empowerment Association for Community Help • San Francisco Baykeeper • Sierra Club • Snake River Waterkeeper • Socially Responsible Agriculture Project • Waterkeeper Alliance • Waterkeepers Chesapeake

August 18, 2025

Via E-mail to NAEMS@epa.gov

Re: ***Draft AP-42 Chapter 9, Section 4 – Livestock and Poultry Feed Operations and Air Emissions Estimating Methodologies for Animal Feeding Operations***

Dear NAEMS Group,

The undersigned organizations concerned about air pollution from animal feeding operations ("AFOs") submit the following comments on Draft AP-42 Chapter 9, Section 4 – Livestock and Poultry Feed Operations and Air Emissions Estimating Methodologies for Animal Feeding Operations ("Draft EEMs"), published by the United States Environmental Protection Agency ("EPA").[1] AFOs are leading sources of dangerous air pollution, including ammonia, hydrogen sulfide, particulate matter, and volatile organic compounds. Air pollution from AFOs can cause serious health problems or even death for workers and people living nearby. Nonetheless, EPA has delayed action to control this pollution for at least two decades, while it slowly gathered data through its National Air Emissions Monitoring Study ("NAEMS"), and then developed and published the Draft EEMs. During EPA's long delay, AFOs across the United States have emitted substantial quantities of air pollution without appropriate oversight—including millions of tons of ammonia, potentially resulting in ***nearly 140,000 premature deaths***.

[1] *See* EPA, *Draft AP-42 Section 9.4 Livestock and Poultry Feed Operations* (2024) ("Draft EEMs"), https://www.epa.gov/system/files/documents/2024-11/draft_ap-42_section_-9.4_livestock_and_poultry_feed_operations_nov_2024.pdf; *see also AP-42: Compilation of Air Emissions Factors from Stationary Sources*, EPA, https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors-stationary-sources (last updated May 28, 2025) (announcing initial "90-day public review period" for the Draft EEMs and "extend[ing] the public comment period deadline to August 18, 2025").

We strongly urge EPA to finalize the Draft EEMs without further delay. Despite monitoring emissions from only 25 AFOs—that is, less than one percent of the nearly 14,000 AFOs that agreed to help fund NAEMS and make their facilities available for emissions testing—EPA used appropriate technology to gather data, and it followed a reasonable statistical process to develop the Draft EEMs. Although we recommend that EPA make a few small improvements to the Draft EEMs now, including developing guidance on the appropriate use of each model, EPA already has completed a process more complex than AP-42 requires. After finalizing the Draft EEMs, EPA should continue to gather data—especially from the largest AFOs—and refine its models, as contemplated in AP-42. However, EPA cannot justify the additional, avoidable harm to human health and the environment that certainly would result from any further delay.

FACTUAL BACKGROUND

AFOs Emit Substantial Quantities of Air Pollution.

Meat and dairy production in the United States today looks very different than it did just 40 years ago.[2] While most animals once were raised on small, diversified, and independent farms, they now are primarily produced in industrial-scale AFOs, including especially large facilities classified as concentrated animal feeding operations or CAFOs.[3] For example, according to the United States Department of Agriculture ("USDA"), in 1987, only eight percent of swine were held in facilities with 5,000 or more swine.[4] By 2022, that percentage had increased more than ninefold; 75 percent of swine were held in facilities with 5,000 or more

[2] *See* James M. MacDonald & William D. McBride, USDA, *The Transformation of U.S. Livestock Agriculture: Scale, Efficiency, and Risks*, at 1, 5 (2009), https://www.ers.usda.gov/publications/pub-details?pubid=44294; *see also* James M. MacDonald, *Tracking the Consolidation of U.S. Agriculture*, 42 Applied Econ. Persps. & Pol'y 361, 370 tbl. 3 (2020).

[3] *See* 40 C.F.R. § 122.23(b)(1) (defining an "animal feeding operation" or "AFO" as "a lot or facility . . . where . . . [a]nimals . . . have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and . . . [c]rops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility"); *id.* § 122.23(b)(6) (defining a "Medium CAFO" as an AFO that confines a certain number of animals—for example, 200 to 699 mature dairy cows, 750 to 2,499 swine each weighing 55 pounds or more, or 16,500 to 54,999 turkeys); *id.* § 122.23(b)(4) (defining a "Large CAFO" as an AFO that confines at least a certain number of animals—for example, 700 mature dairy cows, 2,500 swine each weighing 55 pounds or more, or 55,000 turkeys).

[4] *See* U.S. Dep't of Commerce, *1987 Census of Agriculture* 30 tbl. 32 (1989), https://agcensus.library.cornell.edu/wp-content/uploads/1987-United_States-1987-01-full.pdf.

swine.[5] Likewise, the percentage of dairy cows held in facilities with 500 or more cows has grown dramatically, increasing from nine percent in 1987 to 75 percent in 2022.[6]

A single AFO can generate more waste than an entire city. According to the U.S. Government Accountability Office, a dairy facility "meeting EPA's large CAFO threshold of 700 dairy cows can create about 17,800 tons of manure annually, which is more than the about 16,000 tons of sanitary waste per year generated by the almost 24,000 residents of Lake Tahoe, California."[7] And, as of 2007, all of the breeding and market swine in North Carolina together generated over 17 million tons of manure annually,[8] which is nearly 2.5 times the amount of sanitary waste—urine and feces—generated each year by the human residents of North Carolina.[9] Unlike human waste, however, AFO waste generally is not treated or disinfected prior to disposal.

When AFO waste decomposes, it releases hydrogen sulfide ("H_2S") and ammonia ("NH_3"), along with hundreds of other pollutants.[10] In some regions, agricultural hydrogen sulfide emissions can be a major contributor to total sulfur emissions.[11] And, as of 2017, livestock waste was the largest source of ammonia emissions in the United States.[12] According to the Draft EEMs, a single median-sized swine finishing AFO in Duplin County emits over 300

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[5] *See* USDA, *2022 Census of Agriculture* 19 tbl. 19 (2024), https://www.nass.usda.gov/Publications/AgCensus/2022/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf.

[6] *See* U.S. Dep't of Commerce, *supra* note 4, at 30 tbl. 30; *see also* USDA, *supra* note 5, at 16 tbl. 12.

[7] U.S. Gov't Accountability Off., *Concentrated Animal Feeding Operations: EPA Needs More Information and a Clearly Defined Strategy to Protect Air and Water Quality from Pollutants of Concern* 19 (2008), https://www.gao.gov/assets/gao-08-944.pdf.

[8] *See* EPA, *Literature Review of Contaminants in Livestock and Poultry Manure and Implications for Water Quality* 114 tbl. A-5 (2013), https://nepis.epa.gov/Exe/ZyPDF.cgi/P100H2NI.PDF?Dockey=P100H2NI.PDF.

[9] On average, a person generates 3.72 pounds of sanitary waste (urine and feces) per day. *See* U.S. Gov't Accountability Off., *supra* note 7, at 58. The population of North Carolina is 10,439,388. *See North Carolina*, U.S. Census Bureau, https://data.census.gov/profile/North_Carolina?g=040XX00US37 (last visited Aug. 13, 2025).

[10] *See* Zifei Liu et al., *Ammonia and Hydrogen Sulfide Emissions from Swine Production Facilities in North America: A Meta-Analysis*, 92 J. Animal Sci. 1656 (2014); Virginia T. Guidry et al., *Hydrogen Sulfide Concentrations at Three Middle Schools near Industrial Livestock Facilities*, 27 J. Exposure Sci. & Env't Epidemiology 167 (2017).

[11] Anders Feilberg et al., *Contribution of Livestock H_2S to Total Sulfur Emissions in a Region with Intensive Animal Production*, 8 Nature Commc'ns (2017).

[12] *See 2017 National Emissions Inventory (NEI) Data*, EPA, https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data#dataq (last visited Aug. 11, 2025) (scroll down to the "Data Queries" section, select "Ammonia – NH3" in the "Pollutant" selection box, and submit).

pounds of ammonia on an average summer day.[13] On the same day, the county's largest AFO emits over 12,500 pounds of ammonia.[14]

In addition, AFOs generate substantial quantities of particulate matter ("$PM_{2.5}$" and "PM_{10}") including animal feces, skin cells, and feed.[15] AFOs also contribute indirectly to particulate matter pollution through their emissions of particulate matter precursors, such as ammonia.[16] As a result, ambient levels of particulate matter near AFOs often exceed federal air quality standards.[17] In California's Central Valley, which has some of the worst air quality in the nation, animal waste is a major contributor to high concentrations of inhalable fine particulate matter known as $PM_{2.5}$.[18] Heightened concentrations of particulate matter associated with AFOs disproportionately affect socially vulnerable, minority populations with limited health insurance coverage.[19]

Air Pollution from AFOs Poses Serious Threats to Human Health.

Numerous studies show that air pollutants and odors from AFOs travel into nearby communities,[20] and the experiences of community members corroborate these studies. Exposure

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[13] *See* Ex. A, NH_3 Sample Calculation Assumptions; Draft EEMs at 9.4.4-16 tbl. 9.4-4; *Animal Facility Map*, N.C. Dep't Env't Quality, https://www.deq.nc.gov/about/divisions/water-resources/permitting/animal-feeding-operations/animal-facility-map (last updated Nov. 25, 2024).
[14] *See* sources cited *supra* note 13.

[15] Sanaz Chamanara et al., *Geography of Animal Feeding Operations and Their Contribution to Fine Particulate Matter Pollution in Vulnerable Communities in the United States*, 6 Commc'ns Earth & Env't (2025); Mohammad Ruzlan Habib, Eunice Arzadon & Sergio Capareda, *Particulate Matter Annual Emission Factors for Dairy Facilities and Cattle Feedlots of Texas, USA*, 328 Atmospheric Env't (2024).
[16] Katie E. Wyer et al., *Ammonia Emissions from Agriculture and Their Contribution to Fine Particulate Matter: A Review of Implications for Human Health*, 323 J. Env't Mgmt. (2022); Susanne E. Bauer, Kostas Tsigaridis & Ron Miller, Significant Atmospheric Aerosol Pollution Caused by World Food Cultivation, 43 Geophysical Rsch. Letters 5394 (2016).
[17] *See* Env't Integrity Project, *Hazardous Pollution from Factory Farms: An Analysis of EPA's National Air Emissions Monitoring Study Data* 1–2 (2011), https://environmentalintegrity.org/wp-content/uploads/2016/11/2011_HazardousPollutantsFromFactoryFarms.pdf.
[18] *See* Brendan Borrell, *In California's Fertile Valley, Industry and Agriculture Hang Heavy in the Air*, Undark Magazine (Dec. 3, 2018), https://undark.org/article/air-pollution-california/.
[19] Chamanara, *supra* note 15.
[20] *See* Dana Cole, Lori Todd & Steve Wing, *Concentrated Swine Feeding Operations and Public Health: A Review of Occupational and Community Health Effects*, 108 Env't Health Persps. 685, 693 (2000) (explaining that gases, dusts, and odors from CAFOs can travel long distances and cause health concerns in neighboring communities); *see also* JoAnn Burkholder et al., *Impacts of Waste from Concentrated Animal Feeding Operations on Water Quality*, 115 Env't Health Persps. 208, 309 (2007) (citing studies showing that ammonia from swine CAFOs commonly moves off-site to contaminate the overlying air); Kelley J. Donham et al., *Community Health and Socioeconomic Issues Surrounding Concentrated Animal*

to CAFO air pollution can cause serious health problems and even death.[21] A recent study found that ammonia emissions from waste management practices at AFOs cause at least 6,900 deaths per year, and particulate matter traceable to ammonia emissions from the application of manure and other fertilizers causes an additional 4,900 premature deaths per year.[22] Exposure to AFO air pollutants also can cause nausea, headaches, dizziness, runny nose, scratchy throat, burning eyes, coughing, wheezing, and shortness of breath.[23] One study found that people living up to two miles from a CAFO experienced increased rates of these symptoms.[24] Other studies found that children attending schools near CAFOs experienced asthma symptoms, including wheezing, and adolescents living near livestock farms were more prone to respiratory abnormalities.[25] In a study that directly measured air pollutants associated with hog AFOs, researchers found that higher levels of $PM_{2.5}$ were associated with increased wheezing and reduced lung function, while higher concentrations of H_2S and PM_{10} were linked to irritation and respiratory symptoms.[26] Additionally, hog odors increased the likelihood of breathing difficulties.[27]

Feeding Operations, 115 Env't Health Persps. 317, 318 (2007) (noting that air quality assessments in communities near CAFOs show concentrations of hydrogen sulfide and ammonia); Yelena Ogneva-Himmelberger, Liyao Huang & Hao Xin, *CALPUFF and CAFOs: Air Pollution Modeling and Environmental Justice Analysis in the North Carolina Hog Industry*, 4 ISPRS Int'l J. Geo-Information 150 (2015) (finding that ammonia concentrations in areas downwind of swine CAFOs were up to three times higher than the average concentration in the watershed, exposing approximately 3,500 people to ammonia concentrations higher than the minimal risk level); Kathleen M. Kurowski et al., *Swine Production Intensity and Swine-Specific Fecal Contamination of Household Surfaces at Residence of Industrial Livestock Operation Workers and Community Residents, North Carolina, USA*, 985 Sci. Total Env't (2025) (finding swine fecal contamination of homes proximal to industrial hog operations in North Carolina).

[21] Elise Pohl & Sang-Ryong Lee, *Local and Global Public Health and Emissions from Concentrated Animal Feeding Operations in the USA: A Scoping Review*, 21 Int'l J. Env't Rsch. & Pub. Health (2024).

[22] *See* Nina G.G. Domingo et al., *Air Quality-Related Health Damages of Food*, 118 PNAS 1, 2 fig. 1 (2021).

[23] *See* Kendall M. Thu et al., *A Control Study of the Physical and Mental Health of Residents Living Near a Large-Scale Swine Operation*, 3 J. Agric. Safety & Health 13, 16–18 (1997); Vanessa R. Coffman et al., *Self-Reported Work Activities, Eye, Nose, and Throat Symptoms, and Respiratory Health Outcomes Among an Industrial Hog Operation Worker Cohort, North Carolina, USA*, 64 Am. J. Indus. Med. 403 (2021); Wyer, *supra* note 16.

[24] Thu, *supra* note 23.

[25] *See* Maria C. Mirabelli et al., *Asthma Symptoms Among Adolescents Who Attend Public Schools That Are Located near Confined Swine Feeding Operations*, 118 Pediatrics e66, e71 (2006); Pauline Kiss et al., *Residential Exposure to Livestock Farms and Lung Function in Adolescence – The PIAMA Birth Cohort Study*, 219 Env't Rsch. (2023).

[26] *See* Leah Schinasi et al., *Air Pollution, Lung Function, and Physical Symptoms in Communities near Concentrated Swine Feeding Operations*, 22 Epidemiology 208 (2011).

[27] *Id.*

Odors from AFOs also can cause psychological harm. Researchers have found that AFO neighbors regularly subjected to livestock odors experience significantly higher rates of tension, depression, anger, confusion, and fatigue, as compared with otherwise similar people who do not live near AFOs.[28] These negative moods are concerning not only in their own right, but also because "mood has been found to play a role in immunity [] and can potentially affect subsequent disease."[29]

In addition to harming physical and psychological health, air pollutants and odors from AFOs can significantly diminish neighbors' quality of life. For instance, children who suffer from asthma symptoms, which can result from exposure to CAFO air pollution, miss opportunities to engage in social, recreational, and physical activities.[30] Similarly, studies show that odor from swine AFOs prevents neighbors from participating in activities like "barbequing, . . . socializing with neighbors [and family], gardening, working outside, playing, drying laundry outside, opening doors and windows for fresh air and to conserve energy, . . . growing vegetables," and even sleeping through the night.[31]

Federal Action to Control Air Pollution from AFOs is Long Overdue.

Although EPA and other federal agencies have long been aware of the substantial and well-documented harms associated with exposure to air pollution from AFOs, they have allowed AFOs to escape regulation necessary to protect public health. In 1998, a group of nearly 50 scientists participating in an expert workshop convened in part by EPA agreed that "odorous emissions from animal operations . . . have an impact on physical health."[32] That same year, air quality experts at a workshop organized by the Centers for Disease Control concluded that "adequate evidence currently exists to indicate airborne emissions from large-scale swine facilities constitute a public health problem."[33] Despite these findings, in 2005, EPA offered AFOs the opportunity to sign a Consent Agreement and Final Order ("Consent Agreement"), allowing them to avoid liability for past and ongoing violations of the Clean Air Act ("CAA"), as

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[28] *See* Susan S. Schiffman et al., *The Effect of Environmental Odors Emanating from Commercial Swine Operations on the Mood of Nearby Residents*, 37 Brain Rsch. Bull. 369 (1995).
[29] *Id.* at 370.
[30] *See* Mirabelli, *supra* note 25, at e72.
[31] M. Tajik et al., *Impact of Odor from Industrial Hog Operations on Daily Living Activities*, 18 New Sols. 193, 201 (2008); *see also* Nathaniel S. MacNell, Chandra L. Jackson & Christopher D. Heaney, *Relation of Repeated Exposures to Air Emissions from Swine Industrial Livestock Operations to Sleep Duration and Awakenings in Nearby Residential Communities*, 7 Sleep Health 528 (2021).
[32] Kendall M. Thu, *Public Health Concerns for Neighbors of Large-Scale Swine Production Operations*, 8 J. Agric. Safety & Health 175, 179 (2002) (quoting Susan S. Schiffman et al., *Potential Health Effects of Odor from Animal Operations, Wastewater Treatment, and Recycling of Byproducts*, 7 J. Agromedicine 7, 57 (2000)).
[33] *Id.* at 180.

well as the Emergency Planning and Community Right to Know Act and the Comprehensive Environmental Response, Compensation, and Liability Act.[34]

Under the Consent Agreement, EPA required participating AFOs to pay a nominal civil penalty and aid in the development of emissions estimating methodologies by contributing to the cost of conducting NAEMS and making their facilities available for emissions testing.[35] Upon publication of final emissions estimating methodologies, EPA theorized, AFOs would be better able to estimate their ongoing emissions of air pollution and, thus, would be better equipped to come into compliance with longstanding federal law.[36] EPA initially estimated that the Consent Agreement would come to an end by 2010, at which point, the Agency anticipated that it would have published final emissions estimating methodologies and participating AFOs would have "assess[ed] their emissions, appl[ied] for any applicable CAA permits, and install[ed] any necessary emission reduction controls."[37]

Fifteen years later, EPA finally is accepting comments on its Draft EEMs, but it has not announced any intention to finalize the emissions estimating methodologies by a date certain, to say nothing of its plans for requiring facilities to obtain permits and install emissions controls. EPA's delay has had grave consequences. According to one estimate based on data from EPA's 2014 National Emissions Inventory, ammonia emissions from livestock waste handling at CAFOs resulted in approximately 6,900 premature deaths nationwide.[38] Extrapolating from this estimate, inadequately controlled ammonia emissions from CAFOs may have resulted in approximately 140,000 premature deaths since 2005, when EPA entered the Consent Agreement, and approximately 186,300 premature deaths since 1998, when experts convened by EPA and CDC acknowledged that AFO emissions threatened public health.

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[34] *See* Animal Feeding Operations Consent Agreement and Final Order, 70 Fed. Reg. 4958, 4959 (Jan. 31, 2005).
[35] *Id.* The civil penalty ranged from $200 to $1,000 per AFO, depending on the number of animals confined, up to a cap of $10,000 to $100,000 per AFO owner, depending on the number of AFOs owned. The study contribution totaled approximately $2,500 per AFO.
[36] *Id.*
[37] Off. of Inspector Gen., EPA, *Improving Air Quality: Eleven Years After Agreement, EPA Has Not Developed Reliable Emission Estimation Methods to Determine Whether Animal Feeding Operations Comply with Clean Air Act and Other Statutes* 10 (2017) ("OIG Report"), https://www.epa.gov/sites/production/files/2017-09/documents/_epaoig_20170919-17-p-0396.pdf.
[38] Domingo, *supra* note 22.

DISCUSSION

I. EPA Should Finalize the Draft EEMs Without Additional, Unnecessary Delay.

A. Despite monitoring air pollution at relatively few AFOs, EPA used appropriate instrumentation to gather data.

Nearly 14,000 dairy, poultry, and swine AFOs participated in EPA's Consent Agreement.[39] Through NAEMS, EPA complied with detailed requirements to monitor emissions of ammonia, hydrogen sulfide, particulate matter, and volatile organic compounds ("VOCs") over two years at just 25 facilities—that is, approximately 0.2% of participating AFOs.[40] The monitored AFOs included nine dairy facilities across six states, five poultry facilities across four states, and eleven swine facilities across four states (Table 1).[41] EPA collected measurements of each of the five pollutants at each facility in each state except Texas, where EPA did not report any $PM_{2.5}$ or PM_{10} emissions. Despite the limited scope of the NAEMS dataset—including the fact that EPA did not monitor any beef cattle facilities, which, given their significant emissions, we urge EPA to do in the near future—EPA generally used appropriate instrumentation to gather emissions data at each location.[42]

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[39] EPA, *Consent Agreement and Final Order* (2005), https://www.regulations.gov/document/EPA-HQ-OAR-2004-0237-0695; OIG Report at 16; Claudia Copeland, Cong. Rsch. Serv., *Air Quality Issues and Animal Agriculture: EPA's Air Compliance Agreement* (2014), https://nationalaglawcenter.org/wp-content/uploads/assets/crs/RL32947.pdf.

[40] Overview Report; Sally Shaver, EPA, *Update on the Animal Feeding Operations Consent Agreement and Final Order - Monitoring Study* (2006), https://www.nrcs.usda.gov/sites/default/files/2022-10/EPA-Update-November-2006.pdf (total AFOs in agreement).

[41] EPA, *Development of Emissions Estimating Methodologies for Animal Feeding Operations Volume 1: Overview Report Draft* (2024) ("Overview Report"), https://www.epa.gov/system/files/documents/2024-11/draft_vol_1_overview_report_nov_2024.pdf.

[42] *See* E-mail from Viney Aneja, Professor in the Dep't of Marine, Earth & Atmospheric Scis., N.C. State Univ., to Mustafa Saifuddin, Staff Scientist, Earthjustice (July 26, 2023) (on file with Earthjustice) (characterizing EPA's data collection methods for broiler AFOs as "state of the art"); E-mail from Viney Aneja, Professor in the Dep't of Marine, Earth & Atmospheric Scis., N.C. State Univ., to Mustafa Saifuddin, Staff Scientist, Earthjustice (August 23, 2023) (on file with Earthjustice) (characterizing EPA's data collection methods for layer AFOs as "state of the art"); E-mail from Viney Aneja, Professor in the Dep't of Marine, Earth & Atmospheric Scis., N.C. State Univ., to Mustafa Saifuddin, Staff Scientist, Earthjustice (May 21, 2024) (on file with Earthjustice) (characterizing EPA's data collection methods for dairy AFOs as "state of the art"); E-mail from Viney Aneja, Professor in the Dep't of Marine, Earth & Atmospheric Scis., N.C. State Univ., to Mustafa Saifuddin, Staff Scientist, Earthjustice (April 24, 2023) (on file with Earthjustice) (characterizing EPA's data collection methods for swine AFOs as "state of the art").

STATE	TOTAL AFOs IN CONSENT AGREEMENT	DAIRY AFOs MONITORED	POULTRY AFOs MONITORED	SWINE AFOs MONITORED	MEDIAN NH_3 lbs/day	MEDIAN H_2S lbs/day
CA	299	1	2	0	9.29	0.17
IA	1694	0	0	2	23.3	6.68
IN	519	2	1	2	65.8	0.81
KY	235	0	1	0	24.5	0.07
NC	1441	0	1	4	10.7	0.32
NY	159	1	0	0	19.7	0.35
OK	749	0	0	3	22.5	1.68
TX	687	1	0	0	1539	21.9
WA	53	2	0	0	72.6	1.43
WI	24	2	0	0	20	0.61
U.S.	**13,899**	**9**	**5**	**11**	**19.7**	**0.49**

Table 1. Facilities monitored in NAEMS and median observed NH_3 and H_2S emissions by state.[43]

B. Since 2010, EPA has spent nearly fifteen years fitting statistical models to the data gathered through NAEMS.

Following data collection, EPA developed 82 Draft EEMs, each of which estimates emissions of a particular pollutant from a particular facility type.[44] For example, one model predicts NH_3 emissions from swine finishing barns without pits, while a separate model predicts H_2S emissions from dairy lagoons. To develop each model, EPA first processed the data collected through NAEMS and compared emissions across sites to identify potential sources of variation. Based on these observations and a review of related scientific literature, EPA then identified environmental and facility-related variables likely to predict emissions, such as live animal weight ("LAW"), animal inventory, ambient relative humidity ("ambRH"), ventilation rate, and ambient temperature.

Following reasonable statistical methods to compare potential models, EPA evaluated each potential combination of variables to identify the simplest combination of variables with the greatest predictive power to estimate air pollution. For example, to predict NH_3 emissions from a farrowing barn facility, EPA compared six different potential models, each with some

[43] *See Animal Feeding Operations – 2012 Monitored AFOs*, EPA Web Archive, https://archive.epa.gov/airquality/afo2012/web/html/index.html (last visited Aug. 12, 2025); Sally Shaver, EPA, *Update on the Animal Feeding Operations Consent Agreement and Final Order - Monitoring Study* (2006), https://www.nrcs.usda.gov/sites/default/files/2022-10/EPA-Update-November-2006.pdf (total AFOs in agreement).
[44] *See generally* Draft EEMs.

combination of 4–6 potential input variables. It then evaluated the performance of each potential model in terms of how well the model was able to predict observed emissions, and it selected the model with the best statistical performance and greatest ease of use. In general, EPA repeated this process for each pollutant type and facility type.

The particular type of statistical modeling selected by EPA (linear mixed effects models) requires certain assumptions regarding the shape of the distribution of data.[45] In order to comply with these assumptions, EPA chose to natural log transform the emissions data in NAEMS. This strategy is commonly practiced to shift data distributions to better comply with the requirements of particular statistical modeling frameworks.[46] Due to this choice, to use the Draft EEMs, users must back-transform model outputs using parameters provided by EPA to convert model outputs into interpretable units (e.g., kilograms NH_3 per day). While this data transformation is commonly practiced to comply with modeling assumptions, it is critical to note that this strategy has limitations. In particular, EPA's approach leads to unintended nonlinearities with the potential for unlikely values as predictions extend further from conditions observed in the underlying NAEMS data. As described in further detail below, EPA should provide guidance on the appropriate range of input conditions for use for each model and gather additional data from high emissions scenarios to constrain estimates on the higher end, including by requiring the largest facilities to collect monitoring data. In the future, EPA should also explore alternative modeling strategies to appropriately address the distribution of emissions data while reducing unintended model behaviors.

In addition to the 82 Draft EEMs, EPA added nine new emissions factors for VOCs to AP-42.[47] Due to issues with the quality and quantity of VOC data gathered through NAEMS, EPA was unable to construct full emissions estimating methodologies for VOCs. Instead, EPA published a call for information and conducted a literature review to identify emissions factors for VOCs. In contrast to the Draft EEMs, which attempt to account for multiple potential sources of variation in emissions and which were constructed through a more complex statistical model selection process, the emissions factors for VOCs are simply based on average observed rates of emissions per unit animal per day.

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[45] Holger Schielzeth et al., *Robustness of Linear Mixed-Effects Models to Violations of Distributional Assumptions*, 11 Methods Ecology & Evolution 1141 (2020).

[46] *Id.*

[47] EPA states that due to limitations in the quality and quantity of data for VOCs, it was not able to use the same statistical modeling process it used for other pollutants and instead reports simplified emissions factors (grams per day per head) based on the NAEMS data and literature reviews. *See* Draft EEMs at 9.4.5-20 tbl. 9.4-7.

Despite these limitations, the Draft EEMs offer a reasonable starting point to allow facilities to estimate and report emissions. These models are an improvement from having *no model,* as has been the case for this sector following years of delay. Additionally, EPA's approach for model development exceeds the baseline requirements for inclusion in AP-42. EPA has outlined the process to be followed for developing new emissions factors for inclusion in AP-42.[48] By following a process that is more complex than required, EPA already has delayed publication of the Draft EEMs. Instead of changing the structure of its models or its process for developing those models now, EPA should finalize the Draft EEMs without additional, unnecessary delay. After the Draft EEMs are finalized, and AFOs have come into compliance with clean air laws, EPA can continue to refine its models according to established process.[49]

C. The Draft EEMs are generally ready to use.

The Draft EEMs can be readily implemented to estimate air pollution from existing facilities. Facility owners can generate emissions estimates based on publicly available meteorological data and information they are likely to have about their facilities, such as the number of animals held in confinement or the number of manure lagoons on their site. Individual AFO operators would need only specify between one and four input variables (such as temperature or live animal weight) to run any given model. Most of the models require only one or two input variables, which should be readily available to most operators based on their knowledge of their facility or local meteorological data. The models are similar in complexity to other models in AP-42, which have been used for decades to estimate air pollution from other sectors, including models for Municipal Solid Waste Landfills (Section 2.4), Organic Liquid Storage Tanks (Section 7.1), and Aggregate Handling and Storage Piles (Section 13.2.4). These other models require site-specific data, multi-step calculations, and the use of kinetic equations or process-based modeling to describe chemical transformations of pollutants.

The Draft EEMs can already be used to generate air pollution estimates and identify significant sources of air pollution. For example, based on AFO inventory and location data from the North Carolina Department of Environmental Quality, we are able to generate estimates for air pollution from specific existing facilities. Using publicly available data on facility sizes and meteorological data, we estimate that a single lagoon at a median sized swine finishing CAFO in Duplin County could generate over 260 pounds of ammonia on an average summer

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[48] EPA, *Procedures for Preparing Emission Factor Documents* (1997), https://nepis.epa.gov/Exe/ZyPDF.cgi/2000EAVH.PDF?Dockey=2000EAVH.PDF.
[49] *See id.*

day, while a lagoon at the largest swine finishing CAFO in the county would generate over 1,800 pounds of ammonia.[50]

D. Prior to finalizing the Draft EEMs, EPA should make a few small improvements that would not require significant delay.

Although the models are generally ready to implement, EPA should make a few small improvements prior to their finalization. The changes we note below are simple adjustments that should not significantly delay publication and implementation of the models.

1. EPA should specify the appropriate range of input conditions for each model's use, offer guidance for how to estimate emissions for scenarios outside of these ranges, and require additional monitoring from facilities outside these ranges.

EPA should include guidance on the appropriate range of input variables for which each model should be utilized. For example, EPA should provide acceptable ranges of inventory, temperature, windspeed, and relative humidity for models requiring these inputs. EPA should include a note that models should not be used under input variable ranges which yield negative emissions values. There are a few specific models which produce unreasonable negative emissions across a reasonable range of inputs (Table 2). For example, the model for $PM_{2.5}$ from layer poultry at manure-belt facilities yields negative emissions values when inventory is below 239,000 poultry. Similarly, dairy lagoon models for NH_3 and H_2S yield negative values below -11°C, which is not an unreasonable winter temperature at some facilities. EPA should constrain the use of these models to prevent negative emissions predictions and check these models for errors that may need to be corrected prior to their finalization.

[50] *See* Ex. A, NH_3 Sample Calculation Assumptions; Draft EEMs at 9.4.4-16 tbl. 9.4-4; *Animal Facility Map*, *supra* note 13.

ANIMAL	POLLUTANT	FACILITY TYPE	FRACTION NEGATIVE	RANGE OF INPUTS YIELDING NEGATIVE EMISSIONS
POULTRY	PM2.5	Layer; Manure Belt	0.52	Negative below 239,000 poultry
DAIRY	NH3	Lagoon	0.28	Negative below -11C
DAIRY	H2S	Lagoon	0.28	Negative below -11C
SWINE	NH3	Open Source; Breeding-Gestation Lagoon	0.28	Negative at low windspeed and low temperature combinations, including some scenarios below 1.3C
DAIRY	PM2.5	Milking	0.26	Negative below -10C
SWINE	H2S	Gestation; Shallow	0.20	Negative at low temperature and low live-animal-weight combinations, including some scenarios below 55 Mg live animal weight.
POULTRY	NH3	Layer; Manure Shed	0.15	Negative at low temperature and low inventory combinations, including some scenarios below 168,000 poultry
POULTRY	H2S	Layer; Manure Shed	0.15	Negative at low temperature and low inventory combinations, including some scenarios below 197,000 poultry
DAIRY	PM10	Milking	0.13	Negative at low temperature and high humidity combinations, including some scenarios below -1C
DAIRY	NH3	Naturally Ventilated	0.10	Negative at low windspeed and low inventory combinations, including some scenarios below 100 cows

Table 2. Models that yield negative emissions estimates for 10% or more of model runs randomly sampled across a reasonable range of inputs. *To quantify the likelihood of negative emissions, each model was run 1,000 times based on a random selection of input values drawn from the range of inputs observed in NAEMS (e.g., random selections of temperature values from the range observed across sites). Most of the 82 Draft EEMs produce a reasonable range of postive emissions values when run at representative meteorological and facility input values. However, the models listed here yielded negative emissions estimates across 10% or more of simulations run based on inputs representing the observed range of input values in NAEMS. Models with high Fraction Negative values yielded negative emissions estimates more frequently than models with low Fraction Negative values.*

2. EPA should provide ratings for each model reflecting the quality and quantity of data used to build each model.

EPA should assign ratings to the Draft EEMs to provide a "general indication of [their] reliability[] or robustness."[51] Between 1995 and 2018, quality ratings in AP-42 were letter-based, ranging from A (excellent) to E (poor).[52] Since 2018, EPA has shifted to a more objective

[51] EPA, *Introduction, in AP-42: Compilation of Air Emissions Factors* 8 (2024), https://www.epa.gov/system/files/documents/2024-01/introduction_2024.pdf.
[52] *Id.* at 9.

rating process to create quantitative Factor Quality Indexes ("FQI").[53] To further support quantitative rather than subjective ratings, in 2024, EPA also published an Emissions Factor Uncertainty Assessment, which rates existing emissions factors based on uncertainty ratios for a range of probability levels.[54] EPA should follow all applicable processes to include appropriate ratings for each of the new models for livestock and poultry feed operations.

3. EPA should develop a user-friendly emissions calculator tool.

EPA should complete the development of an emissions calculator to facilitate easy use of the models. EPA has developed similar calculators for other contexts, for example, to allow users to estimate diesel emissions,[55] greenhouse gas emissions,[56] and greenhouse gas equivalencies.[57] EPA also provides automated estimation tools for other sectors in AP-42, such as the LandGEM tool for estimating emissions from municipal solid waste landfills[58] and the TANKS emissions estimation software for estimating emissions from liquid storage tanks.[59] An air pollution emissions calculator would allow users to enter their input data (e.g., location and facility size) and download emissions estimates based on the emissions estimation methodologies, without having to perform calculations on their own. A user-facing calculator would simplify calculations and reduce errors from individual calculations. EPA has indicated that it has already begun development of this type of calculator for air pollution from AFOs and sought comment on this issue in November 2023.[60] EPA should accelerate these efforts and make a user-friendly emissions calculator available as soon as possible.

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[53] *Id.* at 10.

[54] RTI In'tl, *Emission Factor Uncertainty Assessment Review Draft* (2007), https://www.epa.gov/sites/default/files/2020-11/documents/ef_uncertainty_assess_draft0207s.pdf.

[55] *Diesel Emissions Quantifier (DEQ)*, EPA, https://cfpub.epa.gov/quantifier/index.cfm?action=main.home (last visited Aug. 12, 2025).

[56] *Simplified GHG Emissions Calculator*, EPA, https://www.epa.gov/climateleadership/simplified-ghg-emissions-calculator (last updated Jan. 11, 2025).

[57] *Greenhouse Gas Equivalencies Calculator*, EPA, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (last updated Feb. 24, 2025).

[58] *Landfill Gas Emissions Model (LandGEM)*, EPA, https://www.epa.gov/land-research/landfill-gas-emissions-model-landgem (last updated May 19, 2025); EPA, *AP-42 Section 2.4 Municipal Solid Waste Landfills* (2025), https://www.epa.gov/system/files/documents/2025-05/c2s4_5_2025_final.pdf.

[59] *TANKS Emissions Estimation Software, Version 5*, EPA, https://www.epa.gov/air-emissions-factors-and-quantification/tanks-emissions-estimation-software-version-5 (last updated July 14, 2025); EPA, *AP-42 Section 7.1 Organic Liquid Storage Tanks* (2024), https://www.epa.gov/system/files/documents/2024-10/c7s1_2024_clean.pdf.

[60] *See* Potential Future Regulation for Emergency Release Notification Requirements for Animal Waste Air Emissions Under the Emergency Planning and Community Right-to-Know Act (EPCRA), 88 Fed. Reg. 80222 (Nov. 17, 2023); *see also* Earthjustice et al., Comment Letter on Potential Future Regulation

II. After Finalizing the Draft EEMs, EPA Should Continue to Assimilate Additional Data, Particularly from Large AFOs, to Improve Model Performance.

EPA should finalize the Draft EEMs with the minor revisions suggested above, while continuing to collect additional data to support future model refinements. A process exists for making post-publication revisions of AP-42 models based on additional data.[61] EPA should continue to assimilate new data to revise and improve the current models according to this process. As explained above, however, additional data is not required to finalize the current models.

A. EPA should gather additional data from large AFOs, including by requiring AFOs above a certain size to measure and report emissions.

As noted above, EPA monitored only 25 AFOs. This is a small fraction of all AFOs that EPA could have monitored across the country. Indeed, there were nearly 14,000 AFOs participating in the Consent Agreement alone.[62] The majority of respondents to the Consent

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for Emergency Release Notification Requirements for Animal Waste Air Emissions Under EPCRA (Feb. 15, 2024), https://www.regulations.gov/comment/EPA-HQ-OLEM-2023-0142-0379.

[61] EPA, *Recommended Procedures for Development of Emissions Factors and Use of the WebFIRE Database* (2024), https://www.epa.gov/system/files/documents/2024-09/final-webfire-procedures-document_aug-2024.pdf.

[62] EPA, *Consent Agreement and Final Order for CAA 06-0021C thru 06-0702C* (Apr. 17, 2006), https://yosemite.epa.gov/OA/EAB_WEB_Docket.nsf/Filings%20By%20Appeal%20Number/9D6AE0A8F846398085257154006C2A56/$File/Final%20Order%204.17.06.pdf; EPA, *Consent Agreement and Final Order for CAA 06-0703C thru 06-0906C* (May 5, 2006), https://yosemite.epa.gov/OA/EAB_WEB_Docket.nsf/Filings%20By%20Appeal%20Number/BFA715819D02062F852571650052BC3A/$File/Final%20Order%205.5.06.pdf; EPA, *Consent Agreement and Final Order for CAA 06-0907C thru 06-2111C* (July 19, 2006), https://yosemite.epa.gov/OA/EAB_WEB_Docket.nsf/Filings%20By%20Appeal%20Number/711DADC7D3C8C696852571B0006E9094/$File/Final%20Order%207.19.06.pdf; EPA, *Consent Agreement and Final Order for CAA 05-0001C thru 05-0020C* (Jan. 27, 2006), https://yosemite.epa.gov/OA/EAB_WEB_Docket.nsf/Filings%20By%20Appeal%20Number/660E4D8A76B70EA085257108005C720C/$File/Final%20Order%201.27.06.pdf; EPA, *Consent Agreement and Final Order for CAA 06-2466C* (Aug. 21, 2006), https://yosemite.epa.gov/OA/EAB_WEB_Docket.nsf/Filings%20By%20Appeal%20Number/9FCCF18D22C36CA0852571D3006ADAD3/$File/Untitled.pdf; EPA, *Consent Agreement and Final Order for CAA 06-2468C thru 06-2618C* (Dec. 12, 2006), https://yosemite.epa.gov/OA/EAB_WEB_Docket.nsf/Filings%20By%20Appeal%20Number/65A5CB62DBB8DC6B852572440058620C/$File/Final%20Order.pdf; EPA, *Consent Agreement and Final Order for CAA 06-2112C thru 06-2464C* (Aug. 7, 2006), https://yosemite.epa.gov/OA/EAB_WEB_Docket.nsf/Filings%20By%20Appeal%20Number/95C3346E3F1C1E26852571C30063AAFD/$File/Final%20Order5.pdf; EPA, *Consent Agreement and Final Order for CAA-HQ-2008-01c* (Oct. 24, 2008),

Agreement do not disclose farm sizes, but the Consent Agreement included at least 1,669 Large CAFOs and at least 71 AFOs that are at least ten times as large as the Large CAFO threshold.[63] In the future, EPA should greatly expand the number and types of monitored sites, including by requiring AFOs above a certain size to measure and report emissions, and it should continue to collect data over a longer duration of time. EPA should monitor beef cattle facilities and develop additional models for estimating emissions from these facilities. Additionally, EPA should begin collecting data from a broader range of environmental conditions (e.g., higher temperatures) and facility sizes across all categories. This will be critical to expand the appropriate range of input conditions for which these models can accurately predict emissions from facilities with different conditions than those monitored under NAEMS.

Critically, EPA has collected very few observations of ammonia or hydrogen sulfide emissions at or near 100 lbs/day (Figure 2). Indeed, 84% of NH_3 emission measurements and 99% of H_2S emissions measurements in NAEMS are below this threshold. This poor data coverage of higher emissions is due to EPA's failure to monitor larger facilities, rather than a lack of higher emissions occurring. *First*, existing literature suggests that many AFOs generate emissions well above this threshold.[64] *Second,* even given these limited observations of threshold exceedances at a few facilities within NAEMS, we would expect thousands of exceedances of the NH_3 threshold when scaled to the national or annual scale. *And finally*, when the draft models are applied to actual larger facilities, there are thousands of facilities that are likely to exceed the 100 lbs/day threshold for NH_3. For example, according to the USDA Census of Agriculture, there were 834 dairies with 2,500 or more cattle in 2022.[65] Based on a statistical likelihood analysis fitted to the NAEMS data, these dairies have greater than a 95% likelihood of exceeding the 100 lbs/day NH_3 threshold.[66]

After finalizing these models, EPA should prioritize collecting data representing high emission rates, at or above the 100 lbs/day threshold. In order to collect these observations, EPA

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https://yosemite.epa.gov/oa/EAB_Web_Docket.nsf/Unpublished~Final~Orders/EA01C9266EEEC971852574EC0069B0CB/$File/Final%20Order...1.pdf.

[63] There were 2,621 respondents to the Agreement, representing nearly 14,000 facilities. Only 1,098 shared farm counts, listing 1,669 Large CAFOs and at least 71 AFOs that are at least ten times as large as the Large CAFO threshold. *See* sources cited *supra* note 62 (combining values from full list of agreements).

[64] Wyer, *supra* note 16; Liu, *supra* note 10; Brandon M. Lewis et al., *Modeling and Analysis of Air Pollution and Environmental Justice: The Case for North Carolina's Hog Concentrated Animal Feeding Operations,* 181 Env't Health Persps. 087018-1 (2023); Liye Zhu et al., *Sources and Impacts of Atmospheric NH_3: Current Understanding and Frontiers for Modeling, Measurements, and Remote Sensing in North America*, 1 Current Pollution Reps. 95 (2015); Env't Integrity Project, *supra* note 17.

[65] USDA, *supra* note 5, at 19 tbl. 17.

[66] *See* Ex. B, Declaration of Rose Abramoff ("Abramoff Decl.") ¶ 13.

should expand the geographic coverage of air pollution monitoring efforts, focusing on the largest facilities under high temperature conditions. For example, the largest swine facility monitored by EPA in NAEMS held 2,550 hogs and pigs.[67] This is a poor representation of the largest swine facilities. According to the 2022 USDA Census of Agriculture, there were 3,540 swine facilities with over 5,000 hogs and pigs in the U.S.[68] In North Carolina alone, there were 1,421 swine CAFOs larger than the largest swine facility monitored in NAEMS.[69]
These facilities contained 91% percent of all swine in the state and are likely to account for the majority of air pollution from swine CAFOs (Figure 1).

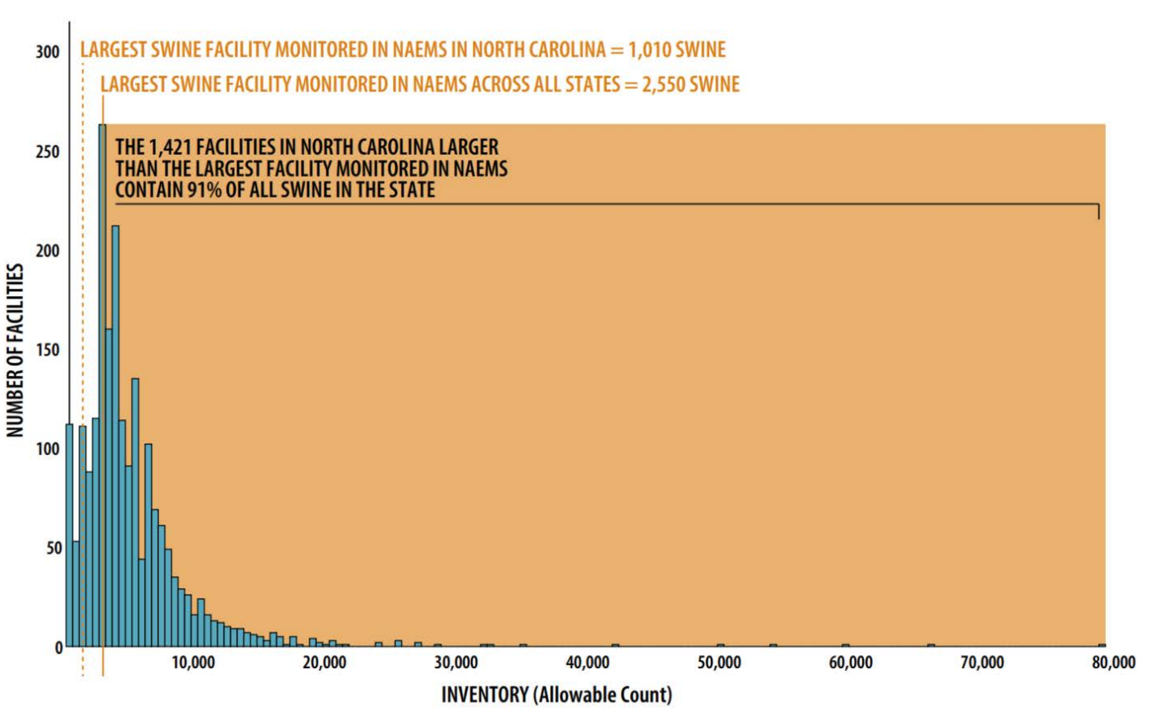

Figure 1. Distribution of swine CAFOs in North Carolina by number of swine permitted. *Vertical lines indicate size of largest facilities monitored in NAEMS in North Caolina (dashed) and across the country (solid). Shaded region shows facilities in North Carolina larger than the largest facility monitored in NAEMS, which contain 91% of total swine inventory.*[70]

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[67] *Draft AP-42 Chapter 9, Section 4 - Livestock and Poultry Feed Operations and Air Emissions Estimating Methodologies for Animal Feeding Operations*, EPA, https://www.epa.gov/afos-air/draft-ap-42-chapter-9-section-4-livestock-and-poultry-feed-operations-and-air-emissions (last updated Mar. 13, 2025) (Emission Data Files for Animal Feeding Operations).
[68] USDA, *supra* note 5, at 19 tbl. 19.
[69] *Animal Facility Map*, *supra* note 13.
[70] *Id.*

Similarly, the largest dairy facility monitored by EPA held 3,623 cows.[71] In Tulare County, CA, alone there were 46 facilities with more than 3,623 cows, including one facility with 108,329 calves and one with 10,325 mature dairy cows (as of March 2025).[72] Thus, there are thousands of swine facilities and hundreds of dairy facilities across the U.S. that are larger than those monitored in NAEMS. These larger facilities will be critical to monitor as they are likely to contribute substantially to air pollution.[73] Indeed, the 834 dairy CAFOs in the United States with 2,500 or more milk cows contain 42% of all milk cow inventory across the country, and the 3,540 swine CAFOs with 5,000 or more swine contain 75% of all swine inventory across the country.[74] As emissions are likely to scale with inventory and these larger facilities are more likely to hold manure in lagoons, they are likely to account for the largest emissions and the most exceedances of regulatory thresholds.

[71] *Draft AP-42 Chapter 9, Section 4*, *supra* note 67 (Emission Data Files for Animal Feeding Operations).
[72] Cal. Env't Prot. Agency, *California Integrated Water Quality System Project (CIWQS) Regulated Facility Report (Detail)*, CA.gov, https://ciwqs.waterboards.ca.gov/ciwqs/readOnly/CiwqsReportServlet?reportID=8210359&inCommand=drilldown&reportName=RegulatedFacilityDetail&program=ANIMALWASTE (last visited Aug. 12, 2025).
[73] According the 2022 USDA Census of Agriculture, there were 834 farms with 2,500 or more dairy cattle and 3,540 farms with 5,000 or more hogs and pigs. USDA, *supra* note 5, at 19 tbls. 17, 19.
[74] *Id.*

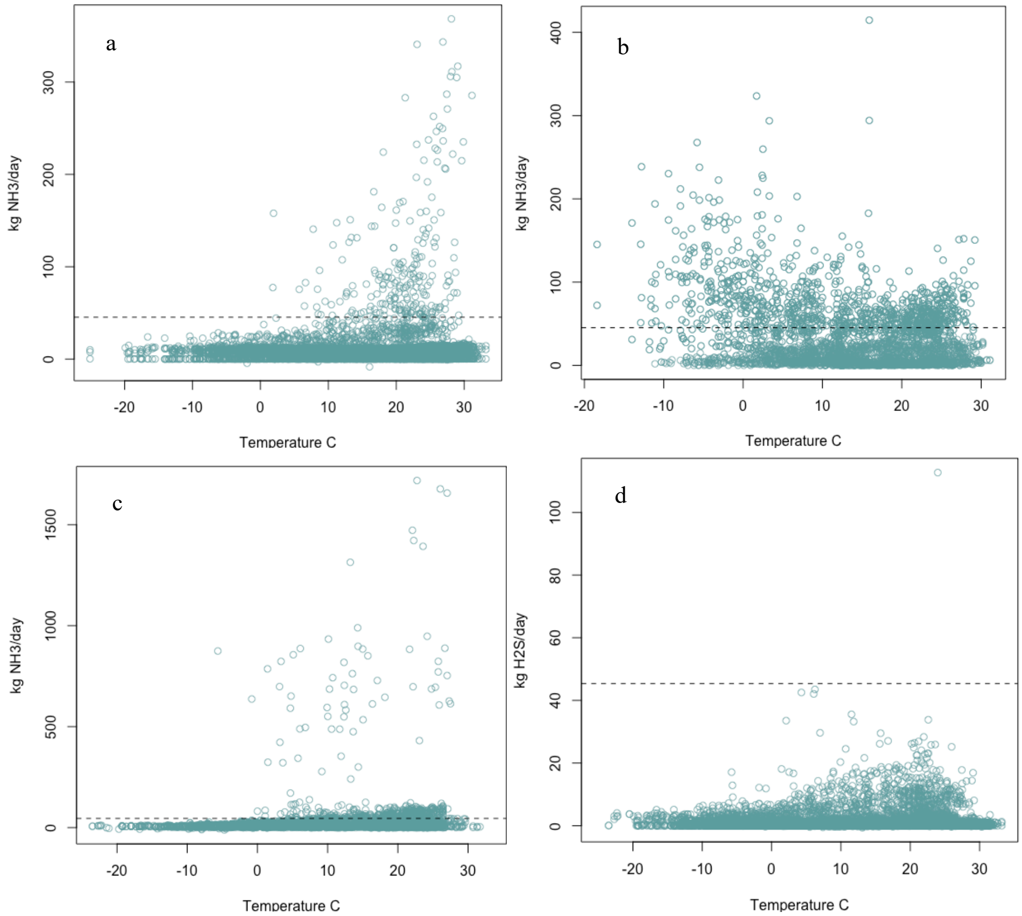

Figure 2. NH_3 emissions across all (a) swine, (b) poultry, and (c) dairy facilities monitored in NAEMS. (d) H_2S emissions across all facilities monitored in NAEMS. Dashed lines show 100 lbs/day.

B. EPA should use existing data from NAEMS to identify and set priorities for future data collection.

Despite its limitations, the NAEMS dataset can be used to optimize future air pollution sampling. EPA may productively use the data it has gathered thus far to develop a sampling strategy designed to improve model performance. EPA should broadly assess the uncertainty of current models and their sensitivity to different input variables to identify specific facilities to prioritize for additional measurements. This process will allow EPA to efficiently assimilate new data with the greatest potential for future model improvements.

1. **EPA should prioritize collecting additional data underlying models with the greatest uncertainties.**

EPA should develop a sampling strategy that prioritizes improvements to models with the greatest uncertainties for sources likely to contribute the most to total air pollution. EPA performed an uncertainty analysis to quantify the difference between model predictions and observed emissions for each model. This analysis quantifies how far observations within the NAEMS dataset deviate from model predictions. In other words, models associated with low uncertainty are ones that more closely capture variation observed across the NAEMS dataset, while models associated with high uncertainty are ones for which there exist observations within the NAEMS dataset that deviate more substantially from model predictions. All models are associated with some degree of uncertainty as it would be intractable to capture all sources of variation in this context. Thus, these models may still provide useful predictions, and EPA may productively use its estimates of uncertainty to establish priorities in terms of which models would benefit most from additional data collection. Table 3 below shows NH_3 models ordered by the magnitude of uncertainty in lbs/day. Based on this, EPA should prioritize collecting additional measurements of ammonia from larger poultry facilities, lagoons at larger swine facilities, and larger dairy facilities. Although specific models may generate estimates with broad uncertainty ranges under particular conditions, there is high confidence that many thousands of facilities exceed regulatory emissions thresholds even if the particular magnitude of the emissions exceedance carries uncertainty.[75]

2. **EPA should prioritize monitoring input variables to which emissions rates show the greatest sensitivity.**

EPA should use sensitivity analyses to identify which specific input variables it should prioritize for additional data collection. Sensitivity analyses, like the one summarized in Table 3 below, quantify the degree to which model outputs (i.e., emissions) vary in relation to model inputs (e.g., facility details or meteorological inputs). EPA may use these analyses to identify a range of input variables to prioritize for additional data collection. For example, several of the Draft EEMs show the highest sensitivity to inventory, suggesting EPA should obtain measurements from larger facilities. Lagoon emissions were also sensitive to windspeed and temperature, indicating that EPA should monitor lagoons across a broader range of temperatures and windspeeds.

[75] Ex. B, Abramoff Decl. ¶ 13.

ANIMAL	FACILITY	UNCERTAINTY LBS/DAY/SOURCE	INPUT VARIABLE WITH GREATEST SENSITIVITY
POULTRY	Layer: High Rise	87746	Inventory [1.36]
POULTRY	Layer: Manure Belt	49882	Inventory [1.47]
SWINE	Grow-Finish Lagoon	44421	Windspeed [0.85]
SWINE	Breeding-Gestation Lagoon	28646	Windspeed [0.82]
DAIRY	Naturally Ventilated	19759	Inventory [2.17]
SWINE	Gestation	10346	LAW [0.99]
DAIRY	Mechanically Ventilated; Flush	9393	Inventory [1.98]
DAIRY	Mechanically-Ventilated, Scrape	9393	Inventory [1.97]
SWINE	Gestation; Shallow	9123	LAW [1.05]
SWINE	Gestation; Deep	9123	LAW [1.05]
DAIRY	Lagoon	7966	Temperature [0.25]
POULTRY	Broiler	7205	LAW [0.38]
POULTRY	Layer: Manure Shed	6375	Inventory [1.47]
SWINE	Finishing	2139	LAW [1.22]
SWINE	Finishing: Shallow	2088	LAW [1.19]
SWINE	Finishing: Deep	2088	LAW [1.18]
SWINE	Farrowing	199	LAW [1.10]
SWINE	Basin	91	Temperature [0.07]
DAIRY	Milking	26	Temperature [0.19], Inventory [1.08]*
DAIRY	Corrals	26	AmbRH [0.75], Inventory [1.05]*

LAW = Live Animal Weight; **AmbRH** = Ambient Relative Humidity

Table 3. Draft EEMs for NH_3 ordered by decreasing uncertainty. *The uncertainty value is the one generated by the EPA (Sr, or standard deviation of daily residuals, i.e., the difference between model-predicted and observed or measured emissions), by varying one input at a time. We converted this value to the common units of lbs/day (per facility). To generate a sensitivity index of the effect of each model's inputs on emissions, models were run across the range of inputs observed in NAEMS and the change in emissions per change in each model input was quantified.*

These values were normalized by calculating the ratio of mean input/mean emissions to derive a unitless sensitivity index of the form: percent change in Y / percent change in X. For example, an index of -1 means that for every 1% increase in inventory, emissions fall by 1%. Two dairy models showed highest sensitivity to inventory despite this not being one of the input variables because emissions are output in units per head, which are then scaled by inventory to allow for inter-model comparisons.

C. EPA should incorporate additional data sources to improve future model iterations.

As noted above, EPA should require additional monitoring from the largest facilities to support future model improvements.[76] In addition to expanding direct measurements of air pollution at individual AFOs (as done in NAEMS) and continuing to integrate data from peer-reviewed scientific studies, EPA should also consider emerging opportunities to vastly increase observations of air pollution from CAFOs through low-cost sensors and remote sensing. EPA has explored the use of low-cost sensors to measure particulate matter during smoke events.[77] EPA should explore similar strategies for rapidly increasing data underlying air pollution models for AFOs. Additionally, EPA should explore opportunities to integrate data from satellite remote sensing technology, which is increasingly capable of identifying emission sources and estimating pollutant concentrations, including for ammonia from industrial agricultural sources.[78] This combination of additional approaches could provide EPA with cost-effective tools for greatly expanding the dataset used to develop models in AP-42.

D. In future model iterations, EPA should explore alternative modeling strategies.

In the future, EPA should explore opportunities to leverage correlations among air pollutants to increase data underlying individual models. EPA has currently developed models for each air pollutant separately. However, an improved understanding of particulate matter emissions may also help refine models for ammonia and hydrogen sulfide emissions, as these pollutants are often highly correlated. EPA should explore the potential for estimating air pollutants that are more challenging to measure based on these relationships.

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[76] *In re Peabody W. Coal Co.*, 12 E.A.D. 22, 2005 WL 428833, at *12 (EAB Feb. 18, 2005); *In re Shell Offshore, Inc.*, 15 E.A.D. 536, 2012 WL 1123876, at *19 (EAB Mar. 30, 2012).
[77] Karoline K. Barkjohn et al., *Correction and Accuracy of PurpleAir $PM_{2.5}$ Measurements for Extreme Wildfire Smoke*, 22 Sensors 9669 (2022).
[78] Mahmoud A. Hassaan et al., *Assessing Vulnerability of Densely Populated Areas to Air Pollution Using Sentinel-5P Imageries: A Case Study of the Nile Delta, Egypt*, 13 Sci. Reps. (2023); Akirah Epps et al., *Satellite Observations of Atmospheric Ammonia Inequalities Associated with Industrialized Swine Facilities in Eastern North Carolina*, 59 Env't Sci. Tech. 2651 (2025); Martin Van Damme et al., *Industrial and Agricultural Ammonia Point Sources Exposed*, 564 Nature 99 (2018); Lieven Clarisse et al., *Tracking Down Global NH_3 Point Sources with Wind-Adjusted Superresolution*, 12 Atmospheric Measurement Techs. 5457 (2019).

EPA should also explore alternative modeling strategies in future model iterations while continuing to assimilate additional data. For example, the current approach of using natural log transformed data to address non-normal distributions results in unintended nonlinearities in model predictions. EPA should explore alternative strategies to address these distributional issues, such as through generalized linear models or other statistical approaches.

EPA should also consider shifting away from a purely statistical modeling approach towards process-based models to more directly represent the biophysical processes generating emissions.[79] Indeed, the Science Advisory Board ("SAB") recommended that EPA develop a process-based model to estimate air pollution from AFOs in 2013.[80] There are several examples of process-based models for air pollution and other contexts available in scientific literature.[81] For example, Rumsey and Aneja (2014) developed a mass-transfer model to predict H_2S emissions from manure at swine AFOs.[82] Similarly, McQuilling and Adams (2015) developed process-based models to predict NH_3 emissions from beef cattle, swine, and poultry operations,[83] and Leytem et al. (2018) have developed a process-based model to estimate NH_3 emissions from dairy lagoons in Idaho.[84] In the future, EPA should build from these examples, existing data, and expanded data collection efforts to explore alternative modeling frameworks to best predict air pollution from AFOs.

CONCLUSION

There is no question that AFOs emit substantial quantities of air pollution that can result in death and serious injury.[85] In delaying regulation of this pollution for over two decades while it conducted NAEMS and prepared the Draft EEMs, EPA effectively determined that the harms of uncontrolled AFO pollution were outweighed by the benefits associated with easing the burden of compliance with clean air laws for AFO owners and operators. No other industry has required—or received—such handholding. Whatever the merits of EPA's past determination, it

[79] K. Cuddington et al., Process-Based Models Are Required to Manage Ecological Systems in a Changing World, 4 Ecosphere 1 (2013).
[80] SAB, EPA, *SAB Review of Emissions-Estimating Methodologies for Broiler Animal Feeding Operations and for Lagoons and Basins at Swine and Dairy Animal Feeding Operations* (2013), https://nepis.epa.gov/Exe/ZyPDF.cgi/P100J7UW.PDF?Dockey=P100J7UW.PDF.
[81] *Id.*
[82] Ian C. Rumsey & Viney P. *Aneja, Measurement and Modeling of Hydrogen Sulfide Lagoon Emissions from a Swine Concentrated Animal Feeding Operation*, 48 Env't Sci. Tech. 1609 (2014).
[83] Alyssa M. McQuilling & Peter J. Adams, Semi-Empirical Process-Based Models for Ammonia Emissions from Beef, Swine, and Poultry Operations in the United States, 120 Atmospheric Env't 127 (2015).
[84] April B. Leytem et al, *Ammonia Emissions from Dairy Lagoons in the Western U.S.*, 61 Transactions ASABE 1001 (2018).
[85] Chamanara, *supra* note 15; Mirabelli, *supra* note 25.

is now time for EPA to act. For the reasons above, we strongly urge EPA to finalize the Draft EEMs without additional unnecessary delay and, after publication, to continue gathering data and refining its models.

If you have any questions about our comments or requests, please do not hesitate to contact Alexis Andiman, aandiman@earthjustice.org, or Mustafa Saifuddin, msaifuddin@earthjustice.org.

Sincerely,

Earthjustice
Animal Legal Defense Fund
Boone County Farmers and Neighbors
Center for Food Safety
Conservation Law Center
Dakota Resource Council
Dakota Rural Action
Don't Waste Arizona
Endangered Habitats League
Environmental Law & Policy Center
Environmental Working Group
Flow Water Advocates
Friends of Toppenish Creek
Jefferson County Farmers & Neighbors
Michiganders for a Just Farming System
Milwaukee Riverkeeper
Missouri Coalition for the Environment
Ohio Environmental Council
Rural Empowerment Association for Community Help
San Francisco Baykeeper
Sierra Club
Snake River Waterkeeper
Socially Responsible Agriculture Project
Waterkeeper Alliance
Waterkeepers Chesapeake

Exhibit A

NH_3 Sample Calculation Assumptions & Results

We estimated ammonia emissions from the median and largest swine CAFOs in Duplin County, NC[1] and Martin County, MN.[2] We assumed each facility contained a swine barn and a manure lagoon. We assumed all swine at each facility were divided evenly across the finishing barns and used a default manure management system. We ran swine models for ammonia emissions from a finishing swine barn with a default manure system and for ammonia emissions from a finishing lagoon using the draft EEMs.[3] We used weather data, including ambient air temperature and wind speed, from the nearest weather station to each facility in the Automated Surface Observing System (ASOS), and adjusted the wind speed to the target height of 2.5m using equation [V = (Z/Zr)^m * Vr] from the reported weather system height of 33 feet.[4] To calculate live animal weight, we multiplied the inventory of each facility by an estimated average swine weight of 158.75 pounds. We estimated the average swine weight by assuming a linear growth rate of swine from 40 pounds to a final weight of 270-285 pounds, which are the typical starting and final weights of swine in farrow-to-finish operations.[5] We did not have measurements of the lagoon sizes on the farms, so we assumed a lagoon surface area of 20,000 square meters per farm, equal to the lagoon area used in EPA's sample calculations in Section 8-1 of the Development of Emissions Estimating Methodologies for Animal Feeding Operations Volume 2: Swine.[6] To calculate estimated total farm emissions, we summed the estimates of emissions from the barn and lagoon at each facility.

We estimated ammonia emissions from the median and largest dairy CAFO in Tulare County, CA.[7] We assumed each facility contained a milking center, barn, and manure lagoon, and we estimated ammonia emissions from each. We used weather data, including ambient air temperature and wind speed, from the ASOS network. We assumed the total farm inventory

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[1] *Animal Facility Map*, N.C. Dep't Env't Quality, https://www.deq.nc.gov/about/divisions/water-resources/permitting/animal-feeding-operations/animal-facility-map (last updated Nov. 25, 2024).
[2] Pollution Control Agency, *Feedlots in Minnesota*, Minn. Geospatial Commons, https://gisdata.mn.gov/dataset/env-feedlots (last visited Aug. 18, 2025).
[3] *See* EPA, *Draft AP-42 Section 9.4 Livestock and Poultry Feed Operations* (2024) ("Draft EEMs"), https://www.epa.gov/system/files/documents/2024-11/draft_ap-42_section_-9.4_livestock_and_poultry_feed_operations_nov_2024.pdf.
[4] Nat'l Oceanic & Atmospheric Admin., *Automated Surface Observing System (ASOS) User's Guide* (1998), https://www.weather.gov/media/asos/aum-toc.pdf.
[5] Econ. Rsch. Serv., *Hogs & Pork - Sector at a Glance*, USDA, https://www.ers.usda.gov/topics/animal-products/hogs-pork/sector-at-a-glance (last visited Aug. 18, 2025).
[6] EPA, *Development of Emissions Estimating Methodologies for Animal Feeding Operations Volume 2: Swine Draft* (2024), https://www.epa.gov/system/files/documents/2024-11/draft_vol_2_swine_report_nov_2024.pdf.
[7] Cal. Env't Prot. Agency, *California Integrated Water Quality System Project (CIWQS) Regulated Facility Report (Detail)*, CA.gov, https://ciwqs.waterboards.ca.gov/ciwqs/readOnly/CiwqsReportServlet?reportID=8210359&inCommand=drilldown&reportName=RegulatedFacilityDetail&program=ANIMALWASTE (last visited Aug. 12, 2025).

equaled the barn and milking center inventory at each facility. We estimated ammonia emissions using each possible barn type to get a range of estimated barn emissions estimates since we do not know the types of barns used at each facility. We ran the draft EEMs for naturally ventilated barns, mechanically ventilated barns with a scrape manure system, and mechanically ventilated barns with a flush manure system.[8] We also estimated ammonia emissions from the milking centers. We did not have measurements of the lagoon sizes on the farms, so we assumed a lagoon surface area of 10,000 square meters per farm, equal to the lagoon area used in the sample calculations in Section 8-1 of the Development of Emissions Estimating Methodologies for Animal Feeding Operations Volume 5: Dairy.[9] To calculate estimated total farm emissions, we summed the estimates of emissions from the barn, milking center, and lagoon at each facility.

[8] *See* Draft EEMs at 9.4.5-20 tbl. 9.4-7.

[9] EPA, *Development of Emissions Estimating Methodologies for Animal Feeding Operations Volume 5: Dairy Draft* (2024), https://www.epa.gov/system/files/documents/2024-11/draft_vol_5_dairy_report_nov_2024_0.pdf.

County, State	Facility Name	Facility Type	Inventory	Emissions (lbs NH3/day)
Duplin, NC	MKM Farms	Swine Finishing	3520	Barns: 61 Lagoons: 268 Total: 329
Duplin, NC	Magolia III	Swine Finishing	48520	Barns: 10637 Lagoons: 1874 Total: 12512
Martin, MN	Whispering Pines	Swine Finishing	3300	Barns: 51
Martin, MN	Family Farms	Swine Finishing	6300	Barns: 104
Tulare, CA	Legendary Farms Dairy	Dairy	1604	Naturally-ventilated Barn: 1037 Mechanically-ventilated scrape Barn: 568 Mechanically-ventilated Flush Barn: 504 Milking Emissions: 179 Lagoon Emissions: 124
Tulare, CA	Vander Eyk & Son Dairy	Dairy	10325	Naturally-ventilated Barn: 1.24 * 10^16 Mechanically-ventilated scrape Barn: 3.01 * 10^9 Mechanically-ventilated Flush Barn: 2.67 * 10^9 Milking Emissions: 1151 Lagoon Emissions: 124

Exhibit B

DECLARATION OF ROSE Z. ABRAMOFF, PH.D.

I, Rose Z. Abramoff, declare as follows:

I. QUALIFICATIONS AND RELEVANT EXPERIENCE

1. My name is Rose Z. Abramoff. I am an assistant professor at the University of Maine. I obtained a Ph.D. in Biology with a certificate in Biogeochemistry from Boston University in 2015. I am an expert on environmental modeling.

2. Previously, I was a postdoctoral researcher at Lawrence Berkeley National Laboratory for three years and Le Laboratoire des Science du Climate et de l'Environnement for three years. I have also been an Associate Scientist at Oak Ridge National Laboratory and a Project Scientist at Lawrence Berkeley National Laboratory.

3. I have co-authored over 30 scientific papers, including research on agricultural systems and statistical and process-based environmental modeling. I have also served as a contributing author to the Second State of the Carbon Cycle report, published by the U.S. Department of Energy, Office of Science.

4. An accurate copy of my curriculum vitae is attached to and incorporated into this Declaration as **Exhibit 1**.

II. OBSERVATIONS ON DRAFT AP-42 CHAPTER 9, SECTION 4 – LIVESTOCK AND POULTRY FEED OPERATIONS AND AIR EMISSIONS ESTIMATING METHODOLOGIES FOR ANIMAL FEEDING OPERATIONS.

5. I have reviewed and assessed the data gathered through the National Air Emissions Modeling Study ("NAEMS") as well as the models reported in AP-42 Chapter 9, Section 4 - Livestock and Poultry Feed Operations ("Draft EEMs"). I have also run the 82 draft models at least 1,000 times each under a range of input settings, and I have performed original statistical analyses to evaluate the underlying data.

6. This Declaration contains my expert opinions, which I hold to a reasonable degree of scientific certainty. My opinions are based on my application of professional judgment and expertise to specific facts and data, namely, to the facts and data included in documents related to the Draft EEMs. Facts and data of this type are typically and reasonably relied upon by experts in my field.

7. The United States Environmental Protection Agency ("EPA") monitored only 25 sites in the NAEMS. This limited dataset makes it challenging to confidently estimate emissions under scenarios that differ from those observed.

8. EPA failed to monitor the largest animal feeding operations ("AFOs"), which are likely to generate the highest rates of emissions.

9. Despite the limited dataset, EPA used reasonable statistical methods to fit the models to the data in NAEMS.

10. EPA chose reasonable meteorological and facility details as potential predictors for each model. However, in the future, EPA should explore the potential for including co-pollutant emission rates as potential predictors. For example, emissions rates for ammonia ("NH_3") and hydrogen sulfide ("H_2S") are often highly correlated, and EPA should explore opportunities to leverage these correlations to predict emissions of one pollutant or the other.

11. EPA followed a reasonable statistical approach to compare model performance across multiple potential models and select final draft models for each subcategory.

12. EPA's choice to natural log transform data is a common strategy to help data comply with regression assumptions. However, this choice leads to unintended nonlinearities even following back-transformation. Here, this can lead to unlikely estimates, particularly under high input values. EPA should explore alternative strategies to address non-normal data

distributions in the future. Most importantly, EPA should gather additional data from large facilities and high emissions scenarios to help constrain high-end estimates.

13. The data collected through NAEMS can already be used to determine whether a facility of a given size is likely to emit pollution above a certain threshold. For example, based on my analysis of the NAEMS data, all dairies with over 2,500 cattle have greater than a 95% likelihood of exceeding 100 lbs/day of NH_3.

14. EPA should use the limited data it has collected through NAEMS to identify facilities with a high likelihood of emitting pollution above certain thresholds. EPA should require these facilities to obtain permits and adopt mitigating strategies to reduce air pollution, as appropriate, and require these facilities collect additional direct measurements. These data would help refine predictions and support future model development.

15. EPA should continue to expand data collection to support future model improvements. EPA should increase the number of sites monitored and collect data from a wider distribution of facility sizes, with particular attention to the largest facilities.

16. EPA should draw inferences from its existing uncertainty analyses and sensitivity analyses to identify priorities for future data collection that will most directly improve future model iterations.

17. EPA should explore opportunities to integrate other air pollution data sources, including estimates of air pollution derived through remote sensing.

I declare, to the best of my knowledge, the foregoing is true and correct. Executed this 15th day of August 2025, in Orono, Maine.

Rose Z. Abramoff, Ph.D.

Exhibit 1

Rose Zheng Abramoff
Email: rose.abramoff [at] maine.edu
GitHub: github.com/rabramoff
Address: Orono, ME, USA

Appointments Held

- **2025–** Assistant Professor of Forest Science, School of Forest Resources, University of Maine
- **2024–** Director, Wintergreen Earth Science, LLC
- **2023** Project Scientist, Climate and Ecosystem Sciences Division, Lawrence Berkeley National Laboratory
- **2022–2023** Associate Scientist, Environmental Sciences Division and Climate Change Science Institute, Oak Ridge National Laboratory
- **2018–2021** Postdoctoral Researcher, Laboratoire des Sciences du Climat et de l'Environnement (LSCE, French National Laboratory of Climate and Environmental Science)
- **2015–2018** Postdoctoral Researcher, Climate and Ecosystem Sciences Division, Lawrence Berkeley National Laboratory
- **2009–2015** Teaching Fellow, Boston University

Education

- **2015** PhD in Biology: Ecology, Behavior and Evolution, Boston University
- **2015** Certificate in Biogeoscience, Boston University
- **2009** BA in Biology and Theater & Dance, Amherst College

Grants & Awards (last 10 years)

- **2025-2027** NSRC Quantifying forest carbon pools and fluxes following partial harvest in northern conifer forests, Co-PI
- **2024–2025** Earthjustice contract to evaluate EPA AFO model performance
- **2023–2028** Schmidt Futures Virtual Earth System Research Institute (VESRI) Project: CALIPSO – Carbon Loss In Plants, Soils and Oceans, Co-PI
- **2023–2027** DOE RENEW DE-FOA-0002757: Training a diverse STEM workforce to measure and model energy, water, and carbon budget, Co-PI
- **2022–2024** DOE Transformational Decarbonization Initiative LDRD: Selecting belowground processes for durable soil carbon No. 11146 Co-PI
- **2021–2025** H2020 LC-SFS-22-2020 Forest Soils Research and Innovation Action No. 101000289, Task Leader (10 M € across 20 institutions)
- **2020–2021** Marie Curie Individual Fellowship No. 834169
- **2018–2020** "Make Our Planet Great Again" Fellowship
- **2017–2018** LBNL EESA Early Career Development Grant
- **2015** BU Biogeoscience Symposium Outstanding Oral Presentation

Selected Service & Outreach

Professional Service & Memberships

- **2025** Co-Organizer, Dartmouth Soil-climate feedback across sub-Saharan Africa Workshop
- **2023** Co-Organizer, Anthromes, CO_2, and Terrestrial Carbon Workshop
- **2023** Co-Organizer, American Academy of Microbiology Colloquium
- **2020** Co-Organizer, Machine Learning for the Study of Climate and its Impact Workshop
- **2019–2021** Co-Organizer, Biogeo Seminar Series
- **2019** Expert Reviewer, Working Group I, IPCC Sixth Assessment Report
- **2017–2021** Member, European Geophysical Union
- **2017–2018** Science Advisor, The Climate Music Project
- **2016** Organizer, CCIWG International Decade of Soil Workshop
- **2014–** Reviewer for 20+ journals (Nature Climate Change; Nature Communications; Global Change Biology; Ecology Letters; New Phytologist; Earth's Future; Soil Biology & Biochemistry; Journal of Ecology; Geoscientific Model Development; Biogeosciences; Agricultural & Forest Meteorology)
- **2012–** Member, American Geophysical Union

Boards & Committees (last 10 years)

- **2025–** George H. Denton Professorship of Earth Sciences Review Committee
- **2023–** Board President, Climate Emergency Fund
- **2022–2025** Co-Chair, AGU Soil Processes and the Critical Zone Technical Committee
- **2022–2023** Steering Committee Member, American Academy of Microbiology Colloquium
- **2021–** Member, AGU Soil Processes and the Critical Zone Technical Committee
- **2021–** Scientific Advisory Board Member, Deep Soil Ecotron
- **2016–2019** Member, LBNL Women Scientists and Engineers Council Empowerment Committee
- **2016–2017** Steering Committee Member, CRS BASIS
- **2015–2017** Executive Committee Member, AGU Global Environmental Change

Mentorship & Outreach (last 10 years)

- **2025-2027** MS Advisor, Cameron Chin
- **2025-2027** PhD Committee Member, Maxwell Naah
- **2025-2025** MS Committee Member, Ashlynn Amick
- **2025** PhD Committee Member, Genevieve M. Goebel, Dartmouth College
- **2022–2024** PhD Committee Member, Hunter Seubert, University of Missouri
- **2022–2024** Postdoctoral Co-Advisor, Elisa Bruni
- **2018** Master’s Thesis Reader, Valentino Weber, ETH Zürich
- **2015–2016** Volunteer & Team Leader, CRS BASIS

Publications & Talks

Peer-Reviewed Articles, Book Chapters & Policy Briefs

- **2025** Torn MS, **Abramoff RZ**, et al. Large emissions of CO_2 and CH_4 due to active-layer warming in Arctic tundra. *Nature Communications* 16:124.
- **2024 Abramoff RZ**, Torn MS, et al. Large emissions of CO_2 and CH_4 due to active-layer warming in Arctic tundra: Supporting Data. *ESS Dive Dataset*.
- He X, Abs E, Allison SD, Tao F, Huang Y, Manzoni S, **Abramoff RZ**, et al. Microbial carbon use efficiency in the land carbon cycle: Emerging multi-scale insights. *Nature Communications* 15:8010.
- **Abramoff RZ**, Warren JM, et al. Shifts in belowground processes along a temperate forest edge. *Landscape Ecology* 39:100.
- Saifuddin M, **Abramoff RZ**, Foster E, et al. Keeping Offset Markets Out of Soil: Soil Carbon Sequestration Cannot Substitute for Fossil Fuel Emissions Reductions. *Frontiers in Ecology and the Environment*.
- Ťupek B, Lehtonen A, et al., **Abramoff RZ**, et al. Modeling boreal forest's mineral soil and peat C dynamics... *Geoscientific Model Development* 17:5349–5367.
- Wasner D, **Abramoff RZ**, et al. Role of climate, mineralogy... *Global Biogeochemical Cycles* 38:7.
- Lennon J, **Abramoff RZ**, et al. Priorities for integrating microorganisms into Earth system models... *mBio* 15:5.
- He X, **Abramoff RZ**, et al. Contribution of carbon inputs to soil carbon accumulation... *Nature* 627: E1–E3.
- Georgiou K, ..., **Abramoff RZ**, et al. Emergent temperature sensitivity of soil organic carbon... *Nature Geoscience*.
- **2023** Khurana S, **Abramoff RZ**, et al. Interactive effects of microbial functional diversity... *Ecological Modelling* 486:110507.
- Le Noë J, Manzoni S, **Abramoff RZ**, et al. Soil organic carbon models need independent time-series validation... *Communications: Earth & Environment* 4:158.
- Hu J, Hartemink AE, ..., **Abramoff RZ**, et al. A Continental-Scale Estimate of Soil Organic Carbon Change... *JGR: Biogeosciences* 128:5.
- **Abramoff RZ**, Ciais P, et al. Adaptation Strategies Strongly Reduce the Future Impacts of Climate Change... *Earth's Future* 11.
- Lucash MS, ..., **Abramoff RZ**, et al. Burning trees in frozen soil... *Ecological Modelling* 481.
- Mäkipää R, **Abramoff RZ**, et al. Policy Brief 7: Forest soils can increase climate... *European Forest Institute*.
- Mäkipää R, **Abramoff RZ**, et al. How does management affect soil C sequestration... *Forest Ecology and Management* 529.
- **2022** Bruni E, Chenu C, **Abramoff RZ**, et al. Multi-modelling predictions show high uncertainty... *European Journal of Soil Science* 73.
- Doetterl S, **Abramoff RZ**, et al. Effects of abiotic factors affecting soil organic carbon... (Book Chapter in *Understanding and fostering soil carbon sequestration*).
- Todd-Brown KEO, **Abramoff RZ**, et al. Reviews and syntheses: The promise of big soil data... *Biogeosciences* 19.

- Georgiou K, Jackson RB, ..., **Abramoff RZ**, et al. Global capacity and controls of mineral-associated carbon in soils. *Nature Communications* 13.
- Green J, Ballantyne A, **Abramoff RZ**, et al. Surface temperatures reveal patterns of vegetation water stress... *Global Change Biology* 28:9.
- Riley WJ, Sierra C, ..., **Abramoff RZ**, et al. Next generation soil biogeochemistry model representations... (Book chapter).
- **Abramoff RZ**, Guenet B, et al. Improved global-scale predictions of soil carbon stocks with Millennial Version 2. *Soil Biology and Biochemistry* 164.
- **2021** Saifuddin M, **Abramoff RZ**, et al. Identifying Data Needed to Reduce Parameter Uncertainty... *JGR: Biogeosciences* 126:12.
- Huang Y, Ciais P, ..., **Abramoff RZ**, et al. A global map of root biomass across the world's forests. *Earth System Science Data* 13:9.
- Zhu P, **Abramoff RZ**, et al. Uncovering the past and future climate drivers of wheat yield shocks... *Earth's Future* 9:5.
- **Abramoff RZ**, Finzi AC. Are above- and below-ground phenology in sync? *New Phytologist* 205:3.
- **2020** Zhang H, Goll D, ..., **Abramoff RZ**, et al. Microbial dynamics and soil physicochemical properties... *Global Change Biology* 26.
- **2019 Abramoff RZ**, Torn MS, et al. Soil organic matter temperature sensitivity... *Global Biogeochemical Cycles* 33:6.
- **2018** Contributing author to: 2nd State of the Carbon Cycle Report. Chapter 12: Soils.
- Sulman BN, ..., **Abramoff RZ**, ... Multiple models and experiments underscore large uncertainty... *Biogeochemistry* 141:2.
- Savage K, Davidson EA, **Abramoff RZ**, Finzi AC. Partitioning Soil Respiration... *Biogeochemistry*.
- **Abramoff RZ**, Xu X, et al. The Millennial model... *Biogeochemistry*.
- **2017** Georgiou K, **Abramoff RZ**, et al. Microbial community-level regulation... *Nature Communications* 1223.
- **Abramoff RZ**, Davidson EA, Finzi AC. A parsimonious modular approach... *JGR: Biogeosciences* 122.
- **2016 Abramoff RZ**, Finzi AC. Seasonality and partitioning of root allocation... *Ecosphere* 7:11.
- **2015** Finzi AC, **Abramoff RZ**, et al. Rhizosphere processes are quantitatively important... *Global Change Biology* 21:5.
- **Abramoff RZ**, Finzi AC. Are above-and below-ground phenology in sync? *New Phytologist* 205:3.

Datasets & Code Releases

- **2024 Abramoff RZ**, et al. Large emissions of CO_2 and CH_4 due to active-layer warming in Arctic tundra: Supporting Data. *NGEE Arctic*, DOI: 10.15485/2475418.
- **Abramoff RZ**, Warren JM, et al. NIST: Soil Respiration, Moisture, Temperature... *ORNL, DOE*, DOI: 10.25581/ornlsfa.024/1837084.
- **2023 Abramoff RZ**, Ciais P, et al. rabramoff/ProjectYield: Crop yield analysis release. *Zenodo*, DOI: 10.5281/zenodo.7670875.

- **2022 Abramoff RZ** rabramoff/Millennialv2: First release of Millennial. *Zenodo*, DOI: 10.5281/zenodo.6353519.
- **2021 Abramoff RZ** rabramoff/DAMM-MCNiPv0: First release. *Zenodo*, DOI: 10.5281/zenodo.5608424.
- **2017** Vaughn L, Zhu B, et al., **Abramoff RZ**, et al. Soil Mesocosm CO_2 Emissions... *NGEE-Arctic, ORNL*, DOI: 10.5440/1364061.
- **2016 Abramoff RZ**, Finzi AC. Phenology and Carbon Allocation of Roots at Harvard Forest 2011–2013. *LTER Network*, DOI: 10.6073/pasta/b2fe6d68f23ad815f62a022826028328.

Invited Oral Presentations (last 3 years)

- **2025** Forest Ecosystem Ecology Guest Lecture, University of Maine (March)
- **2025** Land and Sea Guest Lecture, Maine College of Art and Design (March)
- **2025** Soil carbon and environmental justice, Climate Change Initiative Seminar Series, UMass Lowell (February)
- **2024** Center for Ecosystem Science and Society Seminar, Northern Arizona University (September 2024 & January 2023)
- **2024** Soil Carbon Sequestration and Environmental Justice, GEOG191 Natural Climate Solutions Guest Lecture, UCLA (May)
- **2024** Science During the Climate Emergency: Ethics, Risks and Rewards of Direct Action, EEMB Seminar, UCSB (January)
- **2023** Harnessing privilege to fight climate injustice: building effective grassroots movements, Emory University (November)
- **2023** Will It Stick? Modeling Durable Soil Carbon Stocks..., ASA–CSSA–SSSA International Annual Meeting (October)
- **2023** Vision 2030: Roundtable on Sustainability Research Integrity, Stanford University (April)

Programming Skills

R · Fortran · Python · Matlab · High Performance Computing

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