Technical Support Document

Estimating the Benefit per Ton of Reducing Directly-Emitted $PM_{2.5}$, $PM_{2.5}$ Precursors and Ozone Precursors from 21 Sectors

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September 2023

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Background and Overview

In 2018, the Agency published a Technical Support Document (TSD)describing an approach for estimating the average avoided human health impacts, and monetized benefits related to emissions of $PM_{2.5}$ and $PM_{2.5}$ precursors including NO_x and SO_2 from 17 sectors using the results of source apportionment photochemical modeling.[1] The Agency periodically updates the health, demographic and economic input parameters used to quantify the incidence and dollar value of air pollution-related effects. In 2022, EPA published a Technical Support Document describing these updated input parameters.[2]

This TSD newly updated for the year 2023 further improves upon the TSD published in 2018 by estimating PM and Ozone-related effects using concentration-response parameters that reflect new evidence reported in the most recently published Integrated Science Assessments (ISA) for $PM_{2.5}$ and Ozone and documented in a recently published TSD.[3–5] Below we describe: our approach to calculating a BPT value; the new evidence we use to quantify the number and value of $PM_{2.5}$ and ozone-related effects; and, the limitations and uncertainties associated with application of these estimates. Finally, we summarize the benefit per-ton (BPT) estimates for each of the 21 emission sectors by region or state.

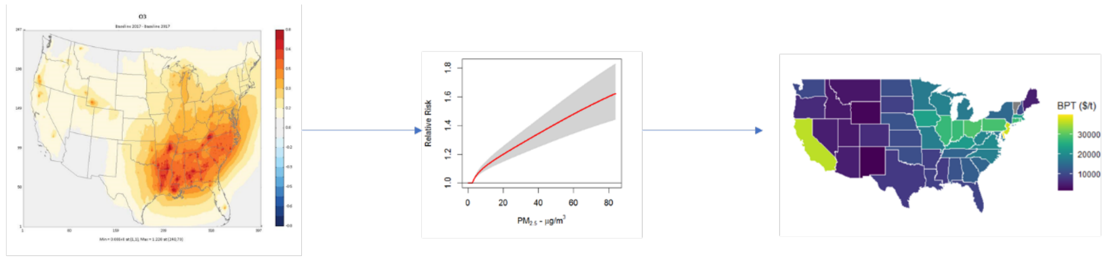
Approach to Calculating Benefit Per-Ton Values

The procedure for calculating benefit per-ton coefficients follows three steps, showngraphically in Figure 1:

1. Using source apportionment photochemical modeling, predict annual average ambient concentrations of primary $PM_{2.5}$, nitrate and sulfate, and ozone resulting from VOC or summer season NO_x attributable to each of 21 emission sectors across the Continental U.S.; see below for a summary of the sectors modeled.

2. For each sector, estimate the health impacts, and the economic value of these impacts, associated with the attributable ambient concentrations of primary $PM_{2.5}$, sulfate and nitrate $PM_{2.5}$, and ozone resulting from VOC or summer season NO_x using the environmental Benefits Mapping and Analysis Program-Community Edition (BenMAP-CE v1.5).[6]

3. For each sector, divide the $PM_{2.5}$-related health impacts attributable to each type of $PM_{2.5}$, and the monetary value of these impacts, by the level of associated precursor emissions. That is, primary $PM_{2.5}$ benefits are divided by direct $PM_{2.5}$ emissions, sulfate benefits are divided by SO_2 emissions, and nitrate benefits are divided by NO_x emissions. Divide the ozone-related benefits by the change in summer season VOC or NO_x.



Simulate air quality attributable to each sector

Estimate number and value of effects

Calculate the benefit per ton of emissions reduced

Figure 1. Steps to Calculating the Benefit Per-Ton of Reducing $PM_{2.5}$ and Ozone Precursor Emissions

Sectors Analyzed

The example above depicts the total $PM_{2.5}$ contribution from the pulp and paper sector, though we repeat this process for each of the 21 sectors, which include:

1. Industrial boilers[A]
2. Brick kilns
3. Cement kilns
4. Coke ovens
5. Electric arc furnaces
6. Ferroalloy facilities
7. Gasoline distribution bulk terminals
8. Internal combustion engines[A]
9. Integrated iron and steel facilities
10. Iron and steel foundries
11. Oil and natural gas
12. Oil and natural gas transmission
13. Paint stripping & miscellaneous
14. Primary copper smelting
15. Pulp and paper facilities
16. Refineries
17. Residential wood stoves
18. Secondary lead smelters
19. Synthetic organic chemical facilities
20. Taconite mining
21. Electricity generating units[A]

For each sector above, we estimated a benefit per-ton value for each of three regions depicted in the map below (Figure 2) with the exception of the sectors denoted with footnote A, for which we estimated a benefit per-ton for each of the 48 contiguous continental states; these include industrial boilers, internal combustion engines, and electricity generating units (EGUs).

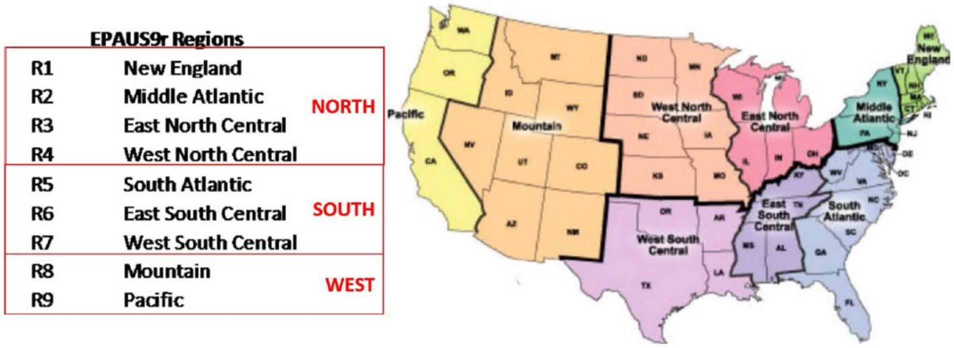


Figure 2. Regions in which the benefit per-ton is calculated

Readers interested in a full discussion of the air quality modeling performed to generate these benefit per ton estimates may consult "Air Quality Modeling Technical Support Document: Source Sector Assessments"[7] for all sectors other than EGUs. A description of the air quality modeling performed to generate the benefit per ton estimates for EGUs is provided in the Regulatory Impact Analysis for the Proposed National Emission Standards for Hazardous Air Pollutants: Coal- and Oil-Fired Electric Utility Steam Generating Units Review of the Residual Risk and Technology Review[8]. Below readers can find a series of tables reporting the $PM_{2.5}$ and ozone precursor emissions for each of the 21 sectors above (Table 1, Table 2, Table 3, and Table 4). The estimated emissions for EGU, internal combustion engine and industrial boiler sectors are reported for each of 48 states. Estimated emissions for all other sectors are reported for each of three regions of the U.S., consistent with Figure 2 above.

Table 1. Annual 2017 Total Emissions (tpy) by Sector and Pollutant

Sector Name & Region	NOx	SO_2	NH_3	VOC	PEC[a]	POA[a]
Brick - *NORTH*	3,458	3,849	79	218	44	383
Brick - *SOUTH*	2,539	5,552	22	702	71	569
Brick - *WEST*	301	292	1	151	5	48
Cement kilns - *NORTH*	36,224	16,432	820	1,755	54	320
Cement kilns - *SOUTH*	45,537	9,378	325	2,464	45	274
Cement kilns - *WEST*	22,818	1,929	554	659	14	84
Coke ovens - *NORTH*	7,635	9,641	24	437	51	142
Coke ovens - *SOUTH*	1,280	1,733	12	170	18	19
Coke ovens - *WEST*	-	-	-	-	-	-
Electric arc furnaces and argon - *WEST*	195	117	-	43	-	3
Electric arc furnaces and argon- *NORTH*	843	591	-	523	1	8
Electric arc furnaces and argon- *SOUTH*	1,752	1,041	-	775	3	36
Ferroalloys - *NORTH*	1,021	2,027	-	175	120	91
Ferroalloys - *SOUTH*	3,245	4,299	3	194	156	111
Ferroalloys - *SOUTH*	-	-	-	-	-	-
Gasoline distribution terminals - *NORTH*	4	-	-	60,481	-	-
Gasoline distribution terminals - *SOUTH*	34	-	-	117,591	-	1
Gasoline distribution terminals - *WEST*	-	-	-	28,186	-	-
Integrated iron and steel - *NORTH*	7,374	7,217	94	2,639	18	887
Integrated iron and steel - *SOUTH*	4,677	1,967	33	865	4	263
Integrated iron and steel - *WEST*	343	60	-	55	1	80
Iron and steel foundries - *NORTH*	1,138	524	57	4,570	45	495
Iron and steel foundries - *SOUTH*	675	246	26	2,058	26	167
Iron and steel foundries - *WEST*	175	163	2	184	1	8
Oil and natural gas - *NORTH*	158,632	13,750	1,790	687,867	191	1,850
Oil and natural gas - *SOUTH*	488,506	45,686	63	1,357,120	699	4,948
Oil and natural gas - *WEST*	149,057	12,933	222	499,533	271	2,448
Oil and natural gas transmissions - *NORTH*	66,288	361	76	6,365	125	1,026
Oil and natural gas transmissions - *SOUTH*	101,291	660	29	20,152	153	1,409
Oil and natural gas transmissions - *WEST*	17,337	321	17	6,271	38	288
Paint stripping - *NORTH*	-	-	-	291,043	-	-
Paint stripping - *SOUTH*	-	-	-	261,702	-	-
Paint stripping - *WEST*	-	-	51	108,850	19	52
Primary copper smelting - *NORTH*	5	141	-	15	-	1
Primary copper smelting - *SOUTH*	3	-	-	-	-	-
Primary copper smelting - *WEST*	245	25,012	3	8	-	7
Pulp and paper - *NORTH*	7,282	1,687	550	4,933	27	170
Pulp and paper - *SOUTH*	49,777	18,649	3,807	56,112	185	942
Pulp and paper - *WEST*	5,388	2,003	466	3,579	28	129
Refineries - *NORTH*	18,221	5,840	434	11,922	266	951
Refineries - *SOUTH*	40,855	14,869	1,486	37,056	620	2,495
Refineries - *WEST*	17,879	7,576	1,620	16,126	240	1,046
Residential woodstoves - *NORTH*	8,195	1,257	3,094	60,605	2,661	42,824
Residential woodstoves - *SOUTH*	5,443	847	2,421	55,948	2,162	34,792
Residential woodstoves - *WEST*	3,663	564	1,582	40,536	1,597	25,702
Secondary lead smelters - *NORTH*	429	3,425	-	65	-	-
Secondary lead smelters - *SOUTH*	298	8,332	-	128	-	-
Secondary lead smelters - *WEST*	-	-	-	-	-	-
Synthetic organic chemical - *NORTH*	10,365	1,960	332	10,814	151	1,269
Synthetic organic chemical - *SOUTH*	21,324	18,390	2,410	13,122	149	822
Synthetic organic chemical - *WEST*	608	51	6	348	7	26
Taconite mining - *NORTH*	38,192	5,090	24	402	124	1,146
Taconite mining - *SOUTH*	-	-	-	-	-	-
Taconite mining - *WEST*	-	-	-	-	-	-

a The sum of PEC and POA was used as a surrogate for primary PM2.5 impacts for this assessment

Table 2. Industrial Boiler Annual 2017 Total Emissions (tpy) by State and Pollutant

State	NOx	SO_2	NH_3	VOC	POA[a]
Alabama	9,508	6,464	14	584	820
Arizona	132	1	1	8	6
Arkansas	10,198	15,207	40	354	524
California	5,706	845	312	581	390
Colorado	2,228	144	22	149	88
Connecticut	165	2	4	8	7
Delaware	833	150	23	27	12
District of Columbia	24	0	-	1	1
Florida	7,347	4,841	297	3,251	815
Georgia	10,397	6,511	7	703	762
Idaho	4,576	702	0	121	135
Illinois	6,386	13,482	194	241	270
Indiana	7,599	10,104	157	398	1,751
Iowa	3,583	3,122	154	239	142
Kansas	2,410	82	40	145	145
Kentucky	3,068	948	71	128	237
Louisiana	25,407	5,587	248	1,792	1,574
Maine	4,208	2,027	113	122	268
Maryland	1,695	8,595	1	25	24
Massachusetts	976	115	24	59	46
Michigan	5,115	3,545	98	212	243
Minnesota	7,601	3,336	175	510	230
Mississippi	4,595	257	0	1,305	575
Missouri	1,437	307	48	103	95
Montana	2,450	295	63	389	48
Nebraska	1,481	434	15	116	153
Nevada	212	16	-	38	46
New Hampshire	137	123	-	4	8
New Jersey	891	65	19	47	70
New Mexico	290	5	0	24	23
New York	3,818	9,005	39	143	145
North Carolina	9,250	4,140	38	733	644
North Dakota	4,915	6,478	122	197	309
Offshore to EEZ	243	4	8	13	8
Ohio	5,803	3,203	156	307	576
Oklahoma	3,221	1,424	15	104	196
Oregon	4,314	244	-	388	364
Pennsylvania	7,309	6,263	398	456	602
Puerto Rico	231	210	-	7	3
Rhode Island	114	12	3	7	5
South Carolina	7,418	5,540	263	497	644
South Dakota	242	83	29	43	43
Tennessee	10,330	13,107	97	319	274
Texas	13,458	7,686	239	1,074	1,072
Tribal Data	285	50	-	24	34
Utah	1,068	1,413	16	35	37
Vermont	45	4	-	7	12
Virginia	5,397	479	113	290	320
Washington	5,162	971	23	349	189
West Virginia	2,444	2,175	14	91	64
Wisconsin	7,826	9,816	33	358	311
Wyoming	5,614	4,628	3	115	58

a POA was used as a surrogate for primary PM2.5 impacts for this assessment

Table 3. Internal Combustion Engines Annual 2017 Total Emissions (tpy) by State and Pollutant

State	NOx	SO_2	NH_3	VOC	POA[a]
Alabama	8,514	79	11	570	194
Arizona	2,109	20	59	51	49
Arkansas	5,444	13	2	302	59
California	4,121	211	599	598	365
Colorado	14,999	143	-	4,813	236
Connecticut	296	8	9	64	24
Delaware	65	19	0	13	14
Florida	7,999	136	26	522	141
Georgia	4,427	121	245	560	382
Idaho	1,140	7	-	34	11
Illinois	5,712	45	10	323	134
Indiana	3,810	22	0	210	40
Iowa	5,885	38	1	344	87
Kansas	23,675	35	58	1,403	190
Kentucky	9,468	15	0	632	174
Louisiana	28,027	235	757	2,118	754
Maine	86	1	0	4	1
Maryland	118	3	19	9	6
Massachusetts	669	71	22	109	23
Michigan	11,179	29	45	931	112
Minnesota	3,895	66	65	176	19
Mississippi	11,784	32	-	734	150
Missouri	3,882	20	0	156	40
Montana	1,682	17	0	544	54
Nebraska	3,507	4	0	277	42
Nevada	652	35	0	39	17
New Hampshire	27	1	-	1	1
New Jersey	424	13	5	101	21
New Mexico	14,348	106	103	2,118	189
New York	2,802	42	54	349	71
North Carolina	1,086	33	51	167	51
North Dakota	1,335	12	-	114	36
Offshore to EEZ	48,915	435	-	1,387	304
Ohio	10,072	32	8	630	201
Oklahoma	47,977	66	-	11,959	769
Oregon	325	4	-	4	4
Pennsylvania	5,155	47	47	830	232
Puerto Rico	4	3	-	0	0
Rhode Island	150	4	0	26	3
South Carolina	728	35	9	53	22
South Dakota	251	8	-	10	63
Tennessee	3,991	17	-	553	50
Texas	57,551	864	928	9,039	2,163
Tribal Data	5,358	22	-	801	37
Utah	2,329	13	14	110	46
Virginia	1,936	41	3	134	40
Washington	770	38	10	54	30
West Virginia	4,914	5	-	322	60
Wisconsin	773	1	9	45	10
Wyoming	11,212	406	15	7,959	556

a POA was used as a surrogate for primary PM2.5 impacts for this assessment

Table 4. EGU Annual Projected 2026 Total Emissions (tpy) by State and Pollutant

State	NOx (summer)	NOx (annual)	SO2	PM_{25} [a]
Alabama & Mississippi	9,836	14,527	1,374	3,797
Arizona & New Mexico	2,607	5,403	2,420	1,119
Arkansas	5,594	9,258	22,306	1,075
California	6,627	16,286	249	4,810
Colorado	5,881	12,725	7,311	1,556
Connecticut & Rhode Island	1,906	4,216	845	535
Delaware	203	320	126	119
Florida	11,590	22,451	8,784	6,555
Georgia	3,199	5,937	1,177	2,452
Idaho & Montana	4,283	9,465	3,528	1,611
Illinois	8,244	16,777	31,322	3,018
Indiana	11,052	36,007	34,990	6,281
Iowa	8,008	17,946	9,042	1,182
Kansas	3,166	4,351	854	709
Kentucky	11,894	25,207	22,940	10,476
Louisiana	10,895	16,949	11,273	3,119
Maine	1,233	3,063	1,147	508
Maryland & DC	1,521	3,047	273	836
Massachusetts	2,115	4,566	839	384
Michigan	11,689	22,378	31,387	3,216
Minnesota	4,192	9,442	7,189	481
Missouri	10,075	34,935	105,916	3,617
Nebraska	8,670	20,274	45,869	1,530
Nevada & Utah	5,148	13,933	11,040	1,594
New Hampshire	224	483	159	--[b]
New Jersey	1,969	4,032	915	729
New York & Vermont	6,250	11,697	1,526	1,652
North Carolina	7,175	15,984	6,443	2,720
North Dakota	8,053	19,276	26,188	1,320
Ohio	9,200	27,031	46,780	4,543
Oklahoma & Texas	18,960	30,589	19,171	5,855
Oregon & Washington	2,300	4,677	186	839
Pennsylvania	12,386	23,965	9,685	3,785
South Carolina	3,251	7,134	6,292	2,082
South Dakota	478	1,054	889	--[b]
Tennessee	790	2,100	1,231	845
Tribal Data	1,337	2,970	6,953	1,329
Virginia	3,607	7,270	820	1,805
West Virginia	7,479	21,450	28,513	2,180
Wisconsin	2,097	4,304	821	1,084
Wyoming	5,026	11,036	8,725	629

a Total primary PM2.5 emissions were tracked for this assessment b New Hampshire emissions summed with Maine. South Dakota emissions summed with North Dakota

Below we provide an expanded discussion of each of the latter two steps to the calculation—estimating health impacts and the economic value of $PM_{2.5}$ attributable to each sector and calculating the benefit per ton coefficients. The discussion of these topics is not intended to be exhaustive, and readers interested in learning more about our approach to performing an air pollution health impact and benefits analysis may consult the TSD accompanying the Revised Cross-State Update RIA.[2]

Estimating the number of $PM_{2.5}$-related health impacts attributable to each sector

In this stage of the analysis, we performed a Health Impact Assessment (HIA), which quantifies changes in the incidence of adverse health impacts resulting from changes in human exposure to ground-level ozone and $PM_{2.5}$ from each sector. HIAs are a well-established approach for estimating the retrospective or prospective change in adverse health impacts expected to result from population-level changes in exposure to pollutants. Computer-based tools such as the environmental Benefits Mapping and Analysis Program(BenMAP) can systematize health impact analyses by applying a database of key input parameters, including health impact functions and population projections. Analysts have applied the HIA approach to estimate human health impacts resulting from hypothetical changes in pollutant levels.

The HIA approach used in this analysis involves three basic steps: (1) utilizing the Comprehensive Air quality Model with extensions (CAMx)-generated estimates of $PM_{2.5}$ levels attributed to each sector; (2) determining the subsequent change in population-level exposure; (3) calculating health impacts by applyingconcentration-response relationships drawn from the epidemiological literature to this change in population exposure.

This procedure is operationalized within BenMAP using a health impact function (Eq 1). We estimated the number of $PM_{2.5}$-related total deaths and illnesses (y_{ij}) during each year i (i=2025, 2030, 2035 and 2040) among populations in each 12km by 12km air quality model grid cell j (j=1,…,J where J is the total number of grids) as

$$y_{ij} = \boldsymbol{\Sigma}_a \, y_{ija}$$

$$y_{ija} = m0_{ija} \times (e^{\beta \cdot C_{ji}} - 1) \times P_{ija}, \quad \text{Eq[1]}$$

where β is the risk coefficient for all-cause mortality for adults in association with $PM_{2.5}$ exposure, m_{0ija} is the baseline all-cause mortality or morbidity rate for populations aged a in grid cell j in year i stratified in 10-year age bins, C_{ij} is annual mean $PM_{2.5}$ concentration in grid cell *j*, and P_{ija} is the number of individuals aged *a* in grid cell *j* in year *i* stratified into 5-year age bins.

Tools such as BenMAP can systematize the HIA calculation process, allowing users to draw upon a library of existing air quality monitoring data, population data and health impact functions.

Figure 3 provides a simplified overview of this approach, using $PM_{2.5}$-related premature mortality as an example, though the procedure is generally the same for other health endpoints and the ozone pollutant. This sequence of steps is performed for each of the 21 sectors for each $PM_{2.5}$ component (primary $PM_{2.5}$, sulfate, nitrate and ammonium) and ozone precursor (NO_x and VOC). The ozone and $PM_{2.5}$ health endpoints quantified and the health impact functions applied in this analysis are detailed in the TSD for the Revised Cross-State Update rule.[2] That TSD includes a detailed discussion of each of the data inputs, analytical assumptions and sources of uncertainty. In the interest of brevity, we do not repeat these here in detail. However, it is worth noting that we exclude the value of several important non-health endpoints, including recreational and residential visibility, climate-related impacts and ecological endpoints. Table 5 below summarizes the endpoints quantified in this benefit per ton TSD.

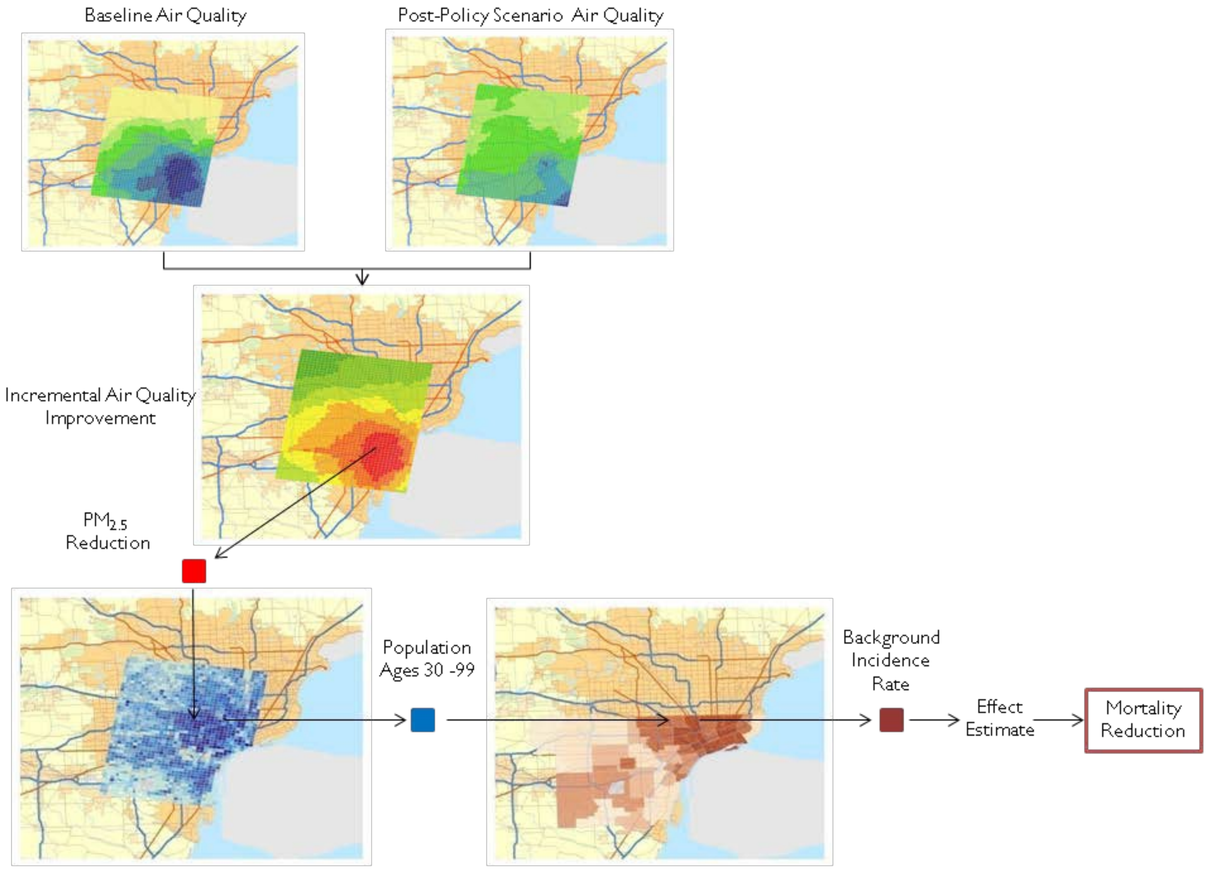


Figure 3. Illustration of the BenMAP Approach to Calculating Cases of Air Pollution-Related Effects

Table 5. Health Effects of Ambient Ozone and $PM_{2.5}$ Quantified and Monetized

Category	Effect	Effect Quantified	Effect Monetized	More Information
Premature mortality from exposure to $PM_{2.5}$	Adult premature mortality from long-term exposure (age 65-99 or age 30-99)	✓	✓	PM ISA
	Infant mortality (age <1)	✓	✓	PM ISA
Nonfatal morbidity from exposure to $PM_{2.5}$	Heart attacks (age > 18)	✓	✓[1]	PM ISA
	Hospital admissions—cardiovascular (ages 65-99)	✓	✓	PM ISA
	Emergency department visits— cardiovascular (age 0-99)	✓	✓	PM ISA
	Hospital admissions—respiratory (ages 0-18 and 65-99)	✓	✓	PM ISA
	Emergency room visits—respiratory (all ages)	✓	✓	PM ISA
	Cardiac arrest (ages 0-99; excludes initial hospital and/or emergency department visits)	✓	✓[1]	PM ISA
	Stroke (ages 65-99)	✓	✓[1]	PM ISA
	Asthma onset (ages 0-17)	✓	✓	PM ISA
	Asthma symptoms/exacerbation (6-17)	✓	✓	PM ISA
	Lung cancer (ages 30-99)	✓	✓	PM ISA
	Allergic rhinitis (hay fever) symptoms (ages 3-17)	✓	✓	PM ISA
	Lost work days (age 18-65)	✓	✓	PM ISA
	Minor restricted-activity days (age 18-65)	✓	✓	PM ISA
	Hospital admissions—Alzheimer's disease (ages 65-99)	✓	✓	PM ISA
	Hospital admissions—Parkinson's disease (ages 65-99)	✓	✓	PM ISA
	Other cardiovascular effects (e.g., other ages)	—	—	PM ISA[2]
	Other respiratory effects (e.g., pulmonary function, non-asthma ER visits, non-bronchitis chronic diseases, other ages and populations)	—	—	PM ISA[2]
	Other nervous system effects (e.g., autism, cognitive decline, dementia)	—	—	PM ISA[2]
	Metabolic effects (e.g., diabetes)	—	—	PM ISA[2]
	Reproductive and developmental effects (e.g., low birth weight, pre-term births, etc.)	—	—	PM ISA[2]
	Cancer, mutagenicity, and genotoxicity effects	—	—	PM ISA[2]
Mortality from exposure to ozone	Premature respiratory mortality from short-term exposure (0-99)	✓	✓	Ozone ISA
	Premature respiratory mortality from long-term exposure (age 30–99)	✓	✓	Ozone ISA
Nonfatal morbidity from exposure to ozone	Hospital admissions—respiratory (ages 65-99)	✓	✓	Ozone ISA
	Emergency department visits—respiratory (ages 0-99)	✓	✓	Ozone ISA
	Asthma onset (0-17)	✓	✓	Ozone ISA
	Asthma symptoms/exacerbation (asthmatics age 5-17)	✓	✓	Ozone ISA
	Allergic rhinitis (hay fever) symptoms (ages 3-17)	✓	✓	Ozone ISA
	Minor restricted-activity days (age 18–65)	✓	✓	Ozone ISA
	School absence days (age 5–17)	✓	✓	Ozone ISA
	Decreased outdoor worker productivity (age 18–65)	—	—	Ozone ISA[2]
	Metabolic effects (e.g., diabetes)	—	—	Ozone ISA[2]
	Other respiratory effects	—	—	Ozone ISA[2]
	Cardiovascular and nervous system effects	—	—	Ozone ISA[2]
	Reproductive and developmental effects	—	—	Ozone ISA[2]

[1]Valuation estimate excludes initial hospital and/or emergency department visits.

[2] Not quantified due to data availability limitations and/or because current evidence is only suggestive of causality.

Estimating the economic value of health impacts attributable to each sector

After quantifying the number of adverse air pollution-attributable impacts, the next step is to estimate the economic value of these events. The appropriate economic value for a change in a health effect depends on whether the health effect is viewed *ex ante* (before the effect has occurred) or *ex post* (after the effect has occurred). Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects by a small amount for a large population. The appropriate economic measure is therefore *ex ante* Willingness to Pay (WTP) for changes in risk. However, epidemiological studies generally provide estimates of the relative risks of a particular health effect avoided due to a reduction in air pollution. A convenient way to use this data in a consistent framework is to convert probabilities to units of avoided statistical incidences. This measure is calculated by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a measure is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature mortality amounts to $1 million ($100/0.0001 change in risk). Using this approach, the size of the affected population is automatically taken into account by the number of incidences predicted by epidemiological studies applied to the relevant population. The same type of calculation can produce values for statistical incidences of other health endpoints.

For some health effects, such as hospital admissions, WTP estimates are generally not available. In these cases, we use the cost of treating or mitigating the effect as a primary estimate. For example, for the valuation of hospital admissions we use the avoided medical costs as an estimate of the value of avoiding the health effects causing the admission. These cost of illness (COI) estimates generally (although not in every case) understate the true value of reductions in risk of a health effect. They tend to reflect the direct expenditures related to treatment but not the value of avoided pain and suffering from the health effect.

Avoided premature deaths account for 98% of monetized PM- and Ozone-related benefits. The economics literature concerning the appropriate method for valuing reductions in premature mortality risk is still developing. The adoption of a value for the projected reduction in the risk of premature mortality is the subject of continuing discussion within the economics and public policy analysis community. Following the advice of the Science Advisory Board's Environmental Economics Advisory Committee (SAB-EEAC), the EPA currently uses the value of statistical life (VSL) approach in calculating estimates of mortality benefits, because we believe this calculation provides the most reasonable single estimate of an individual's willingness to trade off money for reductions in mortality risk.[9] The VSL is a summary measure for the value of small changes in mortality risk experienced by a large number of people.

EPA continues work to update its guidance on valuing mortality risk reductions, and the Agency consulted several times with the SAB-EEAC on the issue. Until updated guidance is available, the Agency determined that a single, peer-reviewed estimate applied consistently best reflects the SAB-EEAC advice it has received. Therefore, EPA has decided to apply the VSL that was vetted and endorsed by the SAB in the *Guidelines for Preparing Economic Analyses* while the Agency continues its efforts to update its guidance on this issue.[10] This approach calculates a mean value across VSL estimates derived from 26 labor market and contingent valuation studies published between 1974 and 1991. The mean VSL across these studies is $6.3 million (2000$).[11] We then adjust this VSL to account for the currency year used for the analysis and to account for income growth from 1990 to the analysis year. Table 6 shows the adjusted VSL estimates for currency years 2000-2019 for the income growth years used in the source apportionment benefit per ton calculations.

Table 6. Value of Statistical Life Estimate Adjusted for Currency and Income Growth years

Currency Year (Inflation)	Base VSL Estimate	With Income Growth to:				
		2020	2025	2030	2035	2040
2000	$6.3	$7.5	$7.6	$7.8	$8.0	$8.2
2001	$6.5	$7.7	$7.9	$8.1	$8.3	$8.5
2002	$6.6	$7.8	$8.0	$8.2	$8.4	$8.6
2003	$6.7	$8.0	$8.2	$8.4	$8.6	$8.8
2004	$6.9	$8.2	$8.4	$8.6	$8.8	$9.0
2005	$7.1	$8.5	$8.7	$8.9	$9.1	$9.3
2006	$7.4	$8.8	$8.9	$9.2	$9.4	$9.6
2007	$7.6	$9.0	$9.2	$9.4	$9.7	$9.9
2008	$7.9	$9.4	$9.6	$9.8	$10.0	$10.3
2009	$7.8	$9.3	$9.5	$9.8	$10.0	$10.3
2010	$8.0	$9.5	$9.7	$9.9	$10.2	$10.4
2011	$8.2	$9.8	$10.0	$10.2	$10.5	$10.8
2012	$8.4	$10.0	$10.2	$10.4	$10.7	$11.0
2013	$8.5	$10.1	$10.3	$10.6	$10.9	$11.1
2014	$8.7	$10.3	$10.5	$10.8	$11.0	$11.3
2015	$8.7	$10.3	$10.5	$10.8	$11.1	$11.3
2016	$8.8	$10.4	$10.7	$10.9	$11.2	$11.5
2017	$9.0	$10.7	$10.9	$11.2	$11.4	$11.7
2018	$9.2	$10.9	$11.1	$11.4	$11.7	$12.0
2019	$9.4	$11.1	$11.3	$11.6	$11.9	$12.2

In valuing premature mortality, we discount the value of premature mortality occurring in future years using rates of 3% and 7%. We assume that there is a "cessation" lag between changes in PM exposures and the total realization of changes in health effects. Although the structure of the lag is uncertain, the EPA follows the advice of the Science Advisory Board-Health Effects Subcommittee to assume a segmented lag structure characterized by 30% of mortality reductions in the first year, 50% over years 2 to 5, and 20% over the years 6 to 20 after the reduction in $PM_{2.5}$. Changes in the cessation lag assumptions do not change the total number of estimated deaths but rather the timing of those deaths.

We express the economic value of the avoided impacts using constant year 2015 dollars, adjusted for growth in real income out to the analysis year using projections provided by the Congressional Budget Office. Economic theory suggests that WTP for most goods (such as environmental protection) will increase if real income increases. Many of the valuation studies used in this analysis were conducted in the late 1980s and early 1990s. Because real income has grown since the studies were conducted, people's willingness to pay for reductions in the risk of premature death and disease likely has grown as well. We did not adjust cost of illness-based values because they are based on current costs. For these two reasons, the cost of illness estimates may underestimate the economic value of avoided health impacts in each analysis year. As with the selection of health studies, the economic valuation estimates applied in this analysis are consistent with those used in the Regulatory Impact Analysis for the Revised Cross-State Update.[2]

Calculating the benefit per-ton estimate

The final step is to divide the incidence of adverse health outcomes, and the economic value of those outcomes, associated with directly emitted $PM_{2.5}$, NO_x and SO_2 (to calculate a PM BPT) and VOC and NOx (to calculate an ozone BPT). The result is a suite of incidence per ton and dollar benefit per ton estimates stratified by sector, pollutant and region or state of the U.S. In the interest of brevity, below we summarize national-level $ per ton estimates for each of the 21 sectors. More detailed benefit per ton and incidence per ton values can be found elsewhere on the BenMAP website.[1] The results for analytical years 2025 and 2030 are presented.

A too-small number of tons in the denominator of the benefit-per ton estimate may yield an unstable (and thus unreliable) benefit per-ton value. For this reason, when calculating the benefit per-ton we first confirmed that the number of pollutant or precursor emissions were 100 tons or more. Several sectors emitted fewer tons than this limit and thus we did not report a benefit per-ton (See Table 1, Table 2, Table 3, Table 4). As a

[1] https://www.epa.gov/benmap/sector-based-pm25-benefit-ton-estimates

means of generating a stable direct PM benefit per-ton for the Electric Arc Furnace sector, we separately calculated the benefit per-ton for this sector as the combined benefits of the Electric Arc Furnace and Integrated Iron and Steel Sectors divided by the emissions of these two sectors. These values are reported as "EAF & IIS (combined)" in each table of results below.

Table 7. Relationship between analysis year and input parameter year

Analysis Year	Population Year	Mortality Incidence Year	Income Growth Year	Currency Year	Emissions Year
2025	2025	2025	2025	--	--
2030	2030	2030	2030	2019	2017
2035	2035	2035	2035	--	--
2040	2040	2040	2040	--	--

Results

Table 8. Summary of the total dollar value (mortality and morbidity) per ton of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursor reduced by each of 21 sectors in 2025 (2019$, 3% discount rate)[A]

Sector	$PM_{2.5}$-Related Benefits				Ozone-Related Benefits	
	Directly emitted $PM_{2.5}$	*SO_2*	*NO_x*	*NH_3*	*NO_x*	*VOC*
Brick kilns	$223,000	$43,100	$26,600	$128,000	$83,700	$11,400
Cement kilns	$153,000	$41,400	$14,300	$63,100	$73,200	$17,900
Coke ovens	$280,000	$52,300	$25,300	--	$65,300	$35,500
Electric arc furnaces	--	$44,700	$18,700	--	$77,800	$6,820
Ferroalloy facilities	$148,000	$44,200	$15,300	--	$102,000	$7,680
Gasoline distribution	--	--	--	--	--	$6,800
Industrial Boilers	$188,000	$41,300	$14,900	$84,400	$68,900	$14,000
Integrated iron & steel	$375,000	$52,500	$23,200	$188,000	$74,300	$14,200
Internal Combustion Engines	$162,000	$37,700	$10,500	$73,400	$58,200	$9,040
Iron and steel foundries	$257,000	$53,100	$23,600		$90,000	$7,860
Oil and natural gas	$95,900	$18,900	$7,900	$23,600	$47,700	$1,780
Oil and natural gas transmission	$136,000	$29,000	$13,400	$72,700	$65,000	$7,960
Paint stripping	--	--	--	--	--	$6,820
Primary copper smelting	--	$9,830	$4,080	--	$52,600	--
Pulp and paper	$141,000	$38,200	$10,900	$50,000	$80,400	$2,260
Refineries	$358,000	$49,600	$22,500	$109,000	$61,100	$12,200
Residential woodstoves	$465,000	$33,900	$32,400	$197,000	$41,400	$13,000
Secondary lead smelters	--	$43,200	$23,000	--	$96,400	--
Synthetic organic chemical	$137,000	$41,600	$16,600	$69,300	$74,600	$5,890
Taconite mining	$60,800	$32,400	$9,150	--	$48,600	$31,500
EAF & IIS (combined)	$368,000	$51,300	$22,400	$188,000	$74,900	$12,100
Electricity generating units	$110,000	$55,200	$7,470	--	$95,500	--

[A] Sectors including industrial boilers, internal combustion engines and electricity generating units modeled at the state level. All other sectors were modeled at the regional level. An excel workbook available here reports the regional and state-level BPT. Cells marked with "--" indicate: (1) sectors for which emissions were <100 tons/year and thus too small to calculate a reliable BPT; or (2) the emission-to-air quality relationship was not modeled for that sector. Ozone-related benefits estimated using concentration-response relationship from long-term exposure mortality study.

Table 9. Summary of the total dollar value (mortality and morbidity) per ton of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursor reduced by each of 21 sectors in 2025 (2019$, 7% discount rate)[A]

Sector	PM2.5-Related Benefits				Ozone-Related Benefits	
	Directly emitted $PM_{2.5}$	*SO_2*	*NO_x*	*NH_3*	*NO_x*	*VOC*
Brick kilns	$200,000	$38,800	$23,900	$115,000	$75,000	$10,200
Cement kilns	$138,000	$37,200	$12,800	$56,700	$65,500	$16,000
Coke ovens	$252,000	$47,000	$22,700	--	$58,500	$31,800
Electric arc furnaces	--	$40,200	$16,800	--	$69,600	$6,110
Ferroalloy facilities	$133,000	$39,700	$13,700	--	$91,300	$6,880
Gasoline distribution	--	--	--	--	--	$6,080
Industrial Boilers	$169,000	$37,200	$13,400	$75,800	$61,700	$12,500
Integrated iron & steel	$337,000	$47,200	$20,800	$169,000	$66,500	$12,700
Internal Combustion Engines	$145,000	$33,900	$9,400	$66,000	$52,100	$8,090
Iron and steel foundries	$231,000	$47,700	$21,200		$80,600	$7,040
Oil and natural gas	$86,100	$17,000	$7,100	$21,200	$42,700	$1,590
Oil and natural gas transmission	$122,000	$26,100	$12,000	$65,300	$58,200	$7,120
Paint stripping	--	--	--	--	--	$6,100
Primary copper smelting	--	$8,830	$3,670	--	$47,000	--
Pulp and paper	$127,000	$34,400	$9,780	$44,900	$72,000	$2,030
Refineries	$322,000	$44,500	$20,200	$97,800	$54,600	$10,900
Residential woodstoves	$418,000	$30,500	$29,200	$177,000	$37,100	$11,700
Secondary lead smelters	--	$38,800	$20,700	--	$86,300	--
Synthetic organic chemical	$123,000	$37,400	$15,000	$62,300	$66,800	$5,270
Taconite mining	$54,600	$29,100	$8,220	--	$43,500	$28,200
EAF & IIS (combined)	$331,000	$46,100	$20,100	$169,000	$67,100	$10,900
Electricity generating units	$98,400	$49,700	$6,710	--	$85,400	--

[A] Sectors including industrial boilers, internal combustion engines and electricity generating units modeled at the state level. All other sectors were modeled at the regional level. An excel workbook available here reports the regional and state-level BPT. Cells marked with "--" indicate: (1) sectors for which emissions were <100 tons/year and thus too small to calculate a reliable BPT; or (2) the emission-to-air quality relationship was not modeled for that sector. Ozone-related benefits estimated using concentration-response relationship from long-term exposure mortality study.

Table 10. Summary of the total dollar value (mortality and morbidity) per ton of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursor reduced by each of 21 sectors in 2030 (2019$, 3% discount rate)[A]

	$PM_{2.5}$-Related Benefits				Ozone-Related Benefits	
Sector	***Directly emitted $PM_{2.5}$***	***SO_2***	***NO_x***	***NH_3***	***NO_x***	***VOC***
Brick kilns	$243,000	$47,200	$29,100	$139,000	$92,800	$12,700
Cement kilns	$169,000	$45,200	$15,600	$69,100	$81,400	$20,000
Coke ovens	$300,000	$56,600	$27,300	--	$71,600	$38,800
Electric arc furnaces	--	$49,000	$20,500	--	$86,600	$7,550
Ferroalloy facilities	$159,000	$48,100	$16,500	--	$112,000	$8,380
Gasoline distribution	--	--	--	--	--	$7,560
Industrial Boilers	$205,000	$45,100	$16,300	$92,000	$76,200	$15,500
Integrated iron & steel	$406,000	$56,900	$25,100	$199,000	$81,600	$15,500
Internal Combustion Engines	$179,000	$41,600	$11,400	$81,500	$64,400	$10,000
Iron and steel foundries	$279,000	$58,000	$25,600		$99,100	$8,660
Oil and natural gas	$105,000	$20,800	$8,610	$26,100	$52,800	$1,980
Oil and natural gas transmission	$147,000	$31,700	$14,500	$80,100	$71,600	$8,780
Paint stripping	--	--	--	--	--	$7,600
Primary copper smelting	--	$11,000	$4,560	--	$59,500	--
Pulp and paper	$155,000	$42,200	$12,000	$54,900	$89,200	$2,520
Refineries	$395,000	$54,800	$24,800	$120,000	$67,900	$13,800
Residential woodstoves	$514,000	$37,100	$35,500	$217,000	$46,300	$14,500
Secondary lead smelters	--	$47,300	$25,000	--	$106,000	
Synthetic organic chemical	$149,000	$45,500	$18,100	$76,600	$82,300	$6,480
Taconite mining	$66,100	$35,200	$9,930	--	$53,500	$34,700
EAF & IIS (combined)	$416,000	$58,100	$25,300	$208,000	$82,500	$13,300
Electricity generating units	$125,000	$62,300	$8,370	--	$126,000	--

[A] Sectors including industrial boilers, internal combustion engines and electricity generating units modeled at the state level. All other sectors were modeled at the regional level. An excel workbook available here reports the regional and state-level BPT. Cells marked with "--" indicate: (1) sectors for which emissions were <100 tons/year and thus too small to calculate a reliable BPT; or (2) the emission-to-air quality relationship was not modeled for that sector. Ozone-related benefits estimated using concentration-response relationship from long-term exposure mortality study.

Table 11. Summary of the total dollar value (mortality and morbidity) per ton of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursor reduced by each of 21 sectors in 2030 (2019$, 7% discount rate)

	$PM_{2.5}$-Related Benefits				Ozone-Related Benefits	
Sector	***Directly emitted $PM_{2.5}$***	***SO_2***	***NO_x***	***NH_3***	***NO_x***	***VOC***
Brick kilns	$219,000	$42,500	$26,100	$125,000	$83,200	$11,400
Cement kilns	$152,000	$40,700	$14,000	$62,100	$72,900	$17,900
Coke ovens	$270,000	$50,900	$24,500	--	$64,200	$34,700
Electric arc furnaces	--	$44,000	$18,400	--	$77,600	$6,760
Ferroalloy facilities	$143,000	$43,200	$14,800	--	$100,000	$7,510
Gasoline distribution	--	--	--	--	--	$6,770
Industrial Boilers	$184,000	$40,600	$14,700	$82,700	$68,300	$13,900
Integrated iron & steel	$365,000	$51,100	$22,600	$179,000	$73,100	$13,900
Internal Combustion Engines	$160,000	$37,300	$10,200	$73,200	$57,700	$8,990
Iron and steel foundries	$251,000	$52,200	$23,000	--	$88,800	$7,760
Oil and natural gas	$94,400	$18,700	$7,730	$23,500	$47,300	$1,780
Oil and natural gas transmission	$133,000	$28,500	$13,100	$72,000	$64,100	$7,870
Paint stripping	--	--	--	--	--	$6,800
Primary copper smelting	--	$9,920	$4,090	--	$53,200	--
Pulp and paper	$140,000	$37,900	$10,700	$49,400	$80,000	$2,250
Refineries	$355,000	$49,200	$22,300	$108,000	$60,800	$12,300
Residential woodstoves	$462,000	$33,400	$31,900	$195,000	$41,400	$13,000
Secondary lead smelters	--	$42,500	$22,500	--	$95,200	--
Synthetic organic chemical	$134,000	$40,900	$16,300	$68,900	$73,800	$5,810
Taconite mining	$59,500	$31,700	$8,930	--	$48,000	$31,100
EAF & IIS (combined)	$358,000	$50,000	$21,800	$179,000	$73,900	$12,000
Electricity generating units[A]	$112,000	$56,000	$7,530	--	$113,000	--

[A] Sectors including industrial boilers, internal combustion engines and electricity generating units modeled at the state level. All other sectors were modeled at the regional level. An excel workbook available here reports the regional and state-level BPT. Cells marked with "--" indicate: (1) sectors for which emissions were <100 tons/year and thus too small to calculate a reliable BPT; or (2) the emission-to-air quality relationship was not modeled for that sector. Ozone-related benefits estimated using concentration-response relationship from long-term exposure mortality study.

Table 12. Summary of the total dollar value (mortality and morbidity) per ton of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursor reduced by each of 21 sectors in 2035 (2019$, 3% discount rate)

	$PM_{2.5}$-Related Benefits				Ozone-Related Benefits	
Sector	***Directly emitted $PM_{2.5}$***	***SO_2***	***NO_x***	***NH_3***	***NO_x***	***VOC***
Brick kilns	$274,000	$53,400	$33,000	$156,000	$103,000	$14,200
Cement kilns	$192,000	$51,000	$17,600	$78,200	$90,400	$22,200
Coke ovens	$333,000	$63,300	$30,500	--	$78,400	$42,300
Electric arc furnaces	--	$55,300	$23,200	--	$96,300	$8,350
Ferroalloy facilities	$176,000	$53,900	$18,400	--	$122,000	$9,110
Gasoline distribution	--	--	--	--	--	$8,400
Industrial Boilers	$232,000	$50,800	$18,400	$104,000	$84,300	$17,300
Integrated iron & steel	$454,000	$63,600	$28,000	$219,000	$89,500	$17,000
Internal Combustion Engines	$204,000	$47,400	$12,800	$93,800	$71,000	$11,100
Iron and steel foundries	$311,000	$65,600	$28,700		$109,000	$9,520
Oil and natural gas	$119,000	$23,500	$9,650	$29,800	$58,200	$2,200
Oil and natural gas transmission	$165,000	$35,700	$16,200	$91,600	$78,600	$9,670
Paint stripping	--	--	--	--	--	$8,490
Primary copper smelting	--	$12,800	$5,270	--	$67,300	--
Pulp and paper	$177,000	$48,100	$13,500	$62,300	$98,900	$2,790
Refineries	$453,000	$62,700	$28,500	$139,000	$75,400	$15,600
Residential woodstoves	$588,000	$42,100	$40,200	$246,000	$51,700	$16,200
Secondary lead smelters	--	$53,400	$28,200	--	$118,000	--
Synthetic organic chemical	$167,000	$51,400	$20,300	$87,300	$90,600	$7,120
Taconite mining	$73,700	$39,500	$11,100	--	$58,800	$38,100
EAF & IIS (combined)	$446,000	$62,300	$27,100	$219,000	$90,700	$14,600
Electricity generating units[A]	$142,000	$69,900	$9,370	--	$139,000	--

[A] Sectors including industrial boilers, internal combustion engines and electricity generating units modeled at the state level. All other sectors were modeled at the regional level. An excel workbook available here reports the regional and state-level BPT. Cells marked with "--" indicate: (1) sectors for which emissions were <100 tons/year and thus too small to calculate a reliable BPT; or (2) the emission-to-air quality relationship was not modeled for that sector. Ozone-related benefits estimated using concentration-response relationship from long-term exposure mortality study.

Table 13. Summary of the total dollar value (mortality and morbidity) per ton of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursor reduced by each of 21 sectors in 2035 (2019$, 7% discount rate)

	$PM_{2.5}$-Related Benefits				Ozone-Related Benefits	
Sector	***Directly emitted $PM_{2.5}$***	***SO_2***	***NO_x***	***NH_3***	***NO_x***	***VOC***
Brick kilns	$246,000	$48,000	$29,700	$140,000	$92,300	$12,700
Cement kilns	$172,000	$45,900	$15,800	$70,300	$81,000	$19,900
Coke ovens	$299,000	$56,900	$27,400	--	$70,300	$38,000
Electric arc furnaces		$49,800	$20,800	--	$86,300	$7,480
Ferroalloy facilities	$158,000	$48,500	$16,600	--	$110,000	$8,170
Gasoline distribution	--	--	--	--	--	$7,520
Industrial Boilers	$208,000	$45,700	$16,500	$93,300	$75,600	$15,500
Integrated iron & steel	$408,000	$57,200	$25,200	$197,000	$80,200	$15,200
Internal Combustion Engines	$183,000	$42,600	$11,500	$84,300	$63,600	$9,970
Iron and steel foundries	$280,000	$59,000	$25,800		$97,500	$8,530
Oil and natural gas	$107,000	$21,100	$8,680	$26,800	$52,100	$1,970
Oil and natural gas transmission	$149,000	$32,100	$14,600	$82,300	$70,400	$8,670
Paint stripping	--	--	--	--	--	$7,600
Primary copper smelting	--	$11,500	$4,730	--	$60,100	--
Pulp and paper	$159,000	$43,200	$12,200	$56,000	$88,600	$2,500
Refineries	$407,000	$56,400	$25,600	$125,000	$67,600	$13,900
Residential woodstoves	$528,000	$37,800	$36,100	$221,000	$46,400	$14,500
Secondary lead smelters	--	$48,000	$25,300	--	$105,000	
Synthetic organic chemical	$150,000	$46,200	$18,300	$78,500	$81,200	$6,390
Taconite mining	$66,300	$35,500	$9,980	--	$52,700	$34,100
EAF & IIS (combined)	$401,000	$56,000	$24,400	$197,000	$81,300	$13,100
Electricity generating units[A]	$128,000	$62,900	$8,420	--	$125,000	--

[A] Sectors including industrial boilers, internal combustion engines and electricity generating units modeled at the state level. All other sectors were modeled at the regional level. An excel workbook available here reports the regional and state-level BPT. Cells marked with "--" indicate: (1) sectors for which emissions were <100 tons/year and thus too small to calculate a reliable BPT; or (2) the emission-to-air quality relationship was not modeled for that sector. Ozone-related benefits estimated using concentration-response relationship from long-term exposure mortality study.

Table 14. Summary of the total dollar value (mortality and morbidity) per ton of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursor reduced by each of 21 sectors in 2040 (2019$, 3% discount rate)

Sector	$PM_{2.5}$-Related Benefits				Ozone-Related Benefits	
	Directly emitted $PM_{2.5}$	*SO_2*	*NO_x*	*NH_3*	*NO_x*	*VOC*
Brick kilns	$301,000	$58,700	$36,400	$169,000	$112,000	$15,500
Cement kilns	$213,000	$56,000	$19,300	$86,100	$98,400	$24,200
Coke ovens	$358,000	$68,700	$33,000	--	$83,700	$45,000
Electric arc furnaces	--	$61,000	$25,500	--	$105,000	$9,020
Ferroalloy facilities	$189,000	$58,900	$20,000	--	$131,000	$9,680
Gasoline distribution	--	--	--	--	--	$9,140
Industrial Boilers	$255,000	$55,700	$20,200	$114,000	$91,200	$18,800
Integrated iron & steel	$494,000	$69,100	$30,400	$232,000	$95,800	$18,200
Internal Combustion Engines	$228,000	$52,700	$14,000	$106,000	$76,600	$12,100
Iron and steel foundries	$336,000	$72,200	$31,200		$117,000	$10,200
Oil and natural gas	$130,000	$25,900	$10,500	$32,900	$62,600	$2,390
Oil and natural gas transmission	$180,000	$39,200	$17,600	$102,000	$84,300	$10,400
Paint stripping	--	--	--	--	--	$9,300
Primary copper smelting	--	$14,700	$5,950	--	$74,600	
Pulp and paper	$196,000	$53,600	$15,000	$69,000	$107,000	$3,040
Refineries	$509,000	$70,100	$31,900	$157,000	$82,000	$17,300
Residential woodstoves	$655,000	$46,400	$44,300	$272,000	$56,700	$17,700
Secondary lead smelters	--	$58,900	$30,900	--	$128,000	--
Synthetic organic chemical	$181,000	$56,500	$22,200	$97,000	$97,600	$7,660
Taconite mining	$79,200	$42,800	$12,000	--	$62,700	$40,400
EAF & IIS (combined)	$485,000	$67,800	$29,500	$232,000	$97,500	$15,700
Electricity generating units[A]	$158,000	$76,400	$10,200	--	$150,000	--

[A] Sectors including industrial boilers, internal combustion engines and electricity generating units modeled at the state level. All other sectors were modeled at the regional level. An excel workbook available here reports the regional and state-level BPT. Cells marked with "--" indicate: (1) sectors for which emissions were <100 tons/year and thus too small to calculate a reliable BPT; or (2) the emission-to-air quality relationship was not modeled for that sector. Ozone-related benefits estimated using concentration-response relationship from long-term exposure mortality study.

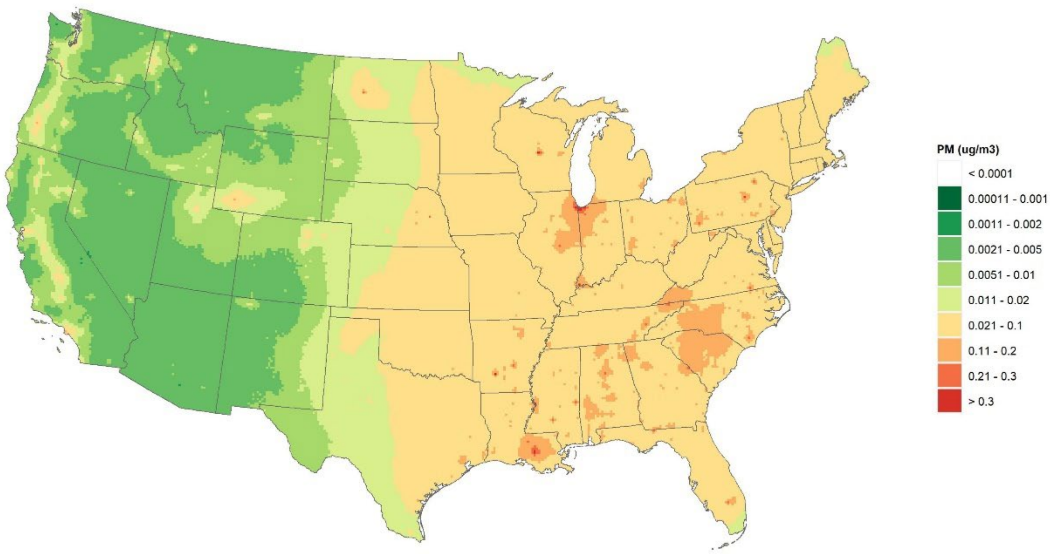
Table 15. Summary of the total dollar value (mortality and morbidity) per ton of directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursor reduced by each of 21 sectors in 2040 (2019$, 7% discount rate)

Sector	$PM_{2.5}$-Related Benefits				Ozone-Related Benefits	
	Directly emitted $PM_{2.5}$	*SO_2*	*NO_x*	*NH_3*	*NO_x*	*VOC*
Brick kilns	$270,000	$52,800	$32,700	$152,000	$100,000	$13,900
Cement kilns	$191,000	$50,300	$17,300	$77,400	$88,200	$21,700
Coke ovens	$322,000	$61,800	$29,600	--	$75,100	$40,400
Electric arc furnaces	--	$54,800	$22,900	--	$94,200	$8,090
Ferroalloy facilities	$170,000	$52,900	$18,000	--	$117,000	$8,690
Gasoline distribution	--	--	--	--	--	$8,190
Industrial Boilers	$229,000	$50,100	$18,200	$102,000	$81,800	$16,800
Integrated iron & steel	$444,000	$62,200	$27,300	$209,000	$85,900	$16,300
Internal Combustion Engines	$205,000	$47,400	$12,600	$94,900	$68,600	$10,800
Iron and steel foundries	$303,000	$65,000	$28,000		$105,000	$9,160
Oil and natural gas	$117,000	$23,300	$9,450	$29,600	$56,100	$2,140
Oil and natural gas transmission	$162,000	$35,200	$15,800	$91,400	$75,600	$9,330
Paint stripping	--	--	--	--	--	$8,330
Primary copper smelting	--	$13,200	$5,340	--	$66,700	--
Pulp and paper	$176,000	$48,200	$13,500	$62,100	$96,400	$2,720
Refineries	$458,000	$63,000	$28,700	$141,000	$73,500	$15,500
Residential woodstoves	$589,000	$41,800	$39,800	$244,000	$50,800	$15,900
Secondary lead smelters	--	$52,900	$27,800	--	$115,000	--
Synthetic organic chemical	$163,000	$50,800	$20,000	$87,200	$87,600	$6,870
Taconite mining	$71,200	$38,500	$10,800	--	$56,200	$36,300
EAF & IIS (combined)	$437,000	$61,000	$26,500	$209,000	$87,400	$14,100
Electricity generating units[A]	$142,000	$68,700	$9,130	--	$135,000	--

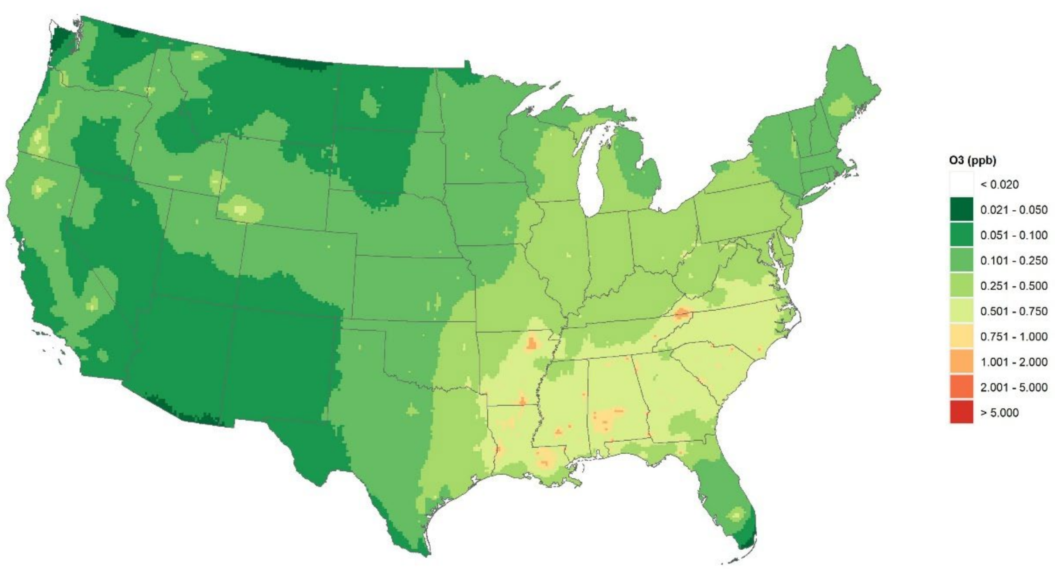
[A] Sectors including industrial boilers, internal combustion engines and electricity generating units modeled at the state level. All other sectors were modeled at the regional level. An excel workbook available here reports the regional and state-level BPT. Cells marked with "--" indicate: (1) sectors for which emissions were <100 tons/year and thus too small to calculate a reliable BPT; or (2) the emission-to-air quality relationship was not modeled for that sector. Ozone-related benefits estimated using concentration-response relationship from long-term exposure mortality study.

Maps

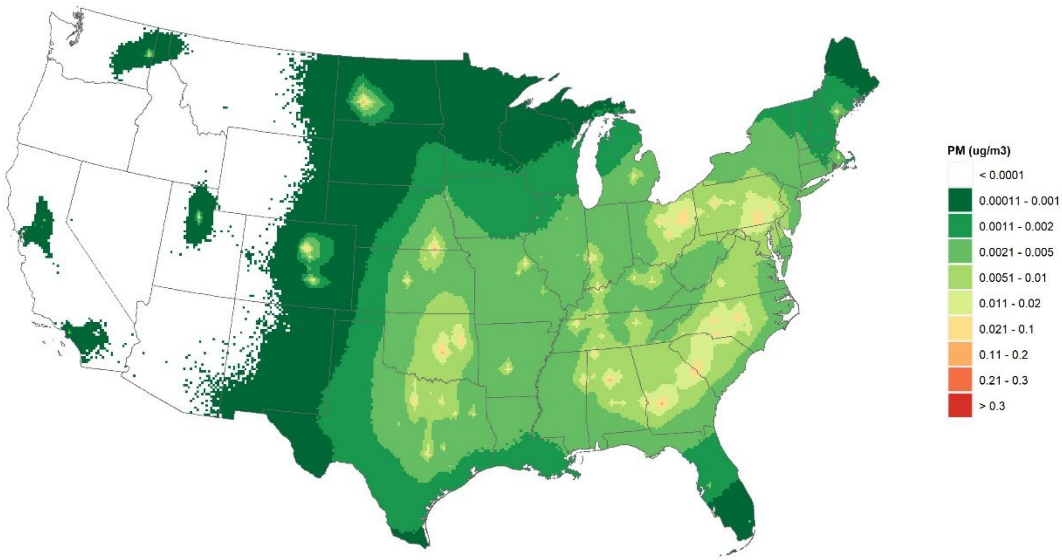
Boilers: Annual Mean PM2.5



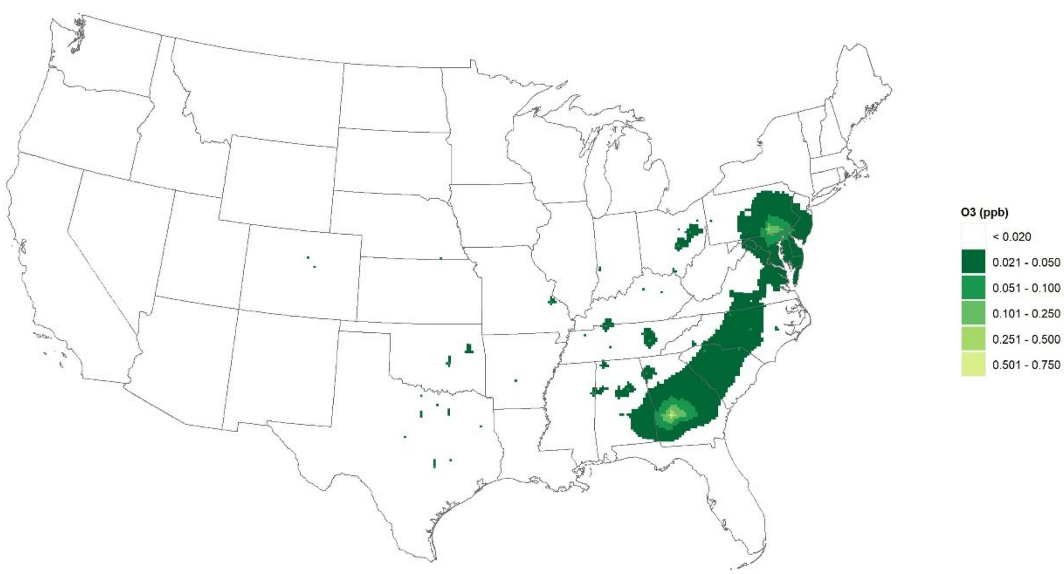
Boilers: Summer Season Ozone



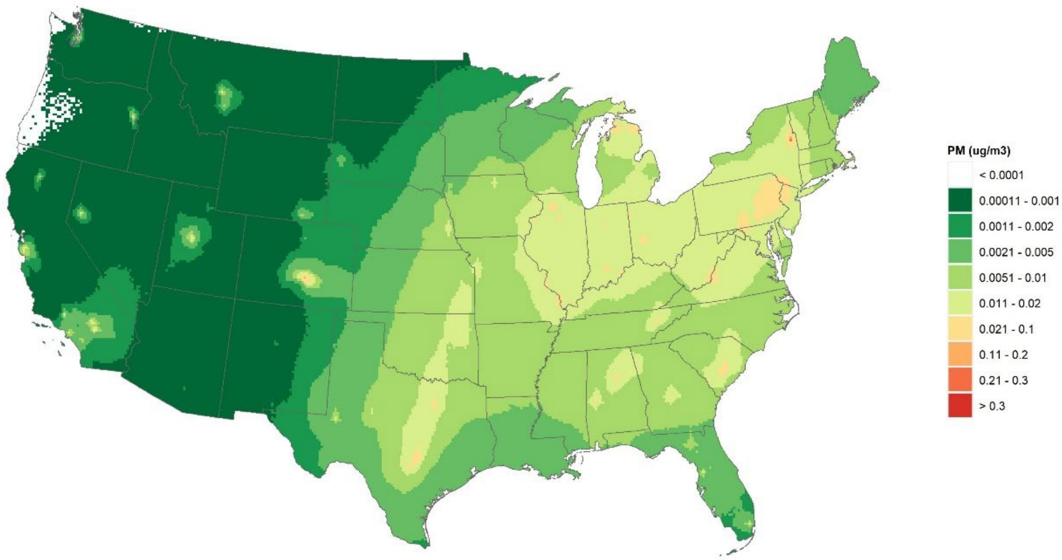
Brick: Annual Mean PM2.5



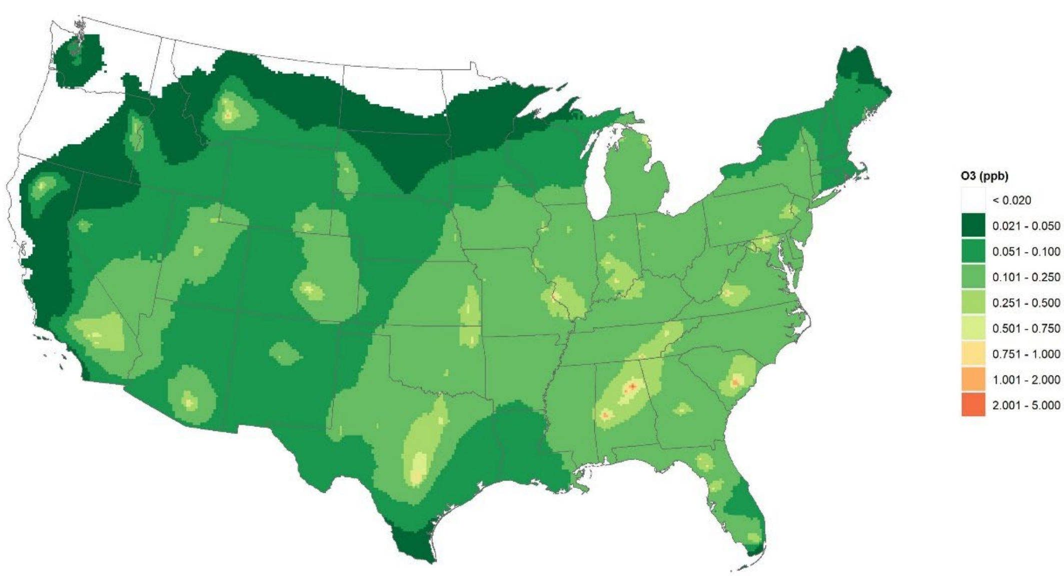
Brick: Summer Season Ozone



Cement Kilns: Annual Mean PM2.5

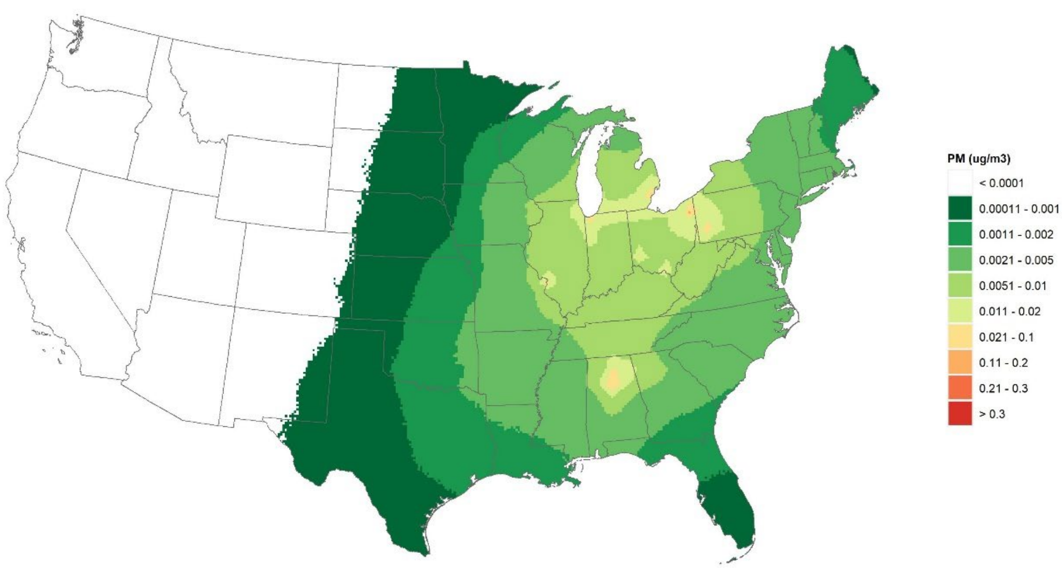


Cement Kilns: Summer Season Ozone

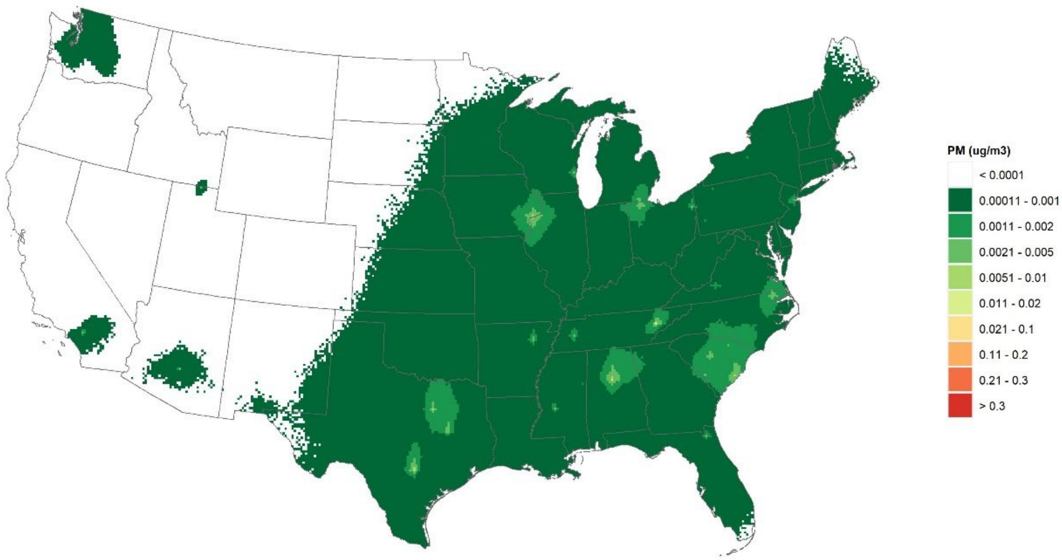


Coke Ovens: Summer Season Ozone

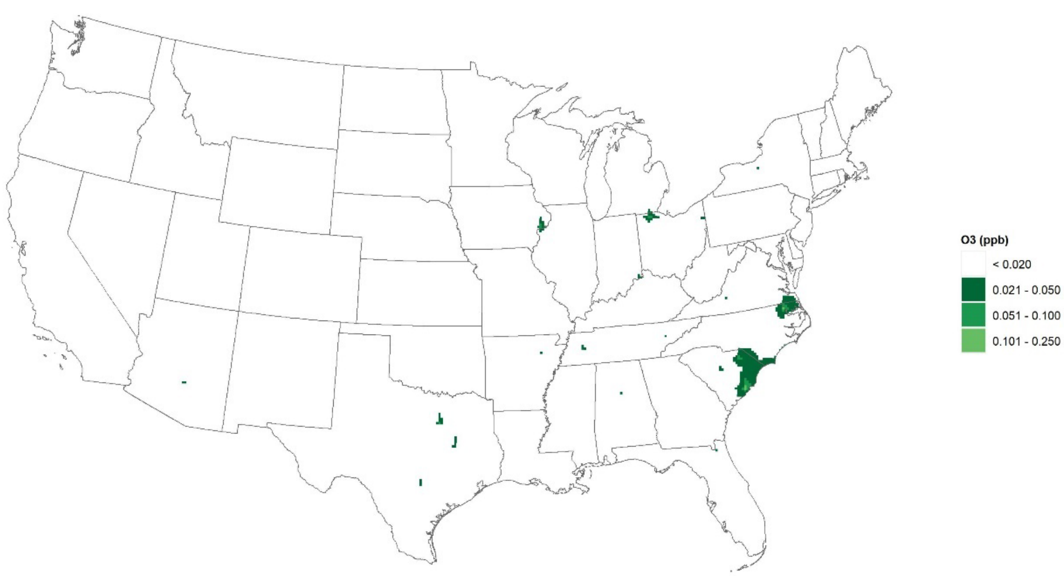
Coke Ovens: Annual Mean PM2.5



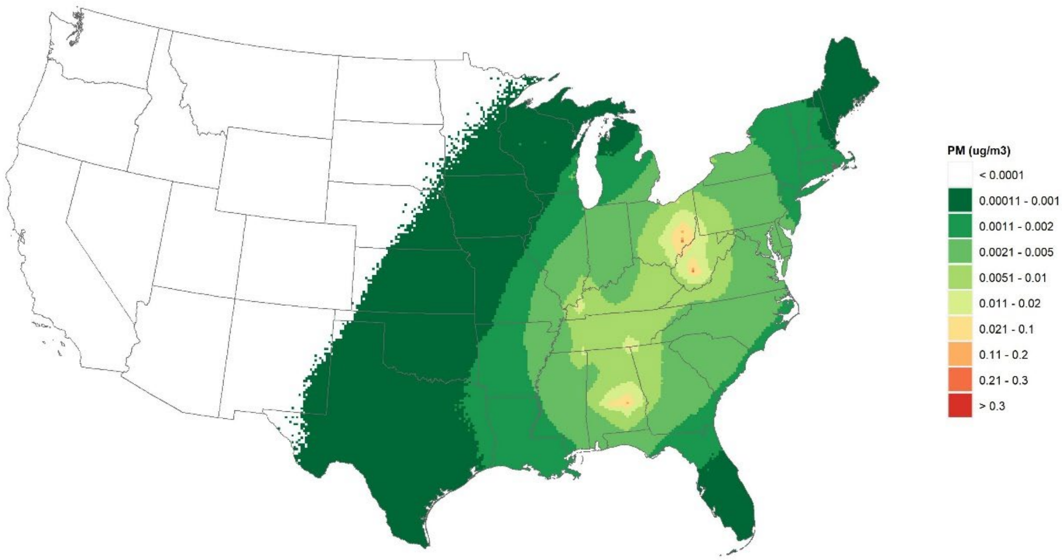
EAF: Annual Mean PM2.5



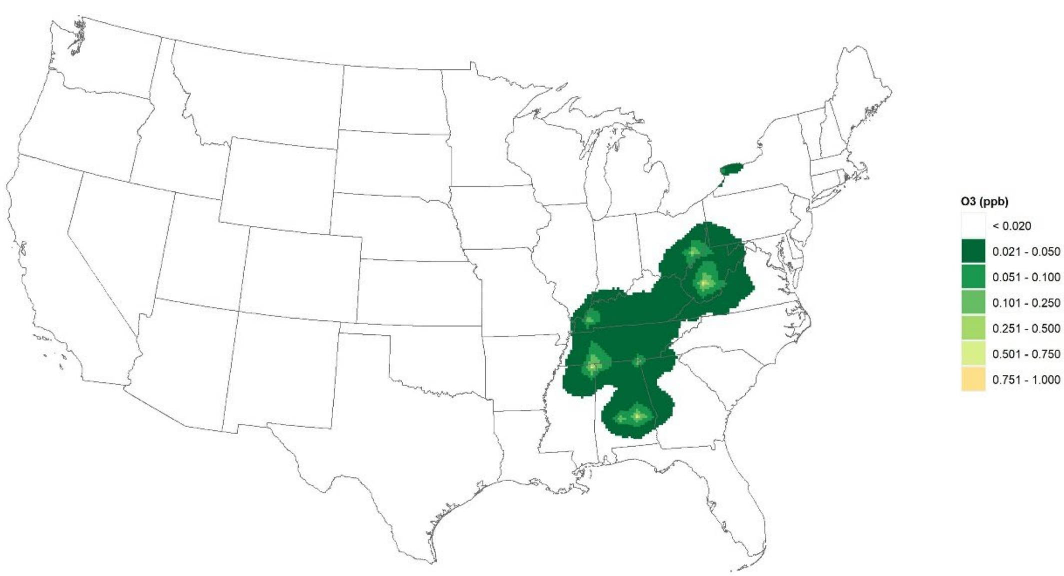
EAF: Summer Season Ozone



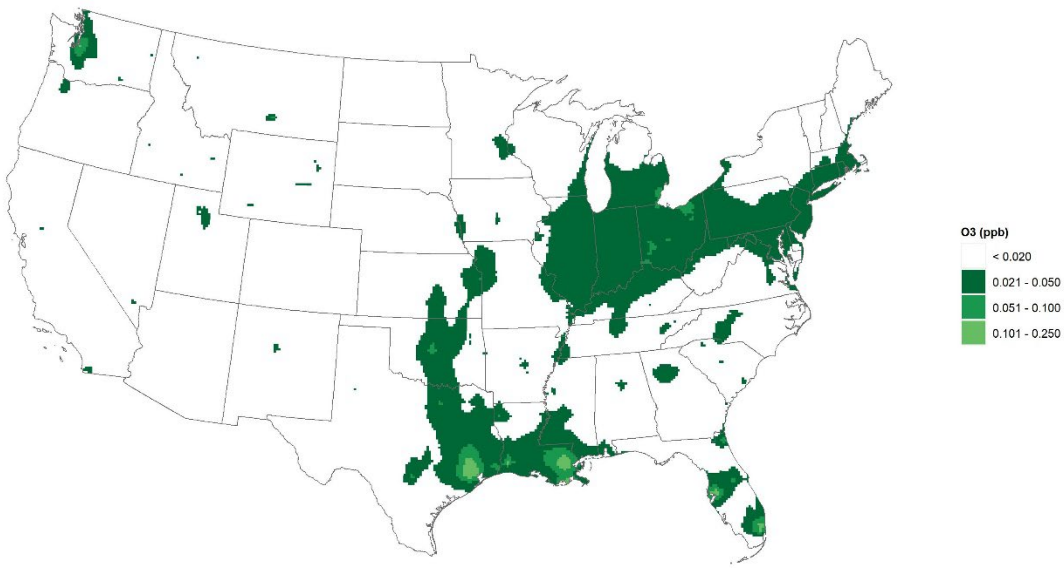
Ferroalloys: Annual Mean PM2.5



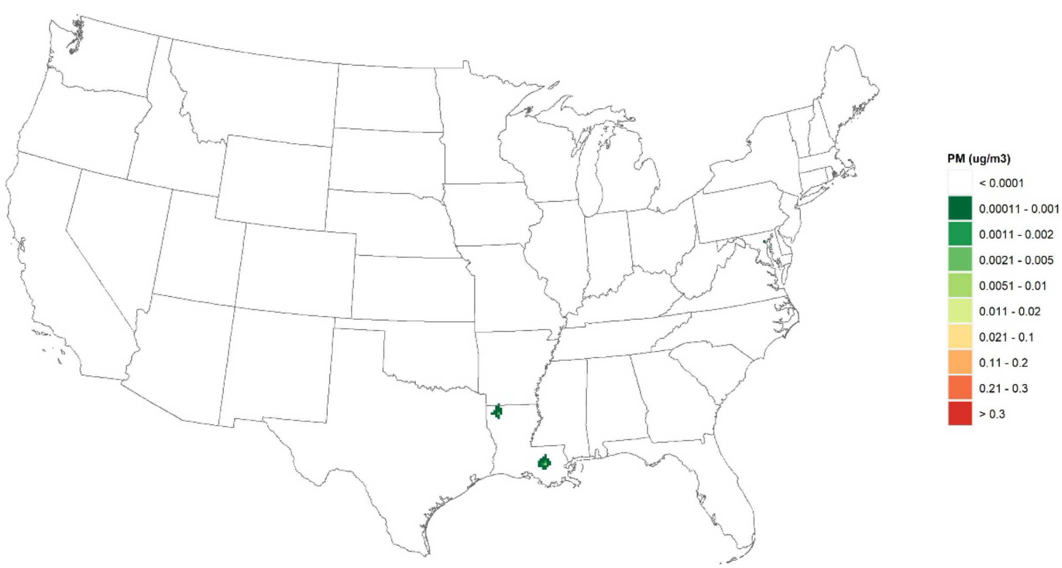
Ferroalloys: Summer Season Ozone



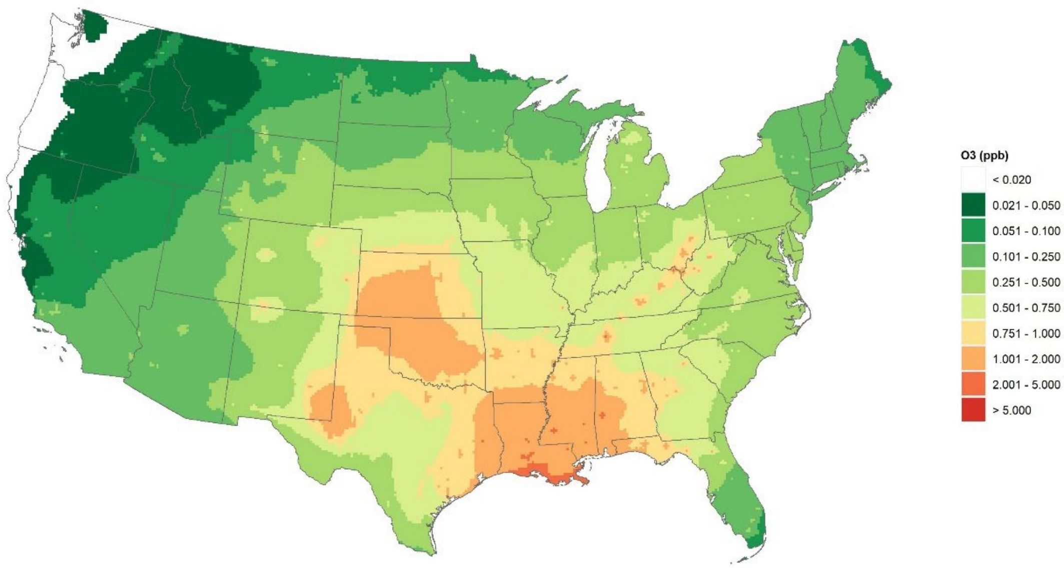
Gas Distribution Terminals: Summer Season Ozone



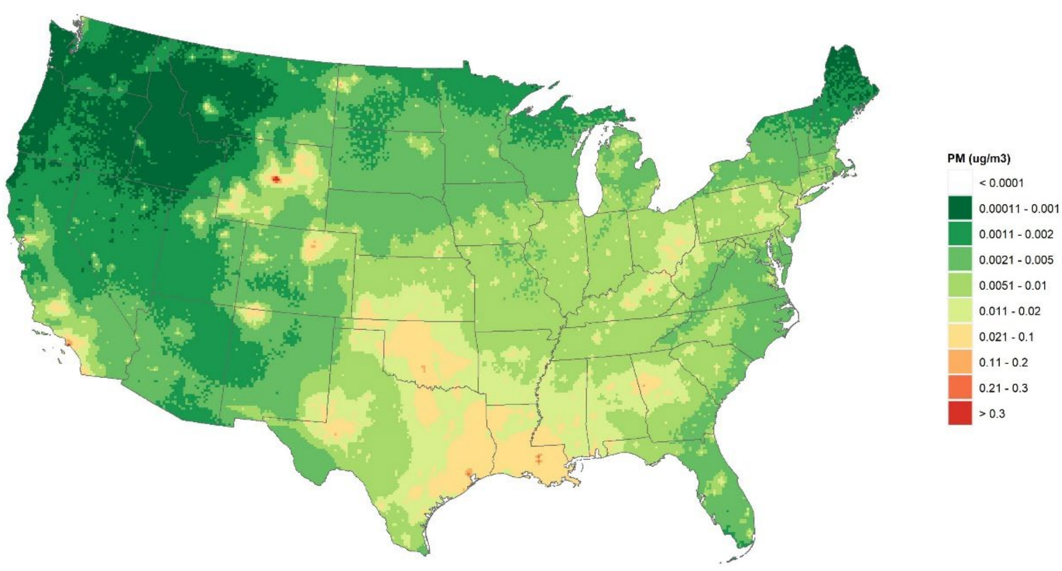
Gas Distribution Terminals: Annual Mean PM2.5



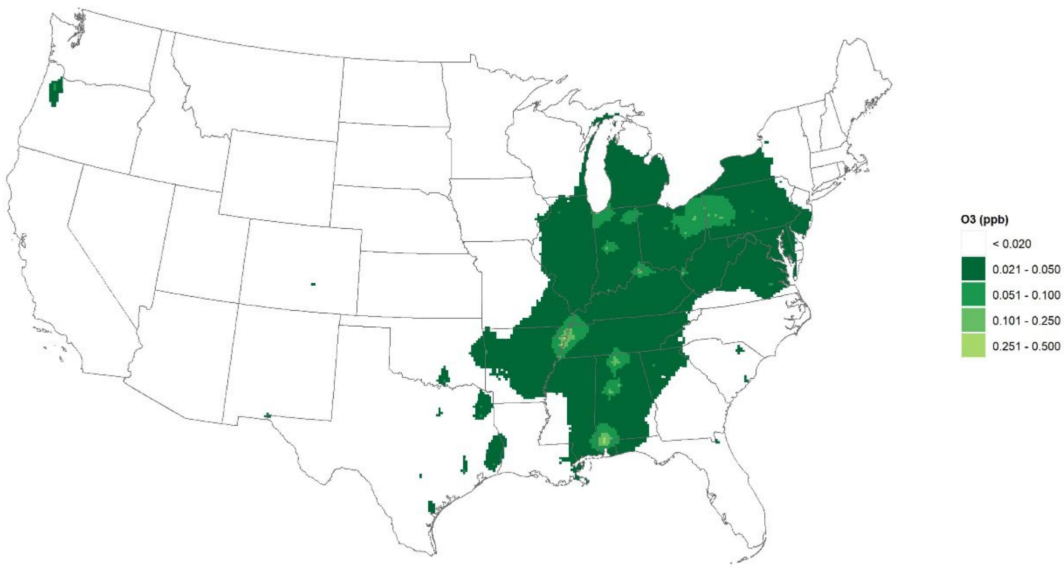
Ice engines: Summer Season Ozone



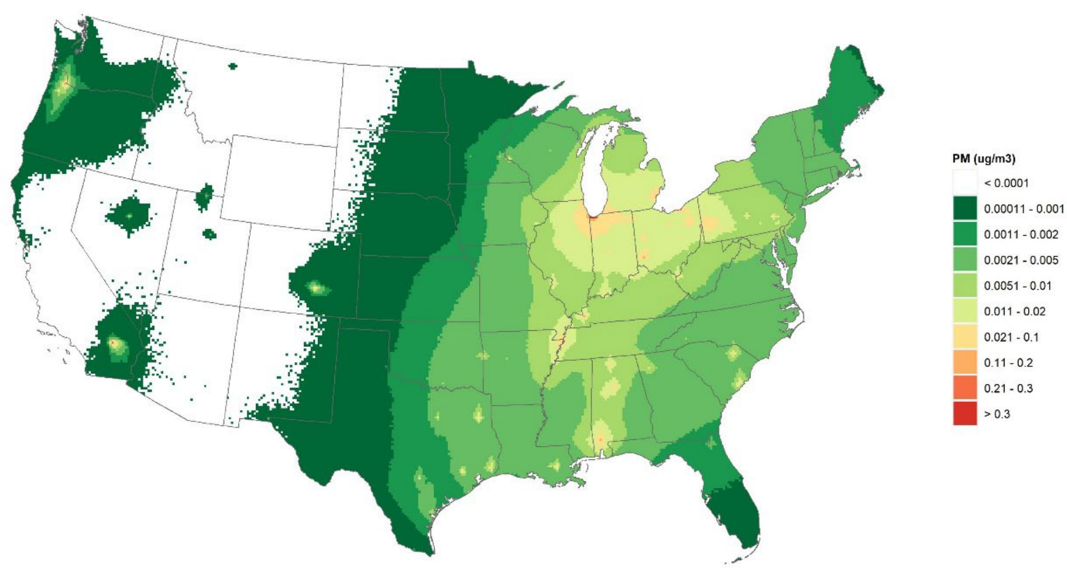
Ice engines: Annual Mean PM2.5



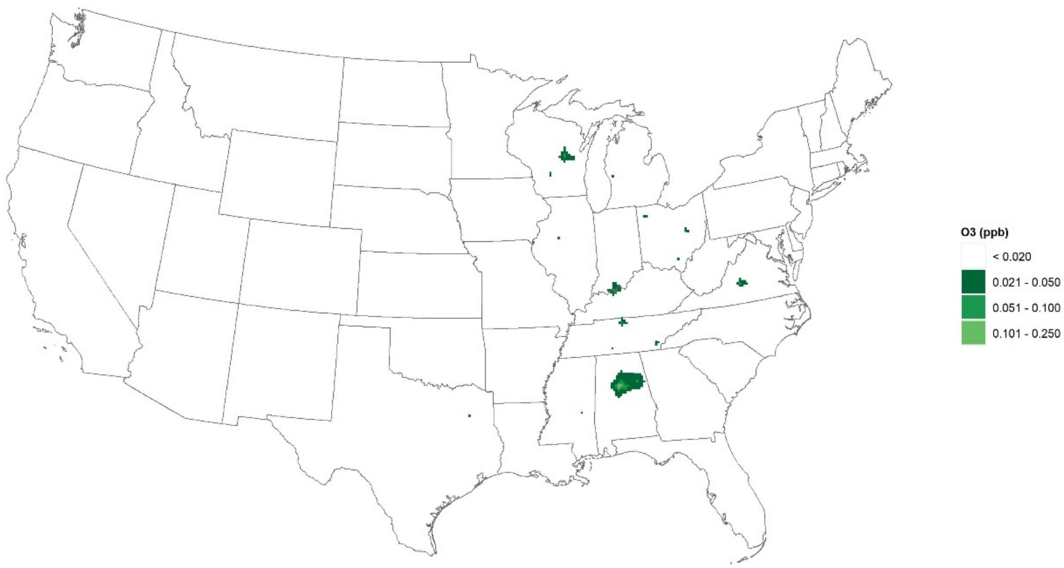
Integrated Iron and Steel: Summer Season Ozone



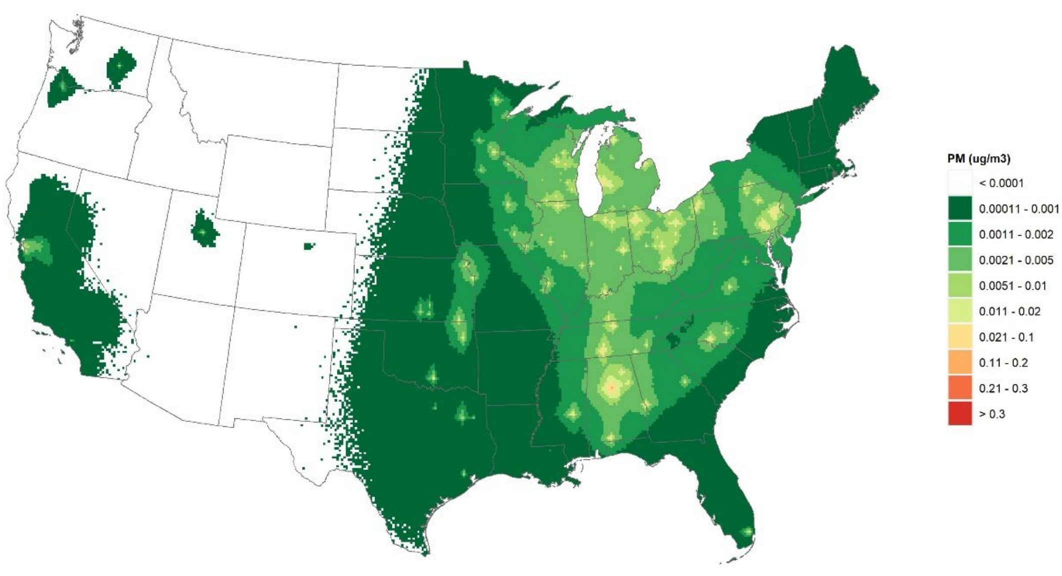
Integrated Iron and Steel: Annual Mean PM2.5



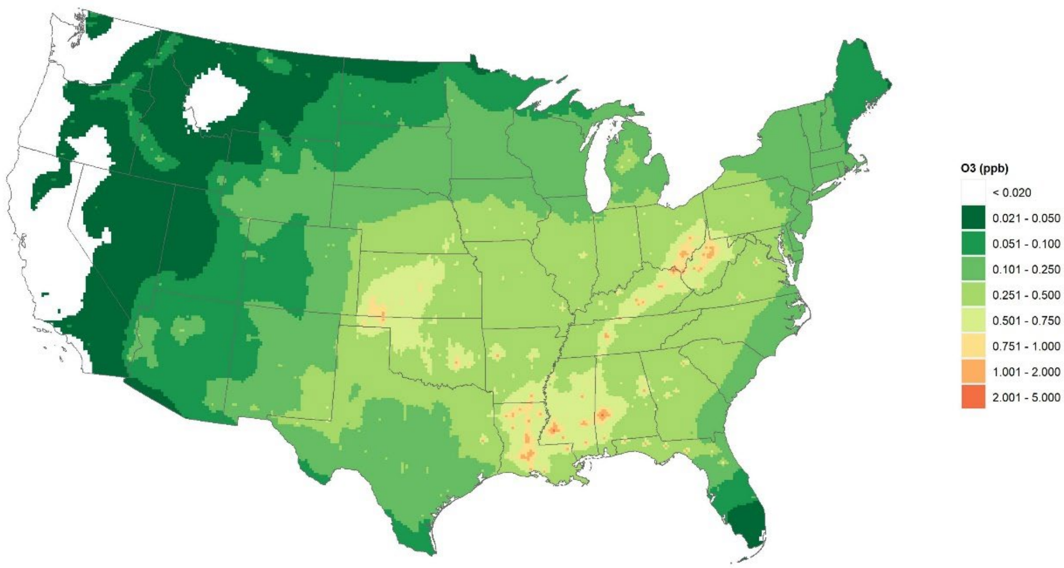
Iron and Steal Foundries: Summer Season Ozone



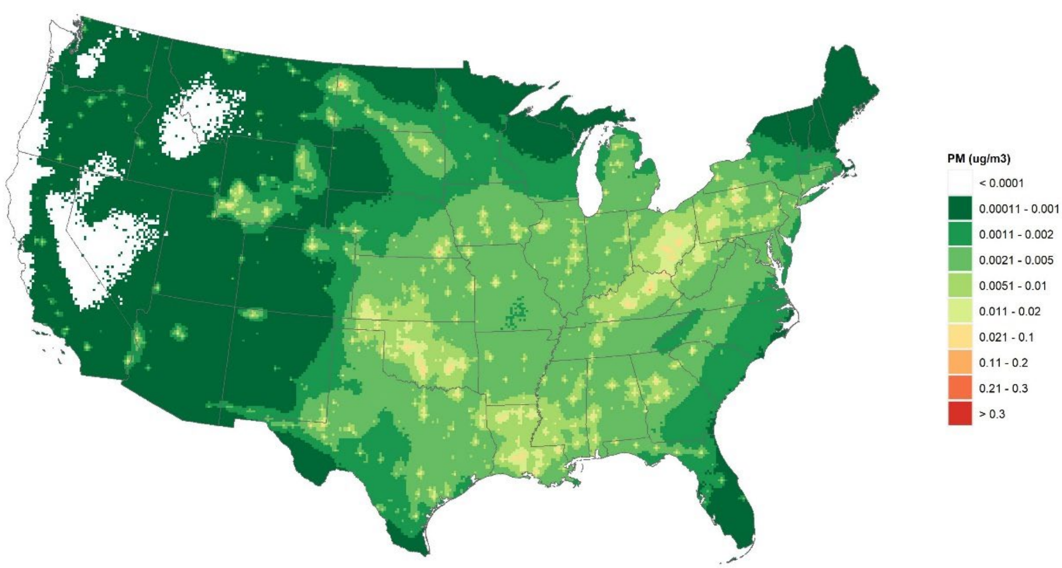
Iron and Steal Foundries: Annual Mean PM2.5



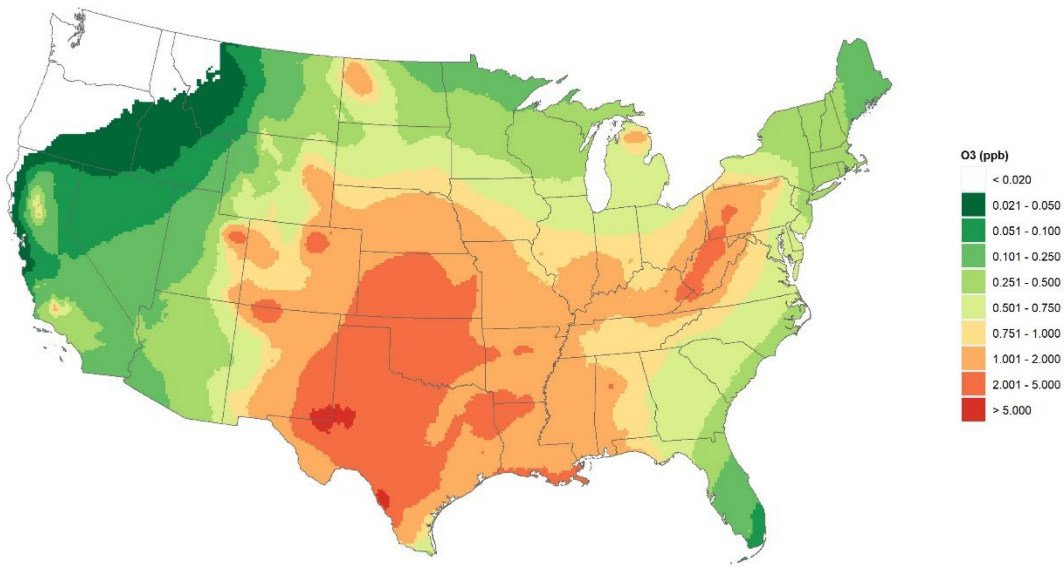
Oil & Gas Trans: Summer Season Ozone



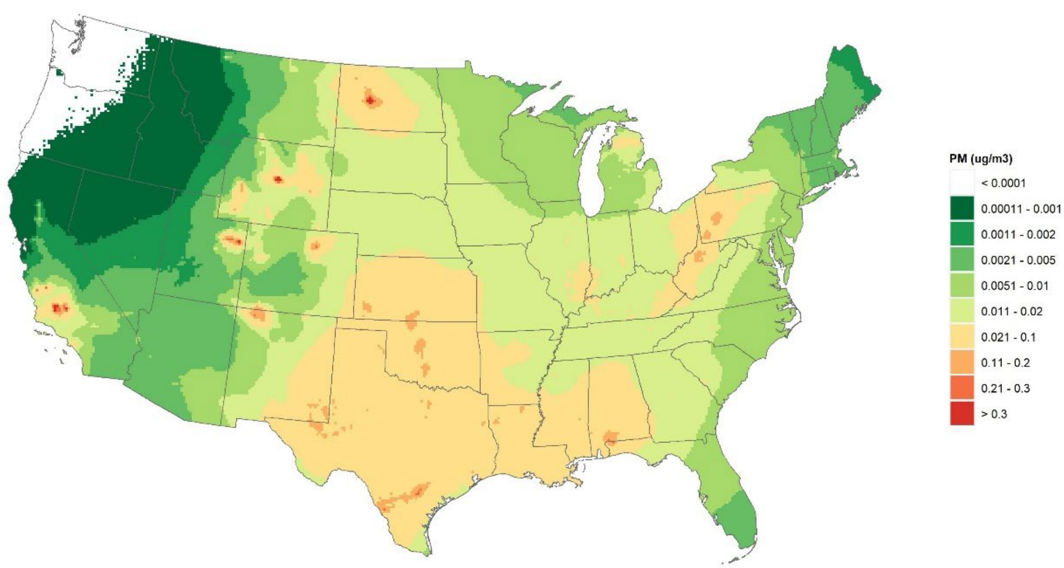
Oil & Gas Trans: Annual Mean PM2.5



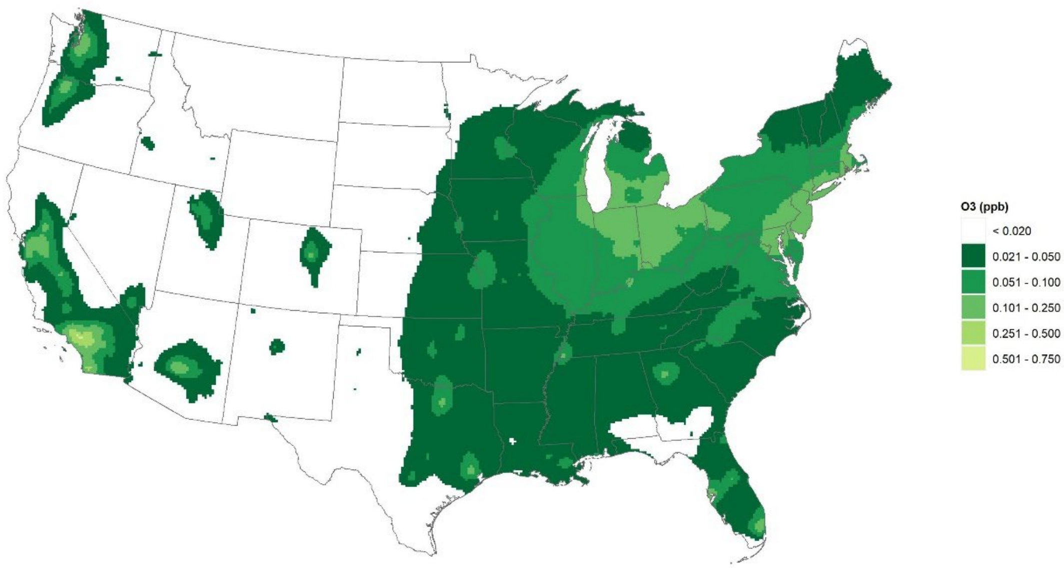
Oil and Natural Gas: Summer Season Ozone



Oil and Natural Gas: Annual Mean PM2.5

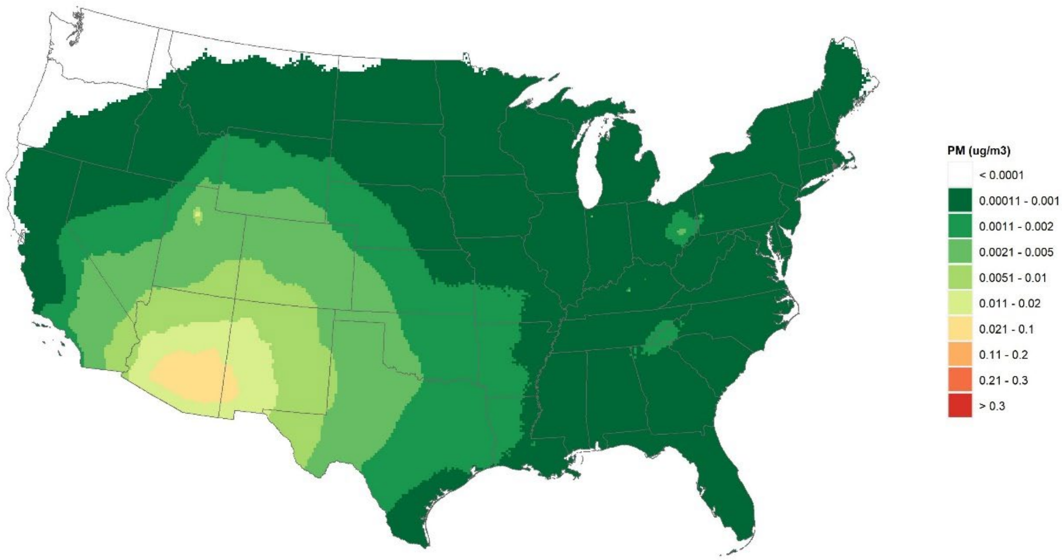


Paint Stripping: Summer Season Ozone



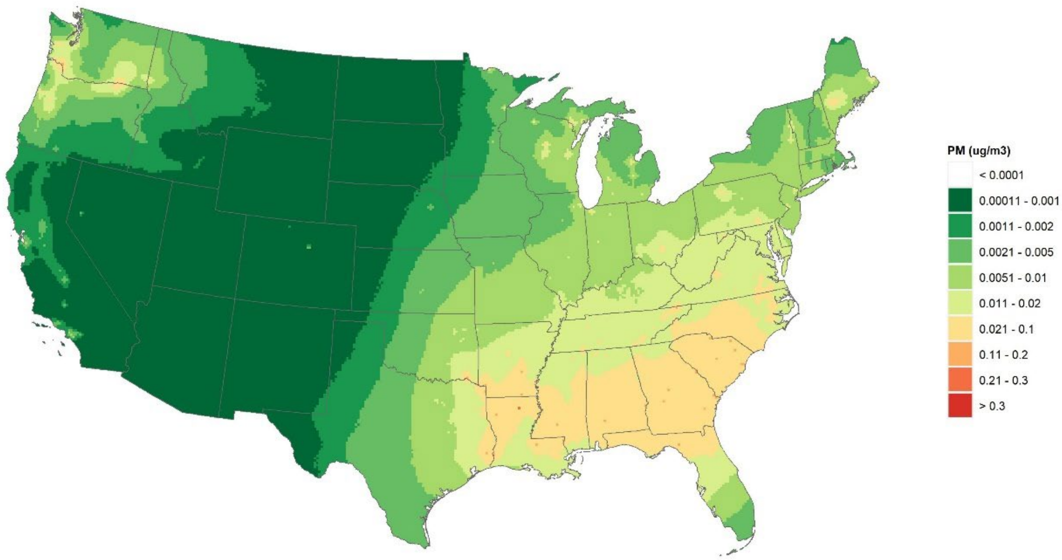
Paint Stripping: Annual Mean PM2.5

Primary Copper: Annual Mean PM2.5

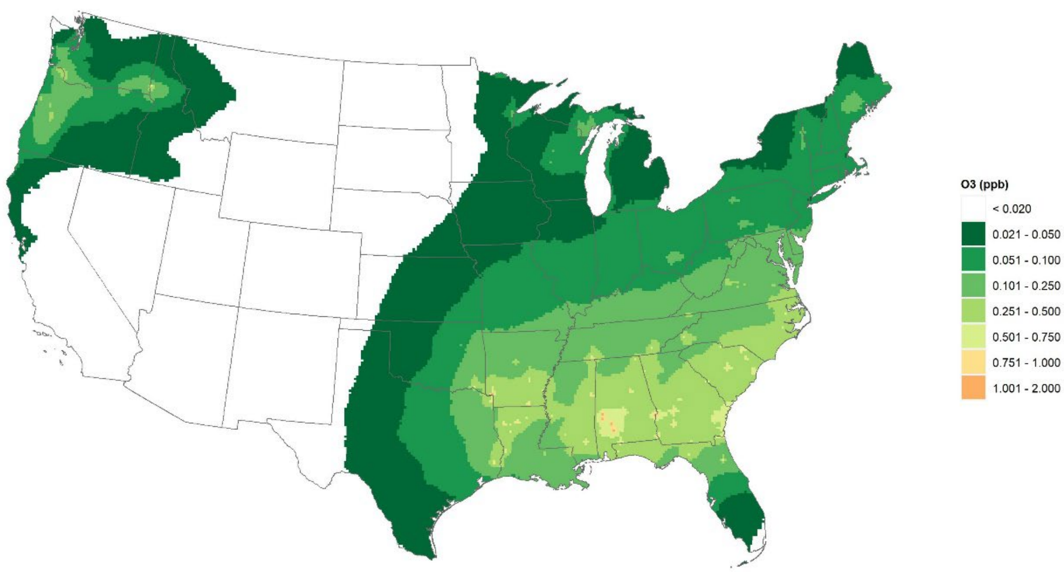


Primary Copper: Summer Season Ozone

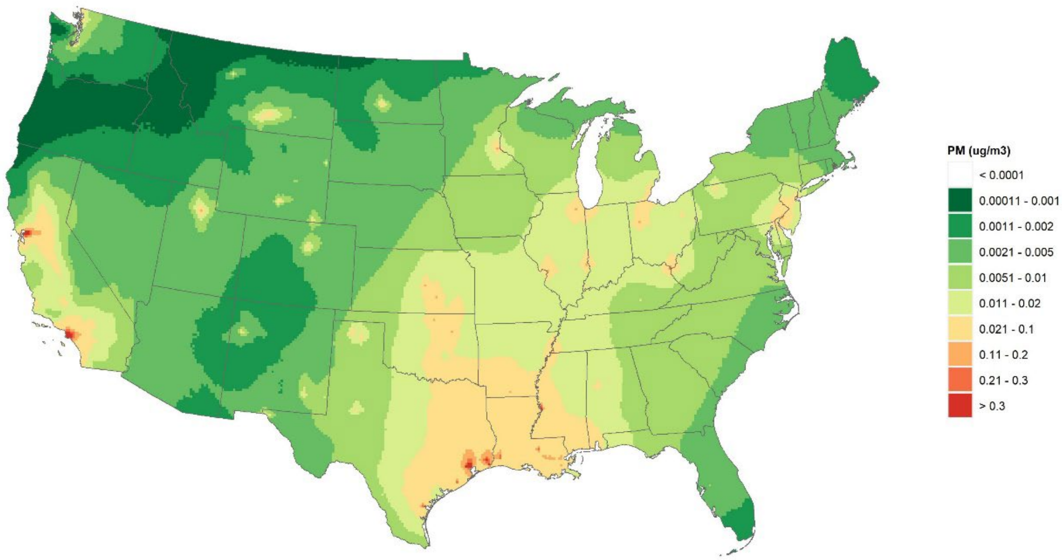
Pulp and Paper: Annual Mean PM2.5



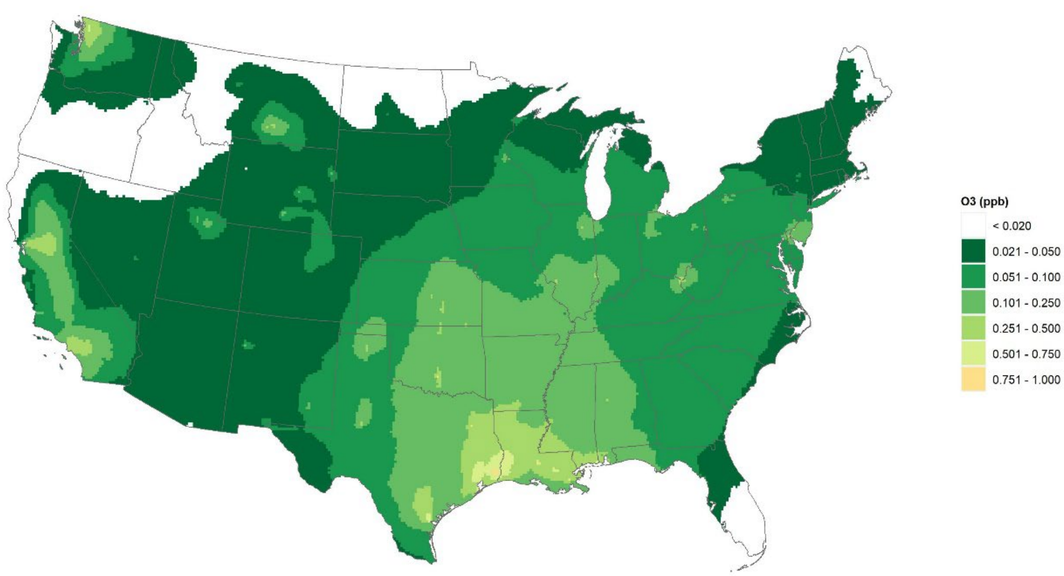
Pulp and Paper: Summer Season Ozone



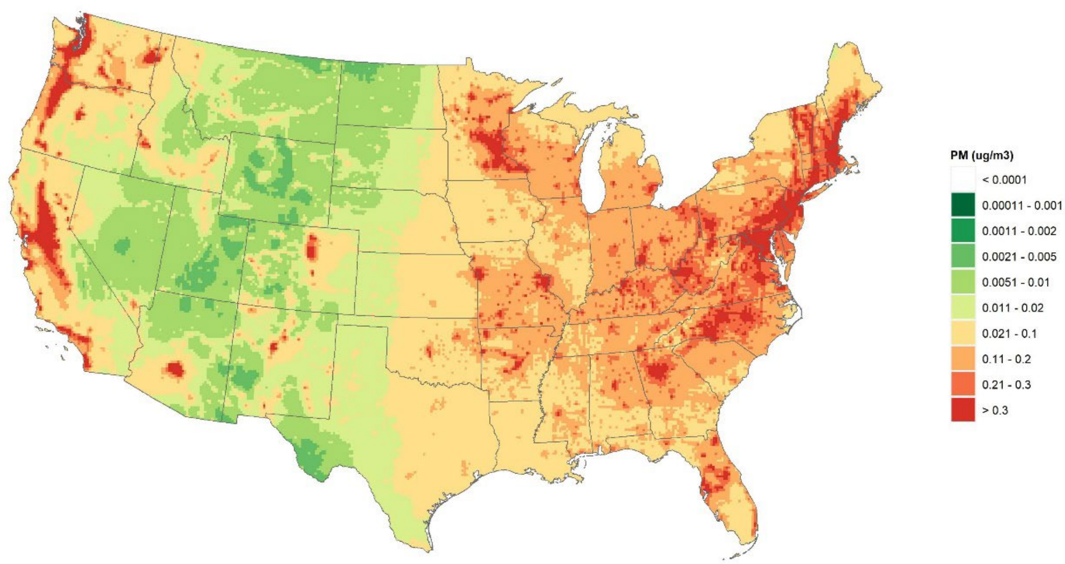
Refineries: Annual Mean PM2.5



Refineries: Summer Season Ozone

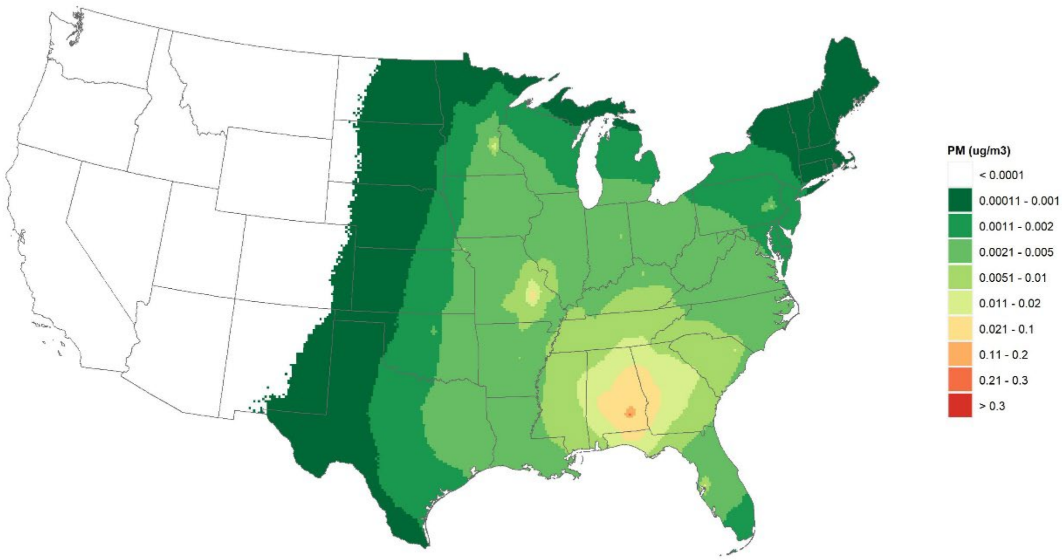


Residential Wood: Annual Mean PM2.5

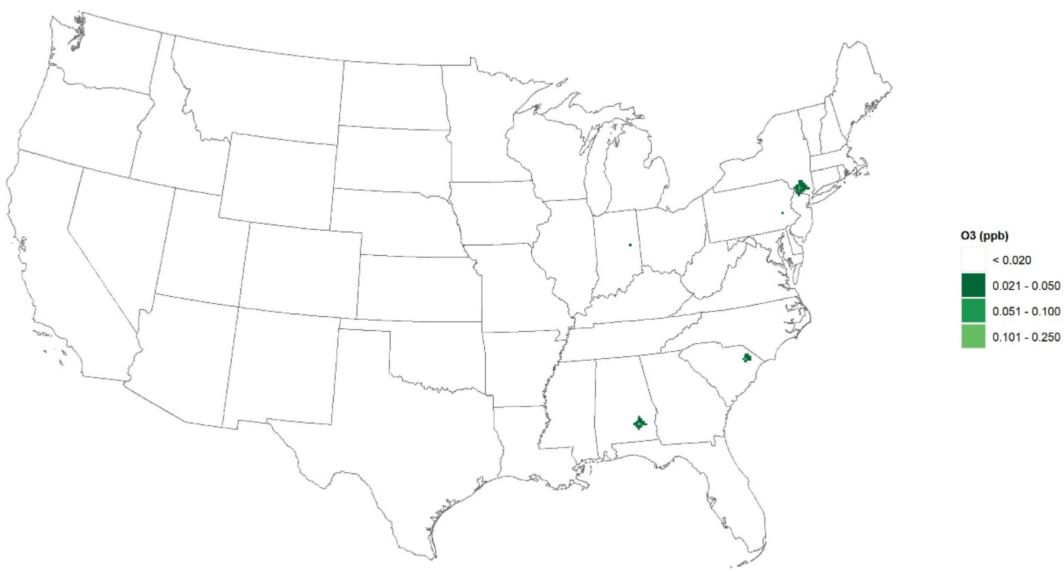


Residential Wood: Summer Season Ozone

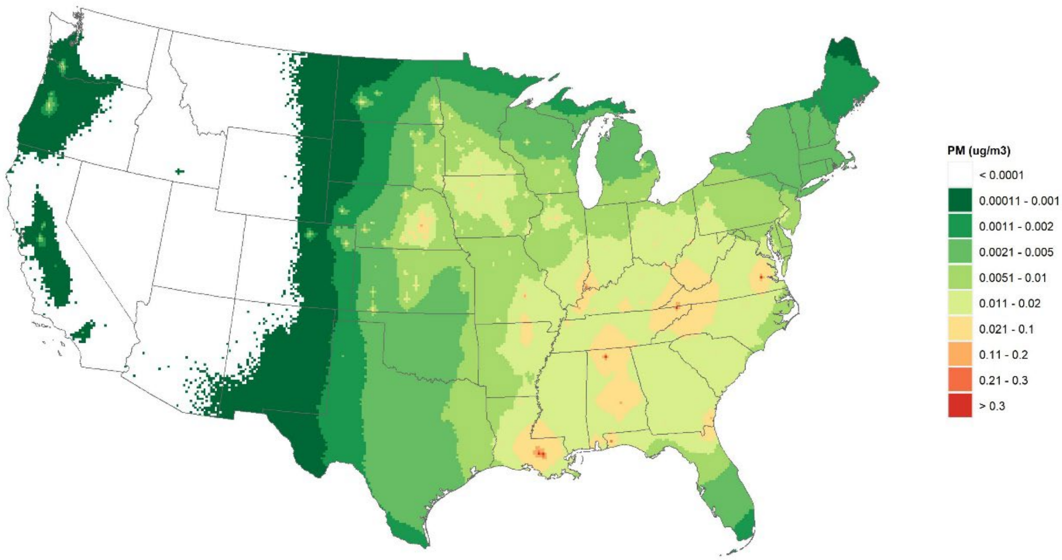
Secondary Lead: Annual Mean PM2.5



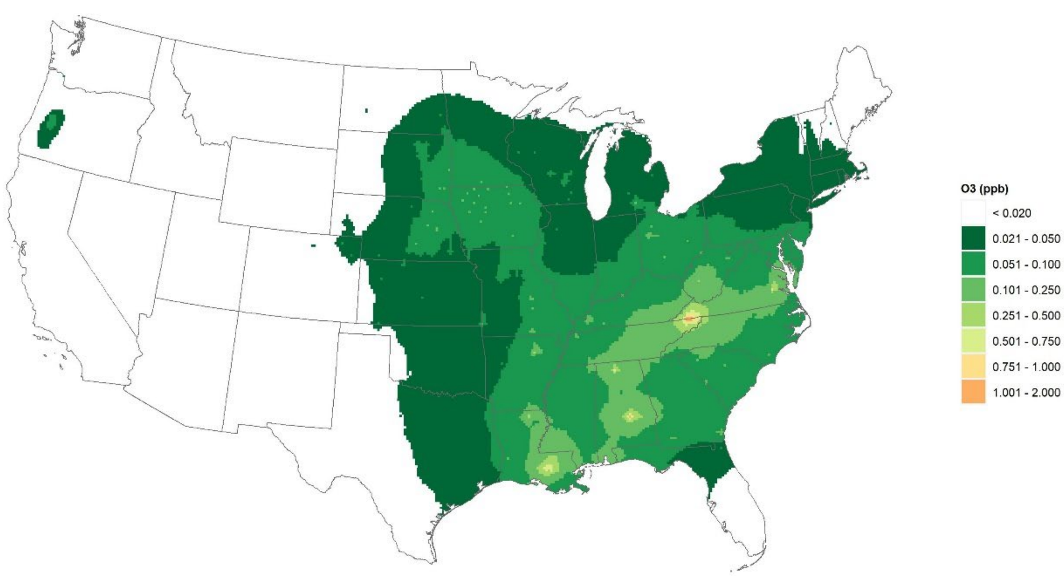
Secondary Lead: Summer Season Ozone



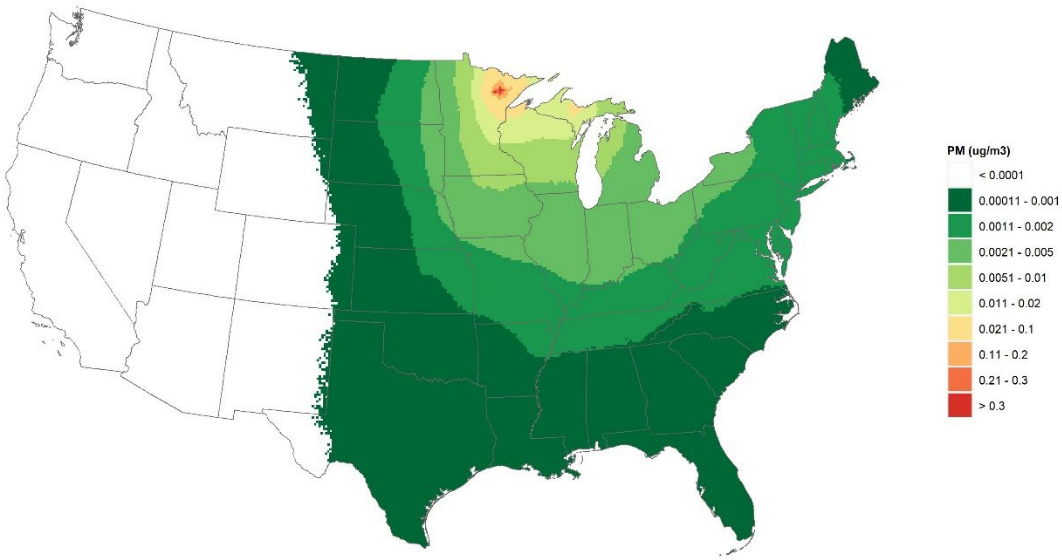
Synthetic Org Material: Annual Mean PM2.5



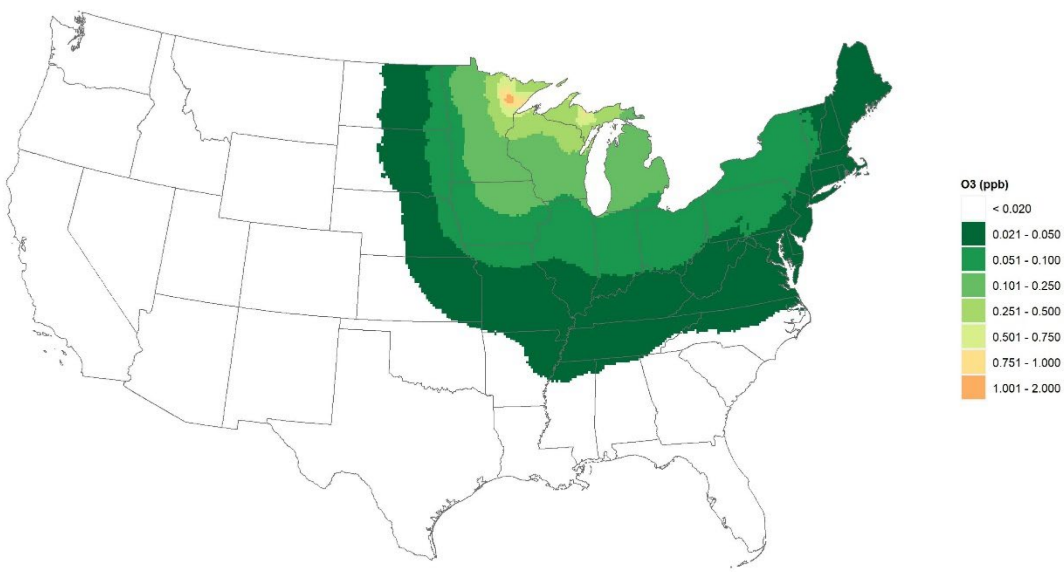
Synthetic Org Material: Summer Season Ozone



Taconite Mining: Annual Mean PM2.5



Taconite Mining: Summer Season Ozone



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