American Lung Association.

Clean Heat, Clean Air:

Health Benefits of Modern Industrial Technologies

About this Report

Clean Heat, Clean Air: Health Benefits of Modern Industrial Technologies evaluates the potential health and climate benefits of replacing fossil fueled industrial boilers across the United States with zero-emission heat pump alternatives. It finds that increasing use of zero-emission heat pump technologies in the temperature ranges in which they are feasible could significantly improve air quality, mitigate greenhouse gases and reduce health harms associated with air pollution and climate change.

This project was developed by the American Lung Association and executed with technical support from ICF Incorporated (ICF), LLC. Following a detailed review of recent work on industrial process heat and evaluation of publicly available data, ICF built an inventory of industrial boilers across the United States.

This study estimates there to be 33,528 industrial boilers operating under 200 °Celsius that use fossil fuels across the country (circa 2020). It builds a new, bottom-up emissions inventory of the criteria and climate pollutants emitted from them. It forecasts the emissions under a business as usual (BAU) growth scenario through 2050 without significant technology changes in this combustion boiler fleet.

The study develops a "Clean Heat" scenario for industry where heat pumps replace combustion boilers, considering feasibility based on operating temperature, technology readiness, the different fuels used in boilers, the different industrial sectors in which they are used, and heat pump performance characteristics. Under this scenario, the report illustrates how much air pollution could be avoided from boilers by switching to heat pumps. It takes into account the increase in electric grid emissions from the additional load on the grid that would be required to support the transition over the coming decades.

Clean Heat, Clean Air

American manufacturing is a critical element of the nation's economy and is projected to grow and expand. At the same time, industrial processes historically reliant on combustion of fossil fuels in the United States are responsible for a significant share of harmful pollutants.

This study by the American Lung Association finds that replacing combustion-based industrial boilers with modern, zero-emission heat pumps could significantly improve air quality, mitigate greenhouse gases and reduce health harms associated with air pollution and climate change.

A phased-in shift within industrial sectors most ready for zero-emission technologies could yield over $1.1 trillion in health benefits and avoid over 77,000 pollution-related deaths and 33 million asthma attacks over the coming decades. This shift could also yield over $350 billion in global climate benefits.

The study used the United States Environmental Protection Agency's (US EPA) Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA) to explore how the changes in emissions would affect public health, including premature deaths, asthma attacks, respiratory and cardiac emergency room visits, work and school days lost, and other impacts of air pollution, as well as to provide a monetization of the health benefits of avoided pollution. All these health endpoints show strong, positive results from implementing the "Clean Heat" Scenario, which would reduce thousands of tons of air pollution including average $PM_{2.5}$ concentrations, avoid tens of thousands of premature deaths and result in over $1 trillion in public health benefits through the year 2050.

Exploring the potential global benefits of greenhouse gas reductions associated with these scenarios, the report found that 1.6 billion metric tons of carbon dioxide equivalent (CO2e) could be avoided through 2050. Applying the Social Cost of Greenhouse Gas metric updated by US EPA in 2023, we found these emissions reductions would result in $351 billion in accrued global climate benefits by 2050 (expressed in 2023$).

Full results, methodology, assumptions, and tools used are available online at: **Lung.org/clean-heat**

The results are clear: moving from combustion-fueled industrial heat to more modern, efficient, zero-emission heat pump technologies will save lives, reduce health emergencies and curb climate pollution.

Executive Summary

This report from the American Lung Association illustrates the potential for dramatic air quality and public health improvements in America's industrial manufacturing sector. The analysis relies on a "Clean Heat" Scenario envisioning the phased-in replacement of combustion-based industrial boilers with more efficient, modern, zero-emission heat pump boiler technologies as demand for American manufacturing and industrial heating processes grows over the coming decades. It focuses on the low- and medium-temperature processes (below 200 °Celsius) where heat pump boilers are most feasible.

The transition to cleaner, more efficient heat technologies over the coming decades could yield staggering benefits in terms of avoided health emergencies and deaths, and more than $1 trillion in cumulative public health benefits through the year 2050.

The industrial sector that uses low- and medium temperature boilers is responsible for manufacturing everyday consumer goods and raw materials including food and beverage processing, production of textiles, paper, plastics, and chemicals.

These diverse industrial systems depend on tens of thousands of combustion-based boilers to produce hot water and steam, approximately 87% of which burn fossil fuels in the process.[1] Others burn wood, other biomass products, and/or waste fuels to generate heat.

U.S. Boiler Inventory (2020)

Fuel Type	Boiler Count
Methane Gas	26,241
Biomass	2,502
Oil Products	2,430
Coal	615
Other Fuels	725
Unclassified	1,015
Total	**33,528**

Combustion-based industrial heat production spews various air pollutants, including nitrogen oxides (NO_x), fine particulate matter ($PM_{2.5}$), sulfur oxides (SO_2) and others that harm public health. The U.S. manufacturing sector is also responsible for almost one-quarter (23%) of directly emitted greenhouse gases (GHG), making it the third leading contributor of these health-threatening pollutants. If fossil fuel-driven power generation for industrial use were factored in, the sector's share rises to 30% of the nation's total greenhouse gas emissions.[2]

Key to this analysis was the evaluation of the baseline fleet of combustion-based boilers currently in operation across the United States. A detailed analysis based on current research[3] of equipment used in industrial processes found that approximately 33,500 boilers are in use across the country, utilizing a mix of combustion fuels that create health risk in their communities.

Many of these boilers serve low- and medium-temperature industrial processes in various economic sectors such as food and beverage production or paper and pulp manufacturing. These lower-temperature boilers have the greatest potential for replacement with modern, efficient, zero-emission heat pump boiler technologies in the near-term. From that foundation, we applied a set of assumptions for technology shift, specifically the replacement of combustion-based boilers (not including existing electric boilers that may be currently in use) with heat pumps at the following intervals based on technology thresholds and readiness at lower temperature applications:

- Near-term (<100 °C) installation year of 2030.
- Medium-term (100 oC -140 °C) installation year of 2035.
- Longer-term (140 oC – 200 °C) installation year of 2040.

We also estimate the emissions impacts from upstream energy demand to fuel the heat pump boilers by relying on BAU projections from the US DOE through 2050.[4] By incorporating changes across end-use heat pumps and factoring in pollution associated with increased power demand, this analysis attempts to provide a more comprehensive illustration of health impacts and benefits as industrial heat demand increases over time.

This analysis shows that the transition to zero-emission industrial technologies is essential to reducing health impacts and protecting clean air progress while growing our industrial economy.

Cumulative Nationwide Health and Climate Benefits of Clean Heat (2030-2050)

Public Health Benefits (2030-2050)					**Value of Benefits** (2030-2050)	
Premature Deaths Avoided	**Asthma Attacks Avoided**	**New Asthma Cases Avoided**	**Lost School Days Avoided**	**Lost Work Days Avoided**	**Total Health Benefit**	**Total Climate Benefit**
77,200	33.2 Million	204,000	13 Million	3.4 Million[b]	$1.11 Trillion[a]	$351 Billion[a]

[a] Calculated in 2023$ with a 2% discount rate. [b] Considering $PM_{2.5}$ exposure only

Additional benefits would be achieved in longer time horizons by further decarbonizing the electric grid. Robust policy responses to encourage and ensure this transition to more efficient and less harmful technologies in the near term will support community-level air quality and health improvements as the industrial sector continues to expand in the United States. Further, ongoing research and development efforts related to expansion of zero-emission technologies in higher-temperature applications will be critical to longer-term emission reductions and health protection.

Health Risks Due to Combustion-Based Industrial Heat

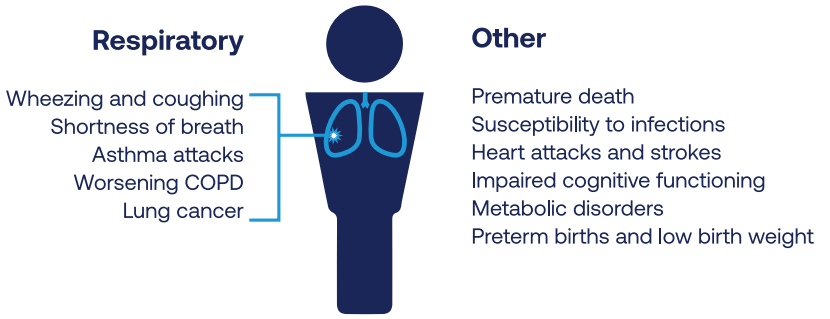
To produce steam or hot water in industrial manufacturing settings, tens of thousands of combustion-based boilers burn methane gas, oil, coal and other fuels which contribute to air pollution burdens across the United States and to global climate change.

Like power generation, transportation and other economic sectors, antiquated combustion technologies are far less efficient and far more harmful to health than modern zero-emission technologies.

Approximately 33,500 boilers across the United States burn fuel and emit various air pollutants that worsen local and regional air quality and contribute to climate change impacts. In some cases, these boilers can play an important, additive role in local air pollution burdens. A report by the American Council for an Energy Efficient Economy noted that smaller boilers are currently operating in 147 counties that fail to meet National Ambient Air Quality Standards for ozone pollution.[5]

According to the American Lung Association's "State of the Air" 2025 report, nearly half of the U.S. population – 156 million people – lives in a community with unhealthy levels of air pollution.[6] Air pollution harms respiratory and cardiovascular health, and these health risks disproportionately impact vulnerable populations including seniors, children, and people with existing diseases. Furthermore, lower-income populations and people of color are more likely to live in areas with higher air pollution exposure. Other socioeconomic factors such as poverty, inadequate access to healthcare, and social stressors contribute to the increased disparity of air pollution burdens and worsened health outcomes.

Air pollution can harm children and adults in many ways



Replacing boilers with industrial heat pump technologies over the coming decades can yield significant pollution reductions and protect public health as the nation's industrial demand grows.

Nationwide Clean Heat Findings

The transition to zero-emission technology for low- and mid-temperature industrial boilers would generate substantial reductions in both climate-forcing emissions and local air pollutants that threaten public health, including smog-forming nitrogen oxides, deadly fine particle pollution and sulfur oxides.

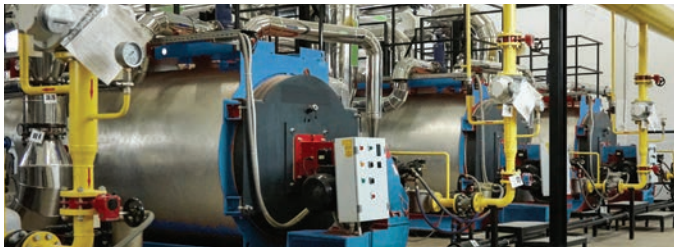
Specifically, the total tons of NO_x, $PM^{2.5}$ and SO_2 that are projected to drop under the Clean Heat scenario compared to the base case amount to significant percentage reductions from current baseline levels. The figure below represents the reductions in these pollutants in specific years evaluated during the study time horizon.

Year	NO_x Reduction	$PM_{2.5}$ Reduction	SO_2 Reduction
2030	↓60%	↓65%	↓56%
2040	↓74%	↓76%	↓71%
2050	↓73%	↓74%	↓72%

The substantial reductions in health-harming pollution across the fleet of industrial heat resources in the United States could yield major benefits to community health: 77,200 pollution-related deaths and 33.2 million asthma attacks could be avoided by 2050 across the United States. Additionally, 204,000 new cases of asthma could also be avoided over that period.

By shifting to more efficient industrial heat technologies, lost work and school days due to illness would drop by the millions in communities across the nation, meaning these investments in clean technology are also investments in productivity and educational attainment.

Similarly, the climate-related social cost benefits calculated from federal estimates[7] could reach $351 billion globally by 2050, resulting from avoiding 1.6 billion metric tons of CO2e emitted into the atmosphere.



Cumulative Nationwide Health and Climate Benefits of Clean Heat (2030-2050)						
Public Health Benefits (2030-2050)					**Value of Benefits** (2030-2050)	
Premature Deaths Avoided	**Asthma Attacks Avoided**	**New Asthma Cases Avoided**	**Lost School Days Avoided**	**Lost Work Days Avoided**	**Total Health Benefit**	**Total Climate Benefit**
77,200	33.2 Million	204,000	13 Million	3.4 Million[b]	$1.11 Trillion[a]	$351 Billion[a]
[a] Calculated in 2023$ with a 2% discount rate. [b] Considering $PM_{2.5}$ exposure only						

Additional health benefit information (i.e., additional health endpoints, underlying research) is available within the technical documentation included as a resource to the online version of this report.

Local Findings

The staggering national findings are driven by major health benefits seen in states with populations that reside in close proximity to industrial sources where the emission reductions are occurring. Notably, 26 of the 48 states included in the results (Alaska and Hawaii are not included in the EPA COBRA modeling tool) achieved health benefits of $25 billion or more over the course of this assessment, with state-specific results ranging from $504 million to $107 billion by 2050. Details for each state are available in the appendices to this report. The following table presents the 15 states with the highest total public health benefits on a monetized basis:

State	Cumulative Health Benefits (2030-2050)	Avoided Premature Deaths	Avoided Asthma Symptoms	Avoided New Asthma Cases	Avoided Lost Work Days	Avoided Lost School Days
Florida	$107.0 B	7,580	2,170,000	13,000	334,000	668,000
Pennsylvania	$82.1 B	5,760	2,010,000	12,100	222,000	756,000
North Carolina	$67.6 B	4,680	2,110,000	13,200	196,000	874,000
New York	$65.0 B	4,570	1,740,000	10,200	289,000	479,000
Illinois	$61.6 B	4,310	1,700,000	10,200	241,000	523,000
Ohio	$58.3 B	4,080	1,510,000	9,170	154,000	579,000
Texas	$53.7 B	3,590	2,560,000	16,300	193,000	1,100,000
California	$47.5 B	3,220	1,870,000	11,700	162,000	800,000
New Jersey	$43.9 B	3,040	1,370,000	8,300	135,000	553,000
Georgia	$43.4 B	2,960	1,660,000	10,500	124,000	751,000
Michigan	$42.8 B	3,010	1,060,000	6,350	121,000	384,000
Virginia	$42.1 B	2,890	1,460,000	9,040	128,000	624,000
Tennessee	$37.7 B	2,620	1,050,000	6,460	101,000	419,000
South Carolina	$32.7 B	2,280	888,000	5,500	79,100	370,000
Indiana	$31.9 B	2,230	895,000	5,460	93,000	328,000

Policy Recommendations for Clean Heat

Policies and investments made in the near term can help capture the health benefit potential of clean heat technologies in the low- to medium-temperature industrial setting, while also driving research and development for additional, higher-temperature applications. Providing clear market signals through stronger pollution controls and incentives for investment at the state and federal level can ensure that cleaner heat becomes the foundation for more efficient, cost-effective, and less polluting American manufacturing for decades to come.

Policy recommendations to facilitate the transition to clean heat technologies in the low- to medium-temperature industrial setting could include:

- State and local permitting requirements and zero-emission standards to ensure stronger pollution controls for industrial heat equipment.
- State and Federal programs to incentivize the shift to modern manufacturing processes over combustion-based technologies by eliminating barriers to initial purchase and ongoing operating costs.
- Consistent and sustained investment in research and development of efficient, zero-emission technologies across all industrial heat applications, especially for the development of higher-temperature applications.
- Public and private educational efforts, calculators, and other tools to support informed choices about the feasibility, efficiency, and cost-effectiveness of modern industrial technologies.
- Utility-level grid readiness planning and investment to meet increased zero-emission industrial needs, reliability and system stability while continuing a shift to cleaner, non-combustion energy sources.

Against the backdrop of EPA's current agenda of regulatory rollbacks, the above policy recommendations assume special significance, particularly at the state or air district level, in incentivizing and investing in modern, efficient zero-emission alternatives in industrial technologies as well as in energy production, buildings and transportation. This is essential for securing healthy air for all.

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[1]United States Department of Energy, National Renewable Energy Lab. Opportunities for Solar Industrial Process Heat in the United States. January 2021. https://research-hub.nrel.gov/en/publications/opportunities-for-solar-industrial-process-heat-in-the-united-sta

[2] US EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022. April 2024. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

[3] Much of the inventory is derived from Embracing Clean Heat, Opportunities for Zero-Emission Industrial Boilers, Trevor Dolan, Andres Restrepo, Cassandra Lopina, Melanie Law, Madison Carroll. May 2025. Available at: https://collaborative.evergreenaction.com/policy-hub/embracing-clean-heat.

[4] Electric grid emissions modeled from United States Department of Energy's Office of Energy Efficiency and Renewable Energy's (EERE) Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model and EERE's National Renewable Energy Lab (NREL) CAMBIUM model. Cambium datasets. National Renewable Energy Laboratory (NREL). (2023). Available at: https://www.nrel.gov/analysis/cambium.html

GREET® (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) models. U.S. Department of Energy (DOE)'s Argonne National Laboratory. (2024). Available at: https://www.energy.gov/eere/greet

[5] The American Council for an Energy-Efficient Economy (ACEEE). Industrial Boilers Keep Burning in Areas Exceeding Air Pollution Limits. February 2025. https://www.aceee.org/blog-post/2025/02/industrial-boilers-keep-burning-areas-exceeding-air-pollution-limits

[6] American Lung Association. State of the Air 2025. April 2025. www.lung.org/sota

[7] United States Environmental Protection Agency. Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances. December 2023. https://www.epa.gov/environmental-economics/scghg

Conclusion

Modern, industrial heat pump technologies are available and will soon be ready to replace thousands of low- and medium-temperature combustion-based boilers in the coming years. This transition can generate significant local health benefits by delivering cleaner and more efficient heat for industrial settings. Educational efforts, policies and investments in more efficient industrial technologies will yield major benefits for American communities and American manufacturers.

Appendix A: State Results (2023$ Billions)

State	Cumulative Health Benefits (2030-2050)	Avoided Deaths	Avoided Asthma Attacks	Avoided New Asthma Cases	Avoided Lost Work Days	Avoided Lost School Days
Alabama	$20.4 B	1,420	596,000	3,700	44,200	268,000
Arizona	$2.2 B	141	106,000	715	2,940	59,000
Arkansas	$13.5 B	941	366,000	2,240	36,000	137,000
California	$47.5 B	3,220	1,870,000	11,700	162,000	800,000
Colorado	$2.9 B	194	146,000	960	8,720	71,100
Connecticut	$13.5 B	935	389,000	2,370	39,300	163,000
Delaware	$4.8 B	330	155,000	965	13,700	65,900
District of Columbia	$2.1 B	143	109,000	684	12,100	46,800
Florida	$107.0 B	7,580	2,170,000	13,000	334,000	668,000
Georgia	$43.4 B	2,960	1,660,000	10,500	124,000	751,000
Idaho	$1.8 B	123	78,200	511	4,270	37,400
Illinois	$61.6 B	4,310	1,700,000	10,200	241,000	523,000
Indiana	$31.9 B	2,230	895,000	5,460	93,000	328,000
Iowa	$6.8 B	473	208,000	1,290	19,400	80,800
Kansas	$4.1 B	279	158,000	1,000	11,500	68,000
Kentucky	$21.7 B	1,510	620,000	3,830	53,000	257,000
Louisiana	$23.3 B	1,610	758,000	4,680	63,300	316,000
Maine	$3.2 B	221	68,100	413	5,740	30,600
Maryland	$28.9 B	1,980	1,020,000	6,230	90,700	432,000
Massachusetts	$25.8 B	1,800	724,000	4,440	84,700	285,000
Michigan	$42.8 B	3,010	1,060,000	6,350	121,000	384,000
Minnesota	$15.0 B	1,050	460,000	2,790	61,500	141,000
Mississippi	$11.6 B	801	353,000	2,180	25,700	157,000
Missouri	$16.1 B	1,120	480,000	2,970	43,400	194,000
Montana	$0.6 B	43	21,600	139	857	11,200
Nebraska	$2.0 B	138	81,000	513	6,300	33,200
Nevada	$2.5 B	168	93,400	629	3,020	51,400
New Hampshire	$4.4 B	307	103,000	626	10,100	44,700
New Jersey	$43.9 B	3,040	1,370,000	8,300	135,000	553,000
New Mexico	$1.0 B	64	42,000	273	1,470	22,400
New York	$65.0 B	4,570	1,740,000	10,200	289,000	479,000
North Carolina	$67.6 B	4,680	2,110,000	13,200	196,000	874,000
North Dakota	$0.6 B	38	20,100	125	1,730	8,250
Ohio	$58.3 B	4,080	1,510,000	9,170	154,000	579,000
Oklahoma	$8.3 B	569	279,000	1,750	22,200	115,000
Oregon	$3.5 B	236	155,000	1,010	7,440	79,400
Pennsylvania	$82.1 B	5,760	2,010,000	12,100	222,000	756,000

Appendix A: State Results (2023$ Billions) continued

State	Cumulative Health Benefits (2030-2050)	Avoided Deaths	Avoided Asthma Attacks	Avoided New Asthma Cases	Avoided Lost Work Days	Avoided Lost School Days
Rhode Island	$3.7 B	257	96,600	597	9,600	41,800
South Carolina	$32.7 B	2,280	888,000	5,500	79,100	370,000
South Dakota	$0.7 B	48	27,600	173	2,040	11,200
Tennessee	$37.7 B	2,620	1,050,000	6,460	101,000	419,000
Texas	$53.7 B	3,590	2,560,000	16,300	193,000	1,100,000
Utah	$1.5 B	94	127,000	864	3,880	66,000
Vermont	$1.4 B	101	32,800	199	2,940	15,300
Virginia	$42.1 B	2,890	1,460,000	9,040	128,000	624,000
Washington	$7.8 B	527	313,000	1,980	25,000	138,000
West Virginia	$9.9 B	694	228,000	1,370	20,000	97,800
Wisconsin	$28.1 B	1,970	731,000	4,410	88,100	247,000
Wyoming	$0.5 B	34	21,000	135	1,010	10,300

NOTE: Monetized health benefits calculated in 2023$ with a 2% discount rate. COBRA modeling results exclude Alaska and Hawaii. Lost work day calculation reflects fine particle exposures only.

Appendix B: State Results by Cumulative Health Benefit (2023$ Billions)

State	Cumulative Health Benefits (2030-2050)	Avoided Deaths	Avoided Asthma Attacks	Avoided New Asthma Cases	Avoided Lost Work Days	Avoided Lost School Days
Florida	$107.0 B	7,580	2,170,000	13,000	334,000	668,000
Pennsylvania	$82.1 B	5,760	2,010,000	12,100	222,000	756,000
North Carolina	$67.6 B	4,680	2,110,000	13,200	196,000	874,000
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Louisiana	$23.3 B	1,610	758,000	4,680	63,300	316,000
Kentucky	$21.7 B	1,510	620,000	3,830	53,000	257,000
Alabama	$20.4 B	1,420	596,000	3,700	44,200	268,000
Missouri	$16.1 B	1,120	480,000	2,970	43,400	194,000
Minnesota	$15.0 B	1,050	460,000	2,790	61,500	141,000
Arkansas	$13.5 B	941	366,000	2,240	36,000	137,000
Connecticut	$13.5 B	935	389,000	2,370	39,300	163,000
Mississippi	$11.6 B	801	353,000	2,180	25,700	157,000
West Virginia	$9.9 B	694	228,000	1,370	20,000	97,800
Oklahoma	$8.3 B	569	279,000	1,750	22,200	115,000
Washington	$7.8 B	527	313,000	1,980	25,000	138,000
Iowa	$6.8 B	473	208,000	1,290	19,400	80,800
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Colorado	$2.9 B	194	146,000	960	8,720	71,100

Appendix B: State Results by Cumulative Health Benefit (2023$ Billions) continued

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Arizona	$2.2 B	141	106,000	715	2,940	59,000
District of Columbia	$2.1 B	143	109,000	684	12,100	46,800
Nebraska	$2.0 B	138	81,000	513	6,300	33,200
Idaho	$1.8 B	123	78,200	511	4,270	37,400
Utah	$1.5 B	94	127,000	864	3,880	66,000
Vermont	$1.4 B	101	32,800	199	2,940	15,300
New Mexico	$1.0 B	64	42,000	273	1,470	22,400
South Dakota	$0.7 B	48	27,600	173	2,040	11,200
Montana	$0.6 B	43	21,600	139	857	11,200
North Dakota	$0.6 B	38	20,100	125	1,730	8,250
Wyoming	$0.5 B	34	21,000	135	1,010	10,300

NOTE: Monetized health benefits calculated in 2023$ with a 2% discount rate. COBRA modeling results exclude Alaska and Hawaii. Lost work day calculation reflects fine particle exposures only.

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