U.S. House Committee on Energy and Commerce

Subcommittee on Environment, Manufacturing, and Critical Materials

"Driving Affordability: Preserving People's Freedom to Buy Affordable Vehicles and Fuel"

[June 22, 2023]

1. Press release from Clean Fuels Development Coalition, June 12, 2023, submitted by the Majority.
2. Letter from the National Association of Convenience Stores to Chair Johnson and Ranking Member Tonko, June 21, 2023, submitted by the Majority.
3. Letter from Alliance for Automotive Innovation to Chair Johnson and Ranking Member Tonko, June 22, 2023, submitted by the Majority.
4. Memo from the Alliance for Automotive Innovation, April 6, 2023, submitted by the Majority.
5. Letter from Growth Energy to Chair Rodgers, Ranking Member Pallone, Chair Johnson, and Ranking Member Tonko, June 22, 2023, submitted by the Majority.
6. Press release from Alliance for Automotive Innovation, June 12, 2023, submitted by the Majority.
7. Press release from Alliance for Automotive Innovation, April 12, 2023, submitted by the Majority.
8. Report from the American Lung Association entitled, "Zeroing in on Healthy Air: A National Assessment of Health and Climate Benefits of Zero-Emission Transportation and Electricity" submitted by Rep. Clarke.
9. A report from the Union of Concerned Scientists and the Greenlining Institute entitled, "Cleaner Cars, Cleaner Air: Replacing California's Oldest and Dirtiest Cars Will Save Money and Lives" submitted by the Minority.
10. A report from the U.S. Environmental Protection Agency entitled, "Climate Change and Children's Health and Well-Being in the United States" submitted by Rep. Ruiz.
11. A report from ICCT entitled, "Assessment of Light-Duty Electric Vehicle Costs and Consumer Benefits in the United States in the 2022-2035 Time Frame" submitted by the Minority.
12. A report from ICCT entitled, "Benefits of Adopting California Advanced Clean Cars II Regulations Under Clean Air Act Section 177" submitted by the Minority.
13. A report from ICCT entitled, "Analyzing the Impact of the Inflation Reduction Act on Electric Vehicle Uptake in the United States" submitted by the Minority.
14. An article from Politico Pro entitled, "EV Popularity Driven by Range and Cost Improvements—Study" submitted by the Minority.
15. A letter from the Union of Concerned Scientists, submitted by the Minority.
16. A letter from Consumer Reports, submitted by the Minority.
17. Report from the Association of Air Pollution Control Agencies entitled "State Air Trends and Successes" submitted by the Majority.
18. Letter from Affiliated Construction Trades Ohio Foundation to Ohio House Transportation Committee Chairman McClain and Committee Members, submitted by Rep. Balderson.

19. Letter from Consumer Energy Alliance to Ohio House Transportation Committee Chairman McClain and Committee Members, June 20, 2023, submitted by Rep. Balderson.
20. Testimony of Scott Hayes for the Ohio House Transportation Committee
21. Letter from Ohio Automobile Dealers Association to Chairman McClain, Members of the Ohio House Transportation Committee, June 20, 2023, submitted by Rep. Balderson.
22. Letter to Chairman McClain, Members of the Ohio House Transportation Committee from American Fuel and Petrochemical Manufacturers, June 20, 2023, submitted by Rep. Balderson.
23. Testimony of Stephanie Kromer from the Ohio Oil & Gas Association before the Ohio House Transportation Committee, June 20, 2022, submitted by Rep. Balderson.
24. Report from the Consumer Energy Alliance entitled "Freedom to Fuel: Consumer Choice in the Automotive Marketplace" submitted by Rep. Balderson.

New Issue Brief Challenges the EV Vision

Jun 12, 2023 | Current News Events, Press Release

Biofuels and a Technology Neutral Strategy the Better Approach

For Immediate Release:

Washington, D.C., June 12, 2023: The widespread introduction of electric vehicles as a means of reducing carbon emissions presents a far greater challenge than the public is being led to believe, according to new research by the Clean Fuels Development Coalition (CFDC).

This conclusion is presented in Reality EV: No Silver Bullet, a new Issue Brief released here this week. Reality EV's research explains the consumer/taxpayer, infrastructure, and environmental constraints single fuel source electric vehicles (EVs) must overcome to live up to their often-claimed perfect solution. In addition, it is estimated that a $2-3 trillion dollar government/taxpayer investment is needed for EVs to replace 50% of the consumer fleet.

CFDC Executive Director Doug Durante said this research is not intended to dismiss the potential contribution of EVs but rather to put them in perspective. "EVs will clearly be a key part of our transportation mix but the reality of cost, consumer choice, re-charging, and many other factors indicates we need to make sure biofuels remain part of the mix," said Durante.

"Mandating EVs and banning the internal combustion engine is simply bad policy, force feeding something that is not ready at the expense of the public."

Regardless of if and when EVs meet all the challenges any new fuel would face, the brief details how the U.S. will continue to use trillions of gallons of gasoline. There are 280 million light duty vehicles registered in the U.S., with 12-15 million or more new cars sold every year. These cars have an average 15 year life span, meaning gasoline will remain the predominant fuel of the next several decades.

“Increasing the octane of gasoline with clean burning ethanol allows for automakers to produce much more efficient vehicles that can provide health and climate benefits now, not decades from now, ” said Durante.

Copies of the Issue Brief can be ***downloaded here*** for hardcopies please contact cfdcinc@aol.com. To view the print edition on line, ***click here***.

For more information on the Clean Fuels Development Coalition, including how you can become a member, contact us.

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June 21, 2023

The Honorable Bill Johnson Chairman Subcommittee on Environment, Manufacturing and Critical Minerals of the Committee on Energy & Commerce U.S. House of Representatives 2125 Rayburn House Office Building Washington, DC 20515	The Honorable Paul Tonko Ranking Member Subcommittee on Environment, Manufacturing and Critical Minerals of the Committee on Energy & Commerce U.S. House of Representatives 2125 Rayburn House Office Building Washington, DC 20515

Re: Hearing on "Driving Affordability: Preserving People's Freedom to Buy Affordable Vehicles and Fuel"

Dear Chairman Johnson and Ranking Member Tonko:

Thank you for the opportunity to provide our thoughts on the subcommittee's hearing on "Driving Affordability: Preserving People's Freedom to Buy Affordable Vehicles and Fuel." This is an important topic for the future of transportation in the United States and we appreciate your attention to the topic.

The National Association of Convenience Stores (NACS) is an international trade association representing the convenience and fuel retailing industry. The convenience and retail fuels industry employed approximately 2.44 million workers and generated more than $906 billion in total sales in 2022, representing more than 3.5 percent of U.S. gross domestic product. Of those sales, approximately $603 billion came from fuel sales alone. The industry, however, is truly an industry of small business. More than 60 percent of convenience stores are single-store operators. Less than 0.2 percent of convenience stores that sell gas are owned by a major oil company and about 4 percent are owned by a refining company. More than 95 percent of the industry, then, are independent businesses.

Members of the industry process more than 165 million transactions every single day. That is the equivalent of about half the U.S. population. In fact, ninety-three percent of Americans live within 10 minutes of one of our industry's locations. These businesses are particularly important in urban and rural areas of the country that might not have many large businesses. In these locations, the convenience store not only serves as the place to get fuel but is often the grocery store and center of a community.

We recognize the challenges that a changing climate presents to all of us – particularly those in the transportation sector. The retail fuel industry is an indispensable part of lowering the carbon footprint of transportation energy in the United States. On behalf of this diverse and forward-thinking industry, we are eager to work with you, the Environmental Protection Agency (EPA), and states to help improve the environmental characteristics of transportation energy in the United States.

One part of addressing carbon emissions in the transportation sector is electric vehicles (EVs). Our industry has made significant investments in EV charging to serve the motoring public operating

EVs.[1] This is a key part of the future of the industry. To be successful, retailers must be attuned to consumer preferences and desires, and our industry believes that over the coming years, more of our consumers will demand electricity as a fuel. We want to be able to sell consumers whatever fuel they want long into the future. This is especially important for the smaller, family businesses who are looking at generational succession and transitions.

While we are supporters of the development of EVs and EV chargers, we have concerns with the approach taken by the EPA in its tailpipe rules. By focusing on tailpipe emissions rather than overall, lifecycle emissions and choosing EVs as the preferred technology rather than other technologies – including internal combustion engines and potentially additional innovations in engines or liquid fuels – the EPA has reached conclusions that are not as effective as they should be for the economy or for the environment.

The same is true for California's advanced clean cars regulations. Those regulations mandate EV technology rather than creating technology neutral performance standards. Having one state set standards relating to greenhouse gas emissions and global climate change does not make sense. While California has a special status in the Clean Air Act to deal with criteria pollutants that interact with California's air quality to create special challenges, climate change is a global problem. We need a coherent federal policy in order to most effectively address climate change. Having individual states pull policy in less effective directions through a focus on a single technology (EVs) and a single source of emissions (vehicle tailpipes) risks undermining a federal approach. We need policies in place that take a clear-eyed look at all emissions related to the transportation sector and that lead to emissions reductions from all vehicle technologies.[2] Only by allowing different technologies to compete on emissions reductions as well as on their appeal to consumers will we get the best environmental and economic outcomes that we can achieve.

For these and other reasons as set forth below in this statement, NACS supports the legislation before the Committee today which would override the technology-specific mandates in EPA's proposed rule and in California's regulations.

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[1] See "Circle K expands fast EV charging footprint," Liz Dominguez, RIS News (May 5, 2023) (available at Circle K Expands Fast EV Charging Footprint | RIS News); "7Charge is the 7-Eleven of the future: Ambitious EV fast-charging network and new app," Peter Johnson, Electrek (March 16, 2023) (available at 7-Eleven reveals 7Charge EV fast- charging network and app (electrek.co)); "How Sheetz partnered with Tesla and brought EV charging to rural America," Bloomberg (July 14, 2022) (available at Sheetz, Tesla Teamed Up to Help You to Take an Electric Car Road Trip (bloomberg.com)); "GM, travel operator Pilot to develop EV charging network," David Shepardson, Reuters (July 14, 2022) (available at GM, travel operator Pilot to develop EV charging network | Reuters); "Wawa partners with EVgo to expand electric vehicle charging network," Convenience Store News (March 10, 2022) (available at Wawa Partners With EVgo to Expand Electric Vehicle Charging Network | Convenience Store News (csnews.com)); "Love's Travel Stops and Electrify America add road-trip charging waypoints," Stephen Edelstein, Green Car Reports (Aug. 19, 2020) (available at Love's Travel Stops and Electrify America add road-trip charging waypoints (greencarreports.com)).

[2] It is worth noting that EPA's approach in its 2021 rule, which it has replicated in many ways in the proposed rules,are the subject of legal dispute. Similarly, the waiver allowing California's first advanced clean cars regulation is the subject of litigation. Nothing in this testimony takes a position regarding the current legal disputes or suggests that EPA has the legal authority under the Clean Air Act to take all the actions we suggest that could be beneficial to the economy and environment or to grant a waiver for California. This testimony is geared to discussing the best policy approaches whether those are achieved through regulation, legislation, or a combination of them.

I. Principles to Guide Policy to Reduce Transportation Emissions

As the Committee examines tailpipe emissions regulations and proposals from EPA and California, we urge you to consider the following policy principles that have been developed by our association and guide our view of these issues. The most expeditious and economical way to achieve environmental advancements in transportation energy technology is through market-oriented, consumer-focused policies that encourage our membership to offer more alternatives. Fuel retailers have demonstrated in recent years that they are prepared to invest in any transportation energy technology that their customers desire. With the right alignment of policy incentives, the private sector is best equipped to facilitate a faster, more widespread, and cost-effective transition to alternatives – including electricity – in the coming years.

As discussed further below, policies that adhere to the following principles will create new jobs, accelerate the deployment of advanced alternative fuel infrastructure and vehicles, benefit consumers through a competitive and robust marketplace and drive massive economic investment and improvements in air quality:

- Science should be the foundation for transportation climate policies.
- Establish performance goals without mandating specific technologies to allow for the benefits of innovation and technology development.
- Develop competitive market incentives to ensure a level playing field and provide long-term consumer benefits.
- Harness existing infrastructure to help commercialize new technology, maximize diverse investments, and achieve near-term and long-term emission reduction goals.
- Set consistent, uniform national policy so that (i) the market has certainty to help it invest, and (ii) state policies do not create inconsistent or counterproductive measures.
- Ensure fair treatment so that all households are not forced to subsidize alternative energy users.

<u>Science should be the foundation for transportation climate policies</u>

Any effort to improve transportation energy's emissions characteristics requires an accurate accounting of the lifecycle carbon intensity associated with particular fuels and technologies. This analysis should include everything from acquisition of natural resources, engine and battery manufacturing, tailpipe emissions, and vehicle end-of-life consequences. It should also be regularly updated so that policy is nimble enough to adjust to efforts to innovate and improve the environmental characteristics of different alternatives. Additionally, every sector of the economy should assume a burden of reducing carbon emissions that is proportionate to its share of nationwide emissions. Focusing more on one source of emissions rather than others could lead to policies that are less effective than they would be if the entire lifecycle of a vehicle is taken into account.

Policy should set performance goals without mandating specific technologies to allow for the benefits of innovation and technology development

While it may be tempting to prematurely pick winners and losers from an energy technology standpoint, sound policy must be grounded in science and recognize that the state of technology can change rapidly. Incentives to invest in alternative fuel technologies should be tied to those technologies' lifecycle environmental attributes rather than the underlying technology itself.

No one solution will decarbonize transportation energy. Policies should incentivize multiple technologies. What policymakers think is the best solution today may be surpassed by subsequent ingenuity and innovation. Sound policy should not stifle innovation by mandating specific fuel solutions. Instead, policy should set performance goals and let the market – guided by consumers – innovate to find the best way to meet those goals.

Retailers' experience is valuable in this respect because they bring a technology-agnostic perspective with an underlying attention and loyalty to consumer preferences and low prices.

Develop competitive market incentives to ensure a level playing field and provide long-term consumer benefits

Fuel retailers today are best positioned to provide alternative sources of transportation energy because they have a keen understanding of consumer preferences and tendencies. Refueling stations are strategically located throughout the country where refueling demand is greatest, competing with one another on price, speed, and quality of service. Those sites include disability accessible restrooms and parking lots, food and beverage options, vehicle service and repair centers, and even showers and other amenities for professional drivers. Consumers demand all of this, regardless of the type of fuel their vehicle consumes.

Existing alternative fuel incentives – such as the Renewable Fuel Standard and biofuel blending and alternative fuel infrastructure tax credits – have allowed retailers to offer less expensive, lower carbon fuels to their customers, while also supporting investments in renewable fuel production. Regardless of how one may feel about ethanol and biodiesel, the incentives Congress established have caused the displacement of significant volumes of petroleum-based fuel with renewable fuels since 2005.

These benefits can be replicated for new technologies if policymakers adopt a market-oriented and consumer-focused perspective. Policy mechanisms worth considering include:

- Ensuring credit regimes and/or tax incentives make alternative fuel less expensive for the end user, thereby providing a stable economic case for upstream investment.

- Permitting all EV charging station owners to generate a profit by selling electricity to EV owners without being subject to regulation as a utility. This allowance is essential if fuel retailers are to have any incentive to invest in EV charging technology.

- Adopting uniform retail pricing measurements (e.g., dollars per kilowatt-hour) and requirements for consumer-friendly price disclosures.

Conversely, policies that at first blush appear to be quick and easy solutions tend to have the unintended consequence of undermining retailers' incentives to invest capital in alternative fuels. This inevitably hinders the growth and expansion of alternative transportation energy. For example, forcing ratepayers to underwrite electric utilities' investment in EV chargers or to subsidize the cost of electricity that charges electric vehicles actually depresses the development of charging infrastructure.

Where this occurs, the utilities are operating in a guaranteed rate of return environment without putting a single dollar at risk. Retailers cannot compete with electric utilities in this environment. While there is good reason for ratepayers underwriting the cost of the grid and other upgrades, there is no public policy rationale why utilities should be given a leg up over private actors who wish to enter the market for chargers that consumers use to power their vehicles. Utilities' ongoing pursuit of this uncompetitive arrangement is a large deterrent to fuel retailers investing in EV charging infrastructure.

The electricity marketplace also needs modernization to create a competitive playing field that attracts private investment that would allow it to adapt to transportation needs. Utilities charge commercial users of electricity "demand" charges on their monthly bills based on the highest rate at which they pull power at a particular time. EV fast charging stations require a large amount of power to be dispensed quickly and result in large demand charges that cannot be passed onto individual drivers. But utilities don't have to pay demand charges themselves. A prohibition on such practices and other ways in which utilities favor their own EV charging stations on pricing is the only way to provide a level playing field and ensure competitive pricing for individual consumers. If utilities are able to use these practices to monopolize EV charging in their areas, they will be able to increase prices and overcharge consumers for the next generation. That classic monopolization behavior should be stopped before it gains too much momentum.

A few states still prohibit the sale of electricity (i.e., fuel) to individual consumers except by price-regulated utilities.[3] This discourages additional deployment of such infrastructure. EV charging station owners must be permitted to generate a profit by selling electricity to EV drivers if they are to have any incentive to invest in the technology.

EV charging infrastructure should not be built at interstate rest areas. Not only would this discourage off-highway fuel retailers from investing in charging infrastructure, but it would signal to prospective EV drivers that they will need to refuel at often desolate, poorly maintained state-run rest areas rather than the off-highway travel centers, convenience and fuel retailers with all of the amenities that drivers have come to expect.

<u>Harness existing infrastructure to help commercialize new technology, maximize diverse investments, and achieve near-term and long-term emission reduction goals</u>.

So-called "range anxiety" is one of the leading reasons why consumers hesitate to purchase EVs. "Range anxiety" does not exist for drivers of internal combustion engine vehicles. Once we get to the point where consumers can "fill-up" their EVs at the local gas station or convenience store, then "range anxiety" will be over for EVs. Seeing the price of electricity on signs at gas stations right beside the prices of unleaded gasoline and diesel fuel will make clear to all Americans that they can purchase any vehicle they want without any concern about changing their driving habits.

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[3] As of this writing, these states include Montana, Nebraska, Tennessee, and Wisconsin.

To get there, we should leverage existing infrastructure. By harnessing existing infrastructure – including removing hurdles to bringing alternative fuels to market – customers will more seamlessly gravitate to new types of fuels and vehicles. American companies have spent more than sixty years building out a refueling infrastructure system that optimizes logistics and maximizes customer benefits. Deployment of new technology that complements this infrastructure will (all else being equal) be less expensive and thus more likely to generate consumer loyalty.

In just the past decade, there has been extraordinary growth in consumption of biofuels such as ethanol and biodiesel, as well as other low carbon fuels such as renewable natural gas, compressed natural gas, renewable diesel, and biobutanol. These are all liquid fuels that are mostly compatible with existing infrastructure that was originally developed for hydrocarbons. With all of these fuels, industry has responded to policy signals by allocating capital toward bringing the fuels to market. Retailers then sell the fuels to consumers for less money than the fuels that were being displaced. This has created enormous environmental benefits in a relatively short period of time. We can build upon current policies to leverage existing infrastructure and achieve meaningful environmental benefits as we work toward reaching our longer-term aspirations.

Set consistent, uniform national policy so that (i) the market has certainty to help it invest and (ii) state policies do not create inconsistent or counterproductive incentives

Federal policy should be designed to lower the cost of alternative fuels to make those sources of transportation energy more competitive with petroleum-based fuels. This is the only way to ensure that consumers will gravitate toward low carbon technologies. Although some state incentive programs adopt this approach, others have vacillated between different approaches in a way that does not allow private market participants to plan long-term investments in alternatives. Such inconsistent policies are ultimately self-defeating, and that approach should be avoided.

Ensure fair treatment so that all households are not forced to subsidize alternative energy users

Fundamental tenets of fairness dictate that users of transportation energy, including alternative energy sources, pay for that energy and related infrastructure. Unfortunately, this is not occurring today in two ways:

First, when utilities rate-base their EV infrastructure investments, it raises the monthly utility bills for all of a particular rate class, even though the benefits are confined to a small group of users. It is patently unfair and inequitable for policymakers to force most households to subsidize the refueling costs for EV drivers. Vehicle owners should pay the costs of powering their own vehicles in order to create a market system that will keep energy prices down and avoid regressive charges.

Second, it is imperative that highway infrastructure funding comes from all highway users, and not just those that rely on a particular technology. Any user fee to generate increased revenue for highways must capture all vehicles that use the roads.

Addressing transportation emissions and their contribution to climate change, we should all be aware that there are no perfect answers. All vehicles have emissions associated with their manufacture and use. Even "zero emission vehicles" have emissions from their operation because the production of the energy that they need to operate – such as electricity or hydrogen – produces emissions. In order to understand the policy benefits and costs of any action in this area, we need to examine the full, life-cycle emissions of all of these options.

II. EPA's Proposed Tailpipe Rules

We have concerns that EPA's tailpipe rules put a thumb on the scale of EV technology rather than harnessing the benefits of competition among different current and potential future vehicle technologies.[4] EPA estimates that its rules will result in 60 percent of new light duty vehicle sales being electric in 2030 and 67 percent of new sales being electric in 2032. In fact, those appear to be the only realistic ways for the regulated community to comply with EPA's rules.

EVs are the exclusive road to compliance with EPA's proposal in part because EPA looks more clearly at tailpipe emissions rather than the full lifecycle emissions from these vehicles. That is a flawed approach. The energy needed to power EVs, electricity, has emissions associated with it. The construction of EVs, particularly the batteries, also have associated emissions. EPA should fully account for all of these emissions. Such a full accounting of the relative advantages and disadvantages of the different vehicle technologies and the energy used to power them would lead to different policy choices than EPA has made in its proposal.

Prior to its current rules, EPA set tailpipe standards that individual vehicles would need to meet in order to be sold. The agency's most recent proposals, however, depart from this traditional approach by setting rules for average across vehicle fleets. That is the mechanism used to move those fleets from ones that primarily consist of internal combustion engine vehicles to ones that primarily consist of electric vehicles. This approach tells automakers what types of vehicles to make and sell rather than ensuring the vehicles they sell meet a certain standard.

Engineering resources have already moved decidedly away from internal combustion engine vehicle work toward work on EVs. Some of that movement is market-driven, but EPA's rule risks zeroing out new innovations in emissions reductions for internal combustion engine vehicles. Because there is no way for manufacturers to comply based on internal combustion engine vehicles, they would not see a return from making new investments in developing that technology. Finalizing regulations that push people to that conclusion would be a mistake that would risk all of us missing out on potentially large emissions reductions.

EPA's proposals for heavy duty vehicles raise similar concerns. EPA's proposal would result in electrifying 50 percent of vocational trucks, 35 percent of short-haul tractors, and 25 percent of long-haul tractors by 2032. But heavy-duty trucks are far behind light duty vehicles in the move to electrification. The challenges to electrifying the sector are enormous. Heavy duty trucks cannot use light duty EV charging infrastructure and require two 8,000-pound batteries to operate. It could take 10 hours to charge those trucks and that would provide them with only a few hundred miles of range.[5] By contrast, a diesel truck can fuel in about 15 minutes and get 1,200 miles of range. The implications for the cost and efficiency of moving goods by truck based on those figures would create large cost increases for virtually all goods sold in the United States and challenge supply chains needed to get those goods to market at all.

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[4] As noted previously, there is existing litigation challenging EPA's statutory authority to factor EVs into these regulations and to use fleetwide averaging rather than requiring minimum standards for all vehicles in its rule. It is beyond the scope of this testimony to analyze those legal questions.

[5] "Trucking industry worries US EPA put 'cart before the horse' with emissions proposal," Jasmin Melvin, S&P Global (April 19, 2023) (available at Trucking industry worries US EPA put 'cart before the horse' with emissionsproposal | S&P Global Commodity Insights (spglobal.com)).

III. Challenges for EPA's Proposed Tailpipe Rules

A. Consumers and the Market

EPA's proposed rules would force the market toward EVs regardless of how the market develops. Fighting market forces, and consumer sentiment, tends to be a losing battle. Our industry knows this well. With 165 million transactions each day, our industry stays very close to the pulse of American consumers. The industry must and does sell things that consumers want to buy. That is the only way to stay in business.

Consumers are not yet ready to buy EVs on the scale that EPA proposes. During the first quarter of this year, EVs were 6.91 percent of new car sales across the nation.[6] That put EVs on pace to sell about 1 million new vehicles in 2023. While that is a rapid increase in sales from past years, EVs are a long way away from rivaling internal combustion engine vehicle sales. For example, in 2022 alone, just three vehicles – the Ford F150, Dodge RAM, and Chevy Silverado – sold a combined 1.5 million new vehicles. There are wildly differing estimates on how quickly EV sales will increase. S&P Global Mobility estimates that by 2030, EVs will be 40 percent of new vehicle sales. The Energy Information Administration, on the other hand, estimates that EVs will be 17 percent of new vehicle sales by 2030. McKinsey has the highest estimate and projects that EVs will be 48 percent of new vehicle sales by 2030.

Given these varying estimates – all from highly respected sources – we should be cautious about how much we know about consumers' willingness to purchase, and manufacturers' ability to deliver, EVs at the rates required by EPA's proposed rules. EPA writing rules does not mean that challenges related to supply chains for making the vehicles or consumer sentiment will change. We need to deal with those realities.

Even without the supply chain and consumer preference challenges, combustion engines will not disappear from the U.S. landscape in the foreseeable future. For example, no matter how much we may like EVs, internal combustion engine vehicles stay on the road for a long time. There were 285 million cars in operation in the United States at the end of 2022.[7] About 3 million of those vehicles are electric.[8] And, there are more than double the number of used car sales in the United States each year than there are new car sales – more than 43 million used cars were sold in 2021 compared to 15 million-plus new cars.[9] The average age of a car in operation in the United States is 12.2 years.[10] Of course, that is just the average of those currently in operation. With sales of used cars, many vehicles remain in operation for years beyond that time period. The average full life of a vehicle in the United States is about 16 years – and that average means some vehicles are lasting more than 20 years.[11] Given those realities, we need to get efficiency gains and emissions reductions from all vehicle technologies. Let's look at it another way. As noted previously, McKinsey estimates that by 2030, 48 percent of new vehicle sales in the United

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[6] Data from WardsIntelligence.

[7] "Number of vehicles in operation in the United States between 1st quarter 2018 and 4th quarter 2022,"(available at U.S.: vehicles in operation 2022 | Statista).

[8] "How Many Electric Cars Are There in the United States? We Found Out," Georgette Kilgore (March 20, 2023)(available at How Many Electric Cars Are There in the United States? We Found Out (8billiontrees.com)).

[9] "U.S. new and used car sales 2010-2021," Mathilde Carlier (July 22, 2022) (available at https://www.statista.com/statistics/183713/value-of-us-passenger-cas-sales-and-leases-since-1990/).

[10] S&P Global Mobility, "Average Age of Vehicles in the US Increases to 12.2 years," (Apr. 17, 2023) (available at https://www.spglobal.com/mobility/en/research-analysis/average-age-of-vehicles-in-the-us-increases-to-122- years.html).

[11] Stillwater Associates, Oak Ridge National Laboratory.

States will be EVs. Given the rate of turnover of the fleet, the number of used vehicle sales and other factors, they estimate that at that point in 2030, EVs will constitute just 17 percent of the vehicles in operation around the country. Importantly, they also looked at what those numbers will mean for gasoline demand. Based on those figures and the fact that many ofthe internal combustion engine vehicles on the road at that time will be less efficient than the vehicles that the new EVs replaced, McKinsey concludes that the reduction in gasoline demand based on the increased number of EVs on the road will be only 4 percent.

Simply put, that 4 percent reduction in gasoline demand alone is not a complete solution to our climate change challenges in the transportation sector. We need to focus on the entire picture includingall vehicle technologies and liquid motor fuels as well as electricity.

B. Regional Differences

Regional differences add to these challenges. Today, EVs are very concentrated based on geography. Just 15 states account for more than 81 percent of all EVs on the road today and by 2030 the top 15 states are still projected to account for more than 75 percent of all EVs.[12]

Weather differences contribute to this picture. EVs lose significant range in cold weather. Consumer Reports has found that driving short trips with frequent stops in cold weather can reduce EV range by as much as 50 percent.[13] States with large rural areas can also present challenges for EVs today. Getting from one town to the next in some areas of the country can require driving more than one hundred miles. Current infrastructure limitations in some of those areas can affect drivers' interest in EVs. Some of the regional concentration of EVs might actually be helpful from an environmental perspective. The state in which a vehicle is operated can dramatically change the relative carbon emissions results of EVs compared to internal combustion engine vehicles. That is because the emissions picture of electricity generation varies quite a bit across the nation. A 2022 report from The Fuels Institute analyzing these differences is instructive.[14] The report noted that there are higher emissions associated with manufacturing an electric vehicle than an internal combustion engine vehicle due to the process of manufacturing the batteries. In states with relatively low carbon profiles for electricity generation, however, electric vehicles started to show an emissions advantage over internal combustion engine vehicles after about 19,000 miles of driving.[15] Over the lifetime of the vehicles, the emissions advantages of electric vehicles operated in those states were quite significant. In general, many western and northeastern states fell into this category based on the profile of electricity generation in those states which tracks to some extent the states that account for larger numbers of EVs than most other states.

In states with higher carbon emissions from electricity generation, it took about 82,000 miles of operation before EVs showed any life-cycle carbon emissions advantages over internal combustion engine vehicles.[16] And, over a 200,000-mile lifetime of the vehicles in those states, the electric vehicles showed emission advantages that were relatively modest. In fact, in those states, hybrid electric vehicles

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[12] S&P Global Mobility (as of July 2021)
[13] "How Temperature Affects Electric Vehicle Range," Jeff S. Bartlett and Gabe Shenhar, Consumer Reports (Aug. 22, 2022) (available at How Temperature Affects Electric Vehicle Range - Consumer Reports).
[14] "Life Cycle Analysis Comparison: Electric and Internal Combustion Engine Vehicles," The Fuels Institute (Jan. 2022)(available at FI_Report_Lifecycle_FINAL.pdf (fuelsinstitute.org)).
[15] "Life Cycle Analysis Comparison" at 42.
[16] Id. at 43.

showed a greater carbon emissions advantage over 200,000 miles relative to fully electric vehicles than those fully electric vehicles did relative to internal combustion engines. Examples of the states used in that analysis were Iowa, Texas, and Tennessee.

The report also looked at states that generated very high carbon emissions to produce electricity. In those states, such as West Virginia, internal combustion engine vehicles showed a decided carbon emissions advantage relative to electric vehicles throughout the entire 200,000-mile life of the vehicles.[17] Here again, hybrid electric vehicles had a better emissions profile than either fully electric vehicles or internal combustion engines.

None of this should be read to diminish the fact that, overall, there are emissions advantages to EVs relative to other technologies on average. But, we should recognize that that is not true everywhere across the nation. EPA's rules envision a homogenized national system relying on one technology. While a national approach is necessary and called for by the law, that doesn't mean the same technology should be pushed everywhere and in every situation. In order to get the best results on emissions and fight climate change, we should ensure that policies are calculated to allow for and take advantage of all vehicle technologies and get them competing with one another to make improvements that will yield additional advantages to emissions and the climate. Focusing more on one technology (EVs) or source of emissions (the tailpipe) will have differential and negative impacts in some locations compared to others and lead to demonstrably worse results than policies that incorporate and contemplate the use of all technologies and take account of full lifecycle emissions.

C. Electricity Market Challenges

One of the most-recognized factors limiting consumer adoption of EVs is referred to as "range anxiety." That may or may not be the best way to describe it, but many consumers have questions about whether they will be able to conveniently charge their vehicles when, where, and in a time period that works for their lives if they drive an EV. While some argue that should not be a large concern because about 80 percent of EV charging takes place at home, that snapshot figure is misleading and does not take into account growth in the population of consumers who may want to consider EVs.

While the Department of Energy (DOE) reports that 63 percent of housing units have a garage or carport,[18] only 65.9 percent of Americans own their home.[19] The willingness and ability of renters to install charging equipment in a garage is questionable. In addition, many of the garages in DOE's figure are associated with multi-family housing. Those garages often do not have individual spaces for every vehicle driven by occupants of those buildings and many of them will not be willing to spend the funds to have large percentages of those vehicle spaces equipped with chargers.

It is also worth noting that many garages are not available for vehicle charging. Different surveys of homeowners have found that large numbers of people (37 percent and 75 percent in different surveys) use their garages for storage and do not park a single car in that space.[20] Those realities also do not account for all the ways in which Americans use their vehicles. Many Americans drive for vacations, work trips, and road trips of all kinds. And, many of them do not want to have a car that works for them day-to-day

[17] Id. at 43.
[18] Fact #958: January 2, 2017 Sixty-three percent of all Housing Units have a Garage or Carport | Department ofEnergy
[19] U.S. homeownership rate 2022 | Statista
[20] "Why a Third of Garages Don't House Cars," Diana Ionescu, Planetizen News (May 5, 2022) (available at Why a Third of Private Garages Don't House Cars | Planetizen News)

but limits their ability to make periodic longer trips.

The bottom line is that we need more charging on-the-go. Our industry is providing that, but the infrastructure is not yet adequate and there are major impediments to it fully developing. One thing, however, is clear: drivers of internal combustion engine vehicles do not hesitate to purchase those vehicles due to "range anxiety." They refuel their vehicles on-the-go and have confidence that they can drive to virtually any corner of the nation and have access to the transportation energy they need. Our industry has addressed that issue for most drivers and can do so for EV drivers. When EV drivers routinely see price signs on the street that include not just pricing for gasoline and diesel fuel but also pricing for electricity, the "range anxiety" issue will be solved.

To reach that goal, however, we need change. First and foremost, electricity markets need to change. We need abundant private market investment in EV charging infrastructure to serve EV drivers. That will only happen if businesses are able to make a return on those investments.

Today, the business case for investing in EV charging does not exist because of the electricity markets. Electricity markets are dominated by local monopoly providers. These electric utilities routinelyimpose something called a demand charge on commercial users of electricity. A demand charge is an amount added to a monthly utility bill that is not based on the amount of electricity used by that business. Instead, the charge typically is based on the highest rate of usage the business has during the two 15-minute periods in a month in which the business draws electricity from the grid at the highest pace. EV fast chargers must draw a lot of electricity from the grid quickly in order to charge a vehicle quickly. In fact, having just one fast charger in use essentially doubles the amount of electricity that a typical convenience store with fuel pumps uses at one time. If two fast chargers operate at the same time, the impact is even more dramatic. This can add thousands of dollars to a convenience store's monthly utility bill that it cannot possibly recover from drivers charging their cars.

The inability to recover those huge demand charges is not just because the amounts are too large, but also because some utilities own and operate chargers themselves – and they do not impose demand charges on themselves. The combination of demand charges and utility operation of fast chargers amounts to an unfair business practice that threatens to block many investments in EV charging infrastructure.

Businesses in our industry are making these investments today, but they are struggling to make a profitable return on those investments. Instead, they are using the opportunity to learn about the market – including how serving EV customers will impact in-store sales of food and other items. And, in part, these are bets on the future in the hopes that policies related to electricity sales to vehicles will change in time to make these investments worthwhile. No one should assume that the presence of EV chargers at these locations today means that market problems have been solved. We have a long way to go to ensure there is a business case for these investments such that the infrastructure can be built to the scale that is needed to support future EV drivers.

A second, related problem is that some utilities are charging all of their electricity customers more on their monthly bills in order to pay for the installation and operation of EV chargers. Private businesses do not have a guaranteed, uncompetitive pool of funds at hand to use to pay these expenses. This creates an unlevel playing field and keeps private investment on the sidelines. It also saddles utility customers with added costs that go to others in their community who use it to fuel their EVs. There are real equity issues in play here given the relative income levels of EV drivers today.

The last Congress made an effort to address these problems in the Infrastructure Investment and Jobs Act (IIJA). Section 40431 of that law requires states to consider electricity rate changes to incentivize private investment in EV charging infrastructure. Dealing with the problems associated with demand charges and the rate-basing of the cost of EV chargers would be needed to fulfill that part of the IIJA. Unfortunately, this has not led to changes that are necessary to facilitate more investment and development of this infrastructure. More is needed.

Georgia recently passed a new law[21] that can provide a blueprint for dealing with these challenges. It would limit utility rate-basing of the cost of EV charging stations to allow the private market to invest. But, if there are truly markets that are underserved by the private sector, it would allow utilities to meet those needs through rate-basing. The Georgia law implemented the recommendations of Georgia's Joint Legislative Study Committee on the Electrification of Transportation.

We should be clear that utilities have an important role to play in the development of EV charging infrastructure. They will need large investments in generation, transmission and related infrastructure to help ensure that more vehicles can be electric while also supporting the many other growing demands on electricity capacity. Funds and focus are needed on the development of all of that electricity infrastructure to support the full range of uses of electricity. The one thing that should be a matter of market competition, however, are the EV chargers themselves. If we fix problems so that the chargers are a point of competition, utilities will be able to focus on their imperatives, and what they do best, while market forces will help EV drivers get the best competitive pricing and services possible – just like drivers of internal combustion engines have enjoyed for decades.

Another, related impediment to EV charging is maintenance of those chargers. A number of studies have found that large percentages of the chargers deployed around the nation are inoperable at any given time.[22] A major reason for this is because there is no business case for operating EV chargers.

When the electricity market problems noted above are addressed and private market investors are able to make a profit selling drivers electricity, the maintenance problem largely will be solved. Businesses simply will not allow equipment that makes them money to stay broken for long. Unfortunately, utilities and businesses that do not make a profit on EV chargers do not have the financial incentives to ensure they are operating. EV drivers are facing challenges finding chargers that work as a result.

D. Electricity Grid Challenges

Large increases in the numbers of EVs will present challenges for the generation and transmission of electricity. How much of a challenge this will present varies significantly based on who isdoing the analysis. One estimate, from the Electric Power Research Institute (EPRI), is that EVs will require 8 to 13 percent more electricity in 2030 than we had in 2021.[23] EPRI also projects the need for a 10 percent

[21] GA Senate bill 146.
[22] See "Why America's EV chargers keep breaking," David Ferris, Politico (April 12, 2023) (available at Why America's EV chargers keep breaking - POLITICO); "EV charging stations in the US are plagued by reliability issues: study," Iulian Dnistran, InsideEVs (Feb. 13, 2023) (available at EV Charging Stations In The US Are Plagued By Reliability Issues: Study (insideevs.com)); "The EV charging experience: Why it's broken and how to fix it," Jon Asmussen, the EV Report (Dec. 29, 2022) (available at The EV Charging Experience: Why It's Broken and How to FixIt - The EV Report).
[23] "Can the Power Grid Handle a Wave of New Electric Vehicles," Bart Ziegler, Wall Street Journal (Feb. 5,2022)(available at Can the Power Grid Handle a Wave of New Electric Vehicles? - WSJ).

expansion of high voltage transmission capacity to get that power to the places that need to use it. But EPRI's analysis assumed far fewer EVs on the road than does EPA's proposed rules. A number of other studies include other estimates of the need for more generation and transmission of electricity, but we are not aware of any of them to date that have contemplated the full impact of EPA's proposed rules. Having 67 percent of new car sales EVs by 2032 is an order of magnitude more than most aggressive estimates assumed prior to publication of EPA's proposal. This puts us in new territory and we would be well advised to study it carefully.

In addition, many studies of the grid in this context assume large numbers of EV drivers charging at off-peak hours – through a combination of choice and policy changes. But there is reason to doubt whether this can happen. As noted, home charging is likely to be a much smaller part of the picture of charging EVs in the future than it is today. And, consumer behavior is notoriously difficult to change. The evening rush hour is a time of peak energy usage today. We don't see a policy change that is going to convince drivers that need to charge their cars to get home from work that they should wait and charge them at another time. If people were amenable to waiting to drive home, traffic in many cities would have been sufficient to change their behavior already.

Many of the studies of the grid challenges presented by EVs have not taken into account other ways in which the nation is adding to those challenges. For example, the Department of Energy estimates that a large data center requires the same amount of power as about 80,000 households.[24] Data centers already consume about 3 percent of the world's electricity,[25] and the number of those centers is likely to grow. U.S. businesses and consumers are using data and connected devices (including EVs) more than in the past and that will increase in the future. These facilities will require more power.

We are also expanding electricity use in other ways. Many places are pushing changes that move homes and businesses away from heat pumps and gas stoves toward electric heat and appliances. These changes will increase the need for generating capacity and transmission.

E. Other Challenges

EPA's proposals fail to provide a vision to meet a number of other challenges as well. For example, EV batteries require large amounts of rare earth minerals that are not produced in sufficient quantities in the United States to satisfy current, let alone future, demand. According to the Congressional Research Service, manufacturing EV batteries depends "on five critical minerals whose domestic supply is potentially at risk for disruption: lithium, cobalt, manganese, nickel, and graphite."[26] Manganese and graphite are not currently mined in the United States at all.[27] Ensuring that sufficient quantities of these minerals are available to meet the increased production needs contemplated by EPA's proposed rules will present ongoing challenges.

EVs also require far more microchips than internal combustion engine vehicles – about twice as many.[28] The nation has already had problems meeting the microchip needs of manufacturing vehicles

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[24] "Understanding Data Center Energy Consumption," Josh Mahan, C&C Technology Group (April 20, 2023) (available at Understanding Data Center Energy Consumption - C&C Technology Group (cc-techgroup.com)).
[25] Id.
[26] "Critical Minerals in Electric Vehicle Batteries," Congressional Research Service (Aug. 29, 2022) (available at R47227 (congress.gov)).
[27] Id.
[28] "How many chips are in our cars?" Electronics Sourcing (May 4, 2022) (available at How many chips are in our cars? | Latest

during the past couple of years. Unless production of those chips increases substantially, a large upsurge in electric vehicle production could put new strains on those supply chains.

Road maintenance presents another obstacle to EV use. EVs are much heavier than similar internal combustion engine vehicles due to the weight of their batteries. EV trucks in particular will take a large toll on U.S. roads. Currently, however, highway funding comes from motor fuel taxes. There is no policy plan to make up for shortfalls in highway funding if EVs dramatically increase in market share. Such a plan is needed.

IV. Challenges for California's Vehicle Mandate Rules

California's advanced clean cars regulations face similar challenges. These regulations require increasing numbers of "zero emission vehicles." The first set of regulations took effect in California last year and by their terms apply through 2025. The second set of regulations covers the years 2026 through 2035. By 2035, the regulations call for 100% of new vehicles sold in the state to be "zero emission." As noted above, however, the term "zero emission" is a misnomer. The electricity (or hydrogen) used to fuel the vehicles and the extensive work needed to create batteries for the vehicles all create significant emissions. Those emissions should not be ignored, and other technologies should have the opportunity to improve performance such that they can rival or exceed the emissions properties of EVs and similar technologies.

California's rules assume what will happen with vehicle and energy technology innovation in the future. The most effective climate policies need not and should not do that. None of us can know for certain what innovation might take place that could impact the effectiveness of these different technologies. That is why an approach emphasizing performance standards in light of the full picture of all of the emissions associated with the different technologies would be the most effective way to deal with this area of regulation.

California's regulatory approach implicates all of the policy challenges noted above with respect to EPA's rules. But, the state's rules also raise other questions. To understand this, it helps to recognize the reasoning behind California's unique treatment in the Clean Air Act. California's geography creates problems with respect to smog and criteria pollutants. The combination of air quality challenges are unique to the state. Giving California the space to make policy choices with respect to those specific air quality challenges makes sense.

But that reasoning does not apply to climate change. Indeed, greenhouse gas emissions and climate change create global challenges that are divorced from the unique air quality issues in California. We need to work together as a nation, and with other nations, to tackle those challenges in a coherent way. Viewed through that lens, we should focus on federal policy choices and not individual states making policy for the nation. As noted above, forcing one technology choice might well show positive emissions results in one state while leading to negative emissions results in other states – not to mention that ignoring improvements with other technologies may result in missed emissions reduction opportunities.

V. Potential Gains from Combustion Engines and Liquid Fuels

As noted previously, one of the concerns with EPA's proposed tailpipe rules is that it will stunt

Articles News (electronics-sourcing.com)).

additional gains that could be made in curbing emissions from internal combustion engine vehicles.

Those gains could come both from advances in vehicle technology and advances in liquid motor fuels. Specifically, higher octane fuels that use more renewables can help improve engine efficiency and reduce emissions. These and other improvements could be integral components of a comprehensive strategy to reduce lifecycle transportation emissions, but EPA's proposals discourage any pursuit of these types of innovations in vehicle engines and in liquid fuels because compliance can only be achieved by abandoning those technologies in favor of EVs.

One straightforward path to improvement is presented by increased use of renewable fuels. Renewable diesel fuel, biodiesel, ethanol, and other renewables have lower carbon intensities and emissions than the petroleum products they can displace in the liquid fuel supply. Estimates are that renewable diesel[29] reduces carbon intensity by 65 percent compared to petroleum-based diesel,[30] and ethanol has 44 to 52 percent lower greenhouse gas emissions than gasoline.[31] Other advanced fuels such as renewable gasoline could produce significant emissions improvements as could changes in the production processes for traditional petroleum-based fuels.

These changes could improve the emissions profiles not just of new vehicles but of existing vehicles as well. Those vehicles will be on the road for many years and we should not ignore the chances we have to improve their emissions. Just like a disproportionate focus on tailpipe emissions is limiting, a focus on new vehicles is too narrow to get the best outcomes.

The industry has demonstrated consistent reductions in emissions and gains in efficiency through focus on the internal combustion engine. DOE's Office of Energy Efficiency and Renewable Energy has estimated that over the past 30 years, advances in internal combustion engines has reduced emissions of criteria pollutants by more than 99 percent.[32] Since model year 2004, carbon dioxide emissions have fallen 25 percent and improved in fourteen of seventeen years while fuel efficiency has increased by 32 percent.[33] Similarly, data from the Bureau of Transportation Statistics from 2011 to 2018 shows that engine efficiency has reduced light duty fuel consumption.[34] While light duty vehicle miles traveled increased by 9 percent during that time period, fuel consumption only grew 3.65 percent. The miles these vehicles were able to drive per gallon increased by about 5 percent. Given that McKinsey projects the increase in EV sales through 2030 will only reduce gasoline consumption by 4 percent, the improvements we have already seen from internal combustion engines are eye-opening. We simply cannot afford to be dismissive of the benefits that additional improvements in internal combustion engines and liquid fuels may provide if we give those in the industry a reason to invest in advances in the efficiency of those technologies.

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[29] It is worth noting that other government policy, specifically, tax credits for sustainable aviation fuel (SAF) are pulling feedstocks away from the production of renewable diesel in a way that is harmful to the environment. Thesame volume of feedstock produces more renewable diesel than SAF and therefore displaces more petroleum- based fuel. These policies too should be changed to allow the market to pursue the best environmental and economic uses of these feedstocks to help us achieve more of our desired policy goals.

[30] See Alternative Fuels Data Center: Renewable Diesel (energy.gov).

[31] See Ethanol vs. Petroleum-Based Fuel Carbon Emissions | Department of Energy.

[32] See Internal Combustion Engine Basics | Department of Energy.

[33] "Highlights of the Automotive Trends Report," EPA (updated Dec. 12, 2022) (available at Highlights of theAutomotive Trends Report | US EPA).

[34] "Vehicle Miles Traveled by Highway Category and Vehicle Type," Bureau of Transportation Statistics (available atVehicle Miles Traveled by Highway Category and Vehicle Type | Bureau of Transportation Statistics (bts.gov)).

Unfortunately, EPA's proposal sends a clear message to the market that investments in these liquid fuel alternatives would result in stranded investments.[35] If government policy is going to pick another technology as the preferred technology, there is little reason for businesses to invest in other solutions even though those solutions could deliver important emissions reduction benefits. Recognizing the history and the potential of different approaches, it is clear that using policy to give all existing and new technologies the chance to compete for market share and emissions reductionswill yield better results than focusing on a single approach.

VI. The Committee's Legislation

As the Committee considers legislation in this area, we urge you to consider the full range of challenges that we have set forth in this statement. In particular, the "Preserving Choice in Vehicle Purchases Act" and the "Choice in Automobile Retail Sales Act" directly address the principles we have laid out here. These bills move policy away from picking technology winners and losers and thereby create opportunities for all vehicle and energy technologies to develop to best meet consumers' needs and environmental policy goals. We appreciate the Committee focusing on these pressing issues and look forward to working with you on these and related issues as the process moves forward.

* * *

We appreciate the opportunity to provide our views on EPA's tailpipe proposals and California's regulations. EPA, policymakers throughout the Administration and Congress, and the states face real challenges in addressing climate change and other environmental issues. If we are to be successful in meeting those challenges in the transportation sector, however, we must take a holistic approach and seek improvements everywhere we can. EPA's tailpipe proposals and California's regulations take too narrow a focus and therefore will not lead to the outcomes we need for the climate or the economy. We look forward to working with the Congress and EPA to try to get to policies that will chart the best path forward.

Sincerely,

Doug Kantor
NACS General Counsel

cc: Members of the Subcommittee on
Environment, Manufacturing, and Critical Minerals

[35] It is also worth noting that EPA's proposal conflicts with Congress' policy decisions in enacting the renewable fuels standard (RFS). The RFS calls for billions of gallons of renewable fuels to be part of the mix of fuels sold intothe market each year. But compliance with EPA's proposed rule would of necessity reduce the volume of renewable fuels that could be sold.

June 22, 2023

The Honorable Bill Johnson
Chairman
Subcommittee on Environment,
Manufacturing, and Critical Minerals
2082 Rayburn House Office Building
Washington, DC 20515

The Honorable Paul Tonko
Ranking Member
Subcommittee on Environment,
Manufacturing, and Critical Minerals
2369 Rayburn House Office Building
Washington, DC 20515

Chairman Johnson and Ranking Member Tonko:

On behalf of the Alliance for Automotive Innovation ("Auto Innovators"), I appreciate the opportunity to submit this letter for the record to ensure the perspective of the auto industry in the U.S. is reflected at your hearing entitled "Driving *Affordability: Preserving People's Freedom to Buy Affordable Vehicles and Fuel."* The global auto industry is undergoing a generational transformation and the next decade may well define which nations shape the future of automotive innovation and manufacturing. Amid intense global competition, we must work collaboratively to support the development, commercialization, and acceptance of the innovative technologies that will redefine motor vehicle transportation for decades.

Auto Innovators was formed in 2020 to serve as the singular, authoritative, and respected voice of the automotive industry in the United States. Our members represent the full automotive industry, from the manufacturers producing most vehicles sold in the U.S. to autonomous vehicle innovators to equipment suppliers, battery producers and semiconductor makers. As the nation's largest manufacturing sector, the automotive industry is responsible for nearly 10 million U.S. jobs and represents 5.5 percent of the country's gross domestic product.

Recently, John Bozzella, President and CEO of the Alliance for Automotive Innovation (Auto Innovators) published a blog entitled, "EPA EV Rules: What it Means for China and the Auto Market."

Based on his decades of experience in the auto industry, the knowledge and information provided by Auto Innovators' members and outside research he made three key observations.

1. If U.S. regulators and policymakers move too fast on EV mandates over the next several years, China will gain a stronger foothold in America's EV battery supply chain and eventually our auto market.
2. If the US moves too slow on electrification, we will cede the field to China opening the door for China to lock up global EV supply chains and expand into other global markets.
3. The EPA proposed GHG NPRM isn't feasible without certain public policies and considering today's market and supply chain conditions.

This hearing is, in essence, an embodiment of the challenge we face as an industry – and nation - in this period of transformation for the auto industry. At a hearing focused on legislation directly impacting the auto industry, both the majority and the minority declined our offer to have Auto Innovators testify at the hearing. As the voice of the automakers responsible for the vast majority of new vehicles sold in the U.S. - and who will be responsible for building the millions of battery electric vehicles required to meet EPA's target of 60+ percent in less than a decade - it is unfortunate that our perspective was not considered the right fit for this hearing. This speaks volumes to the state of discourse around the future of our industry.

However, because the stakes are too high and the impact too great if the transformation taking place in the new American auto industry is disrupted, our perspective is essential for policymakers, our nation's economic security and our electric future.

If indeed we are serious about the shared goal of enhancing American leadership in the global automotive market, the private sector, Congress, and the Administration must work together to create and implement a comprehensive plan based on the market dynamics that are changing the industry. Make no mistake, this is a lead-or-follow moment. We can take political sides and cause further harm, or we can invest and innovate to become a global leader.

Building domestic supply chains that reduce dependence on Chinese minerals and batteries, building out ubiquitous and reliable charging, and incentivizing manufacturers to invest in domestic facilities is crucial to establishing the American automotive industry as a global leader. And each of these steps creates job and investment opportunities in communities across the nation. The transformation to electrification is well underway and it is greater than any one policy, branch, or level of government.

EPA Proposed GHG standards

As noted in blogs and letters Auto Innovators have written since EPA's April NPRM announcement on GHG regulation, there is a gross underestimation of the challenges and market realities that the auto industry is facing while pushing for increase electric vehicle adoption. Early aspirations for the auto industry and the Administration hovered around 40-50 percent EV sales by 2030, EPA's proposal moved the goalpost to 60+ percent. In contrast, the Battery Electric Vehicle (BEV) market share in 2022 was less than 6 percent. Thus far in 2023, BEVs make up roughly 7 percent of the market.

While the EPA clearly has a role to play in the shift to electrification, this type of aggressive increase in BEV sales is contingent on several factors outside of manufacturers' controls including massive and concurrent increases in charging infrastructure (residential and public), increased battery critical minerals mining and processing, and enhanced electric grid capacity – areas already lagging in the U.S. A successful transition into the electric future requires a steady, methodical approach in developing these multiple factors for success. The pace of policy changes and investments must match ambitions to be a global leader. Moving too fast or too slow will jeopardize America's position in the electric vehicle market and jobs.

Complementary Policies

Congress created the renewable fuel standard (RFS) program to reduce greenhouse gas emissions and expand the nation's renewable fuels sector while reducing reliance on imported oil in 2005. Congress and EPA have clearly established a role for electricity in the RFS, and EPA's electric Renewable identification numbers (eRINs) proposal should not be further delayed or abandoned. EPA approved the biogas electricity pathway in 2014, and Congress has expressed ongoing support for its implementation. The House and Senate Appropriations Committees, for example, have directed EPA to process electricity applications in annual reports dating back to 2018.

EPA has long recognized the many environmental and economic benefits associated with eRINs, including critical reductions in greenhouse gas emissions. This long-awaited opportunity is timelier than ever. eRINs are complementary to other federal policies that encourage the production of renewable fuels and eRINs will directly support the electrification of the U.S. vehicle fleet and the broad market transformation of the electric vehicle and biogas power sectors.

So, what other steps can we take collectively on the path to global leadership in the automotive sector?

1. **Infrastructure Development:** A robust charging infrastructure is crucial to support widespread electric vehicle (EV) adoption. This includes expanding the number of public charging stations, increasing the charging speed, and ensuring accessibility across urban and rural areas. Investments in charging infrastructure by both the government and private sector are essential.

2. **Incentives and Policies:** Government incentives and policies play a significant role in promoting EV adoption. These can include tax credits, rebates, grants, and subsidies for purchasing electric vehicles and installing charging infrastructure. Additionally, policies that prioritize electrification in public transportation and fleet vehicles can accelerate the transition.

3. **Cost Reduction:** Affordability is a major factor for consumers when considering electric vehicles. Continued technological advancements and economies of scale can lead to lower manufacturing costs, which can then be passed on to consumers. Additionally, incentives and financial programs that offset the higher upfront cost of EVs can make them more accessible to a broader range of consumers.

4. **Collaboration and Partnerships:** Collaboration between automakers, energy providers, and governments is crucial to create a cohesive and integrated ecosystem for electric vehicles. This involves coordinating efforts to ensure interoperability between charging networks, sharing best practices, and aligning strategies to achieve common goals.

5. **Research and Development:** Continued investment in research and development is necessary to improve battery technology, increase range, reduce charging time, and enhance overall vehicle performance. This can be supported through public and private funding, partnerships with academic institutions, and collaborations with industry.

6. **Consumer Awareness and Education**: Raising awareness about the benefits of electric vehicles, dispelling myths, and providing accurate information is essential to overcome consumer skepticism and promote adoption. Education campaigns can focus on the environmental advantages, cost savings, and improved driving experience of EVs.

7. **Grid Integration:** As the number of electric vehicles increases, ensuring the grid's capacity to handle the additional demand is crucial. Smart charging infrastructure, vehicle-to-grid (V2G) technology, and time-of-use pricing can help manage the charging load and optimize energy distribution.

8. **Battery Recycling and Disposal:** Developing efficient and sustainable processes for battery recycling and disposal is critical. This ensures the responsible handling of end-of-life batteries, reduces environmental impact, and enables the recovery of valuable materials for reuse.

9. **Equity and Accessibility:** Efforts should be made to ensure that the benefits of vehicle electrification reach all communities and income groups. Policies should address barriers to access, such as limited charging infrastructure in low-income neighborhoods, and prioritize equitable distribution of incentives and benefits.

Conclusion

Consumer demand for electrification is growing at home and abroad. Electrification represents a fundamental change in the way Americans have driven for more than a century. A comprehensive, long-term wholistic strategy is necessary to guide the transition to electric vehicles. This includes setting clear targets, establishing regulatory frameworks, and regularly reviewing and updating policies based on technological advancements and market dynamics. It requires collaboration among various stakeholders, sustained public and private investments, supportive federal and state policies, and a shared vision for a clean and sustainable transportation future.

Sincerely,

Garrick C. Francis
Vice President, Federal Affairs
Alliance for Automotive Innovation

CC: Energy and Commerce Committee members

Attachments:
Auto Innovators Memo: Auto Perspective on Coming EPA Emissions Rules (April 6, 2023)
Auto Innovators Blog: How to think about EPA's New Greenhouse Gas Rules (April 12, 2023)
Auto Innovators Blog: EPA's EV Rules: What it Means for China and the U.S. Auto Market (June 12, 2023)

ALLIANCE FOR AUTOMOTIVE INNOVATION

MEMO

TO: Interested Parties
FROM: Alliance for Automotive Innovation
DATE: April 6, 2023
RE: Auto perspective on coming EPA emissions rules

The Environmental Protection Agency (EPA) is expected to propose new light-duty vehicle greenhouse gas (GHG) and criteria emissions rules for model year 2027 through 2032 shortly. Alliance for Automotive Innovation will formally respond after reviewing the expansive proposal.

In the meantime, this memo outlines important questions and relevant data to consider when evaluating the feasibility of these regulations.

What is EPA expected to announce?
EPA's proposed GHG rules for 2027 and beyond will result in significantly more stringent greenhouse gas and criteria emissions standards than ever before. The EPA proposal – and a separate Corporate Average Fuel Economy (CAFE) rulemaking proposal from the Department of Transportation expected in the coming months – will indicate how the administration plans to meet President Biden's goal that one out of every two new light-duty vehicles sold to consumers by 2030 are electric vehicles.

Automakers are committed to electrification and net zero carbon technology.
Globally, automakers will invest $1.2 trillion toward vehicle electrification by 2030, including significant investments in U.S.-based EV and battery manufacturing. Multiple manufacturers have announced a goal to be EV-only in the 2040 timeframe with supportive policies in place.

Current U.S. EV market data:

- 91 EV models (sedans, vans, pickup trucks, utility vehicles) currently for sale;
- 150 EV models expected for sale by 2026;
- EV market share of new vehicles sold in 2022: 7 percent (2021: 4.35 percent);
- EV market share of new vehicle sales reached almost 10 percent in December 2022.

Are the EPA rules feasible?
Even with positive EV sales momentum and product excitement, there are challenges to the electrification transition ahead. This requires a massive, 100-year change to the U.S. industrial base and the way Americans drive.

A clear-eyed assessment of market readiness is required. The answer on rule feasibility is: It depends.

Success will be tied to both supportive public policies and favorable market conditions outside the vehicle, notably, charging infrastructure, affordability, supply chains, critical mineral availability and utility capacity. Regulatory mandates alone will not address the conditions (again, *outside* the vehicle) that will determine the ultimate success of the EV transition.

Can drivers conveniently fuel EVs?
This is a big unknown and a market condition the country has to get right.

Reliable and ubiquitous public charging and action to address private and shared charging for multi-unit dwellings is essential to a successful transition and will determine whether GHG, CAFE rules and other mandates are feasible (or not).

The administration has committed $7.5 billion to public charging. That's a good step, but at the end of 2022, there were only 100,000 non-proprietary public charging outlets in the U.S.

Even with 934,958 new EVs added to the roads in 2022, there were less than 25,000 non-proprietary public new chargers added. That means 38 new EVs for every new public port. That's not enough. (The recommended ratio is seven EVs for every charger).

McKinsey & Company estimates $35 billion is needed for public EV charging stations by 2030.

S&P Global suggests the country needs 800,000 public charging ports by 2025 and 2.3 million by 2030.

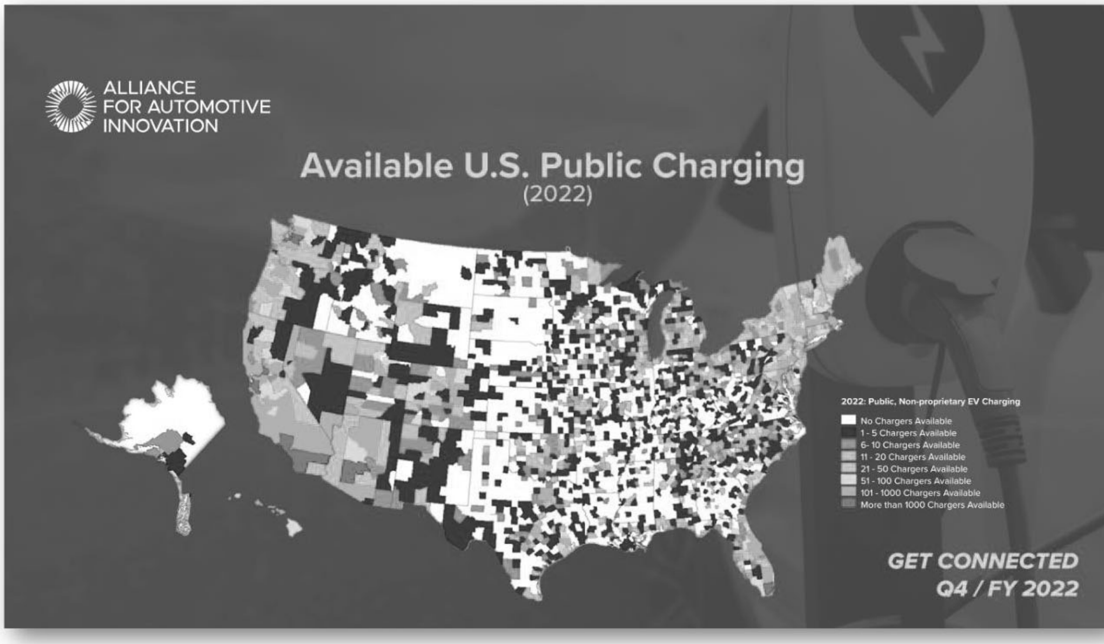
Most EV owners today are single family homeowners with access to reliable, low-cost, convenient home charging. This lack of public charging raises serious questions about equity and accessibility and whether there will be an EV charging network that reaches Americans in *all* corners of the country. Residential charging is necessary in multifamily and rental housing and in low-income communities.

Looking at the 3,100 counties in the U.S. in 2022, the insufficiency of public charging is stark:

- 63 percent had five or fewer EV chargers installed;
- 39 percent had zero;
- The top 14 counties with EV chargers accounted for 30 percent of all U.S. charging infrastructure.

What about those 25,000 new public EV chargers added in 2022? How does that number breakdown?

- 53 percent of counties added no new chargers;
- 75 percent of counties added five or fewer chargers;
- 51 percent of added charging infrastructure was in just two percent of counties;
- 25 percent of added U.S. charging infrastructure was in California;
- 160 counties added one new charger.



What about the bipartisan infrastructure law and Inflation Reduction Act (IRA)? Won't that help increase EV adoption and affordability?
To increase EV adoption, consumer purchase incentives at the federal and state level are critical to reach all buyers, including lower income drivers.

The IRA's 30D tax credit provides a purchase incentive of up to $7,500 for 37 different EV models today. The IRA also includes a $4,000 tax rebate for used EVs purchased by buyers with lower incomes.

Remember this: the IRA's revised 30D EV tax credit (with strict new rules on the origin of critical minerals and battery components that kick-in after April 18) means fewer EVs will qualify for the $7,500 customer purchase incentive.

About 40 percent of the 91 EVs on the market qualified for the 30D credit as of March 2023. That number will shrink when the Treasury Department's content requirements (40 percent critical mineral threshold and 50 percent battery component threshold for 2023) are implemented on April 18. See: EV Tax Credit: Is This as Good as it Gets?

The manufacturing tax credits and the various federal incentives and grants to help build an EV supply chain and globally competitive battery manufacturing platform is a positive policy.

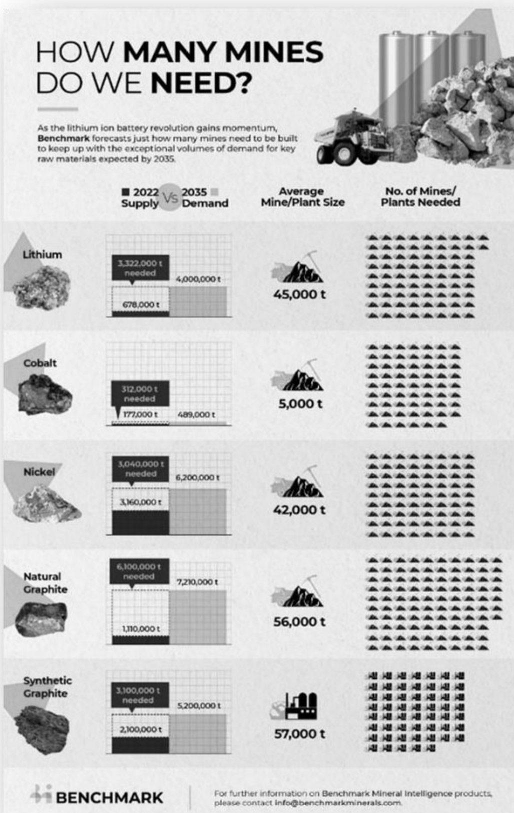
However, it remains to be seen to what extent the infrastructure and supply-side provisions of these laws will have in the development of the U.S. EV market over the course of the proposed greenhouse gas rule (model year 2027-2032).

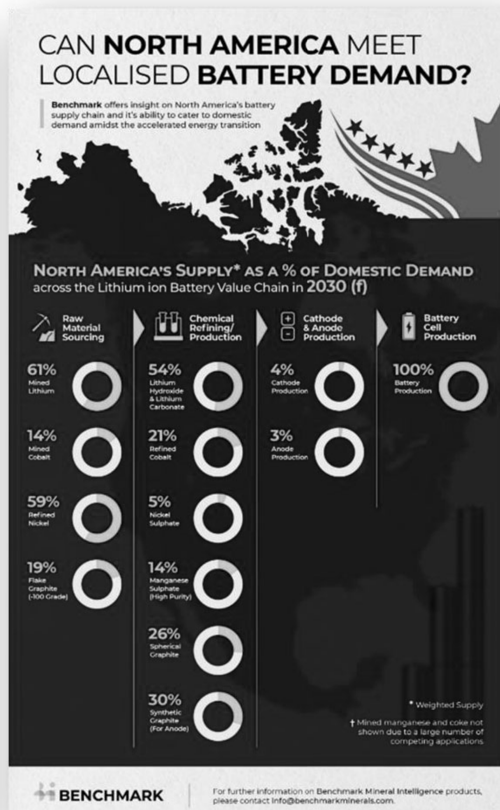
Can automakers secure the necessary battery critical minerals and processing to power EVs?
An open and consequential question.

Critical Minerals: Benchmark Minerals Intelligence (BMI) reports about 300 new mines (graphite, lithium, nickel, and cobalt) are needed globally to meet the battery demand for EVs and stationary energy storage systems by 2035.

Processing: Raw critical minerals from the mine are just the first step. Those minerals must be processed, refined and turned into cathodes and anodes before battery cell production. BMI estimates that 90 percent of anode production currently occurs in China.

By 2030, it is estimated that North America will domestically fulfill only 3.5 percent and 3.4 percent of its cathode and anode demands respectively. To avoid dependence on countries like China, vastly more of these processing and production facilities are needed in the U.S., North America and allied countries.





Monumental amounts of capital are being invested in zero carbon personal mobility. Every dollar invested in internal combustion technology is a dollar *not spent* on zero carbon technology. And vice versa.

Automakers and battery partners have already committed $110 billion in the U.S. to electrify products. Requiring large investments for incremental gains from gas-powered engines comes at the expense of where our collective focus ought to be: *electrification*.

EPA should act quickly, working with the petroleum industry, to lower the carbon intensity of liquid fuels. This will pay far higher returns by reducing emissions from not only new gasoline vehicles (including PHEVs), but from the millions of light-duty gas vehicles on the road.

The auto industry opposes this and any new GHG rules, right?
Far from it. Look at the record.

In December of 2021, EPA published its 'Vehicle Greenhouse Gas Emissions Standards' rule setting motor vehicle GHG standards for cars, light trucks and other vehicles in model years 2023 to 2026. That rule is expected to produce an improvement in fleetwide GHG emissions of more than 28 percent from emissions in model year 2022.

This rule is being challenged in federal court by 16 attorneys general (in Texas, Alabama, Alaska, Arkansas, Arizona, Indiana, Kentucky, Louisiana, Mississippi, Missouri, Montana, Nebraska, Ohio, Oklahoma, South Carolina and Utah) and various fuel interests.

Automakers – the regulated industry – *did not oppose* those rules and are on record that EPA's rules (though challenging and aggressive) should remain in place. In fact, Alliance for Automotive Innovation intervened in the litigation *on behalf* of EPA's 2023-2026 rules and asked the D.C. Circuit to protect the 2021 rule as written.

America's electric transformation is well underway. The vehicles are in production and automakers are committed to the shift.

The question isn't whether it can be done, it's how fast can it be done… and how fast will depend almost exclusively on having the right policies and market conditions in place to achieve the shared goal of a net zero carbon automotive future.

Auto industry fuel economy and emissions: a record of achievement

Department of Energy: "Over 14 percent of all the light-duty vehicles produced in 2022 had fuel economy of 35 miles per gallon (MPG) or higher, with 6.9 percent achieving fuel economy of 60 MPG or higher. In 1975, about two-thirds (67 percent) of all light-duty vehicles produced had fuel economy of 15 MPG or less, but in 2022 just 0.3 percent fell into this category."

EPA Trends Report: "New vehicle real-world CO2 emissions are at a record low and fuel economy remains at a record high."

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June 22, 2023

The Honorable Cathy McMorris Rodgers
Chair
House Committee on Energy and Commerce
2125 Rayburn House Office Building
Washington, DC 20515

The Honorable Frank Pallone
Ranking Member
House Committee on Energy and Commerce
2125 Rayburn House Office Building
Washington, DC 20515

The Honorable Bill Johnson
Chairman
Subcommittee on Environment, Manufacturing,
and Critical Materials
House Committee on Energy and Commerce
2125 Rayburn House Office Building
Washington, DC 20515

The Honorable Paul Tonko
Ranking Member
Subcommittee on Environment, Manufacturing,
and Critical Materials
House Committee on Energy and Commerce
2125 Rayburn House Office Building
Washington, DC 20515

Chairs McMorris Rodgers and Johnson, and Ranking Members Pallone and Tonko:

We write to you today regarding the Subcommittee on Environment, Manufacturing, and Critical Materials hearing titled "Driving Affordability: Preserving People's Freedom to Buy Affordable Vehicles and Fuel." Thank you for holding this hearing and for calling attention to the issues facing manufacturers of liquid fuels. Higher blends of biofuels like ethanol offer reduced-cost, lower-carbon solutions available to American families at the pump today.

Growth Energy is the world's largest association of biofuel producers representing 93 U.S. plants that produce nearly nine billion gallons of cleaner-burning, renewable fuel annually; 115 businesses associated with the production process; and tens of thousands of biofuel supporters across the country. Our ultimate objective is to work together to bring better and more affordable choices to consumers at the fuel pump, support energy independence, improve air quality, and protect the environment for future generations.

Today's hearing includes discussion of H.R. 3337, the Fuels Parity Act, introduced by Committee member Rep. Mariannette Miller-Meeks of Iowa. We are grateful to Rep. Miller-Meeks for introducing this legislation to both increase domestic production of ethanol for use at the pump and to accurately reflect the carbon-reducing benefits of biofuels for cars on the road today. First, this bill puts corn-starch ethanol on par with all other feedstocks that can qualify as an advanced biofuel under the Renewable Fuel Standard (RFS).

Currently, under the RFS, biomass-based fuels can be considered as advanced biofuels provided that they achieve a 50-percent greenhouse gas (GHG) reduction; however, corn starch is the only feedstock that is prohibited from qualifying as an advanced biofuel regardless of the GHG reduction achieved. Brazilian sugarcane ethanol can be an advanced biofuel, but corn starch ethanol cannot. The fibrous outer shell of a kernel of corn, known as corn kernel fiber, can be an advanced biofuel, but corn starch ethanol cannot. Sorghum, the closest plant-based cousin to corn and a feedstock that is often processed right along with corn starch, can be an advanced biofuel and corn starch ethanol cannot. The same ground that grows corn also grows things like soybeans, wheat, and barley – all of which can be advanced biofuels. So long as corn starch ethanol can achieve a 50 percent GHG emission reduction, it should be afforded the same opportunity to be an advanced biofuel like every other feedstock.

Additionally, Rep. Miller-Meeks' legislation calls on the U.S. Environmental Protection Agency (EPA) to use the U.S. Department of Energy (DoE) Argonne National Laboratory Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model. By requiring the use of GREET, the bill would direct EPA to utilize the best available science to determine the greenhouse gas benefits of biofuels, while also ensuring that feedstocks are accurately judged based on their actual carbon performance.

While we are grateful for the discussion of the Fuels Parity Act, a hearing on the freedom to buy affordable fuel is incomplete without mentioning the role that higher blends of biofuel like E15, a 15-percent biofuel-blended fuel, play in reducing costs at the pump. Last summer amid record-high gas prices, E15 provided savings as high as nearly a dollar per gallon compared to regular E10 in some areas of the country[1]. This summer, we have already seen instances of $.60-per-gallon savings at the pump thanks to E15[2]. These are meaningful reductions. To date, Americans have driven over 75 billion miles on E15; it's available at over 3,000 stations in 31 states and can be used by 96% of cars of the road today. Unfortunately, due to outdated federal regulations, E15 cannot be sold year-round. In order for American families to reap the benefits of these cost savings, we urge the committee to consider and pass H.R. 1608, the Consumer and Fuel Retailer Choice Act, legislation to make year-round sales of E15 permanent.

In addition to providing cost savings, biofuels play an important role in reducing carbon emissions today. Biofuels like ethanol reduce carbon emissions by nearly 50% compared to regular gasoline[3]. And when it comes to E15, a simple move to E15 would reduce CO_2 emissions by more than 17 million tons — the equivalent of taking nearly 4 million cars off the road each year[4]. Increased blends of ethanol also mean less pollution and healthier communities. A study by the University of California Riverside found that ethanol blends reduce toxic emissions by up to 50 percent, including smog-producing pollutants and ultra-fine particulates[5].

Let us be clear – liquid fuels will continue to play a dominant role in the transportation sector now and for decades to come. Therefore, it is imperative to consider the vital role that affordable and environmentally sustainable fuel options, such as ethanol, will play in reducing greenhouse gas emissions from the current and future vehicle fleet, rather than putting the thumb on the scale for one, single technology. As the Subcommittee engages with EPA on its proposed tailpipe emissions standard, we encourage you to ask EPA

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[1] https://growthenergy.org/wp-content/uploads/2022/10/One-Sheeter_DigitalB.pdf
[2] https://twitter.com/GrowthEnergy/status/1666878829535559699
[3] https://iopscience.iop.org/article/10.1088/1748-9326/abde08/pdf
[4] http://www.airimprovement.com/reports/national-e15-analysis-final.pdf
[5] https://growthenergy.org/2022/08/02/carb-shares-additional-data-on-evaluation-of-e15/

to provide strong and clear policies to encourage the adoption of high-octane, low-carbon ethanol blends like E15. This low-carbon fuel is available now, saves drivers money at the pump, and can be used in almost every car already on the road today. That's a win for all sides.

Finally, yesterday EPA released their final Renewable Volume Obligations (RVOs) for 2023, 2024, and 2025 under the RFS. In short, EPA's final RFS rule undermines the potential for growth in low-carbon biofuels. While the RFS remains one of America's most successful clean energy policies, its full potential as a climate solution remains untapped – yet again. EPA's decision to lower its ambitions for conventional biofuels runs counter to the direction set by Congress and will needlessly slow progress toward climate goals. While the final rule offers a modest improvement in advanced volumes, EPA inexplicably failed to extend that recognition to conventional biofuels. The ethanol industry has more than adequate supply to meet the higher volumes that were originally proposed in December 2022. Choosing not to put that supply to good use in decarbonizing the transportation sector runs counter to this administration's previously stated commitments and undermines the goal of reaching net-zero by 2050.

Thank you again for the opportunity to submit testimony at this important hearing. We stand ready to work with the Committee to deliver reduced-cost, lower-carbon transportation solutions for all Americans.

Sincerely,

Emily Skor, CEO
Growth Energy

Contact: Brian Weiss
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(202) 326-5571

FOR IMMEDIATE RELEASE
June 12, 2023

EPA's EV Rules: What it Means for China and the U.S. Auto Market

By John Bozzella

For policymakers, "China" is cut and dry. Binary. Good, bad. Friend, foe.

I'm just a car guy, but when it comes to the global auto industry, I know this: "China" is complicated.

First, it's a giant auto market that's nearly twice the size of the U.S. market. U.S. based automakers are manufacturing American-built vehicles with American labor and exporting automobiles *to China*. Today. That's just the outbound.

There's inbound too. Automotive components and finished vehicles are exported *from China* into the U.S., trade that supports American auto employment and customer affordability. That two-way trading relationship will grow.

It's also true that China is both the leading electric vehicle maker and consumer in the world. Chinese automakers aren't household names in the U.S., but BYD sold 1.9 million EVs last year and is bigger than Tesla. Great Wall Motors, SAIC and others are out there too.

Because of that sheer size (and the 15-year head start on electrification) they've been able to essentially corner the market on major parts of the global EV supply chain – notably the mining and processing of critical minerals (lithium, cobalt, nickel and graphite) used to produce EV batteries.

That advantage is at the heart of America's current EV challenge:

How to accelerate the U.S. transition to automotive electrification *and* prevent China from locking up the global supply chains that are foundational to a successful shift?

If U.S. regulators and policymakers move too fast on EV mandates over the next several years, I predict China gains a stronger foothold in America's EV battery supply chain and eventually our automotive market.

I'm talking about the Environmental Protection Agency's proposal to require 37 percent of new light-duty cars and trucks to be *battery* electric vehicles by 2027… and 60+ percent by 2030. (Last year, BEV sales were just under 6 percent).

Increased automotive electrification and carbon reduction is a mission that automakers share with EPA and the Biden administration. That should be clear enough by the EV technology we've championed and brought to market (97 sedans, utility vehicles, pickup trucks, vans and counting), the major battery manufacturing partnerships across the Midwest and South, and the localization of manufacturing and supply chains inside the U.S. Private sector investment of $115 billion (so far) toward electrification.

I've said the EPA proposal wasn't feasible without certain public policies and in light of today's market and supply chain conditions.

There's not enough charging and uncertain utility and grid capacity. Here's the big one – and where China looms largest – essentially no domestic or allied supply of battery critical minerals, processing and components until 2025 (and even then, nowhere near enough to supply what's needed).

That's what should be keeping policymakers up at night.

It's hardly news that China dominates the critical mineral mining and processing universe. The U.S. imports 100 percent of its graphite. Almost one-third comes from China.

According to BMI, of the two leading components in an EV battery – the anode and cathode – China is expected to produce almost 90 percent of the anode active material and 80 percent of the cathode active material in 2030.

We just don't mine or process these minerals in the U.S. There's been little progress on long overdue permitting and mining reform here – and even if it magically happened overnight, it would be a decade or more before it made a material difference.

The administration still hasn't completed a process to work with our allies and trading partners to secure those minerals either.

So, it's a pretty grim picture on battery critical minerals despite record investments in recent years.

With that windup… what happens if EPA gets its way and requires a five-fold increase in *battery* electric vehicle sales in four years and a 10-fold increase in six years?

The minerals have to come from somewhere, right? Enter China and Chinese-backed mining companies in Chile, The Democratic Republic of the Congo and Indonesia.

They'll supply the minerals and processing needed to produce the batteries… needed to build the vehicles… needed to comply with EPA's regulation. Got that?

In other words, official U.S. policy will have thrown open the doors (and the ports, as it were) to China. Before long, Chinese automakers will accelerate their entrance into the American market with low-priced EVs that meet the aggressive (and arbitrary) EPA requirements for model years 2027-2032.

And it will be subsidized, scratch that… *incentivized* by American public policy. Unintended consequences… there's no sugarcoating it.

Alarmist? I don't think so.

Morgan Stanley recently outlined this catch-22. They described the 'China case' (aka move fast like EPA proposes), the 'de-risking case' (high EV adoption, with a geographically diversified supply chain), and the 'slow EV case' (self-explanatory).

Here's what they said about the China case: "The path we're on now, despite existing legislation that attempts to incentivize onshoring, pushes rapid EV adoption which inherently increases reliance on a China-dominated battery supply chain."

That's my take, but it's actually more complicated.

If the U.S. moves too slow on electrification, we've got a China risk too. Failure to scale up and move with sufficient urgency gives China the running room to lock up global EV supply chains and expand into other global auto markets.

And if China moves deeper into the U.S. auto market and sells the EVs necessary to meet EPA's mandates, it can, in turn, sell credits to American and other automakers that don't sell as many EVs. Tesla's been running that play for years, but this is a whole new level.

I'm talking about allowing Chinese automakers to double-dip and make (more) money precisely *because* EPA is requiring an electric ramp up that's not possible – right now.

This is our Goldilocks problem. Too fast: advantage China. Too slow: advantage China.

And EPA's proposed regulations put us in the too fast/advantage China category.

Europe offers a warning of what could happen here. The EU has prioritized the reduction of carbon emissions at the expense of almost everything else – including its industrial base. With a 2035 ban on fossil fuel vehicles looming, Chinese manufacturers gained a foothold and entered the European market at a budget price point. They achieved a 5 percent share of Europe's EV market in the first nine months of 2022 and on a steady march to hit 20 percent by 2025.

As the New York Times recently reported: "European carmakers are frantically trying to build the supply chains they need to churn out electric vehicles." But given generous government subsidies and other support, Chinese EV makers can't be beat on affordability. The country's control of battery supply chains also shields them from disruptions and price spikes.

I’m not making the case for stopping on EVs or to rely on internal combustion engines and fossil fuels in perpetuity. There’s product momentum. We can’t stop.

This is the case for getting the rules right – and balanced.

The case for weighing our climate and carbon reduction goals with national and economic security objectives. So American supply chains can catch up. So automakers can plow finite resources into the electrification future and appeal to customers on a realistic timeframe that achieves the ultimate goal: automotive electrification and carbon reduction that doesn’t set back the economy, our industrial base and consumers.

I’ll never bet against American ingenuity – especially in the auto industry, but policy and pace matter. Regulations (even imperfect ones) are designed to engineer a specific outcome.

EPA should ease up and reassess this rule before it helps cement China’s place in the U.S. auto market.

How should EPA do it? I’ll pick that up in my next post…

John Bozzella is president and CEO of Alliance for Automotive Innovation.

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ALLIANCE FOR AUTOMOTIVE INNOVATION

BLOG

FOR IMMEDIATE RELEASE
April 12, 2023

Contact: Brian Weiss
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How to Think About EPA's New Greenhouse Gas Rules…

By John Bozzella

The Environmental Protection Agency (EPA) is out with its proposed light-duty vehicle greenhouse gas (GHG) and multi-pollutant rules for model year 2027 through 2032.

Immediate reaction: Two things can be true at the same time (and in this case they are).

Yes, America's transition to an electric and low-carbon transportation future is well underway. EV and battery manufacturing is ramping up across the country because automakers have self-financed billions to expand vehicle electrification.

It's also true that EPA's proposed emissions plan is aggressive by any measure. By that I mean it sets automotive electrification goals in the next few years that are… very high.

In fact, the proposal exceeds the administration's *own 50 percent electrification target* (see executive order 14037) announced in August 2021 – with auto industry support – by requiring more than one EV for every new gas vehicle sold by 2030 and potentially two EVs for every gas vehicle just two years later.

And it goes beyond the National Blueprint for Transportation Decarbonization – a government-wide plan rolled out recently by four cabinet agencies that doubled down on the 50 percent target from 2021.

To be clear, 50 percent was always a stretch goal and predicated on several conditions. Those included supportive policies like the manufacturing incentives in the Inflation Reduction Act (that have only just begun to be implemented) and tax credits to support EV purchases and affordability.

How will EPA justify exceeding the carefully considered and data-driven goal announced by the administration in the executive order and the more recent national blueprint? That's a key question as the rulemaking unfolds and something to look for in the expansive proposal.

You might be thinking: "Of course the auto industry would resist going faster."

A couple of points to consider when evaluating this rule and its ultimate feasibility:

Automakers are fully committed to an electric and low-carbon transportation future.

There are now 91 EV models on the market – across all segments and price points. Electric vehicles were 10 percent of new vehicles sales in December, and automakers have invested billions in U.S.-based EV and battery manufacturing. I could go on about sales and product excitement. (We do, here.)

But EV sales momentum is only the beginning of the story.

Remember this: a lot has to go right for this massive – and unprecedented – change in our automotive market and industrial base to succeed, especially as 284 million light-duty vehicles across the country (that average 12 years in age) remain on the roads. As of last year, EVs accounted for just over one percent of all light-duty vehicles.

EPA and the petroleum industry should act quickly to concurrently lower the carbon intensity of liquid fuels. This will produce higher and faster returns by reducing emissions from not only new gas vehicles (including plug-in hybrid EVs), but from the millions of light-duty gas vehicles currently on the road.

Monumental amounts of capital are being invested in zero carbon personal mobility.

One challenge: every dollar invested in internal combustion technology is a dollar *not spent* on zero carbon technology. And vice versa.

Why does that matter? Automakers and battery partners have already committed $110 billion in the U.S. to electrify products. Requiring self-financed investments from automakers for incremental gains from gas-powered engines comes at the expense of where our collective focus ought to be: electrification. That’s the future.

So, are EPA’s new standards feasible? Will they accelerate the EV transformation?

It depends. First, factors outside the vehicle, like charging infrastructure, supply chains, grid resiliency, the availability of low carbon fuels and critical minerals will determine whether EPA standards at these levels are achievable. Did EPA consider factors *outside the vehicle* when it crafted its proposal?

To some extent, the baseline policy framework for the transition has come into focus. But it remains to be seen whether the refueling infrastructure incentives and supply-side provisions of the Inflation Reduction Act, the bipartisan infrastructure law, and the CHIPS and Science Act are sufficient to support electrification at the levels envisioned by the proposed standards over the coming years.

One thing we know for sure today: IRS’s new rules for the 30D EV consumer tax credit – with stricter sourcing rules for critical mineral and battery components starting April 18 – means far fewer EV models will qualify for the $7,500 purchase incentive.

Another challenge: There are 100,000 publicly available, non-proprietary charging outlets in the U.S. for three million EVs on the road. That's a ratio of 29 EVs per charger… and not enough.

Whatever happened to a national plan?

Finally, as various government agencies – federal and state – release competing or overlapping requirements for both EV and gas-powered vehicles, we've got to remember to get the balance right.

About six years ago we had one national standard to reduce carbon in personal mobility, providing nationwide consumer and environmental benefits through a single, streamlined regulatory path for automakers.

EPA's new proposal on the other hand was developed separately from the Department of Transportation's coming Corporate Average Fuel Economy (CAFE) standards expected later this spring and not in concert with EPA.

We're committed to constructive engagement between the regulators (EPA, DOT, DOE, California Air Resources Board) and the regulated. We also believe a successful EV transformation requires several sustained commitments: sound, realistic and consistent policy; smart regulation; and concurrent action from the non-automotive sectors of the economy – namely utilities, critical mineral mining and processing operators, infrastructure providers, and energy producers.

The question isn't can this be done, it's how fast can it be done, and how fast will depend almost exclusively on having the right policies and market conditions in place to achieve the shared goal of a net zero carbon automotive future.

More to say during the comment period in the weeks and months ahead...

John Bozzella is president and CEO of Alliance for Automotive Innovation.

Alliance for Automotive Innovation MEMO on EPA emissions rules (*April 6, 2023*).

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American Lung Association.

Zeroing in on Healthy Air

A National Assessment of Health and Climate Benefits of Zero-Emission Transportation and Electricity

About this Report

Zeroing in on Healthy Air finds that a widespread transition to zero-emission cars, trucks, buses and other vehicles, coupled with non-combustion, renewable energy resources would yield tremendous air quality, public health and climate benefits across the United States. To illustrate the potential benefits, a transition to 100 percent sales of light-duty passenger vehicles and medium-and heavy-duty vehicles were assumed over the coming decades, along with a transition to non-combustion electricity generation.

Zeroing in on Healthy Air builds off the 2020 Road to Clean Air report by the American Lung Association, and illustrates the potential scale of benefits to public health, air quality and climate change if the United States accelerates the course to a zero-emission transportation sector coupled with non-combustion renewable sources like wind and solar energy. While similar to the 2020 “Road to Clean Air” report on zero-emission transportation, this report stands alone. Updates to technical models, assumptions and methods do not allow for direct comparisons between “Road to Clean Air” and this new analysis.

The American Lung Association developed this project with the assistance and technical support of ICF Incorporated, LLC (ICF). Using a series of modeling tools, ICF provided estimated fleet characteristics and emissions profiles (US EPA MOVES2021 model, ICF’s custom fleet modeling), emissions associated with fuel and electricity generation (Argonne National Lab GREET Model, ICF’s custom IPM model) and health outcomes associated with changes in emissions (US EPA COBRA health model). ICF conducted a comprehensive analysis of the potential health and climate benefits of this transition as a consultant to the American Lung Association, which is solely responsible for the content this report. Additional details on the structure of the report, a full methodology and assumptions about future vehicle fleets, changes in the electric power grid and citations are detailed in the technical report document prepared by ICF for the American Lung Association. Available online at Lung.org/ev.

Contents

Executive Summary

Zeroing in on Healthy Air is a report by the American Lung Association illustrating the public health urgency of policies and investments for transitioning to zero-emission transportation and electricity generation in the coming decades. These sectors are leading sources of unhealthy air in the United States. Today, over four in ten Americans — more than 135 million people — live in communities impacted by unhealthy levels of air pollution. Research demonstrates that the burdens of unhealthy air include increased asthma attacks, heart attacks and strokes, lung cancer and premature death. These poor health outcomes are not shared equitably, with many communities of color and lower income communities at greater risk due to increased exposure to transportation pollution. The transportation sector is also the largest source of greenhouse gas emissions that drive climate change, which threatens clean air progress and amplifies a wide range of health risks and disparities.

This report finds that a national shift to 100 percent sales of zero-emission passenger vehicles (by 2035) and medium- and heavy-duty trucks (by 2040), coupled with renewable electricity would generate over $1.2 trillion in public health benefits between 2020 and 2050. These benefits would take the form of avoiding up to 110,000 premature deaths, along with nearly 3 million asthma attacks and over 13 million workdays lost due to cleaner air. This report calculates the emission reductions possible from shifting to vehicles without tailpipes, as well as eliminating fuel combustion from the electricity generation sector so that neither those living near roads or near electricity generation would be subjected to unacceptable doses of toxic air pollution. The report also highlights the fact that the shift to zero-emission transportation and electricity generation in the United States will yield avoided global climate damages over $1.7 trillion.

By expediting investments and policies at the local, state and federal levels to reduce harmful pollution, all communities stand to experience cleaner air. Policies and investments must prioritize low-income communities and communities of color that bear a disproportionate pollution burden. State and local jurisdictions should act to implement policies as soon as possible, including in advance of the benchmarks used in this report's methodology. These actions are needed to achieve clean air, reduce health disparities and avoid even more dire consequences of climate change.

Zeroing in on Healthy Air

In the United States, transportation and electricity generation are leading sources of unhealthy air and the pollutants that cause climate change.

Those living near highways, ports, railyards, warehouses, and other transportation hubs are at greater health risk, as are those impacted by fuel refining, electricity generation and processes.

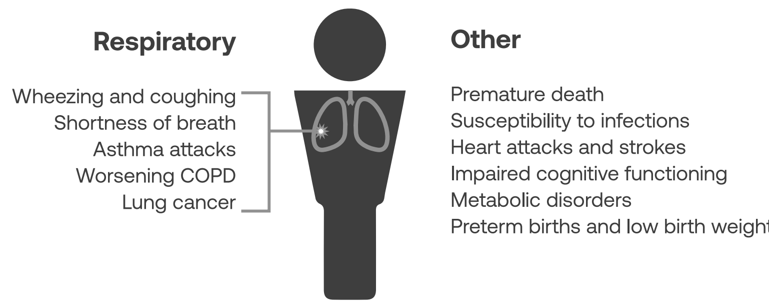
The widespread, rapid shift to zero-emission transportation and electricity generation is critical to healthy air, and can yield more than $1.2 trillion in health benefits and 110,000 pollution-related deaths avoided over the coming decades along with over $1.7 trillion in global climate benefits.

The Public Health Need for Zero Emissions

Air Pollution Remains a Major Threat to Americans' Health

Despite decades of progress to clean the air, more than 4 in 10 of all Americans — 135 million — still live in a community impacted by unhealthy levels of air pollution.[ii] Those impacted by polluted air face increased risk of a wide range of poor health outcomes as the result of increased ozone and/or particle pollution.[iii] The adverse impacts of pollution from the transportation and electricity generation sectors are clear, and must be recognized as a threat to local community health, health equity and a driver of major climate change-related health risks. Even with certification to meet existing standards, it is clear that combustion technologies often generate far greater levels of pollution in the real world than on paper.

Air pollution can harm children and adults in many ways



> "The shift to zero-emission transportation and electricity generation will save lives and generate massive health benefits across the United States. It is critical that we ensure these benefits are realized in the near term in communities most impacted by harmful pollution today."

Harold Wimmer, American Lung Association President and CEO

Location Matters: Disparities in Exposure Burden

Exposure to pollution with its associated negative health consequences is dictated by where someone lives, attends school or works. In general, the higher the exposure, the greater the risk of harm. Many communities face disproportionate burdens due to pollution generated from production, transportation, refining and combustion of fuels along the transportation and electricity generating systems. Lower income communities and communities of color are often the most over-burdened by pollution sources today[iv] due to decades of inequitable land use decisions and systemic racism.

The American Lung Association's State of the Air 2021 report illustrated the disparities in pollution burdens across the United States, noting that a person of color in the United States is up to three times more likely to be breathing the most polluted air than white people.[v] All sources of harmful air and climate pollution must shift rapidly away from combustion and toward zero-emission technologies to ensure all Americans have access to the benefits of less-polluting technologies.

> **"Pollution from the transportation sector has been a long-standing obstacle to advancing environmental justice, as many communities of color and low-income families live near areas where pollution from vehicles and engines is abundant, and therefore experience disproportionate exposures to this pollution."**
>
> US EPA
> Transportation and Environmental Justice
> Fact Sheet March 2022

> "Rapidly eliminating emissions from the transportation and electricity generation sectors must be a national priority. The nationwide transition to electric vehicles is urgently needed to improve lung health and advance health equity."
>
> Harold Wimmer
> American Lung Association President and CEO

For those living in close proximity to major transportation hubs like highways, ports, railyards or warehouses, tailpipe (or "downstream") emissions yield an outsized risk to community health.

Similarly, "upstream" emissions from transportation fuels generate localized health burdens near oil and gas extraction sites, refineries and even local gas stations, all of which generate toxic air pollution and threaten community health.

Health of communities all along the electricity production system — from the extraction of fossil fuels such as coal, oil and gas, transportation of these fuels, and combustion at the power plant itself — can be adversely impacted.

Estimated Benefits of Zero-Emission Transportation and Electricity Generation

The combustion of fuels in the electricity generation and transportation sectors is a major contributor to the health and climate burdens facing all Americans. These sources of pollution also create significant disparities in pollution burdens and poor health, especially in lower-income communities and communities of color. The transition to non-combustion technologies is underway and must continue to accelerate to protect the health of communities today and across the coming decades. Key findings are presented below:

Pollution Reduction Benefits from Zero-Emission Transportation

Accelerating the shift to zero-emission transportation and non-combustion electricity generation will generate major reductions in harmful pollutants. Key pollutants included in this research are described below along with projected on-road pollution reductions with the shift to zero-emission technologies when compared with a modeled "Business As Usual" case for the on-road fleet.

Pollutant	Impact	On-Road Pollution Reductions by Year		
		2030	2040	2050
Nitrogen Oxides (NOx)	NOx and VOCs are building blocks for ozone ("smog") and contribute to particle pollution formation and a wide range of health impacts including asthma attacks, heart attacks, strokes, and premature death. Breathing VOCs can irritate the eyes, nose and throat, can cause difficulty breathing and nausea, and can damage the central nervous system as well as other organs. Some VOCs can cause cancer. NO2 is associated with increased risk of asthma attacks, ER visits, hospitalizations and a range of other health consequences.	**-6%** ↓	**-56%** ↓	**-92%** ↓
Volatile Organic Compounds (VOC)		**-8%** ↓	**-42%** ↓	**-78%** ↓
Fine Particle Pollution (PM2.5)	Particle pollution can increase the risk of heart disease, lung cancer and asthma attacks and can interfere with the growth and work of the lungs. Major health impacts include asthma attacks, heart attacks, stroke, COPD, lung cancer and death.	**-8%** ↓	**-43%** ↓	**-61%** ↓
Sulfur Dioxide (SO2)	Contributes to wheezing, shortness of breath and chest tightness, reduced lung function, increased risk of hospital admissions or emergency room visits.	**-15%** ↓	**-67%** ↓	**-93%** ↓
Greenhouse Gases (GHG)	Drives climate change health risks, including extreme weather, wildfires and degraded air quality among others.	**-14%** ↓	**-66%** ↓	**-93%** ↓

Benefits of Moving All Vehicle Classes to Zero-Emissions

All vehicles must move to zero-emission technologies to ensure the most robust public health benefits occur. The 2020 passenger vehicle fleet represents approximately 94 percent of the nation's on-road vehicle fleet and generates over 1 million tons of ozone- and particle-forming NOx emissions, and over 33,400 tons of fine particles annually. Heavy-duty vehicles represent approximately six percent of the on-road fleet in 2020, but generate 59 percent of ozone- and particle-forming NOx emissions and 55 percent of the particle pollution (including brake and tire particles).

Differentiating the relative impacts of fleet segments is particularly important when considering the concentrations of heavy-duty vehicles in environmental justice areas near highways, ports, railyards and warehouse settings. For greenhouse gases (GHG), the 2020 light duty vehicle fleet generates approximately 69 percent of GHG emissions, while the heavy-duty fleet produces 31 percent.

The table below illustrates the relative emission reduction benefits of on-road transportation electrification for each the light-duty fleet and the medium- and heavy-duty segments compared with the "Business-As-Usual" case. It is important to note that these on-road reductions could yield major benefits within each class, with light-duty vehicles reducing nearly twice the GHGs as heavy-duty, while heavy-duty engines could yield approximately eight times the smog- and particle-forming NOx emissions when compared with the light-duty fleet. Ultimately, all segments produce harmful pollutants and must move quickly to zero-emissions to protect health and reduce climate pollution.

Pollutant	**Light Duty:** On-Road Emission Reductions (Tons per Year, Percent Reduction)			**Heavy Duty:** On-Road Emission Reductions (Tons per Year, Percent Reduction)		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**
Nitrogen Oxides	-23,124 **-8%**	-80,975 **-61%**	-111,168 **-92%**	-51,274 **-6%**	-478,879 **-55%**	-887,640 **-92%**
Volatile Organic Compounds	-49,080 **-9%**	-195,520 **-41%**	-347,094 **-76%**	-4,316 **-5%**	-41,379 **-51%**	-80,375 **-87%**
Fine Particles	-2,903 **-10%**	-11,369 **-42%**	-16,170 **-58%**	-644 **-4%**	-5,737 **-43%**	-9,682 **-68%**
Greenhouse Gases (CO2e, Short Tons)	-198 M **-18%**	-733 M **-70%**	-1.0 B **-94%**	-37 M **-7%**	-322 M **-58%**	-572 M **-92%**

National Results: Public Health and Climate Benefits

The shift to zero-emission transportation and non-combustion electricity generation could yield major health benefits throughout the nation in the coming decades. Cumulatively, the national benefits of transitioning away from combustion in the transportation sector toward 100 percent zero-emission sales and a non-combustion electricity generation sector could generate over $1.2 trillion in health benefits across the United States between 2020 and 2050. These benefits include approximately 110,000 lives saved, over 2.7 million asthma attacks avoided (among those aged 6-18 years), 13.4 million lost works days and a wider range of other negative health impacts avoided due to cleaner air.[1,2] IIn addition to these health benefits, this analysis found that over $1.7 trillion in global climate benefits could be achieved with a reduction of over 24 billion metric tons of GHGs by mid-century.[3]

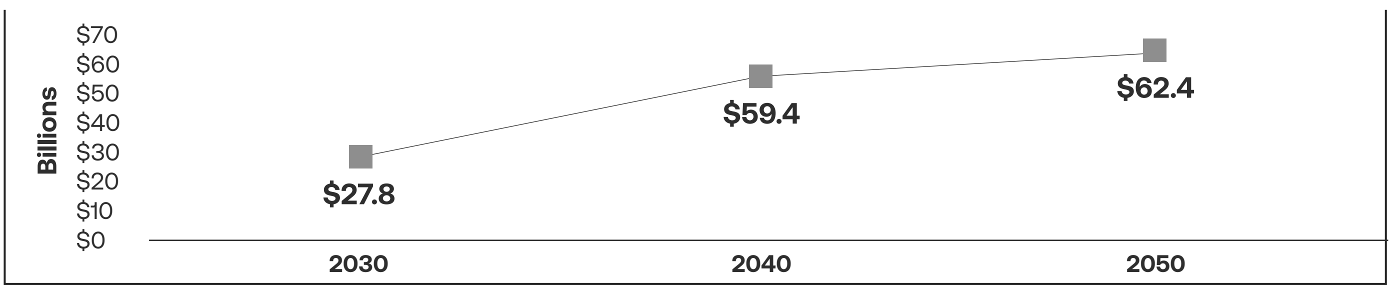
National Scale Benefits to Health and Climate (Cumulative: 2020-2050)

Public Health Benefits 2020-2050			Value of Benefits 2020-2050	
Premature Deaths Avoided	Asthma Attacks Avoided	Lost Work Days Avoided	Public Health Benefits	Climate Benefits
110,000	2.78 M	13.4 M	$1.2 T	$1.7 T

Near-Term Health Benefits

While the benefits noted above are cumulative between 2020 and 2050, this analysis also finds that annual health benefits could reach into the tens of billions by the end of this decade – nearly $28 billion in 2030 alone. Health benefits increase significantly as deployments of zero-emission technologies in the transportation and electricity generating sectors expand.

Annual Health Benefits (Billions)



Note: Total values presented for all vehicles using high estimate of benefits using a 3% discount rate and using 2017$.

[1]Note that the analysis and report include ozone-precursor emissions data. However, ozone-related health effects are not included in this report. US EPA's COBRA model relies on PM2.5 health effects to assess and monetize impacts. Results therefore do not include significant health burdens posed by ozone pollution throughout the United States independent of those related to PM reductions, as described in the health effects section of this report.

[2]In all cases, avoided health costs are presented in 2017 dollars. The value of avoided mortality estimates is grown from EPA's 1990 value of a statistical life to future years using standard income growth data and are presented in 2017 dollars. These results reflect the benefits of cumulative emission reductions estimated between 2020 and 2050, utilizing the American Lung Association's on-road and upstream emissions scenarios. Health results include the number of avoided adverse health impacts and the economic value of these health risk reductions at a 3% discount rate and reflect higher range estimates associated with the Di et al. (2017) health study. Greenhouse gas emission benefits are based on interim SCC values published in February 2021 by the Interagency Working Group on Social Cost of Greenhouse Gases, United States Government.; climate benefits are also presented in 2017$ values at a 3 percent discount rate.

[3]The social cost of CO2 emissions (SC-CO2) is a measure, in dollars, of the long-term damage done by a ton of carbon dioxide (CO2) emissions in a given year. This dollar figure also represents the value of damages avoided for a small emission reduction (i.e., the benefit of a CO2 reduction). SC-CO2 is intended to be a comprehensive estimate of climate change damages and includes changes in net agricultural productivity, human health, property damages from increased flood risk, and value of ecosystem services. However, not all important damages are included due to data limitations. Note that the climate change benefits of clean electricity generation are limited to the transportation-driven marginal increases in emissions, and do not include all benefits from the entire grid shifting to non-combustion sources, which differs from the whole-grid approach to air pollutants.

State Results: Public Health Benefits Across the United States

Every state in the U.S. stands to experience significant public health benefits from the widespread implementation of zero-emission transportation and electricity resources over the coming decades. As shown below, more than half of the states could experience more than $10 billion in cumulative public health benefits. Two states (California and Texas) could exceed $100 billion in health benefits, and six more states (Pennsylvania, Florida, Ohio, New York, Illinois, and Michigan) could see benefits exceeding $50 billion by 2050. These benefits cover a wide range of avoided health impacts, three of which (premature deaths, asthma attacks, lost workdays) are shown in the table below.

State	Cumulative Health Benefits, 2020 - 2050			
	Health Benefits (Billions)	Premature Deaths Avoided	Asthma Attacks Avoided	Lost Work Days Avoided
California	$169.0	15,300	440,000	2,160,000
Texas	$104.0	9,320	346,000	1,520,000
Pennsylvania	$86.8	7,940	148,000	735,000
Florida	$85.6	7,760	142,000	766,000
Ohio	$68.5	6,280	137,000	635,000
New York	$68.2	6,200	159,000	825,000
Illinois	$59.5	5,410	138,000	670,000
Michigan	$51.4	4,700	97,400	466,000
New Jersey	$43.6	3,960	92,400	464,000
Indiana	$36.8	3,360	83,000	373,000
North Carolina	$35.3	3,210	79,100	387,000
Virginia	$29.7	2,700	70,900	350,000
Georgia	$29.3	2,640	78,500	385,000
Maryland	$27.8	2,530	63,600	315,000
Tennessee	$24.9	2,180	53,800	255,000
Kentucky	$20.4	1,850	43,000	200,000
Wisconsin	$19.2	1,760	39,300	186,000
Missouri	$18.8	1,710	41,300	193,000
Massachusetts	$18.0	1,640	35,500	195,000
Louisiana	$17.8	1,610	40,800	184,000
South Carolina	$17.0	1,550	32,000	154,000
Arizona	$15.1	1,360	38,500	182,000
Minnesota	$14.9	1,350	36,600	171,000
Alabama	$14.3	1,300	28,300	134,000

State	Cumulative Health Benefits, 2020 - 2050			
	Health Benefits (Billions)	Premature Deaths Avoided	Asthma Attacks Avoided	Lost Work Days Avoided
Connecticut	$13.7	1,250	27,400	143,000
Oklahoma	$12.3	1,120	31,700	136,000
Iowa	$10.8	989	24,500	108,000
West Virginia	$9.8	898	16,100	81,200
Colorado	$9.5	857	31,200	151,000
Arkansas	$9.5	865	20,300	90,700
Mississippi	$8.5	773	18,300	80,600
Nevada	$7.5	676	14,800	78,900
Kansas	$6.9	625	18,100	77,400
Washington	$5.9	531	15,000	73,200
Utah	$5.7	506	26,100	94,300
Nebraska	$5.2	476	14,300	60,500
Delaware	$5.1	462	11,200	55,100
Maine	$4.5	402	5,870	31,000
New Hampshire	$3.9	356	5,860	32,800
Rhode Island	$3.8	348	6,570	35,600
New Mexico	$3.0	273	7,380	32,300
Oregon	$2.7	242	5,600	28,300
Vermont	$2.0	183	2,880	15,700
Idaho	$1.8	166	4,850	20,000
District of Columbia	$1.7	149	5,680	36,400
South Dakota	$1.6	143	4,140	16,500
North Dakota	$1.5	133	3,300	14,800
Montana	$1.3	122	2,550	11,800
Wyoming	$0.9	81	2,290	9,870

Note: Health results include the number of avoided adverse health impacts and the economic value of these health risk reductions at a 3% discount rate and reflect higher range estimates associated with the Di et al. (2017) health study. Mortality estimates are grown from EPA 1990 value of a statistical life using standard income growth data while non-fatal costs are presented in 2017$ values.

Note: Data for Alaska and Hawaii are not presented in this report because the US EPA COBRA Model provides health outputs for the contiguous United States.

Local Results: Public Health Benefits Across America

Communities across the United States stand to benefit from the widespread transition to zero-emission transportation and electricity generation. As transportation emissions are a dominant source of local exposures in many communities, a carefully and equitably designed shift to non-combustion transportation can mean cleaner air for all, and especially those most burdened by pollution from these sources today. Similarly, a shift away from fossil-fueled electricity generation is critical to improving the health of those most impacted by emissions from power plants, including in lower-income, rural communities across the United States.

This analysis found that the 100 U.S. counties (roughly 3 percent of all counties assessed) with the highest percent populations of People of Color could experience approximately 13 percent of the cumulative health benefits of this transition ($155 billion, between 2020-2050). Expanding this further, the 500 U.S. Counties (16 percent of counties assessed) with the highest percent populations of People of Color could experience 40 percent of the benefits, or $487 billion cumulatively between 2020 and 2050. It is also clear that the presence of benefits within these counties does not directly translate to benefits to individual neighborhoods or residents, however. This is an indicator of the urgent need to center equity in policies and investments to ensure access to the benefits of pollution-free mobility and power.

Additional analysis of the benefits in rural communities, lower-income communities, and neighborhood exposure levels could provide deeper insights into more equitable policy and investment designs. At a broader scale, this analysis shows a leveling of benefits across the country as the locations of power plants and transportation hubs are often impacting communities with varying socioeconomic characteristics.

As shown in the table on the next page, communities across the United States could experience billions in public health benefits, and significantly reduce premature deaths, asthma attacks and other negative health consequences of polluted air through 2050. The table includes the 25 Metropolitan Areas across the United States showing the largest cumulative health benefits by 2050 considering the shift to non-combustion electricity generation and zero-emission transportation.

Top 25 Metro Areas, Public Health Benefits		Cumulative Public Health Benefits 2020-2050			
		Health Benefits (Billions)	Premature Deaths Avoided	Asthma Attacks Avoided	Lost Work Days Avoided
1.	Los Angeles-Long Beach, CA	$95.5	8,680	241,000	1,210,000
2.	New York-Newark, NY-NJ-CT-PA	$84.2	7,660	206,000	1,070,000
3.	Chicago-Naperville, IL-IN-WI	$46.5	4,230	113,000	552,000
4.	San Jose-San Francisco-Oakland, CA	$42.5	3,850	113,000	561,000
5.	Philadelphia-Reading-Camden, PA-NJ-DE-MD	$41.1	3,760	86,600	424,000
6.	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA	$38.9	3,540	104,000	516,000
7.	Miami-Port St. Lucie-Fort Lauderdale, FL	$36.5	3,320	62,300	342,000
8.	Houston-The Woodlands, TX	$33.4	3,000	130,000	568,000
9.	Detroit-Warren-Ann Arbor, MI	$29.2	2,690	55,100	268,000
10.	Dallas-Fort Worth, TX-OK	$28.0	2,530	88,300	405,000
11.	Boston-Worcester-Providence, MA-RI-NH-CT	$22.7	2,070	43,000	238,000
12.	Atlanta-Athens-Clarke County-Sandy Springs, GA-AL	$20.9	1,890	59,400	296,000
13.	Cincinnati-Wilmington-Maysville, OH-KY-IN	$20.7	1,900	51,600	233,000
14.	Cleveland-Akron-Canton, OH	$20.3	1,870	31,500	153,000
15.	Pittsburgh-New Castle-Weirton, PA-OH-WV	$19.9	1,830	26,100	138,000
16.	Orlando-Lakeland-Deltona, FL	$12.9	1,160	22,400	121,000
17.	San Diego-Chula Vista-Carlsbad, CA	$12.4	1,100	29,200	151,000
18.	Indianapolis-Carmel-Muncie, IN	$12.2	1,120	32,000	144,000
19.	St. Louis-St. Charles-Farmington, MO-IL	$12.2	1,120	25,800	122,000
20.	Minneapolis-St. Paul, MN-WI	$11.7	1,070	30,700	145,000
21.	Phoenix-Mesa, AZ	$11.0	994	30,700	145,000
22.	Tampa-St. Petersburg-Clearwater, FL	$10.9	988	20,100	108,000
23.	Charlotte-Concord, NC-SC	$9.2	833	23,200	113,000
24.	Harrisburg-York-Lebanon, PA	$8.8	805	16,500	78,700
25.	San Antonio-New Braunfels-Pearsall, TX	$8.8	791	25,200	112,000

Note: Health results include the number of avoided adverse health impacts and the economic value of these health risk reductions at a 3% discount rate and reflect higher range estimates associated with the Di et al. (2017) health study. Mortality estimates are grown from EPA 1990 value of a statistical life using standard income growth data while non-fatal costs are presented in 2017 $ values.

Note: The counties assigned to a metropolitan area follow the groupings determined by the White House Office of Management and Budget (OMB) and used by the U.S. Census Bureau. The Metropolitan Statistical Areas and Combined Statistical Areas are used as the basis for considering populations at risk in these urban areas because they reflect the “high degree of social and economic interaction as measured by commuting ties,” as OMB describes them. In some cases, metropolitan area results may exceed state results due to geographies of metropolitan areas crossing state lines.

Policy Recommendations to Achieve Public Health and Climate Benefits

At every level of government, transportation and energy decisions are essentially public health decisions. The phase-out of combustion in the transportation and electricity generation sectors is critical as the nation transitions to a healthier future. Continued investments in combustion technologies may prolong the use of harmful fuels or otherwise delay investment in healthier choices today. Public leaders must align transportation and energy decisions and investments with the protection of public health and reductions in harmful emissions.

Recommended Federal Policies to Achieve Public Health Benefits of Zero-Emission Transportation and Electricity Generation

The Federal Government has a critical opportunity to move the nation to healthier, pollution-free transportation and power systems through a combination of strong policies and investments in zero-emission technologies and infrastructure, actions that enjoy broad public support according to a recent American Lung Association poll.[vi] A key down payment was made in the transition to zero-emission transportation with the President signing the Bipartisan Infrastructure Law in November 2021. This law invests $2.5 billion in zero-emission school buses and set $7.5 billion in motion to expand the national infrastructure for zero-emission vehicles — an important start to the larger, and longer-term public/private investments needed. These investments must not only continue and scale up, but must be paired with stronger laws and rules to reduce harmful air and climate pollution:

- Fully implementing the provisions of the bipartisan infrastructure and vehicle investments and continuing to increase funding for non-combustion electricity generation and transportation as the nation continues to invest in a healthier future.
- Extending and increasing incentive and grant programs to support zero-emission vehicle purchases by consumers, transit agencies, school districts and other entities.
- Leading by example by converting public fleets to zero-emission vehicles immediately.
- Congress must pass legislation to accelerate the transition to zero-emission transportation more broadly than contained in the Bipartisan Infrastructure Law and to ensure more equitable distribution of clean air benefits.
- US EPA must act quickly to update National Ambient Air Quality Standards (NAAQS) for NO2, SO2, carbon monoxide, lead, ozone and particle pollution in line with the scientific understanding of what levels are appropriate with an adequate margin of safety of the most vulnerable communities.
- US EPA and the National Highway Traffic Safety Administration (NHTSA) must adopt standards that drive the complete transition to zero-emission passenger vehicles.
    - EPA has finalized regulations that help clean up carbon pollution from the light-duty vehicle sector through Model Year 2026. NHTSA must finalize the Corporate Average Fuel Economy Standards (CAFE) regulations through 2026 for light-duty vehicles.
    - These actions must be followed by increasingly stronger rules beyond 2026 that deliver on President Biden's goal for 50 percent of vehicles sold in the United States to be zero-emission by 2030, and a more complete transition to follow shortly thereafter.

- US EPA must move quickly to approve the next generation standards for heavy-duty trucks in 2022 that acknowledge the growing market for combustion-free medium- and heavy-duty vehicles:
  - More stringent greenhouse gas emission standards for heavy trucks by 2027
  - 90 percent reduction in smog-forming NOx emissions for new trucks by 2027
  - These actions must be followed by stronger rules for subsequent years that drive a complete transition to zero-emission heavy-duty vehicles
- The Biden Administration's Justice40 initiative must ensure that major investments are made in environmental justice communities throughout the United States. These investments must ensure that the benefits of zero-emission technologies are felt in historically underserved and over-polluted communities.
  - Treat 40 percent investment as a minimum requirement
  - Ensure that investments are located in communities of concern, and that health, climate and other benefits actually accrue within these communities
- Increase and sustain policies, incentives and investments to accelerate non-combustion renewable electricity generation and the retirement of combustion-based power plants to achieve the Biden Administration's target for 100 percent carbon pollution-free electricity by 2035.

Broad Public Support for Transportation Electrification

70% of American voters believe the federal government should:

- implement policies that support a transition to zero-emission vehicles; and
- require that by 2040 all new freight trucks, buses and delivery vans sold in the U.S. must produce zero tailpipe emissions.

American Lung Association Poll, 2021

Recommended State Policies to Achieve Public Health Benefits of Zero-Emission Transportation and Electricity Generation

Under the Federal Clean Air Act, California holds the authority to seek a waiver to enact stronger-than-national standards to address its air pollution challenges, while states can — and increasingly do — follow these more health-protective rules. At present, 15 states have adopted zero-emission vehicle standards and increasing numbers are pursuing zero-emission truck requirements. In addition to adopting these standards, states must invest in the fueling infrastructure needed to support the growing market, while also supporting the transition to non-combustion renewable power.

State	Zero Emission Vehicle Standard	Zero Emission Truck Standard	Zero Emission Truck MOU
California	●	●	●
Colorado	●		●
Connecticut	●		●
Hawaii			●
Maine	●		●
Maryland	●		●
Massachusetts	●	●	●
Minnesota	●		
Nevada	●		
New Jersey	●	●	●
New York	●	●	●
North Carolina			●
Oregon	●	●	●
Pennsylvania			●
Rhode Island	●		●
Vermont	●		●
Virginia	●		●
Washington	●	●	●
Washington, DC			●

Note: The California Zero Emission Vehicle standard sets increasing requirements for zero-emission passenger vehicle sales. The California Advanced Clean Truck standard sets similar sales percentages for medium- and heavy-duty truck sales. The Multi-State Memorandum of Understanding creates a coordinated approach to achieving 30 percent zero-emission truck sales by 2030 and 100 percent sales by 2050.

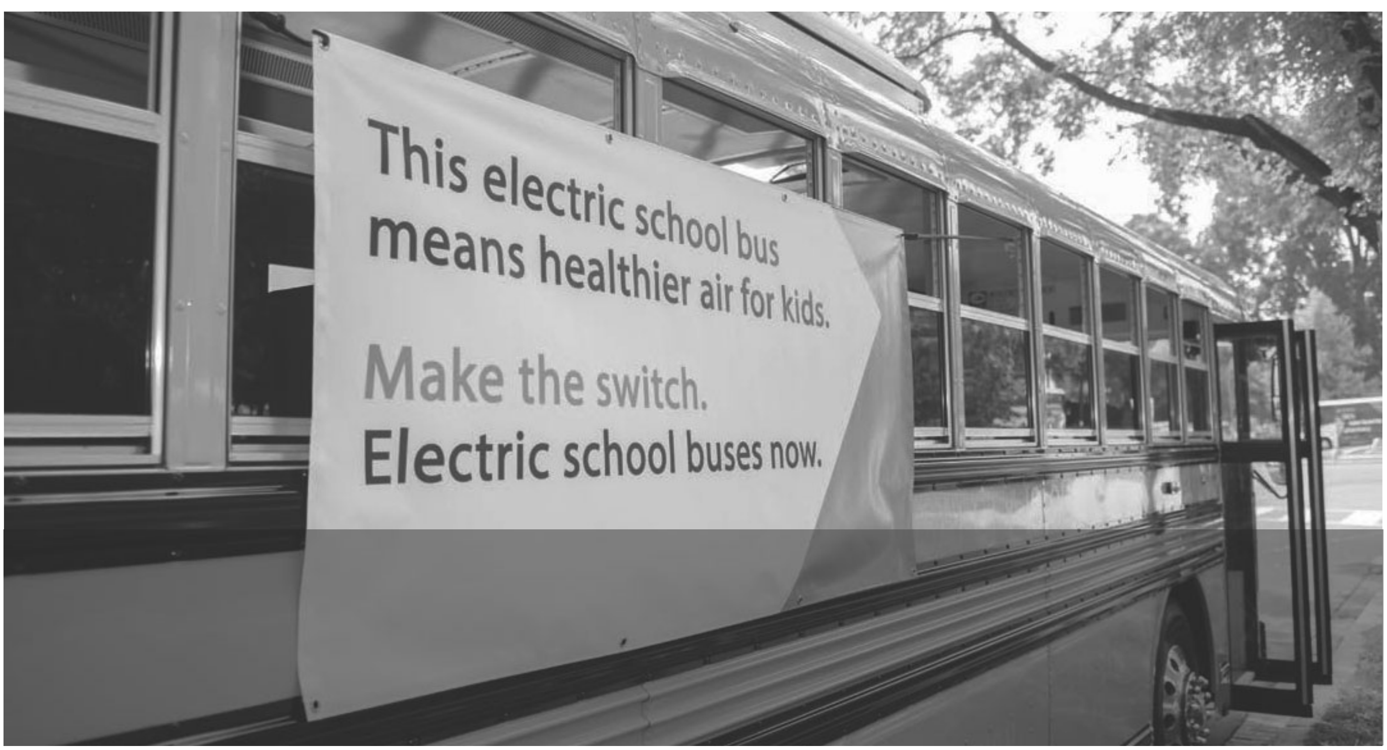
- States must adopt state standards for passenger vehicles and medium- and heavy-duty trucks to require that 100 percent of sales are zero-emissions.
- States must lead by example by converting public fleets to zero-emission vehicles.
- States must establish incentive programs to accelerate zero-emission mobility options and set clear requirements for the equitable distribution of incentive funding and infrastructure investments so that all communities (including urban, rural, lower-income, etc.) have access to the benefits of zero-emission mobility.
- States must remove barriers to equitable utility investments in zero-emission infrastructure serving all communities, and invest in upgrades needed to integrate light-, medium- and heavy-duty zero-emission vehicles across the grid.
- California must utilize its unique Clean Air Act authority to develop and implement stringent near- and long-term zero-emission standards (e.g., Advanced Clean Cars, Advanced Clean Trucks) that support attainment of NAAQS and state climate policies while also ensuring equity is central to policy design.
- States must enact programs and investments in infrastructure, consumer rebates and other supportive programs to join the growing list of jurisdictions following these more health-protective Advanced Clean Cars and Advanced Clean Trucks standards.
- States must not preempt actions by local governments seeking to expand zero-emission fueling infrastructure and clean electricity installations or to set more protective building codes.
- States can also join regional or other partnerships such as the Regional Electric Vehicle Midwest Coalition or the Multi-State Memorandum on Zero Emission Trucks to leverage broader resources to achieve healthier transportation.
- States must adopt and accelerate clean electricity standards, modernize electric grids and ensure equitable access to clean electricity to ensure full benefits of non-combustion electricity generation and transportation.

Recommended Local Policies to Achieve Public Health Benefits of Zero-Emission Transportation and Electricity Generation

In planning and building bike lanes and sidewalks, transit routes and carpool lanes, local government decisions impact how we move, and how safely and easily it is we do so. Local decisions can also ease the transition to zero-emissions. There are examples across the nation of public agencies, rural and urban transit fleets and school districts incorporating or fully converting to zero-emission technologies within their own fleets and make it easier for residents and businesses to make the switch and capture the benefits of cleaner air. Local governments must:

- Develop resources with utilities, manufacturers, local and regional governments and others to accelerate regional deployment of zero-emission vehicles, electricity and associated infrastructure
- Shift public fleets to zero-emissions across all weight classes.
- Establish simplified renewable energy and zero-emission fueling infrastructure installation processes for businesses, homeowners, renters and apartment managers.
- Coordinate with local agencies to implement zero-emission mobility options for lower-income neighborhoods, including car share, bike share, on-demand transit, etc.
- Ensure building code requirements follow best practices for charging readiness.
- Develop non-financial incentives such as preferred parking, sidewalk charging or other, visible measures to support residents in this transition.

At all levels, local, state and federal partners must collaborate and coordinate to deliver the framework for accessible, sustainable and reliable deployment of zero-emission transportation.



Conclusion

Too many Americans face unhealthy air that is being polluted by the transportation and electricity generation sectors. Climate change is making air pollution worse. This is especially true in lower-income communities and communities of color experiencing highly concentrated doses of pollution from diesel hotspots, refineries, power plants and other fossil fuel facilities. To reduce air pollution burdens and disparities, and to protect public health against the worst impacts of climate change, policies and investments must align with rapid reduction and elimination of combustion in these sectors. Doing so could yield over $1.2 trillion in public health benefits across the United States between 2020 and 2050 and $1.7 trillion in climate benefits. Acting now provides opportunities for major benefits in the near term and establishes pathways for generations to breathe healthier air.

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[i] American Lung Association. Health Impact of Air Pollution. April 2021. https://www.lung.org/research/sota/health-risks
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[vi] American Lung Association poll. June 2021. https://www.lung.org/media/press-releases/seventy-percent-of-voters-support-federal-action

Cleaner Cars, Cleaner Air

Replacing California's Oldest and Dirtiest Cars Will Save Money and Lives

www.ucsusa.org/resources/cleaner-cars-cleaner-air
www.greenlining.org/publications/cleaner-cars-cleaner-air

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June 2023

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Introduction

California has a long history of poor air quality resulting from transportation pollution on its roads. Toward reducing such pollution, the federal Clean Air Act, enacted in 1963, expanded states' ability to set tailpipe emissions standards. As early as 1966, California's climate, geography, and large number of vehicles led it to initiate regulatory action to reduce pollution from passenger cars and trucks (CARB, n.d.a). Since 1970, the state has used its authority under the Clean Air Act to require technological solutions to minimize emissions, initially using measures like mandating catalytic converters in new cars and now requiring the sale of electric vehicles and other zero-emissions vehicles (Reichmuth 2022).[1]

As a result of these regulations, the air-polluting emissions of today's new passenger vehicles are much lower than those of older ones. However, the improved tailpipe-pollution regulations only apply to new cars and trucks. Older vehicles are tested for emissions through the Smog Check program, but those inspections only verify that they meet the standards in place when the vehicles were manufactured (BAR 2022). Therefore, even with fully functional emissions equipment, older vehicles will pollute at higher levels than newer ones.

Currently, gasoline engines power the overwhelming number of passenger vehicles on the road. Their emissions both directly and indirectly produce fine particulate matter, defined as airborne particles less than 2.5 micrometers in diameter. These particles, referred to as $PM_{2.5}$, are small enough to penetrate deeply into the lungs, and some can enter the bloodstream. $PM_{2.5}$ is responsible for significant and life-shortening health impacts, including but not limited to lung disease, cardiovascular disease, and cancer.

Previous studies by the Union of Concerned Scientists (UCS) and others have shown that exposure to $PM_{2.5}$ pollution from on-road transportation is inequitably distributed (Reichmuth 2019; Plummer et al. 2022). On-road vehicles in California expose people of color to disproportionately high levels of $PM_{2.5}$ pollution. On average, Black Californians are exposed to 43 percent more $PM_{2.5}$ pollution than are White Californians and Latino Californians to 39 percent more (Reichmuth 2019).[2]

Cleaner Cars, Cleaner Air builds upon those findings by examining the impact specifically of older cars. While older vehicles are a relatively small fraction of personal vehicles, the large amount of pollution they create is experienced inequitably across California, just as with transportation pollution in general. Latino and Black Californians and low-income and disadvantaged communities face the brunt of the impacts of old vehicles. Policies to reduce the use of older vehicles would yield environmental, public health, and economic benefits for Californians, as well as taking a step toward addressing longstanding environmental injustices.

Tribal communities throughout the state also bear unacceptable levels of pollution, but, due to data limitations, we could not analyze the number of old vehicles owned by Tribal residents or estimate the health and economic impact of their pollution on tribal communities (August et al. 2021). Among the relevant factors is the persistence of many infrastructure needs. For example, rural dirt roads often provide the access to Tribal communities where the associated exposure to dust and dirt impacts upper respiratory illnesses (August et al. 2021).

A Fraction of the Vehicles on California Roads, Older Cars and Trucks Pollute More Than Newer Ones

Beginning with model year 2004, California has implemented Low-Emission Vehicle (LEVII) tailpipe pollution standards for passenger vehicles (CARB 2008). As a result, passenger cars and trucks made before that year produce much more tailpipe pollution per mile than do newer passenger cars and trucks.[3] In fact, pre-2004 vehicles emit almost three times as much smog-forming nitrogen oxides pollution as do all 2004 and later vehicles combined. This is the case even though older passenger vehicles make up only 19 percent of those in the state and 12 percent of miles driven. They are responsible for 73 percent of all nitrogen oxides exhaust from passenger vehicles and 64 percent of reactive organic gases. Both types of pollutant can react in the atmosphere to form $PM_{2.5}$.

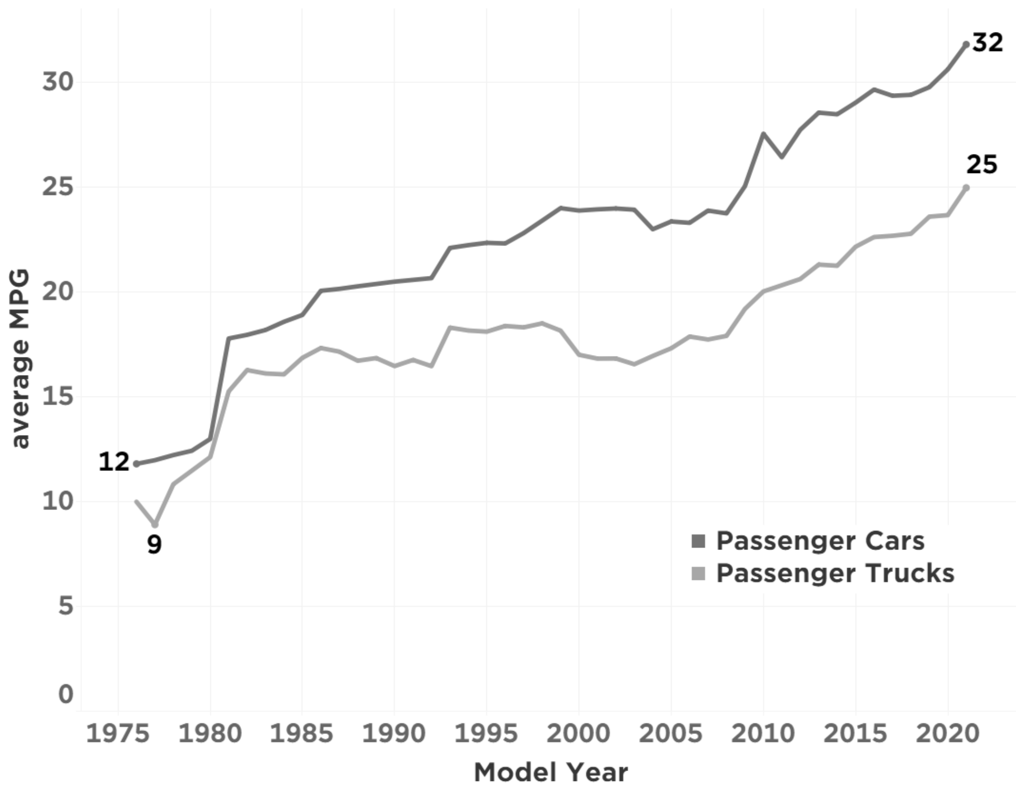
In addition to causing more air pollution due to lower emissions standards, the poorer fuel economy of older cars increases global warming emissions per mile driven while increasing fuel costs for drivers (Table 1 and Figure 1). Older cars average 23 miles per gallon (MPG); older trucks average 17 MPG. In contrast, new cars in California average more than 30 MPG and new trucks 25 MPG. Moreover, older cars cost more to maintain. For example, 20-year-old cars fail the required Smog Check twice as often as do 10-year-old vehicles (BAR 2022).

TABLE 1. Older Vehicles Produce a Disproportionate Amount of Harmful Air Pollutants

	Pre-2004 Passenger Vehicles	2004–2021 Passenger Vehicles
Vehicles registered	4.8 million (19%)	20.7 million (81%)
Annual mileage	33 billion miles (12%)	253 billion miles (88%)
Annual emissions of nitrogen oxides (NO_x) exhaust	39,900 tons (73%)	14,500 tons (27%)
Annual emissions of reactive organic gases	43,400 tons (64%)	24,300 tons (36%)

Although older vehicles represent fewer than one-fifth of the cars on California roads, they produce more nitrogen oxides and reactive organics gas emissions than all newer vehicles combined.

FIGURE 1. The Rising Fuel Efficiency of Gasoline and Diesel Passenger Cars and Trucks



The fuel efficiency of older gasoline and diesel vehicles is much lower than that of current cars and trucks, with well over a two-fold improvement for both cars and trucks between 1976 and 2021. SOURCE : EMFAC n.d.a.

To put that in perspective, driving a 20 MPG car for 10,000 miles would produce over five metric tons of carbon dioxide and the fuel would cost $2,500 at $5 per gallon; an efficient gasoline car (40 MPG) would emit half the amount of carbon dioxide and cut the fuel costs in half. The emissions from driving the average electric car in California 10,000 miles are even lower: less than 1 metric ton of global warming pollution per year (Reichmuth 2023). And global-warming emissions from using electric vehicles should fall further as the state transitions to lower-carbon sources of electricity (CEC 2021).

Fine Particulate Matter Pollution Has Significant Health Impacts

Passenger cars and trucks from model year 2003 and earlier emit tailpipe pollutants that lead to the formation of fine particulate matter at a much higher rate than do vehicles beginning with model year 2004.[i] In particular, the emissions of nitrogen oxides and reactive organic gases are significantly higher than those from newer gasoline or diesel vehicles. These pollutants are emitted in the vehicle exhaust. (Volatile organic compound emissions also come from gasoline that evaporates during refueling and from leaks in vehicle fuel tanks and lines.)

Pollutants like nitrogen oxides and reactive organic gases react in the atmosphere to form $PM_{2.5}$ in addition to the $PM_{2.5}$ present in vehicle exhausts.

It has been estimated that $PM_{2.5}$ is responsible for the vast majority of the 3 to 4 million annual deaths attributed to air pollution worldwide. While $PM_{2.5}$ is not the only air pollutant that adversely affects health, it is estimated to be responsible for approximately 95 percent of the global public health impacts from air pollution (Landrigan et al. 2018; Lelieveld et al. 2015). Using 2014–2016 data, the California Air Resources Board (CARB), the state's air-quality regulator, has estimated that cardiopulmonary causes related to $PM_{2.5}$ exposure contribute to roughly 5,400 premature deaths in the state each year, as well as 2,800 hospitalizations for cardiovascular and respiratory diseases and 6,700 emergency room visits for asthma (CARB, n.d.b.).

Both acute and chronic exposure to $PM_{2.5}$ have been linked to illness and death (Brook et al. 2010). Short-term exposure to elevated levels of $PM_{2.5}$ can exacerbate lung and heart ailments, cause asthma attacks, and lead to both increased hospitalizations and mortality from cardiovascular diseases (Orellano et al. 2017; Pope and Dockery 2006). Chronic exposure also increases death rates attributed to cardiovascular diseases, including heart attacks, and it has been linked to lung cancer and other adverse impacts (Fine, Sioutas, and Solomon 2008). Chronic exposure to $PM_{2.5}$ in pregnancy and childhood has been linked to slowed lung-function growth and the development of asthma, among other negative health impacts (ALA 2018; Gehring et al. 2015; Gauderman et al. 2004; Johnson et al. 2021).

Exposure to Harmful Air Pollution from Older Vehicles Is Inequitably Distributed

The California Air Resources Board has published data on the fuel type, model year, vehicle class, and registration location of most of the state's passenger cars and trucks.[4] CARB also estimates the rate of air-pollution emissions for vehicles by fuel type, model year, region of the state, and vehicle class. By combining these datasets, we estimated the local air-pollutant emissions from both older and newer cars. Using the InMAP air-quality model, we estimated the formation and transport of $PM_{2.5}$ pollution in the state from the use of older passenger vehicles (defined as model years 1976 through 2003) and newer ones (model years 2004 through 2021) (Tessum, Hill, and Marshall 2017).[5] These results were used with US Census data to estimate the exposure of Californians to harmful $PM_{2.5}$ pollution from the use of passenger cars and trucks and from the subset of pre-2004 vehicles.[ii] *See the appendix for more information on the methodology.*

Our analysis shows that $PM_{2.5}$ exposure is inequitably distributed across California's racial and demographic groups. All of the areas with the highest exposure to $PM_{2.5}$ from older vehicles are in the southern half of California and mainly in central Los Angeles (Figure 2). The communities with the highest pollution burden due to $PM_{2.5}$ from older vehicles—more than twice the state average—have higher percentages of low- and moderate-income households than areas unburdened by air pollution from these vehicles.

Exposure is also inequitably distributed by income. In the parts of the state with the highest exposure to $PM_{2.5}$ pollution from older vehicles, over half of households have an income of less than $60,000 a year. In areas with the least exposure, only 35 percent of households have an income of less than $60,000 a year (Figure 3). On average, higher income households are exposed to lower concentrations of $PM_{2.5}$ from all passenger vehicles; lower-income households have higher exposure.

The disparity based on income is significantly worse when considering only older vehicles. Higher-income households (over $200,000) have on average 18 percent lower exposure than the state average (Table 2).

TABLE 1. Exposure to Older-Vehicle $PM_{2.5}$ Pollution Is Much Lower for the Highest-Income Households

Household Income	Less than $20,000	$20,000 – $60,000	$60,000 – $100,000	$100,000 – $150,000	$150,000 – $200,000	Greater than $200,000
Exposure relative to state average from all passenger vehicles	4%	1%	1%	-2%	-4%	-9%
Exposure relative to state average from older passenger vehicles	5%	3%	0%	-5%	-9%	-18%

Higher-income households in California are exposed to exposure to fewer vehicle emissions. The disparity is especially evident for pollution from older vehicles.

We also found racial and ethnic disparities in exposure to air pollution from passenger vehicles. For all passenger cars and trucks, White people are on average exposed to 17 percent lower concentrations of $PM_{2.5}$ than the state average; Latino Californians are exposed to 13 percent higher concentrations; Black people are exposed to 11 percent higher concentrations.

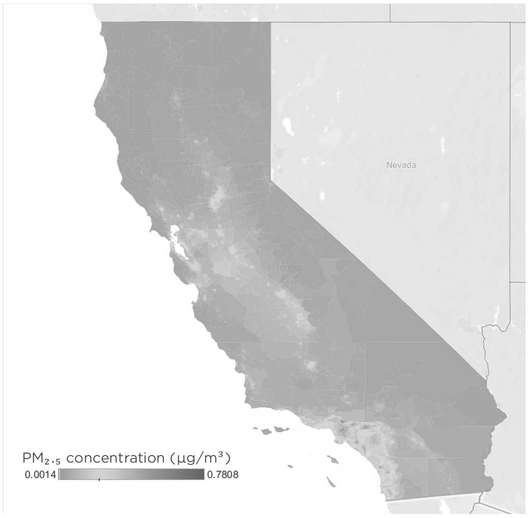
These disparities, too, are greater when considering only pollution from older vehicles. White people are on average exposed to 20 percent lower concentrations of $PM_{2.5}$ from older vehicles than the state average. Latino Californians are exposed to concentrations 19 percent higher than the state average; Black people are exposed concentrations 12 percent higher.

Communities with the highest exposure to $PM_{2.5}$ from older vehicles—greater than twice the state average—are home to much higher percentages of people of color than the state as a whole. In these areas with the highest exposure, 67 percent of residents are Latino and 8 percent are Black; the statewide population is 40 percent Latino and 5 percent Black. In contrast, those same areas of highest exposure are only 13 percent White; the state population is 36 percent White (Figure 4).

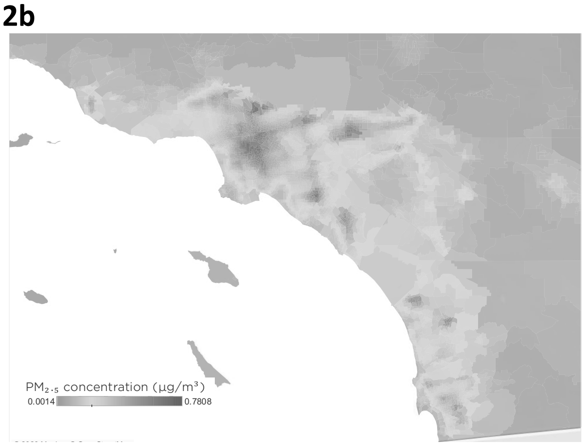
Further, Californians who already face the worst exposure to pollution from all sources combined also face the brunt of emissions from older vehicles. Increased exposure to $PM_{2.5}$ pollution from older vehicles correlates with a community's score on CalEnviroScreen 4.0, a screening methodology that helps identify communities that are disproportionately burdened by multiple sources of pollution. People in the highest-scoring (most-burdened) census tracts in CalEnviroScreen 4.0 are exposed to twice the concentration of pollution from older vehicles as are those in the lowest-scoring census tracts (Figure 5).

FIGURE 2: $PM_{2.5}$ Pollution from Older Vehicles Is Highest in Southern California

2a



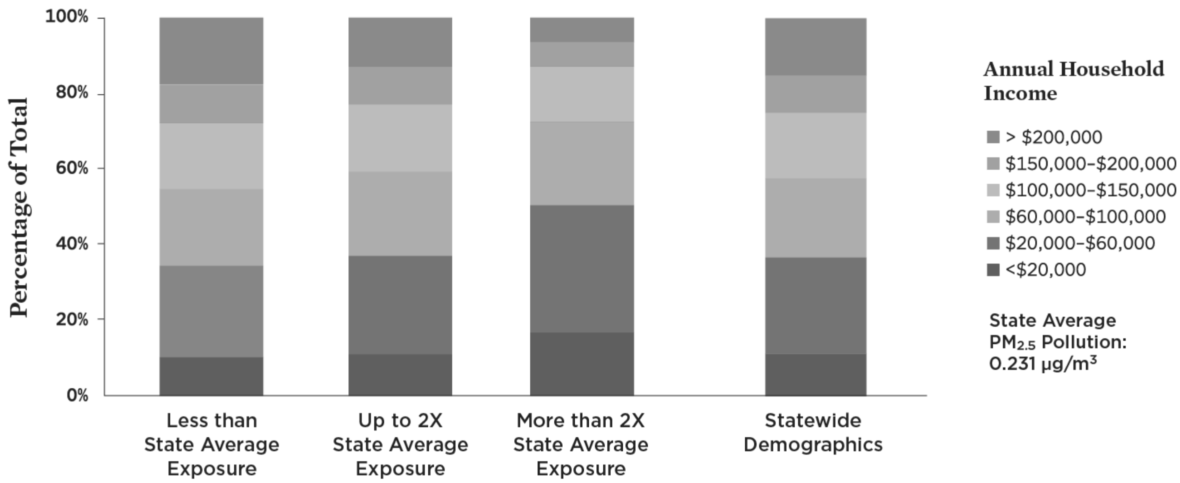
2b



2c

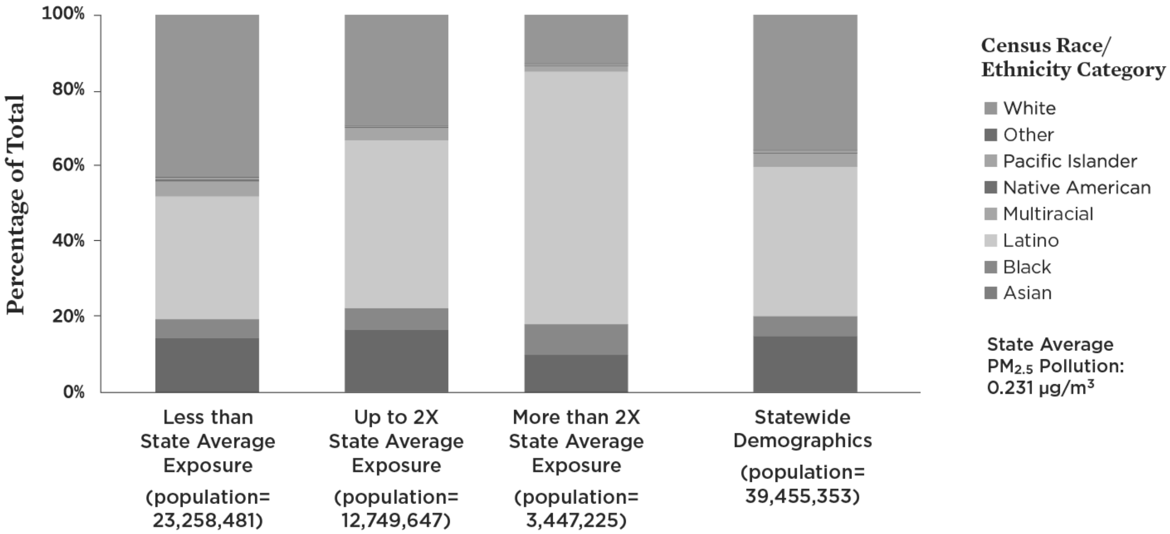
$PM_{2.5}$ pollution from older vehicles is highest in the southern half of California (2b), particularly in Los Angeles and Long Beach. $PM_{2.5}$ pollution concentrations reflect total emissions from older vehicles, including driving, starting, and evaporative emissions.

FIGURE 3. Household Income and Pollution from Older Cars



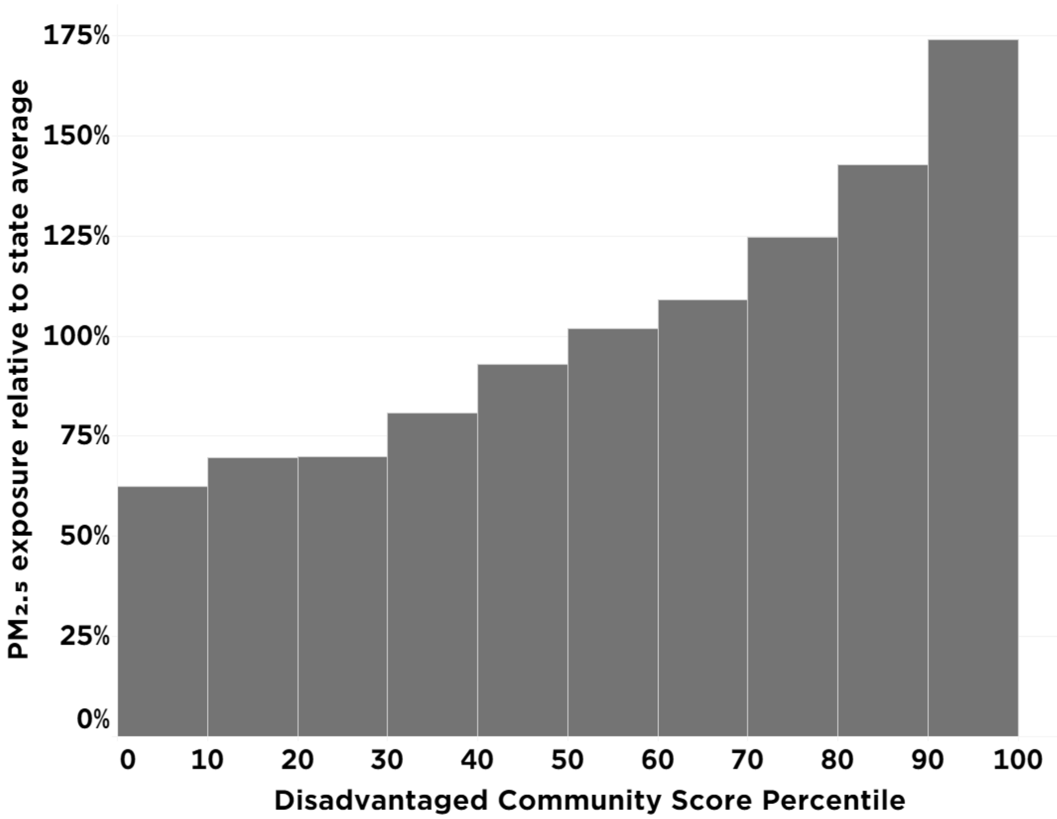
Communities with the highest exposure to pollution from older cars have higher fractions of lower-income households. More than half the households are low income (less than $60,000 household income) in the areas with highest exposure to $PM_{2.5}$ air pollution from older cars and trucks.

FIGURE 4. $PM_{2.5}$ Pollution from Older Cars and Race/Ethnicity



Communities with higher exposure to $PM_{2.5}$ pollution from older vehicles have higher fractions of Latino and Black people than do low-exposure communities. For example, Latino Californians are exposed to concentrations 19 percent higher than the state average.

FIGURE 5. Exposure of Environmentally Disadvantaged Communities to Older-Vehicle Pollution



Communities that are designated as disadvantaged based on their CalEnviroScreen Score have more exposure to pollution from older vehicles. One factor California uses to designate disadvantaged communities is a score above the 75th percentile from the CalEnviroScreen tool.

Estimating Premature Deaths Due to Pollution from Older Vehicles

To estimate premature deaths from $PM_{2.5}$ pollution exposure resulting from using older vehicles, we examined two scenarios. One scenario evaluated only emissions from starting a vehicle; the second considered all tailpipe and evaporative emissions. We chose these scenarios because the rates of air-pollution emissions from gasoline vehicles are much higher when starting a vehicle engine after a period of inactivity as a cold exhaust system results in lower catalytic converter performance and therefore more air pollutant emissions.

For passenger vehicles, it is reasonable to assume that cold starts often occur at or near where the vehicle is registered. Emissions also occur as the vehicle moves, with some likely occurring in or near the registration location. However, the fraction of emissions occurring near that location is not known. Similarly, we do not know the location of evaporative emissions, though some fraction likely occurs at the registration location.

These scenarios provided a range for the estimated premature deaths in California, in one case only considering cold-start emissions at the location of vehicle registration and in the second case assuming that all tailpipe emissions happen where the vehicle is registered (Table 3). We estimated that older-vehicle emissions led to between 97 and 421 premature deaths per year. The impacts were concentrated in Southern California, especially Los Angeles County.

TABLE 3. Premature Deaths Due to Older-Vehicle Emissions in California

	Estimated Premature Deaths Due to Older-Vehicle Start Emissions	Estimated Premature Deaths Due to Older-Vehicle Total Emissions
Los Angeles County	34	170
San Diego County	10	43
Orange County	9	43
San Bernardino County	5	23
Riverside County	5	20
All Other California Counties	34	122
Total	**97**	**421**

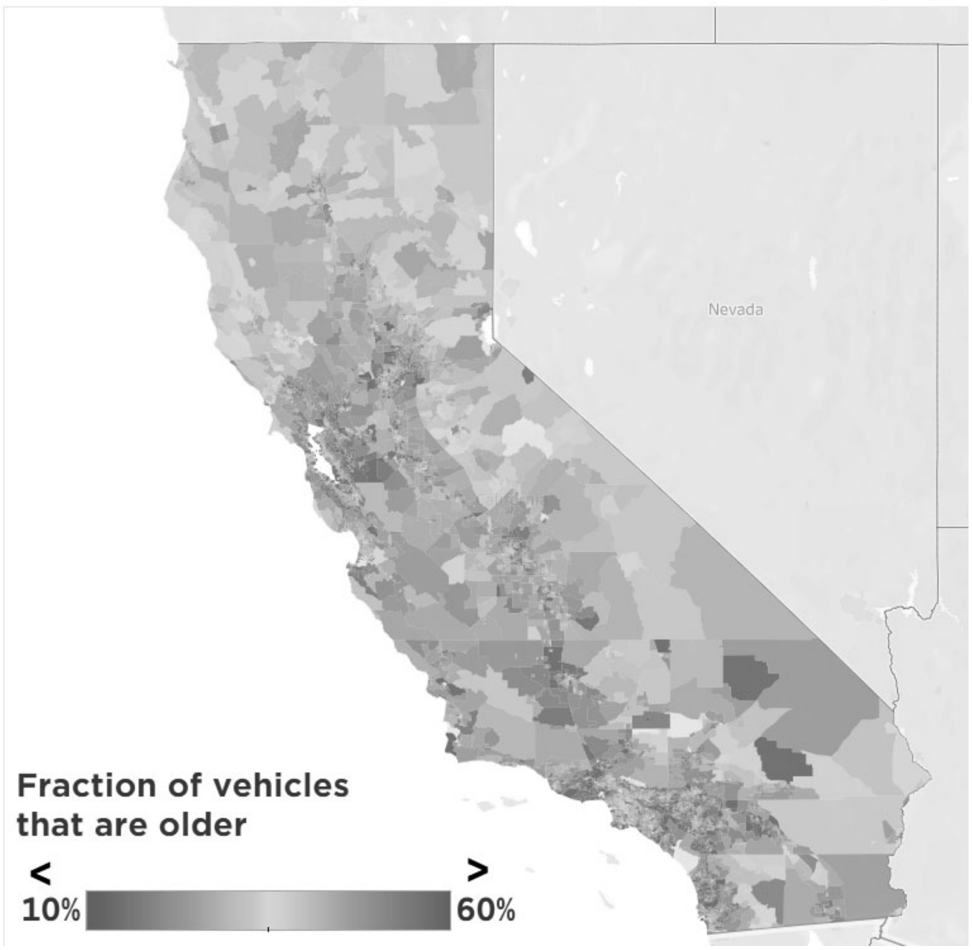
Premature deaths due to older-vehicle emissions are higher in Southern California. Los Angeles County alone accounts for over one-third of the state total.

Note: Total emissions includes driving, starting, and evaporative emissions.

Rural Areas Have a Higher Proportion of Older Vehicles

While Southern California's urban areas have the most older vehicles (and highest exposure to the resulting pollution), rural areas have higher proportions of older vehicles (Figure 6). For example, in rural Modoc, Trinity, and Sierra counties, over 40 percent of vehicles are model year 2003 or older. In contrast, Orange, San Francisco, and Riverside counties, all of which are much more urban, have the lowest percentages of older cars.

FIGURE 6. The Fraction of Older Vehicles in Rural and Urban Areas



Rural areas of California have higher proportions of older cars even though the total number of old cars is lower than in urban areas.

Recommendations: Policies to Reduce Inequitable Exposure to Pollution

Based on the impacts of older cars on local air quality and public health, it is imperative that the California agencies administering incentive programs for retiring and replacing vehicles prioritize getting the oldest cars off the state's roads. Policymakers should also ensure that programs benefit disadvantaged and low-income communities. Moreover, when developing policies and programs, California should involve—and in meaningful ways—the communities most impacted by older-vehicle emissions. This will help the state identify approaches to reducing the inequitable distribution of this pollution from older passenger vehicles.

UCS and The Greenlining Institute recommend the following changes in state policies and programs:

- **Prioritize incentives toward priority populations owning old cars.** State agencies should integrate programmatic changes to existing incentive programs, such as Clean Cars All and the Clean Vehicle Assistance Program, to prioritize investing in low-income and disadvantaged communities with high concentrations of older cars.[6] By doing so, the state can target high-polluting cars and make better use of limited funding. Given the high concentration of old-vehicle pollution in Southern California—and particularly in the Los Angeles area—the state should evaluate whether current incentive programs adequately serve the most deserving old-car owners in those regions. Incentives need to be logistically and economically attractive to old-car owners to encourage them to upgrade to cleaner electric cars or more fuel-efficient gas models that are more affordable to operate.

- **Target outreach and education to areas with high concentrations of old cars and limited uptake of zero-emissions vehicles.** State and local agencies should target their limited outreach and education funds. In light of our analysis, state outreach and education must be sensitive to the fact that older-car pollution disproportionately burdens Latino and Black communities. Multilingual and culturally accessible outreach and education are essential, and collaboration with trusted community-based organization can improve the results.

- **Provide transportation solutions that go beyond private passenger vehicles.** Even as California seeks to reduce vehicle miles traveled, it continues to invest in vehicle incentive programs that prioritize car ownership. Agencies should consider higher funding for programs that promote alternative modes of transportation, such as e-bikes, car sharing, and public transportation. One option is to dedicate more funding to the Clean Mobility Options component of Clean Cars 4 All, along with supporting other efforts that use a bottom-up approach and enabling communities to define their needs. Also key are land-use decisions that reduce the need to drive and encourage the use of alternative modes of transportation. This strategy could be particularly fruitful in the denser, urban hubs of greater Los Angeles where a substantial portion of older-vehicle pollution is concentrated.

- **Evaluate and adjust incentive programs based on changing conditions in the electric-vehicle market.** While California mandates that all new vehicles sold in the state by 2035 be zero-emissions, today's selection of zero-emissions vehicle (ZEV) models is limited. Not many lower-priced ZEV models are available, and even fewer are available in larger-size classes like SUVs and full-size pickup trucks. Despite generally declining prices for electric vehicle components like batteries, the pandemic's impact on the supply chain has led to price increases for both new and used EVs. California should continue to evaluate and adapt its incentive programs to best assist people based on their needs. While a complete switch to zero-emissions technology will happen in the longer term, the prices and limited supply of electric vehicles can make their purchase difficult in the near term. Thus, the state should not discourage owners from switching to other types of cleaner and cheaper-to-fuel vehicles, even those that are not zero-emissions. In rural areas, where alternatives to personal vehicles are less prevalent, California should continue encouraging people to switch to cheaper-to-fuel vehicles, especially drivers and owners of larger-size classes like pickup trucks. This is particularly important given that the largest proportion of older cars are in largely rural areas where public transit and micro-mobility alternatives are more difficult to implement. Transportation electrification should continue to be a priority, but simply switching from older to newer vehicles can still result in meaningful emissions reductions under current economic conditions.

Saving Money and Lives

As California endeavors to decarbonize its transportation sector, it must place a strong emphasis on phasing out the worst-polluting vehicles. This analysis by UCS and the Greenlining Institute demonstrates that pollution from older vehicles disproportionality burdens Latino and Black Californians, low-income communities, and other populations already experiencing substantial exposure to pollution. To reduce climate-changing emissions and protect communities from harmful air pollution, California must make retiring older vehicles a priority.

State regulators and policymakers will need to ensure that *all* Californians have access to cleaner transportation options. Vehicle incentive programs must be adequately funded and prioritize populations most burdened by older-vehicle pollution. More broadly, transportation options in both cities and rural areas must be improved and expanded to offer affordable, accessible alternatives to owning passenger vehicles.

A cleaner, safer transportation future for all Californians is possible. To realize it, the state must commit to retiring the dirtiest polluters on the road. With sustained investment and targeted policies, California can protect its vulnerable communities from harmful air pollution, saving money and lives.

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Appendix: Methodology

Estimating Vehicle Emissions

To estimate the location of light-duty vehicles in California, we used the EMFAC Fleet Database of the California Air Resources Board (CARB) for vehicle model years 1976 through 2021 (EMFAC, n.d.a). That database provides on-road vehicle population estimates at the level of US Census Block Group. The EMFAC data are generated based on vehicle registration data from the California Department of Motor Vehicles.

The EMFAC Fleet Database gives the number of vehicles in a census block group of a particular model year, fuel type, and vehicle type. We filtered the data to eliminate other vehicle types by selecting EMFAC Fleet Database vehicle types P, T1, T2, and T3, corresponding to passenger cars and trucks with gross vehicle weight ratings up to 8,500 pounds.

The data were also filtered to remove census block groups with low population but anomalously high numbers of vehicle registrations, such as airport rental-car facilities, used automobile wholesalers, and auction storage facilities. The analysis excluded vehicles powered by natural gas.

We merged the filtered EMFAC Fleet Database with the EMFAC2021 Emissions Inventory (v1.0.2) per vehicle of NO_x, reactive organic gases, SO_x, direct $PM_{2.5}$, and NH_3 emissions for calendar year 2020 using vehicle type, fuel type, sub-area, and model year (EMFAC, n.d.b). Emissions rates were calculated using only cold-start emissions as a lower bound and total running emissions as an upper bound. The resulting dataset of emissions was summed by census block group and combined with the census block shapefile from the Census Bureau.

Modeling $PM_{2.5}$ Exposure

We estimated formation and transport of $PM_{2.5}$ using the InMAP v1.9.6 reduced-form, air-quality model with variable grid size between 1 and 12 kilometers (Tessum, Hill, and Marshall 2017).

We mapped the resulting $PM_{2.5}$ concentrations to census block groups using area-weighted interpolation. We combined the concentrations with data from the American Community Survey for the years 2017 through 2021 to determine particulate air-pollution exposure by demographic groups (US Census Bureau, n.d.). The $PM_{2.5}$ concentration data were also combined with scores on the California Environmental Protection Agency's CalEnviroScreen to provide a framework for stratifying estimated $PM_{2.5}$ exposures across census tracts (OEHHA 2023). We used the population-weighted annual average concentration as the primary metric of exposure to $PM_{2.5}$. For health impacts, we assumed a no-effect threshold concentration of zero micrograms per cubic meter because a lower bound has not been established for health effects of chronic $PM_{2.5}$ exposure (Pinault et al. 2016). We used the hazard ratio for all-cause mortality from Krewski et al. (2009).

ACKNOWLEDGMENTS

The Union of Concerned Scientists' work on this report was made possible by the generous support of the Energy Fund, the Heising-Simons Foundation, and UCS members.

The authors would like to thank the following people for their thoughtful review of the report: Jill Sherman-Warne, Native American Environmental Protection Coalition; Bahram Fazeli, Communities for a Better Environment; Prof. Julian Marshall, University of Washington; Laurel Plummer, California Office of Environmental Health Hazard Assessment.

UCS thanks Professor Pablo Saide and the UCLA Institute of Environment & Sustainability's 2021 Senior Practicum team (Anna Schneider, Aria Soeprono, Michelle Yep, Vivian Kha, and Weihao Shao) for discussions and analysis that helped in the design of this work.

Organizational affiliations are listed for identification purposes only. The opinions expressed herein do not necessarily reflect those of the organizations that funded the work or the individuals who reviewed it. The Union of Concerned Scientists and The Greenlining Institute bear sole responsibility for the report's contents.

ENDNOTES

[1] The Clean Air Act allows other states to adopt California's stronger vehicle standards.

[2] This report uses the term Latino to describe persons answering "yes" to the US Census question "Is this person of Hispanic, Latino, or Spanish origin?" The census collected race data in a separate question. The term White describes persons answering "no" to the Hispanic, Latino, or Spanish ethnicity question and choosing the response "White" in response to "What is this person's race?" The term Black describes persons answering "no" to the Hispanic, Latino, or Spanish question and choosing "Black or African Am." in response to "What is this person's race?" (US Census Bureau 2021).

[3] On-road vehicles also produce $PM_{2.5}$ from wear on tires and brakes.

[4] CARB's publicly available data do not include model year for vehicles manufactured before 1976, and some data are masked for privacy reasons.

[5] We excluded vehicles older than 1976; our input sources lacked detailed data on vehicles manufactured before 1976. The newest vehicles in the dataset were model year 2021.

[6] Clean Cars 4 All provides an incentive to scrap older, polluting cars and replace them with a zero- or low-emissions vehicles or transit vouchers. See: https://ww2.arb.ca.gov/our-work/programs/clean-cars-4-all. The Clean Vehicle Assistance Program provides grants and loans to lower-income buyers for the purchase of a zero-emissions vehicle. See https://cleanvehiclegrants.org/.

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https://doi.org/10.47923/2023.15101

Climate Change and Children's Health and Well-Being in the United States

APRIL 2023

United States Environmental Protection Agency

Front Matter

ACKNOWLEDGEMENTS

This report was developed by EPA's Office of Atmospheric Protection (OAP) and contains modeling contributions from Federal agency analysts, academic experts (including Aaron Bernstein, Patrick Kinney, Jisung Park, Keith Spangler, and Gregory Wellenius), and consultants (including Industrial Economics, Inc.). Support for the report's production was provided by Industrial Economics, Inc.

PEER REVIEW

The methods of the climate change impacts analyses described herein have been peer reviewed in the scientific literature. In addition, this report was peer reviewed by four external and independent experts in a process independently coordinated by Eastern Research Group, Inc. EPA gratefully acknowledges the following peer reviewers for their useful comments and suggestions: Samantha W. Ahdoot, Rupa Basu, Timothy W. Collins, and Kari C. Nadeau. The information and views expressed in this report do not necessarily represent those of the peer reviewers, who also bear no responsibility for any remaining errors or omissions. Appendix G provides more information about the peer review.

RECOMMENDED CITATION

EPA. 2023. Climate Change and Children's Health and Well-Being in the United States. U.S. Environmental Protection Agency, EPA 430-R-23-001.

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DATA AVAILABILITY

Data generated from the analyses of this report can be accessed on the following website: http://www.epa.gov/cira/climate-change-and-childrens-health-and-well-being-united-states-report

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Appendices

Appendices with additional analytic details, information on data sources, and supplemental results are provided online at http://www.epa.gov/cira/climate-change-and-childrens-health-and-well-being-united-states-report

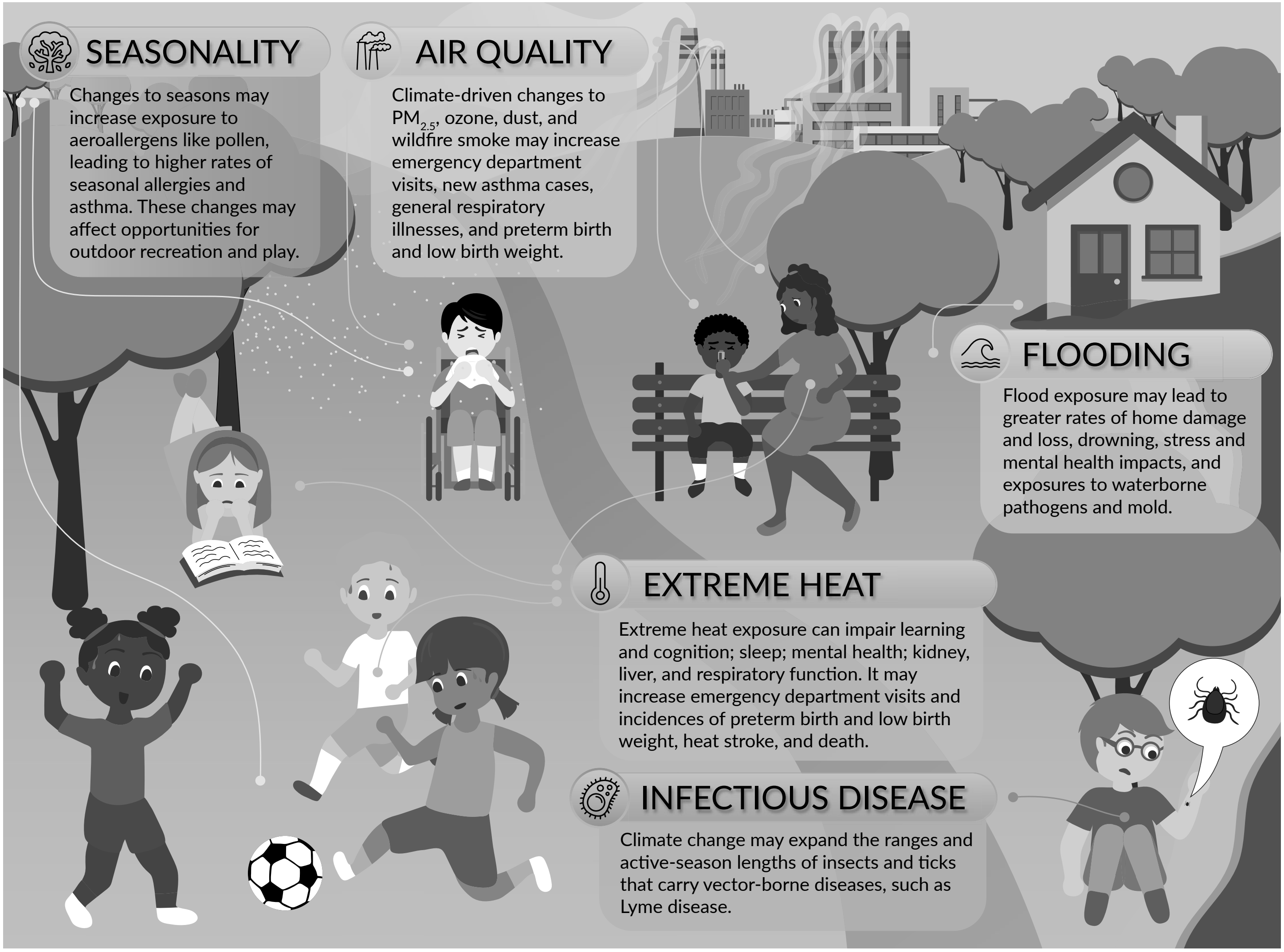
A final appendix covers the peer review process and information quality procedures undertaken.

EXECUTIVE SUMMARY

Introduction

Our climate is changing, and the health and well-being of children will continue to be affected in many ways. Children are uniquely vulnerable to climate change in part because of the natural physiology of developing and growing bodies. Exposures to climate-related stressors can occur in a variety of ways, some of which are distinctive to children, including through outdoor play and at school. Children, and young children especially, have less control over their physical environments, less knowledge about health effects from climate change, and less ability to remove themselves from harm. Climate impacts experienced during childhood can have lifelong consequences stemming from effects on learning, physical development, chronic disease, or other complications.

This report investigates five climate-related environmental hazards associated with children's health and well-being in the contiguous United States (U.S.): extreme heat, poor air quality, changes in seasonality, flooding, and different types of infectious diseases. It provides national-scale quantification of risks to children for a subset of key impacts, in addition to reviewing a broad set of pathways in which climate stressors affect children's health. The analyses presented in this report are part of the EPA's Climate Change Impacts and Risk Analysis (CIRA) project, a framework using consistent inputs to enable comparison of impacts across time and space. The infographic below shows some examples of ways children can be exposed to harmful conditions in a changing climate.



EXECUTIVE SUMMARY

Analysis Approach

The analyses in this report rely on existing evidence establishing links between environmental conditions and impacts on children to project what our changing climate may mean for future generations. Results are summarized by degree of global warming relative to recent conditions. Each detailed analysis follows three main steps:

1 **Establish current risks to children:** Existing literature and data are used to document or model conditions for children during a baseline period of 1986-2005.

2 **Project future environmental conditions:** The rich array of climate data provided in general circulation models (GCMs), or climate models, are employed to project future climate hazards.

3 **Estimate future impacts on children:** Statistical relationships from peer-reviewed, relevant literature are leveraged to project impacts on children's health resulting from exposures to climate change-associated hazards.

Risks are documented for all children in the contiguous U.S., with additional consideration for effects at local and regional scales. The analyses also examine the extent to which certain groups of overburdened children (Black, Indigenous, and people of color, or BIPOC; low income; limited English speaking; and children without health insurance) may be disproportionately exposed to the most severe impacts.

The report also highlights recent literature documenting other pathways in which the five climate stressors of interest may affect children, including potential future magnitudes of each outcome. Finally, some health outcomes from climate change can be prevented or reduced through well-timed and appropriate action; see Chapter 8 of this report for more information on ways to minimize health impacts to children.

FIVE DETAILED ANALYSES

Heat and learning: Heat negatively impacts children through learning, among other pathways. This analysis quantifies how heat experienced during the school year reduces learning, values those learning losses in terms of lost future income, and demonstrates the important role of air conditioning (A/C) in schools and homes in facilitating effective learning.

Air quality and children's health: Existing evidence clearly links poor air quality with various adverse health effects in children, including asthma. This analysis considers how a warming climate will change childhood exposures to particulate matter ($PM_{2.5}$) and ozone (O_3), and then quantifies the related effects on respiratory diseases and related outcomes.

Pollen and children's health: Climate change can increase children's pollen exposures as seasons lengthen and temperatures warm. This analysis examines how changes in oak, birch, and grass pollen may lead to more visits to healthcare facilities, prescriptions filled for allergy medications, and emergency department (ED) visits for asthma among children.

Coastal flooding and children's homes: During flooding events, children experience safety risks, psychological stress associated with displacement and loss, as well as health risks from water-borne pathogens and mold in flooded structures. This analysis estimates the number of children who may experience temporary or permanent displacement from their homes because of coastal flooding.

Lyme disease: Varying temperature and precipitation patterns are likely to alter the habitat, range, and density of pathogens, vectors, and hosts that can cause disease among children. Lyme disease, carried by blacklegged (deer) ticks, is one such disease. This analysis projects the number of new Lyme disease cases in parts of the country.

EXECUTIVE SUMMARY
Key Findings

Results of the detailed analyses are presented for increases in global average temperature of 2°C and 4°C above levels observed in 1986-2005. For the flooding analysis, analogous results for 50 cm and 100 cm of global sea level rise are described. Average impacts across climate models are highlighted, in addition to the minimum and maximum estimates projected by the models. In situations where overburdened children may be disproportionally exposed to the most severe impacts, those findings are provided as well. The summary below also discusses other key pathways through which children are likely to be affected by climate change in the future.

David L. Ryan / The Boston Globe via Getty Images

Temperature increases of 2°C and 4°C of global warming are associated with, on average, 4% and 7% reductions in academic achievement per child, respectively, relative to average learning gains experienced each school year. Across each cohort of graduating students, the total lost future income attributable to these learning losses may reach $6.9 billion ($1.9 to $12.7 billion) at 2°C and $13.4 billion ($8.9 to $18.3 billion) at 4°C. In contrast, installing A/C in schools is less costly, although this action only partially mitigates these effects, and may further induce GHG emissions that contribute to climate impacts. Black, Hispanic or Latino, and low income students report the lowest rates of current A/C in schools, and therefore are likely to experience these impacts disproportionately.

Another way to measure the magnitude of heat's effects on children's health is the number of ED visits associated with high temperature days. Existing evidence suggests the number of ED visits among children are expected to increase between May and September each year as summer temperatures continue to rise.

EXECUTIVE SUMMARY

Key Findings

New diagnoses of asthma associated with $PM_{2.5}$ and O_3 exposure are estimated to increase by 34,500 (27,900 to 42,800) per year at 2°C of global warming up to 89,600 (74,100 to 108,000) at 4°C. On average, this represents a 4% and 11% increase relative to baseline incidence. ED visits and hospital admissions due to general respiratory conditions are projected to increase, as are school days lost because of these effects. The analysis further projects additional premature deaths among newborns. Most impacts stem from climate-induced changes in weather conditions that worsen concentrations of $PM_{2.5}$ and O_3, although wildfires and ground-level dust in the arid Southwest also play a role. BIPOC children are more likely to experience new asthma diagnoses associated with $PM_{2.5}$ exposure, specifically.

Wildfire smoke is comprised of numerous air pollutants that pose significant human health impacts, including adverse birth outcomes. New research documents the association between exposure to wildfire smoke and risk of preterm birth, suggesting a dramatic potential increase in this outcome as wildfire activity continues to increase.

At 2°C of global warming, an additional 5,800 (4,800 to 8,000) asthma-related ED visits in children are anticipated annually from exposures to oak, birch, and grass pollen, increasing to approximately 10,000 (9,500 to 11,000) additional visits annually at 4°C of warming. Less severe outcomes, like visits to healthcare facilities for seasonal allergies (allergic rhinitis) and prescriptions for allergy medications for children, may increase by 41,000 (34,000 to 57,000) visits and 121,000 (101,000 to 167,000) prescriptions annually at 2°C of warming. On average, the health impacts associated with pollen exposure increase 17% and 30% at 2°C and 4°C, respectively. Limited English-speaking, BIPOC, and uninsured children are more likely to experience these impacts stemming from oak pollen exposure, specifically.

Changing seasonality also will alter the ways children play or recreate outside. Overall, new evidence suggests that lengthening warm seasons are expected to result in more time spent on outdoor recreation, especially boating and water sports. On the other hand, the number of trips associated with some recreation types, like skiing and cold-water fishing, is projected to decrease under climate change.

EXECUTIVE SUMMARY

Key Findings

If no additional adaptation actions are taken, approximately 185,000 (159,000 to 437,000) children are estimated to experience complete home loss from coastal flooding at 50 cm of global sea level rise increasing to 1.13 million (477,000 to 3 million) at 100 cm. More than 1 million additional children living in coastal areas may be temporarily displaced from their homes annually due to flooding at both 50 cm and 100 cm. Well-timed adaptation measures, including building sea walls, could delay or prevent many of these impacts; however, they themselves are costly. Children in each of the overburdened groups considered in this report are disproportionally affected by temporary home displacement at 50 cm and complete loss of home at 100 cm.

Inland flooding, also known as riverine flooding, could increase in the future due to climate change. Existing research suggests children will experience damage to their homes from flooding in these areas.

In 21 Eastern states and the District of Columbia, an additional 2,600 (-7,500 to 20,200) new Lyme disease cases per year are projected among children under 2°C of global warming. At 4°C of global warming, the increase is much more extreme: 23,400 (7,800 to 47,000) additional cases per year. These additional cases represent a 31% to 272% increase above baseline infection levels, respectively. States in the northernmost areas of the Northeast and Midwest regions are expected to see most of new cases among children. Research demonstrates that Lyme disease may be under-reported and undertreated among some overburdened populations, increasing the likelihood of more severe outcomes in these communities.

West Nile Virus (WNV) carried by mosquitos is likely to see a change in new cases as temperatures increase, including among children. While existing evidence suggests the estimated increase in new cases of West Nile Neuroinvasive Disease (WNND), a severe outcome associated with WNV, is anticipated to be small in magnitude, growing numbers of cases could be indicative of greater rates of other types of mosquito-borne diseases.

EXECUTIVE SUMMARY

Regional Highlights

Finally, this report documents where climate-induced impacts on children are projected to be most acute. Among the impacts considered, this section identifies the states and regions that are likely to experience the greatest impacts, including emerging areas of interest. The map below summarizes the findings for 2°C of global warning and 50 cm of global sea level rise. By synthesizing results across regions, the map demonstrates how children can experience multiple climate stressors simultaneously. However, the map does not convey the geographic distribution of all climate change impacts on children, or where baseline impacts are high.

NORTHWEST

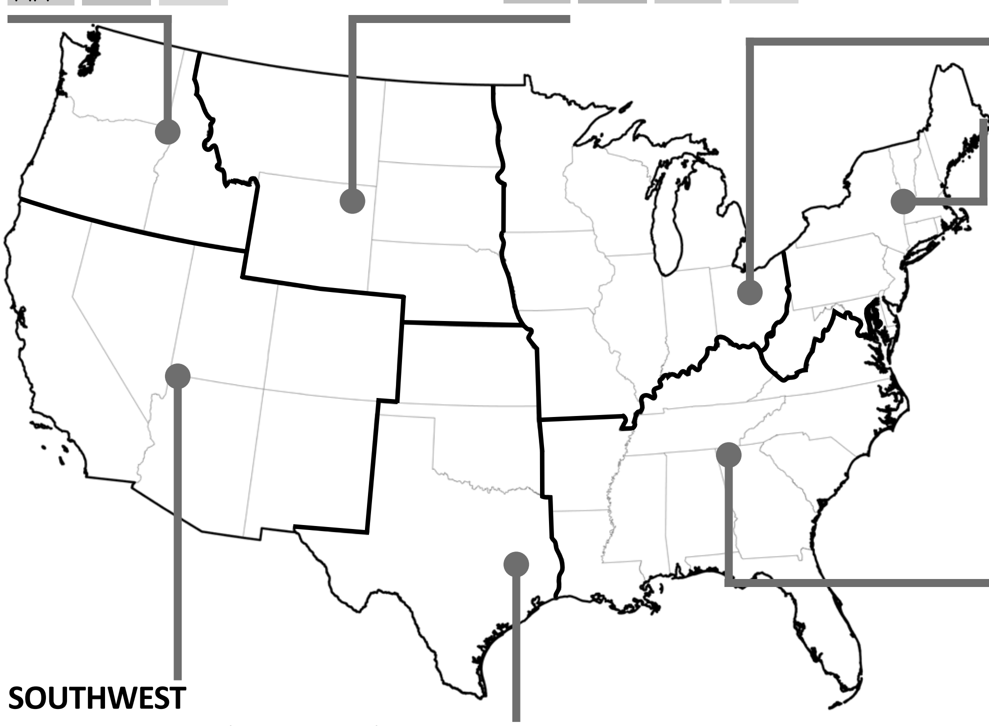
ID and OR are projected to have high concentrations of wildfire smoke, while some of the highest rates of respiratory health impacts among children nationally are projected in WA due to degrading air quality from the climate-induced sources in this analysis. Additionally, increased grass pollen is projected to result in high adverse health effects per capita in OR. Inland flooding effects are among the greatest in the country.

NORTHERN GREAT PLAINS

WY is among the states with the highest projected learning losses per child nationally given high warming and low current A/C coverage. WNND incidence rates may be greatest in ND, NE, and SD, compared to national rates. MT and WY are projected to experience some of the highest rates of health effects to children from wildfire smoke. Inland flooding effects are among the greatest in the country.

MIDWEST

Increasing climate-driven concentrations of O_3 in IL, IN, and OH may contribute to some of the highest rates of air quality health effects on children nationally. MI is projected to experience some of the most considerable learning losses per student due to heat exposure, while MI and MN experience the most extreme per capita increases in Lyme disease cases. IN and OH are projected to see the greatest impacts on children's health of across all included pollen types.



NORTHEAST

ME, NH, and VT are among the states with the highest projected learning losses per child from high temperatures during the school year, as well as low current A/C coverage. These states may also experience the greatest increase in Lyme disease rates. Children in WV and VT are most likely to experience health impacts associated with oak and birch pollen exposures. MD and DC may have some of the highest rates of climate-driven air quality impacts per child, where O_3 is the primary exposure.

SOUTHWEST

Dust in AZ, CO, NM, and UT is projected to adversely impact respiratory health among children. Wildfire smoke stemming from future fire activity in CA is projected to lead to high rates of poor health outcomes, such as asthma. WNND incidence rates are projected to be among the highest in AZ and CO. Inland flooding effects are high in this region.

SOUTHERN GREAT PLAINS

Increases in exposures to grass pollens may lead KS and OK to have some of the highest rates of ED visits for asthma among children. Children in central TX are expected to see considerable per capita health impacts from exposures to oak and grass pollen.

SOUTHEAST

Children in coastal areas of GA, LA, NC, SC, and VA are the most likely to be affected by the impacts of coastal flooding on their homes, assuming no additional protective measures are taken. Inland flooding effects also are high in this region. Climate-driven changes to $PM_{2.5}$ exposure may lead to significant air quality health impacts in AL, GA, NC, and SC. KY may experience among the greatest rates of pollen-related and combined air quality-induced impacts on children nationally.

Glossary

This glossary provides a reference for important terms used throughout the report. For most terms, a technical definition from an external source is provided. For other terms where a specific definition is used in this report, that use case is provided instead of or in addition to a technical definition.

Adaptation – Actions taken to prepare for and/or adjust to climate change impacts.[1] This is complementary to, but separate from, mitigation.[2]

Aeroallergens – Airborne, natural substances such as plant or tree pollen, or mold or fungal spores, that produce an allergic reaction, often presenting as allergic rhinitis (also known as "hay fever"), allergic conjunctivitis, or other respiratory effects like asthma.[3]

Asthma (diagnosis) – A disease that causes inflammation and constriction (narrowing) of the airways to the lungs, limiting or preventing air from entering or exiting the lungs. Asthma is more common in children than adults and is more common in boys than girls.[4]

Asthma attack – A temporary worsening of asthma resulting in difficulty breathing, wheezing, severe cough, or hospitalization, which may be trigged by environmental stressors such as such as aeroallergens, wildfire smoke, or air pollution (triggers discussed in this report).[5]

Baseline – A quantity or scenario (such as of emissions of a pollutant) that is used as a default against which a change is compared. In this report, "baseline" refers to conditions in 1986-2005.

Children – In this report, "children" refers to people younger than 18 years of age. See Chapter 1 for a more detailed definition.

Climate change-related gentrification – The process that leads to the displacement of low-income populations as wealthier residents seek safety from natural, climate change-related hazards to areas that face fewer natural risks or implement hazard mitigation measures.[6]

Climate model – A set of mathematical equations that characterizes how energy and matter interact in different parts of the ocean, atmosphere, and land.[7] Some climate models are referred to as general circulation models or GCMs.

Climate stressor – A condition, event, or trend related to climate that can exacerbate hazards.[8] The climate stressors covered in this report include heat, air quality, flooding, changing seasonality, and infectious diseases.

Coastal flooding – Coastal flooding occurs when water inundates or covers normally dry coastal land as a result of high or rising tides or storm surges.[9] Coastal flooding results from a combination of factors, including waves, tides, storm surges (intense waves of inrushing saltwater which arise during storms), and changes in sea level over time. The most intense storm surges occur during hurricanes and Nor'easters, when low barometric pressures (which temporarily force an increase in ocean levels) and wind-driven water combine to push coastal water landward. The forces behind coastal flooding exhibit natural vulnerability, but sea levels and the intensity and frequency of hurricanes and other coastal storms can be worsened by climate change—as the climate warms, sea levels rise due to the combination of thermal expansion of water volume, melting of glaciers and other ice sheets, and other factors.

Contiguous United States – The 48 adjoining U.S. states and the District of Columbia, which excludes Alaska, Hawai'i, and U.S. territories.

Degree of global warming – A change in the global average surface temperature of one degree above a specific baseline or time period. In this report, degrees of global warming are described relative to averages observed in or modeled for the 1986-2005 period.

Environmental justice – the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.[10]

Flash flood – Flooding resulting from heavy rainfall, officially within 6 hours from the start of the precipitation event. Flash floods can occur in rivers and streams, but also in the built environment, such as paved streets.[11]

Greenhouse gas mitigation or emissions mitigation – The process of reducing greenhouse gas (GHG) emissions or strengthening GHG sinks that take GHGs out of the atmosphere. This is complementary to, but separate from, adaptation.[12]

Heat stress – A general term that refers to a variety of health outcomes that result from exposure to heat over a sustained amount of time. The exact temperature and duration of exposure that can lead to illness is dependent upon the person, the activity they are undertaking, their access to drinking water, comorbidities they may have, and other factors. A few examples of severe illnesses that exist under this umbrella term include the following:

- *Heat stroke*, which refers to the inability of a person's body to self-regulate or cool down. This quickly can lead to death.
- *Heat exhaustion*, which presents as a number of symptoms, including headache, nausea, fatigue, and others.
- *Rhabdomyolysis*, which is the breakdown of muscle tissue. This can cause organ failure and death.[13]

Home loss – In this report, "home loss" refers to the loss of physical, home-based space by a person due to some sort of environmental condition, including flooding or wildfire.

Infectious diseases – Illnesses that may be spread from bacteria or viruses.[14]

Lyme disease – Illness caused by the bacterium *Borrelia burgdorferi*, which is spread to humans by tick bites. Most commonly, in the U.S., Lyme is spread by the deer tick, also known as the blacklegged tick (*Ixodes scapularis* Say). It also is spread by the Western blacklegged tick, *I. pacificus* Cooley and Kohls.[15]

Managed retreat – The process by which coastal communities move away from areas endangered by climate change-related hazards.

Ozone (O_3) – A greenhouse gas and air pollutant that occurs naturally (stratospheric ozone) or is created through the release and reaction of volatile organic compounds and nitrogen oxides in the presence of sunlight (ground-level, or tropospheric, ozone)[16]

Particulate matter ($PM_{2.5}$ and PM_{10}) – Airborne particles that are less than 2.5 ($PM_{2.5}$) or 10 (PM_{10}) micrometers in diameter. This report primarily focuses on the health effects from exposure to ambient $PM_{2.5,}$ which can contribute to the development of asthma, diabetes, COPD, heart attacks, and other respiratory and cardiac conditions.[17] PM_{10} refers to particles that are 10 micrometers or smaller and may be visible to the naked eye. While these particles are larger, and therefore may not be inhaled as deeply into the lungs, this type of particulate matter can still cause considerable injury to the lungs and airways, leading to chronic effects such as asthma and COPD.[18]

Pathogen – An organism such as a bacteria, virus, fungus, or parasite that harms its host upon exposure. Examples include *Vibrio* spp., Lyme disease via *B. burgdorferi,* and West Nile Virus. They can be spread to humans via food, water, animal vectors, or other humans.[19]

Pluvial flooding – Flooding occurring from excessive precipitation that cannot be immediately absorbed into soil or drained away.[20]

Riverine flooding – Flooding that occurs when a river or stream overflows its banks.[21]

Seasonality – Recurring events or processes that are correlated with seasons, such as rising temperatures at the end of winter or the onset of allergies during ragweed season.

Social vulnerability (also, "socially vulnerable") – Referring to the measure or level of vulnerability of a particular population in the face of different types of environmental stressors and natural hazards.[22] This report includes the following variables as measures of social vulnerability: age (which is a prevailing factor throughout this report), race, ethnicity, poverty status, whether English is a child's first or primary spoken language, and whether a child is covered by health insurance.

Storm surge – A rise in coastal water levels during a weather event (e.g., hurricane, tropical storm), as a consequence of winds propelling ocean water towards the shore. Storm surge can be extremely powerful and cause considerable flooding. It is generally the cause of the majority of injuries, property damage, and deaths during tropical weather events.[23]

Vibriosis – Illness resulting from exposure to non-cholera-causing *Vibrio* species.[24]

West Nile Virus – The most common mosquito-borne illness in the U.S. West Nile does not frequently cause severe illness in children, and typically presents as cold-like symptoms, although it may have extreme health effects on children who are immunocompromised. Such effects may include temporary or permanent paralysis or death.[25]

Chapter 1: Introduction

The goal of this report is to describe and quantify some of the future impacts of climate change on children across the U.S. using the best-available literature and data.

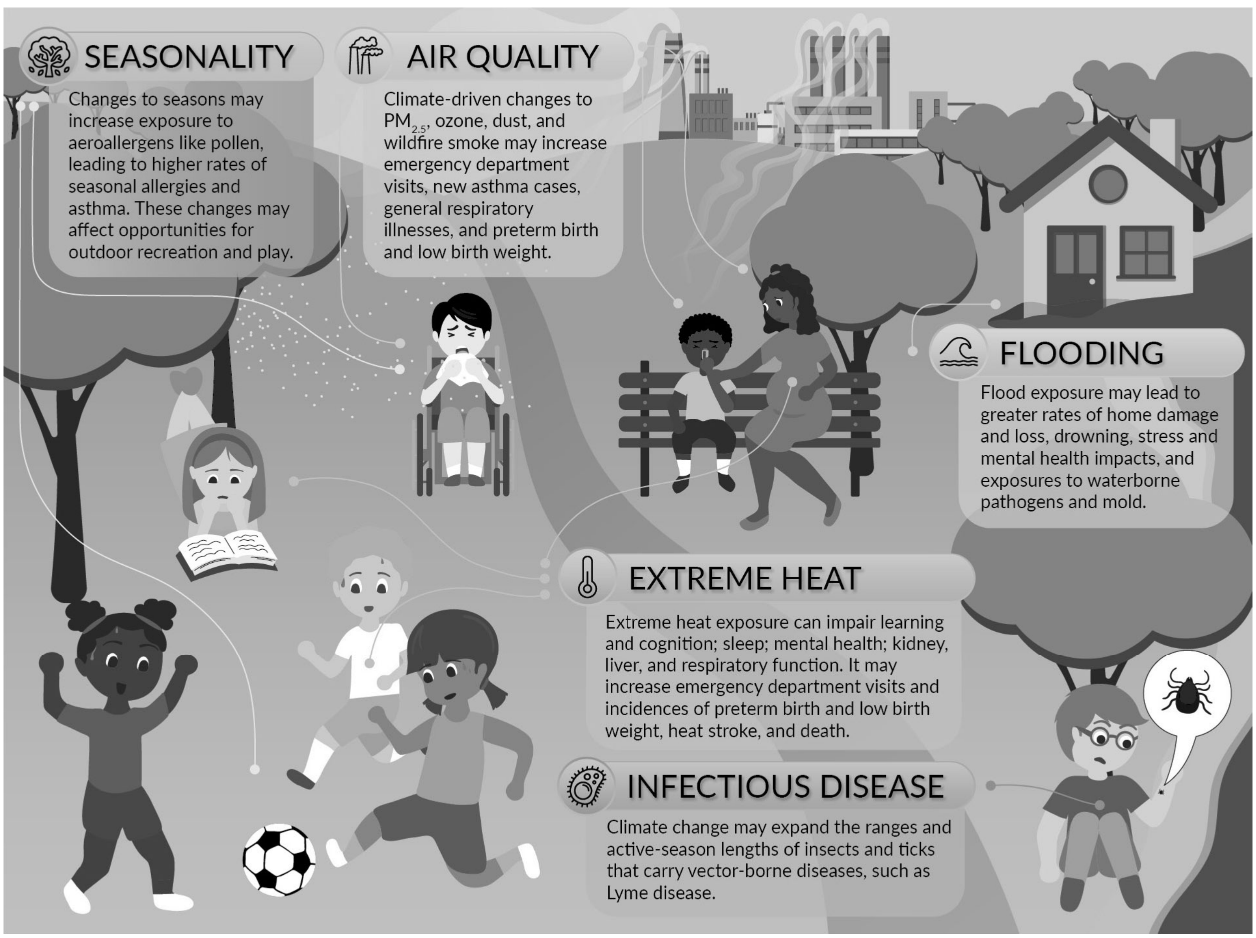
The intended audience includes parents, healthcare providers, researchers, public health practitioners, and decision makers who design and implement strategies and policies to reduce these risks through greenhouse gas mitigation and adaptation.

Our climate is changing, and the health and well-being of children will continue to be affected in many ways.[26] Multiple lines of evidence show risks to children through increasing temperatures, rising sea levels, changing rainfall patterns, more extreme wildfire seasons, and shifting patterns of disease exposure.[27] Children are uniquely vulnerable to climate change in part because of the natural physiology of developing and growing bodies.[28] They physically, psychologically, and socially experience health effects differently from adults.[29]

For example, a baby may be born early and underweight if the pregnant mother experiences a heatwave or is exposed to poor air quality.[30,31] Poor birth outcomes such as these can lead to lifelong effects on behavior and learning.[32] Likewise, children of all ages can develop asthma or cardiac conditions, or be exposed to heat or diseases that can have short- and long-term health consequences.[33,34,35] They also may experience psychological or cognitive effects from exposure to stress or trauma preceding, during, or following severe weather.[36,37] Where possible, a qualitative discussion of the mental health effects of climate change on children is provided throughout the report and in greater depth in Appendix A.

Exposures can occur in a variety of ways, some of which are unique to children. Play – essential to children's healthy physical and emotional development, as well as the very essence of childhood – can change the pathways and extent to which children are exposed to different hazards.[38,39] Outside of play, children can be exposed to hazards by breathing in air pollutants, living in a home or attending a school that is not air conditioned, living in a floodplain, or getting bitten by a tick or mosquito.[40,41,42] Children also have less control over their physical environment than adults. For instance, young children may be unable to open car doors when the inside conditions become unpleasant or dangerous or cannot mask themselves when air quality is noticeably poor. Figure 1 shows some examples of ways in which children can be exposed to harmful conditions in a changing climate via the climate stressors covered in this report.

Figure 1: Examples of Climate Stressors and Impacts on Children



Notes: This figure illustrates the five climate stressors covered in this report as well as some of the ways children are affected by the chosen stressors. See Chapter 2 for details. The figure is not intended to provide a comprehensive accounting of all ways through which children are affected by climate change.

Many health outcomes from climate change can be prevented or minimized through well-timed and appropriate action (see Chapter 8 for more information on ways to minimize health impacts to children). For example, during extreme heat, it is important for children to hydrate often, to play outside earlier or later in the day when temperatures are cooler, and to seek shade to rest and cool off. Monitoring local air quality alerts, especially during wildfire smoke and ash warnings, and limiting children's time outdoors when the air quality is poor, can help reduce exposure and potential health effects. Successful strategies to minimize adverse health outcomes in children depend on a combination of social factors, improved forecasting of weather and climate conditions, and better understanding of how climate change impacts will vary in a changing climate.

This report provides national-scale, multi-sector analyses focused on quantification of projected health risks to children in the contiguous U.S. from climate change. It investigates climate stressors including changes to the frequency and intensity of extreme heat, climate-driven effects on air quality, flooding, changes in seasonality (measured by recreation opportunities and pollen exposures), and different types of infectious diseases. The analyses consider and quantify how children may experience physical harm, and where possible, the extent to which effects disproportionately fall on overburdened children. The report builds on a framework developed by EPA in a 2021 report on climate change and social vulnerability.[43]

Each chapter includes the following components: a discussion of a climate stressor, a literature review of the known attributable health effects, and projections of how risks may change in the U.S. under different levels of future warming. The report concludes with a chapter on actions for addressing and preparing for these risks, through applications of hazard mitigation and adaptation measures, improved risk communication to support healthy choices for children and their parents and caregivers, and recommendations for future research.

The analyses presented in this report are part of the EPA's Climate Change Impacts and Risk Analysis (CIRA) project, a multi-model framework using consistent inputs to enable comparison of climate-driven impacts across time and space.[44] The purpose of CIRA is to quantify the physical effects and economic damages of climate change in the U.S. Using detailed models of sectoral impacts (e.g., human health, infrastructure, and water resources), the project seeks to quantify and monetize how risks, impacts, and damages may change in response to greenhouse gas mitigation and adaptation actions. The data and methods follow this framework and are applied in the detailed analyses in this report. Each underlying study has been peer-reviewed and published in the scientific literature; the corresponding research papers are cited throughout this report and in the appendices.

This report is intended to provide insights about risks to children's health across multiple impacts and future levels of global warming, with consideration for important sources of uncertainty involved with projecting future risks. It is not designed to be a comprehensive assessment of climate change impacts on children. Estimates should not be interpreted as definitive predictions of future impacts at a particular time or place. Instead, the intention is to produce estimates using the best available data and methods, identified by extensive literature reviews and prior analyses. The analyses can be revisited and updated as science and modeling capabilities continue to advance. Finally, there are many potential effects of climate change that are not explored in this report due to limitations of available data and robust methodologies. Therefore, the results capture only a portion of the potential risks to children's health.

The analyses presented in this report focus on how children experience the impacts of climate change *as children* (see definition below). Another important dimension of how climate change will affect children is through the increasing intensity of impacts they may experience *as future adults*. For instance, a child born the year this report was published may live to see the effects of a changing climate into the 22nd century, which are projected to be even more extreme than the impacts experienced by adults today. Projections of the cumulative effects of climate change on current and future generations of children is beyond the scope of this report.

How are children defined in this report?

U.S. EPA's Policy on Children's Health defines children's environmental health as the effect of environmental exposure during early life: from conception, infancy, early childhood, and through adolescence until 21 years of age. In this report, the term "children" encompasses individuals aged 0-17, or the period immediately postpartum (newborn) through the age customarily acknowledged in the U.S. as the end of childhood. Specific analyses may use narrower age ranges in which the underlying studies and methods indicate specific age groups. For instance, several studies are specific to school-aged children (aged 5-17) or infants only (aged less than one year). When possible, the report accounts for fetal effects, including preterm birth and low birth weight.

Chapter 2: Approach

This report takes an expansive approach to documenting climate risks to children, including both qualitative descriptions of the pathways by which climate affects children's health and quantified health impacts for key endpoints. The quantified impacts are summarized using an "impacts by degree of global warming" framework used in this and other EPA reports on climate change impacts.

This chapter describes the analytic approaches used throughout this report to assess the impacts of climate change on children's health and well-being in the contiguous U.S. It first explains the selection of the five specific climate stressors assessed in this report and then describes the three types of analyses conducted for each: a literature summary identifying impacts of climate change in children, a detailed analysis of one key impact pathway, and a discussion of emerging climate change impacts.

Lastly, this chapter provides an overview of the standard analytic approach used for the detailed analysis of each of the five climate stressors, including details on the impacts by degree approach, adaptation assumptions, how uncertainty is conveyed, geographic considerations, and how disproportionate risks to overburdened children are assessed.

CLIMATE STRESSORS

This report focuses on five climate stressors that are likely to impact children in unique ways: *extreme heat, air quality, changing seasons, flooding,* and *infectious diseases*. The selection of these specific climate stressors was guided by findings from recent research synthesizing the current state of understanding about how climate change affects children,[45] along with the availability of methodologies to quantify future risks for each. Many other types of climate stressors can and do interfere with the health and well-being of children in the U.S. beyond what is covered in this report.

IMPACT ANALYSIS TYPES

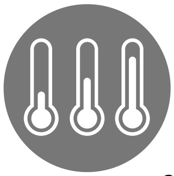
Each of the following chapters explores three types of evidence pertaining to the risk of impacts on child health for a particular climate stressor. Figure 2 summarizes the specific analyses for the five climate stressors covered in the report.

- Literature reviews summarize evidence that establishes pathways between climate stressors and various health outcomes among all children, with consideration for environmental justice concerns.
- Detailed analyses provide quantitative assessments of ways in which changing environmental conditions could affect children via a well-established impact pathway also known to be of substantial magnitude. Following the CIRA approach, results are summarized by degree of global warming relative to baseline conditions in 1986-2005. Analyses convey changes in risks to children, discuss geographies where impacts are concentrated, and when possible, determine whether already overburdened populations are more likely to be disproportionately affected than other groups.
- Emerging climate impact discussions highlight new literature quantifying other key climate-impact pathways of harm to children's health. These discussions indicate where deeper analysis is needed to further characterize future impacts.

Figure 2: Summary of Climate Stressors, Analyses, and Emerging Impacts Included in this Report

Climate Stressors	Detailed Analyses*	Emerging Climate Impacts
Extreme heat	Learning losses	Emergency department (ED) visits
Air quality	$PM_{2.5}$ and O_3 and children's health	Wildfire smoke and fetal health
Changing seasons	Pollen and children's health	Outdoor recreation
Flooding	Coastal flooding and children's homes	Inland flooding and children's homes
Infectious diseases	Lyme disease	West Nile Virus

**Specific impacts (endpoints) associated with each detailed analysis are summarized in the following section.*



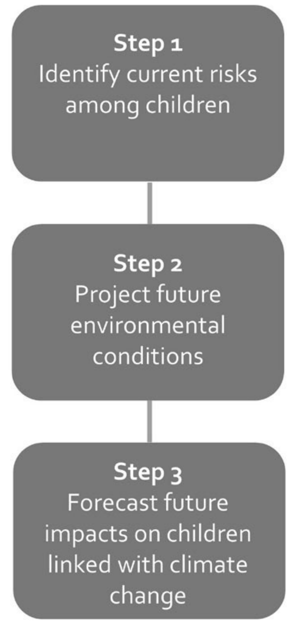
ANALYTIC APPROACH IN DETAILED ANALYSES

Detailed analyses in each chapter follow a standard analytic approach, which is summarized in this section and described in more detail in Appendix A. Individual analyses rely on specific data sources, methods, and assumptions that are explained in the relevant chapters and accompanying appendices.

STEPWISE ANALYTIC APPROACH

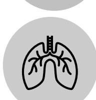
Each detailed analysis follows a three-step approach to estimate future impacts on children (see Figure 3). Step 1 identifies current risks among children using literature and quantitative data to document or model conditions in 1986-2005. This baseline represents the reference point for understanding future changes. Step 2 draws on existing climate data provided by six general circulation models (GCMs), or climate models, to project future climate hazards, including temperatures, rainfall, and sea level rise. To provide a simple and common climate change metric for all analyses, the climate projections are indexed to changes in global temperature per degree Celsius from the baseline. The detailed climate scenarios are drawn from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) and represent a recent, well-established understanding of how climatic conditions may change in the future.[46] The climate scenarios in Step 2 also enable projections of other environmental conditions associated with climate change, such as changes in air quality and pollen exposure. Finally, Step 3 uses the climate data generated in Step 2 as an input to a variety of models that estimate the impacts on children's health from changes in climate variables and compares the outcomes to a future without climate change, while accounting for changes in population. The analyses leverage existing statistical relationships from peer-reviewed literature to make the connections between climate and impacts.

Figure 3: Overarching Stepwise Analytic Approach

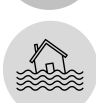


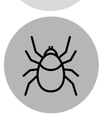
The detailed analyses in this report focus on the following endpoints:


Heat and learning: Learning losses per child relative to a normal year of learning and future lost income associated with learning losses across each graduating student cohort.


Air quality and children's health: Cases of asthma, incidence of hay fever, lost school days, ED visits for asthma, hospital admissions for respiratory illness, and infant deaths.


Pollen and children's health: Prescriptions filled for allergy medications, first doctor visit for hay fever, and ED visits for asthma.


Coastal flooding and children's homes: Children at risk of temporary or total home loss with consideration for different protective adaptation scenarios.

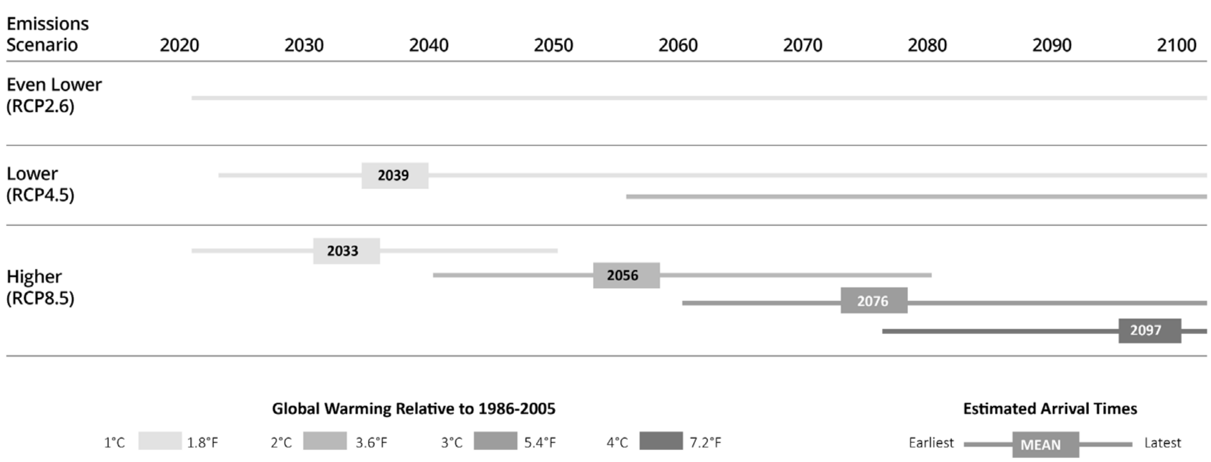

Lyme disease: Cases of Lyme disease in 21 states and the District of Columbia caused by changes in extent and range of the blacklegged tick and Lyme-disease causing bacteria.

IMPACTS BY DEGREE OF WARMING

Climate impacts are generally expected to become worse as the Earth continues to warm. To synthesize results across impacts, each analysis presents results for incremental increases in global warming relative to mean conditions in 1986-2005 (baseline). As described in Sarofim et al.,[47] this approach eliminates confusing scenario jargon and aids comparability across analyses. Impacts in this report are presented for global average temperature increases of 2°C and 4°C (equivalent to 3.6°F and 7.2°F; see accompanying appendices for results at other degrees of warming).

Figure 4 shows that under a "higher GHG emissions" scenario, climate models on average project that global temperature increases of 2°C and 4°C could be reached by the years 2056 and 2097, respectively, but the uncertainty range around this central estimate spans several decades. For "lower emissions" futures, which are considered more likely as of the writing of this report, the arrival of these temperatures could be pushed back further into the future. The "even lower emissions" scenario reflects emissions reduction action that is generally sooner and more aggressive than is considered likely as of the writing of this report.[48]

Figure 4: Projected Timing for Global Average Temperature Changes



Notes: This figure describes the range (lines) and mean (boxes) estimated arrival times for each degree of global warming above mean levels observed in 1986-2005 across global climate models and emissions scenarios.

SEA LEVEL RISE PROJECTIONS

The coastal flooding analysis in Chapter 6 summarizes results associated with changes in global average sea level rise in 25 cm increments relative to a baseline sea level period from the year 2000. To compare the baseline with the impacts summarized by degree of warming, the analysis highlights impacts at 50 cm (equivalent to 19.7 inches) and 100 cm (equivalent to 39.4 inches) of global sea level rise, which are commonly used index values for this metric (see Appendix A for details).[49] The projected changes in global average sea level generally correspond to higher changes in sea level in the U.S. For instance, U.S. sea level rise may be more than 50% greater than global sea level rise, particularly along the Atlantic and Gulf coasts, where land levels are falling as sea levels rise.[50]

What is 1°C of global warming?

The "degrees of warming" considered in this report are relative to temperature levels in 1986-2005, the baseline considered in the CIRA project. Care should be taken when viewing these results in relation to other analyses that use different baselines, like the targets under the Paris Agreement that consider degrees of warming relative to pre-industrial times. After adjusting for the differences in baselines, 2°C of warming relative to 1986-2005 would translate to 2.45°C of warming relative to pre-industrial times. For context, by 2020, global mean temperatures had risen roughly 0.5°C above the 1986-2005 baseline mean temperature.[51]

Additionally, the "degrees of warming" referred to throughout this report relate to changes in *global* mean temperatures. Warming across the planet is not uniform because the oceans, which comprise a majority of Earth's surface, are slower to warm than the land. 1°C of global warming results in more than 1°C of warming in areas that largely comprise land surfaces. At 2°C of global warming, large areas of the contiguous U.S. are projected to experience average annual temperature increases between 3°C and 4°C (5.4°F and 7.2°F). At 4°C of global warming, most of the contiguous U.S. is projected to experience temperature increases between 5°C and 6°C (10.8°F and 12.6°F). See Appendix A for details.

FUTURE POPULATIONS OF CHILDREN

The detailed analyses incorporate projections of the future population of children. The analyses rely on U.S. Census data for 2010 as well as future projections published in EPA's Integrated Climate and Land Use Scenarios version 2 (ICLUSv2) model through 2100.[52] Populations for a given future year are matched with the "arrival year" for each climate scenario, as described in Figure 4. Appendix A provides more details on the methods and data sources used to model both baseline and future populations of children expected to experience the impacts described in this report.

ADAPTATION ASSUMPTIONS

Populations may adapt to climate change in many ways, with some actions limiting the impact of climatic exposure, and other actions potentially exacerbating impacts. The detailed analyses of this report treat adaptation in two different ways. The coastal flooding analysis directly models a baseline "no additional adaptation" scenario as well as a "with adaptation" scenario that incorporates specific assumptions, using a simplified cost-benefit analysis, about future investments in coastal flood risk management. All other analyses assume no additional adaptation beyond the extent to which populations have already adapted to recent climatic changes or weather variations.

These treatments reflect the current state of the underlying impacts literature, where only a few studies of children's health and well-being currently incorporate the efficacy of future adaptation actions which might be undertaken to reduce children's health risks. For instance, the air quality, pollen, and Lyme disease analyses do not account for potential technological advancements or changes in behavior that may result in more- or less-severe health impacts on children in the future. The "with adaptation" scenario in the coastal flood risk analysis is intended to be illustrative and does not represent a specific policy at national or regional levels; no specific programs, authorities, or policy mechanisms were considered or evaluated.

UNCERTAINTY AND PRECISION CONSIDERATIONS

There are important sources of uncertainty involved with estimating the future impact of climate change on children's health. The underlying peer-reviewed health studies used in the extreme heat, air quality, changing seasons, and infectious disease chapters include statistical analyses which incorporate confidence intervals to characterize estimation uncertainty – the flooding analyses, however, rely on process-based simulation modeling approaches that do not include statistical representations of the uncertainty in flood response to changes in climate. The technical appendices that accompany this main report provide some insight into the uncertainty ranges associated with the estimates employed for projection purposes, where applicable.

There is also uncertainty about how the climate will change in the future. This uncertainty is reflected, in part, in the differences in outputs across available global climate models. The detailed analyses presented in this report use the findings from up to six global climate models; the impacts presented reflect averages across those models (with ranges reflecting the low and high estimates from among the suite of global climate models employed in these analyses). For coastal impacts, which are connected to specific index values for future sea-level rise (50 and 100 cm), uncertainty in the estimates is characterized by uncertainty bounds reported in a recent NOAA report that provides global mean projections as well as the 17th and 83rd percentiles.[53] We use these bounds to estimate the number of children impacted in contiguous U.S. for each increment from 25 cm to 100 cm. There is also uncertainty regarding future population, as well as how people may adapt to climate change in the future. Combining these various sources of uncertainty was not attempted in this report.

GEOGRAPHIC CONSIDERATIONS

In addition to describing total impacts across all children in the contiguous U.S., the report showcases the spatial distribution of those impacts, building on the spatial granularity inherent in the underlying climate models, as well as population projections incorporated into the analysis. To accomplish this, total impacts on children's health are mapped at the census block group, census tract, or county levels, consistent with the underlying input data. Further, each detailed analysis identifies the five states where the impacts per child are projected to be highest. The accompanying technical appendices provide additional detail on the concentration of total impacts, taking into account the influence of population projections as well.

DISPROPORTIONATE RISKS TO OVERBURDENED POPULATIONS

Where possible, the detailed analyses examine the degree to which children within several demographics living in the contiguous U.S. (Black, Indigenous, and people of color (BIPOC); low income; limited English speaking; and children without health insurance) may be disproportionately exposed to the most severe impacts of climate change, building on an approach in a 2021 EPA report.[54] The detailed analyses conclude by estimating the likelihood that these groups of concern live in geographic areas with the highest projected climate change effects. This likelihood is based on current demographic distributions and projected changes in climate conditions. The estimated risks for each demographic group are presented relative to each group's reference population, defined as all individuals other than those in the group analyzed. Due to data limitations, this report does not consider all possible dimensions of social vulnerability that children may experience, although it includes summaries of existing literature within each chapter that discuss potential impacts that may affect these individuals.

While differential risks to children can be linked to specific physiological differences between children and adults, the disproportionate risks to overburdened populations tend to be associated with social, historical, healthcare, and institutional disparities between groups. Climate change will continue to exacerbate existing inequities in children's health. Due to a deeply rooted system of discrimination and oppression (i.e., structural racism), Black, Indigenous, and other communities in the U.S. are often particularly vulnerable to environmental hazards, including the effects of climate change. For example, historic practices of redlining have created lasting effects and are correlated with low-income neighborhoods and communities of color in urban areas being disproportionately exposed to heat islands (e.g., lower vegetative cover and greater blacktop coverage leading to higher temperatures).[55]

Which overburdened populations of children are considered?

Black, Indigenous, and people of color (or BIPOC): This report uses the term BIPOC to refer to individuals identifying as Black or African American; American Indian or Alaska Native; Asian; Native Hawaiian or Other Pacific Islander; and/or Hispanic or Latino. It is acknowledged that there is no "one size fits all" language when it comes to talking about race and ethnicity, and that no one term is going to be embraced by every member of a population or community. The use of BIPOC is intended to reinforce the fact that not all people of color have the same experience and cultural identity. This report therefore includes, where possible, results for individual racial and ethnic groups.

Low income: Children living in households with income that is at or below twice the Federal poverty threshold for their household size.

Limited English speaking: Children living in households where all members 14 years and over older have at least some difficulty with speaking English.

No health insurance: Children without health insurance.

Notes: 1) These definitions rely on standard variables in the U.S. Census Bureau's American Community Survey.[56] 2) Due to data limitations, this report does not analyze the impacts of climate change in Hawai'i, Alaska, or U.S. territories. However, the analyses use demographic data from the U.S. Census which includes individuals living in the contiguous U.S. who identify as "American Indian or Alaska Native" and "Native Hawaiian or Other Pacific Islander." For more information, please see Appendix A.

Chapter 3: Extreme Heat


David L. Ryan / The Boston Globe via Getty Images

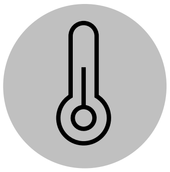
Chapter highlights

This chapter describes examples of how heat affects children’s health and well-being, and how those risks are expected to increase in a warming climate. Children’s physical, cognitive, and mental health may be affected by climate-induced temperature increases, extreme heat, and increased frequency of heat waves.

One key way that heat negatively impacts children is through learning. This chapter first quantifies how heat experienced during the school year reduces learning and then monetizes those losses in terms of lost future income. Holding constant current levels of school and home A/C availability, temperature increases of 2°C and 4°C of global warming are associated with 4% and 7% reductions in average academic achievement per child, respectively, relative to average learning gains experienced each school year. The lost annual future income across each cohort of graduating students may reach $6.9 billion ($1.9 to $12.7 billion) at 2°C of global warming and $13.4 billion at 4°C ($8.9 to $18.3 billion). Installing A/C in schools is less costly, although it only partially mitigates these effects, and will exacerbate climate impacts if the electricity used is not from renewable sources. Black, Hispanic, and low-income students are likely to experience these impacts disproportionately.

This chapter also documents the relationship between increased summer temperatures and ED visits at children’s hospitals in the U.S. For each 1°F (equivalent to 0.6°C) increase between May and September, the number of ED visits at U.S. children’s hospitals could increase by 113 visits per day, or over 17,000 visits over the five-month period.

HOW CLIMATE CHANGE AFFECTS HEAT AND CHILDREN



Heat is one of the most apparent indicators of climate change. Increasing average surface temperature will generally lead to both less cold weather and more hot weather: the hottest temperatures in the future may be warmer than any experienced in recent decades.[57] In addition to overall warming, climate change is intensifying heat waves and extreme heat events. In particular, the U.S. is seeing higher temperatures year-round, with hotter summers and longer heatwaves.[58] Heat can have a wide range of health impacts, regardless of location.[59,60,61] Many of these effects are especially pronounced on the young and old, pregnant women, people who have certain preexisting health conditions, and outdoor workers.[62,63,64]

IMPACTS OF HEAT ON CHILDREN

Heat can affect children in many ways, in part because children's bodies respond differently to heat than adults; this also is true for pregnant women and fetuses.[65,66,67] Thermoregulation, which refers to how the body maintains a normal internal temperature despite changing external temperatures,[68] is at the core of the physiological response to excess heat. If the body is unable to properly cool itself, excess heat can lead to dehydration and organ damage. This can manifest as lightheadedness, fainting, muscle breakdown, renal (i.e., kidney) failure, seizure, coma, or death in extreme cases.[69,70,71]

Children are particularly susceptible to heat-induced adverse health outcomes because their bodies are not as efficient at thermoregulation as adults. For example, children also do not sweat as much as adults, limiting a key method the body uses to cool itself. This is especially true for the youngest children (including infants) and girls more than boys.[72,73] Research shows that children with preexisting health conditions—including asthma, other respiratory conditions, impaired kidney function, and endocrine disruption (e.g., diabetes[74,75,76])—are also more vulnerable to the effects of heat.

Exposures to heat can take several forms. Tragically, one of the best-known metrics is the number of children who die each year after being

Heat effects on children

- Excess heat in children can lead to fainting, muscle breakdown, organ failure, seizure, coma, or death in extreme cases.
- Heat is linked to poor cognitive function and reduced ability to concentrate or learn.
- Children are at greater risk of developing anxiety or depression due to high heat.
- Heat can affect children in utero.
- "Heat islands" and lack of access to A/C exacerbate these effects among overburdened populations.
- Increasing humidity may also impact children's health, although it is not explored in this report.

left in hot cars.[77,78] Another unfortunate example is children collapsing during sporting activities in hot weather.[79] A child playing in heavy sports equipment or participating in other types of exerting activities in hot weather may find it very difficult to maintain sufficient fluid levels. Children may not receive enough encouragement to drink water or may be susceptible to pressure not to take breaks when they feel heat-related discomfort.[80] While there are recommendations for how to adapt to increased heat exposure—such as guidelines for sports practices and games,[81,82] car-based alert systems that remind parents about a child in the backseat,[83] and communications messaging around risk[84]—children remain vulnerable in these settings.

Other heat effects may occur in the home or at school, especially in spaces that lack A/C. Heat is linked to poor cognitive function and the ability to concentrate or learn, reducing learning outcomes. One reason for this effect is that cognitive function declines during excessive heat, leading to slower reaction times on assessments.[85] A second reason is that heat affects the ability to have a "good night's sleep," which can lead to cognitive disruption and learning difficulties.[86,87,88] Further, hot classrooms may be distracting and unmotivating. Finally, on extremely hot days, students may miss or intentionally avoid school, particularly if the school is not air-conditioned.[89] Emerging evidence also suggests that extreme heat experienced in utero can have long-term cognition impacts on children and are linked to losses in income and earning potential.[90]

Play is a fundamental component of childhood, and research suggests that children's activity levels may vary due to high heat during outside play, including recess. This is especially true in areas that historically have had cooler average temperatures;[91] thus, children in these areas may be less able to adapt (acclimatize) to hotter temperatures.[92] While seemingly less severe, this can have implications for children's physical and mental health.[93,94]

Adverse mental health impacts are also associated with rising temperatures. Children are at greater risk of developing anxiety or depression due to high heat.[95] Adolescents especially may respond to heat with irrational and aggressive behaviors. Extreme heat linked to climate change has been connected to increases in violent behavior and crime,[96,97,98] all of which may impact children directly.[99] Additionally, research shows that climate change is likely to increase suicide rates in adults and children.[100]

Children from overburdened households are at particular risk of experiencing harm due to high temperatures.[101] Poverty can leave children at greater risk of harm from heat exposure; race and other demographics are correlated with high exposure and risk of heat-related impacts.[102] A 2016 scientific assessment found that children—especially non-White, economically disadvantaged individuals (among other characteristics)—are more vulnerable to adverse health outcomes such as death due to heat exposure.[103] Poverty is linked with adverse health outcomes, stress, and poor cognition, and heat compounds these effects for children.[104] Heatwaves also have been linked to preterm labor,[105] especially in non-White, less-affluent populations.[106] This, consequently, can result in low birth weight,[107] as well as subsequent developmental effects.[108]

Urban heat islands often are found in lower-income, predominantly BIPOC communities, exposing residents to greater concentrations of higher temperatures.[109] Additionally, many vulnerable households do not have A/C due to cost or because the home was built when A/C was not common or necessary.[110] Research shows connections between poverty and race with exposure to both higher temperatures in an area as well as A/C access.[111] The combination of exposure to high heat plus poor health outcomes has been linked to the socioeconomic demographics of a given area, along with access to A/C.[112]

Finally, a changing climate will moderate average cold temperatures across most of the contiguous U.S. While this chapter focuses on heat, changes in cold temperatures likely will benefit some aspects of children's health. For instance, mortality associated with extreme cold is projected to decrease as the climate warms.[113] Children are particularly susceptible to mortality associated with extreme cold as they are less able to regulate their body temperature than adults.[114] However, several studies have shown that the adverse effects of heat outweigh any potential benefits from reductions in cold-related effects and, therefore, this chapter focuses on quantifying the former.[115,116]

HEAT AND LEARNING LOSSES

This section analyzes the connection between heat experienced during the school year and learning losses among children. As described in the previous section, heat is linked with poor cognitive function and reduced ability to concentrate or learn. This report leverages national-level findings from Park et al. to model adverse education effects among high school students, the cohort examined in the study.[117] Park et al. investigated how heat inhibits learning among students in the contiguous U.S. and how A/C in schools and homes reduces those effects. The analysis presented in this report uses that historical relationship to assess how students may suffer from heat during future school years.

Figure 5: Heat and Learning Analysis Steps

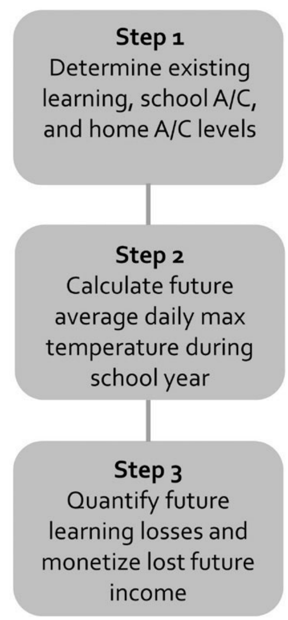
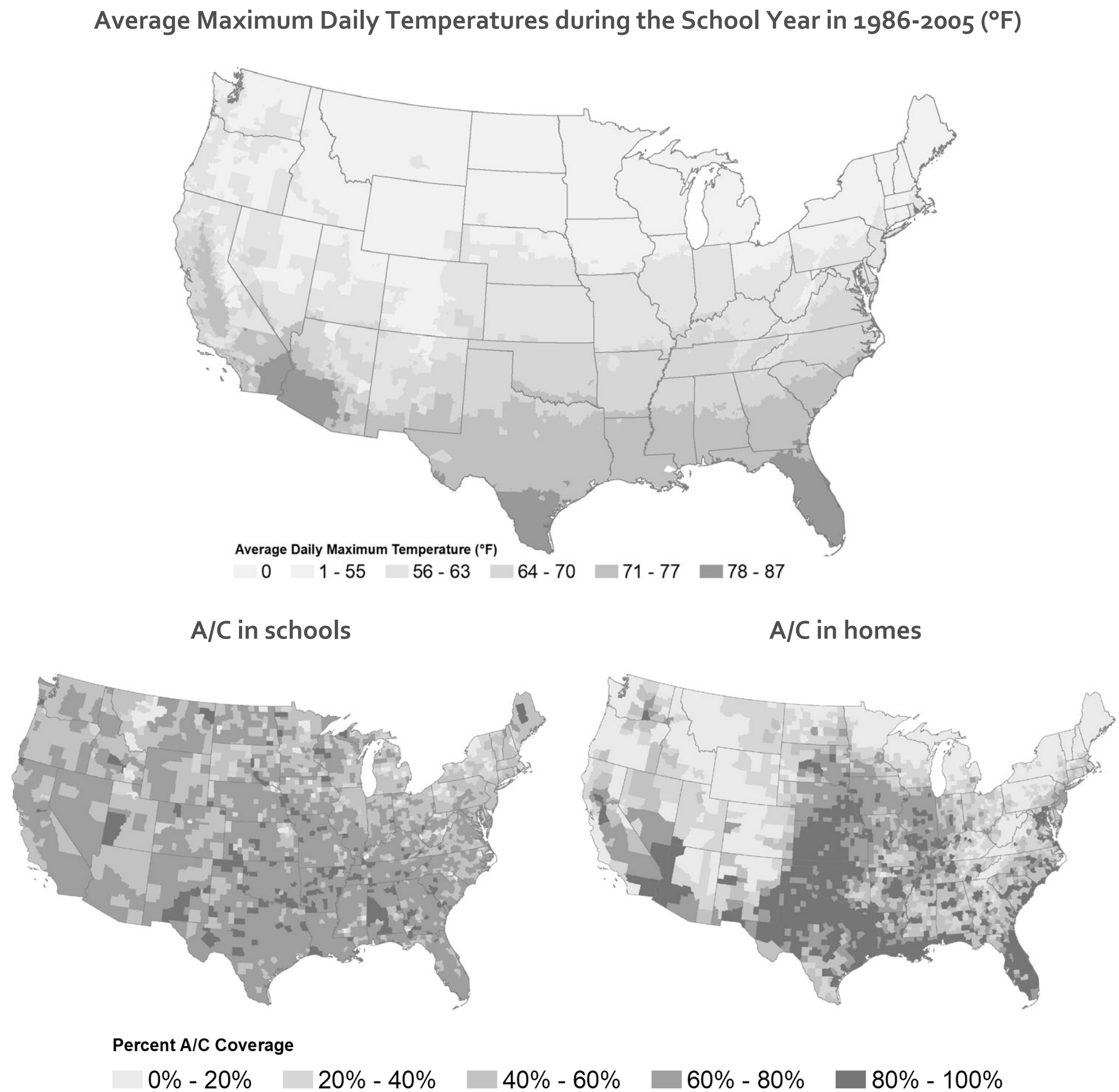


Figure 5 summarizes the three overarching steps of the analysis, with more details about the methods and underlying data sources in Appendix B. First, several data sources are assembled to determine existing learning gains each academic year as well as current levels of A/C in schools and homes. Then, because school calendars vary considerably across the county, this analysis considers local start and end dates for the school year to determine how future temperatures will rise during that time by census tract (for instance, states in the South generally start in early to mid-August whereas states in the North and Midwest often begin in late August or early September). Finally, the analysis quantifies learning losses in terms of percent reduction in learning relative to average gains per school year, then values those losses in terms of lost future income using findings from Chetty et al.[118] By valuing learning losses, the analysis can compare findings to the total projected cost of installing A/C in schools as an adaptation strategy, using estimates presented in LeRoy et al.[119]

Figure 6 demonstrates why accounting for local A/C coverage is important to accurately project learning losses associated with heat. The top map presents baseline average maximum daily temperatures during the local school year (1986-2005), while the middle and bottom maps describe the current distribution of A/C in schools and homes, respectively. As shown, the regions that currently experience the warmest academic years (the South and Great Plains) already have the most protection from existing A/C. On the other hand, regions historically characterized by milder temperatures during the school year have less school and home A/C coverage, particularly in the Northeast, Midwest, and across the Rocky Mountains. This analysis highlights where future infrastructure investments are most needed as temperatures warm.

Figure 6: Baseline Average Maximum Daily Temperatures During School Years in °F (Top), A/C Coverage in Schools (Bottom Left), and A/C Coverage in Homes (Bottom Right)



Notes: The top map shows average daily maximum temperatures (°F) at the county level during state-specific school calendar years in the baseline considered across this analysis (1986-2005). The middle and bottom maps show the current coverage of A/C at the county level, assembled from various sources described in Appendix B.

Figure 7: Projected Additional Impacts of Heat on Learning Among Children

Degrees of Global Warming	Lost Future Income Per Year Per Child	Total Lost Future Income Per Year Across Graduating High School Students
2°C	$1,300 *($380 to $2,400)*	$6.9 billion *($1.9 to $12.7 billion)*
4°C	$2,300 *($1,600 to $3,200)*	$13.4 billion *($8.9 to $18.3 billion)*

Notes: This graphic presents the results of the heat and learning losses analysis at 2°C (equivalent to 3.6°F) and 4°C (equivalent to 7.2°F) of global warming, expressed in 2021 dollars. The results describe additional impacts relative to the baseline (1986-2005) and assume populations of children will increase over the 21st century (see Chapter 2, Appendix A). The table displays the average and range across climate models. Average lost future income per child is population-weighted (see Figure 9 for variation across the country). Total lost income per year considers learning losses experienced by each cohort of graduating high school students. Figure 8 compares these results with baseline levels. Appendix B provides results for additional degrees of global warming.

Across the contiguous U.S., the average maximum daily temperatures during the school year are projected to reach 69.7°F by the time global temperatures have increased by 2°C and 73.9°F by the time of 4°C of global warming (see Appendix B for details). These temperature levels correspond to temperature increases of 5.8°F and 10°F relative to baseline school year temperatures at 2°C and 4°C of global warming, respectively. While baseline high temperatures are concentrated in the South (see Figure 6), increases in temperatures relative to baseline school-year temperatures are found throughout the contiguous U.S., including in parts of the Midwest and Northeast (see Appendix B for details). Importantly, Park et al. do not find evidence that cold weather affects learning, so all increases in temperatures are anticipated to contribute to learning losses.

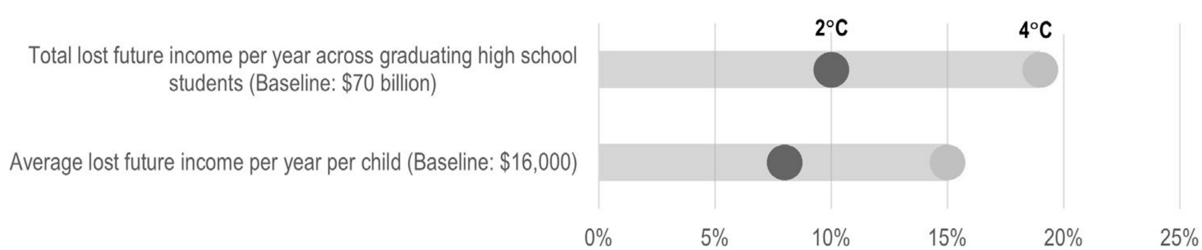
Holding current market penetration of school and home A/C constant (see Figure 6), these temperature increases are associated with approximately 4% and 7% reductions in learning relative to average learning gains experienced each academic year at 2°C and 4°C of global warming, respectively. Applying a valuation approach used by Park et al. that relies on information from Chetty et al., these learning losses are projected to translate into future lost annual income per student on the order of $1,300 (ranging from $380 to $2,400 across climate models) and $2,300 ($1,600 to $3,200) at the same temperature thresholds (2021 dollars). To put these numbers in context, the median weekly earnings reported by the U.S. Bureau of Labor Statistics for 25- to 35-year-old workers translates to roughly $48,000 in annual income in 2021.[120] The average income losses associated with heat experienced as a student are equivalent to between 3% and 5% of annual earnings for the median worker in that age cohort.

Considering lost future income across all graduating high school students each year is a way to demonstrate the magnitude of learning losses across the contiguous U.S. Applying this approach, the total lost future income related to learning shortfalls could reach $6.9 billion per year at 2°C of global warming ($1.9 to $12.7 billion) and $13.4 billion per year at 4°C ($8.9 to $18.3 billion). Relative to temperature-related achievement impacts experienced during the baseline period (1986-2005), future total earnings gaps are projected to increase by 10% and 19% at 2°C and 4°C of global warming, respectively (see Figure 8).

These estimates are large in magnitude and suggest that heat can have long-term negative impacts on academic performance and income gains when experienced during childhood. Further, these projected impacts only consider the effects of heat exposure on learning during high school, and research is mounting that heat experienced by elementary and middle school students also contributes to learning losses.[121] This newer research suggests the potential for cumulative impacts not accounted for in the projections presented in this report. In other words, the impacts presented here are likely to underestimate the total impact of heat on accumulated learning throughout childhood.

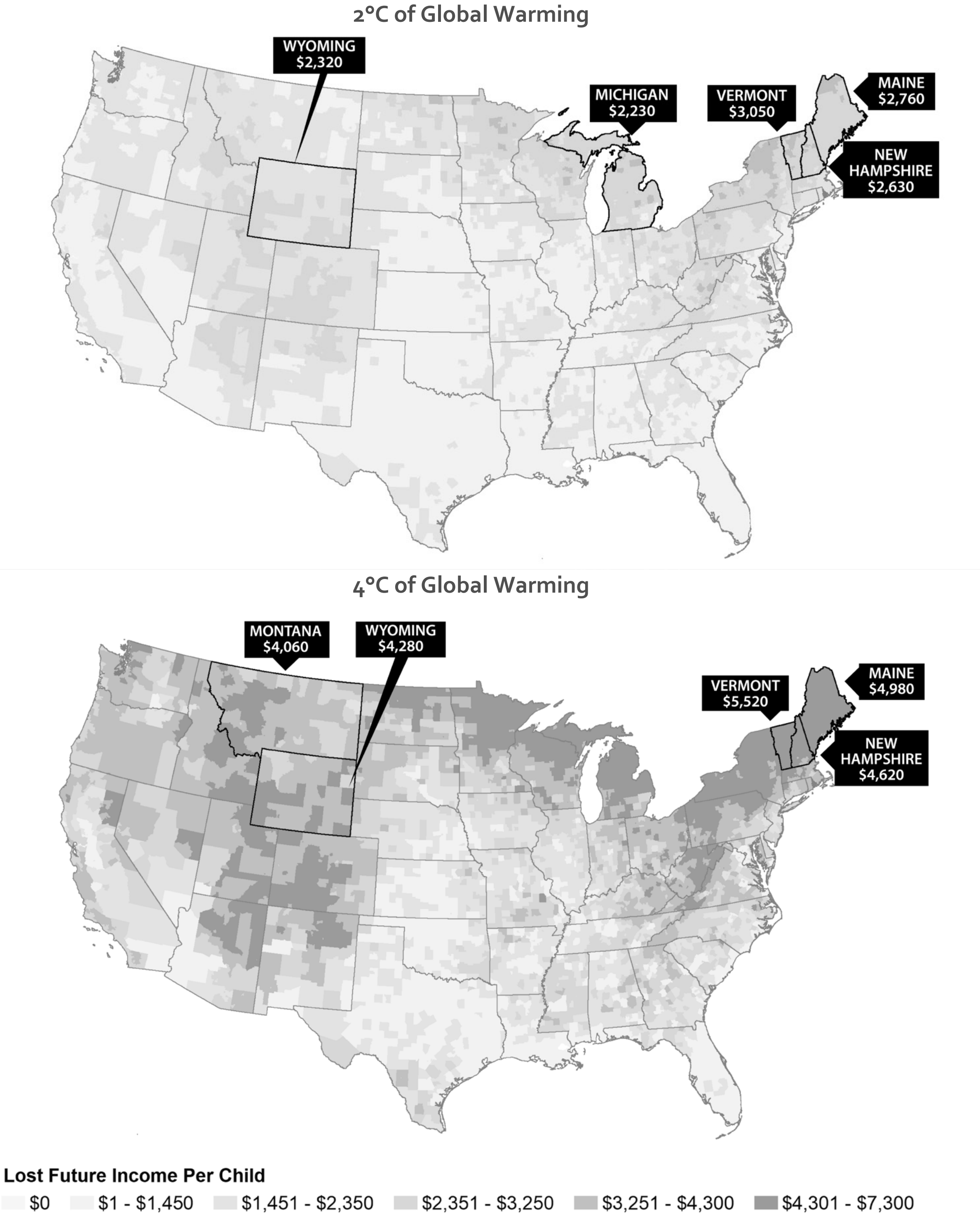
As shown in Figure 9, not all students experience these impacts uniformly. At 2°C of global warming, the states with the highest projected learning losses per student are Maine, Michigan, New Hampshire, Vermont, and Wyoming. Once temperatures reach 4°C of global warming, Montana is another state with among the highest impacts per student, nationally. These and other states in the Northeast, upper Midwest, and mountainous areas experience a confluence of relatively high warming during future school years compared with baseline temperatures and relatively low current A/C coverage. While the Southeast and Southwest regions are expected to warm considerably, and to levels greater than in the cooler states, learning losses are partially mitigated by the existing availability of A/C in these areas.

Figure 8: Estimated Percent Change in Heat and Learning Loss Impacts Relative to Baseline



Note: This graphic describes how the student achievement impacts associated with heat increase relative to baseline conditions (1986-2005), as listed in the figure and under assumptions described in Appendix B. The teal circles show increases between baseline and 2°C of global warming; the orange circles convey increases at 4°C.

Figure 9: Estimated Distribution of Lost Future Income Per Student Per Year from Heat



Notes: These maps present lost future income per child attributable to learning losses from heat exposure during school years. Areas with darker shading have higher rates of learning losses. The five states with the highest learning losses per child are outlined in black. See Appendix C for more details on the distribution of impacts.

These findings can be compared to the cost of installing A/C in schools. LeRoy et al. estimate the cost of furnishing all public schools in the contiguous U.S. with A/C to be $42.4 billion, including $40.5 billion in new installations, $414.8 million in upgrades to existing HVAC technology, and $1.5 billion in annual operating and maintenance costs.[122] Assuming HVAC systems have a 20-year lifespan and applying a 3% discount rate, this would equate to an annualized cost of installing and maintaining HVAC systems in U.S. public schools of approximately $4.2 billion. In other words, the annualized cost of installing and maintaining A/C systems in schools is less than the projected annual lost income associated with learning losses from heat at both 2°C and 4°C of global warming. Holding aside the fact that many school systems would be challenged to find resources to pay for these investments, having A/C in school does not mitigate the potential for learning losses entirely. Park et al. show that learning losses are erased only with A/C in school *and* at home. This suggests that additional investments in home A/C infrastructure are also necessary to eliminate these risks. Analogous estimates of the cost of installing, upgrading, and maintaining A/C in all homes are not available for comparison. While Park et al. focus on the role of A/C in mitigating the adverse heat-indued learning impacts, relying on A/C to reduce these impacts also poses other climate-related challenges, including the increase in energy use that could contribute to further GHG emissions that worsen climate change.[123] Chapter 8 of this report explores other ways of protecting children from these effects.

Appendix B explores how average learning losses per student decrease under different school A/C coverage scenarios. Even when increasing A/C in schools by 10 percentage points across the contiguous U.S., students still experience learning losses relative to baseline at 4°C of global warming.

Park et al. use student-level data to reveal that hot school days disproportionately impact learning among BIPOC students and students living in low-income households. The authors found that the negative impact of prior year heat on Black and Hispanic students was three times larger than the impact on white students. Similarly, the impact of prior year heat on students in lower-income zip codes was twice as large as those from higher-income zip codes.

The results from Park et al. reflect the fact that Black, Hispanic, and low-income students generally experience differential ambient heat exposure *and* have less access to A/C in their schools and at home. Even in places where all students are exposed to the same levels of heat, the learning losses to wealthier students may be offset via supplementary enrichment and instruction. The analysis by Park et al. relies on highly granular data that can explore important variations among students within the same general location; however, the student-level data were not available for this report. The text below describes the current understanding of how overburdened communities may experience the most significant learning impacts associated with heat.

What do we know about the disproportionate impacts of heat on learning?

Disproportionate exposure to heat: Vulnerable communities, especially those living within urban areas, are disproportionately exposed to extreme heat in part because of residential segregation caused by historical housing policies.[124] Hoffman et al. found that land surface temperatures in historically redlined areas were warmer than in non-redlined areas in 108 urban areas across the U.S., increasing the burden of heat on BIPOC and low-income residents, including children. Similarly, another study found that people of color were more likely to live in census tracts with higher surface urban heat island intensity compared to White people in 97% of the largest urbanized areas in the U.S., further emphasizing the disparities in exposure to heat among subpopulations.[125] Park et al. also described mean temperature by race and income, finding that Black and Hispanic children were exposed to higher ambient temperatures (68.8°F on average) than White children (64.2°F on average). Average temperatures in this study during the school year did not vary by income.

Disproportionate access to A/C in homes: Literature and data describing A/C availability in households by demographic group is minimal. Park et al. noted that Black and Hispanic households were 7% and 6% less likely to have access to A/C compared to White households, respectively. Across urban areas specifically, recent research shows that intra-city variation in A/C coverage in homes is considerable, and that the prevalence is much lower in areas with multiple indicators of social vulnerability.[126] A survey administered in 2009 by the California Energy Commission (CEC) shed light on potential disparities in access to A/C in homes by race and income in one state. CEC found that 56% of American Indian households, 57% of Black households, 58% of Hispanic households, and 62% of Asian households had air conditioning statewide.[127] In comparison, 68% of White households were air-conditioned. Additionally, 61% of California households with income below $30,000 had air conditioning, compared to 69% of households with income between $75,000 and $150,000.

Disproportionate access to A/C in schools: Access to A/C in schools varies by demographic group as well. Park et al. found that Black and Hispanic students were 1.6% more likely to be in schools with inadequate A/C than White students. Lower-income students were 6.2% more likely to be in schools with inadequate A/C than higher-income students.

HEAT AND EMERGENCY DEPARTMENT VISITS

Another way to measure the magnitude of heat's effects on children's health and well-being is the number of emergency department (ED) visits associated with high temperature days. Bernstein et al. offer an assessment of the relationship between daily maximum temperature and the incidence of ED visits among a sample of 47 children's hospitals across the U.S.[128] The authors find that location-specific high heat days in May through September are associated with a 17% greater likelihood of an ED visit. Information presented in the study suggests each degree above 62°F is associated with a 0.5% increase in daily incidence of ED visits at the children's hospitals in the study sample.

Extrapolating these findings specifically to all 222 children's hospitals with EDs in the contiguous U.S. indicates what the future may mean for serious health impacts on high-temperature days. Children's hospitals are within 80 miles of 92% of children in the country,[129] and thus can provide services to the most acute cases of heat-related illness. Data from the Healthcare Cost and Utilization Project's Kids' Inpatient Database (HCUP-KID, 2016 and 2019) documents approximately 22,000 ED visits per day between May and September at children's hospitals, equivalent to 3.4 million per summer. Temperature increases of 1°F between May and September would increase the number of ED visits at children's hospitals by 113 visits per day, or over 17,000 visits over the five-month period. A more detailed assessment of these future risks across all hospitals with EDs would better inform planning among healthcare providers.

Chapter 4. Air Quality

Chapter highlights

Climate change is likely to worsen air quality and cause or exacerbate air quality-related negative health outcomes among children. Existing evidence clearly links exposure to air pollutants with various adverse health effects in children, including asthma and other respiratory diseases. Exposure to poor air quality is also associated with limiting brain development. Many of these impacts emerge in childhood and affect people throughout their lives.

This chapter includes a quantitative analysis of long- and short-term childhood exposures to climate-driven changes in outdoor particulate matter ($PM_{2.5}$) and ground-level ozone (O_3) as well as related effects on respiratory diseases such as asthma. Results show that new annual cases of asthma could increase by 4% to 11% at 2°C and 4°C of global warming, respectively. ED visits and hospital admissions from respiratory conditions also are expected to increase, as are school days lost as a result of these effects. Most impacts stem from climate-induced changes in O_3 and $PM_{2.5}$, although wildfires and ground-level dust in the arid Southwest also play a role. Low-income and BIPOC children are more likely than others to experience new asthma diagnoses associated specifically with $PM_{2.5}$ exposure.

Fetal health effects can occur when pregnant women are exposed to poor air quality during pregnancy. Projected increases in wildfire activity are associated with heightened levels of $PM_{2.5}$ and PM_{10} and could result in more adverse birth outcomes. An additional 7,700 and 13,600 premature births may be attributable to wildfire annually at 2°C and 4°C of warming, respectively. At 4°C, this represents a 92% increase in premature births relative to the baseline level of births affected by wildfire smoke.

HOW CLIMATE CHANGE DEGRADES AIR QUALITY AND IMPACTS CHILDREN

Climate change is likely to worsen air quality at the national level primarily due to changes in environmental conditions, such as changes in temperature, precipitation, and wind patterns, that can lead to increases in ambient particulate matter and ground-level (or tropospheric) O_3.[130,131,132,133] Wildfire smoke, dry and dusty conditions due to drought, and changes in agricultural activities can also lead to increases in ambient concentrations of O_3, particulate matter, and other harmful pollutants like carbon monoxide and nitrogen oxides, which can damage the health of children.[134,135,136,137,138,139,140] In addition, wildfires can also burn manmade structures such as homes and vehicles that release toxic chemicals into the air when they combust.[141,142] The resulting smoke can travel far from the immediate area, impacting children and adults at considerable distances from the original location for weeks or even months after an event occurs.[143] Exposures to fine and coarse dust are also projected to increase as climate change progresses, particularly in the arid Southwest.

IMPACTS OF AIR QUALITY ON CHILDREN

Children are particularly vulnerable to the effects of air pollution for a variety of reasons.[144,145,146] Infants and children have more immature lungs compared to adults; as a result, their lungs can be more susceptible than those of adults to harm following exposures to toxins and hazards.[147] They also generally breathe faster than adults and take in more air relative to their size and body weight, thus increasing their relative exposure to air pollution compared to adults.[148] As a result, short-term and long-term (i.e., annual) exposures to air pollution have been shown to have significant effects on child lung function and development, as well as impacts on brain development.[149,150,151]

Short-term exposure to air pollution can cause or worsen asthma, one of the most common childhood diseases, and among the most common reasons for child ED and hospital visits nationwide.[152] Particulate matter from wildfire smoke has been shown to trigger asthma attacks in children more than other sources of

Poor air quality and children

- Worsening air quality is linked with asthma and other respiratory diseases, cancer, and dermatitis in children.
- Decreased lung function in childhood may lead to chronic, severe respiratory conditions in adulthood.
- Preterm birth, low birth weight, and birth defects are associated with *in utero* exposures.
- Poor air quality can affect brain development and mental health.
- Children in many overburdened populations are more likely to live in areas with poor air quality and therefore often suffer these health effects more acutely.

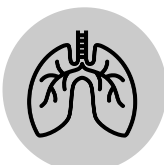
PM.[153] In addition, children have the highest rate of coarse dust-related asthma visits to EDs relative to all age groups, an important consideration for those living in the dry and dusty conditions of the Southwest.[154] Air pollution is also linked with lung injury and inflammation, school loss days, rhinitis, upper and lower respiratory symptoms, cancer, dermatitis, autism spectrum disorder, and even infant death, among others.[155,156,157,158,159,160]

Long-term exposure of pregnant women to air pollution can also have serious implications for fetuses, leading to lifelong health effects. Pollutants are transferred to the fetus from the mother's bloodstream when she breathes them in and can reduce blood flow and oxygen to the fetus due to inflammation. In turn, reduced blood flow and oxygen levels can lead to adverse birth outcomes including preterm birth (i.e., earlier than 37 weeks) and low birth weight (i.e., <2500 grams, or approximately 5.5 pounds), limited fetal growth, birth defects, or stillbirth.[161,162,163,164,165,166,167,168] Exposure to poor air quality can also lead to smaller head circumference, which is associated with memory, learning, and concentration challenges in childhood; and abnormal abdominal (stomach/midsection) circumference, an indicator of a propensity for obesity and other types of metabolic conditions.[169,170] Exposure to particulate matter can also lead to a greater likelihood of pregnancy complications, including blood clots, dangerously high maternal and fetal blood pressure, preeclampsia, gestational diabetes, and childhood diabetes.[171,172,173,174,175,176,177] Studies have shown that increased exposure to any amount of air pollution during the first 14-16 weeks of pregnancy, even at levels below national standards, are associated with abnormal fetal development.[178,179,180]

Changes in lung function in children—measured using a spirometer, often when individuals have respiratory illness or are being tested for asthma—can have lifelong impacts, as this can be indicative of the potential quality of respiratory health in adults.[181] Poor childhood lung function has been linked to chronic, severe respiratory conditions such as chronic obstructive pulmonary disease (COPD) and other types of degenerative lung ailments later in life.[182,183] Impaired lung function from air pollution can continue into adulthood, even if an individual's exposure decreases;[184] however, it is unclear whether effects are reversible.[185]

Long-term exposure to air pollution can also affect brain development and mental health.[186,187,188] Infants and children younger than five years old experience rapid growth, particularly of the brain.[189] The brain is among the fastest developing organs in a child's body and can be greatly impacted by inhaled toxins and particulate matter, leading to cognitive effects.[190] Some evidence suggests that poor air quality can contribute to the development of neurocognitive disorders such as autism and attention deficit/hyperactivity disorder.[191,192] School-aged children may experience poor academic performance if they live in areas with higher air pollution.[193] Poor air quality may affect sleep patterns, which also has mental health implications.[194]

Certain social factors make children more vulnerable to the health effects of poor air quality, including race, ethnicity, and income.[195] Overall, research indicates that increased air pollution-related health risks associated with race and ethnicity are linked to social, historical, healthcare, and institutional disparities between groups. In general, infants born to racial and ethnic minorities are at greatest risk of adverse health outcomes related to air pollution exposure.[196] Black and Hispanic mothers have been shown to be especially at risk for preterm birth and low birth weight related to air pollution.[197,198] Children in lower-income households are more likely to live in areas with poor air quality and are more likely to have worse health outcomes.[199] For instance, BIPOC children are more likely to live in areas closer to a factory or road with heavy traffic, exposing them to more pollution,[200] and are less likely to have an adequate air filtration system in their home.[201] Wildfires are known to increase particulate matter and toxic gas concentrations far above national standards,[202] and these elevated exposures have been shown to be disproportionately higher among children in lower-income households.[203,204] Race appears to play a significant role in making some children more vulnerable to harm from poor air quality. Black children, especially, are more likely to live in areas with expected increases in childhood asthma cases related to climate-driven changes in air pollution.[205,206,207] Similarly, Black individuals—including children—have been shown to face greater health effects from air quality, which may result from a wide range of factors including systemic social inequalities, a historical lack of social capital, and/or baseline health status and ability to avoid and mitigate harmful climate-related air pollution exposures.[208]



AIR QUALITY AND CHILDREN'S HEALTH

The health outcomes associated with long- and short-term exposure to poor air quality are numerous. To convey the magnitude of impacts associated with respiratory conditions specifically, this detailed analysis uses existing evidence from several epidemiological studies to project changes in health and health-related effects among children associated with heightened levels of outdoor $PM_{2.5}$ and O_3. These include:

- New diagnoses of asthma (Tetreault et al.[209])
- Incidence of hay fever (Parker et al.[210])
- School days lost from respiratory issues (Gilliland et al.[211])
- ED visits associated with asthma (Alhanti et al.[212] and Mar and Koenig[213])
- Hospital admissions for respiratory issues (Ostro et al.[214])
- Infant mortality (Woodruff et al.[215])

While ambient concentrations of $PM_{2.5}$ and O_3 have many sources, this analysis targets the changes in annual ambient concentrations expected from climate-induced changes in environmental conditions (Fann et al.[216]) (i.e., the climate penalty), ambient dust concentrations in the Southwestern U.S. (Achakulwisut et al.[217]), and wildfire activity in the West (Neumann et al.[218]). These studies address the impact of climate change on $PM_{2.5}$ and O_3 air quality, but other studies have focused on how greenhouse gas emission reduction policies can reduce air pollutant emissions and have a positive effect on air quality and, by extension, children's health.[219]

Figure 10 describes the steps of the analysis, with further details on the methodology available in Appendix C. This analysis considers all areas of the contiguous U.S. except for changes in southwest dust exposure, which is restricted to four states in the Southwestern U.S. where these impacts are particularly substantial. Future impacts are quantified using U.S. EPA's Benefits Mapping and Analysis Program (BenMAP),[220] a tool that estimates the human health impacts of air quality changes using air quality data, spatially resolved baseline incidence data, and concentration-response functions for short-term and long-term exposure, derived from epidemiology studies. BenMAP applies the relationship between these components to the population experiencing the change in pollution exposure to calculate the resulting health impacts. For presentation purposes, impacts are summed across pollutants and pollutant sources.

Figure 10: Analytic Steps in Air Quality Analysis

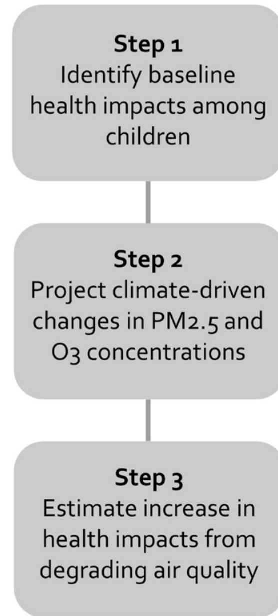


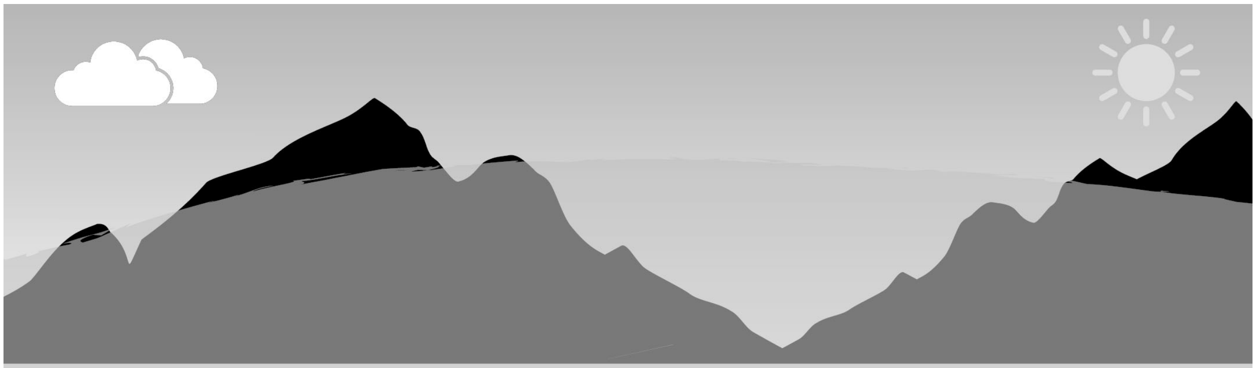
Figure 11 summarizes the analysis findings. An additional 34,500 (ranging from 27,900 to 42,800 across climate models) asthma cases per year among children are projected across the contiguous U.S. at 2°C of global warming, increasing to 89,600 (74,100 to 108,000) additional cases annually at 4°C. These impacts are fueled predominantly by climate-driven changes in ambient $PM_{2.5}$ and O_3. At 4°C of warming, 98% of new cases of asthma are attributable to climate-driven changes in ambient $PM_{2.5}$ and O_3 concentrations, 82% of which are from O_3 alone. In contrast, 1.5% and 0.5% of total cases are attributable to southwestern dust and western wildfires, respectively.

Other respiratory impacts are projected to be substantial, as well. The analysis estimates 6,240 (5,210 to 7,300) additional ED visits for asthma per year at 2°C of global warming, increasing to 15,800 (14,500 to 17,200) additional visits annually at 4°C, representing a considerable reaction to air pollution in children with asthma. Additional cases of hay fever per year among children are estimated to increase by 228,000 (179,000 to 276,000) at 2°C of global warming and 554,000 (447,000 to 662,000) at 4°C. Among the more severe effects, 332 (230 to 430) additional respiratory hospitalizations among children per year are estimated at 2°C, increasing to 785 (353 to 1,220) per year at 4°C. Finally, this analysis also projects additional deaths among newborns. At 2°C of global warming, an estimated 7 (4 to 10) additional newborn deaths annually attributable to climate change, increasing to 15 (6 to 25) additional deaths at 4°C.

What about other air pollutants?

This analysis specifically considers the relationships between children's health and changes in $PM_{2.5}$ and O_3 associated with climate change. The association between human health impacts and long-term exposure to these pollutants is widely studied and documented in epidemiological literature, and projected future pollutant concentrations were available for use in the detailed analysis portion of this chapter. Beyond the pollutants considered here, children will also be negatively affected by various other pollutants that degrade air quality, including ambient dust with particle size larger than $PM_{2.5}$ (called the PM coarse fraction), carbon monoxide, nitrogen dioxide, sulfur dioxide, and the complex mixtures of particulates and organic compounds that make up wildfire smoke.[221,222] Children's exposure to these pollutants may change in the future, leading to changes in the incidence of various health effects, including respiratory symptoms in children and long-term health outcomes when the children become adults. In other words, the health outcomes projected in this section are only a subset of all health impacts to children which could result from climate-induced changes in air quality.

Figure 11: Projected Additional Annual Impacts of Air Quality on Children's Health



Degrees of Global Warming	New Asthma Cases	Incidence of Hay Fever/ Rhinitis	ED Visits for Asthma	School Days Lost	Infant Deaths	Hospital Admissions for Respiratory Illness
2°C	34,500 *(27,900 to 42,800)*	228,000 *(179,000 to 276,000)*	6,240 *(5,210 to 7,330)*	2,240,000 *(1,850,000 to 2,630,000)*	7 *(4 to 10)*	332 *(230 to 430)*
4°C	89,600 *(74,100 to 108,000)*	554,000 *(447,000 to 662,000)*	15,800 *(14,500 to 17,200)*	5,480,000 *(5,170,000 to 5,790,000)*	15 *(6 to 25)*	785 *(353 to 1,220)*

Notes: This graphic presents the results of the air quality analysis at 2°C (equivalent to 3.6°F) and 4°C (equivalent to 7.2°F) of global warming. The results describe additional impacts per year, conditions relative to baseline (1986-2005), and assume populations of children will increase over the 21st century (see Chapter 2, Appendix A). The table displays the average and range across climate models. Figure 12 provides baseline levels and age ranges for each health outcome included. Appendix C provides results for additional degrees of global warming.

The direct medical costs and indirect productivity losses associated with these health impacts may be substantial. For instance, research documents that the lifetime medical and productivity costs associated with new asthma diagnoses are approximately $49,600 per case,[223] while the one-year medical costs stemming from hay fever incidence are about $670 per case,[224] with the potential for further costs over a lifetime if symptoms persist (2021 dollars). ED visits for asthma may result in medical costs of approximately $550 per visit,[225,226] while hospitalizations can cost approximately $10,000 per inpatient visit.[227]

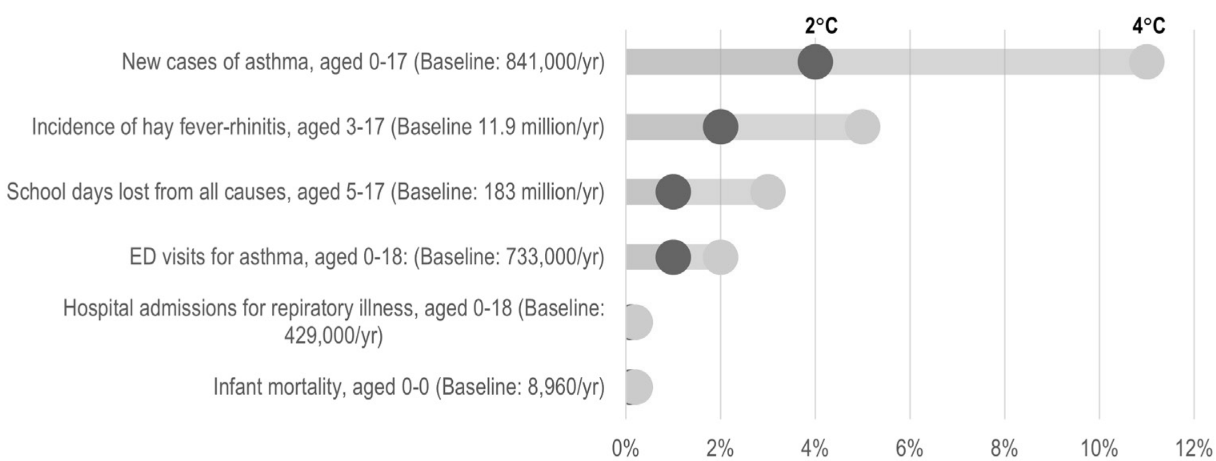
To demonstrate how children's schedules and learning may be interrupted by these health impacts, the analysis projects how climate-driven changes in air pollution will affect school attendance specifically. Across the school-age population (aged 5-17), an additional 2.24 million (1.85 to 2.63 million) school days lost per year are projected at 2°C of warming, increasing to an additional 5.48 million (5.17 to 5.79 million) annually at 4°C. To put these numbers in context, the projected absences at 4°C of warning translate to 0.1 lost days per child per school year. These absences are likely to disproportionately affect children with preexisting conditions, such as asthma.[228] If the population is restricted to children with asthma, each child is expected to miss an additional 1 day of school each year due to climate-driven changes in air pollution levels at 4°C of global warming. Currently, students with asthma miss an average of 4.5 days per school year, amounting to a total of 164 million lost school days nationally.[229]

Research is not available to project what lost school days may mean in terms of current and future costs to children. For example, missing school and after school enrichment or play may affect a child's quality of life, and frequent absences from school may contribute to reduced academic performance and affect cognition and future income. However, available research does translate sick days for children to lost productivity for their parents and caregivers. The health impact valuation literature often assumes approximately $120 per day in lost productivity for adults for each day spent tending to illness for themselves or their dependents.[230]

Finally, the pain and suffering associated with losing an infant is immeasurable. Current practice in health valuation suggests applying a value of approximately $10 million per adult death to account for how much people are willing to pay to reduce their risks of a fatality. Research is limited on how much parents and caregivers value reducing fatal risks to their children, although evidence suggests society may value the health and well-being of children more than adults.[231]

Figure 12 depicts how these various impact measures change relative to their baseline levels (1986-2005) as climate change progresses. Over 4.2 million children across the nation currently have asthma, and over 840,000 new cases are diagnosed annually.[232,233] Relative to these levels, new cases of asthma attributable to climate increase by 4% and 11% at 2°C and 4°C of global warming, respectively—the largest percent increases across the impact measures assessed. The percent change in incidence of hay fever, school days lost, and ED visits from asthma all increase between 1% and 5%. Hospitalizations from respiratory illnesses and infant mortality linked to climate-induced changes in air quality are projected to increase by up to 0.2% at 4°C of global warming.

Figure 12: Estimated Percent Change in Air Quality Impacts Relative to Baseline



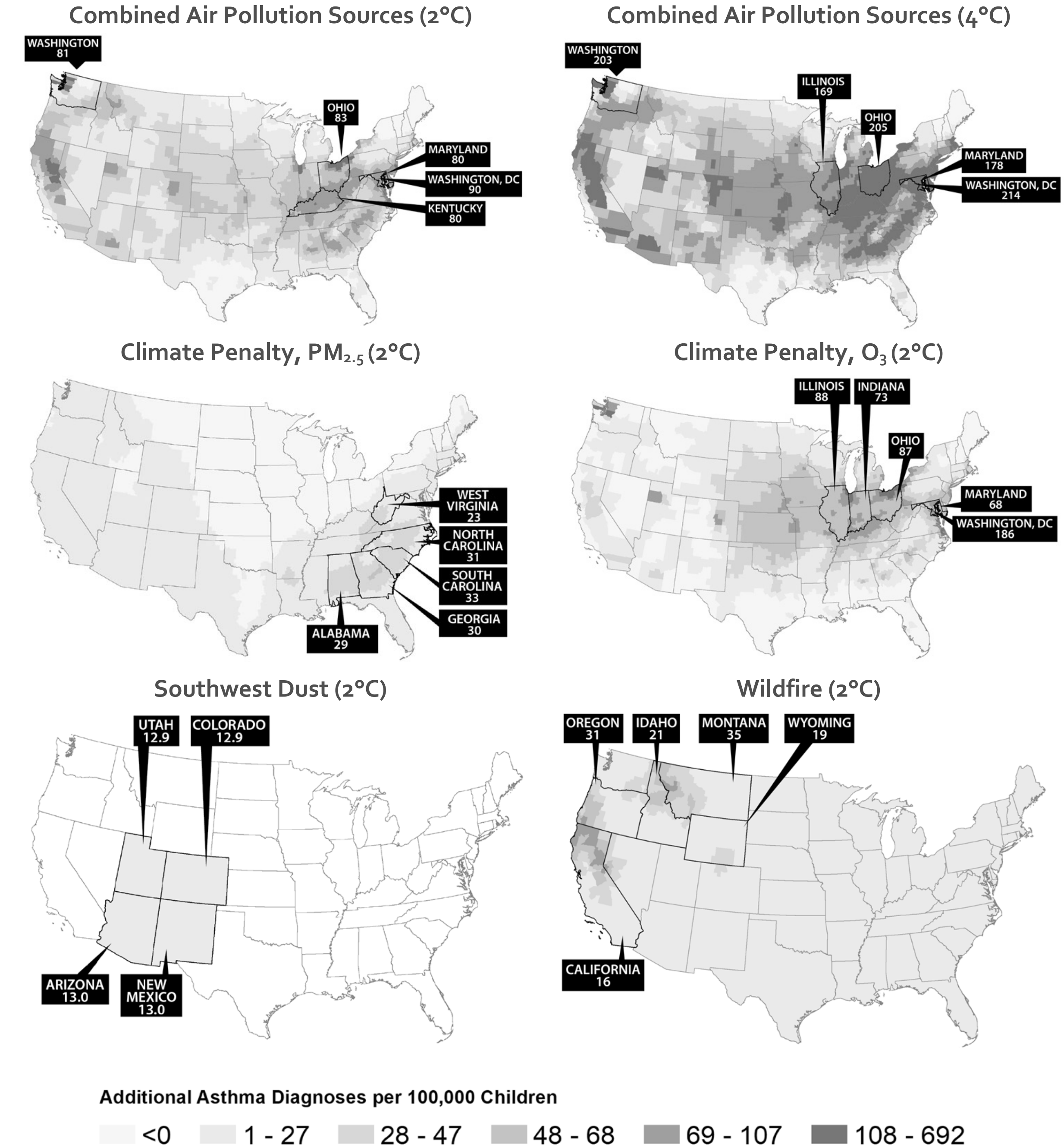
Note: This graphic describes how the health impacts associated with climate-driven changes in air quality increase relative to baseline conditions (1986-2005), as listed in the figure and under assumptions described in Appendix C. The teal circles describe increases between baseline and 2°C of global warming; the light blue circles convey increases at 4°C.

Figure 13 shows the geographic distribution of children aged 0-17 (per 100,000) experiencing new diagnoses of asthma due to climate-driven changes in air quality at 2°C and 4°C of global warming combined across all air pollutant sources and by specific air pollutant type and source. These maps clearly show that the spatial distribution of changes in air quality varies significantly by air pollutant type and source. For instance, the climate-induced changes in $PM_{2.5}$ are concentrated in the Southeast, while related changes in O_3 are highest in some parts of the Midwest and Northwest. Changes to air quality from climate-induced wildfire activity are most acute in the Northwest. Finally, as the name implies and given the spatial scope of the underlying analyses, the impacts associated with ambient dust are confined to four states in the Southwest.

Combined, the greatest impacts are observed in the inner Midwest and Appalachian regions, where O_3 concentrations are expected to increase, and on the West Coast where wildfire activity degrades air quality. Rates are also high across several states in the Southeast where climate-induced increases in $PM_{2.5}$ levels are greatest. The maps identify the five states with the highest number of affected children per 100,000 across air pollutant sources, including the District of Columbia, Kentucky, Maryland, Ohio, and Washington State at 2°C of global warming; Illinois also is among the top states nationally at 4°C. Wildfire $PM_{2.5}$ drives new cases in Washington, while climate-induced increases in O_3 concentrations drive the majority of impacts in the other top states.

Other impacts quantified in this analysis follow similar spatial patterns (see Appendix C). For instance, the increase in school days lost per 100,000 individuals at 2°C of global warming is highest across the Midwest and Mid-Atlantic (the District of Columbia, Illinois, Indiana, Ohio, and Maryland) where O_3 levels associated with changing temperature and precipitation patterns are expected to be most pronounced. Following that, climate-driven changes in precipitation and temperature may also lead to decreased air pollution in some locations. This analysis shows that children in some parts of the contiguous U.S.—such as parts of Maine, New Hampshire, Vermont, Florida, and Texas—are expected to experience decreases in respiratory impacts as conditions change in the future.

Figure 13: Estimated Distribution of Additional Asthma Diagnoses from Air Quality Changes

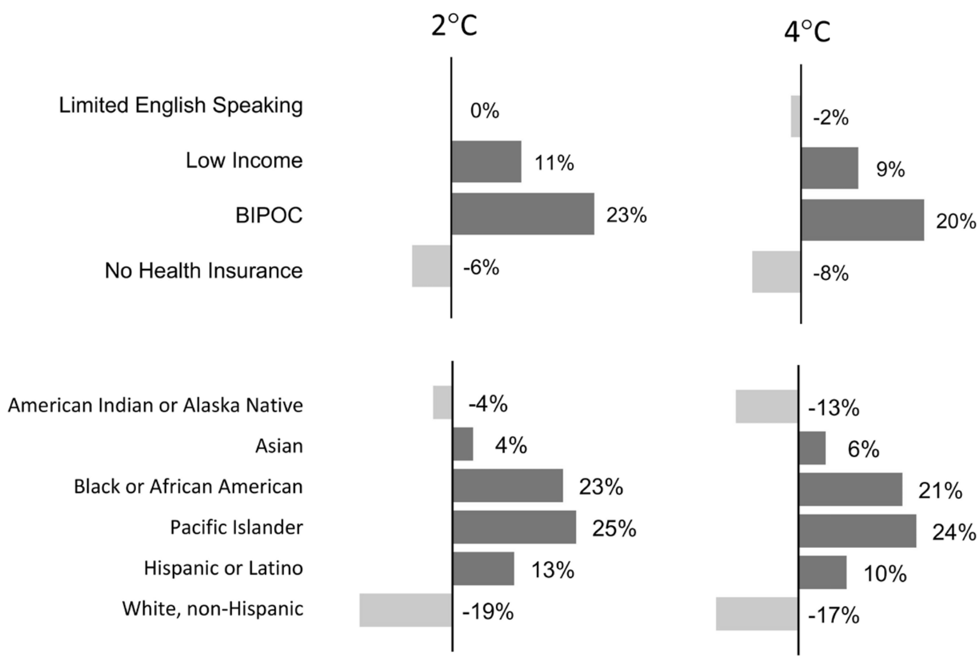


Notes: The maps present new asthma diagnoses attributable to climate-driven changes in air quality per 100,000 children per year. Areas with darker shading have higher rates of affected children. The five states with the highest rates of affected children relative to the county populations are outlined in black. The top two maps show the additional impacts combined across pollution sources for both 2°C and 4°C of global warming. The remaining four maps show the contributions from specific pollutant sources at 2°C specifically. See Appendix C for more details.

Finally, Figure 14 presents the results of the analysis describing the likelihood that certain groups of overburdened children live in areas with the greatest projected number of new asthma diagnoses annually per 100,000 children, following methods described in Chapter 2 and Appendix A. The analysis considers $PM_{2.5}$ and O_3 separately, as the pollutants' contributions to health effects vary across space. Low-income children are 11% and 9% more likely to experience the highest incidence of new asthma diagnoses attributable to climate-driven changes in short-term $PM_{2.5}$ exposure at 2°C and 4°C of global warming, respectively. Similarly, BIPOC children are 23% and 20%, respectively, more likely to experience these effects at the same temperature thresholds. When exploring these same measures by racial and ethnic group, the analysis finds that Asian, Black or African American, Pacific Islander, and Hispanic or Latino children are all more likely than their reference populations to experience the highest likelihood of new asthma cases linked with climate-driven changes in $PM_{2.5}$ exposure.

The analysis does not identify that the socially vulnerable groups of children considered in this report are more likely to be diagnosed with asthma attributable to climate-driven changes in short-term O_3 exposure, specifically. However, among BIPOC children, Asian and Black or African American children are more likely to experience impacts than their reference population, and at levels similar to the $PM_{2.5}$ assessment. More details of the O_3 results are available in Appendix C.

Figure 14: Likelihood of Disproportionate Asthma Impacts Attributable to $PM_{2.5}$ Exposure on Overburdened Children



Notes: These graphics present the results of the social vulnerability analysis of new asthma diagnoses among children attributable to $PM_{2.5}$ exposure linked with climate change, following the methods described in Chapter 2 and Appendix A. The estimated risks for each socially vulnerable group are presented relative to each group's reference population, defined as all individuals other than those in the group analyzed. Populations represent those living in the contiguous U.S. but identifying as a particular race/ethnicity. Analogous results related to O_3 exposure are included in Appendix C.

WILDFIRE SMOKE AND FETAL HEALTH

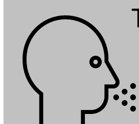
Wildfire activity across the western U.S. is increasing due to hotter temperatures, more lightning strikes, and more variable precipitation. Wildfire smoke is comprised of numerous air pollutants, notably $PM_{2.5}$ and PM_{10}, which pose a threat to human health, including adverse birth outcomes. For instance, Amjad et al.[234] assessed the impacts of wildfire exposure during pregnancy, finding evidence of association between maternal smoke exposure and low birth weight, particularly when smoke exposure occurred late during pregnancy. Similarly, Heft-Neal et al.[235] evaluated the association between wildfire smoke exposure and risk of preterm birth (<37 weeks) in California, finding that 3.7% of observed premature births were attributable to wildfire during the study period.

This report extrapolates the findings from Heft-Neal et al. to consider what these adverse health impacts might look like nationwide, given future warming conditions and associated wildfire activity. The percentage of premature deaths attributable to wildfire activity from Heft-Neal et al., baseline data on premature births from CDC,[236] and average future $PM_{2.5}$ concentrations associated with wildfires from Neumann et al.[237] are used to estimate additional premature births attributable to wildfire at 2°C and 4°C of global warming (see Appendix C for further details). Nationwide, this analysis suggests an additional 7,700 and 13,600 premature births per year at 2°C and 4°C of global warming, respectively, attributable to wildfire annually relative to a 2010 baseline of 14,700 annual premature births. At 4°C, this represents a 92% increase in premature births relative to the baseline number of births affected by wildfire smoke. Additional research by Childs et al. found that population exposure to moderately high wildfire smoke levels in California has increased four-fold in the last decade, suggesting that estimates of a doubling of wildfire exposure and of wildfire-induced premature births may be conservative.[238] Premature births are associated with $38,600 per case in direct health care costs throughout the first five years of life and $2,300 in costs in subsequent years (2021 dollars).[239]

Chapter 5. Changing Seasons

Chapter highlights

Climate change is altering seasonality in numerous ways, leading to longer warm seasons and shorter cool seasons. While seasonality-related changes have a myriad of health and well-being effects on children, this chapter focuses on the effect of seasonality changes on pollen exposure as well as opportunities for participation in outdoor recreation.



This chapter provides a detailed assessment of how children's health may suffer from pollen exposure as seasons lengthen and temperatures warm. At 2°C of global warming, the analysis projects an additional 5,800 (4,800 to 8,000) asthma-related ED visits per year in children from oak, birch, and grass pollen exposures, increasing to approximately 10,000 (9,500 to 10,700) additional asthma-related ED visits at 4°C of warming. Far larger impacts are expected on outcomes like physicians' visits for allergic rhinitis and prescriptions filled for allergy medications, which are projected to increase by 72,000 (68,000 to 77,000) and 211,000 (199,000 to 224,000) visits per year, respectively, at 4°C of warming. These impacts are associated with 17% and 30% increases above baseline at 2°C and 4°C. Some groups of overburdened children are more likely to experience the most severe impacts associated with oak pollen exposure specifically.

The chapter concludes by highlighting several studies that estimate how the number of outdoor recreation trips may change with climate. Overall, lengthening warm seasons are expected to result in more time spent on outdoor recreation, especially boating and water sports. On the other hand, the number of trips associated with some recreation types, like winter recreation and cold-water fishing, will decrease under climate change.

HOW CLIMATE CHANGE AFFECTS SEASONALITY AND IMPACTS CHILDREN'S HEALTH

Climate change is altering seasons in the U.S., leading to longer warm seasons, decreases in natural snow cover, and shorter periods of prolonged cold weather.[240,241,242,243] Increasing temperatures and changing rainfall patterns are extending the growing season, resulting in longer and more intense pollen and allergy seasons.[244,245,246] Warming ambient air temperatures translate into warming water temperatures, which in turn may increase growth of bacteria and harmful algae, leading to increased potential for exposure to waterborne toxins and pathogens.[247,248] Additionally, longer warm seasons and decreased rainfall increase the potential for more frequent and severe wildfires and droughts, particularly in the western U.S. Shorter cold seasons reduce snowpack melt, thus affecting snow-based recreational activities as well as water supply.

IMPACTS OF CHANGING SEASONALITY ON CHILDREN

This chapter explores health impacts from lengthening and intensifying pollen seasons and effects on opportunities for participation in outdoor recreation and play stemming from changes in various weather conditions (temperatures, precipitation, and, subsequently, snowpack).

There are many health effects that can occur from exposure to plant-, fungi-, and tree-based aeroallergens, all of which could be more abundant in a warmer climate. These include conditions such as allergic conjunctivitis, atopic dermatitis of the skin (eczema), and allergic rhinitis (commonly known as hay fever).[249,250] Some research suggests that there may be correlations between hay fever or eczema and attention deficit/hyperactivity disorder (ADHD) in children.[251,252,253] Most diagnosed cases of hay fever in the U.S. are in children, with the highest rates in southern and southeastern states.[254,255] Studies show that historically, states with higher pollen counts and greater rates of pediatric hay fever have sustained either higher temperatures, with drier conditions and a greater number of sunny days, or wetter weather.[256] Pollen particles in the respiratory tract also may weaken the ability of children's immune

Seasonal changes and children

- This chapter explores the effects of changing seasons associated with airborne allergens (like pollen) and on outdoor recreation participation.
- Asthma and other respiratory conditions associated with pollen exposures are likely to become more common and severe as seasons lengthen.
- Overburdened children are more susceptible than other children to adverse health outcomes associated with pollen exposure.
- Recreation types that benefit from an extended warm season will likely see an increase in participation among children, whereas winter recreation will see a decrease in participation.

systems to respond to common viruses, thus putting children at risk of developing more respiratory infections during high pollen seasons.[257] Finally, mold is another source of environmental aeroallergens, releasing spores into the air. Studies have shown that areas with warmer temperatures and higher precipitation rates have more outdoor mold aeroallergens, which can cause allergic and respiratory diseases, particularly in children.[258,259]

Asthma is among the most common childhood respiratory diseases. It is triggered or exacerbated by plant- and fungi-based aeroallergens.[260,261] This can pose health risks to children who are sensitive to these types of allergens and can lead to sickness, missed school days, or worsened performance in school.[262,263] Exposures to tree and other plant pollen also increase the risk of asthma-related ED visits in children.[264,265] Furthermore, research has shown increases in the volume of prescriptions filled for allergies and ED visits for asthma attacks in young children during times of peak pollen counts in the atmosphere in urban and rural environments.[266,267,268,269] This has environmental justice and equity implications as childhood asthma cases occur disproportionately in children belonging to Tribes or children of color living in urban areas that often have worse air quality and poorer health outcomes.[270,271,272,273,274]

Additionally, climate change increasingly will affect personal choices that children and their families make about spending time outdoors, as well as the quality of outdoor recreational spaces.[275,276] Outdoor recreation is important to maintaining general well-being, particularly for children's behavioral, social, and mental health benefits.[277,278,279] As children interact more with nature, they are shown to have decreased stress and improved mental health, and are likelier to maintain a healthier body weight.[280,281]

Recreational activities that benefit from longer warm seasons may see an increase in future participation among children. This increased time spent outdoors is likely to be beneficial to children given the positive physical and mental health associations. However, not all children have equal access to outdoor recreation, particularly children living in poverty and BIPOC children.[282] These children may miss out on the benefits of outdoor recreation opportunities. Children who live in socioeconomically disadvantaged areas often have fewer opportunities to engage in outdoor recreation for multiple reasons, including limited availability of transportation to wilderness areas, financial limitations, or a general lack of access to green spaces and safe areas to play in their neighborhoods.[283,284,285,286,287]

Winter recreation—including skiing and snowmobiling—is one example of where climate change might *decrease* participation among children.[288,289,290] In addition to the reduction in access to these activities, children in communities that rely on the revenue brought in by winter activities may experience decreased financial security when jobs disappear, which can have myriad downstream effects such as food insecurity, mental health challenges, difficulty concentrating and learning, and limited access to healthcare.[291,292,293] While climate change may also contribute to an increase in cold snaps, primarily through changes in circulation patterns, winter recreation impact research indicates that cold periods will be reduced as the climate warms overall.

Extended warm seasons will increase exposure to waterborne hazards such as harmful algal blooms (HABs) or pathogens like *Cryptosporidium*.[294,295,296,297,298] HABs subsequently can limit recreational activities such as fishing, swimming, or playing on the beach;[299,300] additionally, Tribal communities' use of water bodies for subsistence fishing and as sacred resources may be disrupted by these hazards.[301,302] Waterborne hazards can also affect children indirectly when the hazards result in fisheries closures, reductions in tourism dollars, or other effects to their parents' or caregivers' livelihoods.[303,304,305,306,307]

POLLEN AND CHILDREN'S HEALTH

This analysis projects increases in adverse health outcomes among children from more frequent and greater exposure to pollen resulting from climate change. It relies on findings from Neumann et al.,[308] which studied the relationship between increasing season length attributable to climate change for various pollen sources (oak, birch, and grass) and the projected number of future ED visits associated with asthma. Because ED visits represent a relatively rare outcome resulting from pollen exposure, the analysis also considers how the number of physicians' visits associated with allergic rhinitis and prescription fills for allergies may increase in the future. The analysis is guided by findings from Saha et al.[309] that link these health outcomes to intensity of exposure to a broader selection of tree, grass, and weed pollen, including ragweed.

Figure 15: Pollen Analysis Steps

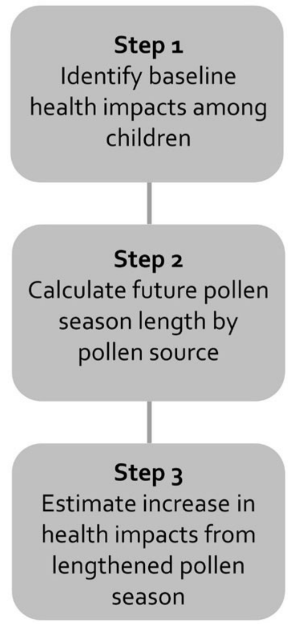


Figure 15 summarizes the analysis steps; more detail about data sources and assumptions is provided in Appendix D. Like the air quality analysis presented in Chapter 4, future health effects associated with climate-driven changes in seasonal conditions are quantified using U.S. EPA's BenMAP[310] model (see Chapter 4 for details). To forecast health impacts, the analysis starts with data from a study projecting future ED visits for asthma. Then, estimates of future physicians' visits and prescription fills associated with a lengthening pollen season are scaled by the rate of change in projected ED visits, for each degree of global warming.

What are the sources of pollen and aeroallergens that affect children?

Different types of plants and trees produce different types of pollen or other aeroallergens. Ragweed is a common type of allergen-producing plant that grows across the U.S.,[311] including in urban areas,[312] and is known to cause irritation and inflammation of the respiratory tracts of sensitive individuals.[313] One ragweed plant can release up to a billion pollen grains into the air over the course of a season.[314] Oak tree pollen is another allergen that has been implicated in increased numbers of ED visits related to asthma.[315,316,317,318]

Finally, while mold is not a plant, molds release spores, another type of environmental allergen. Studies have shown that areas with warmer temperatures and higher precipitation rates can lead to increases in outdoor mold aeroallergens that can cause allergic and respiratory diseases, particularly in children.[319,320] The same types of increases in outdoor mold spore production have been seen after extreme weather events.[321]

Figure 16: Projected Additional Annual Impacts of Pollen on Children's Health

Degrees of Global Warming	Prescriptions Filled for Allergies	First Doctor Visit for Allergic Rhinitis	ED Visits for Asthma
2°C	121,000 *(101,000 to 167,000)*	41,000 *(34,000 to 57,000)*	5,800 *(4,800 to 8,000)*
4°C	211,000 *(198,000 to 224,000)*	72,000 *(68,000 to 77,000)*	10,000 *(9,500 to 11,000)*

Notes: This graphic presents the results of the pollen exposure analysis at 2°C (equivalent to 3.6°F) and 4°C (equivalent to 7.2°F) of global warming. The results describe additional impacts per year for children, conditions relative to baseline (1986-2005), and assume populations of children will increase over the 21st century (see Chapter 2, Appendix A). The table displays the average and range across climate models. Figure 17 provides baseline levels for each included health impact. Appendix D provides results for additional degrees of global warming.

At 2°C of global warning, the analysis projects an average of 5,800 (ranging from 4,800 to 8,000 across climate models) additional asthma-related ED visits per year among children from pollen exposure (Figure 16). Once global temperatures reach 4°C above baseline levels, there are projected to be an additional 10,000 (9,500 to 11,000) ED visits per year associated with asthma exacerbations among children. First-time pediatric visits to physicians for allergic rhinitis are projected to increase by 41,000 (34,000 to 57,000) and 72,000 (68,000 to 77,000) annually at 2°C and 4°C of warming, respectively. Pollen exposure could also result in an estimated 121,000 (101,000 to 167,000) to 211,000 (198,000 to 224,000) additional prescriptions filled for allergies each year at the same temperature thresholds.

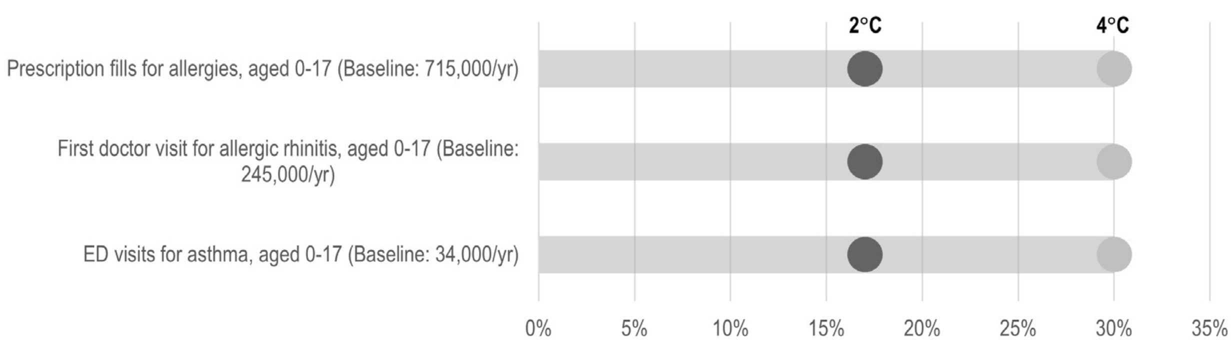
Relative contributions of oak, birch, and grass pollen to these total health impacts are also explored. At 2°C of warming, 45% of cases are associated with birch pollen, 31% with oak pollen, and 24% with grass pollen. Likewise at 4°C of warming, the contributions are 41% from birch pollen, 35% from oak, and 24% from grass. Taken together, birch pollen is expected to be the largest contributor to future climate-induced ED visits for asthma among the three sources explored in this analysis.

Figure 17 provides additional information about how these health impacts are projected to increase in the future relative to levels observed in the baseline. Neumann et al. estimated ED visits would increase by 17% at 2°C of global warming and by 30% at 4°C. The analysis presented in this chapter directly relies on these percent changes to estimate the future total number of doctors' visits for allergic rhinitis and prescription fills for allergies. Therefore, Figure 17 conveys that these two less severe health impacts will increase by the same percent. Further research is needed to more definitively predict if these health measures are likely to increase at the same future rate.

There are several key reasons these results might represent a lower bound of the potential magnitude of allergen-induced suffering among children in the future. First, Neumann et al. consider only the effects associated with *lengthening* pollen seasons, although *intensifying* pollen seasons also are linked with climate change and may result in more illnesses among children. These links to climate change include changes to seasonality but are also connected to changes in pollen production and allergenicity associated with elevated carbon dioxide in the atmosphere because plants use carbon dioxide as an input to photosynthesis.[322] In addition, the health outcomes in the Neumann et al. study stem only from oak, birch, and grass pollen exposures, although pollen from all species of trees, grass, and weeds, especially ragweed, will affect children.[323,324,325] Finally, beyond pollen, childhood exposures to other allergen sources such as mold could increase under climate change and result in additional adverse health effects on children.[326,327]

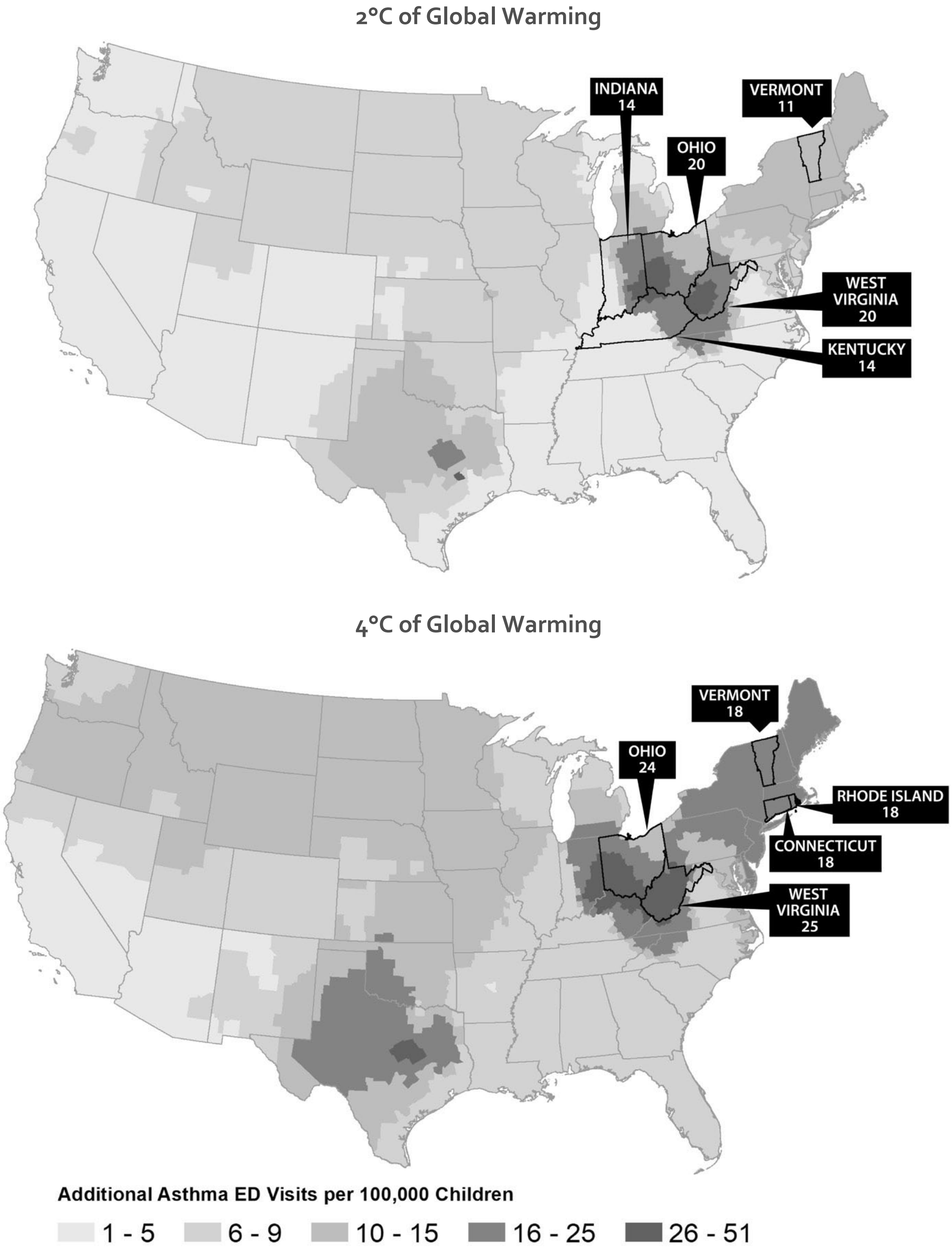
The health burdens associated with pollen exposure can impose costs on children, their caregivers, and society more generally. ED visits are typically associated with direct medical costs of approximately $550 per case (2021 dollars).[328,329] The costs of prescriptions for allergic rhinitis are approximately $130 per year, where patients may need one or more prescriptions filled annually.[330] Visits to physicians are often valued at approximately $150 per visit. Experiencing both mild and serious symptoms from exacerbations of allergies and asthma may result in child absences from school or other enjoyable activities, as well as lost productivity for their parents and caregivers. Even when children attend school, the discomfort and distraction associated with experiencing pollen allergy symptoms can significantly diminish school performance.[331]

Figure 17: Estimated Percent Change in Pollen Health Impacts Relative to Baseline



Note: This graphic describes how the health impacts associated with pollen exposure linked to climate change increase relative to baseline conditions (1986-2005), as listed in the figure and under assumptions described in Appendix D. The teal circles describe increases between baseline and 2°C of global warming; the green circles convey increases at 4°C.

Figure 18: Estimated Distribution of Additional Asthma-Related ED Visits Per 100,000 Children



Notes: These maps present additional asthma-related ED visits attributable to exposure to oak, birch, and grass pollens at the county level. Areas with darker shading have higher rates of affected children. The five states with the highest rates of affected children relative to the county populations are outlined in black. See Appendix D for more details on the spatial distribution as well as impacts by pollen source (oak, birch, and grass).

Figure 18 highlights the regional distribution of these future pollen-induced health impacts. As shown, the incidence of asthma-related ED visits per 100,000 children is highest in parts of the Northeast, Midwest, and Mid-Atlantic regions. The five states with the highest impacts per 100,000 children at 2°C of global warning are Indiana, Kentucky, Ohio, Vermont, and West Virginia. At 4°C of warming, Connecticut and Rhode Island experience among the highest per capita rates nationally. Children are also impacted at a higher rate in central Texas. California and the Southwest region are among the areas projected to experience the lowest pollen-related pediatric health impacts per capita.

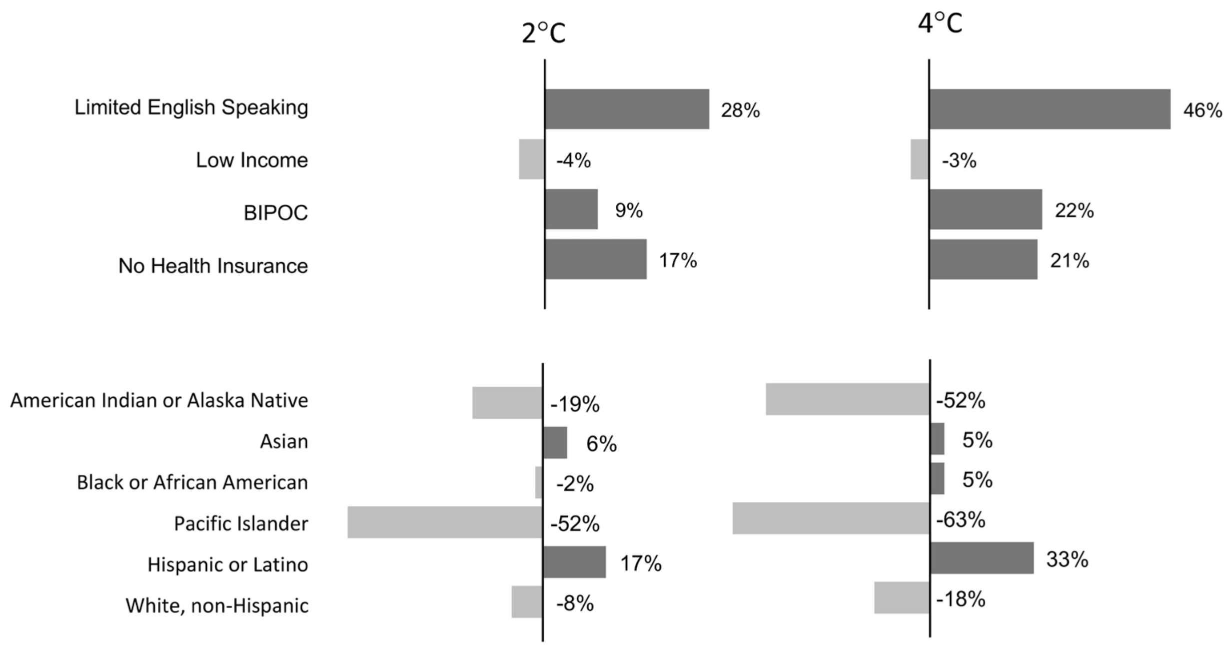
Appendix D provides more detail on the spatial distribution of future asthma-related ED visits linked to each pollen source considered in Neumann et al. As shown, birch pollen is the main contributor to these health impacts experienced throughout Indiana, Kentucky, Ohio, and West Virginia. ED visits associated with oak pollen are more common throughout the Northeast region, whereas grass pollen contributes to higher concentrations of cases in the Northwest region as well as Utah and Kansas. Both oak and grass pollen contribute to the higher rates in central Texas.

Finally, Figure 19 presents the results of the analysis describing the likelihood that overburdened populations of children live in areas with the greatest projected number of asthma-related ED visits from pollen exposure per 100,000 children, following methods described in Chapter 2 and Appendix A. The analysis does not identify that the overburdened populations of children are more likely to experience the greatest impacts associated with combined effects of oak, birch, and grass pollen. White, non-Hispanic children are most likely to experience pollen-related health impacts (see Appendix D). It should be noted that vulnerability to pollen-related morbidity depends only in part on pollen exposures. Equally important are underlying rates of allergies and asthma, which numerous studies have shown are disproportionally high among BIPOC children.[332,333]

However, when disaggregating the analysis by pollen type, the health impacts associated with oak pollen are shown to be concentrated among some of the groups assessed. The underlying pollen exposure data suggest that the higher exposures to birch and grass pollen tend to occur in suburban and rural areas, while exposure to oak pollen is at least as prevalent and perhaps somewhat higher in urban areas – and urban areas tend to be better correlated with the locations of overburdened children.

For instance, children living in limited English-speaking households are 28% and 46% more likely to experience the highest incidence of ED cases for asthma attributable to oak pollen exposure at 2°C and 4°C of global warming, respectively. Further, children not covered by health insurance are 17% and 21% more likely to experience these effects at the same temperature thresholds. Across groups, BIPOC children also experience these effects disproportionately. When evaluating by racial and ethnic group, the analysis finds Hispanic or Latino and Asian children are the groups driving these measures at 2°C of global warming; Black or African American children are also among the groups experiencing the highest likelihood of ED visits from oak pollen exposure at 4°C of global warming.

Figure 19: Likelihood of Disproportionate ED Visits for Asthma Impacts Attributable to Oak Pollen Exposure on Overburdened Children



Notes: These graphics present the results of the social vulnerability analysis of asthma-related ED visits among children attributable to oak pollen exposure linked with climate change, following the methods described in Chapter 2 and Appendix A. The estimated risks for each group are presented relative to each group's reference population, defined as all individuals other than those in the group analyzed. Populations represent those living in the contiguous U.S. but identifying as a particular race/ethnicity. Analogous results related to birch and grass pollen are included in Appendix D.

OUTDOOR RECREATION

Research demonstrates that climate change will alter recreational access, opportunities, and preferences through changes in seasonality. This section highlights several studies that project future recreation access under climate change. While none of these studies are specific to children, they provide suggestive evidence for how recreational opportunities will change for children in the future.

All Outdoor Recreation

Willwerth et al. predicted the future number of outdoor recreation trips for Americans aged 15 and older resulting from changes in temperature and precipitation.[334] The authors find that participation in outdoor recreation increases as weather warms, driven by time spent on water sports and boating, and that individuals in the northern and southern regions respond differently to the warmest days. If individuals continue to respond to temperature as they have between 2003 and 2019, the authors project a net increase of 157 million outdoor recreation trips across all types annually at 2°C of warming in the contiguous U.S. (not global), and up to 288 million trips at 4°C of warming.

Winter Recreation

Wobus et al. assessed how winter recreation, including skiing and snowmobiling, will decrease without reliable snow in the future.[335] The authors project that by 2050, the U.S. will see a net decrease of 17.4 million winter recreation trips annually under a lower emissions scenario (RCP4.5) and 21.5 million trips annually under a higher emissions scenario (RCP8.5). Children currently represent the majority of skiers and snowboarders in the U.S.[336]

Freshwater Fishing

Jones et al. document how increases in ambient temperatures are likely to raise stream temperatures and decrease the areas suitable for cold-water fishing (e.g., fly-fishing for trout).[337] They estimate that annual cold-water fishing days will decline by 1.25 million days by 2030, to 6.42 million days by 2100. Instead, anglers will spend more time fishing in warm-water habitats. This is notable as the largest share of fishing participants in the U.S. are between ages 6 and 12.[338]

Recreation at Reservoirs

Chapra et al. model how increasing temperatures and changing precipitation levels will affect the frequency of HABs in large reservoirs, and how closures will impact recreation, including swimming and boating.[339] They estimate that the 279 reservoirs and lakes covered in the study will experience a projected 1.2 million to 5.3 million visitor-days lost per year by 2090.

Chapter 6. Flooding

Chapter highlights

This chapter describes how flooding affects children and how those impacts are expected to increase as the climate changes. Evidence shows that children experience increased safety risks—including drowning—during flooding events, as well as mental stress associated with displacement from their homes and communities. Exposures to waterborne pathogens and mold in flooded structures also pose health risks. Stress can affect birth outcomes.

This report quantifies the number of children who may experience adverse effects due to flooding in coastal areas; specifically, children who may experience short-term displacement from their home as well as those at risk of losing their homes completely. If no additional adaptation measures are taken, approximately 185,000 (159,000 to 437,000) children are projected to lose their homes from coastal flooding at 50 cm of global sea level rise, increasing to 1.13 million (477,000 to 3 million) at 100 cm. More than 1 million additional children may be temporarily displaced from their homes due to coastal flooding at both 50 cm and 100 cm. Adaptation, including building sea walls, could prevent these impacts for many children. The greatest flooding impacts are concentrated along the Atlantic and Gulf coastlines. Children in overburdened households are projected to experience these impacts disproportionately.

Inland (or riverine) flooding will increase in many areas due to climate change, although fewer children are projected to experience these impacts relative to coastal flooding. For instance, at 4°C, an estimated 560,000 children could be temporarily or permanently displaced from their homes.

HOW CLIMATE CHANGE EXACERBATES FLOODING AND IMPACTS CHILDREN

The frequency of flooding events due to sea level rise will continue to worsen as the climate changes.[340] This includes **inland flooding**, which is the type seen following heavy rainfalls or snowmelt, when flash-flooding occurs during a severe storm, or when rivers or other water bodies overrun their banks,[341] and **coastal flooding**, which refers to nuisance or high-tide flooding, storm surge, high waves that occur during coastal storms, and inundation related to sea level rise.[342] Storm surge is a particular concern; it is the most common cause of physical injury and death during hurricanes, and it also can flood large coastal areas, causing property damage and persistent health risks.[343] The impacts of storm surge can be compounded when surges coincide with high tides, making the flooding that much more extreme and destructive to life and property.[344] Scientific assessments and indicators developed over the past decade have demonstrated a high likelihood of climate change exacerbating or causing coastal flooding, inundation, and inland flooding.[345,346]

IMPACTS OF FLOODING ON CHILDREN

Children face myriad threats from flooding. The physical health impacts of flooding can include cuts, bruises, sprains, and broken bones, which may have short- or long-term health effects.[347] However, tragically, drownings are among the most common types of reported injuries.[348] According to data from the National Oceanic and Atmospheric Administration, between 2017 and 2021, 92 individuals who were 19 and younger were reported to have died from flood-related drownings, representing 16% of all flood-related drownings.[349] Child drownings often are associated with falling into swimming pools or other similar circumstances; however, flood-related injuries and fatalities involving children often occur from slips and falls into or near flooded waterbodies.[350] Additionally, children may be injured or killed if a car they are riding in becomes swept away or overwhelmed by flash-flooding.[351] Research shows that as precipitation amounts have increased in parts of the country, so too have flooding events,

Flooding and children

- Children are susceptible to increased safety risks during floods, including drownings.
- Flooding increases children's exposure to waterborne pathogens, as well as mold in damaged structures.
- Temporary or permanent displacement from homes and communities can create mental health challenges for children.
- Stress experienced by pregnant women during a flooding event can negatively impact birth outcomes.
- Overburdened populations often live in flood-prone areas and are more likely to experience flood impacts.

including flash-flooding.[352] This is especially significant as flash-flooding is responsible for the highest number of flooding-related deaths.[353,354]

The risk of disease may increase during or after flooding events. For example, children may be exposed to pathogens like the norovirus or bacteria of the genus *Vibrio*, either through open wounds in their skin[355] or ingesting drinking water. Depending upon the species, pathogens can cause a range of health effects, including ear infections, flu-like symptoms, or death.[356] Such health effects may become a greater issue in the future as increased cases of vibriosis[357] (any infection resulting from exposure to non-cholera-causing *Vibrio* genus bacteria) and norovirus[358] (the latter due largely to effluent and increased sewage runoff)[359] have been linked to climate change.[360] While many children may not suffer long-term effects from pathogens, immunocompromised children are at greater risk of severe illness or death.[361] Children can be exposed to different types of chemical and biological pollutants or pathogens if they ingest contaminated water either accidentally, by water splashing into their mouths, or from contaminated drinking water sources caused by infrastructure failures during flood events.[362]

Homes that experience flooding are more likely to have dangerous levels of mold, which is linked to increased incidence of asthma in children.[363] Research also shows that mold-related asthma diagnoses and incidences are likely to increase with climate change.[364,365] There are demonstrated correlations between childhood asthma, race, and socioeconomic status, meaning that exposure to flooding could worsen health equity concerns.[366,367]

Pregnant women and fetuses are also at increased risk of experiencing harm associated with flooding. Psychological stress experienced by mothers can be imparted to fetuses during pregnancy, which in turn can lead to adverse pregnancy and birth outcomes, such as preterm birth, low birth weight, and stillbirths, among other effects.[368,369] Limited studies point to ways in which prenatal stress incurred during flooding conditions can lead to cognitive effects in offspring or a failure to thrive.[370,371] Additional ways in which pregnant women may experience harm during flooding include gastrointestinal issues linked to exposures to pathogens or dehydration due to lack of clean water,[372] which can impact the health of the fetus.

Flooding can also impact children's mental health. For example, children may experience post-traumatic stress disorder (PTSD) upon exposure to climate change-related trauma from extreme weather events, such as destructive flooding, or after physical injury or loss of their home.[373,374] PTSD may be short-term or chronic and can manifest in a variety of ways in children, including regressions in toilet-training and communications skills, panic attacks, and a propensity for aggressive behavior.[375,376,377] Stress in childhood, and especially in adolescence, that is related to climate change or exposure to extreme events can contribute to lifelong mental illness, including depression or attachment disorders. It also may contribute to the development of substance misuse disorders.[378,379]

Flooding can disproportionately affect low-income and BIPOC populations. Many flood-prone areas in the U.S. are predominantly disadvantaged, non-White communities.[380] Furthermore, residents within these same demographics are at risk of experiencing "worse" or exacerbated short- or long-term impacts (e.g., displacement or chronic health conditions) of severe tropical weather-related flooding, such as hurricanes, compared to White and/or wealthier communities.[381] As an example, Hurricane Harvey and its documented impacts on the residents of the Greater Houston area have fallen disproportionately on a broad range of disadvantaged, non-White communities.[382,383,384,385,386]

Managed retreat, as well as climate change-related gentrification (see "Glossary" for definitions), are felt most acutely by low-income and BIPOC populations that are more likely to have limited resources or fewer options to move.[387,388] Additionally, leaving a particular area of land or body of water that has cultural or historic significance to communities, including BIPOC individuals, can cause psychological and emotional trauma.[389] As sea level rise increases due to climate change, coastal housing in many parts of the country is losing its value, while inland areas are becoming more and more expensive. This minimizes the flexibility of many coastal inhabitants to relocate.[390] Additionally, groups with strong personal and cultural ties to an area may experience heightened levels of trauma if moving becomes a necessity.[391] Experiencing or exposure to gentrification, loss of housing or housing uncertainty, or observing stress among trusted parents or caregivers may affect children's mental health.[392]

COASTAL FLOODING AND CHILDREN'S HOMES

This section describes an analysis of coastal flooding risks to children through impacts on their homes. The analysis leverages the National Coastal Property Model (NCPM), including recent evidence from Neumann et al.,[393] to model the number of children likely to be temporarily displaced from or lose their home because of coastal flooding. The following two measures of risk are proxies for a larger set of risks to children associated with coastal flooding:

1. *Number of children likely to be temporarily displaced:* This scenario is associated with a high likelihood of temporary home displacement, such as relocation while minor flooding subsides and structures are repaired. This scenario results in various risks to children, including financial and mental stress or loss of schooling opportunities. When children return to their homes following the flooding event, the structures may contain levels of mold that pose health risks to children. Temporary displacement is triggered by damages to residences associated with storm surge, a coastal hazard amplified by sea level rise.
2. *Number of children likely to lose their home:* This scenario considers the high likelihood of permanent home loss through repeated flooding episodes causing damage or permanent inundation and serves as an indicator of the most severe impacts of coastal flooding. For instance, children forced to abandon their homes may experience the financial stress that is placed on families that require new housing. This may be worsened by the mental stress associated with displacement from a community and sites of personal and cultural importance, as well as the threat of housing uncertainty. Concurrent or subsequent disrupted school attendance may also lead to lower educational attainment. Home loss can be triggered by intense and repeated damage from storm surge or by permanent inundation from sea level rise.

Figure 20 summarizes the steps in the coastal flooding analysis, with more details in Appendix E. First, children living in structures experiencing flooding damage under current conditions are identified for the entire contiguous U.S. coastline. Next, the analysis forecasts future coastal flooding from sea level rise and storm surge resulting from climate change. The NCPM then identifies the annual expected damages to residential structures within a 150 m grid. The temporary home displacement scenario evaluates homes with minor damage (2% annual expected damages). The home loss scenario considers properties once annual expected damages reach 10%. Finally, to approximate the number of children who may experience these flooding risks, the analysis maps the 150 m grids to census block groups to calculate the number of children living in those areas. Across all 302 coastal counties, the 2010 U.S. Census identifies over 17.2 million children, equivalent to 23% of all children in the contiguous U.S. By the end of the century, this is expected to grow to 24.5 million children across coastal counties. To show how flooding impacts may progress over the 21st century, results showcase both 50 cm and 100 cm of global mean sea level rise (see Chapter 2).

Figure 20: Coastal Flooding Analysis Steps

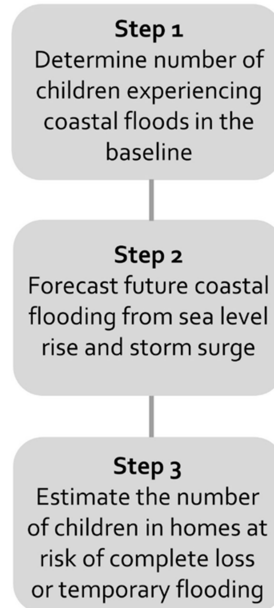
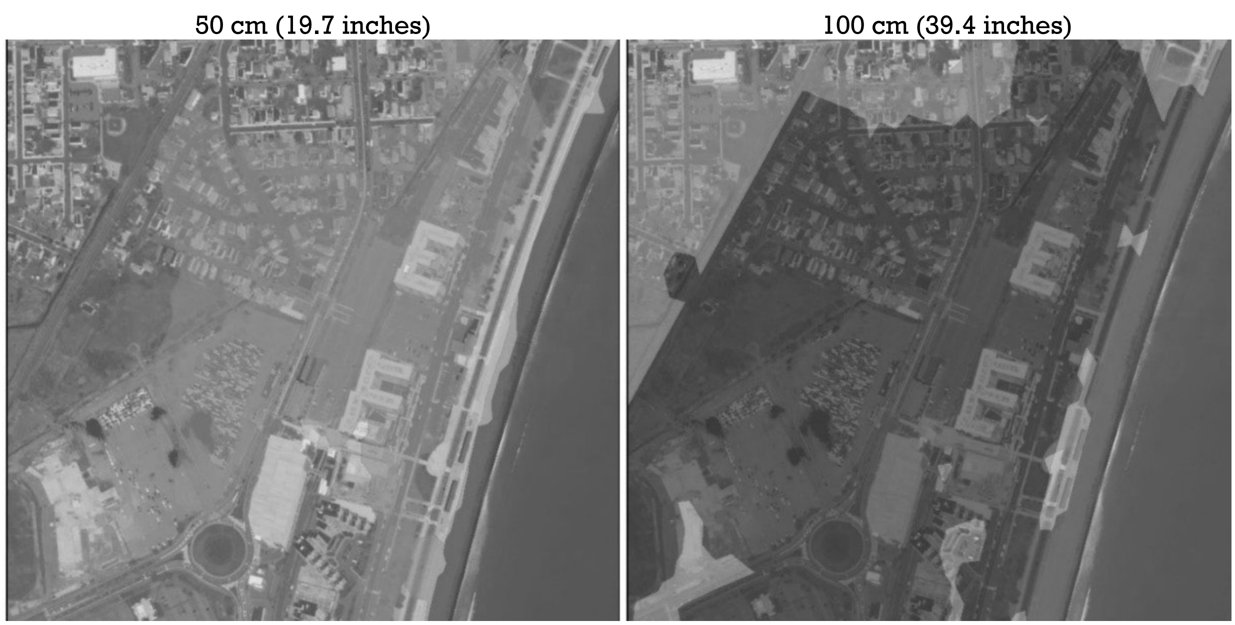


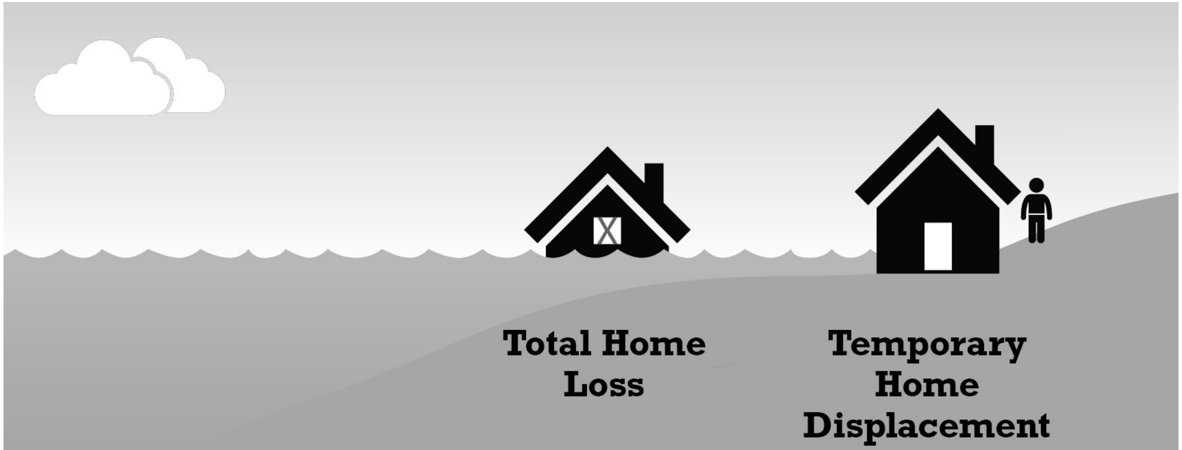
Figure 21 provides an example of the flooding risk severity and global sea level rise scenarios included in this analysis. As shown in the lefthand graphic, the 50 cm scenario generally projects more homes with some amount of flooding that likely results in temporary displacement of families, with fewer homes completely lost. Then, at 100 cm, many more homes are permanently lost, including homes that experienced temporary damage at 50 cm. In other words, homes change from the temporary damage category to the more severe home loss category as sea level rise progresses.

Figure 21: Flooding Scenarios in One Coastal Area



Notes: These maps present an illustrative example of how coastal flooding progresses between 50 cm and 100 cm.

Figure 22: Projected Additional Coastal Flooding Impacts on Children Assuming No Additional Adaptation



Global Mean Sea Level Rise	Number of additional children living in these homes in coastal areas	
	Total Home Loss	**Temporary Home Displacement**
50 cm	185,000 *(159,000 to 437,000)*	1.01 million
100 cm	1.13 million *(477,000 to 3.0 million)*	1.08 million

Notes: This graphic presents the results of the coastal flooding analysis at 50 cm (equivalent to 19.7 inches) and 100 cm (equivalent to 39.4 inches) of global sea level rise. The impacts assume populations of children will increase over the 21st century (see Chapter 2, Appendix A) and convey the impacts to children under the "no additional adaptation" scenario. The results describe additional coastal flooding impacts on children relative to baseline conditions (see Figure 23). Temporary home displacement refers to the number of children affected each year, whereas the number of children affected by home loss is cumulative (i.e., all children affected by home loss at or before the sea level rise threshold). The table displays the average and a statistically derived range of uncertainty for sea level rise for the 50 and 100 cm projections. Chapter 2 and Appendix E provide additional detail on the specific basis for estimating uncertainty in sea level risk and the Appendix provides results for additional global sea level rise thresholds and assuming "with adaptation."

In addition to the severity scenarios and global mean sea level rise projections, the NCPM models two different assumptions about how communities adapt to the threat of coastal flooding by building levees or sea walls, investing in beach nourishment, and elevating properties. The "no additional adaptation" scenario assumes properties maintain the current level of protection, even in cases where some building codes may require it in the future, while the "with adaptation" scenario assumes properties are protected when the benefits of protection outweigh the financial costs of implementing the protection measures.

Figure 22 summarizes the findings of the coastal flooding risk analysis assuming "no additional adaptation" conditions. As indicated in the figure caption, the count of children experiencing home loss considers all homes lost up to and including the time when sea level reaches the indicated sea level rise threshold. The analysis finds that temporary home displacement would affect an additional

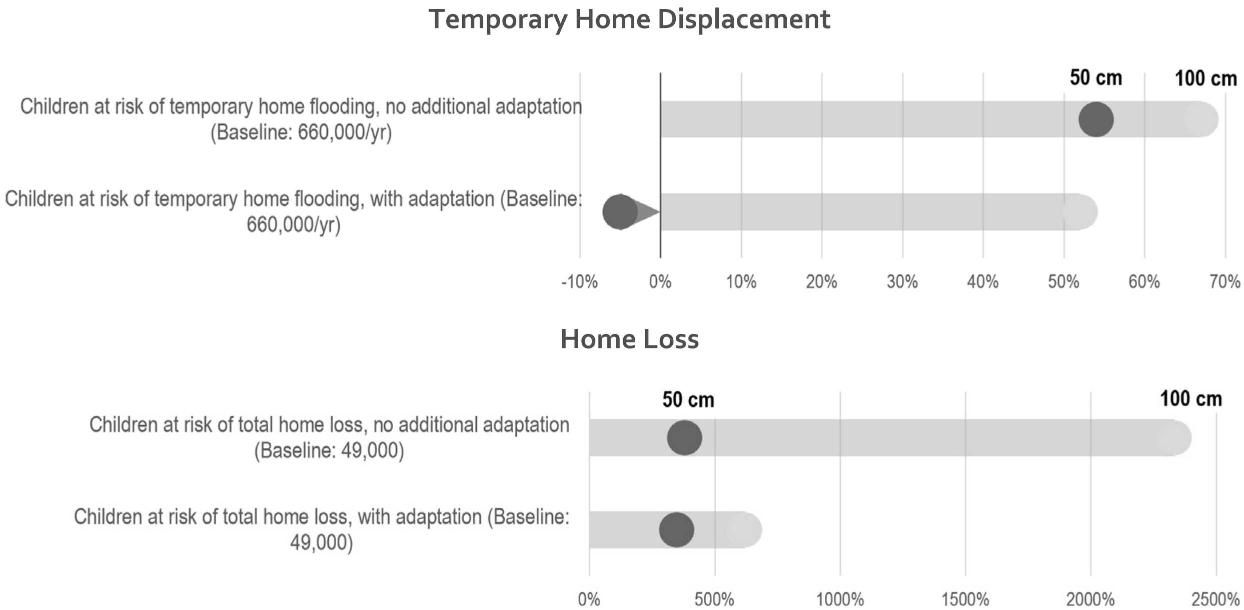
1.01 million children per year at 50 cm and 1.08 million children per year at 100 cm. Complete home loss is projected to affect 185,000 (ranging from 159,000 to 437,000 across climate models) children cumulatively as sea levels rise to 50 cm above current levels. The number of children cumulatively affected by home loss increases to 1.13 million (477,000 to 2.96 million) at 100 cm of sea level rise.

The "with adaptation" scenario projects that the number of children affected by coastal flooding is less widespread, but the effects of adaptation are site- and context-specific. Home loss is projected to affect an estimated 170,000 (149,000 to 216,000) additional children and 300,000 (223,000 to 603,000) additional children at 50 cm and 100 cm of global mean sea level rise, respectively. Relative to the "no additional adaptation" scenario, adaptation prevents home loss for an estimated 16,000 children at 50 cm on average across models. By the time global mean sea level rise reaches 100 cm, adaptation could prevent home loss for 830,000 children on average, suggesting that well-timed adaptation is especially effective at reducing risks under more significant global sea level rise levels. The maps of impacts by state in Appendix E show that this substantial benefit of cost-effective adaptation, where adopted, is uneven across states. For example, for 100 cm, adaptation reduced the number of children experiencing total home loss in Florida by more than a factor of 10, and in California by a factor of 2, but in North Carolina by less than 15 percent.

Adaptation prevents temporary home displacement for an estimated 380,000 children per year at 50 cm on average but only 124,000 children per year at 100 cm, since protection in response to coastal flooding risks tends to prioritize areas that are at the highest risk of significant damage. While the risk reduction benefits of coastal adaptation are apparent, the financial and time investments necessary to implement such protection will be large (on the order of at least several billions of dollars annually, and hundreds of billions through the end of the century) and are an important consideration for the interpretation of these results.

The relatively high number of children still likely to be affected by coastal flooding under the "with adaptation" scenario implies that there are limits to adaptation. Adaptation is a complex process and is difficult to forecast. Many adaptation response decisions in coastal zones are not made with strict cost-benefit decision rules, particularly at the local level. Other factors may include local zoning bylaws, future land use plans, the presence of development-supporting infrastructure, or proximity to sites of high cultural value. The analytical framework of the NCPM provides a simple, benefit-cost decision framework that can be consistently applied for regional and national-scale analysis, but the exact areas where adaptation is implemented may be more or less extensive than reported here.

Figure 23: Estimated Percent Change in Coastal Flooding Impacts Relative to Baseline Conditions



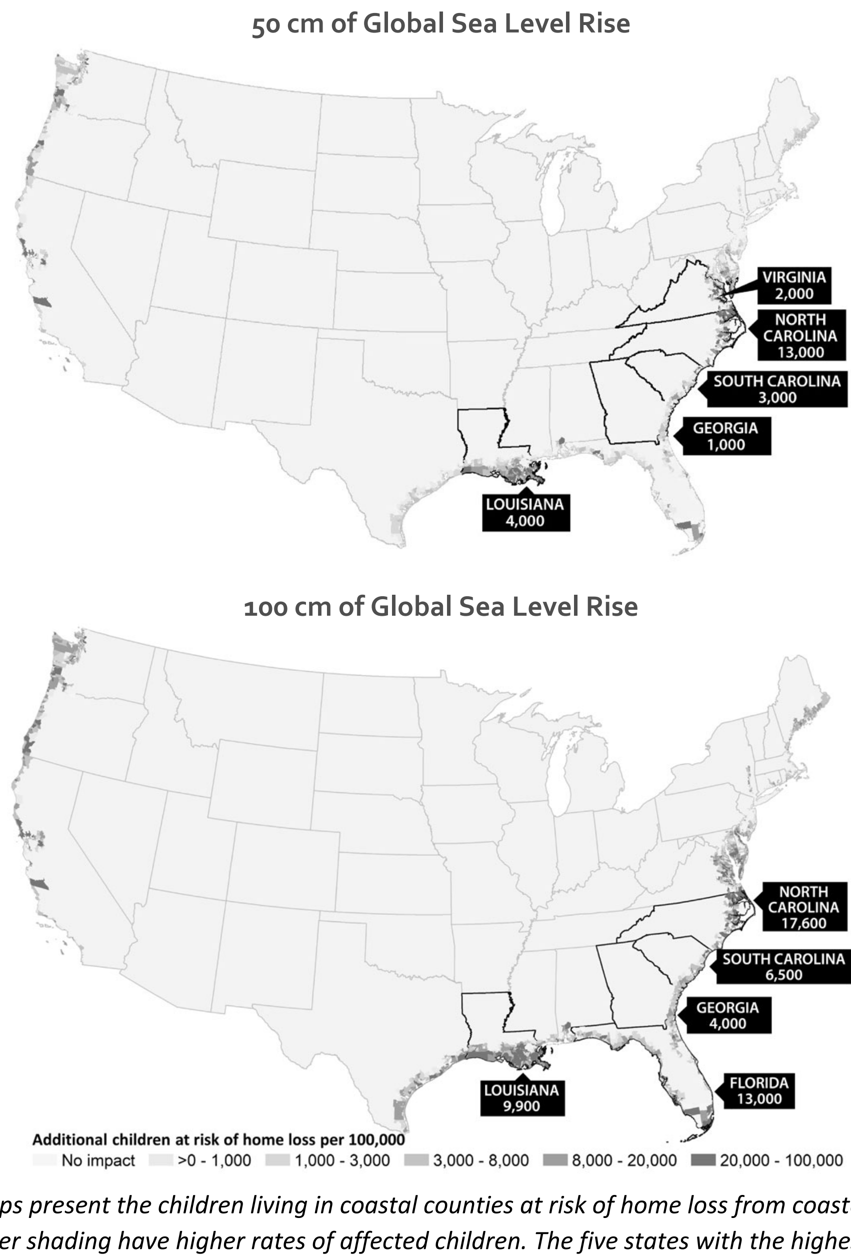
Notes: This graphic describes how the number of children affected by coastal flooding damage to their homes will increase relative to baseline (1986-2005) under assumptions described in Appendix E. The teal (darker) circles describe increases between baseline and 50 cm of global sea level rise; the light blue circles convey increases at 100 cm. "Comets" highlight leftward movement and therefore decreases relative to baseline. The graphic includes temporary displacement and home loss (with different axes) under the "no additional adaptation" and "with adaptation" scenarios.

Figure 23 compares these various future flooding impacts to current conditions, further demonstrating how conditions will change over time. While children currently experience the effects of coastal flooding in many areas, families in homes that have sustained significant damage are likely to have already moved elsewhere, meaning the number of children observed in damaged structures currently is very low. Using various techniques and assumptions to approximate the number of children in previously flooded structures, this analysis identifies around 49,000 children in homes lost to flooding and 660,000 in temporarily damaged homes.

This means that the number of children temporarily displaced by flooding will increase between 47% and 67% under the analysis's "with adaptation" and "no additional adaptation" scenarios at 100 cm. Children experiencing complete home loss increases far more dramatically, in part because the measure captures *cumulative* home loss. Even at 50 cm, the additional children who may sustain home loss increases 3.5 times "with adaptation" and 3.8 times assuming "no additional adaptation." At 100 cm, up to 23 times the number of children could experience total home loss if there is "no additional adaptation" —even with adaptation, the estimated number of children who may lose their home is 6.2 times the current number of children at risk from this type of loss.

Figure 24 describes the geographic distribution of children affected by home loss at 50 cm and 100 cm of global mean sea level rise assuming "no additional adaptation." Regionally, the affected children are concentrated along the Mid-Atlantic and the Gulf coastlines. At 50 cm, the five states with the highest number of affected children living in coastal counties per 100,000 are Georgia, Louisiana, North Carolina, South Carolina, and Virginia. Florida also is among the states with the highest impacts nationally at 100 cm of sea level rise. As shown, children on the Pacific and the upper-Atlantic coasts of the U.S., including the Northern New Jersey and Long Island geographies that were severely affected by Superstorm Sandy, may be spared the worst of future coastal flooding impacts. These results reflect, in part, the coastal protection infrastructure deployed given the known coastal floodplain risks in these areas. Future adaptation to these threats also may alter the geographies with the highest concentrations of children affected.

Figure 24: Estimated Distribution of Additional Children's Home Loss from Coastal Flooding

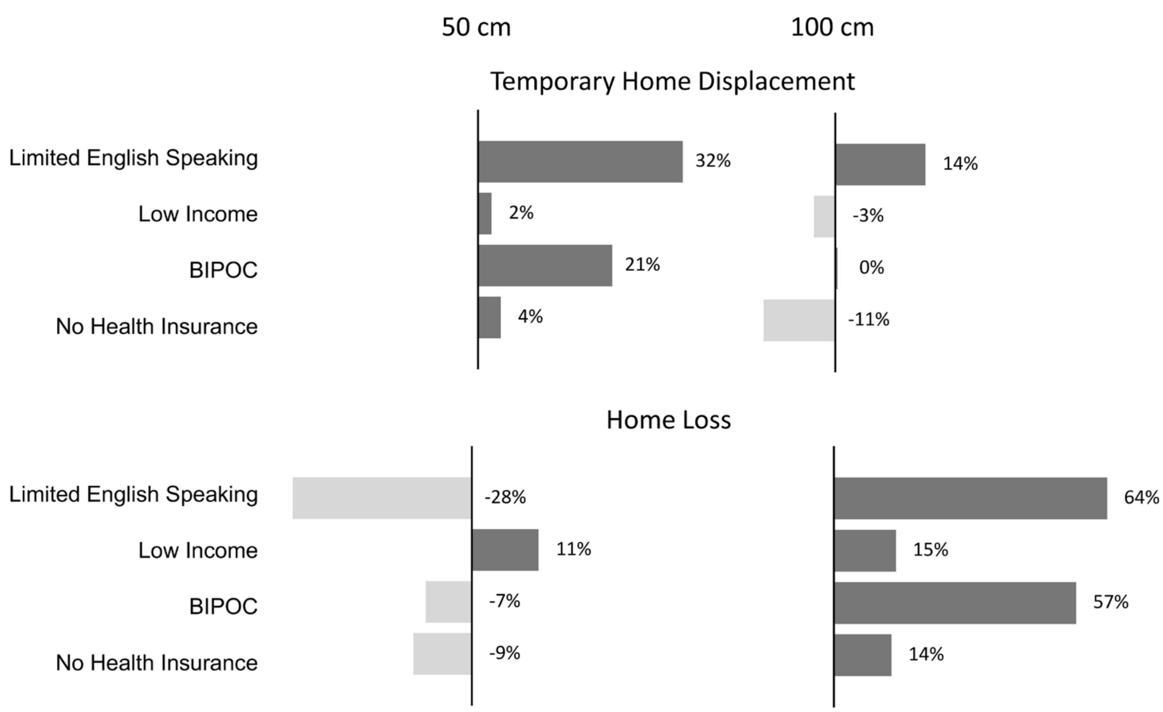


Notes: These maps present the children living in coastal counties at risk of home loss from coastal flooding impacts. Areas with darker shading have higher rates of affected children. The five states with the highest rates of affected children relative to the coastal county populations are outlined in black. The risks assume "no additional adaptation" (see Appendix E for the "with adaptation" scenario).

Finally, Figure 25 explores the social vulnerability dimensions of the impacts predicted in the "no additional adaptation" scenario, implementing the methods described in Chapter 2 and Appendix A. Overall, children in the demographic groups assessed are more likely to be disproportionately impacted by temporary home displacement at 50 cm and complete loss of home at 100 cm. These results may be reflective of the fact that the same child's home may be temporarily damaged at 50 cm but completely lost at 100 cm.

For instance, children in limited English-speaking households are 32% more likely to be affected by temporary home displacement at 50 cm of global sea level rise, decreasing to 14% at 100 cm respectively because a different group of homes and set of children are affected under the two scenarios. At 100 cm, children in limited English-speaking households are 64% more likely to experience home loss, representing a significant increase in disproportionate impacts relative to 50 cm. BIPOC children are 21% more likely to experience effects at 50 cm; these households generally are Hispanic or Latino. At 100 cm, BIPOC children are 57% more likely to suffer home loss, although these effects are concentrated among Asian and Pacific Islander children. Low-income children and children not covered by health insurance also experience disproportionate impacts from temporary flooding at 50 cm and complete home loss at 100 cm, although to a lesser extent than the other groups.

Figure 25: Likelihood of Disproportionate Coastal Flooding Impacts on Overburdened Children



Notes: These graphics present the results of the social vulnerability analysis of coastal flooding impacts on children, following the methods described in Chapter 2 and Appendix A. The differences in risk are measured for the "no additional adaptation" scenario specifically (see Appendix E for other analysis details). The estimated risks for each socially vulnerable group are presented relative to each group's reference population, defined as all individuals other than those in the group analyzed. Populations represent those living in the contiguous U.S. but identifying as a particular race/ethnicity.

INLAND FLOODING AND CHILDREN'S HOMES

Inland flooding, including riverine flooding ("fluvial flooding") and flash floods associated with extraordinary precipitation events ("pluvial flooding"), will impact children through damages to their homes and the potential for displacement. Riverine flooding occurs when excessive rainfall over an extended period collects across a watershed and causes a river to exceed its capacity. Because a warmer atmosphere can hold more moisture than a cooler atmosphere, climate change is expected to change the frequency and magnitude of precipitation and flooding across the country.[394] Flood risk from high excessive riverine flow is widespread in the contiguous U.S. and growing because of climate change, as well as changes in housing and population density.[395,396] Flood risks associated with high rainfall events are widespread nationally and appear to be increasing in frequency, particularly as a result of hurricane-induced rainfall, but are only beginning to be understood comprehensively as a serious flood risk and a source of inequitable flood risk exposure.[397]

A recent study that connects the frequency and severity of inland flooding events to climate change also provides insights on how children may be affected.[398] The analysis considers annual expected property damages from flooding, the same metric as the coastal flooding analysis presented earlier in this chapter. With 2°C and 4°C of global warming, the greatest impacts are projected to occur in the Northern Great Plains and Northwest regions, with a significant and large burden of damage also seen in the Southwest and Southeast. At 2°C of global warming, nearly 200,000 additional children may live in areas where flood damage could cause a temporary evacuation. At 4°C, the estimate of children affected grows to more than 550,000 individuals. Using a metric of more severe flood damage, including permanent home loss, nearly 17,000 children might be affected at 2°C of warming, and more than 55,000 at 4°C. These results are informative about the number of children that may be affected by climate-induced riverine floods and offer a useful comparison to the coastal flooding results presented earlier in the chapter, where far more children will be impacted. Note that flood-proofing or other adaptation was not considered in this study. Appendix E provides more details on the methods used for this analysis.

Chapter 7: Infectious Diseases

Chapter highlights

This chapter describes how varying temperature and precipitation patterns linked with climate change are likely to alter the habitat, range, and density of pathogens, vectors, and hosts that result in disease among children. Similarly, as people spend more time outdoors as temperatures warm, especially in the "shoulder seasons" of spring and fall, children are more exposed to ticks and mosquitos that carry vector-borne diseases.

Lyme disease, carried by blacklegged ticks, is one such disease that will be influenced by changing temperatures and rainfall patterns. Across the 21 states and the District of Columbia in which Lyme disease is currently prevalent, the detailed analysis presented in this chapter projects an additional 2,600 (-7,500 to 20,200) new cases of Lyme per year among children at 2°C of global warming (31% increase relative to baseline). At 4°C of global warming, the increase relative to baseline is much more extreme: 23,400 (7,800 to 47,000) additional cases per year among children (272% increase). States in the northernmost areas of the Northeast and Midwest regions are expected to see the majority of new cases among children.

West Nile Virus (WNV), carried by mosquitos, is also likely to see a change in new cases as temperatures increase. Existing research estimates an additional 59 cases per year of West Nile Neuroinvasive Disease (WNND), a severe outcome associated with WNV, among children at 2°C of global warming, rising to 133 cases at 4°C. The regions with the largest increases in cases include the Southern Great Plains and the Southeast. While small in magnitude, these results may indicate an increase in other mosquito-borne diseases as well.

HOW CLIMATE CHANGE ALTERS INFECTIOUS DISEASE AND IMPACTS CHILDREN

Temperature and precipitation levels affect the habitat, range, and density of pathogens, vectors, and hosts. Therefore, as the climate changes, the geographic extent and concentrations of the organisms that spread disease will change, including mosquitos and ticks.[399,400,401,402,403,404,405,406] Diseases may no longer be common or endemic in some areas due to increased temperatures or changes in precipitation levels, but the diseases may become endemic in new parts of the country or may be present for longer periods of the year in others. Finally, human behavior is an important element in the spread of vector-borne diseases. As the climate warms, and it becomes possible or necessary for some individuals to spend more time outside, the opportunity increases for exposures to ticks, mosquitos, and other vectors to occur.[407]

IMPACTS OF INFECTIOUS DISEASES ON CHILDREN

Mosquitos and ticks are key causes of childhood vector-borne diseases linked to climate change. Lyme disease is one of the best-known and most common vector-borne diseases in the U.S.[408] People develop Lyme disease after being bitten by the blacklegged tick (also known as the deer tick, *Ixodes scapularis* Say) or the western blacklegged tick (*I. pacificus* Cooley and Kohls) infected with the bacteria *Borrelia burgdorferi* sensu stricto.[409] In 2019, the U.S. Centers for Disease Control and Prevention (CDC) reported 35,000 confirmed and probable cases in the U.S. Of those, children between the ages of 0 and 19 experienced 6,560 confirmed and probable cases—approximately 32% of total cases.[410] Children aged 5-9 have the highest historical incidence rate of Lyme disease of any age group.[411] Symptoms include a range of short-term effects, including a classic rash (erythema migrans; commonly known as the "bullseye" or "target" rash). In some instances, children can also experience lifelong or life-threatening effects, including lethargy; neurological impacts, such as facial paralysis commonly known as Bell's Palsy; meningitis; juvenile arthritis; and carditis, also known as

Infectious diseases and children

- Climate change will influence the geographic extent and concentration of organisms that spread disease, including mosquitos and ticks.
- Lyme disease, transmitted via ticks, can result in a short-lived rash or lifelong neurological or heart conditions.
- West Nile Virus, transmitted via mosquitos, is generally mild in children, except for those who are immunocompromised. Other diseases associated with mosquitos include Zika, chikungunya, dengue, and malaria, and are currently rare in the U.S.
- Food- and water-borne diarrheal diseases could also become more prevalent in the U.S. under climate change.

inflammatory heart disease.[412,413,414,415] Juvenile arthritis generally is the most common, severe long-term effect.[416] Research suggests that longer periods between exposure and treatment are linked to more serious and persistent health outcomes in children.[417] Lyme disease can also result in a rare syndrome with non-specific, generally subjective symptoms that has become known as “chronic Lyme” or “post-treatment Lyme disease syndrome,” in which symptoms persist for more than six months post-treatment.[418] At this time, few studies exist for pediatric cohorts that detail how children's health may be affected over the long term.[419,420]

Other tickborne diseases that are endemic in the U.S. include anaplasmosis, babesiosis, and Rocky Mountain spotted fever.[421,422,423,424] Each is transmitted by the bite of different tick species across the country, and some may occur as concurrent infections with Lyme disease.[425] Rocky Mountain spotted fever also is known as rickettsiosis, the general name for diseases caused by the bacteria *Rickettsia* spp.[426] Rickettsiosis mostly commonly is found in children and can cause extremely serious health effects and lead to death.[427,428]

WNV is the most common domestic mosquito-borne disease in the U.S.[429] In the U.S., it is spread primarily by the species *Culex pipiens, C. tarsalis*, and *C. quinquefasciatus.*[430] In children, the primary means of exposure are via mosquito bites,[431] although WNV can be transmitted from mother to child *in utero* and through breast milk.[432,433] Fortunately, WNV does not typically present symptomatically or seriously as frequently in children as in adults (1-5% of WNV cases present in children); however, it can cause severe health effects in young patients, especially those who are immunocompromised.[434] Symptoms and health outcomes span from mild (including rash, gastrointestinal upset, and flulike symptoms[435]) to severe (including encephalitis, symptoms similar to polio myelitis and meningitis, paralysis, and other effects, including death[436,437]). Further, WNV can cause less-specific damages to the central nervous system and associated chronic health effects.[438,439] The long-term ramifications of these more severe health outcomes are considerable, as they can lead to permanent damage or death, especially in immunocompromised children.[440,441]

Mosquitos are successful vectors for numerous other diseases that can have deleterious health impacts in children. Since 2015, the Zika virus has spread primarily via *Aedes* spp. mosquitos[442] in tropical and subtropical environments.[443] The virus can be transmitted during pregnancy to a fetus and can lead to extremely serious birth defects, including brain damage (such as microcephaly).[444] Children also can be exposed to and develop complications from the Zika virus, which generally has milder health effects[445] but still may impact cognition in severe cases.[446] These effects can have lifelong consequences for children and parents, which researchers project could cost millions to billions of dollars in healthcare costs.[447] Other global mosquito-borne diseases associated with considerable child health concerns include chikungunya, dengue, eastern equine encephalitis, and malaria.[448,449,450] Each can have severe health implications for children, including the potential to cause neurological damage and moderately high mortality rates.[451,452,453] Fortunately, current incidence rates in the U.S. are low for each of these types of diseases and commonly are associated with international travel. However, incidence rates have been increasing over the past few decades, and the diseases have the potential to become endemic in the U.S.[454,455,456,457,458]

Other types of infectious diseases, such as those that are food- or water-borne diarrheal diseases, could become more prevalent in the U.S. under climate change. For example, *Cryptosporidium,*[459] *Salmonella,*[460] *Escheria coli (E.coli),*[461] and *Shigella*[462]all have links to climate change and cause gastrointestinal illness. The pathogens are likely to become more prevalent with increases in extreme rainfall, changes in temperature that promote bacterial growth, insufficient or damaged infrastructure, considerable storm runoff, poor wastewater management, or some combination of these elements.[463,464,465] The subsequent illnesses can lead to childhood deaths if left untreated, owing to resultant malnutrition and dehydration.[466,467] This is especially true in younger and immunocompromised children.[468]

Infectious disease presents many potential issues related to disparities across demographic groups. Research suggests correlations between underdiagnosis or misdiagnosis of Lyme disease, in part because the rash may be difficult to detect on darker skin.[469,470,471] Additionally, Black children may be less likely to receive antibiotics either as a precautionary measure or as treatment.[472,473] Research shows that Black individuals experience greater rates of Lyme carditis, which is linked to delayed treatment.[474] Limited research also demonstrates that proportionately there is a greater cost of Lyme disease and other types of tick-borne illnesses and treatment that is borne by low-income individuals who either cannot afford treatment, or who seek or receive delayed healthcare, relative to those who are not low income or have health insurance.[475,476] Similarly, other types of infectious diseases in the U.S. have had disproportionately adverse effects on different populations of children. For instance, the Zika virus was found to have the greatest impacts on Hispanic or Latino children, including newborns, infants, and older individuals.[477] Areas of higher incidence of mosquito-borne illnesses, such as Zika or WNV, frequently are in low-income areas.[478,479]

LYME DISEASE

This section quantifies the potential increase of Lyme disease cases among children linked with future temperature and precipitation associated with climate change. It leverages the analysis by Yang et al. (in review),[480] which associates national historical precipitation and temperature patterns (e.g., changes in national temperatures, rather than global temperatures) with new cases of Lyme disease among children in the eastern U.S., where the disease currently is prevalent.* Based on the historical relationship, the authors project the future number of Lyme disease diagnoses associated with infections from the blacklegged tick and the bacteria that causes Lyme disease as linked with climate change.

Figure 26: Lyme Disease Analysis Steps

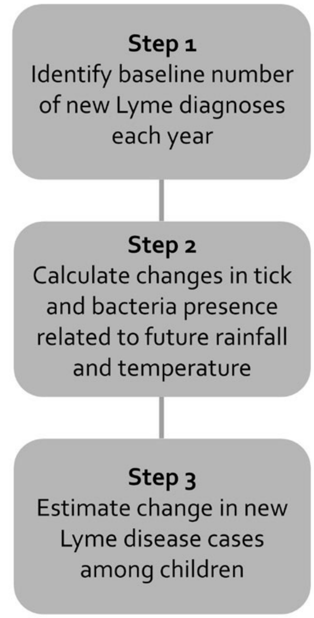


Figure 26 describes the analysis steps taken for this report, with more details about the methods, data sources, and assumptions provided in Appendix F. First, baseline Lyme disease diagnoses among children are derived from data maintained by the U.S. Centers for Disease Control and Prevention. Next, changes in tick and Lyme disease-causing bacteria presence related to future rainfall and temperature are modeled. Finally, presence is used to estimate Lyme disease cases among children.

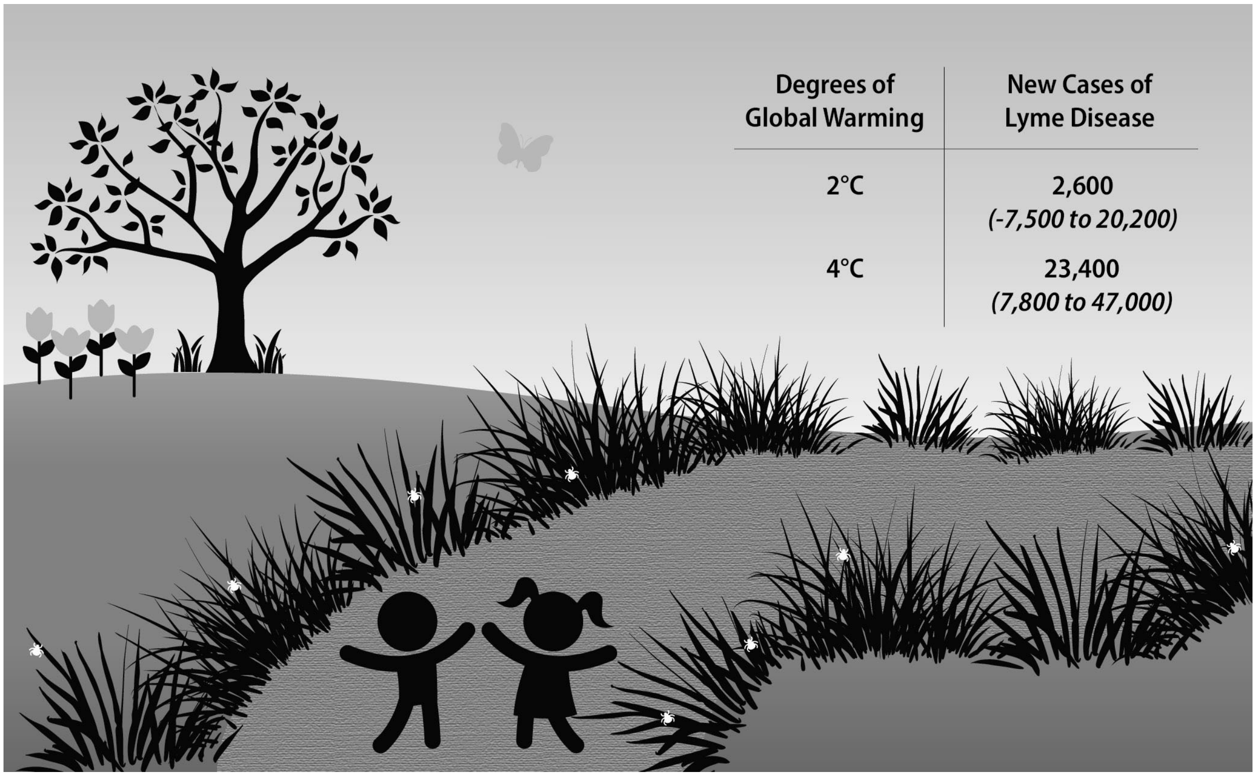
Yang et al.'s analysis confirms that ticks and the Lyme disease-causing bacteria are highly sensitive to temperature and precipitation conditions, and that their range and prevalence are expected to increase as climate continues to change. In general, this means that areas of the U.S. with suitable climatic conditions and habitat to support tick populations generally shift northward. However, differences in rainfall trajectories, and potential impacts on tick and host movements or behaviors, make for a more nuanced geographic picture of future tick habitat.

How are Lyme disease and climate change connected?

Lyme disease is closely connected with climatic conditions. Disease transmission occurs most often between nymphal ticks and humans, other mammals, rodents, and birds.[481] Longer periods of warmer temperatures and increased humidity earlier in the year allow ticks to emerge sooner and stay active for longer.[482,483] That said, the ticks and their hosts will not extend to or remain in areas that are too hot or cold,[484] have heavy rainfall, or are overly wet or dry.[485] As land use changes and host animals expand their ranges, so do ticks; and, as a consequence, Lyme disease is found in new locations.[486,487] Another important factor is that certain hosts such as lizards do not process or carry the bacteria; therefore, disease transmittal is not as common where these host species are the primary food sources for the ticks.[488] Additionally, with moderate warming, humans may spend more time outside (i.e., in typically cooler northern regions), which may increase opportunity for exposure to ticks and thus to Lyme.[489] All of these changes are reflected in how Lyme disease cases over the past 30 years have spread into new areas and increased.[490]

* The study scope includes 21 states (Connecticut, Delaware, Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia, and Wisconsin) as well as the District of Columbia.

Figure 27: Projected Additional Cases of Lyme Disease Among Children Per Year Attributable to Climate Change

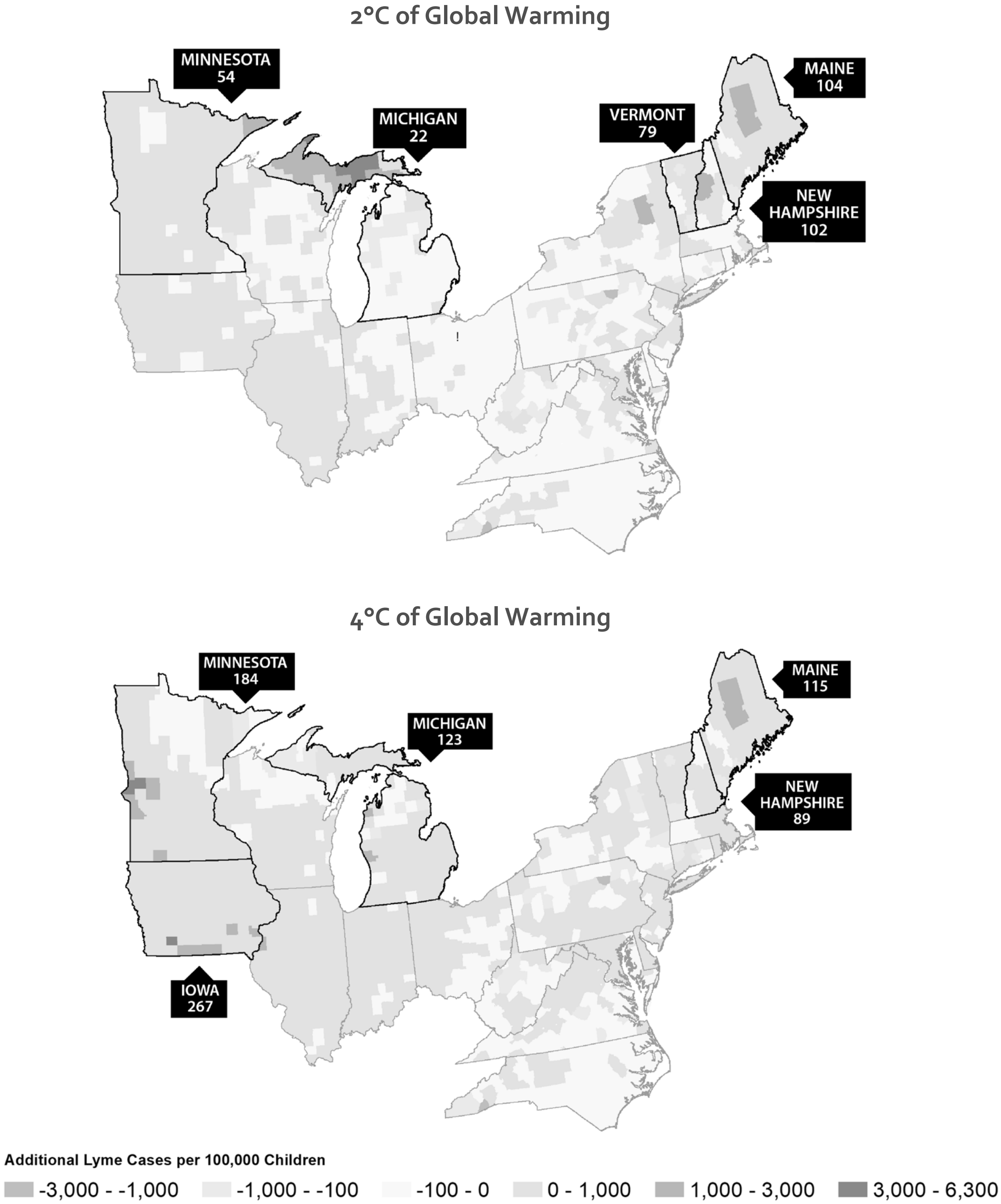


Notes: This graphic presents the results of the Lyme disease analysis at 2°C (equivalent to 3.6°F) and 4°C (equivalent to 7.2°F) of global warming. The results describe additional impacts per year for children living in the study region (see Figure 28 for details) and conditions relative to baseline (1986-2005), and assume populations of children will increase over the 21st century (see Chapter 2, Appendix A). The table displays the average and range across climate models. Figure 29 provides baseline levels. Appendix F provides results for additional degrees of global warming.

Figure 27 summarizes the estimated number of additional cases of Lyme disease among children linked with these changing climatic conditions. Across the 21 states and the District of Columbia included in Yang et al.'s sample, the analysis estimates an additional 2,600 (ranging from 7,500 to 20,200 across climate models) cases per year among children at 2°C of warming, and 23,400 (7,800 to 47,000) additional cases per year at 4°C of warming. In order words, these projections suggest a dramatic increase in cases at more extreme warming levels. Even so, it is well-documented that Lyme disease is underreported,[491,492,493] with CDC estimates that as few as one in ten actual cases are captured in its data. Because the estimates in this analysis are calibrated based on historical reporting, the actual number of future cases similarly may be different.

Recent research is limited regarding the cost of Lyme disease in children. Yang et al. identify an average healthcare cost of approximately $4,200 per case of Lyme disease, adjusted from Adrion et al.,[494] which considers children in the sample, although the study also includes all adults under age 65 (2021 dollars). Beyond healthcare costs, there may be indirect costs associated with lost productivity, including lost workdays among parents caring for sick children, as well as quality of life losses among affected children and their caretakers.

Figure 28: Estimated Distribution of Additional Lyme Cases Per Year Among Children



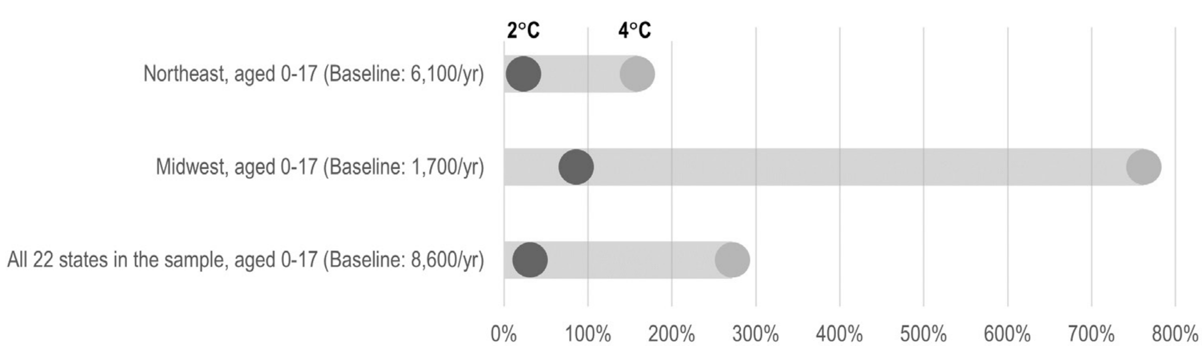
Notes: These maps present new Lyme cases attributable to climate change per year relative to baseline levels at 2°C and 4°C of global warming. Areas with darker purple shading have higher rates of affected children; areas with darker yellow shading see the largest reduction relative to baseline infections. The five states with the highest rates of affected children relative to the county populations are outlined in black. See Appendix F for more details.

Figure 28 conveys the spatial patterns of these new cases of Lyme disease per 100,000 children at 2°C and 4°C of warming relative to the baseline, where purple shading highlights increases in new cases and yellow shading emphasizes decreases in new cases. As shown, not all areas are expected to experience additional cases of Lyme disease among children at either temperature threshold. In fact, most of the 21 states and the District of Columbia show pockets of both increasing and decreasing case rates. Overall, the states with the most additional cases are in the northernmost parts of the Northeast and Midwest. Michigan is one state where the spatial extent of new cases dramatically changes between the two temperature levels; increasing case rates are experienced only in the Upper Peninsula at 2°C of global warming while other areas of the state demonstrate increasing rates starting at 4°C of global warming.

These regional patterns are further illustrated in Figure 29, which depicts changes in new cases relative to their baseline levels (1986-2005) as climate change progresses among the 21 states and the District of Columbia included in the analysis. Across this geography, the number of cases increases 31% and 272% at 2°C and 4°C of warming, respectively. At the regional level, increases relative to baseline are less in the Northeast than in the Midwest, although baseline rates are currently significantly higher in the Northeast.

Finally, following the analytical methods for assessing social vulnerability as described in Chapter 2 and Appendix A, this analysis does not determine that overburdened populations of children are more likely to live in areas with the greatest climate-driven increases in Lyme disease cases. The social vulnerability analysis finds that White, non-Hispanic children are 73% to 93% more likely to live in areas with the highest potential for Lyme disease at 2°C and 4°C of warming (see Appendix F). This does not mean that there are no inequities associated with Lyme disease (see earlier discussion in this chapter); rather, they may not be captured through this analysis. As evidenced by existing research and discussed elsewhere in this chapter, early-stage Lyme disease may be underreported and undertreated among some overburdened populations, which increases the probability of more severe outcomes in these communities.

Figure 29: Estimated Percent Change in New Cases of Lyme Disease Per Year Among Children Relative to Baseline by NCA Region and Overall



Note: This graphic shows the number of new annual Lyme disease cases associated with climate change relative to baseline conditions (1986-2005) by NCA region and overall under assumptions described in Appendix F. The teal circles present increases at 2°C while the purple circles convey increases at 4°C.

WEST NILE VIRUS

Climate change is projected to alter the geographic distribution of West Nile Virus (WNV) and its vectors, causing additional disease outbreaks stemming from infected mosquitos. Approximately 1% to 5% of all WNV cases present symptomatically in children, and these cases are usually milder than in adults.[495] However, the lack of severity may result in under-reporting or misclassification among younger individuals.[496] Cases of West Nile neuroinvasive disease (WNND) occur in less than 1% of people infected with WNV, and frequently result in hospitalization for severe symptoms that are harder to misclassify or ignore.[497]

Belova et al. estimated the future number of WNND cases associated with increasing temperatures in the U.S. among people of all ages.[498] The authors rely on data that show approximately half of all U.S. counties reported at least one WNND case between 2004 and 2012, meaning the suitable habitat for mosquitos carrying WNV is much broader geographically than the suitable habitat for ticks that cause Lyme disease. At the baseline, the Southern Great Plains region of the U.S. has the highest incidence rates for WNV infections.

The study findings translate to 1,490 and 3,330 additional cases of WNND at 2°C and 4°C of global warming, respectively, compared to a baseline of 971 annual cases. According to the U.S. CDC, children accounted for approximately 4% of all WNND cases reported from 1999 to 2007.[499] Applying that proportion to the Belova et al. results, the analysis estimates an additional 59 cases of WNND among children at 2°C of global warming, rising to 133 cases at 4°C. Children living in North Dakota, South Dakota, Nebraska, Colorado, and Arizona are more likely to be impacted at the highest rates per capita as climate changes. The regions with the highest projected total cases include the Southern Great Plains as well as the Southeast. The direct medical costs stemming from WNND across all ages are approximately $46,000 per case (2021 dollars).

These results demonstrate that the number of WNND cases resulting from climate change among children is not expected to be significant, particularly relative to the increases in Lyme disease cases at 1°C of global warming. However, WNND is just one outcome of an WNV infection, and WNV is just one of many mosquito-transmitted diseases that affect children. Therefore, the results from Belova et al. may indicate that other diseases that involve mosquitos as vector species could increase in the future as the climate continues to change.

Chapter 8: What You Can Do

Many health outcomes from climate change can be prevented or minimized through well-timed and appropriate action. Successful strategies to minimize adverse health outcomes depend on a combination of social factors, improved forecasting of weather and climate conditions, and further research to better understand the relationship between climate change and how children may be impacted.

This report showcases some of the ways in which children are vulnerable to a variety of health effects from climate change due to biological and developmental factors. It also demonstrates how climate change can have unequal effects on overburdened populations due to differences in exposure, sensitivity, and adaptive capacity, which are influenced by historic inequities deeply rooted in our laws, policies, and institutions.

There is an urgency to act to reduce emissions of greenhouse gases that cause climate change, while also taking actions to reduce health risks to children. Importantly, there are steps all of us can take to reduce these risks to current and future generations of children. This final chapter is designed to facilitate a call to action by proposing steps people can take to reduce the impacts of climate change on children's health. The chapter concludes with recommendations on how researchers can work to fill critical gaps in our understanding of these risks.

MINIMIZE HEALTH IMPACTS TO CHILDREN

This section summarizes some of the actions people can take to minimize the impacts of climate change on children. These suggestions draw from abundant resources EPA and other Agencies have assembled (external sources underlined).

Talk about the risks of living in a changing climate with children, their friends, schools, physicians, sports teams and coaches, and other parents. If you have questions about how climate risks may impact the health of a child, consult with medical professionals for their recommendations.

Educate children and community members (parents, schools, recreation programs, etc.) about how to recreate safely while limiting their exposures to environmental hazards, including vector-borne diseases and elevated temperatures. This includes encouraging children to wear insect repellant to avoid tick and mosquito bites, being aware of where ticks live, and preventing mosquito bites. Urge children to hydrate often, exercise earlier in the day when temperatures are cooler, find shade and indoor places to cool off, and wear safe sunscreen when outdoors. Empowering children and helping them understand their individual risks at all stages will contribute to their individual resilience against climate change impacts.

How is the EPA helping to minimize the health impacts of climate change on children?

EPA's mission is to protect and improve human health and the environment. Helping vulnerable populations such as children adapt to and protect themselves against climate impacts is fundamental to that ethos. EPA endeavors to protect children's health in a variety of ways, including by providing information on how to keep children safe during and after different types of natural disasters, as well as researching climate change effects on children. The agency also researches how climate change can exacerbate childhood exposures to chemical contaminants.

Keep track of local air quality using the Air Quality Index and pollen counts on your local weather reports. Also, pay attention to wildfire, smoke, and ash warnings. When the air quality is poor, consider limiting children's time outdoors, and have children avoid playing near high-traffic areas.

Keep kids safe during and after an extreme weather event. Work with clinicians to develop community guidelines and develop action thresholds for specific local conditions and areas. Make sure your family has an evacuation or safety plan if you live in an area prone to severe weather. After a flood, watch for signs of mold and be sure to clean and dry affected areas. Focus on providing children access to clean potable water and avoid having them wade in floodwaters or be exposed to debris from disasters. If children are exposed to storms or floods, watch for gastrointestinal illness.

Know your community and community members, and if you see neighbors who may need a hand, help out! Learn what climate stressors could impact you based on where you live. Use EPA's EJSCREEN tool to identify areas that may have higher environmental burdens and vulnerable populations. Become aware of adaptation resources and solutions available in your community and support the development of those that are needed, including evacuation strategies and disaster response strategies.

Discover ways you can work with your neighbors and your community to integrate smart growth and environmental justice to prepare for and lessen the impacts of climate change, address disparities, and build healthy neighborhoods. Work with communities to improve home efficiency and insulation, and to develop community heat and cold action plans to protect against illness.

Learn the locations of large, industrial U.S. greenhouse-gas emitting facilities and how much they emit using the Facility-Level Information on GHGs Tool (FLIGHT).

Learn about adaptation mechanisms that can be used to protect you and your family from climate hazards, including subsidies to help cover the costs of residential A/C and heat use and flood resilience measures. Develop heat action and response plans to help your community prepare for and prevent heat-related illness.

Plant trees and other vegetative cover to help offset heat while encouraging a sense of community. Overburdened communities are especially vulnerable to the impacts of urban heat islands, particularly in the summer. Encourage investments in green and cool roofs, permeable pavements, and smart growth development practices.

Help increase climate change data and understanding with students by participating in citizen science projects, which encourage public participation in scientific research.

Learn more about climate change science so that you can speak knowledgeably about the greenhouse effect and the causes of climate change, and even be able to answer some commonly asked questions about climate change.

Get involved in decision making. Local governments have voluntary advisory boards and neighborhood councils where you can help to shape policies and funding decisions. They need diverse participants, including people from the neighborhoods most affected by climate change and health and environmental hazards.

CONTRIBUTE TO SLOWING CLIMATE CHANGE

Individuals can take actions to reduce greenhouse gas emissions that cause climate change. Reducing greenhouse gas emissions has immediate and long-term benefits in reducing climate change and its impacts. The long-term benefits are particularly important in children's lifetimes.

Promote environmental stewardship by encouraging your community schools, homeowners, and local businesses to reduce their greenhouse gas emissions by managing their energy use and waste generation. Reducing emissions is at the essence of limiting climate change, thus preventing the most severe health effects reviewed in this report.

Heat and cool your home smartly by properly sealing and insulating your home; upgrading to ENERGY STAR certified windows, doors, and heating and cooling systems, including certified smart thermostats; and maintaining your heating and cooling equipment. For a whole-house systems approach, use the ENERGY STAR Home Advisor tool or Home Performance with ENERGY STAR. Also, consider other improvements such as rooftop gardens, cool roofs, sustainable landscaping, and switching to green power generated from renewable energy sources like rooftop solar. Take advantage of state and Federal tax credits for residential renewable energy installation projects, such as those for solar panels and for energy-efficient appliances and vehicles.

Take advantage of no-to-low-cost energy-saving tips, such as adjusting thermostats and turning off lights when space is unoccupied, unplugging electronics when not in use, using ENERGY STAR LED lightbulbs, adjusting window shades to reduce heating and cooling requirements, and installing programmable thermostats. Use EPA's Best Value Finder to find the lowest-priced ENERGY STAR certified products.

Use greener transportation as much as possible. Biking, walking, carpooling, and public transportation can significantly reduce greenhouse gas emissions. Choose an energy-efficient vehicle or switch to an electric vehicle.

FILL KEY RESEARCH GAPS

This report is intended to provide a snapshot of some of the ways in which children's health and well-being may be affected by different climate change-related stressors. However, it is not comprehensive, and it shows how much we still do not know about the relationship between climate change and how children may be impacted physically, psychologically, socially, and inequitably. This section highlights some of these concepts for consideration in efforts to improve research on climate and children's health. Note that references to "demographics" pertain to race, ethnicity, gender, sex, and socioeconomic status.

- Due to data limitations, the analyses in this report consider impacts in the contiguous U.S. specifically. This is due in part to the lack of research focused on climate change effects on children outside of this geographic area. Future efforts should include climate stressors and health outcomes in Alaska, Hawai'i, and the U.S. territories. For further information on data limitations, please see the Technical Appendices accompanying this report.
- Future analyses should incorporate a broader set of child demographics that could be used for 1) better understanding population-specific effects and 2) understanding how different socioeconomic factors could amplify or worsen effects, or result in different health outcomes than those measured in this report. For example, additional investigation is needed on the effects of heat on learning, specifically from an equity lens, factoring in how aggregated characteristics may modify outcomes.
- There are limited data on how climate change causes or exacerbates developmental and mental health effects in children. Therefore, research into how children are being affected, both conceptually and in ways that can be quantitatively measured, is needed. For example, extreme events affecting housing, such as floods and wildfires, can have short- and long-term impacts on children who may experience stress and anxiety from the fear of losing their home, or may experience post-traumatic stress disorder.
- It is difficult to conduct epidemiological and qualitative studies to understand the effects of climate change events on birth and health outcomes during the periods of pre-conception through early childhood. However, the more data of these types that are available, the better future assessments can be of how children are impacted by climate stressors.
- Future analyses should be expanded with the availability and application of data from electronic health records, including doctor's office and ED visits, hospital admissions, and prescription records. These data would provide a nuanced level of detail regarding specific health issues that could be connected to climate data. Additionally, epidemiological studies

focusing on compounded effects at a national scale and adjusting for different demographics could help to address limitations to data availability.

- Pursue analyses of climate change-induced effects at fine spatial resolutions, and with consideration for effects on individual and combined demographics. Research at finer spatial scales would capture a more precise picture of how effects are impacting specific areas and subpopulations of children and their short- and long-term health outcomes.
- As described in this report, well-timed adaptation has the potential to reduce substantially some of the adverse effects of climate change on children (e.g., protection of coastal properties, or installation of air conditioning to reduce learning losses from extreme heat). However, it is currently difficult to project where and to what extent these adaptation measures might be implemented, and the timing of their adoption nationwide. Research advancements are necessary to improve society's ability to forecast the likely implementation of adaptation measures, costs and benefits, and their long-term effectiveness.
- Further development of metrics/indicators is needed to help quantify how well society is doing to address children's health risks as they relate to climate change mitigation and adaptation responses.

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WHITE PAPER

OCTOBER 2022

ASSESSMENT OF LIGHT-DUTY ELECTRIC VEHICLE COSTS AND CONSUMER BENEFITS IN THE UNITED STATES IN THE 2022–2035 TIME FRAME

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ACKNOWLEDGMENTS

This work is conducted with generous support from the Aspen Global Change Institute, the Heising-Simons Foundation, and the Energy Foundation. Critical reviews on an earlier version of this report were provided by Georg Bieker, Tom Cackette, Dave Cooke, Hongyang Cui, Ashok Deo, Chet France, John German, Chris Harto, Kathy Harris, Joe Mendelson, Dan Meszler, Peter Mock, Simon Mui, Eamonn Mulholland, Margo Oge, Spender Reeder, Gary Rogers, and Zifei Yang. Their review does not imply an endorsement, and any errors are the authors' own.

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EXECUTIVE SUMMARY

As global electric vehicle production volumes proliferate, their costs decline and the prospects of a transition to electric vehicles increase. Governments around the world are working to accelerate the transition to zero emission transportation to meet air quality, climate, energy security, and industrial development goals. The United States is looking to reverse its laggard position by promoting electric vehicles with actions in the supply chain, regulations on automakers, incentives for consumers, and support to deploy charging infrastructure.

Improvements in battery and electric vehicle technology lead to research questions about how quickly electric vehicle costs will decline and reach price parity with conventional vehicles, and also about the magnitude of the associated fuel-saving benefits. This paper analyzes bottom-up vehicle component-level costs to assess battery electric, plug-in hybrid electric, and conventional vehicle prices across the major classes of the U.S. light-duty vehicle market through 2035. We apply these cost estimates to evaluate vehicle costs and their broader consumer benefits and discuss the implications for vehicle emission regulations in the United States.

Figure ES1 summarizes the findings for average conventional gasoline and electric vehicle prices through 2035 for U.S. cars, crossovers, SUVs, and pickups, which represent all light-duty vehicle sales in the United States. Conventional vehicles in these classes are compared with battery electric vehicles (BEVs) with electric ranges from 150 to 400 miles and plug-in hybrid electric vehicles (PHEVs) with ranges of 20 to 70 miles. Battery electric vehicles have upfront prices that are about $3,000 to $25,000 greater than their gasoline counterparts in 2022. With declining electric vehicle battery and assembly costs, shorter-range BEVs of 150 to 200 miles are projected to reach price parity by 2024–2026, followed by mid-range BEVs with 250 to 300 miles around 2026–2029, and the longest-range BEVs with 350 to 400 miles around 2029–2032. PHEV prices decline at a relatively slower rate due to their relatively smaller battery packs and the additional combustion powertrains; no PHEVs in any class reach price parity with conventional vehicles over the time frame of this analysis.

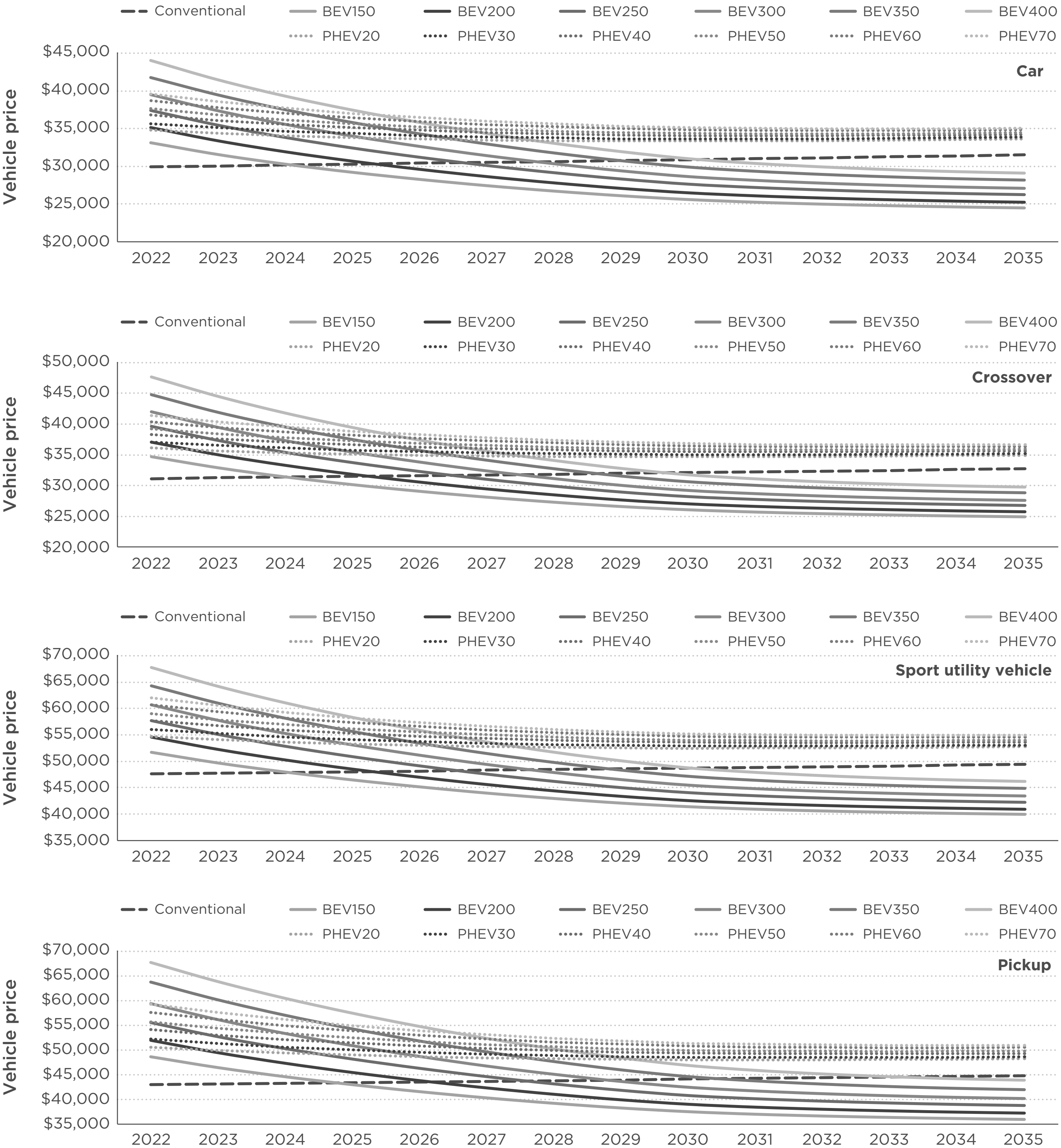

Figure ES1. Conventional, battery electric, and plug-in hybrid electric vehicle prices of cars, crossovers, sport utility vehicles, and pickups in the United States for 2022–2035.

Table ES1 summarizes the year by which battery electric vehicles reach price parity with conventional vehicles, based on the same data presented in Figure ES1. As shown, for a given electric vehicle range, the expected timing for price parity is similar for cars, crossovers, and SUVs. Price parity for pickup trucks is about one year delayed for BEVs with 300-mile range or less. For the largest and heaviest 350-mile and 400-mile range pickups, price parity is delayed by two to three years, respectively, compared to the other vehicle classes.

Table ES1. Summary of year by which battery electric vehicle price parity is reached

Vehicle class	Range (miles)					
	BEV-150	BEV-200	BEV-250	BEV-300	BEV-350	BEV-400
Car	2024	2025	2027	2028	2029	2030
Crossover	2024	2025	2027	2028	2029	2030
SUV	2024	2025	2027	2028	2029	2030
Pickup	2025	2026	2028	2029	2031	2033

Note: Numbers in table are rounded to the nearest year.

Our analysis leads us to three high-level conclusions:

Battery electric vehicle purchase price parity is coming before 2030 for BEVs with up to 300-miles of range across all light-duty vehicle classes. Continued technological advancements and increased battery production volumes mean that pack-level battery costs are expected to decline to about $105/kWh by 2025 and $74/kWh by 2030. These developments are critical to achieving electric vehicle initial price parity with conventional vehicles, which this analysis finds to occur between 2024 and 2026 for 150- to 200-mile range BEVs, between 2027 and 2029 for 250- to 300-mile range BEVs, and between 2029 and 2033 for 350- to 400-mile range BEVs. These findings apply to electric cars, crossovers, sport utility vehicles (SUVs), and pickup trucks, which cover all light-duty vehicle sales in the United States. Pickups, which represent 15% of new 2020 light-duty vehicle sales, are the slowest to reach price parity. Battery cost sensitivity analyses illustrate the key impact of battery costs on price parity timing. Increasing the annual battery cost reduction from 7% to 9% typically accelerates the timing for parity by about 1 to 2 years, while decreasing the annual battery cost reduction from 7% to 3% typically delays parity by about 1 to 4 years.

Battery electric vehicles provide significant cost savings to drivers several years before purchase price parity. The first-owner six-year cost of ownership analysis, which includes cost savings from using electricity instead of gasoline and reduced maintenance needs, shows how new vehicle buyers will have an attractive new vehicle purchase proposition for battery electric vehicles in the 2022 to 2027 time frame based on economics alone. By 2025, BEVs with up to 300 miles of range have a six-year cost of ownership that is less than comparable gasoline models in every light-duty vehicle class. The longest-range 400-mile range pickups are last to reach ownership parity and do so in 2027. Typical six-year fuel and maintenance cost savings range from $6,600 to $11,000 per vehicle purchased in 2025, with the greatest absolute savings for the pickup and SUV class. These lower annual operating costs greatly offset BEVs' higher initial purchase price and enable ownership parity several years before initial purchase parity. The relative fuel savings of BEVs are greatest in the near term, and moderately decline in later years due to the greater relative efficiency improvement expected of conventional vehicles. PHEVs with 50 miles of electric range approach first-owner cost of ownership parity with conventional vehicles by 2030, but their 2030 six-year ownership costs are $7,500 to $11,300 greater than those of 300-mile range BEVs.

Transitioning to battery electric vehicles unlocks billions of dollars in consumer savings. Although the upfront costs of transitioning to BEVs in the near term are substantial, the benefits quickly outweigh the costs. Following a path to meet President Biden's goal of 50% electric vehicle sales by 2030, we estimate that annual costs are greatest in 2022 at about $4.5 billion, when BEVs' upfront incremental price is the greatest. As annual BEV sales increase and upfront incremental prices are reduced, BEVs begin to reach first-owner cost of ownership parity with conventional vehicles. The net consumer benefits outweigh the costs beginning in 2024, and the net benefits continue to grow as BEV sales increase. By 2027, the annual net present value of consumer benefits surpasses $18 billion and reaches about $70 billion by 2030. Capturing these benefits will require continued BEV market growth to about 2 million annual sales by 2025 and about 8 million annual sales by 2030. On average, the individual first-owner consumer savings for new 300-mile range BEVs purchased in 2030 is about $9,000.

Our findings have direct relevance to policies aiming to promote zero-emission vehicle (ZEV) uptake and reduced greenhouse gas and conventional pollutant emissions from light-duty vehicles. Despite the evidence on electric vehicle purchase and ownership cost parity, the transition is not inevitable and continues to rely on market-driving policies. Regulations and ZEV targets can only be as ambitious as they are feasible, and feasibility relies heavily on costs and benefits. Our findings that new battery electric vehicles with up to 400 miles of range in every light-duty vehicle class will reach purchase price parity with conventional light-duty vehicles by 2033 and ownership parity several years sooner shows that strong ZEV regulations and performance standards in this time frame can be implemented and lead to billions of dollars in cost savings for consumers. Such regulations are critical to ensure that continued industry investments are made and consumer benefits are realized.

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INTRODUCTION

The global transition to zero-emission vehicles continues to accelerate. On an annual basis, global light-duty electric vehicle sales—including both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)—increased from less than 10,000 in 2010, to more than 1 million in 2017, more than 3 million in 2020, and more than 6.5 million in 2021. Globally, nearly 17 million cumulative light-duty electric vehicles were sold through 2021 (EV-Volumes, 2022). BEVs represent about 70% of these sales and PHEVs represent 30%. As shown in Figure 1, the three markets of China, Europe, and the United States, where there are the most supporting policies in place, accounted for 92% of those sales. With this market growth, battery manufacturing and electric vehicle production continue to proliferate, and the development of a global automotive supply chain is underway.

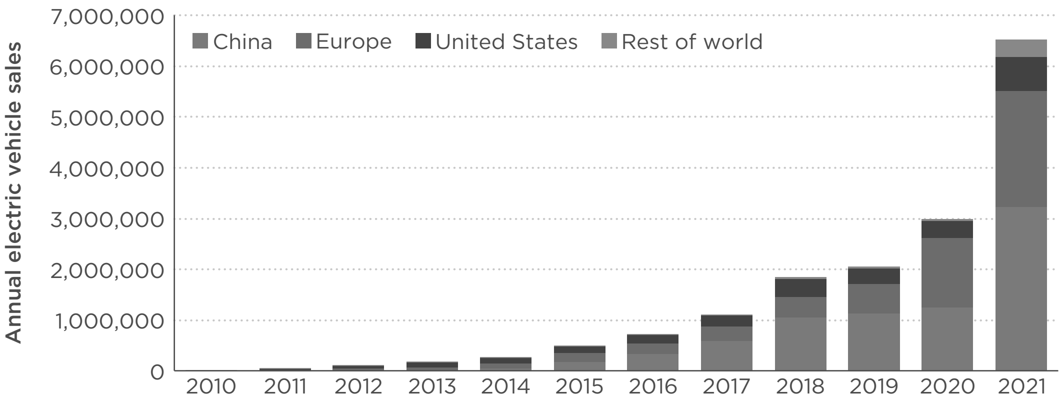


Figure 1. Annual global light-duty electric vehicle sales, 2010–2021 (based on EV-Volumes, 2022).

The United States is the third largest electric vehicle market behind China and Europe, and the gap has widened since 2017 (Bui, Slowik, & Lutsey, 2021). Of the 17 million cumulative electric vehicles sold globally through 2021, about 14% were sold in the United States, compared to 32% in Europe and 47% in China. After stalling at about 330,000 annual electric vehicle sales from 2018 to 2020, the U.S. electric vehicle market has grown to about 670,000 in 2021. Over this same time period, the electric vehicle sales share of new light-duty vehicles in the United States increased from about 2% to 4.5%.

Regulations that require increased electric vehicle production and sales are the foundational driver of electric vehicle model availability and increased volume. Many of the strongest electric vehicle markets globally are in China, driven by the New Energy Vehicle (NEV) regulation coupled with local policies (Cui, 2018; Hall, Cui, & Lutsey, 2020; Liu, Zhao, Liu, & Hao, 2020). Most electric vehicle sales in North America are in regions that adopt California's zero-emission vehicle (ZEV) regulation, which requires electric vehicles to reach 8% to 15% of new vehicle sales by 2025 (California Air Resources Board [CARB], 2017; Lutsey, 2018). Strong vehicle emission regulations can also accelerate uptake, as seen with Europe's jump to a 19% combined BEV and PHEV sales share in 2021, up from 3% in 2019, largely due to the stronger 2020 vehicle CO_2 regulation (Mock, 2019; Mock & Yang, 2022).

Policymakers around the world are considering stronger emission regulations that could require far greater electric vehicle penetration in the 2030–2035 time frame. Many governments have targets for 100% sales of zero-emission new vehicles by

2030–2040, and some have begun to develop enforceable regulations (Cui, Hall, Li, & Lutsey, 2021). The European Union is likely to introduce a light-duty vehicle regulation for 100% zero-emission vehicles by 2035 (Krukowska & Nardelli, 2021). China's proposed NEV regulations include a NEV credit target of 28% by 2024 and 38% by 2025 (MIIT, 2022), which could lead to a NEV sales share of at least 20% for passenger cars by 2025, the official national target (China State Council, 2020). There are also semi-official targets for 40% by 2030 and over 50% by 2035 (Society of Automotive Engineers [SAE] China, 2020). California is developing a regulation for 100% zero-emission vehicles by 2035 (Office of Governor Gavin Newsom, 2020; California Air Resources Board, 2021) and several additional states are likely to adopt California's standards (Northeast States for Coordinated Air Use Management [NESCAUM], 2022). The United States will update its vehicle regulations and has set a target for 50% of all new light-duty sales in 2030 to be battery electric, plug-in hybrid, or fuel cell (White House, 2021).

As governments work to implement these ambitious targets, key questions regarding electric vehicle costs and benefits arise. Questions about whether and how ZEV regulations and performance standards will affect consumer costs, both at the point of vehicle purchase and from a consumer ownership perspective, are critical to their development. More stringent ZEV targets and regulations are increasingly feasible and cost-effective with the continued decline in electric vehicle costs. To that aim, this paper analyzes bottom-up vehicle component-level costs to assess average plug-in electric (BEV and PHEV) and conventional vehicle prices across the major U.S. light-duty vehicle classes (car, crossover, sport utility vehicle, pickup) through 2035. These cost estimates are used to evaluate vehicle costs and broader consumer effects, as well as to discuss the implications for vehicle emission regulations in the United States.

The world has faced numerous major global challenges in the 2020 decade. The ongoing COVID-19 pandemic, the Russia-Ukraine war, supply chain disruptions, trade friction, and inflation have affected every sector of the world economy. These global challenges have already had several clear and immediate effects on the automotive sector in the near term, including higher upfront vehicle prices, more expensive gasoline, and increased battery raw material prices. The extent and duration to which these effects will continue to be felt are highly uncertain and not quantified here. Rather, this study is focused on the long-term outlook for light-duty vehicle technology, costs, and consumer benefits.

VEHICLE COST ANALYSIS

This section analyzes battery and electric vehicle manufacturing costs in the 2022–2035 time frame and compares them with the costs for manufacturing conventional gasoline vehicles. Based on the detailed engineering analysis of electric vehicle component costs, average BEV and PHEV costs for car, crossover, sport utility, and pickup light-duty vehicle classes in the United States are analyzed. The vehicle cost analysis is generally based on the approach of similar previous analyses (Lutsey, Cui, & Yu, 2021; Lutsey & Nicholas, 2019a, 2019b; National Academies of Sciences, Engineering, and Medicine, 2021) with several key improvements. Compared to the previous work, this analysis is updated with new research, data inputs, and U.S. light-duty vehicle technical specifications. The overall methodology and the key analytical differences compared to our previous work are described in more detail in the following sections.

BATTERY PACK COST

This analysis applies the most recent estimates for battery pack production costs and future projections based on detailed bottom-up technical studies of battery cost elements and overall battery pack costs. Projections with explicit technical specifications for battery pack production (e.g., material, cell, and pack costs; cost versus production volume; bottom-up cost engineering approach, etc.) and detailed automaker statements are included. Compared to the analysis of battery pack-level costs shown below, cell-level costs typically make up from 70% to 80% of pack-level costs (Anderman, 2019; Bloomberg New Energy Finance, 2021); unless cell and pack costs are stated within each study, a pack-to-cell cost ratio of 1.33 is assumed for 2020, improving to 1.25 by 2030. Although different studies assess the associated costs differently, this analysis refers to the battery pack cost as seen by a manufacturer of light-duty vehicles, including battery production cost and any associated indirect costs to the supplier. Battery pack costs for heavy-duty vehicles would be somewhat higher than assessed here, due to different battery pack performance requirements, modularization, and relatively lower production volumes (Basma, Saboori, & Rodriguez, 2021).

Recent sources help characterize global 2020–2021 battery costs. Based on industry surveys, volume-weighted average global BEV pack-level prices were approximately $126 per kilowatt-hour (kWh) in 2020 and $118 per kWh in 2021 (Bloomberg New Energy Finance, 2020, 2021). About 45% of global electric vehicle battery production through 2019 occurred in China (Slowik, Lutsey, & Hsu, 2020); China battery pack costs for a given battery chemistry and production volume are typically 20% lower than estimates for the United States and Europe (Lutsey et al., 2021). For this assessment of U.S. electric vehicle costs, the industry-average battery costs are determined based on the sources below.

Figure 2 summarizes the data sources used to inform our projections for battery pack cost reductions through 2035, including expert sources, research literature projections, and automaker announcements. Our battery cost review includes the most recent projections by expert sources including the California Air Resources Board (2022), Roush Industries Inc. (see Saxena, Stone, Nair, & Pillai [forthcoming]), Bloomberg New Energy Finance (2020, 2021), UBS (2020) and technical research studies, including Mauler, Lou, Duffner, and Leker (2022), Nykvist, Sprei, and Nilsson (2019), Penisa et al. (2020), Hsieh, Pan, Chiang, and Green (2019), and Berckmans et al. (2017). The automaker announcements shown include Volkswagen for $135 per kilowatt-hour in

2021–2022 (Witter, 2018), Tesla for $55/kWh in 2025 (Tesla, 2020), and Renault and Ford for $80/kWh in 2030 (Automotive News, 2021a, 2021b; Ford, 2021). Not shown due to uncertainties related to timing, General Motors in 2020 announced continued improvements toward below $100/kWh at the cell level, and Volkswagen in 2021 announced developments toward "significantly below" $100/kWh at the pack-level (General Motors, 2020; Volkswagen, 2021).

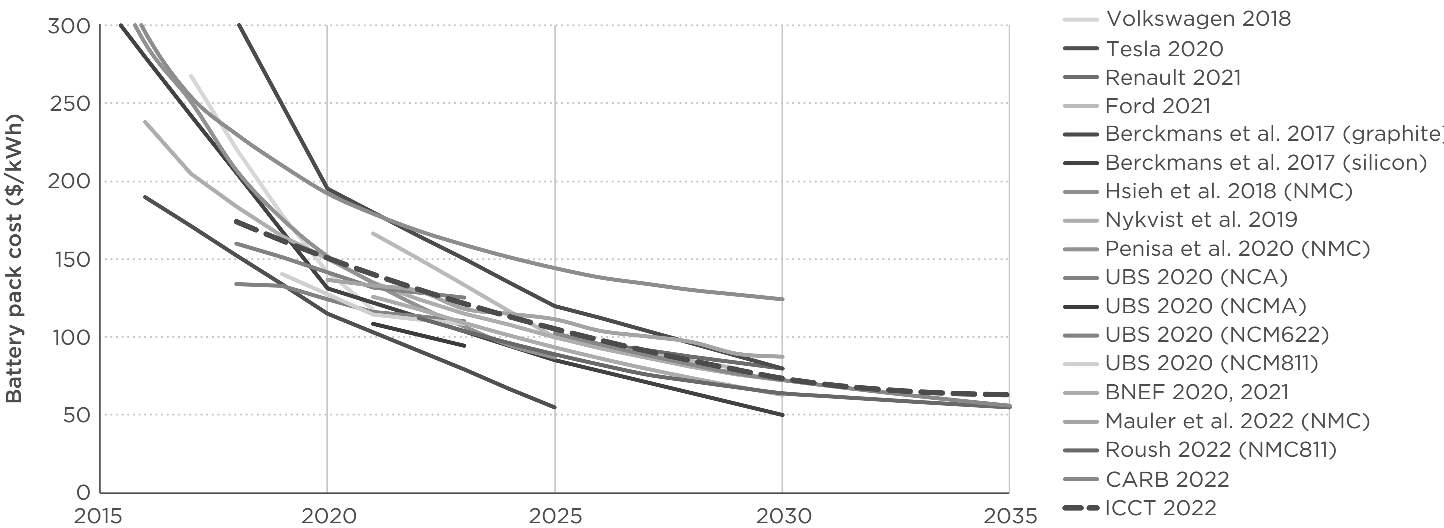


Figure 2. Electric vehicle battery pack costs from technical studies and automaker statements.

The "ICCT 2022" black hashed line shows the U.S. battery pack cost estimate applied in this analysis for a BEV with a nominal 50 kWh battery pack. As shown, pack-level costs decline from $131 per kWh in 2022 to $105/kWh in 2025, $74/kWh in 2030, and $63/kWh in 2035; this represents a 7% annual reduction over the 2022–2030 time frame, which declines to an average annual reduction of 3% over the 2030–2035 time frame. A decreasing pack-to-cell ratio with increasing pack capacity is applied, which means that larger battery packs have lower per-kilowatt-hour costs (Safoutin, McDonald, & Ellies, 2018). Pack-level costs per kWh for PHEVs are 23% higher than those for BEVs throughout the analysis, based on CARB (2022).

The ICCT 2022 curve is the same battery pack cost curve as our previous study (see Lutsey & Nicholas, 2019a); we provide an updated review based on the most recent expert, research literature, and automaker announcements to put that projection into context, and find that it still appropriately represents industry average battery costs. The projected continued decline in battery pack costs represents a continued trend toward lower cost and higher specific energy electrode materials, as well as improvements in cell and pack manufacturing. For battery materials, a continued global trend toward a higher market share of batteries using cobalt- and nickel-free lithium iron phosphate (LFP) cathodes is anticipated, resulting in lower overall material costs. In parallel, depending on the market segment, a continuous trend to nickel-rich nickel-manganese-cobalt (NMC) cathodes (e.g., NMC811) is typically expected. Nickel-rich NMC cathodes have higher specific energy and require less of the expensive cobalt. The addition of silicon to a graphite silicon composite anode can help to increase the specific energy (Berckmans et al., 2017). With continued improvements in battery specific energy, measured in Watt-hours per kilogram (Wh/kg), and volumetric energy density, measured in Watt-hours per liter (Wh/L) (U.S. Department of Energy, 2022a), the mass of materials per unit energy is reduced, and battery pack size is smaller and lighter for a given electric vehicle range, thus reducing total pack costs. Other factors include continued improvements in the cell-to-pack ratio and reduced production costs per unit volume due to an increase in production volume per pack design from about 50,000 to 100,000 battery packs annually in 2020 to about 500,000 and greater from 2025.

The battery cost projections in this analysis are based on improvements and innovations that do not require fundamental technological breakthroughs or nascent next-generation battery technologies such as solid-state batteries or sodium-ion batteries. Such breakthroughs could potentially lead to lower battery costs than quantified here, along with advancements in faster charging speeds and improved safety.

Battery raw materials. Against all these factors contributing to a continued decline in battery cell- and pack-level costs, the cost of battery raw materials—especially cobalt, nickel, and lithium—is an increasing concern in 2022 as many materials are listed at record high prices (Bloomberg New Energy Finance, 2022). This is due to many factors including inflation, the Ukraine-Russia war, and trade friction. The global supply of raw materials appears tight in the years ahead, and there is risk that the rate of battery cost reductions could decline in the near term if raw material prices remain elevated or continue to increase (Bloomberg New Energy Finance, 2022; International Energy Agency, 2022).

At the same time, high raw material prices may also lead to a shift in battery chemistries. High cobalt and nickel costs are expected to reinforce the trend toward cheaper nickel- and cobalt-free LFP cathodes (International Energy Agency, 2022). Sudden cost increases for cobalt and nickel raw material are particularly challenging for batteries with NMC and nickel-cobalt-aluminum oxide (NCA) cathodes because of their high cobalt and nickel content. Although automakers and battery suppliers typically enter long-term battery and raw material contracts, the industry may further respond by shifting to lower-cost LFP cathodes in the mid- to long-term. This trend is already being observed in 2021–2022 for manufacturers including Ford, Tesla, and Volkswagen (Foote, 2022; Volkswagen, 2021; Wayland, 2021).

Several of the battery cost projections from the journal publications shown in Figure 2 are based on batteries with NMC cathodes, and some considered raw material prices in their cost models. The differences between the cost projections generally result from various assumptions on future raw material costs and learning rates. The Hsieh et al. (2019) finding of battery pack costs of $124/kWh in 2030 underscores the key linkage between raw material prices and battery pack costs. Their projections are based on a two-stage learning curve model that incorporates raw material price projections and learning in battery manufacturing. The finding of $124/kWh in 2030 for NMC battery packs is based on an assumed annual cobalt price increase of $13.3/kg, from $25.36/kg in 2016 to about $211/kg in 2030, which the authors call "probably an overestimate." For context, $211/kg is about 2.5 times greater than prices during the cobalt price peaks in March 2018 and March 2022, and about six times greater than the average prices in 2017 and 2019 (Trading Economics, 2022; Wentker, Greenwood, & Leker, 2019). The Hsieh et al. finding of $124/kWh is also based on an increase in nickel and lithium prices by $1.3/kg and $1.9/kg annually, from $9/kg and $40/kg in 2016 to $27/kg and $67/kg in 2030, respectively. Hsieh et al. also analyze an alternative scenario where material prices remain constant and find an NMC-based battery pack price of $93/kWh in 2030.

Other studies also quantified the impact of increasing raw material prices on total battery manufacturing costs. For batteries using NMC cathodes, Penisa et al. (2020) found that learning and innovation have greater influence on battery pack costs than raw material price increases, and the authors quantify that doubling the price of lithium and cobalt increases battery pack prices by 5% to 10%. Similarly, older Bloomberg New Energy Finance research found that doubling lithium prices could increase battery prices by 8%, based on 2017 prices (Bloomberg New Energy Finance, 2017). However, as battery pack prices continue to fall, raw material prices represent a growing share of the total costs, and changes in raw material prices have a greater relative effect on total costs. Mauler et al. (2022) applied future material price expectations and cost reductions based on innovation and found costs of NMC-based battery cells of about \$70/kWh in 2030 based on 2020 raw material prices, which we estimate to be about \$87/kWh at the pack level. When the researchers apply raw material price increases, the cost reductions are decreased; under the "most pessimistic" raw material price expectations, the cost reductions from innovation are fully offset, and cell-level costs are about \$104/kWh in 2030. This is based on an annual price increase of 5.5% for lithium, 9% for nickel, and 12% for cobalt. For context, these annual raw material price increases are similar to those applied in Hsieh et al. (2019), which were 4% for lithium, 8% for nickel, and 16% for cobalt. The researchers did not analyze a scenario where future raw material prices are reduced relative to 2020 prices; doing so would result in further battery cost reductions.

Despite the risk of fluctuating material prices, a 2021 battery cost review finds that many expert studies have long-term confidence and optimism in stable battery market growth, and a continued decline in battery costs regardless of raw material price developments is expected (Mauler, Duffner, Zeier, & Leker, 2021). Experts at Roush Industries (Rogers, Nair, & Pillai, 2021a) argue that projecting battery cell costs based on raw material prices is not a reliable indicator of future cell costs, based on technological improvements in the battery cell, pack, and vehicle integration that allow for greater specific energy and reduced raw materials per kilowatt-hour. As shown in Figure 2, Roush predicts pack-level battery costs of about \$90/kWh in 2025 and \$65/kWh in 2030. Furthermore, automakers and battery suppliers typically enter long-term battery and raw material contracts and thus are less vulnerable to price volatility of raw materials, as evidenced by recent supply deals by Ford, General Motors, Stellantis, Tesla, and Volkswagen (Foldy, 2022; Hull & Stringer, 2022; McLain & Rogers, 2022; Reuters, 2022a, 2022b; Scheyder, 2022). Nevertheless, the price parity findings in this analysis are tested for their sensitivity to annual battery cost reductions further below.

VEHICLE MANUFACTURING COSTS

Electric vehicle manufacturing costs are estimated on a bottom-up vehicle component cost basis. These costs are determined for representative vehicle classes in the U.S. new passenger vehicle market. The steps include initially quantifying the reference conventional vehicles and their technical specifications and then estimating the detailed components for equivalent electric vehicles and their associated costs.

Conventional vehicles. Table 1 summarizes the sales share and average technical specifications for model year (MY) 2020 U.S. conventional vehicle sales across the light-duty vehicle classes as applied in this analysis, based on data from the National Highway Traffic Safety Administration (2022). The market-leading vehicle classes are crossovers (35% of U.S. MY 2020 sales), cars (27%), SUVs (23%), and pickups (15%); detailed information about how the classes are defined is in the notes below

Table 1. The analysis below evaluates costs for those four classes. Average vehicle characteristics, including market share, rated engine power, curb weight, footprint, fuel economy, and price, are used to define reference conventional vehicles. The fuel economy values shown reflect the U.S. Environmental Protection Agency consumer label values. The prices shown reflect the manufacturer suggested retail price (MSRP).

Table 1. Average characteristics for 2020 reference combustion vehicles.

Vehicle class [a]	MY 2020 sales	Sales share	Rated power (kW)	Curb weight (lb)	Footprint (ft^2)	Fuel economy [b] (mpg)	Price [c] (2020 USD)
Car	3,579,198	27%	153	3,288	47	31.3	$29,709
Crossover	4,686,767	35%	146	3,594	46	28.0	$30,919
SUV	3,062,536	23%	227	4,583	54	21.5	$47,380
Pickup	1,943,537	15%	253	4,904	66	19.0	$42,765
Fleet average	**13,272,038**	**100%**	**182**	**3,931**	**51**	**26.1**	**$36,126**

Note: Based on data from NHTSA (2022).
[a] Our car class comprises NHTSA's SmallCar and MedCar "technology classes." Crossovers comprise SmallSUVs, which contains SUV-body style vehicles with curb weight, footprint, and 0-60 acceleration times similar to those of cars. SUVs comprise NHTSA's MedSUV class, which includes minivans, vans, and SUV-body style vehicles with characteristics greater than cars; about 97% of SUVs are categorized as light trucks. Our pickup class matches NHTSA's pickup class; about 96% of new pickups use gasoline fuel and the rest use diesel. Examples of high-selling MY2020 crossover vehicles include Honda CR-V, Ford Escape, and Toyota RAV4.
[b] US consumer label-equivalent fuel consumption (mpg) in miles per gallon of gasoline.
[c] Prices are in 2020 dollars.

The NHTSA baseline dataset for MY 2020 vehicles provides information on vehicle class, engine and transmission technology, and price on a model-by-model basis. We assess 2020 baseline combustion vehicle powertrain total costs (i.e., direct and indirect) by sales-weighting the total costs of these technologies for each vehicle class. A summary of total powertrain costs for each class is shown in Table 2. Estimates of aftertreatment system total costs and all-wheel drive/four-wheel drive (AWD/4WD) total costs were added to the engine and transmission total costs to quantify the full combustion powertrain total costs. Aftertreatment costs were estimated based on sales-weighted engine displacement and the corresponding aftertreatment system cost in Blanco-Rodriguez (2015), adjusted to 2020 dollars by a 1.08 inflator (U.S. Inflation Calculator, 2022) and scaled upward by 10% to account for U.S. emissions standards' increased stringency over Europe's (Blumberg & Posada, 2015). More recent cost estimates of gasoline aftertreatment systems are unavailable.

The total costs for AWD/4WD were approximated as $1,500 for cars, $2,000 for crossovers, $3,000 for SUVs, and $3,500 for pickups. These total costs were estimated by comparing the price premium between four-wheel drive/two-wheel drive models and their AWD/4WD counterparts within the NHTSA database. Although AWD premiums varied widely across vehicle makes and models, the total costs shown in Table 2 reflect lower-end values. Average AWD/4WD costs are calculated from the sales-weighted share of AWD/4WD vehicles from the NHTSA MY 2020 database. Other powertrain total costs associated with nonplugin combustion vehicles include electrical improvements up to and including strong hybridization. The mild and strong hybridization portion of "other" total costs in the table below are small compared to the overall powertrain total costs, due to relatively low market penetration of electrification technologies. In the 2020 combustion vehicle fleet, around 5% of the overall powertrain total costs for cars and crossovers, less than 2% of the costs for SUVs, and less than 0.5% of the costs for pickups are from electrification technology costs up to and including strong hybridization.

Table 2. Sales-weighted average powertrain total costs for 2020 reference combustion vehicles.

	Car	Crossover	SUV	Pickup
Engine	$5,852	$5,826	$6,455	$6,957
Emission control	$359	$351	$509	$648
Transmission	$2,367	$2,281	$2,341	$2,248
AWD/4WD	$294	$1,210	$1,888	$2,662
Other costs	$777	$979	$751	$532
Sum of powertrain costs	$9,649	$10,647	$11,943	$13,048

Note: Other costs comprise all electrification technology total costs up to and including strong hybridization.

This analysis applies an updated approach to quantifying conventional vehicle manufacturing costs compared to our previous work (see Lutsey & Nicholas, 2019a). Previously, conventional vehicle manufacturing costs were assessed based on UBS (2017) estimates of powertrain costs, nonpowertrain direct costs, and indirect costs. This analysis assumes that the average price for each class shown in Table 1 represents a fixed percentage markup over direct manufacturing costs. NHTSA applies a retail price equivalent (RPE) factor of 1.5 in its CAFE standards. This means that the total costs are estimated as 1.5 times direct costs. We apply an RPE factor of 1.5 for all vehicle classes. Thus, we estimate vehicle direct manufacturing costs for combustion vehicle classes as average price divided by 1.5. Dividing the powertrain total costs in Table 2 by 1.5 gives powertrain direct costs. Subtracting powertrain direct costs from vehicle direct costs (calculated from the prices in Table 1) gives the remaining nonpowertrain direct costs (chassis, trim, assembly, etc.). The results of these calculations are shown in Table 3. As a point of reference, the U.S. Environmental Protection Agency (EPA, 2009) dissected RPE into its constituent components. Fleet average automaker profit was found to be around 6% of direct costs (supported by automaker financial reports), and total dealer selling and markup contributors amount to around 16% of direct costs. As discussed further below, these same markups were assumed to apply to electric vehicles on a fleetwide average.

Table 3. Baseline 2020 combustion vehicle direct, indirect, and total price.

		Car	Crossover	SUV	Pickup
Direct	Powertrain	$6,433	$7,098	$7,962	$8,699
	Nonpowertrain	$13,373	$13,514	$23,625	$19,811
	Total direct	$19,806	$20,612	$31,587	$28,510
Indirect	Depreciation, amortization, R&D, administration and expenses, automaker profit, dealer selling and markup	$9,903	$10,306	$15,793	$14,255
Total price		**$29,709**	**$30,919**	**$47,380**	**$42,765**

This analysis assumes that post-2026 U.S. light-duty vehicle regulations will continue to require new conventional vehicle fuel economy to improve annually, regardless of the level of electric vehicle penetration. Conventional vehicle efficiency improvements and the associated increase in manufacturing costs are modeled based on Lutsey, Meszler, Isenstadt, German, and Miller (2017). At the time of Lutsey et al. (2017), the 2015 baseline car and truck fleets considered therein were already respectively 23% and 20% more efficient than the “zero technology” vehicle that represented the start point for technology application. Those 2015 fleets corresponded to the first package of efficiency technologies applied in Lutsey et al. The 2020 fleet, which forms the baseline for the present analysis, is a further 7% to 9% more efficient than the 2015 fleets, according to two-cycle tailpipe compliance values in the EPA's 2021 fuel economy trends report (EPA, 2022).

Improvements beyond the 2020 baseline are estimated based on Lutsey et al. (2017) assuming the baseline 2020 fleet has already had the second technology package cost and effectiveness applied. For an annual average efficiency improvement of 3.5%, corresponding to a total 30% improvement from 2020 to 2030, total cost-effectiveness after adjusting for inflation was estimated as an average of about $39 per percent reduction for cars and crossovers and about $43 per percent reduction for SUVs and pickups. Although the technology packages and costs in Lutsey et al. are outdated, we consider these adjusted cost-effectiveness values to be near recent estimates of promising combustion vehicle technologies (e.g., 48V mild hybrids, high compression ratio Miller and Atkinson engines, high energy ignition) (Dornoff, German, Deo, & Dimaratos, 2022; Rogers, Nair, & Pillai, 2021b).

Beyond 2030, an average cost per percent improvement of about $56 for cars and crossovers and about $61 for SUVs and trucks was applied for the remaining approximately 11.4% improvement through 2035. This level of cost is assumed to represent deeper levels of electrification, further engine improvements, and high levels of mass reduction and aerodynamic improvements (these latter two are also applied to electric vehicles, discussed below). For a 41.4% overall improvement through 2035, total costs are expected to increase by about $1,800 for cars and crossovers and about $2,000 for SUVs and pickups representing increases of about $1,200 and $1,300, respectively, in direct costs. This cost increase is equivalent to about 1% increase in powertrain direct costs per year. Table 4 summarizes the conventional vehicle fuel economy in miles per gallon (mpg) applied in this analysis for 2020, 2022, 2030, and 2035, as well as the associated cost increase relative to 2020.

Table 4. Summary of modeled new combustion vehicle fuel economy (mpg) for 2020, 2022, 2030, and 2035, and cost increase due to improved efficiency.

	Label fuel economy (mpg)				Increase in total costs relative to 2020 vehicle				Increase in direct costs relative to 2020 vehicle			
Vehicle class	2020	2022	2030	2035	2020	2022	2030	2035	2020	2022	2030	2035
Car	31.3	33.6	44.6	53.3	–	$225	$1,180	$1,823	–	$150	$787	$1,215
Crossover	28.0	30.1	40.0	47.8	–	$227	$1,183	$1,823	–	$151	$789	$1,215
SUV	21.5	23.0	30.6	36.6	–	$248	$1,295	$1,994	–	$166	$863	$1,329
Pickup	19.0	20.4	27.2	32.5	–	$250	$1,298	$1,994	–	$167	$865	$1,329
Fleet average	26.1	28.0	37.2	44.5	–	$234	$1,225	$1,887	–	$157	$817	$1,258

Using the SUV class as an example, Table 4 shows how an average new conventional SUV is estimated to improve in efficiency from 21.5 mpg in 2020 to 30.6 mpg in 2030 and 36.6 mpg by 2035. This comes with an average total cost increase of $1,295 by 2030 and $1,994 by 2035, relative to 2020. On average across the four vehicle classes, our U.S. new conventional gasoline vehicle fleet improves from a consumer label efficiency of about 26.1 mpg in 2020 to 37.2 mpg in 2030, while seeing a $1,225 total cost increase. By 2035, the average new gasoline vehicle fuel economy is about 44.5 mpg, which comes with an average total cost increase of $1,887 from 2020. The increase in direct costs shown on the right of Table 4 is the increase in total costs divided by 1.5.

Electric vehicles. Table 5 summarizes the electric vehicle specifications for 2022 and 2030 for six different electric ranges of BEVs and PHEVs. The BEV and PHEV capabilities and rated power (kW) are matched with those of the reference conventional vehicles (see Table 1). The table shows electric vehicle range, electric efficiency, and battery pack size and cost, and gasoline fuel consumption for PHEVs. The technical specifications are based on official electric vehicle range and efficiency values from the U.S. Department of Energy and reflect consumer label efficiency (U.S. Department of Energy, 2022b). Although it is not shown, we apply a charging efficiency factor of 93% for all years. A useable-to-total battery pack size ratio is also applied based on average high-volume MY 2022 electric vehicles such that BEVs can use 92% while PHEVs can use 85% of the kWh, which increases for new vehicles by less than 1% per year through 2030, based on the best available models from 2022. For context, several BEV models including the BMW i4, Chevrolet Bolt EV, Chevy Bolt EUV, Hyundai Ioniq 5, Nissan Leaf, Polestar 2, and Volvo C40 and XC40 have a useable-to-total battery ratio of 96% or greater in 2022. For PHEVs, the lower assumed useable battery fraction is due to the higher-power-to-energy packs having restrictions for thermal management, durability, and safety. Additional details about PHEV motor and engine sizing required to maintain the performance neutrality shown in Table 5 are discussed later.

Table 5. Technical characteristics of electric vehicles for 2022 and 2030.

	Battery electric vehicle (BEV)									Plug-in hybrid electric vehicle (PHEV)									
		Car		Crossover		SUV		Pickup			Car		Crossover		SUV		Pickup	
	Range [a]	2022	2030	2022	2030	2022	2030	2022	2030	Range	2022	2030	2022	2030	2022	2030	2022	2030
Rated power (kW)		153	153	146	146	227	227	253	253		153	153	146	146	227	227	253	253
Fuel economy (mpg)		--	--	--	--	--	--	--	--		37	54	32	45	26	37	23	25
Efficiency (kWh/mile)[b]	BEV-150	0.27	0.19	0.32	0.20	0.37	0.24	0.45	0.31	PHEV-20	0.37	0.27	0.42	0.34	0.54	0.36	0.65	0.45
	BEV-200	0.28	0.20	0.33	0.21	0.38	0.26	0.46	0.33	PHEV-30	0.38	0.27	0.42	0.34	0.54	0.37	0.66	0.45
	BEV-250	0.28	0.21	0.34	0.22	0.39	0.27	0.47	0.35	PHEV-40	0.38	0.27	0.42	0.34	0.54	0.37	0.66	0.46
	BEV-300	0.29	0.22	0.35	0.24	0.40	0.28	0.48	0.36	PHEV-50	0.38	0.27	0.42	0.34	0.55	0.37	0.66	0.46
	BEV-350	0.30	0.23	0.36	0.25	0.40	0.30	0.49	0.38	PHEV-60	0.38	0.27	0.42	0.34	0.55	0.37	0.66	0.46
	BEV-400	0.31	0.25	0.36	0.26	0.41	0.32	0.50	0.40	PHEV-70	0.38	0.27	0.42	0.34	0.55	0.37	0.66	0.46
Battery pack[c] (kWh)	BEV-150	41	27	50	29	57	35	70	45	PHEV-20	8	6	9	7	12	8	14	10
	BEV-200	56	38	67	41	77	49	94	63	PHEV-30	12	8	14	11	18	12	22	14
	BEV-250	72	50	86	53	98	64	119	82	PHEV-40	17	11	18	14	24	16	29	19
	BEV-300	88	64	105	67	119	82	144	104	PHEV-50	21	14	23	18	30	20	36	24
	BEV-350	105	78	125	83	141	100	170	128	PHEV-60	25	17	28	22	36	24	44	29
	BEV-400	123	94	145	100	164	120	197	154	PHEV-70	30	20	33	25	42	28	51	34
Pack cost[d] ($/kWh)	BEV-150	$134	$79	$131	$78	$129	$77	$126	$75	PHEV-20	$165	$97	$165	$97	$165	$97	$165	$97
	BEV-200	$129	$76	$126	$75	$124	$74	$121	$72	PHEV-30	$165	$97	$165	$97	$165	$97	$165	$97
	BEV-250	$125	$74	$122	$73	$120	$71	$117	$69	PHEV-40	$165	$97	$165	$97	$165	$97	$165	$97
	BEV-300	$122	$71	$119	$71	$117	$69	$117	$67	PHEV-50	$165	$97	$165	$97	$165	$97	$165	$97
	BEV-350	$119	$70	$117	$69	$117	$67	$117	$66	PHEV-60	$165	$97	$165	$97	$165	$97	$165	$97
	BEV-400	$117	$68	$117	$67	$117	$66	$117	$66	PHEV-70	$165	$97	$165	$97	$165	$97	$165	$97

Note: Numbers in table are rounded.
[a] BEV-150 = 150-mile range battery electric vehicle; BEV-400 = 400-mile range BEV; PHEV-50 = 50-mile range plug-in hybrid electric vehicle.
[b] Vehicle efficiency and range reflect U.S. consumer label values.
[c] *Battery pack is based on range, electric efficiency, usable fraction of battery pack, and charging efficiency.*
[d] *Larger battery packs have lower per-kWh pack costs, due to a decreasing pack-to-cell ratio (Safoutin, McDonald, & Ellies, 2018).*

The initial 2022 electric vehicle efficiencies in Table 5 are based directly on existing MY 2022 BEV and PHEV models, accounting for increased electricity-per-mile for longer-range electric vehicles. We apply average technical specifications based on several high-volume MY 2022 electric vehicle models within each class. For example, our BEV crossover efficiency is based on the Tesla Model Y, Ford Mach-e, Volkswagen ID 4, Hyundai Kona, Kia Niro, Kia EV6, and Volvo XC40. Electric vehicle efficiency improves annually due to electric component (battery, motor, power electronic) and vehicle-level (mass reduction, aerodynamic, and tire rolling resistance) improvements. The 2030–2035 electric vehicle efficiencies are based on modeling by CARB (2022), accounting for range and adjusting for charging losses. Between 2022 and 2030, we apply an average annual improvement that links the high-volume 2022 average electric vehicle model specifications with the 2030 CARB values. By 2030, the efficiencies are somewhat better than those of the "best in class" models from 2022. For example, our representative 350-mile range battery electric car is 0.23 kWh/mile compared to the 358-mile range 2022 Tesla Model 3 at 0.26 kWh/mile. Our representative 350-mile range crossover in 2030 is 0.25 kWh/mile, compared to the 330-mile range 2022 Tesla Model Y at 0.28 kWh/mile.

The total battery pack costs can be interpreted from the battery pack size (kWh) and cost per kilowatt-hour values shown in Table 5. For example, a 250-mile range battery electric car in 2022 has a 72-kWh battery pack that costs $125/kWh for a total battery pack cost of about $9,000. For a given range, the improved efficiency results in a smaller battery for future models. By 2030, the same 250-mile range battery electric car would require a 50-kWh battery pack at a cost of $74/kWh, for a total battery pack cost of about $3,700.

The other nonbattery manufacturing cost components for electric vehicles are based on several sources. Nonbattery powertrain costs are assessed primarily based on a teardown analysis by UBS (2017) and the National Academies of Sciences Engineering and Medicine fuel economy technology assessment (NASEM, 2021). Virtually all electric vehicles equipped with AWD do so with additional motors, rather than electronic AWD or another AWD system used on combustion vehicles. By matching electric and combustion vehicle power, combined motor power for electric vehicles with multiple motors is the same as the power for single motor vehicles. With additional motors, costs for high voltage cables and motor cooling increase. It is unclear from literature whether motor costs include driveshaft, which would also increase with the number of motors. According to NASEM, future permanent magnet motor costs are expected to decline due to reduced magnetic material requirements. These future costs scale proportionally with motor power, suggesting that certain cost elements that increase with motor number are not included. Further investigation into the true costs of BEV AWD is beyond the scope of this paper. However, manufacturers may opt for induction motors as a second motor in AWD configurations. Absent permanent magnets, induction motors have the potential to decrease AWD costs further, even below the future permanent magnet motor costs shown in NASEM.

Nonpowertrain costs for 2020, including electric vehicle assembly costs, are based on the baseline conventional vehicle nonpowertrain costs for each vehicle class with a 5% decrease due to 30% lower cost of assembly for BEVs, and assembly comprising about 17% of nonpowertrain direct costs (Ford, 2017; König et al., 2021; Vellequette, 2019). From 2020 through 2035, the BEV nonpowertrain components and assembly costs are further reduced by about 5% for several reasons. As automakers expand their BEV model offerings and increase production volumes, there is a shift from modified internal combustion engine (ICE) platforms toward dedicated BEV platforms that enable new areas of cost reductions due to increased economies of scale, cross-segment parts sharing, partnerships among other automakers and suppliers, modified price points on the same vehicle, and better design-to-cost strategies that conventional vehicles have benefitted from for decades (Baik, Hensley, Hertzke, & Knupfer, 2019; Chatelain, Erriquez, Moulière, & Schäfer, 2018; Erriquez, Morel, Moulière, & Schäfer, 2017; Rogers et al., 2021b; Transport and Environment, 2021). To account for electric vehicle mass and aerodynamic drag reduction over time, the full costs of the highest level of mass reduction and aero improvements modeled in Lutsey et al. (2017) are applied incrementally through 2035. Two electric vehicle nonpowertrain cost components were not analyzed due to unavailability of data and presumed small impact: heat pumps, and electric vehicle weight-related modifications to brake rotors/calipers/pads, suspension system, tires, and body structure due to higher mass of electric vehicles.

Table 6 summarizes the direct manufacturing components, costs, and how they are applied in this analysis for an illustrative 250-mile range battery electric vehicle in the car class. Direct manufacturing costs are shown for 2022 and 2030. The direct manufacturing costs are broken down into powertrain (including battery and nonbattery powertrain components) and other direct costs (nonpowertrain and vehicle assembly). The notes column on the right indicates the source and how the costs are applied to other BEV ranges and vehicle classes. The 2017 dollars from the UBS (2017) study are adjusted to 2020 dollars by a 1.06 inflator (U.S. Inflation Calculator, 2022).

Table 6. Battery electric vehicle direct manufacturing costs for a 250-mile range car.

Type	Component	Cost		Notes
		2022	2030 [a]	
Powertrain direct	**Battery pack**	$9,000	$3,700	See Figure 2 and Table 5.
	Thermal management	$250	$235	Based on UBS (2017), costs scale based on presumed vehicle price class based on range and pack size.
	Power distribution module	$240	$290	Based on UBS (2017), costs scale based on vehicle power in kW.
	Inverter	$630	$380	Costs scale based on power (kW) based on NASEM (2021) Table 5.4 and 5.5 of current and future inverter costs in $/kW.
	Electric drive module	$800	$670	Costs scale based on power (kW) based on NASEM (2021) Table 5.2 and 5.3 of current and future motor costs in $/kW.
	DC converter	$140	$130	Based on UBS (2017), costs are consistent for all BEV ranges and vehicle classes.
	Controller	$50	$45	Based on UBS (2017), costs are consistent for all BEV ranges and vehicle classes.
	Control module	$90	$80	Based on UBS (2017), costs are consistent for all BEV ranges and vehicle classes.
	High voltage cables	$520	$485	Based on UBS (2017), costs scale based on vehicle number of motors and vehicle footprint.
	On-board charger	$510	$400	Based on UBS (2017), costs are consistent for all BEV ranges and vehicle classes.
	Charging cord	$140	$130	Based on UBS (2017), costs are consistent for all BEV ranges and vehicle classes.
Other direct	**Nonpowertrain and vehicle assembly**	$12,630	$12,330	BEV nonpowertrain and assembly costs are 5% less than comparable combustion vehicle costs for each vehicle class in 2020. A further 5% reduction is applied from 2020 through 2035.
Total direct manufacturing cost		$25,000	$18,950	

Note: Numbers in table are rounded.
[a] UBS (2017) provides component cost estimates out to 2025. For components where UBS cost data are used, we apply an annual cost reduction of about 1% beyond 2025. The average total decline in BEV nonbattery powertrain costs from 2025 to 2030 is about $500.

Consistent with our previous analysis (Lutsey & Nicholas, 2019a), PHEVs are assumed to inherit the costs of both the combustion and battery electric vehicle powertrain. However, several modifications are made to the respective powertrain costs when applied to PHEVs. From the BEV powertrain, PHEV battery pack sizes are reduced relative to BEVs, due to their much shorter all-electric ranges, varying from 20 to 70 miles. Motor and inverter costs on PHEVs are also reduced 25% to 40%, inversely dependent on range (Hyundai, 2022a; Toyota, 2022a, 2022b, 2022c). Longer range PHEV motors have less cost reduction since they are assumed to have higher power. From the combustion powertrain, total powertrain costs are reduced 10% to 15%, with greater reductions for longer-range PHEVs. As PHEV motors can supplement engine power, the engines on PHEVs do not need to be sized to meet maximum power demands in the same way as ICE-only vehicles. This can lead to some small cost savings. More significant savings arise from the switch to a hybrid transmission (eCVT) from a conventional transmission (NASEM, 2021). From 2030 to 2035, it is assumed that a significant share of nonplugin vehicles will be hybrids, leading to lower average ICE powertrain cost savings for PHEVs, as hybrid vehicles in general benefit from the engine and transmission changes. Consistent with industry, the arithmetic sum of engine and motor powers is greater than the combined rated power (Table 1) (Ford, 2022; Hyundai, 2022a; Toyota, 2022b, 2022c). However, the above-described engine and motor cost reductions lead to PHEV combined rated power equivalent to their ICE-only and BEV counterparts (Table 1).

Figure 3 shows the direct vehicle manufacturing costs for electric and conventional vehicles for cars, crossovers, SUVs, and pickups for six BEV ranges (150, 200, 250, 300, 350, and 400) and a 50-mile PHEV. Costs are shown for 2022 and 2030. As indicated on the left half of the figure, direct manufacturing costs for BEVs in 2022 are higher than those of conventional vehicles for the four vehicle classes, ranging from $1,400 for a 150-mile battery electric car to $18,200 for a 400-mile battery electric pickup. The right of Figure 3 shows how, by 2030, direct manufacturing costs for BEVs are less than those of combustion vehicles for all vehicle classes and electric ranges up to 300 miles. In 2030, direct costs for 400-mile range BEVs are between $800 to $1,250 greater than combustion cars, crossovers, and SUVs, and $3,200 greater than conventional pickups. PHEVs experience relatively lower cost reductions; by 2030, PHEV direct manufacturing costs are $3,400 (cars) to $5,000 (pickups) greater than conventional vehicles. The powertrain costs for PHEVs in the figure include the costs of both the combustion and battery electric vehicle powertrain, as discussed above.

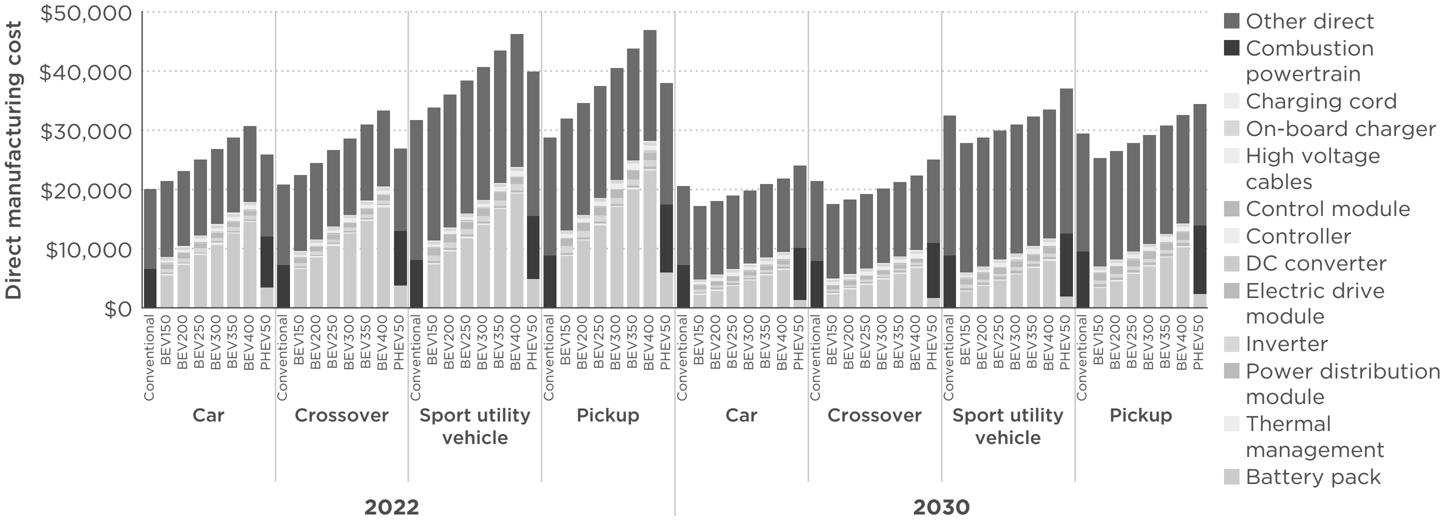


Figure 3. Direct manufacturing costs for conventional and electric vehicles in 2022 and 2030 for cars, crossovers, SUVs, and pickups.

The largest electric vehicle direct cost decreases from 2022 to 2030 are in batteries. For a 300-mile range SUV, for example, reduced battery costs account for about 85% of the total direct manufacturing cost reduction, declining from about $14,000 in 2022 to about $5,650 in 2030. This is the result of reduced per-kilowatt-hour battery cell costs, lower pack-level assembly costs, and improved vehicle efficiency enabling reduced battery size for the same range. Other electric vehicle direct manufacturing cost reductions include nonbattery powertrain costs, which decline by about $500–$800 from 2022 to 2030, and nonpowertrain and vehicle assembly costs, which also decline by about $300–$650 from 2022 to 2030.

VEHICLE PRICES

For electric vehicles, the above direct manufacturing cost analysis is used to estimate electric vehicle prices by technology and electric range. Electric vehicle price is distinguished from the direct manufacturing costs shown in Figure 3 by the addition of indirect costs. Indirect costs include depreciation and amortization (D&A), research and development (R&D), selling and general and administrative expenses (SG&A), automaker profit, and dealer selling and markup. No state or federal tax credits or rebates for electric vehicles are included. In cases where electric vehicles have lower cost than conventional vehicles, the analysis assumes that the vehicles are provided at a lower price to consumers; alternatively, automakers could choose to take additional profits from electric vehicles' manufacturing cost advantage.

Indirect vehicle costs for battery electric vehicles are first assessed based on estimates of D&A, R&D, and SG&A on a per-vehicle basis; automaker profit and dealer selling and markup are assessed separately. Our analysis of D&A, R&D, and SG&A is based automaker financial reporting and how those indirect costs have evolved as their sales volumes have increased. The D&A and SG&A costs for electric vehicles are based on average annual 2017–2021 light-duty indirect cost data for the six largest global automakers in 2021 (Marklines, n.d.) with at least 6 million in annual light-duty sales: Toyota Group (Toyota, 2021a), VW Group (Volkswagen, 2022), Renault-Nissan-Mitsubishi (Mitsubishi, 2022; Nissan, 2022; Renault, 2022), Hyundai-Kia Group (Hyundai, 2022b; Kia, 2022), GM (U.S. Securities and Exchange Commission [SEC], 2022a) and Stellantis (Fiat Chrysler Automobiles, 2020; PSA Groupe, 2020; Stellantis, 2022). Per-vehicle costs are about $1,050 for D&A and about $2,250 for SG&A, and these costs are assumed to remain constant and are applied for all years in the analysis.

The primary driver for declining indirect electric vehicle costs is reduced R&D costs on a per-vehicle basis. For BEVs, R&D costs are based on publicly available data from Tesla, the world's only high-volume all-electric automaker. Specifically, we apply annual R&D costs and annual BEV sales data from Tesla to quantify the R&D costs on a per-vehicle basis for 2017–2021 (U.S. SEC, 2022b). Tesla's annual R&D costs are increased by 50% to account for an expanding product lineup. Future year R&D costs are based on expected U.S. electric vehicle market growth and, thus, greater manufacturing volumes. The Tesla-derived per-vehicle R&D costs are added to D&A and SG&A costs then applied to the broader U.S. automotive market with a three-year lag period to estimate an industry-average BEV indirect cost that declines from about $11,300 per vehicle in 2020, to about $6,450 per vehicle in 2025, and to about $5,400 in 2030. Indirect costs for PHEVs are calculated as the sum product of BEV and ICE indirect costs and the cost share of electric and combustion components of the PHEV powertrain. Average PHEV indirect costs decline from about $9,100 per vehicle in 2020 to about $6,500 per vehicle in 2025 and about $6,200 in 2030.

Electric vehicle automaker profit and dealer selling and markup are calculated based on conventional vehicle markups by applying equivalent per-vehicle D&A, SG&A, and R&D costs to all conventional classes in a manner consistent with electric vehicles. Starting with fleet average conventional vehicle direct costs, a fleet average of 6% automaker profit and a 16% dealer selling and markup are applied to the direct manufacturing costs, based on RPE component breakdown data from EPA (2009). The remaining fleet average indirect costs (D&A, SG&A, R&D) are applied to each class equally. Assuming dealer selling and markup is the same for all classes results in automaker profit margins that vary across vehicle classes: there are lower profits for cars and crossovers and higher mark-ups for SUVs and pickups. Treating electric vehicles with the same adjustments helps to ensure consistent profit margins are built into each vehicle technology. If more automakers shift away from traditional dealerships to online direct-to-consumer sales for electric vehicle sales—as is done by Tesla and is under development by Ford—electric vehicle prices would be reduced.

Figure 4 shows the vehicle prices by technology for 2022 through 2035. From top to bottom are the results for the car, crossover, SUV, and pickup. The black lines represent average conventional gasoline vehicle prices, which rise slightly along with their improved efficiency (see Table 1). BEVs experience substantial cost reductions from 2022 to 2035, as described above. The pink, purple, blue, green, orange, and yellow lines correspond shortest to longest range BEVs. As shown, the BEVs' reduced prices bring price parity with conventional gasoline vehicles as soon as the 2024–2025 time frame, but the timing varies by electric range and vehicle class. Shorter-range BEVs with 150 to 200 miles of range reach price parity around 2024–2026, mid-range BEVs with 250 to 300 miles of range reach price parity around 2026–2029, and the longest-range BEVs with 350 to 400 miles of range reach price parity around 2029–2033. Cars, crossovers, and SUVs reach price parity one to three years earlier than pickups for a given BEV range. PHEVs with 20 to 70 miles of range, shown as the dotted lines, tend to have lower prices than the longest range BEVs in the near term, but are more expensive than any battery electric or combustion vehicle by 2030 for every electric range and vehicle class.

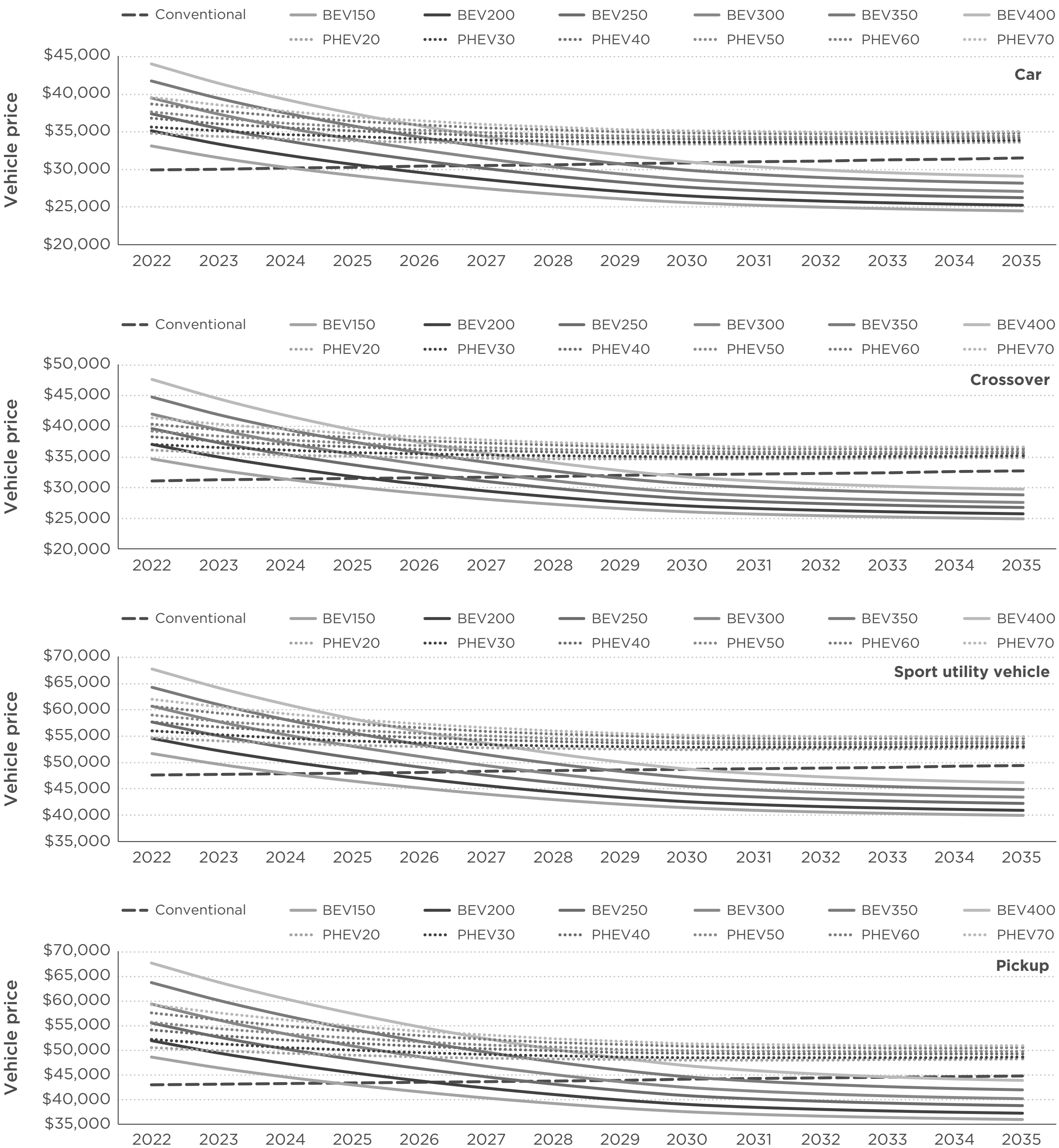


Figure 4. Initial price of conventional and electric vehicles for 2022–2035 for four vehicle classes.

The expected timing for BEV price parity with conventional gasoline vehicles varies slightly among cars, crossovers, and SUVs, across all ranges. However, for heavier and less energy-efficient pickups requiring relatively more kilowatt-hours of battery for each additional mile of electric range, price parity occurs 1 to 3 years later, dependent on range. As previously introduced, the initial conventional vehicle prices in this analysis are based on a sales-weighted assessment of all conventional light-duty vehicles in the United States and, thus, represent average prices. There are, of course, variations in powertrain, performance, luxury features, and other components across conventional and electric vehicles alike. These factors have implications on vehicle price, which means that some models may reach price parity sooner, and others later, than the average values shown here.

Within each vehicle class, longer-range BEVs' larger battery packs add substantial costs over shorter-range BEVs. For example, a car buyer in 2026 can purchase a 200-mile range BEV that is less expensive than a conventional gasoline car. If that car buyer was concerned about range and charging infrastructure, they could pay $3,000 more for a 300-mile range BEV or $6,300 more for a 400-mile range BEV. Similarly, a SUV buyer in 2026 could purchase a 200-mile BEV for less than a comparable gasoline SUV or pay $4,100 more for a 300-mile battery electric SUV or $8,900 more for a 400-mile battery electric SUV. In each situation, vehicle buyers can essentially choose price parity for shorter-range BEVs or pay approximately 10% more for every additional 100 miles of range. These examples demonstrate the trade-off for consumers between lower cost and longer range, and the opportunity for widespread charging infrastructure to enable lower-cost shorter-range vehicle purchases.

Plug-in hybrid electric vehicles with 20 miles to 70 miles of electric range are shown in Figure 4 by the dotted lines. The PHEV price differential versus conventional gasoline vehicles is reduced from 2022 to 2035, but there are no price parity points with conventional vehicles in any class. This is for two primary reasons: PHEVs have the complexity of having both the combustion and electric powertrain components, and the battery pack is a much lower contributor to the PHEV price, so battery cost reductions have a smaller effect on the total price. As an example, the cost differential for a crossover PHEV with a 50-mile electric range is about $8,000 in 2022, which declines to about $3,800 in 2030 and $3,200 in 2035. Overall, by 2035 PHEV prices range from about $2,000 more than their conventional gasoline counterparts for a passenger car PHEV with a 20-mile electric range to $6,200 more for a pickup PHEV with a 70-mile electric range.

The price parity findings were tested for their sensitivity to annual battery cost reductions. Compared to our central case, an annual battery cost reduction of 7% from 2022 through 2030, a lower annual battery cost reduction of 4% (reflecting relatively slower innovation, production volume, and potential raw material price constraints), and a higher annual price reduction of 10% (reflecting greater battery breakthroughs, potentially including solid-state, sodium-ion, or other next-generation battery technologies) are assessed. Toyota, for example, has begun testing solid-state batteries in its electric vehicle concept models, and Nissan aims to sell electric vehicles with solid-state batteries by 2028 (Vijayenthiran, 2022). Nissan estimates solid-state batteries will cost $75/kWh in 2028, which can be reduced to $65/kWh.

Figure 5 illustrates how the year of BEV price parity with conventional vehicles varies with changes to battery cost reductions. The blue triangles reflect the central case findings and are the same as Figure 4 above. The whiskers to the left and right of the blue triangles reflect the price parity findings for the lower and higher battery cost cases, respectively, compared to the central case. The higher battery cost case (4% annual reduction) typically delays price parity by about one year for a 250-mile range BEV and two to four years for a 350-mile range BEV. The lower battery cost case (9% annual reduction) typically accelerates price parity by about one year for a 250-mile range BEV and one to two years for a 350-mile range BEV. The effect of battery cost reduction on the timing for price parity is greater for larger vehicle classes because of their larger battery packs.

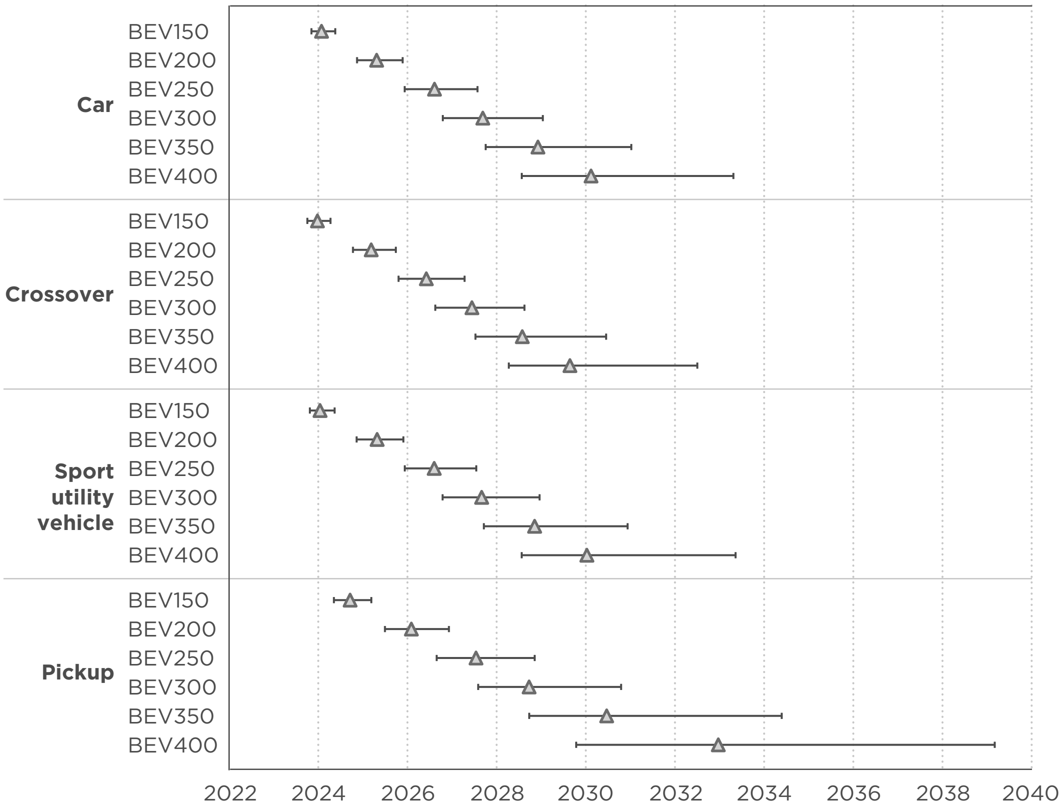


Figure 5. Battery electric vehicle price parity year for varied battery costs.

The Figure 5 results reinforce how price parity in major vehicle classes is expected to be reached in the 2027 to 2028 time frame for 250-mile range BEVs, from 2028 to 2029 for 300-mile range BEVs, and from 2030 to 2033 for the longest-range 400-mile BEVs. The sensitivity demonstrates how relatively higher or lower battery costs lengthen or shorten the expected timing for price parity by a few years, depending on the vehicle range and class. These findings underscore the importance of continued developments regarding battery manufacturing innovation, greater production volumes, and stable raw material prices.

The price parity findings were also tested for their sensitivity to annual electric vehicle energy consumption improvement. Compared to the central case, we reduce the annual BEV improvement by 50% from 2022. Doing so increases the average BEV energy consumption values in Table 5 by 6% in 2025 and 17% in 2030. Increasing BEV energy consumption means that larger, more expensive battery packs are needed for the same all-electric range, and the timing for price parity is delayed. The effect of increased BEV energy consumption on the timing for price parity is greater for larger vehicle classes because of their larger battery packs. We find that reducing annual

BEV efficiency improvement by 50% delays price parity by an average of less than one year for 350-mile range BEVs. Price parity is delayed by an average of about one year for 400-mile range BEVs. These findings illustrate the opportunity for regulatory standards to ensure continued improvements in electric vehicle energy consumption are achieved, such as those under development in the European Union (European Parliament, 2021).

VEHICLE OWNERSHIP COST ASSESSMENT

This section builds on the preceding analysis of manufacturing cost and vehicle price to compare the vehicle technologies on a first-owner cost basis. Analyzing first-owner cost-competitiveness is important to quantifying the value proposition for a prospective electric vehicle buyer. Parameters include vehicle prices from the previous section (manufacturing cost, automaker profit, dealer selling and markup, and other indirect) plus taxes, gasoline and electricity fueling costs, maintenance, and home charging equipment for electric vehicles. Based on evidence that long-range electric vehicles hold their value as well as comparable combustion vehicles, resale value is excluded from the analysis (Harto, 2020).

The first-owner cost of ownership assessment is conducted over a six-year period, based on average vehicle ownership data presented in IHS Markit (2016). The IHS Markit data exclude state, local, and federal subsidies and tax incentives for electric vehicles and their charging infrastructure, providing a technology-neutral comparison. Ownership costs are assessed as a present value, and we apply a discount rate of 5% for all future-year ownership expenditures. The overall methodology generally follows that of Lutsey and Nicholas (2019a), with key updates based on the most recent data and research literature, as discussed below. A 5.6% purchase tax is included, which is approximately the U.S. average.

FUEL AND MAINTENANCE COSTS

Table 7 summarizes the fuel and maintenance cost assumptions and data sources applied in this analysis. Gasoline prices for 2022 are based on data of 2021–2022 U.S. retail gasoline prices by month (U.S. Energy Information Agency [EIA], 2022a), and future years are based on the relative annual projections from the U.S. Energy Information Administration's *Annual Energy Outlook* (U.S. EIA AEO, 2022b). Because the projections in AEO (2022b) were released in early 2022 and thus do not consider the impacts of the Russia-Ukraine war or inflation on gasoline prices, the AEO 2022 "reference case" projections are adjusted upward by about $0.50 based on average monthly 2021–2022 U.S. retail gasoline prices. If average U.S. gasoline prices remain higher than what is reflected in the table, the electric vehicle value proposition would be improved. Electricity prices for home charging are also from the U.S. EIA (2022b), and public DC fast charging electricity prices are from Kelly and Pavlenko (2020). Maintenance costs are from a 2021 U.S. Department of Energy comprehensive quantification of total ownership costs (Burnham et al., 2021). The maintenance costs are adjusted to reflect the maintenance costs for the first owner, based on annual mileage and maintenance service schedules.

Table 7. Summary of gasoline, electricity, and maintenance cost assumptions.

Vehicle technology	Year	Fuel ($/gallon)	Home charging ($/kWh)	DC fast charging ($/kWh)	Maintenance (cents/mile)
Conventional	2022	$3.46	--	--	7.0
	2025	$3.48	--	--	7.0
	2030	$3.52	--	--	7.0
Plug-in hybrid	2022	$3.46	$0.12	--	5.0
	2025	$3.48	$0.13	--	5.0
	2030	$3.52	$0.13	--	5.0
Battery electric	2022	--	$0.12	$0.28	3.6
	2025	--	$0.13	$0.24	3.6
	2030	--	$0.13	$0.20	3.6
Source		EIA AEO (2022)	EIA AEO (2022)	Kelly and Pavlenko (2020)	Burnham et al. (2021)

Annual travel activity is based on data from the National Highway Traffic Safety Administration (2022). For new cars and crossovers, vehicle-miles traveled (VMT) is about 15,900 miles in the first year and declines to about 13,500 in the sixth year. For new SUVs, VMT is about 16,200 in the first year and about 14,200 in the sixth. Pickups have the highest annual VMT at about 19,000 miles in the first year, which declines to about 14,700 in the sixth year. The VMT is identical for electric and conventional vehicles (Chakraborty, Hardman, Karten, & Tal, 2021).

Data on average driving behavior are applied to assess BEV and PHEV consumer annual driving and energy use. For BEVs, a "home charging share" defines the share of VMT that is fueled by a home charger, and all other miles are assumed to be traveled based on energy supplied at a public DC fast charger. The BEV home charging share is informed by an Argonne National Laboratory analysis of "utility factors" and adjusted to account for the likelihood that consumers will seek charging on average about 40 miles before the battery state-of-charge reaches zero (Duoba, 2013). For PHEVs, the "electric driving share" is the fraction of annual miles powered by electricity, and the remaining miles are done on gasoline. Drivers of BEVs and PHEVs are assumed to have access to regular overnight charging. The BEV home charging share and PHEV electric driving share factors applied in this analysis are summarized in Table 8.

Table 8. BEV home charging share and PHEV electric driving share factors.

		Battery electric vehicle		Plug-in hybrid electric vehicle	
		Range	Home charging share	Range	Electric driving share
Electric range	Short	BEV-150	0.84	PHEV-20	0.40
	Short-mid	BEV-200	0.89	PHEV-30	0.52
	Mid	BEV-250	0.93	PHEV-40	0.62
	Mid-long	BEV-300	0.95	PHEV-50	0.69
	Long	BEV-350	0.96	PHEV-60	0.74
	Long-plus	BEV-400	0.97	PHEV-70	0.79
Source		Duoba (2013)		Bradley and Quinn (2010)	

Table 8 shows how a 250-mile range BEV, for example, has a home charging share of 0.93. This means that electricity from a home charger supplies the energy for 93% of annual miles traveled, and public DC fast chargers supply the remaining 7% of miles. Based on the data on annual VMT from above, DC fast charging supplies the energy for about 1,000 miles (cars and crossovers) to 1,200 miles (SUVs and pickups) of annual mileage in the first year. To provide context to these ratios of home to public DC fast charging, a 2020 *Consumer Reports* analysis found that electric vehicles with 250 miles of range require six stops at a DC fast charger each year, which accounts for about 1,200 miles (Harto, 2020).

There are additional ownership costs for BEVs and PHEVs due to their charging needs. The type of home charger and the associated costs are determined based on electric vehicle technology and range, such that BEVs with 150- and 200-mile range and all PHEVs have Level 1 home chargers, whereas BEVs with 250-mile range or greater have Level 2 home chargers. Based on data from Nicholas (2019), average 2020 home charger costs of $540 for Level 1 and $1,350 for Level 2 are included to enable more convenient and lower cost residential charging. These average costs reflect how some home charging situations will require charger upgrades (new wiring and a charger), outlet upgrades (new wiring and a 120-volt wall or a 240-volt dryer-type outlet with no additional charger hardware), or no upgrade. The average home charging costs applied here were corroborated with Bartlett and Shenhar (2020). Costs include hardware and installation, and a 3% decline in per-charger hardware costs per year is applied (Nicholas, 2019).

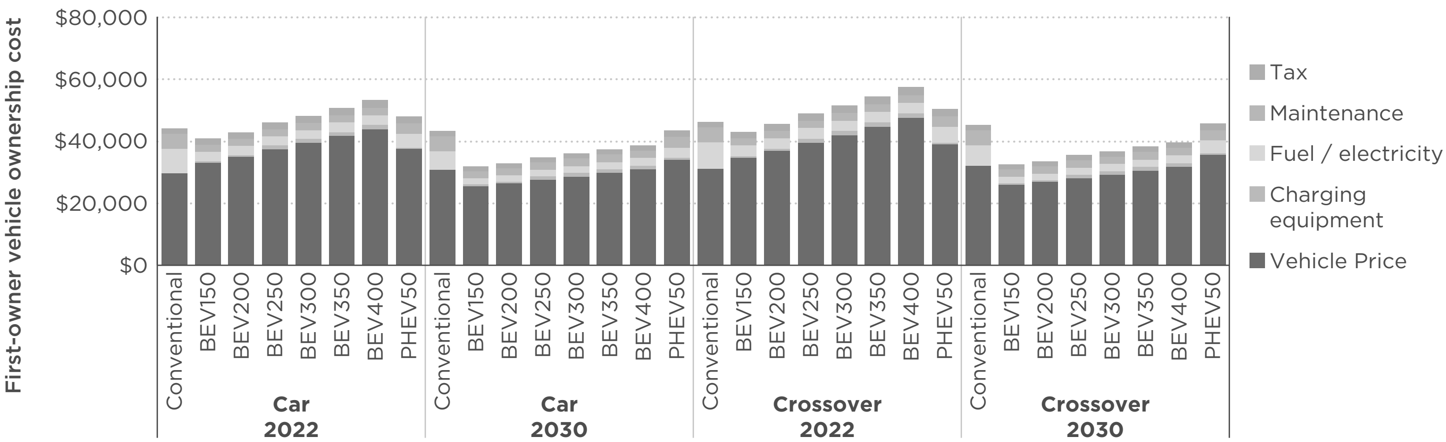
This analysis incorporates estimated efficiency and operational cost impacts of towing. As introduced previously (see Table 1 and Table 5), the capabilities and power (kW) of electric and conventional vehicles are identical in this analysis and reflect the sales-weighted average specifications of U.S. model year 2020 light-duty vehicle sales. For the pickup class, the average rated engine power is 253 kW, and about 75% of model year 2020 pickup sales are capable of heavy towing. The analysis of direct manufacturing costs is based on these specifications and performance requirements. In terms of operational costs, data on towing frequency and total load while towing or hauling are limited. This analysis assumes that on average vehicle owners would tow or haul about 300–380 miles per year for pickups and about 60 miles per year for SUVs. This corresponds to about 2% and 0.4% of annual VMT, respectively. Towing miles are assumed to correspond with longer-distance trips, so BEV refueling is assumed to be done at DC fast chargers.

All vehicles experience significant efficiency losses when towing. Combustion vehicles are assumed to experience a 45% increase in fuel consumption (31% drop in fuel economy), whereas BEVs double their energy consumption and reduce range by 50%. While towing, PHEVs are assumed to operate entirely on charge-sustaining mode. To provide context to these numbers, anecdotal evidence of conventional pickup truck towing tests indicates 20% to 75% reduction in fuel economy (Butler, 2019; Smirnov, 2022; Smith, 2019). Testing of the battery electric Rivian R1T pickup show a range decrease of 40% to 50% (Evans, 2021).

The combined towing effects of efficiency loss and additional refueling at higher-cost DC fast chargers increase the average six-year fuel costs for electric pickups by about 5%. For combustion pickups, towing adds about 1% to the six-year fuel costs. Of course, some consumers may tow less and others more than the average case assessed here. Because towing comes with a significant drop in electric driving range, some consumers with especially high towing frequency and load may choose to pay more upfront for a larger battery and longer electric range. Doing so would increase the upfront vehicle price.

FIRST-OWNER COST OF OWNERSHIP

This section quantifies the first-owner cost of ownership for electric vehicles and compares them with conventional counterparts. Figure 6 shows the six-year ownership costs for new conventional, battery-electric, and plug-in hybrid electric vehicles for cars and crossovers (top) and SUVs and pickups (bottom). The costs are shown for new vehicles in 2022 and 2030, and include vehicle price, charging equipment, fuel and electricity, maintenance, and purchase tax. In 2022, the 150- and 200-mile range BEVs have a lower six-year ownership cost than conventional vehicles for all vehicle classes. By 2028, all ranges of BEVs (i.e., up to 400 miles) in all vehicle classes have a lower six-year ownership cost relative to gasoline vehicles, and many reach ownership parity several years sooner than that. For example, although not shown, first-owner cost of ownership parity year for 300-mile range BEVs is about 2024–2025. The first-owner cost of ownership for PHEVs with 50 miles of electric range is about the same as conventional vehicles by 2030, and about $7,500 to $11,300 greater than the first-owner cost of ownership of 300-mile range BEVs.



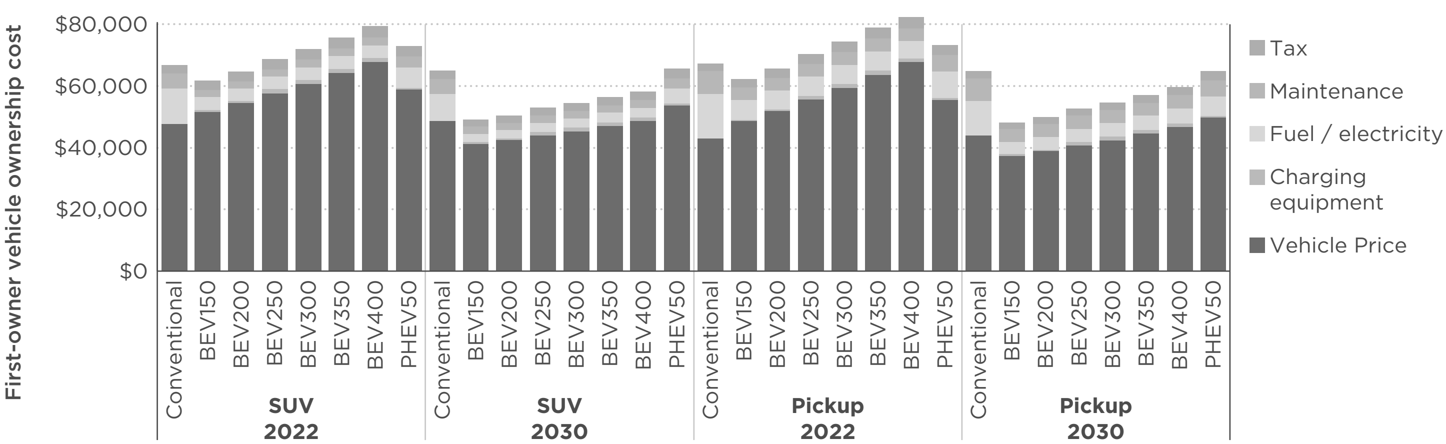


Figure 6. First-owner six-year vehicle ownership costs for cars and crossovers (top) and SUVs and pickups (bottom) for 2022 and 2030.

The biggest change from 2022 to 2030 is in vehicle direct manufacturing costs, as discussed in previous sections. Shifts in operating costs from 2022 to 2030 are comparatively limited. For an example gasoline vehicle of the car class, the discounted six-year fuel costs decline from about $7,700 to $5,900 for new vehicles purchased in 2022 and 2030, respectively, due to the improvements in fuel economy (Table 4). Relative to new gasoline vehicles, new 300-mile range BEVs in 2022 spend $4,800 to $8,400 less on fuel than gasoline cars and pickups, respectively, over a six-year ownership period. By 2030, the relative six-year fuel savings are reduced to about $3,700 to $6,700 for cars and pickups, respectively, due to conventional vehicles' relatively greater annual efficiency improvement and the projected minimal increase in gasoline prices applied in this analysis. About 10% of BEVs' six-year fuel costs are from public DC fast charging, and the rest is from charging at home. The share of DC fast charging costs of total fuel costs is relatively greater for shorter-range BEVs and relatively lower for longer-range BEVs. Six-year maintenance costs are about $2,650 lower for BEVs than gasoline vehicles.

Table 9 provides a different perspective on the consumer value proposition for purchasing a new electric vehicle in the United States in 2030. The table shows, for a new BEV purchased in 2030 or 2035, the number of years of owning and operating a BEV until cost parity is reached. "Immediate" is shown in the cases where the initial upfront price at the time of purchase is already lower than gasoline alternatives. As shown, cost parity is "immediate" for 150- to 350-mile range BEVs purchased in 2030 for every vehicle class shown. For 400-mile range car and pickup BEVs, it takes up to two years of ownership for BEVs' lower operating costs to reach ownership cost parity. By 2035, BEVs of all classes and all ranges immediately have lower ownership costs from the time of purchase. These findings indicate how first-owner six-year cost parity is expected for all electric vehicle ranges in all vehicle classes by 2030, based on the conditions outlined above.

Table 9. Number of years of operation to reach ownership parity.

Vehicle class	Range	Number of years of operation to reach ownership cost parity if purchased in 2030	Number of years of operation to reach ownership cost parity if purchased in 2035
Car	BEV-150	Immediate	Immediate
	BEV-200	Immediate	Immediate
	BEV-250	Immediate	Immediate
	BEV-300	Immediate	Immediate
	BEV-350	Immediate	Immediate
	BEV-400	1	Immediate
Crossover	BEV-150	Immediate	Immediate
	BEV-200	Immediate	Immediate
	BEV-250	Immediate	Immediate
	BEV-300	Immediate	Immediate
	BEV-350	Immediate	Immediate
	BEV-400	Immediate	Immediate
SUV	BEV-150	Immediate	Immediate
	BEV-200	Immediate	Immediate
	BEV-250	Immediate	Immediate
	BEV-300	Immediate	Immediate
	BEV-350	Immediate	Immediate
	BEV-400	Immediate	Immediate
Pickup	BEV-150	Immediate	Immediate
	BEV-200	Immediate	Immediate
	BEV-250	Immediate	Immediate
	BEV-300	Immediate	Immediate
	BEV-350	Immediate	Immediate
	BEV-400	2	Immediate

The cost of ownership analysis does not consider battery replacement, as the available evidence to date suggest relatively little concern about battery failure or extreme degradation. Long-range electric vehicles have not had significant problems to date; Tesla models in the United States with about 150,000 to 200,000 miles have experienced about 10% to 15% range degradation and few battery replacements (Lambert, 2018, 2020: Loveday, 2022). Importantly, these are the electric vehicles with relatively high lifetime driving and DC fast charging usage (frequent DC fast charging can lead to faster battery degradation). Furthermore, industry developments toward 1-million-mile batteries are underway, as evidenced by battery maker CATL, General Motors, and Tesla (Baldwin, 2020; Lienert, 2020). Research shows how NMC-532 graphite cells with exceptional lifetimes have already been developed that are capable of powering an electric vehicle for over 1 million miles, and such performance metrics are being proposed as benchmarks for new battery technologies (Harlow et al., 2019). Although Toyota has sold fewer than 500 BEVs in the United States as of mid-2021, the company claims its new bZ4X will have a 90% battery retention rate over 10 years (Toyota, 2021b).

FLEETWIDE BENEFITS AND COSTS

Building on the above analysis of vehicle prices and first-owner ownership costs, we assess the net present value of the direct consumer costs and benefits from transitioning the U.S. light-duty vehicle fleet to 50% battery electric vehicles by 2030. The net present value analysis includes all of the consumer cost components from the preceding analyses of initial vehicle price and first-owner cost of ownership, which are broadly categorized into three components: (a) upfront incremental price, in which BEV purchase price is greater than their combustion counterparts; (b) upfront reduced price, in which BEV purchase price is lower than combustion counterparts; and (c) six-year operational costs, which include everything except vehicle price from the first-owner cost of ownership analysis above (i.e., home charging equipment, fuel/electricity, maintenance, tax). The analysis does not include additional private or public costs of public charging or social costs associated with upstream petroleum extraction or raw material mining, nor does it include additional benefits of greenhouse gas mitigation, air pollution reduction, reduction in petroleum use and imports, or fuel diversification.

The fleet transition analysis is based on a hypothetical scenario in which annual U.S. BEV sales increase from about 500,000 in 2021 to 2 million by 2025 and about 7.8 million by 2030. This growth corresponds to a BEV share of new light-duty vehicle sales of about 3% in 2021 to 13% in 2025 and 50% by 2030. An average BEV range of 300 miles is assumed for all vehicle classes, and the number of annual BEV sales for each vehicle class is derived from the share of new U.S. light-duty vehicle sales in each class from the model year 2020 NHTSA data in Table 1 (i.e., cars are 27%, crossovers are 35%, SUVs are 23%, and pickups are 15%). The analysis of BEV stock for the assessment of six-year operational costs applies vehicle survival rates by age and class based on NHTSA (2022).

Figure 7 shows the estimated net present value of the costs and benefits of achieving a 50% BEV sales share by 2030 in the United States. Annual costs are greatest in 2022 at about $4.5 billion, when BEVs' upfront incremental price is the greatest. From 2022, annual BEV sales increase and upfront incremental prices are reduced. As 300-mile range BEVs reach price parity in 2028–2029 for cars, crossovers, SUVs, and pickups, the upfront incremental price becomes an upfront reduced price. This is shown by the gray (through 2028) and brown (after 2028) wedges. The large blue wedge includes each of the six-year operational costs previously noted except for vehicle price; it includes home charging equipment, fuel/electricity, maintenance, and tax. Due to significant fuel and maintenance savings, BEVs have lower six-year operational costs compared to gasoline vehicles for all years in this analysis. In 2022, the six-year BEV operational cost is $5,400 (car) to $9,400 (pickup) less than those of gasoline vehicles.

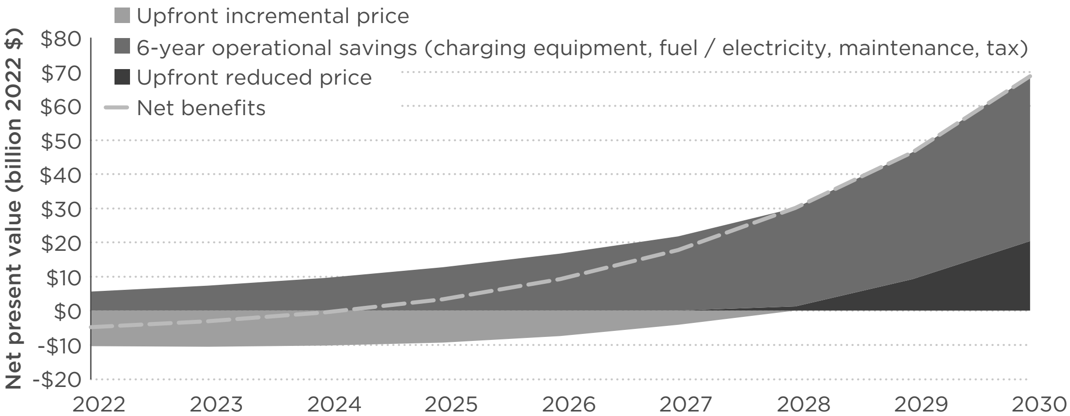


Figure 7. Net present value of the consumer costs and benefits of transitioning to 300-mile range BEVs in the United States: 2022 through 2030.

As shown by the hashed yellow line, the consumer net benefits outweigh the costs beginning in 2024. The net benefits continue to grow as BEV sales increase and price parity approaches. By 2027 the annual net present value benefits surpass $18 billion and reach about $70 billion by 2030. These findings underscore the opportunity to deliver substantial benefits to American consumers by transitioning to BEVs. Achieving the level of benefits quantified here is contingent upon continued market growth to 1 million to 2 million annual BEV sales from 2022–2025, to over 4 million by 2028, and about 8 million by 2030.

DISCUSSION

Governments around the world are setting ever-bolder commitments to zero-emission mobility. Many have targets for 100% ZEV sales by 2030–2040, and some are developing enforceable regulations to meet their targets. In the United States, the Biden administration has set a national target for 50% of new light-duty vehicle sales to be electric by 2030 (White House, 2021). At the state level, California is developing a regulation for 100% zero-emission new light-duty vehicle sales by 2035, and nine additional states have announced their goals for 100% ZEVs as quickly as possible, and no later than 2050 (International ZEV Alliance, 2021).

The preceding analysis quantifies the timing for when electric vehicles make economic sense in the United States, both from a consumer ownership and an initial purchase price perspective. Based on the six-year cost of ownership analysis, nearly every new vehicle buyer in the United States could cost-effectively choose electric over gasoline vehicles by 2030 (see Table 9). Shorter-ranged BEVs reach ownership cost parity the soonest, which is by 2022 to 2023 for 150- and 200-mile range BEVs in all vehicle classes. In terms of upfront purchase price, shorter-range BEVs again reach price parity the soonest, which is by 2024 to 2027 for 150- and 200-mile range BEVs in all vehicle classes. By 2033, initial electric vehicle price parity is anticipated for all classes and ranges (i.e., up to 400 miles).

These findings suggest that achieving the aforementioned national and state-level ZEV targets can be accomplished in a cost-effective manner and deliver substantial economic benefits to consumers. In particular, our study indicates that robust regulations that drive a high ZEV sales share in the 2025–2035 time frame can lead to substantial consumer benefits in terms of vehicle purchase and ownership costs. In other words, electric vehicles' higher upfront cost in 2022 is not a compelling reason to slow the pace of ZEV targets and vehicle efficiency regulations. On the contrary, regulations that drive industry investments and greater production volumes are critical to achieving the pace and scale of battery and electric vehicle cost reductions quantified in this report and the associated timing for price parity. The faster regulations and other policies can drive a transition to electric vehicles, the more consumers will benefit more quickly from lower costs.

Complementary policies and government actions are needed to support the transition to electric vehicles. Electric vehicles' promising economics are contingent on continued battery cost reductions on the order of $105/kWh in 2025 to $74/kWh in 2030, and $63/kWh in 2035. Such developments will rely on continued technological innovation and learning, economies of scale from increased production volumes, and meeting battery and raw material supply demands. New 2021 literature and market research have shown that tightening raw material supply and the associated near-term rise in prices could slow the rate of battery cost reduction (Bloomberg New Energy Finance, 2021; Mauler et al., 2022). As of early 2022, the prices for key metals and raw materials are at record highs, driven by factors including inflation, the Ukraine-Russia war, and trade friction (Bloomberg New Energy Finance, 2022). The extent to which automakers and battery suppliers are already paying more for raw materials and how it will affect near-term battery costs is not yet clear.

The scale of raw material mining and refining will need to keep pace with the demand for battery cells, packs, and vehicle manufacturing, and potential concerns about raw material supply need to be addressed and planned for years in advance (Bloomberg New Energy Finance, 2022; Slowik, Lutsey, & Hsu, 2020). In May 2022, the Biden administration announced new federal funding to boost domestic battery manufacturing and supply chains. The $3.61 billion commitment will support new, retrofitted, and expanded facilities and demonstrations for battery production and recycling, and is part of a larger $7 billion package (U.S. Department of Energy, 2022c). In August 2022, the Administration launched a $675 million program to expand and accelerate critical materials research, development, demonstration, and commercialization for electric vehicles, battery packs, and renewable energy (U.S. Department of Energy, 2022d).

New federal electric vehicle incentives under The Inflation Reduction Act of 2022 link eligibility to the sourcing of raw material and components domestically or from free-trade agreement partners (Taylor, 2022). Several companies are increasing their investments in raw material mining and refining as of mid-2022. In August, BHP announced the company will increase nickel exploration spending due to the surge of electric vehicles (Reuters, 2022c). In July, battery maker Redwood Materials announced a $3.5 billion investment on a battery-materials factory in Nevada (Reuters, 2022d). Tesla is assessing the feasibility of constructing a lithium refinery in Texas (Kharpal, 2022). Continued and greatly expanded efforts to bolster battery production, recycling, and upstream raw material mining and refining will be needed.

The expected timing for first-owner cost parity identified in this analysis is also contingent on consumer access to home charging. For BEVs with at least 250-mile range, the ownership assessment incorporated an average Level 2 home charging cost of $1,350 in 2020, which is quickly paid off by electric vehicles' fuel and maintenance savings. Although the vast majority of early electric vehicle adopters through 2021 have home charging, as the market expands more electric vehicle drivers may not have access to home charging. Drivers that rely on relatively more expensive public DC fast charging do not accrue the same economic benefits as quickly as drivers with home charging, and the timing for ownership parity is delayed. Although not shown in the preceding analysis, we also assessed a "no home charging" case where electric vehicle drivers do not pay for a home charger and charge exclusively at DC fast chargers. Without home charging, the 2025 six-year electric vehicle fuel costs are increased by about $1,360 for a 150-mile car to about $3,200 for a 400-mile pickup.

Without home charging, the timing for ownership cost parity is somewhat delayed. When electric vehicles charge exclusively at DC fast chargers and home charger costs are excluded, the first-owner cost of ownership parity is delayed by an average of about eight months across all of the electric vehicle ranges and classes in the analysis. The higher per-kilowatt-hour electricity costs of DC fast charging over the six-year ownership period are largely offset by the avoided cost of purchasing and installing a home charger. Without home charging, first-owner cost parity is reached before 2028 for all the electric vehicle ranges and classes analyzed. Beyond the six-year ownership period, however, the cost penalty from exclusively DC fast charging increases. This demonstrates the opportunity for widespread access to overnight residential charging options to maximize the economic benefits of electric vehicles. It also indicates the opportunity for continued R&D and greater DC fast charger utilization to enable lower cost fast charging and improve the electric vehicle value proposition.

Different levels of government can help support different aspects of charging deployment. At the federal level, stimulus and clean energy investments, along with tax credits or grants can help broaden home charging access and support broader economic and climate goals. State infrastructure support policies include setting utility rates favorably for EV charging, issuing grants, streamlining permitting, and direct deployment. Local governments can develop EV-ready building and parking codes to accelerate home and near-home charging installation, facilitate curbside charging in residential areas, and streamline local permitting. For Americans where home charging is not possible, governments can help deploy lower-cost near-home public Level 2 charging or provide discounted electricity at DC fast chargers.

This analysis does not consider the effect of any available state, local, or federal subsidies and tax incentives for electric vehicles and their charging infrastructure. In 2022, several U.S. states provide rebates worth about $2,500 for BEVs. At the federal level, there is an electric vehicle income tax credit worth up to $7,500 that is limited to 200,000 electric vehicles sold per manufacturer, and this threshold has been met by Tesla, General Motors, and Toyota (Linkov, 2022). The Inflation Reduction Act of 2022 budget reconciliation bill eliminates the 200,000-vehicle limit and extends tax incentives of up to $7,500 through 2032 (Senate Democrats, 2022). The availability of any federal or state-level incentives for electric vehicles would further reduce electric vehicle prices and greatly accelerate the timing for price parity. The act also provides incentives for domestic production of battery components at up to $45/kWh, which has potential to significantly reduce pack costs and accelerate the timing for electric vehicle price parity (Phillips, Hemmersbaugh, Larson, and Loud, 2022).

CONCLUSIONS

This paper analyzes key questions about the expected timing for electric vehicle parity in the United States based on available technical data and research literature. Electric vehicle manufacturing costs and upfront vehicle prices are quantified across the major light-duty vehicle classes and compared with their conventional gasoline counterparts, illustrating the potential value proposition that many consumers will consider over the next decade. The first-owner cost of ownership assessment further reveals the economic benefits that are accrued from fuel and maintenance savings after vehicle purchase. Our analysis leads us to three key conclusions.

Battery electric vehicle purchase price parity is coming before 2030 for BEVs with up to 300 miles of range across all light-duty vehicle classes. Continued technological advancements and increased battery production volumes mean that pack-level battery costs are expected to decline to about $105/kWh by 2025 and $74/kWh by 2030. These developments are critical to achieving electric vehicle initial price parity with conventional vehicles, which this analysis finds to occur between 2024 and 2026 for 150- to 200-mile range BEVs, between 2027 and 2029 for 250- to 300-mile range BEVs, and between 2029 and 2033 for 350- to 400-mile range BEVs. These findings apply to electric cars, crossovers, SUVs, and pickup trucks, which cover all light-duty vehicle sales in the United States. Pickups, which represent 15% of new 2020 light-duty vehicle sales, are the slowest to reach price parity. Battery cost sensitivity analyses illustrate the key impact of battery costs on price parity timing. Increasing the annual battery cost reduction from 7% to 9% typically accelerates the timing for parity by about 1–2 years, while decreasing the annual battery cost reduction from 7% to 3% typically delays parity by about 1–4 years.

Battery electric vehicles provide significant cost savings to drivers several years before purchase price parity. The first-owner six-year cost of ownership analysis, which includes cost savings from using electricity instead of gasoline and reduced maintenance needs, shows how new vehicle buyers will have an attractive new vehicle purchase proposition for battery electric vehicles in the 2022 to 2027 time frame based on economics alone. By 2025, BEVs with up to 300 miles of range have a six-year cost of ownership that is less than comparable gasoline models in every light-duty vehicle class. The longest-range 400-mile pickups are last to reach ownership parity and do so in 2027. Typical six-year fuel and maintenance cost savings range from $6,600 to $11,000 per vehicle purchased in 2025, with the greatest absolute savings for the pickup and SUV class. These lower annual operating costs greatly offset BEVs' higher initial purchase price and enable ownership parity several years before initial purchase parity. The relative fuel savings of BEVs are greatest in the near term, and moderately decline in later years due to the greater relative efficiency improvement expected of conventional vehicles. PHEVs with 50 miles of electric range approach first-owner cost of ownership parity with conventional vehicles by 2030, but their 2030 six-year ownership costs are $7,500 to $11,300 greater than those of 300-mile range BEVs.

Transitioning to battery electric vehicles unlocks billions of dollars in consumer savings. Although the upfront costs of transitioning to BEVs in the near term are substantial, the benefits quickly outweigh the costs. Following a path to meet the Biden administration's goal of 50% EV sales by 2030, we estimate that annual costs are greatest in 2022 at about $4.5 billion, when BEVs' upfront incremental price is the greatest. As annual BEV sales increase and upfront incremental prices are reduced, BEVs begin to reach first-owner cost of ownership parity with conventional vehicles. The net consumer benefits outweigh the costs beginning in 2024, and the net benefits continue to grow as BEV sales increase. By 2027, the annual net present value of consumer benefits surpasses $18 billion and reaches about $70 billion in 2030. Capturing these benefits will require continued BEV market growth to about 2 million annual sales by 2025 and about 8 million by 2030.

The analysis presented here shows that cost is unlikely to be a direct barrier to battery electric vehicle uptake in the United States after the next several years. Still, the transition is not inevitable and sustained policy support is needed, including ZEV and performance regulations along with complementary infrastructure and supply chain support policies. Our study suggests that ambitious ZEV targets and other policies driving electrification are achievable and can lead to billions of dollars in cost savings for consumers. In fact, a more rapid transition to electric vehicles would provide a greater number of consumers cost savings sooner.

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MAY 2023

Benefits of adopting California Advanced Clean Cars II regulations under Clean Air Act Section 177

Passenger cars and trucks emit climate-warming greenhouse gases (GHGs) as well as air pollutants that are harmful to human health. To improve air quality and mitigate global warming, governments across the United States have announced electrification goals and are implementing policies to accelerate the transition to zero-emissions. In August 2022, California adopted the Advanced Clean Cars II regulations to rapidly reduce light-duty vehicle emissions starting with model year 2026 vehicles. California's Advanced Clean Cars II (ACC II) regulation implements increasingly stringent standards for combustion vehicles while also requiring an increasing number of new light-duty vehicle sales to be zero-emission. Specifically, the regulation requires a shift to at least 68% of new light-duty zero-emission vehicles by 2030 and 100% by 2035.

Section 177 of the Clean Air Act allows other pollution-burdened states to adopt California's emission standards for new motor vehicles. More than a dozen states have adopted California's low-emission vehicle (LEV) or zero-emission vehicle (ZEV) standards under Section 177.[1] The regulatory processes in each of these states require or would benefit from an extensive analysis of the environmental and public health impacts of increasingly stringent ZEV sales and tailpipe pollutant requirements over time.

Adopting the ACC II regulation would dramatically reduce GHG and air pollution emissions. Modeling by Sonoma Technology, Inc. (STI) quantified the emissions reductions for sixteen states: Colorado, Connecticut, Delaware, Maine, Maryland, Massachusetts, Minnesota, New Jersey, New Mexico, New York, Nevada, Oregon, Rhode Island, Vermont, Virginia, and Washington. Together with California, these states account for 37% of the 2022 U.S. light-duty vehicle market and are home to 38% of the U.S. population.[2]

1 California Air Resources Board, "States that have Adopted California's Vehicle Standards under Section 177 of the Federal Clean Air Act," (2023), https://ww2.arb.ca.gov/resources/documents/states-have-adopted-californias-vehicle-standards-under-section-177-federal

2 Light-duty sales data are from the Alliance for Automotive Innovation, "Electric vehicle sales dashboard," (2023), https://www.autosinnovate.org/resources/electric-vehicle-sales-dashboard and population data are from the United States Census Bureau, "State population totals and components of change: 2020-2022," (2023), https://www.census.gov/data/tables/time-series/demo/popest/2020s-state-total.html

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Table 1 summarizes the cumulative emission benefits of adopting ACC II starting in model year 2026 or 2027 compared to a business-as-usual scenario based on U.S. Environmental Protection Agency projections of the Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards.[3] The table shows expected cumulative reductions from 2026 to 2030 and 2026 to 2040 of key air pollutants—nitrous oxides (NO_x) and fine particulate matter ($PM_{2.5}$), measured as reductions in tailpipe emissions—as well as carbon dioxide equivalent, measured along the whole well-to-wheel lifecycle (WTW CO_{2e}).

Table 1. Cumulative emissions reduction potential of adopting California's ACC II regulation

State	Implementation year	2026-2030			2026-2040		
		NO_x (U.S. tons)	$PM_{2.5}$ (U.S. tons)	WTW CO_{2e} (mmt)	NO_x (U.S. tons)	$PM_{2.5}$ (U.S. tons)	WTW CO_{2e} (mmt)
Colorado	2027	1,794	87	8.9	18,903	1,161	113.8
Connecticut	2027	460	31	3.6	4,341	342	39.5
Delaware	2027	123	8	1.2	1,169	85	11.9
Maine	2027	236	16	1.8	2,274	160	19.0
Maryland	2027	668	52	7.1	5,978	585	76.7
Massachusetts	2026	885	74	8.7	8,551	770	94.3
Minnesota	2027	1,843	82	8.0	18,114	1,075	87.0
New Jersey	2027	881	59	8.2	8,886	649	94.2
New Mexico	2027	890	34	3.7	6,708	359	39.2
New York	2026	1,675	132	16.9	15,231	1,373	189.5
Nevada	2027	582	33	3.3	4,328	350	29.7
Oregon	2026	1,260	40	4.3	9,360	408	51.0
Rhode Island	2027	114	7	0.9	1,134	78	10.4
Vermont	2026	74	7	0.9	811	72	9.6
Virginia	2026	2,299	102	12.7	17,511	1,111	139.2
Washington	2026	1,407	61	6.9	12,332	642	77.3

Notes: NO_x and $PM_{2.5}$ are expressed in U.S. tons, CO_{2e} is expressed in million metric tons (mmt).

3 United States Environmental Protection Agency, "Final Rule to Revise Existing National GHG Emissions Standards for Passenger Cars and Light Trucks Through Model Year 2026," (2023), https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-revise-existing-national-ghg-emissions

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Acknowledgements: We thank NESCAUM for their generous support and technical input on data and methods and the United States Climate Alliance and Energy Foundation for their generous support of this work. And, we thank Jeff Houk, Jeremy Hunt, and Amy Smorodin for their contributions.

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WHITE PAPER

JANUARY 2023

ANALYZING THE IMPACT OF THE INFLATION REDUCTION ACT ON ELECTRIC VEHICLE UPTAKE IN THE UNITED STATES

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ACKNOWLEDGMENTS

This work is conducted with generous support from the Aspen Global Change Institute, the Heising-Simons Foundation, and the Energy Foundation. Critical reviews on an earlier version of this report were provided by Anh Bui, Ilma Fadhil, Anand Gopal, Nikita Pavlenko, and Arijit Sen. Their review does not imply an endorsement, and any errors are the authors' own.

This is an updated version to correct an earlier misstatement on our methodology on how the value of the Inflation Reduction Act tax credits are calculated. The previous version can be found at https://theicct.org/wp-content/uploads/2023/01/ira-impact-evs-us-jan23.pdf.

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EXECUTIVE SUMMARY

The Inflation Reduction Act (IRA) of 2022 will move electric vehicle (EV) sales into the fast lane for consumers in the United States across all vehicle types. The $370 billion allocated to climate and clean energy investments dramatically expands tax credits and incentives to deploy more clean vehicles, including commercial vehicles, while supporting a domestic EV supply chain and charging infrastructure buildout.

IRA transportation sector provisions will accelerate the shift to zero-emission vehicles (ZEVs) by combining consumer and manufacturing policies. Consumer tax credits for new and used EVs and tax credits for commercial EVs, along with individual and commercial charging infrastructure tax credits, will increase sales. Domestic supply-chain incentives and investments will boost EV manufacturing and battery production. Critical mineral mining and refining incentives will bolster industrial development.

These investments come at a critical time as the U.S. pivots toward a clean transportation future, helping reduce the 23 percent of total U.S. greenhouse gas (GHG) emissions that come from road transportation. The IRA clean transportation provisions will speed progress towards the Biden administration's EV and climate goals. The U.S. Environmental Protection Agency (EPA) expects to release proposed rulemakings for GHG standards for both light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs) in 2023, and these standards can build upon the progress made by the IRA.

This study assesses the future impact of the IRA on electrification rates for LDV and HDV sales in the United States through 2035. We analyze the value of the personal and commercial EV tax credits, factoring in the various supply chain, income, and price caps on new EVs, and combine this with new estimates of future light-duty and heavy-duty EV cost declines. We find that, on average over the period 2023–2032, the IRA tax credits will reduce light-duty EV purchase costs by $3,400 to $9,050. Using methodologies from the Energy Policy Simulator, we project how these changing costs and incentives over time will affect the LDV and HDV markets in the United States.

We consider Low, Moderate, and High scenarios, depending on how certain provisions of the IRA are implemented and how the value of incentives is passed on to consumers. For LDVs, we also consider a range of states that may ultimately adopt California's new Advanced Clean Cars rule (ACC II), which requires increasing EV sales shares for automakers. For HDVs, we consider states that have adopted California's Advanced Clean Trucks rule and its ZEV targets. These results do not consider federal GHG standards for model years 2027 and beyond.

Figure ES-1 shows the range in our projected EV and ZEV sales shares for LDVs and HDVs from 2023 to 2035. This figure presents our Low, Moderate, and High scenarios, compared to a baseline (no IRA incentives) scenario. Here, we use the term EVs for new light-duty battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). For heavy-duty, the term ZEVs includes new BEVs and hydrogen fuel cell electric vehicles (FCEVs). Used EVs are not included in this analysis.

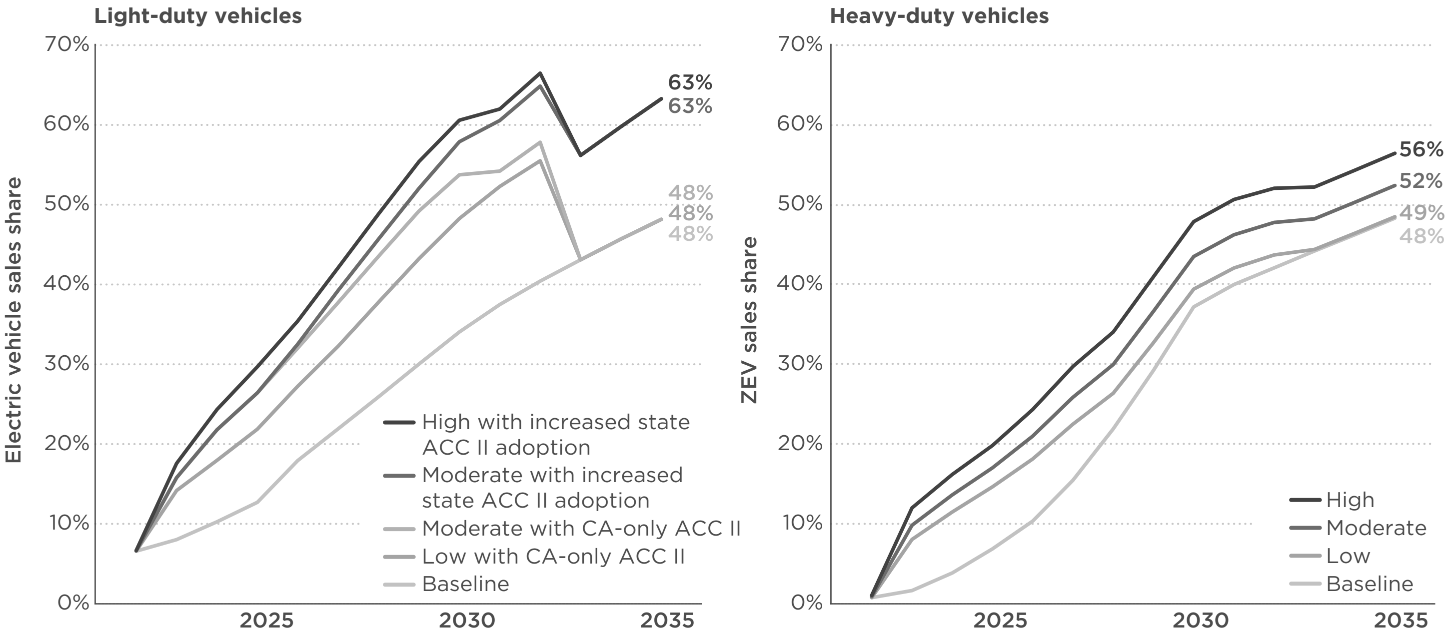

Figure ES-1: Baseline, Low, Moderate, and High projections of EV sales share for light-duty vehicles, considering ACC II adoption in only California versus increased states (left), and ZEV sales share for heavy-duty vehicles with the IRA incentives, 2023-2035 (right)

From these results we draw the following conclusions and policy recommendations:

» **The IRA will accelerate electrification.** For both the light and heavy-duty sectors, we find rapid EV uptake when considering both expected manufacturing cost reductions and the IRA incentives, as well as state policies. By 2030, we find a range of a 48%–61% EV sales share in the light-duty sector, increasing to 56%–67% by 2032, the final year of the IRA tax credits. For heavy-duty, we estimate a range of 39%–48% ZEV sales share by 2030 and 44%–52% by 2032.

» **The IRA enables more stringent federal vehicle standards at a lower cost and higher benefit to consumers.** By providing thousands of dollars in financial incentives to LDV and HDV purchasers, the IRA unlocks widespread consumer benefits while furthering the administration's decarbonization goals. With the IRA, EPA can set more stringent federal LDV and HDV GHG standards than would have been possible otherwise, at lower cost and higher benefit to consumers and manufacturers.

» **The IRA alone is not enough to meet our climate goals.** Previous analyses have found that higher rates of electrification than what we show here will be necessary to meet the U.S. Nationally Determined Contribution (NDC) and to be aligned with the Paris Climate Agreement to limit global warming to well below 2 degrees Celsius.

» **Federal standards can lock in and build on the pace of electrification from the IRA.** The EV and ZEV sales shares we present are not guaranteed and there remains uncertainty in the electrification transition, especially after the IRA tax credits expire. Federal standards can serve as a backstop to ensure the electrification momentum from the IRA continues, particularly after the incentives expire in 2032. Our results suggest that to be technology forcing and deliver substantial climate benefits above the baseline, federal standards would need to drive electrification rates significantly higher than 50% by 2030 for LDVs and above 40% by 2030 for HDVs.

» **Additional action is needed by government and industry.** This analysis shows that, given costs and consumer preferences, electrification can be rapid. It does not account for other non-financial barriers such as lead time for vehicle manufacturing and charging infrastructure development; these challenges are largest in the heavy-duty sector. The rates of electrification we project here can only be achieved if government and industry invest quickly in ZEV assembly and infrastructure.

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INTRODUCTION

U.S. climate policy took a major step forward with the passage of the Inflation Reduction Act (IRA) of 2022. The $370 billion allocated to climate and clean energy investments are expected to deliver deep emission reductions across all sectors of the economy. Such investments come at a critical time as the country seeks to pivot towards clean energy and transportation, reverse its laggard position, and emerge as a global leader on electric vehicles (The White House, 2021). In 2021, the Biden administration called for a 50% electric vehicle sales share for passenger vehicles in 2030 in order to strengthen U.S. leadership on clean vehicles, create good-paying jobs, expand clean vehicle manufacturing, and export electric vehicles globally. The administration also has targets for commercial vehicles: in 2022, the United States committed to a minimum zero-emission heavy-duty vehicle (HDV) sales share of 30% by 2030 and 100% by 2040 (Minjares, 2022).

Several key on-road transportation sector provisions are included in the IRA which will greatly accelerate the shift to plug-in electric and hydrogen fuel cell electric vehicles.[1] Consumer tax credits for new and used electric vehicles, tax credits for electric commercial vehicles, and individual and commercial charging infrastructure tax credits will accelerate market growth. At the same time, domestic supply-chain incentives and investments for electric vehicle manufacturing, battery production, and critical mineral mining and refining will bolster industrial development. This package of demand and supply side policies will be critical to putting the United States on a path to transportation decarbonization.

This white paper analyzes the impact of the IRA on light- and heavy-duty electric vehicle market growth in the United States through 2032. Using recent data on electric and conventional vehicle prices, the analysis models consumer vehicle purchase decisions for electric and internal combustion engine vehicle technologies, taking new federal tax credits into account. The methodology section describes the overall analytical approach, the IRA provisions considered, and how they are applied to develop hypothetical scenarios of future EV sales. The results section summarizes the modeling results for electric vehicle sales and sales shares from 2023 through 2035. This is followed by a discussion of policy implications and conclusions.

1 The IRA's definition of clean vehicles includes plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs). In this research note, the term electric vehicles (EVs) refers to both PHEVs and BEVs, unless otherwise specified.

METHODOLOGY

This analysis largely follows the methodology of a 2022 Energy Innovation Policy & Technology LLC® study examining the IRA's impacts on the ground transportation sector (Baldwin & Orvis, 2022). This analysis uses a customized model based on the Energy Policy Simulator (EPS), an open-source policy model (Energy Innovation, 2022). The model forecasts sales of new vehicles from a choice function.[2] In this study, the model is updated to include the most recent data on U.S. combustion and electric vehicle costs, battery pack costs, vehicle energy consumption, fuel and electricity prices, and charging behavior for electric vehicles. It includes battery electric, plug-in hybrid electric, and gasoline vehicles for light-duty, and battery electric, fuel cell electric, and diesel vehicles for heavy-duty. The light-duty vehicle and battery data on costs, technical specifications, and charging behavior are from a 2022 ICCT assessment of U.S. electric vehicle costs (Slowik, Isenstadt, Pierce, & Searle, 2022). The heavy-duty data are obtained from multiple sources, which are described in detail below. The analysis also incorporates state-level implementation of California's Advanced Clean Cars II and Advanced Clean Trucks Rules to evaluate the combined impact of state regulations and federal incentives on national electric vehicle uptake (California Air Resources Board, 2022a; California Air Resources Board, 2019).

LIGHT-DUTY VEHICLES

The consumer vehicle choice model uses a logit allocation function to estimate the impact of select IRA incentives on new light-duty vehicle sales. The logit function allocates new vehicle purchases to electric and combustion vehicle technologies based on a total cost of ownership (TCO) analysis. The TCO considers purchase, fuel, maintenance, insurance, parking, license, and registration costs, in addition to monetized barriers (e.g., range anxiety) and tax credits and incentives. A 15% discount rate is applied for all future-year ownership expenditures.

The two key inputs to the logit function are the logit exponent and the shareweights. The logit controls the sensitivity of the choice function to the TCO. A higher absolute value for the exponent will push a higher share of sales to the vehicle type with the lowest TCO as compared to a lower exponent. We utilized the same logit exponent values as used in the Global Change Assessment Model (GCAM) v6, which can be found in the model's input data (Joint Global Change Research Institute, n.d.). The shareweights represent non-cost considerations, such as consumer preference and vehicle availability. The shareweights also serve as a calibrating parameter so that the historical sales share in the allocation aligns with historical sales data. A shareweight value of 0 means the allocation will not assign any of the vehicle shares to that technology. The greater a shareweight is relative to the other shareweights, the greater share it will receive in an allocation. For this analysis, we calibrate shareweights in historical years to align the sales share with historical data, and then phase the shareweight to a value of 1 by 2030 using an s-curve. This approach attempts to reflect non-price barriers to EV adoption such as consumer preference and vehicle availability, which are eliminated by 2030. The shareweights for battery-electric light-duty vehicles start at 0.26 in 2021, based on calibration to align with historical sales shares,

2 The choice function uses the modified logit choice function as outlined in the GCAM model. The modified logit computes sales shares using technology-specific shareweights and ownership costs and a common exponent. For more information, see: https://jgcri.github.io/gcam-doc/choice.html. The original Energy Innovation® analysis also modeled vehicle fleet turnover, vehicle stock, and energy consumption and emissions. See https://energyinnovation.org/wp-content/uploads/2022/11/Implementing-the-Inflation-Reduction-Act-A-Roadmap-For-Federal-And-State-Transportation-Policy.pdf

then increase to 0.73 in 2025 and 0.99 in 2030. This 2030 shareweight reflects our expectation that electric vehicle uptake in 2030 will be driven primarily by costs, as opposed to being constrained by supply chains, and that consumer preference difference will be marginal (Joint Global Change Research Institute, n.d.).

The IRA tax credits and incentives applied in this analysis of light-duty electric vehicles include Personal Tax Credits for Clean Passenger Vehicles (30D) worth up to $7,500 and Advanced Manufacturing Production Tax Credits (45X) for batteries worth up to $45 per kilowatt-hour. Per the IRA, several requirements must be met for new passenger vehicles and their buyers to be eligible for the full clean passenger vehicle tax credit. The analysis incorporates estimates of the share of new vehicles that can meet the new domestic assembly and battery sourcing requirements, and applies eligibility restrictions based on the new manufacturer's suggested retail price (MSRP) and adjusted gross income (AGI) caps. More details about these estimates and how they are developed can be found in Baldwin and Orvis (2022). We do not explicitly consider leased vehicles in our analysis and only model the effect of the Personal Tax Credit for light-duty vehicles. Due to uncertainty on how the restriction on battery component and critical mineral sourcing from "entities of concern" will be implemented, we did not account for this requirement in this analysis.

Average U.S. light-duty vehicle prices for 2023 through 2035 are key inputs to the consumer choice model. Purchase price data for new cars, crossovers, SUVs, and pickups, which together represent all light-duty vehicle sales in the United States, are taken from a 2022 ICCT study of conventional and electric vehicle costs (Slowik, Isenstadt, Pierce, & Searle, 2022). Conventional vehicle prices are compared to battery electric vehicles (BEVs) with electric ranges from 150 to 400 miles and plug-in hybrid electric vehicles (PHEVs) with ranges of 20 to 70 miles. Data on the electric range of U.S. electric vehicle sales in 2020 and 2021 are used to calculate the sales-weighted average electric range of new BEVs and PHEVs, and thus the average costs, for the 2022 base year.[3] The average electric range of new BEVs and PHEVs is assumed to increase through 2030. For new BEVs, the sales-weighted average electric range increases from 250 miles in 2022 to 300 miles by 2030. For PHEVs, the sales-weighted average electric range increases from 30 miles in 2023 to 50 miles by 2030. The number of annual electric vehicle sales in each light-duty vehicle class is assumed to resemble that of all new light-duty vehicles in the United States in 2020: 27% cars, 35% crossovers, 23% SUVs, and 15% pickups.[4]

Figure 1 illustrates the sales-weighted average conventional and electric vehicle prices applied in the analysis for 2022 through 2035, before any IRA incentives or tax credits are applied. Average BEV prices decline from about $40,300 in 2022, to about $30,800 by 2030, and to $29,200 by 2035. Price parity with gasoline vehicles is achieved around the 2027–2028 timeframe, driven by continued technological advancements and reduced battery costs.[5] Conventional vehicle prices increase from about $32,000 in 2022, to about $33,100 by 2030, and to about $33,700 by 2035, along with their improved efficiency. PHEVs have the highest prices due to the complexity of having both the combustion and electric powertrain.

3 Based on EV-Volumes, (2022), https://www.ev-volumes.com/

4 Cars are 27%, crossovers are 35%, SUVs are 23%, and pickups are 15%. Based on data from the National Highway Traffic Safety Administration (2022).

5 Based on Slowik, Isenstadt, Pierce, & Searle (2022), the battery pack cost estimate applied in this analysis is $131 per kilowatt-hour (kWh) in 2022, $105/kWh in 2025, $74/kWh in 2030, and $63/kWh in 2035. These values are for a BEV with a nominal 50 kWh battery pack and were informed by a 2022 review of battery cost projections from technical research studies, automaker announcements, and other expert sources.

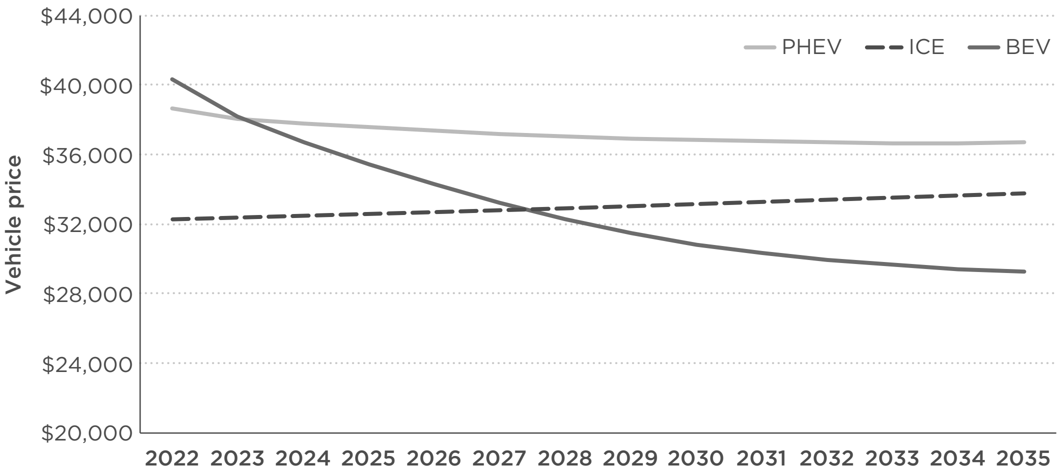

Figure 1. Sales-weighted average conventional and electric vehicle prices applied in this analysis

Several additional factors contribute to the TCO for electric and combustion vehicles that are used in the consumer choice model logit function. Annual fuel costs are calculated using data on conventional and electric vehicle fuel efficiency, annual gasoline and electricity prices, and electric vehicle charging behavior from Slowik, Isenstadt, Pierce, and Searle (2022), and annual vehicle miles traveled is from the Energy Policy Simulator (Energy Innovation, 2022). Per-mile maintenance costs are also from the 2022 ICCT study. Annual vehicle insurance, parking, licensing, and registration costs are from the Energy Policy Simulator and identical for each vehicle technology. This analysis estimates the cost of range anxiety and charging time for BEVs as an additional component of the TCO calculation. The average electric vehicle ownership costs attributed to range anxiety decline from about $8,000 in 2022 to $5,500 in 2030 due to greater electric vehicle range and faster charging speeds. Figure 2 illustrates the average TCO for BEVs, PHEVs, and internal combustion engine (ICE) vehicles in this analysis for a 6-year ownership period and 15% discount rate for future-year expenses. As shown, ICE vehicles have the lowest 6-year ownership costs in 2022 and 2025. By 2030, BEVs have lower 6-year ownership costs than their PHEV and ICE vehicle counterparts, which is primarily due to substantial reductions in vehicle price.

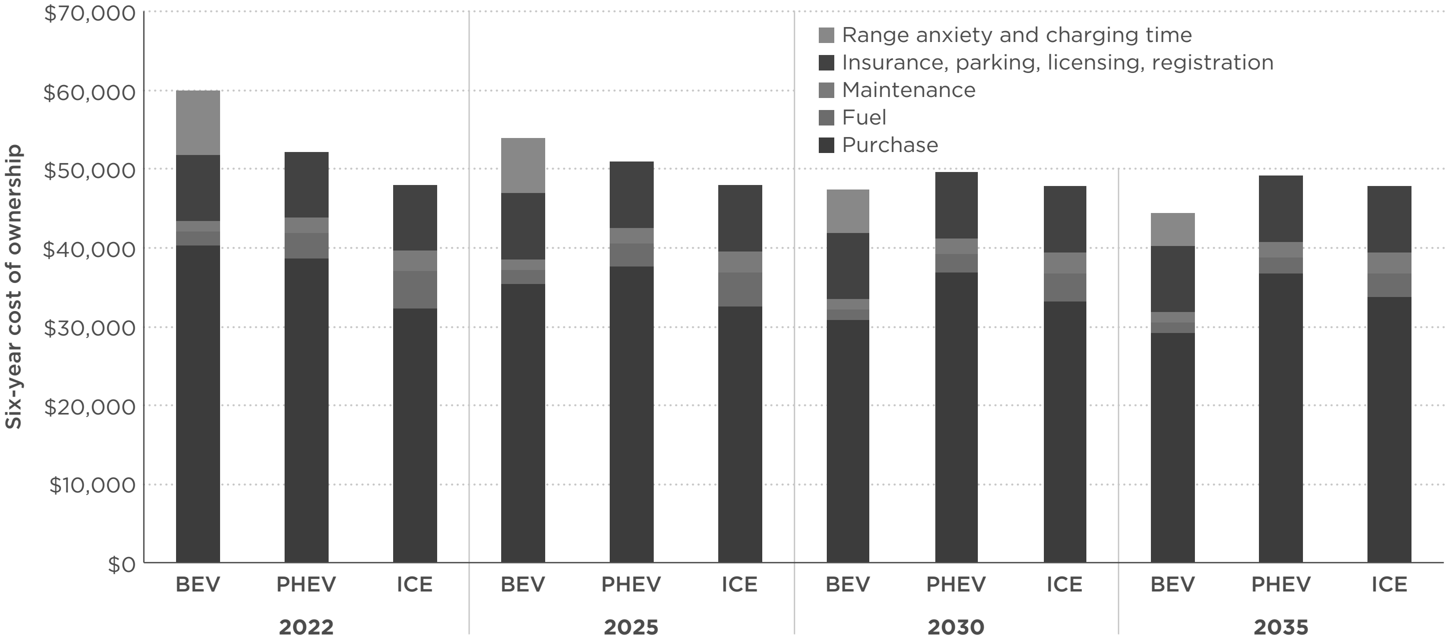

Figure 2. Net present value of six-year ownership costs for new BEVs, PHEVs, and ICE vehicles in 2022, 2025, 2030, and 2035

The IRA tax credits affect the consumer choice model by reducing the TCO for electric vehicles. To analyze the impact of the IRA on U.S. electric vehicle market growth, the analysis includes three hypothetical IRA scenarios—Low, Moderate, and High—that reflect different assumptions surrounding the various IRA provisions. We compare these scenarios against a baseline scenario that excludes the IRA provisions. Table 1 summarizes the three IRA scenarios and how the various electric vehicle incentives, tax credits, and eligibility restrictions are applied for the Passenger Clean Vehicle Tax Credit (30D) and the Advanced Manufacturing Production Tax Credit (45X), using BEVs as an example. The details are discussed below.

Table 1. Summary of Low, Moderate, and High IRA scenarios and how the incentives are applied to battery electric vehicle prices

IRA provision		IRA scenario		
		Low	Moderate	High
Passenger clean vehicle tax credit (30D)	Domestic battery assembly	100% of new BEVs are eligible for the full $3,750 value		
	Critical minerals sourcing	In 2023, it is assumed that 100% of new BEVs meet the critical minerals sourcing requirements and thus are eligible for the full $3,750. For future years, the share of new vehicles that meet the requirements are as follows:		
		76% in 2025 56% in 2030 55% in 2032	79% in 2025 72% in 2030 78% in 2032	82% in 2025 89% in 2030 100% in 2032
	MSRP eligibility	87% of new BEVs qualify		
	AGI eligibility	68% of new BEVs qualify in 2023 and 77% qualify in 2030		
	Final vehicle assembly	Sufficient North American assembly capacity to meet demand		
	Average 30D incentive value 2023–2032:	**$3,400**	**$5,000**	**$6,150**
Advanced manufacturing production tax credit (45X)	Value of $45/kWh battery credit passed to consumer, with phase out by 2033	0% for all years	25% in 2023 50% in 2024–2029 37.5% in 2030 25% in 2031 12.5% in 2032 0% in 2033	50% in 2023 100% in 2024–2029 75% in 2030 50% in 2031 25% in 2032 0% in 2033
	Average 45X incentive value 2023–2032:	**$0**	**$1,450**	**$2,900**
Average incentive value of 30D and 45X combined, 2023-2032:		**$3,400**	**$6,450**	**$9,050**

Note: Numbers in table are rounded.

Passenger Clean Vehicle Tax Credit (30D). Up to $7,500 in consumer incentives are available via the new Passenger Clean Vehicle Tax Credit (30D). Receiving the full amount of $7,500 requires that new electric vehicles meet new requirements for domestic battery assembly and sourcing of critical minerals, each worth up to $3,750 (Plug In America, 2023). Based on a previous Energy Innovation® analysis, we estimate that 100% of new electric vehicles will comply with the domestic battery assembly requirements and thus be eligible for the full $3,750 tax credit in each IRA scenario (Baldwin & Orvis, 2022). The share of new electric vehicles that qualify for the critical minerals incentive, and thus the average value of incentives, are also based on Baldwin & Orvis (2022), which used data on electric vehicle battery mineral composition, market shares, and the share of batteries that are sourced domestically or by free trade agreement countries. Beginning in 2023, it is assumed that 100% of new electric vehicles meet the critical mineral requirement for that year. As electric vehicle production increases, a smaller share of new vehicles meet the critical mineral sourcing requirements thereafter. By 2030, it is assumed that 56% of new sales meet the requirements under the IRA Low scenario, 72% meet them under the IRA Moderate scenario, and 100% meet the requirements under the IRA High scenario.

The average value of tax credits is further reduced due to new eligibility restrictions based on the MSRP, adjusted gross income (AGI), and final vehicle assembly. The new tax credits include an MSRP cap of $55,000 for sedans and $80,000 for SUVs and pickup trucks. The credits also include an AGI cap of $150,000 for individuals and $300,000 for a joint household. It is estimated that 87% of new BEVs will meet the MSRP requirements for all years in the analysis. It is estimated that 68% of new BEV sales meet the AGI limits in 2023, which increases to 77% in 2030 as the market expands beyond early adopters to the majority market. There is also an entities of concern provision that disqualifies any new electric vehicles from the tax credit if any of the battery components or minerals are manufactured, assembled, extracted, processed, or recycled by a foreign entity of concern beginning in the 2024–2025 timeframe.[6] Here, we did not account for any reduction in incentive eligibility based on this requirement because it is not yet clear how it will be implemented. Eligibility for the incentive is also contingent on the vehicle being assembled in North America; future manufacturing capacity in North America was estimated by Bui, Slowik, and Lutsey (2021) and found to be sufficient to meet demand, thus not restricting incentive eligibility. More information about the Clean Vehicle Tax Credit, the eligibility requirements, and how these incentives are quantified, are outlined in Baldwin and Orvis (2022).

Advanced Manufacturing Production Tax Credit (45X). For the Advanced Manufacturing Production Tax Credit (45X), up to $45/kWh of the battery production tax credit can be passed on to consumers in the form of reduced upfront vehicle price. From 2024 through 2029, the assumed percentage of the tax credit value passed to consumers is 0% in the Low scenario, 50% in the Moderate scenario, and 100% in the High scenario. For 2023, these values are reduced by a factor of two. By 2030, the 45X production tax credit begins to phase out, and the percentage passed through is reduced by 25% per year until fully expiring in 2033. More details about the modeling of the battery production tax credit are in Baldwin and Orvis (2022).

For each IRA scenario, the table shows the average value of consumer incentives from the clean vehicle tax credit, battery credit, and both incentives combined over the 2022–2033 timeframe. We find that, on average, consumer incentives for new electric vehicle purchases are worth $3,400 in the IRA Low scenario, $6,450 in the IRA Moderate scenario, and $9,050 in the IRA High scenario.

Based on the data from Table 1, Figure 3 shows the average value the IRA incentives (30D) and tax credits (45X) that are applied to average new battery electric vehicle prices for the Low, Moderate, and High IRA scenarios, which include the Personal Tax Credit for Clean Passenger Vehicles (30D) and the Advanced Manufacturing Production Tax Credit (45X) for batteries. Both incentives expire after 2032. As shown, the sales-weighted average value of BEV incentives in the baseline scenario without the IRA quickly phase down as more manufacturers meet the 200,000-vehicle threshold. In the IRA High scenario, where most new electric vehicles meet all IRA eligibility requirements, the sales-weighted average incentive value is about $10,500 in 2024 and declines to about $6,800 in 2032. The decline in the average incentive per vehicle is due to the decreasing share of new vehicles that meet the minerals sourcing requirements, along with the phase out of the battery production tax credit beginning in 2030. In the IRA Low scenario, where fewer new electric vehicles comply with the IRA incentive provisions and there are no battery tax credits passed through to consumers, the average incentive is about $3,400 per vehicle in 2024, $2,600 in 2027, and $4,500 in 2032; the “U” shaped curve is the

6 Beginning in 2024, new plug-in vehicles will not qualify for the tax credit if the battery components were manufactured or assembled by a foreign entity of concern. Starting in 2025, vehicles will not qualify for the tax credit if the battery’s critical minerals are extracted, processed, or recycled by a foreign entity of concern. Foreign entities of concern are entities that are “owned by, controlled by, or subject to the jurisdiction or direction of a government of a foreign country that is a covered nation (i.e., China, Russia, Iran, or North Korea).” (Bond, 2022).

result of a combination of a declining share of new vehicles that meet the critical minerals sourcing requirements and an increasing share of consumers that meet the AGI caps. Average incentives per vehicle in the IRA Moderate scenario decline from about $7,300 in 2024 to about $5,600 in 2032.

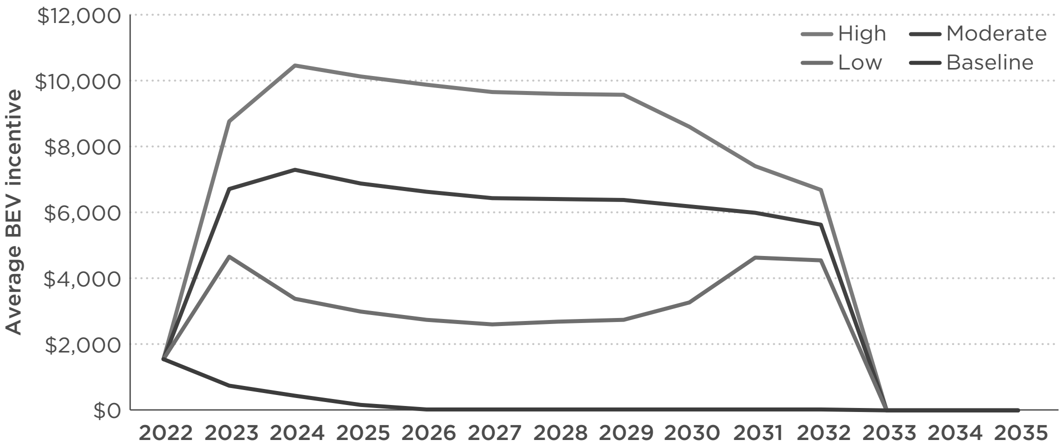

Figure 3. Summary of average IRA incentive values applied to battery electric vehicle prices in the IRA Low, Moderate, and High scenarios

The average BEV incentive values from Figure 3 are applied to the purchase price data for the modeling of consumer choice. Figure 4 shows the average vehicle purchase price for conventional and battery electric vehicles with incentives for the Baseline and Low, Moderate, and High IRA scenarios. As shown, with incentives in the IRA scenarios, upfront price parity is reached in the 2023–2025 timeframe, which is about 3–5 years sooner than without incentives. In the High IRA scenario, the IRA incentives and tax credits reduce electric vehicle prices by up to $10,500, and new BEVs are about $7,000 to $11,000 cheaper than conventional vehicles in the 2025–2030 timeframe.

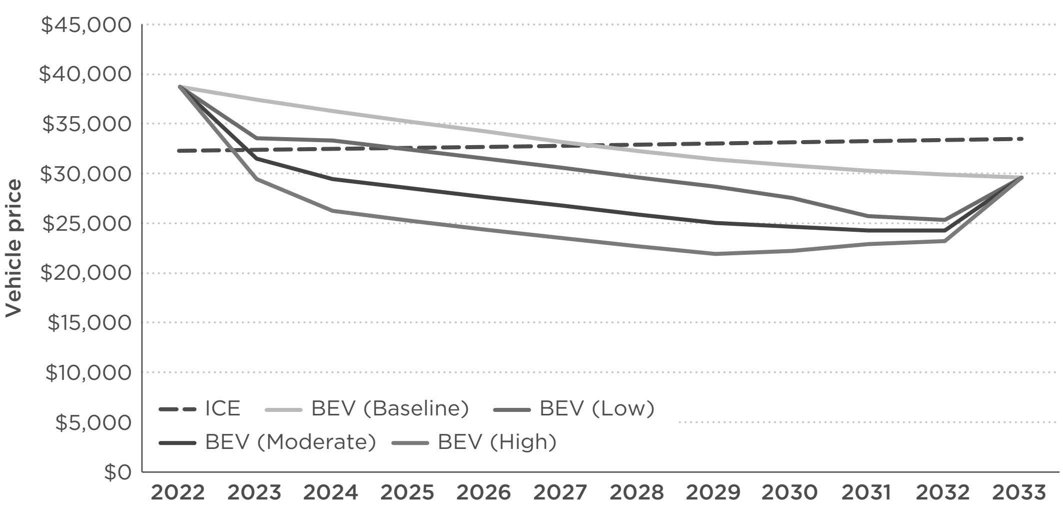

Figure 4. Sales-weighted average new ICE and BEV prices with IRA incentives and tax credits applied

Two additional scenarios are combined with the three IRA scenarios above to incorporate the effects of the state-level Advanced Clean Cars II (ACC II) regulation on national electric vehicle uptake.[7] First, a California-only scenario assumes that California is the only state that implements the ACC II regulation, which requires 100% of new light-duty vehicle sales in the state to be battery electric, hydrogen fuel cell electric, or plug-in hybrid electric by 2035. Second, an Increased ACC II state adoption scenario assumes that all of the states that have adopted ACC I will also adopt ACC II, including California, Colorado, Connecticut, Delaware, Maine, Maryland, Massachusetts, Minnesota, Nevada, New Jersey, New Mexico, New York, Oregon, Rhode Island, Vermont, Virginia, and Washington. States that adopt ACC II are assumed to implement the regulation by model year 2026 or 2027. In both scenarios, the annual targets from California's regulation are used to model electric vehicle uptake in the states adopting ACC II, which are incorporated into the national-level projections from the IRA analysis. The modeled electric vehicle shares in states adopting ACC II increase from 35% in 2026, to 68% in 2030, and to 100% in 2035 (California Air Resources Board, 2022a). The results section discusses the impact of these additional scenarios on our findings in more detail.

HEAVY-DUTY VEHICLES

This study assesses heavy-duty vehicles in Classes 4–8. The retail prices for different zero-emission heavy-duty truck and bus classes are estimated using a bottom-up approach following a methodology developed in two previous ICCT studies: Basma, Saboori, and Rodríguez (2021) and Basma, Zhou, and Rodríguez (2022). This approach considers the vehicle's technical specifications and the individual component manufacturing costs, such as the battery, fuel cell, hydrogen tank, electric drive, electric auxiliaries, and others. These costs are summarized in Sharpe and Basma (2022) and are adjusted to consider average inflation in the United States between 2020 and 2022. The aggregated vehicle manufacturing cost is then converted into retail price using indirect cost multipliers that capture expenses related to research and development, overhead, marketing and distribution, warranty expenditures, and profit markups, as defined in U.S. Environmental Protection Agency and U.S. Department of Transportation (2016). The diesel vehicle retail prices are estimated by averaging publicly available price data in Hunter, Penev, Reznicek, Lustbader, Birky, and Zhang (2021), Burnham, et al. (2021), International ZEV Alliance (2020), California Air Resources Board (2022b), Argonne National Laboratory (2022), Burke and Sinha (2020), and Nair, Stone, Rogers, and Pillai (2022). These retail price estimates are detailed further in a separate publication (Xie, Basma, & Rodríguez, in press).

Retail prices of heavy-duty BEVs and hydrogen fuel cell electric vehicles (FCEVs) before and after IRA incentives are compared with diesel heavy-duty vehicles in Figure 5. Even before IRA incentives are applied, BEVs are projected to reach retail price parity prior to 2030 for Class 4–5 and Class 6–7 rigid trucks, refuse trucks, and transit buses. The IRA incentives accelerate the dates of retail price parity for BEVs to prior to 2030 for Class 8 rigid trucks, short-haul tractor trucks, and all bus classes. Long-haul tractor trucks are the only class for which BEVs do not reach retail price parity within the timeframe of this study, even after IRA incentives. However, the incentives roughly halve the price premium of BEVs compared to diesel long-haul tractor trucks in 2030. In contrast to BEVs, FCEVs are projected to reach retail price parity with diesels only for refuse trucks and some bus classes. As in the case of BEVs, the IRA incentives substantially reduce the price premium of FCEVs for all classes.

7 See Bui, Hall, and Searle (2022).

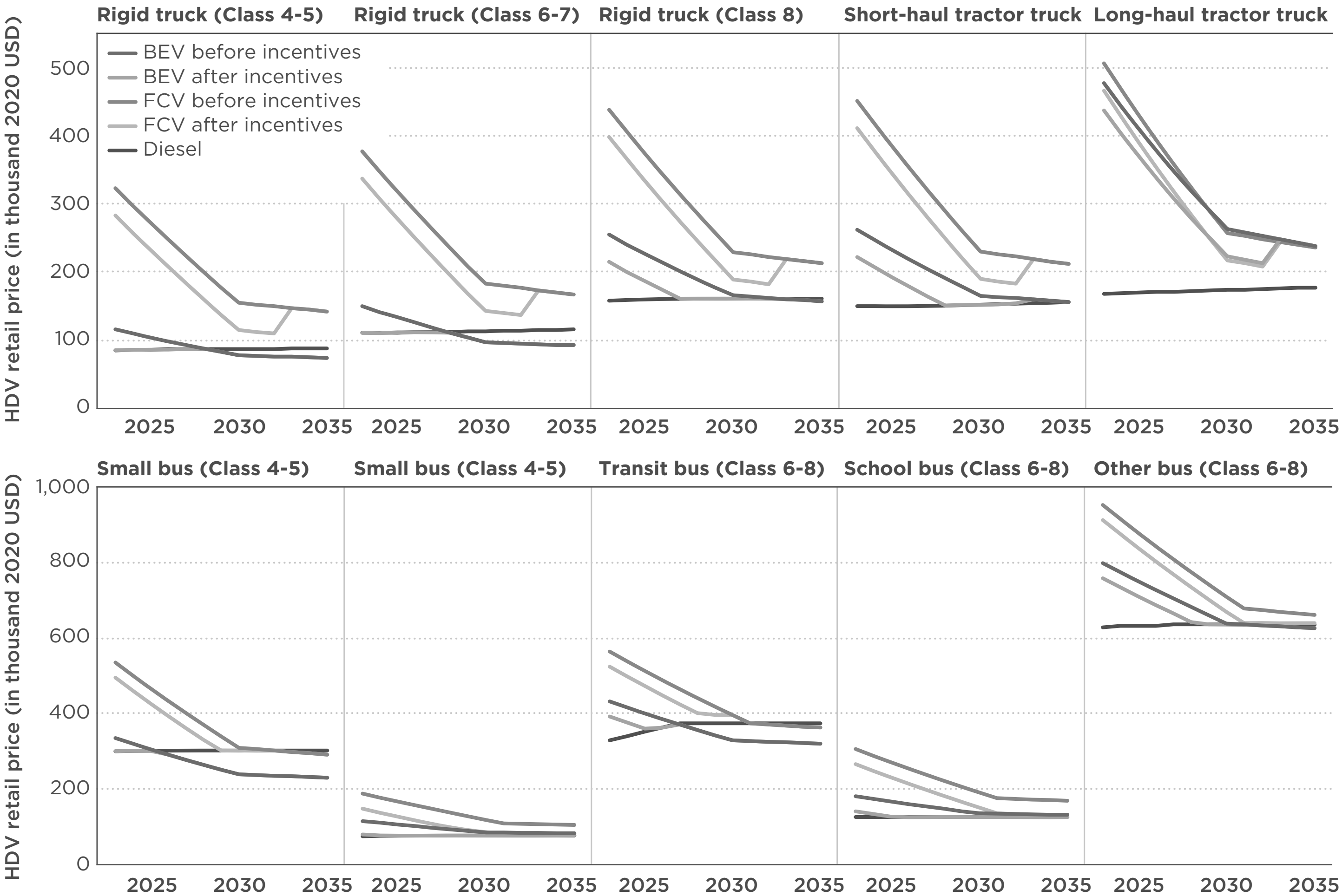

Figure 5. Comparison of BEV and FCEV retail prices with diesel heavy-duty vehicles before and after IRA incentives

The technical specifications of the vehicles are defined based on commercial zero-emission heavy-duty trucks and buses currently available in the United States. Battery and hydrogen tank sizes are based on the vehicle's fuel consumption per mile and the average daily mileage. These parameters are provided in the appendix.

The vehicles' miles per gallon (MPG) are estimated by averaging data based on NREL (2021), ANL (2021), and CARB (2020), and the vehicle average daily mileage data is extracted from MOVES3 for each heavy-duty vehicle class. For small buses, we assumed the same efficiency as for rigid trucks (Class 4–5) for each type of technology. For diesel school buses and other diesel buses, we assumed vehicle efficiency follows the Phase 2 standards for coach buses for model year 2027. For school buses, we assumed the same ratio of BEV to diesel and FCEV to diesel efficiency as for rigid trucks (Class 6–7). For other battery electric and fuel cell electric buses, we assumed the same energy efficiency ratios as for long-haul tractor trucks.

Heavy-duty BEV and FCEV costs are further reduced by the amount of the Qualified Commercial Clean Vehicles Tax Credit (45W) for the years in which it applies (2023–2032). Per the IRA provisions, the value of the tax credit is calculated as the lesser of the incremental cost of a BEV or FCEV compared to its diesel equivalent using the estimated costs in Figure 5, 30% of the cost of the vehicle, or $40,000 (Internal Revenue Service, 2022). We also apply the Advanced Manufacturing Production Tax

Credits (45X) for batteries, based on the battery sizes in Table A1 in the appendix and following the same assumptions as described in the section on light-duty vehicles.

Because vehicle sales shares are projected based on the total cost of ownership, fuel and charging costs are also incorporated in our model. Forecasted diesel prices are taken from the U.S. Energy Information Administration (2022). We estimate the trucks' charging costs by accounting for average electricity rates, charging station costs, and estimated grid upgrade costs. This includes a combination of public and private charging, depending on the vehicle class. Electricity rates vary among and within states depending on utility regulation, type of utility, the presence of regional utilities, and other factors. For this analysis, we collected electricity rate data for seven representative states (California, New York, Texas, Florida, Georgia, Illinois, and Washington), covering different geographic regions and a broad price spectrum while focusing on states with high trucking activity. The electricity rates offered by the biggest utility in each state are used, focusing on primary grid connection applications in which there is a connection to the high-voltage distribution grid. We include demand charges. We then calculate the weighted-average charging cost at the U.S. federal level, providing higher weights for states with higher trucking activity. Data for charging equipment and grid upgrade expenses are adopted from Jesse, Mishra, Miller, Borlaug, Meintz, and Birky (2022). Electricity rate data for the states listed above were collected from PG&E (2022), National Grid US (2022), PSE (2022), ComEd (2022), FPL (2022), Oncore (2022), and Georgia Power (2022). The resulting federal average charging cost in 2022 is 0.1728 $/kWh, out of which ~ 0.047 $/kWh corresponds to charging station and grid upgrade costs.

We follow the methodology developed in a previous ICCT study to estimate the cost of hydrogen fuel for heavy-duty FCEVs. We assume electrolysis is performed on-site at hydrogen refueling stations using renewable electricity, producing green hydrogen (Zhou & Searle, 2022). Thus, the at-the-pump hydrogen price consists of two components, the green hydrogen production cost and the hydrogen refueling station cost. This model, while compromising a smaller production capacity, avoids costs and potentially prolonged infrastructure construction, such as pipelines, to deliver hydrogen. We factor in the impacts of the IRA on hydrogen production costs by applying the renewable electricity (section 45 and 45Y) and clean hydrogen (section 45V) tax credits from 2023 to 2032. Detailed methodology and results for our estimated green hydrogen costs are in the appendix.

We assume the Advanced Clean Trucks (ACT) rule is followed in states that had adopted it as of October 2022 (California Air Resources Board, 2019). The ACT rule requires heavy-duty vehicle manufacturers to sell zero-emission vehicles (ZEVs) as increasing shares of their annual sales from 2024 to 2035. By 2035, ZEV sales would need to be 75% of Class 4–8 straight truck sales and 40% of tractor truck sales to meet these requirements. The states that have adopted the ACT rule include California, Massachusetts, New Jersey, New York, Oregon, and Washington (Electric Trucks Now, 2022). Our assumptions on ZEV uptake in ACT states are the same for all scenarios.

The model structure is the same as for light-duty vehicles above, and shareweights from the GCAM input data are also used.

RESULTS

This section summarizes the findings for new U.S. electric vehicle sales and sales shares from 2023 through 2035. The results are presented first for light-duty vehicles followed by heavy-duty vehicles.

LIGHT-DUTY VEHICLES

Figure 6 summarizes the findings of light-duty electric vehicle shares for 2022 through 2035 for the five scenarios: baseline, IRA Low with California-only ACC II, IRA Moderate with California-only ACC II, IRA Moderate with increased state ACC II adoption, and IRA High with increased state ACC II adoption.

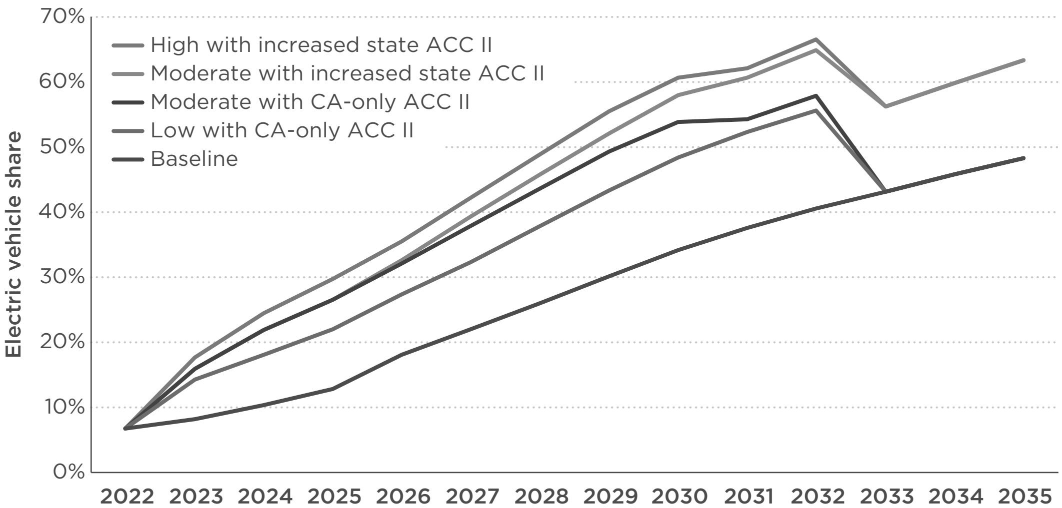

Figure 6. U.S. light-duty electric vehicle sales share for five scenarios, 2022–2035

As shown, electric vehicle sales shares under the baseline scenario increase from about 7% in 2022 to about 13% by 2025, 34% by 2030, and 48% by 2035. With the IRA, electric vehicle prices are reduced and electric vehicle sales shares increase. Under the IRA Low scenario with California-only ACC II adoption, national electric vehicle sales shares reach about 22% by 2025 and about 48% by 2030. Under the IRA High scenario with increased state ACC II adoption, national electric vehicle sales shares increase to about 30% by 2025 and about 61% by 2030. The gap in electric vehicle sales shares between the baseline scenario with no IRA and the IRA scenarios illustrate the effect of the purchase incentives and battery tax credits on consumer purchase decisions. Compared to the baseline scenario, the projected electric vehicle sales shares are nearly doubled in the IRA High with increased state ACC II adoption scenario. Based on our analysis, 2030 electric vehicle sales shares with the IRA range from about 48% (Low) to about 61% (High), indicating the potential for the policy to deliver on President Biden's 2030 50% electric vehicle sales share target.

The decline in electric vehicle sales shares from 2032 to 2033 is due to the expiration of the IRA Personal Tax Credits for Clean Passenger Vehicles (30D) and Advanced Manufacturing Production Tax Credits (45X) for batteries at the end of 2032. By 2033, electric vehicle shares under the IRA Low and IRA Moderate with California-only ACC II scenarios are identical to that of the baseline, because the baseline scenario also assumes that California is the only state with the ACC II regulation. For the IRA High and IRA Moderate scenarios with increased state ACC II adoption, the 2033 electric vehicle sales shares are about 15% greater than the baseline due to increased sales in additional states with the ACC II regulation. From 2033 to 2035, electric vehicle shares continue to increase as technology costs continue to decline (Figure 1).

Table 2 summarizes the electric vehicle sales shares from 2022 through 2035 for the five scenarios, which are identical to the data from Figure 6. The electric vehicle shares include both BEVs and PHEVs. PHEVs, which on average have higher purchase prices than both battery electric and conventional vehicle technologies, account for 12%–14% of the electric vehicle sales in 2023, and this fraction declines to 5%–8% by 2035, depending on the scenario.

Table 2. Summary of electric vehicle sales shares for five scenarios, 2022–2035

Scenario	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Baseline	6.7%	8.1%	10.3%	12.8%	18.0%	22.0%	26.0%	30.1%	34.1%	37.6%	40.5%	43.2%	45.8%	48.2%
Low with CA-only ACC II	6.7%	14.3%	18.0%	21.9%	27.3%	32.3%	37.9%	43.3%	48.3%	52.3%	55.6%	43.2%	45.8%	48.2%
Moderate with CA-only ACC II	6.7%	15.9%	21.9%	26.5%	32.1%	37.8%	43.6%	49.3%	53.8%	54.3%	57.9%	43.2%	45.8%	48.2%
Moderate with increased state ACC II adoption	6.7%	15.9%	21.9%	26.5%	32.6%	39.3%	45.8%	52.1%	57.9%	60.6%	64.9%	56.2%	59.8%	63.3%
High with increased state ACC II adoption	6.7%	17.7%	24.4%	29.8%	35.5%	42.2%	48.9%	55.5%	60.6%	62.0%	66.5%	56.2%	59.8%	63.3%

Table 3 summarizes the findings for electric vehicle sales shares in non-ACC II states, calculated as the difference between the national-level projections from Table 2 and state-level projections for ACC II states based on the annual regulatory requirements, and taking total light-duty vehicle sales into account. Electric vehicle sales shares in the non-ACC II states lag those of ACC II states. Under the baseline scenario, EV shares in non-ACC II states increase from about 16% in 2026, to about 30% by 2030, and to about 35% by 2032. With the IRA, across all modeled scenarios, incentives reduce electric vehicle prices and sales increase as a result. In the IRA Low scenario, EV sales shares in non-ACC II states increase from about 26% in 2026, to about 46% in 2030, and to about 52% in 2032. Electric vehicle sales shares are highest under the IRA High scenario, increasing from about 36% in 2026, to about 56% in 2030, and to about 57% in 2032. Sales shares in non-ACC II states under the IRA Moderate scenario are approximately halfway between the Low and High scenarios and are identical for the California-only ACC II and increased state ACC II scenarios. The decline in non-ACC II state EV sales shares after 2032 is due to the expiration of the IRA incentives, and EV sales shares in non-ACC II states are consistent across all scenarios over this timeframe.

Table 3. Summary of electric vehicle share in all non-ACC II states combined, 2026–2035

Scenario	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Baseline	15.8%	19.2%	22.7%	26.2%	29.6%	32.4%	34.9%	37.2%	39.3%	41.3%
Low with CA-only ACC II	26.3%	30.9%	36.1%	41.2%	45.7%	49.2%	52.0%	37.2%	39.3%	41.3%
Moderate with CA-only ACC II	31.7%	37.1%	42.6%	48.0%	51.9%	51.4%	54.7%	37.2%	39.3%	41.3%
Moderate with increased state ACC II adoption	31.2%	37.1%	42.6%	48.0%	51.9%	51.4%	54.7%	37.2%	39.3%	41.3%
High with increased state ACC II adoption	35.8%	41.7%	47.6%	53.3%	56.2%	53.7%	57.3%	37.2%	39.3%	41.3%

HEAVY-DUTY VEHICLES

Figure 7 presents our estimated sales shares of heavy-duty ZEVs, which includes both battery electric and hydrogen fuel cell electric vehicles, in the IRA Low, Moderate, and High scenarios, compared to a baseline (no IRA incentives) scenario. The projected ZEV sales shares vary greatly across truck and bus categories, for example from 11% to 17% for long-haul tractor trucks and from 70% to 77% for Class 4-5 rigid trucks in 2035. For all vehicle categories, ZEV sales shares increase continually until 2030, when the battery production tax credit begins to phase out and the small bus ZEV sales share declines slightly. ZEV sales shares for short- and long-haul tractor trucks are projected to decline in 2032–2033 as the Qualified Commercial Clean Vehicles Tax Credit phases out. ZEV sales shares of all vehicle categories are projected to increase steadily after 2033 as ZEVs continue to become more cost competitive.

Aggregate sales-weighted average heavy-duty ZEV sales shares in 2030 are projected to be 39% in the IRA Low scenario, 44% in the IRA Moderate scenario, and 48% in the IRA High scenario. These shares increase in 2035 to 47%, 52%, and 56% for the IRA Low, Moderate, and High scenarios, respectively.

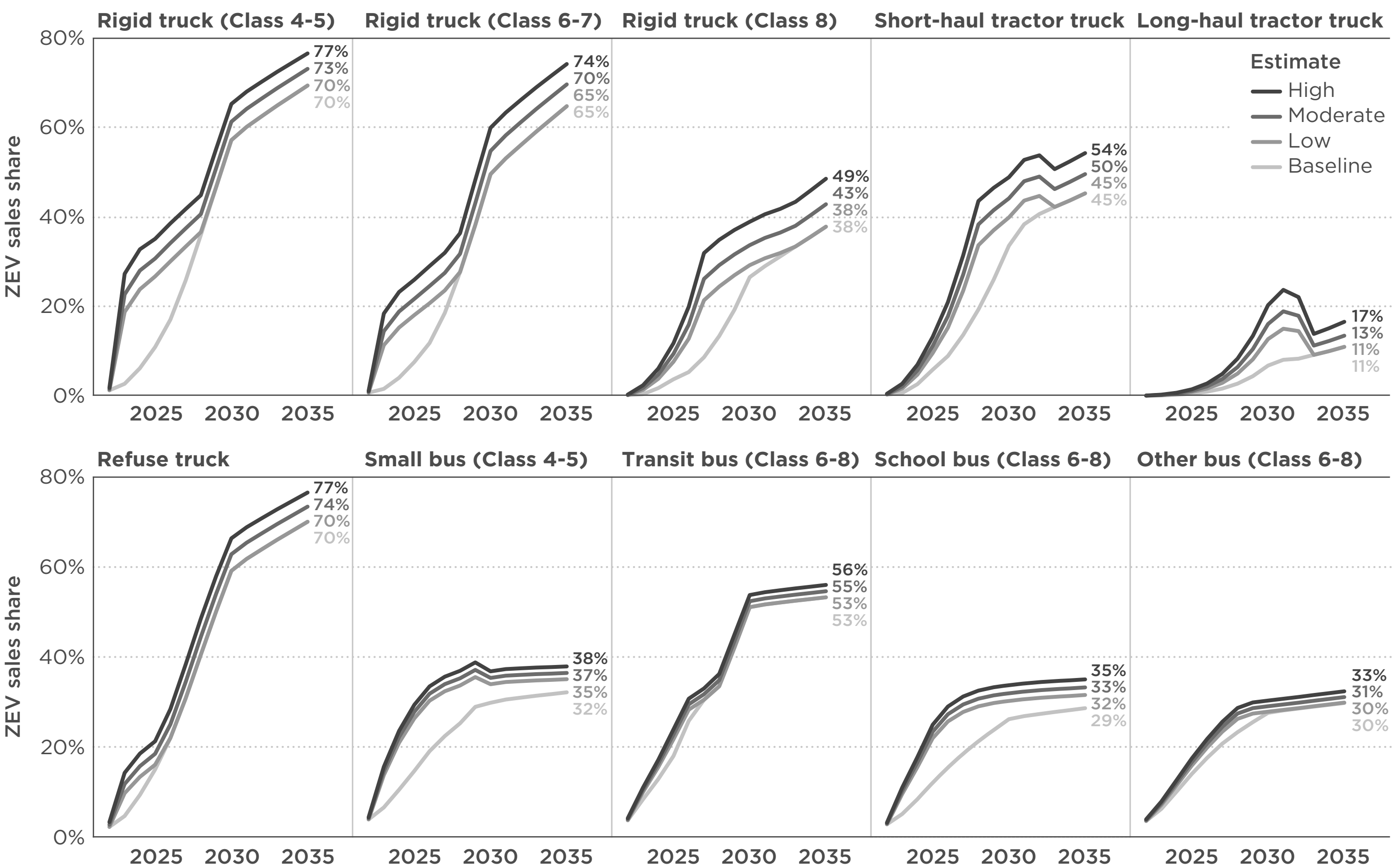

Figure 7. Baseline, IRA Low, IRA Moderate, and IRA High scenarios for U.S. heavy-duty ZEV (BEV + FCEV) sales shares by category, 2022–2035

Our modeling indicates that FCEVs will play only a limited role in the ZEV transition. Table 4 presents the shares of total sales and of ZEV sales that are projected to be FCEVs for each HDV class from 2023 to 2035 in the IRA Moderate scenario. These trends are similar in the IRA Low and High scenarios. For all truck and bus classes, ZEV sales are projected to be dominated by BEVs. Among truck classes, FCEVs make up less than 1% of total sales in all years. FCEVs are projected to have slightly higher adoption among buses, reaching 6.6% of total sales of transit buses in 2035. The reason FCEVs are projected to play such a limited role in the ZEV transition is due to market fundamentals; in contrast to BEVs, which are projected to have substantially lower operating costs, FCEVs are projected to have higher operating costs than diesels since hydrogen will continue to be more expensive than diesel.

Table 4. FCEV share of total sales and share of ZEV sales by HDV category in the IRA Moderate scenario

FCEV share of total sales in IRA Moderate scenario														
HDV class	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Rigid truck (Class 4-5)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.2%	0.2%	0.0%	0.0%	0.1%
Rigid truck (Class 6-7)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.2%	0.1%	0.1%	0.1%
Rigid truck (Class 8)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.5%	0.7%	0.8%	0.3%	0.3%	0.4%
Short-haul tractor truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.3%	0.4%	0.4%	0.3%	0.3%	0.3%
Long-haul tractor truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Refuse truck	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%	0.5%	0.5%	0.5%	0.5%	0.6%	0.6%	0.7%
Small bus (Class 4-5)	0.0%	0.1%	0.1%	0.1%	0.2%	0.3%	0.4%	0.8%	1.4%	1.5%	1.6%	1.7%	1.9%	2.0%
Transit bus (Class 6-8)	0.0%	0.5%	0.5%	0.6%	1.3%	1.6%	1.7%	3.3%	5.9%	6.0%	6.2%	6.3%	6.5%	6.6%
School bus (Class 6-8)	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%	0.4%	0.6%	0.7%	0.9%	1.1%	1.4%
Other bus (Class 6-8)	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.3%	0.4%	0.6%	0.7%	0.9%	1.1%	1.4%	1.6%

FCEV share of ZEV sales in IRA Moderate scenario														
HDV class	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Rigid truck (Class 4-5)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.3%	0.3%	0.3%	0.1%	0.1%	0.1%
Rigid truck (Class 6-7)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.3%	0.3%	0.1%	0.1%	0.1%
Rigid truck (Class 8)	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.6%	1.6%	1.9%	2.2%	0.8%	0.8%	0.8%
Short-haul tractor truck	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.3%	0.7%	0.8%	0.9%	0.6%	0.6%	0.6%
Long-haul tractor truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.2%	0.2%
Refuse truck	0.0%	0.0%	0.1%	0.3%	0.4%	0.5%	0.7%	0.9%	0.7%	0.7%	0.8%	0.8%	0.9%	1.0%
Small bus (Class 4-5)	0.3%	0.5%	0.4%	0.4%	0.7%	0.9%	1.1%	2.1%	4.0%	4.2%	4.5%	4.8%	5.1%	5.5%
Transit bus (Class 6-8)	0.6%	4.9%	3.3%	2.5%	4.6%	4.9%	4.8%	7.6%	11.3%	11.4%	11.5%	11.7%	11.9%	12.1%
School bus (Class 6-8)	0.3%	0.2%	0.2%	0.2%	0.3%	0.4%	0.6%	0.9%	1.4%	1.8%	2.2%	2.8%	3.4%	4.1%
Other bus (Class 6-8)	0.8%	0.7%	0.6%	0.6%	0.7%	0.8%	1.0%	1.4%	2.0%	2.5%	3.1%	3.7%	4.4%	5.1%

DISCUSSION AND POLICY RECOMMENDATIONS

This analysis finds that, with the combined effects of the IRA and technology improvements that will drive down ZEV manufacturing costs, the United States will see rapid electrification over the coming decade. By 2030, we find a range of 48%–61% EV sales share in the light-duty sector, increasing to 56%–67% by 2032, the final year of the IRA tax credits. For heavy-duty, we estimate a range of 39%–48% ZEV sales share by 2030 and 44%–52% by 2032.

We find that the Biden administration's goals of a 50% light-duty EV sales share and a 30% heavy-duty ZEV sales share by 2030 are likely to be exceeded with the influence of the IRA. In the case of heavy-duty vehicles, the administration's target could be exceeded considerably.

However, other analysis has found that the Biden administration's electrification goals would not be sufficient to meet its climate goals. Slowik and Miller (2022) assessed the greenhouse gas (GHG) reductions from light-duty vehicles that are necessary to be compatible with the Paris Climate Agreement to limit global warming to well below 2 degrees Celsius. That analysis found that EV sales shares would need to reach 67% by 2030, coupled with a 3.5% annual increase in the efficiency of combustion engine vehicles, to be compatible with the Paris Agreement. That EV share is higher than the range of results we model here for 2030. Comparing the analysis presented here with the Paris-compatible scenario in Slowik and Miller also shows that, even if all the states that have adopted ACC I also adopt ACC II, the combination of state action and the IRA would still not be sufficient to meet our climate goals.

Other analysis suggests that higher heavy-duty vehicle electrification rates than projected here may also be needed. Buysse, Kelly, and Minjares (2022) find that a heavy-duty ZEV sales share of 46% by 2030 would be needed to be compatible with a scenario of 2 degrees Celsius.

In an earlier analysis using the Energy Policy Simulator model, Orvis, Gopal, Rissman, O'Boyle, Baldwin, and Busch (2022) found that the IRA would significantly reduce GHG emissions, but not enough to put the United States on track to meet is Nationally Determined Contribution commitment to reduce GHG emissions by 50%–52% in 2030 compared to 2005 levels. Thus, additional policy action in the United States is likely necessary to avert the worst effects of climate change.

This analysis is relevant for the U.S. Environmental Protection Agency's next round of rulemaking on light-duty and heavy-duty vehicles. The agency plans to release new proposals for GHG standards by the end of March 2023 (U.S. Environmental Protection Agency, 2022). Because our analysis projects EV and ZEV penetration rates in the absence of federal standards, it can be viewed as a baseline for the purposes of setting those standards. To deliver climate benefits, the new standards will need to advance technology improvements, which could include both electrification as well as efficiency improvements in combustion engine vehicles, faster than is expected under the baseline. Our analysis suggests that setting light-duty standards consistent with an EV penetration rate significantly greater than 50% and heavy-duty standards consistent with a ZEV penetration rate significantly greater than 40% in 2030 may be necessary to deliver additional climate benefits. Another way of viewing our results is that, because of the opportunity for the IRA to deliver such high electrification rates, the federal GHG standards can achieve even greater EV and ZEV penetration and consumer benefits at potentially little additional cost to consumers and automakers.

There is also a role for federal GHG standards to act as a backstop to the IRA and ensure continued growth in EV and ZEV sales shares. The IRA tax credits are set to expire after 2032, and we find that progress in electrification slows after that year. In addition, there is uncertainty in any policy and it is possible that the tax credits could be affected by new legislation or by changes in implementation by future administrations. Setting strong federal GHG standards can help ensure progress in EV and ZEV deployment continues in the face of uncertainty in IRA implementation.

Our modeling approach carries limitations. The GCAM model logit function is based on a single numerical value that orders consumer purchase preferences. This choice indicator approach does not necessarily capture individual preferences, local variations in cost, and other personal factors that would result in economically inferior choices. Furthermore, should battery prices not decline as predicted or consumer acceptance of electric vehicles stalls, our forecasts could be overly optimistic. Conversely, our estimates could be overly conservative if these factors all turned positive.

There are two key non-financial barriers not accounted for in this study: manufacturing lead time and charging infrastructure lead time. These are both greater challenges for the heavy-duty sector than for LDVs. While EVs accounted for 7% of LDV sales in the first half of 2022 in the United States, heavy-duty ZEV sales number only in the hundreds per year at present (Mock & Yang, 2022; Buysse, 2022). Heavy-duty ZEV assembly lines will need to ramp up quickly to deliver the ZEV numbers we project will be demanded on the basis of cost and consumer preferences. Charging infrastructure for heavy-duty vehicles is also expected to take significantly more time to install than for light-duty, since HDV charging depots will increase the demand on the electricity grid at each location to a much greater extent than LDV charging, necessitating time-consuming grid upgrades (Helou et al., 2022). Utilities, industry, and the government will all need to act early to begin making these changes to enable ZEV deployment.

We find that hydrogen is unlikely to play a major role in decarbonizing the U.S. road transportation sector, even when considering the IRA incentives for hydrogen. In this study, we model the cost of green hydrogen, including the incentives from both the clean hydrogen and renewable electricity tax credits in the IRA. We find that the resulting cost of green hydrogen at the pump will still be very high through 2035 (see Table A1 in the appendix). We estimate a sales share of less than 1% for hydrogen FCEVs in each of the truck classes analyzed here. We find up to a 7% FCEV penetration in transit buses, with less than a 2% FCEV sales share for the other bus classes in 2035 (Table 4). Our analysis suggests that battery electric technology will dominate electrification for heavy-duty vehicles. We did not consider light-duty hydrogen vehicles in this analysis.

New guidance from the Treasury Department in December 2022 establishes leased vehicles as eligible for the commercial vehicle tax credit of $7,500 (Internal Revenue Service, 2022). We did not explicitly consider leased light-duty vehicles in our analysis, but do not expect it would greatly change our results. The share of new EVs that are leased has been declining, representing only about 10% of new electric vehicles in the third quarter of 2022 (Webb, 2022). Moreover, the commercial vehicle tax credit is capped at the incremental cost of a BEV compared to a conventional vehicle. As our cost analysis finds that most light-duty EVs will reach cost parity with gasoline vehicles before 2030, we expect the commercial vehicle tax credit to offer a financial benefit compared with the personal tax credit for only the next few years.

We note several uncertainties and limitations, as well as opportunities for additional research. The projections of EV and ZEV uptake in this study are dependent on the choice of logit exponents and shareweights. In this analysis, these parameters are selected to reflect historical consumer preferences for conventional technology and supply chain constraints. In the future, consumer preferences could change to a greater extent than explored here. Future supply chain development, particularly for materials used in battery production, is uncertain, as is infrastructure availability. Infrastructure needs for the heavy-duty sector, purchase price and total cost of ownership projections for battery electric and fuel cell electric heavy-duty vehicles, and analysis of the heavy-duty vehicle electrification pace necessary to meet our climate goals, will be addressed in forthcoming ICCT publications.

CONCLUSIONS

This study assesses the combined impacts of technology improvement and the IRA tax incentives on EV and ZEV deployment rates from 2023 to 2035. From the results presented here, we draw the following conclusions:

» The IRA can potentially drive high rates of electrification over the coming decade. By 2030, we find a range of 48%–61% EV sales share in the light-duty sector, increasing to 56%–67% by 2032, the final year of the IRA tax credits. For heavy-duty, we estimate a range of 39%–48% ZEV sales share by 2030 and 44%–52% by 2032.

» Additional policy is needed in the United States to avert the worst impacts of climate change. The rates of electrification estimated in this analysis are not high enough to be compatible with the Paris Agreement goals or the U.S. Nationally Determined Contribution.

» Battery electric technology will likely play a much larger role than hydrogen in decarbonizing the road transportation sector. This analysis finds less than 1% penetration of hydrogen FCEVs in all truck classes, including long-haul tractor-trailers. We find 7% FCEV penetration for transit buses and 2% or lower FCEV sales shares for other bus classes.

» To deliver substantial additional climate benefits, the U.S. Environmental Protection Agency's federal GHG standards for both light- and heavy-duty vehicles may need to be consistent with electrification rates well above 50% for light-duty and above 40% for heavy-duty vehicles in 2030.

» Strong federal GHG standards for light- and heavy-duty vehicles will also be needed to ensure that the electrification benefits of the IRA continue after the tax credits expire and in case implementation of the tax credits changes.

» Additional action is needed by governments and industry to resolve non-financial barriers to electrification. This includes planning ahead to build charging infrastructure for heavy-duty vehicles and investing in the manufacturing of new vehicle technologies.

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APPENDIX

HEAVY-DUTY VEHICLE PARAMETERS

Table A1. Battery sizes in kWh, 2023–2035

	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Rigid truck (Class 4–5)	135	134	132	131	129	128	126	125	122	121	120	119	118	117
Rigid truck (Class 6–7)	205	203	201	198	196	194	192	190	185	184	182	181	179	178
Rigid truck (Class 8)	400	396	391	387	383	378	374	370	361	358	355	352	349	347
Short-haul tractor truck	455	450	445	440	435	430	426	421	411	407	404	401	398	394
Long-haul tractor truck	1,157	1,138	1,120	1,101	1,083	1,064	1,046	1,027	990	977	965	952	940	927
Refuse truck	405	401	396	392	388	383	379	374	366	363	360	357	354	351
Small bus (Class 4–5)	120	119	117	116	115	114	112	111	108	107	107	106	105	104
Transit bus (Class 6–8)	450	445	440	435	431	426	421	416	406	403	400	396	393	390
School bus (Class 6–8)	180	179	178	177	176	174	173	172	170	169	168	167	166	165
Other bus (Class 6–8)	680	679	678	677	676	674	673	672	670	668	666	664	662	660

Table A2. Summary of HDVs retail prices before incentive, 2023–2035

HDV class		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Rigid truck (Class 4–5)	**Diesel**	86k	87k	87k	88k	88k	88k	88k	88k	88k	88k	89k	89k	89k
	BEV	117k	111k	105k	99k	94k	89k	84k	79k	78k	77k	77k	76k	75k
	FCV	324k	298k	273k	249k	225k	201k	178k	156k	153k	151k	148k	146k	143k
Rigid truck (Class 6–7)	**Diesel**	112k	112k	112k	113k	113k	113k	114k	114k	115k	115k	116k	116k	117k
	BEV	151k	142k	135k	127k	119k	112k	105k	98k	97k	96k	95k	94k	94k
	FCV	378k	348k	319k	291k	263k	236k	209k	184k	181k	178k	174k	171k	168k
Rigid truck (Class 8)	**Diesel**	159k	160k	161k	161k	162k	162k	162k	162k	162k	162k	162k	162k	162k
	BEV	256k	241k	228k	215k	202k	190k	178k	167k	165k	163k	161k	160k	158k
	FCV	439k	407k	375k	345k	315k	286k	258k	230k	227k	223k	220k	217k	214k
Short-haul tractor truck	**Diesel**	151k	151k	151k	151k	151k	152k	152k	153k	154k	155k	155k	156k	157k
	BEV	263k	248k	233k	219k	205k	192k	179k	166k	164k	163k	161k	159k	157k
	FCV	452k	418k	385k	352k	321k	290k	260k	231k	227k	224k	220k	216k	213k
Long-haul tractor truck	**Diesel**	169k	170k	171k	172k	172k	173k	174k	175k	175k	176k	177k	178k	178k
	BEV	478k	443k	410k	378k	348k	318k	291k	264k	259k	254k	249k	244k	239k
	FCV	507k	468k	430k	393k	358k	323k	290k	258k	254k	249k	245k	241k	237k
Refuse truck	**Diesel**	302k	303k	303k	304k	304k	304k	304k	304k	304k	304k	304k	304k	304k
	BEV	337k	322k	307k	293k	279k	266k	253k	241k	239k	237k	236k	234k	232k
	FCV	537k	502k	468k	435k	403k	372k	341k	311k	308k	304k	300k	297k	293k
Small bus (Class 4–5)	**Diesel**	77k	78k	78k	79k	79k	79k	79k	79k	79k	79k	79k	79k	79k
	BEV	117k	113k	108k	104k	99k	95k	91k	87k	87k	86k	86k	85k	85k
	FCV	190k	179k	169k	159k	149k	139k	130k	120k	111k	110k	109k	108k	107k
Transit bus (Class 6–8)	**Diesel**	331k	342k	354k	365k	376k	376k	376k	376k	376k	376k	376k	376k	376k
	BEV	434k	418k	402k	387k	373k	358k	344k	331k	329k	327k	326k	324k	322k
	FCV	566k	540k	515k	490k	466k	443k	420k	398k	376k	373k	370k	367k	365k
School bus (Class 6–8)	**Diesel**	128k	128k	128k	128k	128k	128k	128k	128k	128k	128k	128k	128k	128k
	BEV	183k	176k	169k	162k	156k	150k	143k	138k	137k	136k	135k	134k	134k
	FCV	308k	290k	273k	256k	240k	224k	208k	193k	178k	176k	174k	173k	171k
Other bus (Class 6–8)	**Diesel**	630k	634k	634k	634k	638k	638k	638k	638k	637k	637k	637k	637k	637k
	BEV	800k	776k	752k	729k	707k	684k	662k	640k	638k	635k	633k	630k	628k
	FCV	954k	917k	880k	845k	810k	777k	743k	711k	680k	676k	671k	667k	663k

Notes: Prices are in U.S. dollars. The blue shaded cells indicate the years in which purchase price parity is reached between each ZEV technology and diesel vehicles, and later.

Table A3. Sales shares of heavy-duty vehicles by category in the IRA Moderate scenario, 2023–2035

HDV class		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Rigid truck (Class 4–5)	**BEV**	23%	28%	31%	34%	38%	41%	51%	61%	64%	66%	69%	71%	73%
	Diesel	77%	72%	69%	66%	62%	59%	49%	39%	36%	33%	31%	29%	27%
	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Rigid truck (Class 6–7)	**BEV**	14%	19%	22%	25%	28%	32%	43%	55%	58%	61%	64%	67%	70%
	Diesel	86%	81%	78%	75%	72%	68%	57%	45%	42%	39%	36%	33%	30%
	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Rigid truck (Class 8)	**BEV**	2%	5%	9%	16%	26%	29%	32%	33%	35%	36%	38%	40%	43%
	Diesel	98%	95%	91%	84%	74%	71%	68%	66%	65%	63%	62%	59%	57%
	FCV	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%
Short-haul tractor truck	**BEV**	2%	6%	11%	18%	27%	38%	41%	44%	48%	49%	46%	48%	49%
	Diesel	98%	94%	89%	82%	73%	62%	58%	56%	52%	51%	54%	52%	50%
	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Long-haul tractor truck	**BEV**	0%	1%	1%	2%	4%	6%	10%	16%	19%	18%	11%	12%	13%
	Diesel	100%	99%	99%	98%	96%	94%	90%	84%	81%	82%	89%	88%	87%
	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Refuse truck	**BEV**	12%	16%	19%	25%	34%	44%	54%	63%	65%	67%	69%	71%	73%
	Diesel	88%	84%	81%	75%	65%	55%	46%	37%	34%	32%	30%	28%	26%
	FCV	0%	0%	0%	0%	0%	0%	1%	0%	0%	1%	1%	1%	1%
Small bus (Class 4–5)	**BEV**	15%	22%	28%	32%	34%	35%	37%	34%	34%	35%	35%	35%	35%
	Diesel	85%	78%	72%	68%	66%	65%	63%	65%	64%	64%	64%	64%	63%
	FCV	0%	0%	0%	0%	0%	0%	1%	1%	2%	2%	2%	2%	2%
Transit bus (Class 6–8)	**BEV**	10%	16%	22%	28%	30%	33%	40%	47%	47%	47%	48%	48%	48%
	Diesel	89%	84%	77%	70%	68%	65%	56%	47%	47%	46%	46%	46%	45%
	FCV	1%	1%	1%	1%	2%	2%	3%	6%	6%	6%	6%	6%	7%
School bus (Class 6–8)	**BEV**	10%	17%	23%	27%	29%	31%	31%	32%	32%	32%	32%	32%	32%
	Diesel	90%	83%	76%	73%	70%	69%	68%	68%	67%	67%	67%	67%	67%
	FCV	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%
Other bus (Class 6–8)	**BEV**	8%	12%	17%	21%	24%	27%	28%	29%	29%	29%	29%	29%	30%
	Diesel	92%	88%	83%	79%	75%	72%	71%	71%	70%	70%	70%	69%	69%
	FCV	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%	2%

GREEN HYDROGEN COSTS

We estimate the production cost of green hydrogen using a discounted cashflow (DCF) model, which calculates the current value of investing in a product by accounting for the producer's future annual cash flows. Detailed model assumptions, including the capital and operational costs and financial assumptions, can be found in Zhou & Searle (2022). For the IRA scenarios in this analysis, we use the same DCF model but change certain inputs following the provisions under this law. The tax credits are only applied in years 2023 to 2032, indicating that only producers that started operating early in 2023 would receive the full 10-year credits. The credits are valued at $0.026 per kWh and up to $3 per kg hydrogen, respectively, in 2023, subject to inflation adjustment in future years. Therefore, we assume a 2% annual inflation rate in this study. Per the IRA, the actual amount of hydrogen tax credit is dependent on its life-cycle greenhouse gas emissions—the higher the emissions, the lower the tax credit. In general, green hydrogen has low enough emissions to qualify for the highest $3 per kg hydrogen credit,[8] and the two sets of clean energy tax credits can be combined. In addition, section 6417 of the IRA includes a "direct pay" provision for clean hydrogen producers, where the tax credits are refundable for the first five years of operation. Further, under section 6418, both renewable electricity and clean hydrogen producers are eligible for tax "transferability" by selling their unused tax credits to a buyer who has the tax burden. However, the credits might be transferred, i.e., traded, at a discounted or lower value and could incur due diligence costs (Burton & Vozarova, 2022). Thus, without further details from the IRA, we apply a 15% discount rate to the $0.026 per kWh or $3 per kg hydrogen credit values when the unused renewable electricity or clean hydrogen credits are being transferred. Table A4 shows the estimated levelized green hydrogen production cost with and without the IRA tax credits.

Table A4. Levelized production cost of a new green hydrogen production plant entering the market in a given year, with and without the IRA clean energy tax credits.

Year	With no tax credit	With IRA tax credits
2020	5.59	NA
2021	5.48	NA
2022	5.41	NA
2023	5.35	3.29
2024	5.29	3.40
2025	5.21	3.52
2026	5.16	3.69
2027	5.09	3.93
2028	5.02	4.19
2029	4.95	4.43
2030	4.85	4.58
2031	4.80	4.65
2032	4.75	4.68
2033	4.70	NA
2034	4.59	NA
2035	4.54	NA

The hydrogen refueling station (HRS) cost is based on the study by Reddi et al. (2017). Using the results from that study, we assume the levelized HRS cost to be $6 per kg hydrogen in 2020, decreasing linearly to $2.3 per kg in 2050. These values are consistent with the assumptions in Zhou & Searle (2022), which were based on a European study (European Commission, 2021). The decreasing cost is a result of economies of scale and greater utilization of the HRS. Section 13404 of the IRA provides tax credits to eligible HRSs of up to $100,000. We therefore assume a minor 4% lower HRS cost for the IRA scenario.

The estimated hydrogen price in a given year is the cost of a new project entering production in that year and does not necessarily represent the price to the consumer.

8 See Zhou, Swidler, Searle, and Baldino (2021).

The consumer price will be set based on competition between all hydrogen suppliers, including those that began production in earlier years. In order to estimate a price more representative of the market for each year, we average the costs of producers beginning production in that year and of all producers that began production in earlier years. We thus implicitly assume a linear increase in the number of new hydrogen producers over time. For example, the at-the-pump hydrogen price in 2030 is the average of the 2020–2022 costs when there were no policy incentives and the 2023–2030 costs with the IRA tax credits. Figure A1 shows the at-the-pump green hydrogen price when a new project enters the market each year between 2020 and 2035 and the calculated market price considering all operating projects in that year.

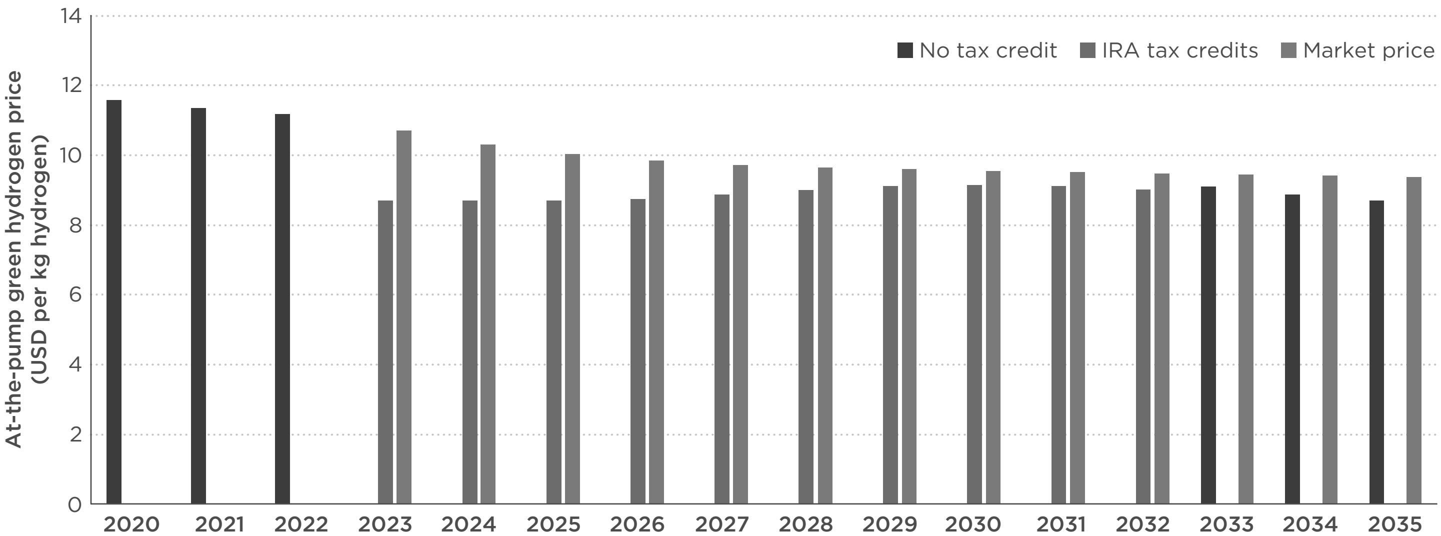

Figure A1. At-the-pump green hydrogen price

DETAILED RESULTS TABLES

Table A5. Projected BEV, PHEV, and total EV sales shares for light-duty vehicles nationwide, 2022–2035

Scenario		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Baseline	BEV	5.3%	7.1%	9.2%	11.5%	16.0%	19.7%	23.5%	27.5%	31.5%	34.9%	37.8%	40.6%	43.2%	45.7%
	PHEV	1.4%	1.1%	1.2%	1.3%	2.1%	2.3%	2.5%	2.6%	2.7%	2.7%	2.6%	2.6%	2.6%	2.5%
	Total EV	6.7%	8.1%	10.3%	12.8%	18.0%	22.0%	26.0%	30.1%	34.1%	37.6%	40.5%	43.2%	45.8%	48.2%
IRA Low with CA-only ACC II	BEV	5.3%	12.3%	15.9%	19.6%	24.4%	29.2%	34.6%	40.0%	45.1%	49.2%	52.5%	40.6%	43.2%	45.7%
	PHEV	1.4%	2.0%	2.2%	2.3%	2.9%	3.1%	3.3%	3.3%	3.2%	3.2%	3.1%	2.6%	2.6%	2.5%
	Total EV	6.7%	14.3%	18.0%	21.9%	27.3%	32.3%	37.9%	43.3%	48.3%	52.3%	55.6%	43.2%	45.8%	48.2%
IRA Moderate with CA-only ACC II	BEV	5.3%	13.8%	19.7%	24.2%	29.2%	34.8%	40.6%	46.4%	50.9%	51.0%	54.8%	40.6%	43.2%	45.7%
	PHEV	1.4%	2.1%	2.2%	2.3%	2.9%	3.0%	3.0%	2.9%	2.9%	3.2%	3.1%	2.6%	2.6%	2.5%
	Total EV	6.7%	15.9%	21.9%	26.5%	32.1%	37.8%	43.6%	49.3%	53.8%	54.3%	57.9%	43.2%	45.8%	48.2%
IRA Moderate with increased state ACC II adoption	BEV	5.3%	13.8%	19.7%	24.2%	29.0%	34.7%	41.0%	47.5%	53.1%	55.1%	59.6%	51.0%	54.6%	58.2%
	PHEV	1.4%	2.1%	2.2%	2.3%	3.6%	4.7%	4.8%	4.6%	4.8%	5.5%	5.3%	5.2%	5.2%	5.1%
	Total EV	6.7%	15.9%	21.9%	26.5%	32.6%	39.3%	45.8%	52.1%	57.9%	60.6%	64.9%	56.2%	59.8%	63.3%
IRA High with increased state ACC II adoption	BEV	5.3%	15.5%	22.5%	27.7%	32.1%	38.2%	44.9%	51.7%	56.5%	56.5%	61.2%	51.0%	54.6%	58.2%
	PHEV	1.5%	2.1%	2.0%	2.0%	3.4%	4.0%	4.0%	3.8%	4.1%	5.5%	5.3%	5.2%	5.2%	5.1%
	Total EV	6.7%	17.7%	24.4%	29.8%	35.5%	42.2%	48.9%	55.5%	60.6%	62.0%	66.5%	56.2%	59.8%	63.3%

SENSITIVITY ANALYSIS RESULTS

Light-duty vehicles

A key component of the logit allocation that determines sales shares is the logit exponent used, which determines the sensitivity of the allocation to the cost parameter. We utilize values from GCAM for this modeling (Joint Global Change Research Institute, n.d.), but note that these values do not appear to be empirically grounded nor updated recently. Given the importance of this component for determing sales shares, the electric vehicle share findings were tested for their sensitivity to variations to the logit exponent. Compared to our analysis above that uses a GCAM value of -8, alternative GCAM values of -6 and -10 (i.e., adding 2 or -2) were applied, reflecting relatively greater and lesser consumer sensitivity to TCO when making purchase decisions. Figure A2 illustrates how the findings of electric vehicle shares vary with adjustments to the logit exponent, indicated by the red hashed area surrounding the black hashed line. As shown, adusting the logit exponent to -6 and -10 has the greatest effect on projections for electric vehicle shares around the 2030–2031 timeframe, at about +/- 5%; this is because of the incentive. The sensitivity analysis shown in Figure A2 is for the Moderate IRA + increased ACC II adoption scenario, but the effects of adjusting the logit exponent are similar for all scenarios.

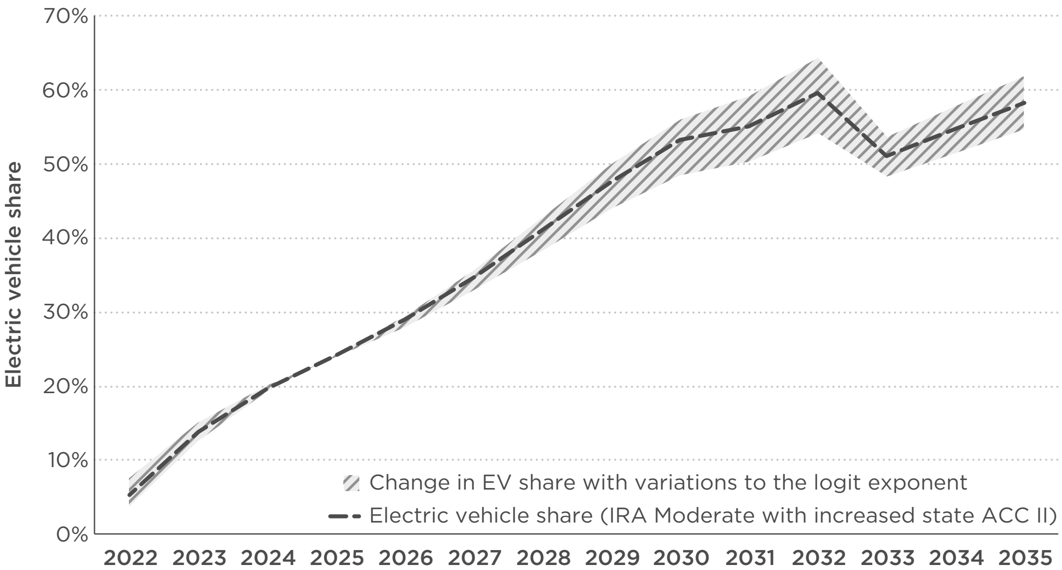

Figure A2. Sensitivity of electric vehicle share findings to variations to the logit exponent, reflecting greater and lesser consumer sensitivity to TCO in purchase decisions. Findings are shown for the IRA Moderate with increased state ACC II adoption scenario.

Heavy-duty vehicles

As with the light-duty vehicle analysis, we test the heavy-duty electric vehicle share findings for their sensitivity to variations to the logit exponent. Compared to the central case of a GCAM value of -8 for non-buses and -3 for buses, alternative GCAM values of -6 and -10 for non-buses and -1 and -5 for buses (i.e., adding 2 or -2) were applied, reflecting relatively greater and lesser consumer sensitivity to TCO, as for light-duty vehicles above. The red hashed areas surrounding the black line in Figure 9 illustrate how the BEV shares for each category of trucks and buses varies with adjustments to the logit expoent. The BEV sales shares for small buses, transit buses, and school buses are more sensitive to the assumption on the logit exponent, while those for short and long haul tractor trucks, Class 8 rigid trucks, and Class 6–8 other buses, are less sensitive to the logit exponent. The sensitivity analysis shown in Figure 9 is for the IRA Moderate scenario, but the effects of adjusting the logit exponent are similar for all scenarios.

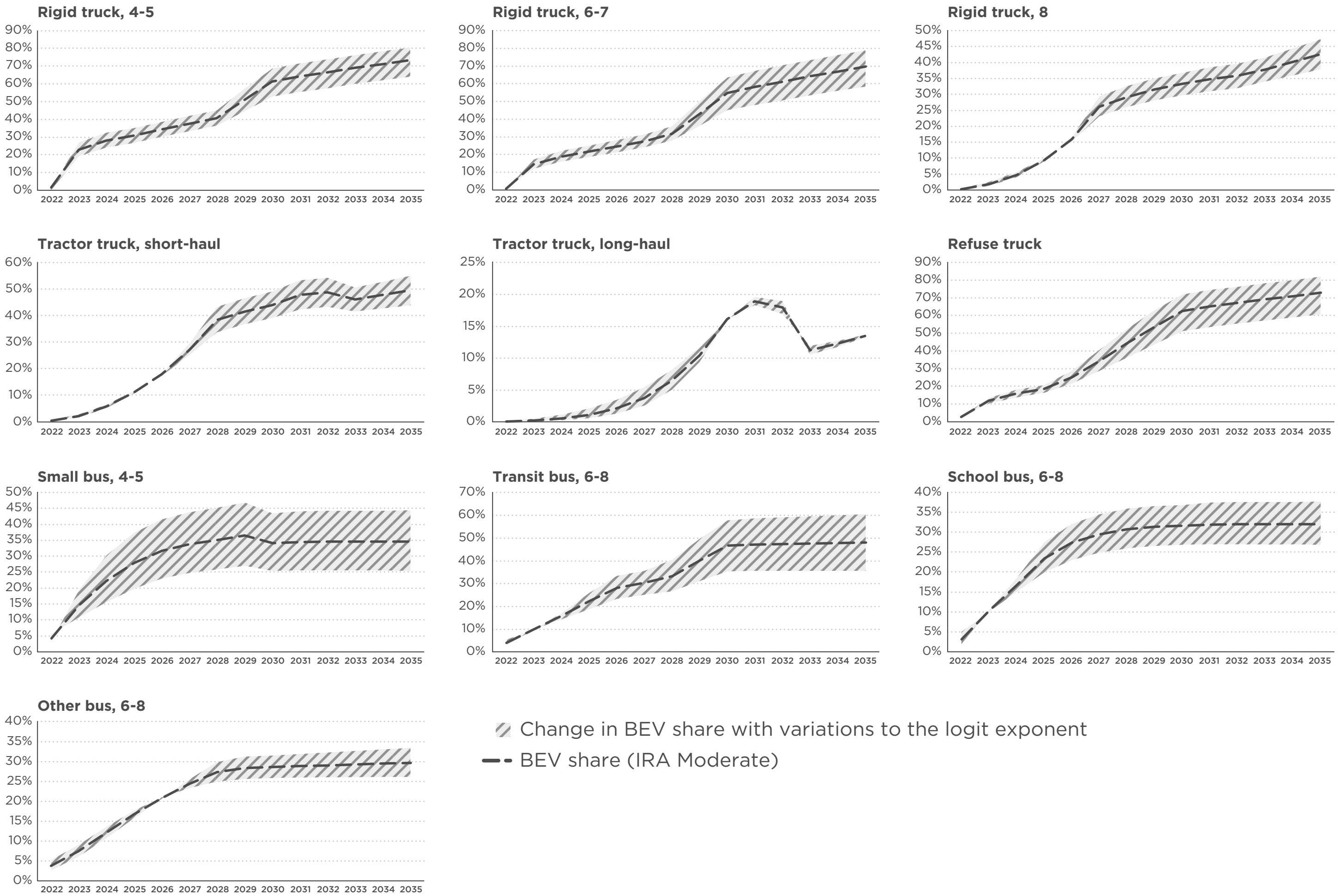

Figure A3. Sensitivity of BEV share findings to variations to the logit exponent for U.S. heavy-duty BEV sales shares by category in the IRA Moderate scenario, 2022–2035.

ENERGYWIRE

EV popularity driven by range and cost improvements — study

By 2030, consumers will be just as likely to buy an electric vehicle as a gas-powered one, thanks to improvements in charging and price, researchers found.

BY: **LAMAR JOHNSON** | 06/07/2023 07:14 AM EDT

A sales associate talks with a prospective buyer of an electric vehicle on the showroom floor of a dealership in Highlands Ranch, Colo., in 2022.| David Zalubowski/AP Photo

ENERGYWIRE | Americans are buying more electric vehicles because technology has caught up to their long-held preferences, according to a new study from researchers at Yale University and Carnegie Mellon University.

The study, published in the *Proceedings of the National Academy of Sciences*, explores whether car buyers changed their preferences between 2012 and 2021. It finds that consumer preferences haven't substantially changed — with range and cost topping the list — but that in recent years, more electric vehicles fit the bill.

“Technology improvements have really been driving consumer acceptance of electric vehicles,” said Kenneth Gillingham, lead researcher and a professor of environmental and energy economics at Yale University.

Electric vehicle sales have soared in the past three years. The International Energy Agency expects EVs to make up 18 percent of the global car market by the end of 2023, up from 4 percent in 2020.

The study predicts that upward trend will continue. By 2030, consumers will be just as or more likely to buy an EV as a gas-powered vehicle, if consumer preferences hold steady and battery-powered EV technology continues to advance at its current pace, researchers found.

Researchers surveyed more than 1,500 SUV and car buyers between December 2020 and September 2021, comparing the results to a 2012-2013 survey they conducted for a study on the differences between consumers in China and the United States.

The survey asked respondents for their preferences on everything from price to power source — including plug-in battery, gasoline or hybrid — and found that consumers consistently opted for cars with more range and a lower price. Researchers then used the survey's findings to project what type of cars consumers might choose in 2030, when EVs will likely go further on a single charge and cost less.

"If every gasoline car had a sibling, and that sibling was an electric car [in 2030]," most new cars and a near-majority of new SUVs sold would be EVs by 2030, Gillingham said in an interview.

Jeremy Michalek, a professor at Carnegie Mellon and director of the university's Vehicle Electrification Group, said in an interview that researchers first hypothesized that a shift in preference or more experience with EVs may be pushing consumers to go electric.

But the study found that buyers still want the same features and that the market has responded with electric vehicles that fit those preferences.

The findings come in the wake of EPA's proposal to limit vehicle emissions. The rules, if finalized, could push automakers to electrify up to two-thirds of new cars and light-duty trucks by 2032.

Nick Nigro, the founder of EV advisory group Atlas Public Policy, also pointed to growth in EV sales and interest from automakers. As more auto manufacturers produce EVs that match the designs of their gas-powered fleets, more people will buy electric versions of their favorite cars, he said.

"We're at the tip of the iceberg," Nigro said in an interview. "In the next few years, they're going to rapidly shift their focus to the cars they want to sell, as opposed to the cars they use to comply with regulations."

The study was completed before the passage of the 2021 bipartisan infrastructure law and the 2022 Inflation Reduction Act, which both included incentives and support for EV adoption.

Some of the policies in the Inflation Reduction Act — including tax credits for new and used EVs— extend out until 2032. Because of that, EV adoption could be faster than projected, argued Katherine Stainken, vice president of policy for the Electrification Coalition.

"Awareness of electric vehicles is on the rise," Stainken said in an interview. "We're going to see some big-time adoption taking place, even in the next three to five years."

[Union of Concerned Scientists

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June 21, 2023

The Honorable Cathy McMorris Rodgers
Chair
House Energy and Commerce Committee

The Honorable Frank Pallone
Ranking Member
House Energy and Commerce Committee

The Honorable Bill Johnson
Chair
Environment, Manufacturing, and Critical Materials Subcommittee

The Honorable Paul Tonko
Ranking Member
Environment, Manufacturing, and Critical Materials Subcommittee

RE: Hearing entitled "Driving Affordability: Preserving People's Freedom to Buy Affordable Vehicles and Fuel"

Chair McMorris Rodgers, Chair Johnson, Ranking Member Pallone, and Ranking Member Tonko-

The Union of Concerned Scientists is science-based nonprofit working for a healthy environment and a safer world. On behalf of our more than half-million supporters, we write in strong opposition to the following bills, which will be discussed at the June 22, 2023 subcommittee hearing:

- H.R. 1435, The Preserving Choice in Vehicle Purchases Act (Rep. John Joyce)
- H.R. 3337, The Fuels Parity Act (Rep. Miller-Meeks)
- H.R. ___, The Choice in Automobile Retail Sales Act of 2023
- H.R. ___, The No Fuel Credits for Batteries Act of 2023

H.R. 1435, The Preserving Choice in Vehicle Purchases Act, aims to "amend the Clean Air Act to prevent the elimination of the sale of internal combustion engines." The Choice in Automobile Retail Sales Act of 2023 aims to prohibit the Environmental Protection Agency (EPA) "from finalizing, implementing, or enforcing" the Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles, which is currently subject to a comment period.

These bills represent blatant attacks on the Clean Air Act, California's longstanding authority to enact clean air and climate programs to address its compelling need to reduce air pollution, and EPA's longstanding authority to set vehicle standards to protect public health and the environment.

Rather than recognize the twin crises of unmitigated climate change[i] and public health impacts from transportation pollution[ii] and the transition to zero-emission vehicles underway[iii] these bills aim to stem the tide of progress towards clean air and a healthy future. We need to move forward, not backwards. These bills should be rejected outright.

H.R. 3337, The Fuels Parity Act removes the exclusion keeping corn starch ethanol out of the advanced biofuel category under the Renewable Fuel Standard (RFS) and requires the EPA to use the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) life cycle analysis model for at least five years. The expansion of corn used for ethanol after the passage of the RFS created problems for water pollution and loss of habitat that undermined the legitimacy of the biofuels industry, which cast a shadow over its future.[iv] Now we are seeing this trainwreck repeated as the oil refiners push to move the lion's share of US vegetable oil production from food to fuel.[v,vi]

Trying to make these problems go away by picking an analysis that hides the problem will not help the biofuel industry address the real problems caused by making food into fuel. To sustainably expand biofuel production we need to bring additional more sustainable biomass resources to the table and make sure that corn and vegetable oil used for fuel is not expanding its footprint and displacing food production and land set aside for nature. With smart policy guidance that focuses on emissions reduction rather than corn and vegetable oil diversion farmers can deliver more climate benefits and make more money on the same acres they are farming today.

The No Fuel Credits for Batteries Act of 2023 prohibits EPA from authorizing the use the credits generated by electricity for RFS compliance, also known as the eRINs (electric renewable identification numbers) pathway. The eRINs pathway does not make any new fuels eligible for the RFS, and certainly does not credit batteries. It simply allows for a wider range of vehicles to use existing qualified biomethane, which has been an approved RFS fuel pathway for many years.[vii] Only a small portion of vehicles run on compressed natural gas, and this technology is increasingly being passed over in favor of electricity in applications like buses where compressed natural gas has found a small niche.

Instead of cutting off pathways for existing fuels, the right fix to the RFS to address the problems with the eRINs pathway would be to update the definition of renewable fuel covered by the RFS to include wind and solar electricity. Renewable electricity is clearly the right fuel for the future of clean transportation, and a smart reform to our nations fuels policies would be to expand the playing field rather than narrowing it.

All four of these bills seem aimed at trying to legislate away technological innovation. Clearly electricity and lower carbon sustainable fuels are going to be an increasingly important part of our fuel mix. Legislators should be forward thinking and take advantages of the opportunities of tomorrow rather than trying to erect barriers.

Sincerely,

Alyssa Tsuchiya

Alyssa Tsuchiya
Senior Washington Representative
Clean Transportation Program
Union of Concerned Scientists

[i] https://www.ipcc.ch/assessment-report/ar6/
[ii] https://blog.ucsusa.org/dave-reichmuth/air-pollution-from-cars-trucks-and-buses-in-the-u-s-everyone-is-exposed-but-the-burdens-are-not-equally-shared/
[iii] https://about.bnef.com/electric-vehicle-outlook/
[iv] https://s3.amazonaws.com/ucs-documents/clean-vehicles/corn-ethanol-and-water-quality.pdf
[v] https://www.reuters.com/business/energy/us-rush-renewable-diesel-may-ignite-fresh-food-fight-maguire-2022-11-08/
[vi] https://theicct.org/wp-content/uploads/2022/01/impact-renewable-diesel-us-jan22.pdf
[vii] https://www.epa.gov/renewable-fuel-standard-program/approved-pathways-renewable-fuel

June 22, 2023

Chair Cathy McMorris Rodgers
Energy and Commerce Committee
U.S. House of Representatives
2125 Rayburn House Office Building
Washington DC 20515

Ranking Member Frank Pallone
Energy and Commerce Committee
U.S. House of Representatives
2125 Rayburn House Office Building
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Subcommittee Chair Bill Johnson
Subcommittee on Environment,
Manufacturing, & Critical Materials
2322 Rayburn House Office Building
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Subcommittee Ranking Member Paul Tonko
Subcommittee on Environment,
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2322 Rayburn House Office Building
Washington DC 20515

Dear Chair Rodgers, Ranking Member Pallone, Subcommittee Chair Johnson, and Subcommittee Ranking Member Tonko:

Consumer Reports (CR) writes in advance of the House Energy and Commerce Subcommittee on Environment, Manufacturing, and Critical Materials hearing on Thursday, June 22, 2023 entitled *Driving Affordability: Preserving People's Freedom to Buy Affordable Vehicles and Fuel* to urge the Committee to support the Environmental Protection Agency's recognized authority under the Clean Air Act to finalize, implement, and enforce the Light- and Medium-Duty Vehicle 2027+ proposed rule. This rule will help save consumers money, lower emissions, and give consumers more options in the marketplace.

CR is an independent, nonprofit and nonpartisan organization that works to create a fair and just marketplace for consumers. Known for its rigorous product testing and ratings, CR also advocates for laws and corporate practices that are beneficial for consumers. It surveys millions of Americans every year, reports extensively on the challenges and opportunities facing today's consumers, and provides ad-free content and tools to 6 million members across the United States. CR is dedicated to amplifying the voices of consumers to promote safety, digital rights, financial fairness, and sustainability.

CR conducts nonpartisan, independent surveys on issues such as consumer awareness of EVs, and analysis on the cost-saving impacts of EPA's proposals to reduce tailpipe emissions, in an effort to provide lawmakers with the insight into the consumer perspective. In evaluating legislation around preserving choice for consumers on EVs and other options at the pump, we ask you to consider the following findings from CR's research in this area:

- Cost Savings
  - Providing consumers with cleaner and more energy-efficient technologies can dramatically lower costs of fuel and energy use, as well as the costs of healthcare and insurance, and doing so will enable them to make purchasing decisions that save them money. Cost savings are especially critical for low-income households which spend a disproportionate amount of their income on fueling costs.[1]
  - A 2020 analysis by CR found that the most popular EVs were already cheaper to own than the most popular and highest-rated gasoline vehicles in their class, even factoring in higher purchase prices. These savings were delivered, despite higher purchase prices, due to EVs saving an average of 60% on fuel and 50% on repairs and maintenance. On average, the study found that EVs sold at that time would save consumers around $6,000 to $10,000 over the lifetime of the vehicle.[2]
- EV Demand
  - A CR nationally representative survey of 8,027 US adults in January and February 2022 shows that 72% of Americans express some level of interest in buying or leasing an electric-only vehicle: 14% would "definitely" buy or lease one if they were to get a vehicle today, 22% would "seriously consider" one, and 35% "might" consider getting one in the future, but not if they were to get a vehicle "today."[3]
  - According to CR's analysis, demand for electric vehicles increased 350% from 2020 to 2022. There are now 45 consumers for every EV being manufactured who say they would "definitely buy" an EV if they were to buy or lease a new vehicle today.[4] Sales of new ICE vehicles dropped by 26% from 2019 to 2022, while EV sales increased by 244%.[5]
  - CR's nationally representative car buying survey of 2,180 US adults from March and April 2022 found that 30% of licensed drivers who were then in the market to buy or lease a new (not a used) vehicle were not even considering a conventional, non-hybrid vehicle.[6]

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[1] *Low-Income Households, Communities of Color Face High "Energy Burden" Entering Recession*, ACEEE, 2020, https://www.aceee.org/press-release/2020/09/report-low-income-households-communities-color-face-high-energy-burden.
[2] *New analysis from CR finds that the most popular electric vehicles cost less to own than the best-selling gas-powered vehicles in their class*, Consumer Reports, October 8, 2020, https://advocacy.consumerreports.org/press_release/new-analysis-from-cr-finds-that-the-most-popular-electric-vehicles-cost-less-to-own-than-the-best-selling-gas-powered-vehicles-in-their-class/.
[3] *Consumer Reports nationally representative survey of 8,027 US adults in January/February 2022*, https://article.images.consumerreports.org/prod/content/dam/surveys/Consumer_Reports_Breakthrough_Energy_18_February_2022.
[4] *Excess Demand, The Looming EV Shortage*, Consumer Reports, March 2023, https://advocacy.consumerreports.org/wp-content/uploads/2023/03/Excess-Demand-The-Looming-EV-Shortage.pdf.
[5] *Id.*
[6] *Car Buying: A National Representative Multi-Mode Survey, 2022 Results*, Consumer Reports, May

Thank you for this opportunity to address these policy measures. CR welcomes the opportunity to discuss how Congress can act on these issues while addressing the needs of consumers.

Sincerely,

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Rep. Mariannette Miller-Meeks
Rep. Jay Obernolte

Rep. Jan Schakowsky
Rep. John Sarbanes
Rep. Paul Tonko
Rep. Yvette Clarke
Rep. Raul Ruiz
Rep. Scott Peters
Rep. Nanette Barragan

2022,
https://article.images.consumerreports.org/prod/content/dam/surveys/Consumer_Reports_Car_Buying_March_2022.pdf.

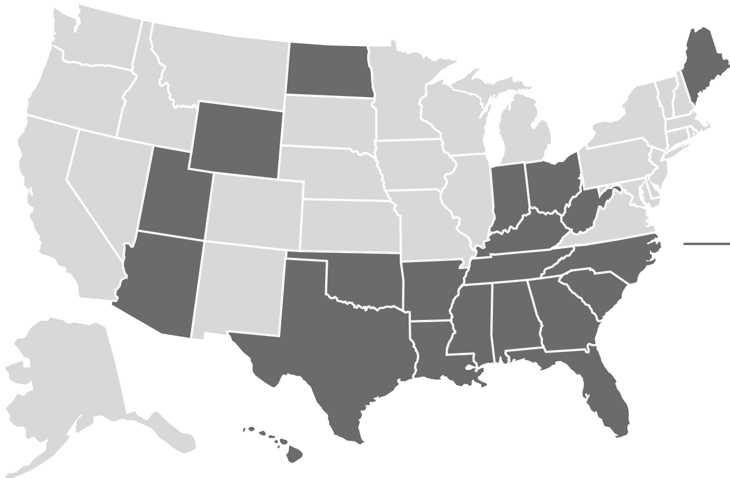
State Air Trends & Successes

THE StATS REPORT
2023 EDITION

AAPCA
THE ASSOCIATION OF AIR POLLUTION CONTROL AGENCIES

AAPCA
THE ASSOCIATION OF AIR POLLUTION CONTROL AGENCIES

State Environmental Agencies Currently Represented on the AAPCA Board of Directors



Alabama	North Carolina
Arizona	North Dakota
Arkansas	Ohio
Florida	Oklahoma
Georgia	South Carolina
Hawaii	Tennessee
Indiana	Texas
Kentucky	Utah
Louisiana	West Virginia
Maine	Wyoming
Mississippi	

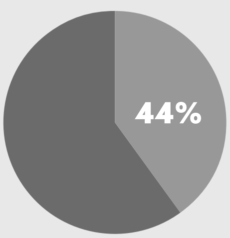
Association of Air Pollution Control Agencies (AAPCA)

The Association of Air Pollution Control Agencies, or AAPCA, is a national, non-profit, consensus-driven organization focused on assisting state and local air quality agencies and personnel with implementation and technical issues associated with the federal Clean Air Act.

Created in 2012, AAPCA represents 48 state and local air pollution control agencies, and senior officials from 21 state environmental agencies currently sit on the AAPCA Board of Directors. AAPCA is housed in Lexington, Kentucky as an affiliate of The Council of State Governments. More information about AAPCA can be found on the Association's website: ***www.cleanairact.org***.

Footprint of AAPCA Member States

State members of the AAPCA Board of Directors have primary responsibility for protecting air quality for a significant portion of the country, as reflected in the following statistics:



An estimated **145.7 MILLION** Americans, about **44%** of the total **U.S. population** in 2022.

From **2012 to 2022**, a **population growth** of

9.4%

compared to national population growth of

6.2%

for the same time period.

38%

38% of **U.S. Gross Domestic Product** (GDP) in 2022.

42%

42% of **U.S. total manufacturing output** and **5.5 MILLION** manufacturing jobs in 2021.

126.6 MILLION motor-vehicles, **45%** of total **motor-vehicles** in the U.S. in 2021.

More than **1.5 MILLION vehicle miles traveled** in 2021, **49%** of the total miles traveled in the U.S.

67% of **U.S. operable petroleum refining capacity** in 2022.

61% of total **U.S. energy production** in 2020, as well as:

- **53%** of **total net electricity generation** in 2022.
- **46%** of **wind generation** in 2022.
- **42%** of **solar generation** in 2022.
- **65%** of **natural gas production** in 2021.
- **70%** of **crude oil production** in 2022.
- **75%** of **coal production** in 2021.

Foreword

Dear Readers,

Today, we're enjoying the best air quality of our lifetimes. Right now, visibility at our greatest natural treasures — our National Parks and Wilderness Areas — is better than we've seen in decades. And we should all be proud of the significant public health benefits resulting from our work. How did we do it? Great federal, state, local and private partnerships and relationships were certainly critical to this success. In my home state of North Carolina, we can see 40 miles further (on the haziest days) than we could 20 years ago in our Class I areas. That's a remarkable improvement!

We continue to make progress in the nation's air quality. State, local, and tribal agencies, including the membership of the Association of Air Pollution Control Agencies (AAPCA), have dedicated significant time and resources to fulfilling this important mission. AAPCA is a consensus-driven organization of 48 state and local air agencies focused on assisting members with implementing technical issues associated with the federal Clean Air Act. Comprised of senior officials from 21 state environmental agencies, AAPCA's Board of Directors is geographically diverse, providing a unique forum of perspectives for us to engage as we work to improve air quality for the more than 145 million Americans we represent. AAPCA's Member States also guide the Association on a consensus basis, seeking to engage our federal co-regulator partners on common principles as we implement the Clean Air Act.

I'm pleased to present the Association's 2023 edition of its annual publication, *State Air Trends & Successes: The StATS Report*. Highlights from this year's report include:

- Since 2000, AAPCA Member States have achieved a 52 percent decrease in the combined emissions of the pollutants (or pollutant precursors) for which there are national ambient air quality standards, or NAAQS.
- The United States has reduced aggregate emissions of criteria air pollutants by 78 percent, from 1970 to 2021.
- From 2000 to 2022, AAPCA Member States reduced emissions of sulfur dioxide (SO_2) and oxides of nitrogen (NO_X) from the electricity sector by 92 percent and 84 percent, respectively.
- From 2000 to 2020, energy-related carbon dioxide (CO_2) emissions in AAPCA Member States declined 20 percent, while energy production increased 49 percent.
- Reported toxic air releases decreased nationally by 26 percent from 2012 to 2021. AAPCA Member States were responsible for roughly 66 percent of that reduction.
- From 2000 to 2020, visibility in 156 national parks and wilderness areas across the U.S. has improved by 33 percent on the clearest days and by 28 percent on the most impaired days.

The recipe that led to those successes will have to be repeated as we tackle major challenges ahead, including climate change and emerging contaminants. As the primary implementers of Clean Air Act programs, state, local, and tribal air agencies are well positioned to address those challenges by working directly with communities, regulated entities, and other stakeholders. Again, we have built the necessary relationships, credibility, and trust for interfacing with the public on environmental challenges. We look forward to continuing our important work as we engage federal partners and other stakeholders to improve air quality across the nation.

Thank you for reading.

MICHAEL ABRACZINSKAS

Director, Division of Air Quality

North Carolina Department of Environmental Quality

President, AAPCA

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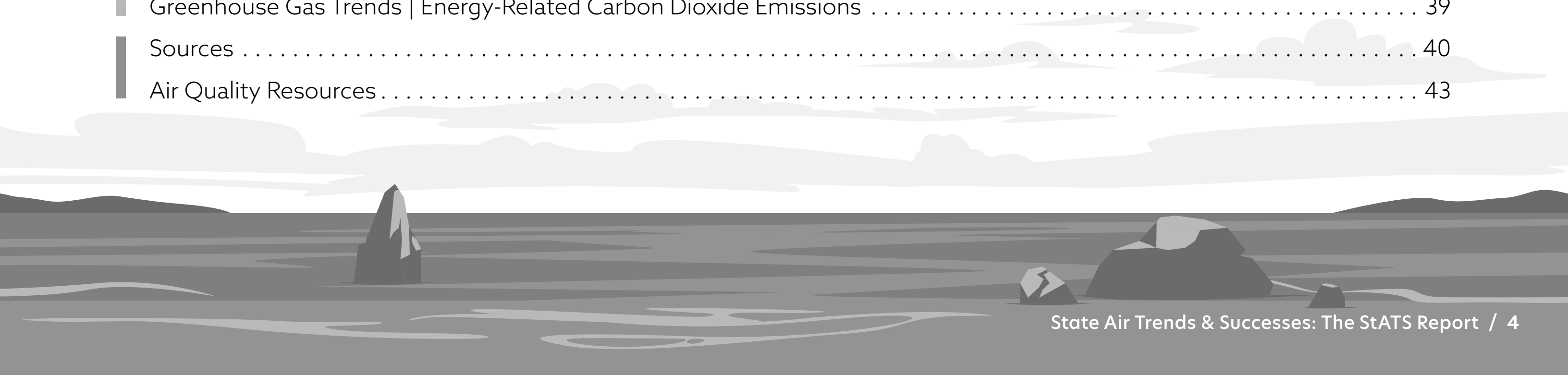


Introduction

State Air Trends & Successes, or *The StATS Report*, examines the remarkable progress that the United States has achieved in air quality under the Clean Air Act, which places precedence on federal, state, and local cooperation. Through cooperative federalism, state and local governments coordinate with the U.S. Environmental Protection Agency (EPA) to implement national standards that protect public health and the environment. *The StATS Report*, published annually by the Association of Air Pollution Control Agencies (**AAPCA**), looks at the central role of state and local air agencies in improving the nation's air quality.

As primary implementers of Clean Air Act rules, state, local, and tribal air agencies work directly with communities, regulated industries, and other stakeholders in their jurisdiction. In this capacity, air agencies have built the necessary relationships, credibility, and trust for interfacing with the public on environmental challenges.

Polling the Public About the Environment

Gallup's annual **Environment poll** suggests that public perception about the nation's environmental and air quality may be contrary to readily available data. In 2023, only 44 percent of respondents were "Very satisfied" (11 percent) or "Somewhat satisfied" (33 percent) with the "quality of the environment in the nation," while 53 percent were "Somewhat dissatisfied" (30 percent) or "Very dissatisfied" (23 percent). Since 2001, respondents worrying a "Great deal" or "Fair amount" about the environment has never been below 62 percent and often hovers near 70 percent. Over the same period, the percentage of respondents that think the environment is "Getting better" has never been above 42 percent and those that think it is "Getting worse" ranged from 48 to 68 percent.

Gallup has regularly queried the public on air pollution, with polling data on the topic going back to 1989. Consistently, the percentage of respondents worried a "Great deal" or "Fair amount" about air pollution breaches 70 percent. In fact, only in one year did polling data show public worry below 70 percent: 69 percent in 2004.

As *The StATS Report* details, national metrics for air pollution and overall air quality reveal a disconnect in the public's perception of environmental trends. From 1990 through 2021, a period that roughly aligns with Gallup's historical polling data on air pollution, **emissions of all six criteria air pollutants** – carbon monoxide (CO), particulate matter (PM_{10} and $PM_{2.5}$), ground-level ozone (O_3), lead (Pb), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) – were down at least 33 percent, with **ambient air concentrations** of CO, O_3, Pb, NO_2, and SO_2 reduced at least 21 percent. Polling data is a limited window into public views, but this disconnect presents a unique challenge as air agencies continue to plan for tough-to-find emissions reductions while also responding to public concern about local and sometimes national and global issues.

Gallup Environment Poll Results, 1989–2022

Question: How much do you personally worry about air pollution?					
Date of Poll	Great deal	Fair amount	Only a little	Not at all	No opinion
2022 Mar 1-18	45%	30%	17%	8%	*
2021 Mar 1-15	41%	32%	20%	8%	*
2020 Mar 2-13	48%	28%	16%	9%	*
2019 Mar 1-10	43%	31%	16%	10%	*
2018 Mar 1-8	46%	30%	17%	7%	*
2017 Mar 1-5	47%	31%	15%	7%	*
2016 Mar 2-6	43%	31%	19%	7%	*
2015 Mar 5-8	38%	33%	19%	10%	*
2014 Mar 6-9	46%	27%	21%	7%	*
2013 Mar 7-10	40%	30%	20%	9%	*
2012 Mar 8-11	36%	35%	22%	7%	*
2011 Mar 3-6	36%	36%	20%	8%	*
2010 Mar 4-7	38%	32%	22%	8%	*
2009 Mar 5-8	45%	31%	18%	6%	*
2008 Mar 6-9	43%	35%	17%	6%	*
2007 Mar 11-14	46%	33%	15%	5%	*
2006 Mar 13-16	44%	34%	15%	7%	*
2004 Mar 8-11	39%	30%	23%	8%	*
2003 Mar 3-5	42%	32%	20%	6%	*
2002 Mar 4-7	45%	33%	18%	4%	*
2001 Mar 5-7	48%	34%	14%	4%	*
2000 Apr 3-9	59%	29%	9%	3%	*

Introduction *(continued)*

Question: How much do you personally worry about air pollution?					
Date of Poll	Great deal	Fair amount	Only a little	Not at all	No opinion
1999 Apr 13-14	52%	35%	10%	3%	*
1999 Mar 12-14	47%	33%	16%	4%	*
1997 Oct 27-28	42%	34%	18%	5%	1
1991 Apr 11-14	59%	28%	10%	4%	*
1990 Apr 5-8	58%	29%	9%	4%	*
1989 May 4-7	63%	24%	8%	4%	*

**Less than 0.5 percent*

Source: Gallup Environment poll data available **here**.

Air Quality Data and Trends: A Good Story to Tell

By virtually any metric, the nation's air is cleaner and healthier than five decades ago, when the Clean Air Act was first passed. *The StATS Report* catalogues key trends and indicators using publicly available data from the U.S. EPA and other federal agencies, such as the U.S. Energy Information Administration that is housed in the U.S. Department of Energy (see page 7, "Types of Air Quality Data and Metrics"). These data are important for understanding how air pollution control and planning efforts have improved air quality, including under the national ambient air quality standards (NAAQS) and regional haze programs as well as for hazardous air pollutants and greenhouse gases. When relevant, this report also presents economic and social indicators, such as gross domestic product (GDP) and population growth, to provide context for some air quality metrics (For example: From 1970 through 2021, U.S. GDP rose nearly 300 percent while aggregate emissions of the six criteria air pollutants fell 78 percent).

State Air Trends & Successes: The StATS Report provides these metrics and trends in three sections:

- The first section, "AAPCA Member State Air Trends & Successes," focuses on the 21 AAPCA Member States, which are responsible for protecting air quality for nearly 146 million Americans, about 44 percent of the U.S. population. These states have seen above-average population growth, are home to more than 5.5 million manufacturing jobs, and produced 61 percent of the nation's total energy in 2020.
- The second section, "American Air Quality in an International Context," documents U.S. air quality improvement and economic indicators alongside other nations. The United States is the clear leader in air quality internationally while ranking first in GDP, second in energy production, and third in population.
- The final section, "Air Quality Trends in the United States," presents trends for ambient concentrations and emissions of pollutants under the NAAQS program, toxic air releases, visibility in national parks, and greenhouse gases – data show marked, prolonged improvement in every metric.

As a whole, *The StATS Report* underscores that environmental protection and economic development can both be achieved – indeed, already have been – through the collaborative efforts of state, local, tribal, and federal governments.

Meeting the Mission of State and Local Air Agencies

While air quality has improved substantially, air agencies continue to strive toward their missions of protecting air quality and public health. Core monitoring, modeling, and emissions inventory efforts have become more – not less – complex and technical, as has the development of state implementation plans (SIPs) to attain/maintain federal air quality standards. Located on the ground in their communities, state, local, and tribal air agencies deeply understand how national environmental efforts must intertwine with local priorities, economic strategies, and social needs.

As noted, the policy, technical, and jurisdictional expertise of air agencies is also critical in their role on the frontlines. Citizens and communities now increasingly look to social media and real-time technology like air sensors to become informed, requiring new and innovative outreach methods by agencies that build on their established credibility. Emerging environmental issues like wildfires, per-and polyfluoroalkyl substances (PFAS), and ethylene oxide (EtO) also continue to push the capacity of state and local air agencies.

In short, driving emissions reductions to better air quality has never been more challenging and resource intensive. The increasingly complex work of understanding air quality problems (and solutions) is now coupled with the need to respond to the public faster and more informed than ever. Despite these challenges and level (sometimes reduced) funding and staffing, air agencies have successfully continued to improve air quality because of dedicated public servants, developing best practices, and adopting technology to advance efficient, cost-effective solutions.

The positive air quality trends presented in *The StATS Report* are the result of sustained work and deep coordination among federal, state, tribal, and local agencies, all of which have a common goal of protecting public health. With increased efforts to improve public engagement and implement new federal regulations and legislation, cooperative federalism remains a proven and necessary framework for achieving successful environmental outcomes.

Types of Air Quality Data and Metrics

This report primarily relies on data from the U.S. Environmental Protection Agency (EPA) and other federal agencies, such as the U.S. Energy Information Administration (EIA), to evaluate air quality trends. These trends include metrics for criteria air pollutants, air toxics and hazardous air pollutants, visibility progress in National Parks and wilderness areas, and greenhouse gases, with sources provided below each chart or graph and in the source notes. Also included in this report are case studies and short excerpts from other relevant analyses, which include links to their source and data.

Criteria Air Pollutant Data

Trends and indicators of air quality can be measured in a variety of ways, but an important group of data to analyze is that of the air pollutants that are regulated under the federal Clean Air Act. Section 109 of the Clean Air Act requires U.S. EPA to establish both primary and secondary national ambient air quality standards, or NAAQS. Primary NAAQS are "standards the attainment and maintenance of which in the judgment of the Administrator, based on such criteria and allowing an adequate margin of safety, are requisite to protect the public health," while secondary NAAQS "specify a level of air quality the attainment and maintenance of which… is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of such air pollutant in the ambient air."[1]

NAAQS have been set for six "criteria" pollutants: carbon monoxide (CO), sulfur dioxide (SO_2), ground-level ozone (O_3), fine and course particulate matter ($PM_{2.5}$ and PM_{10}), lead (Pb), and nitrogen dioxide (NO_2). Individual NAAQS may differ in form (for example, annual fourth highest daily maximum 8-hour concentration average over three years, for ozone), level[2] (often measured in parts per billion or micrograms per cubic meter), and averaging time (from one hour up to one year).[3] U.S. EPA and the Clean Air Scientific Advisory Committee periodically review the adequacy of the NAAQS according to the statute.[4]

Nationally, ambient air pollution data from thousands of monitors across the United States are collected by U.S. EPA and state, local, and tribal air pollution control agencies and provided to the Air Quality System, or AQS. These data are used to "assess air quality, assist in attainment/non-attainment designations, evaluate State Implementation Plans [SIPs] for non-attainment areas, perform modeling for permit review analysis, and prepare reports for Congress as mandated by the Clean Air Act."[5]

U.S. EPA reports on long-term air quality trends by preparing data analyses that show the overall trend lines for pollutant concentrations and emissions. Primary sources that inform this report include:

- Criteria air pollutant concentration data from U.S. EPA's analysis of the AQS that looks at long-term trends in air quality.[6]
- Data showing emissions trends of the criteria pollutants from U.S. EPA's Air Pollutant Emissions Trends Data,[7] which relies on the National Emissions Inventory (NEI). The NEI is "a comprehensive and detailed estimate of air emissions of criteria pollutants, criteria precursors, and hazardous air pollutants from air emissions sources… released every three years based primarily upon data provided [to the Emissions Inventory System (EIS)] by State, Local, and Tribal air agencies for sources in their jurisdictions and supplemented by data developed by the U.S. EPA."[8]
- Design values that are computed and published annually by U.S. EPA and defined as "a statistic that describes the air quality status of a given location relative to the level of the NAAQS… typically used to designate and classify nonattainment areas, as well as to assess progress towards meeting the NAAQS."[9]

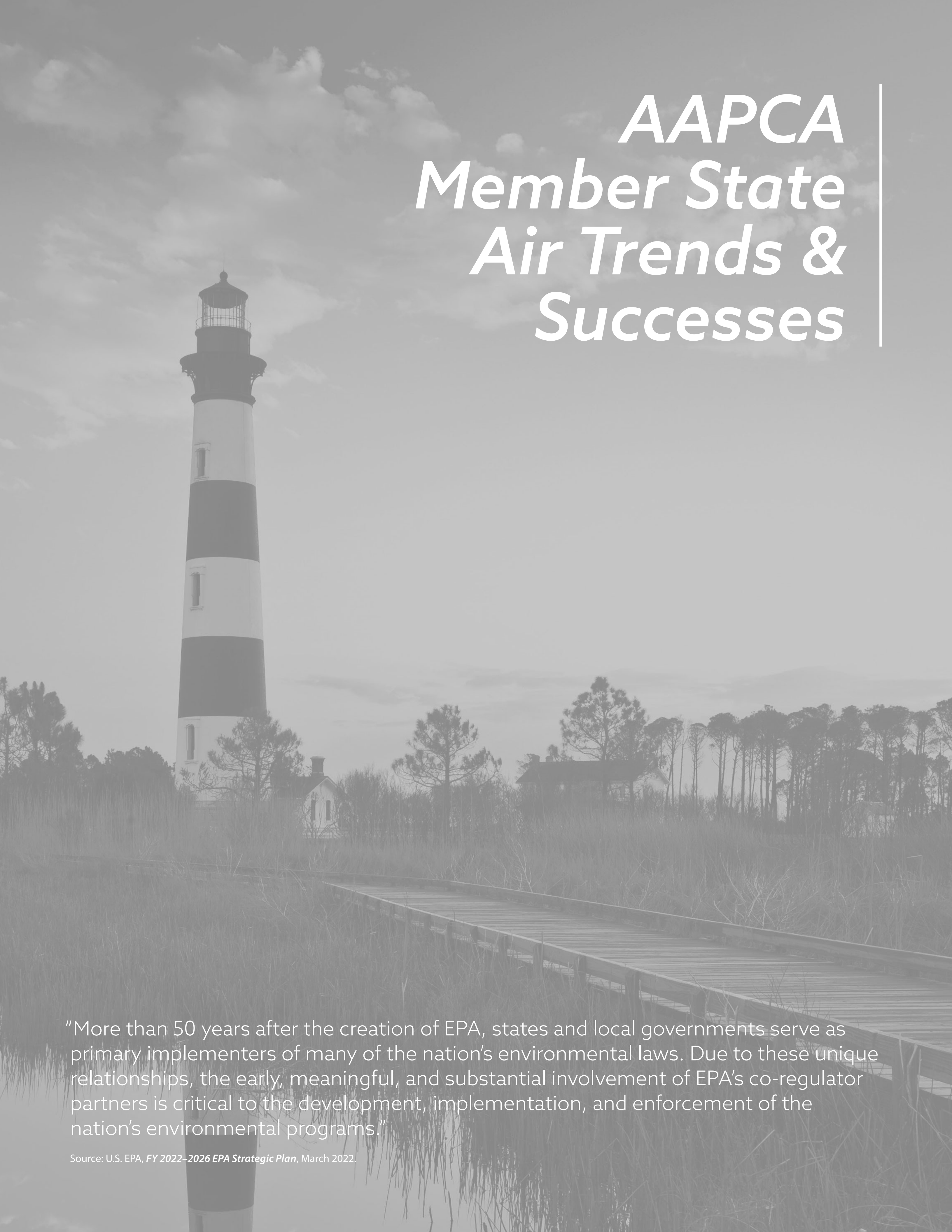
Other Air Quality Data

In addition to tracking criteria air pollutants, U.S. EPA also maintains data and develops analyses on multiple other federal air quality programs used to inform this report, including:

- The Toxic Release Inventory (TRI), which provides a consistent set of data over time for hazardous air pollutants (or air toxics) from source reporting.[10]
- Visibility progress tracked as part of the Regional Haze Program, with long-term trends available in U.S. EPA's annual air quality trends report.[11]
- In an annual progress report, the U.S. EPA publishes power sector emissions data for SO_2, nitrogen oxides (NO_x), and hazardous air pollutants, as well as carbon dioxide (CO_2).[12]

Additionally, greenhouse gas data in this report are primarily from U.S. EPA's annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks*[13] and U.S. EIA reports, such as the *Annual Energy Outlook*, which includes CO_2 emissions data from energy sources.[14]

1 **42 U.S.C. §7409(b)**.
2 U.S. EPA **states**: "Units of measure for the standards are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air (µg/m3)."
3 A chart of the primary and secondary NAAQS by pollutant, which includes averaging time, level, and form, can be found **here**.
4 **42 U.S.C. §7409(d)**.
5 U.S. EPA, **Air Quality System**. U.S. EPA notes that the AQS "also contains meteorological data, descriptive information about each monitoring station (including its geographic location and its operator), and data quality assurance/quality control information."
6 Links to data summary files for national criteria pollutant trends can be found **here**.
7 Data can be found **here**. U.S. EPA notes: "The latest version of the 1970 – 2022 data show the trends for Tier 1 categories which distinguish pollutant emission contributions among major source types… As inventory methods are improved over time, for some emission sources an improved estimation method may be applied 'backwards' to previous year trend estimates."
8 More information on the NEI can be found **here**. U.S. EPA states: "The NEI is built using the Emissions Inventory System (EIS) first to collect the data from State, Local, and Tribal air agencies and then to blend that data with other data sources."
9 U.S. EPA, **Air Quality Design Values**.
10 U.S. EPA, **Toxics Release Inventory (TRI) Program**. Annual TRI National Analysis **here**. U.S. EPA notes that the TRI "is a resource for learning about toxic chemical releases and pollution prevention activities reported by industrial and federal facilities. TRI data support informed decision-making by communities, government agencies, companies, and others. Section 313 of the *Emergency Planning and Community Right-to-Know Act* (EPCRA) created the TRI Program."
11 U.S. EPA, **Air Quality – National Summary**. See also: U.S. EPA, ***Our Nation's Air: Trends Through 2021***, June 2022 (Section: "**Visibility Improves in Scenic Areas**").
12 U.S. EPA, **Power Sector Programs – Progress Report**.
13 U.S. EPA releases the ***Inventory of U.S. Greenhouse Gas Emissions and Sinks*** each April. See also: U.S. EPA, **Greenhouse Gas Inventory Data Explorer**.
14 U.S. EIA, ***Annual Energy Outlook 2023***, March 16, 2023.



AAPCA Member State Air Trends & Successes

"More than 50 years after the creation of EPA, states and local governments serve as primary implementers of many of the nation's environmental laws. Due to these unique relationships, the early, meaningful, and substantial involvement of EPA's co-regulator partners is critical to the development, implementation, and enforcement of the nation's environmental programs."

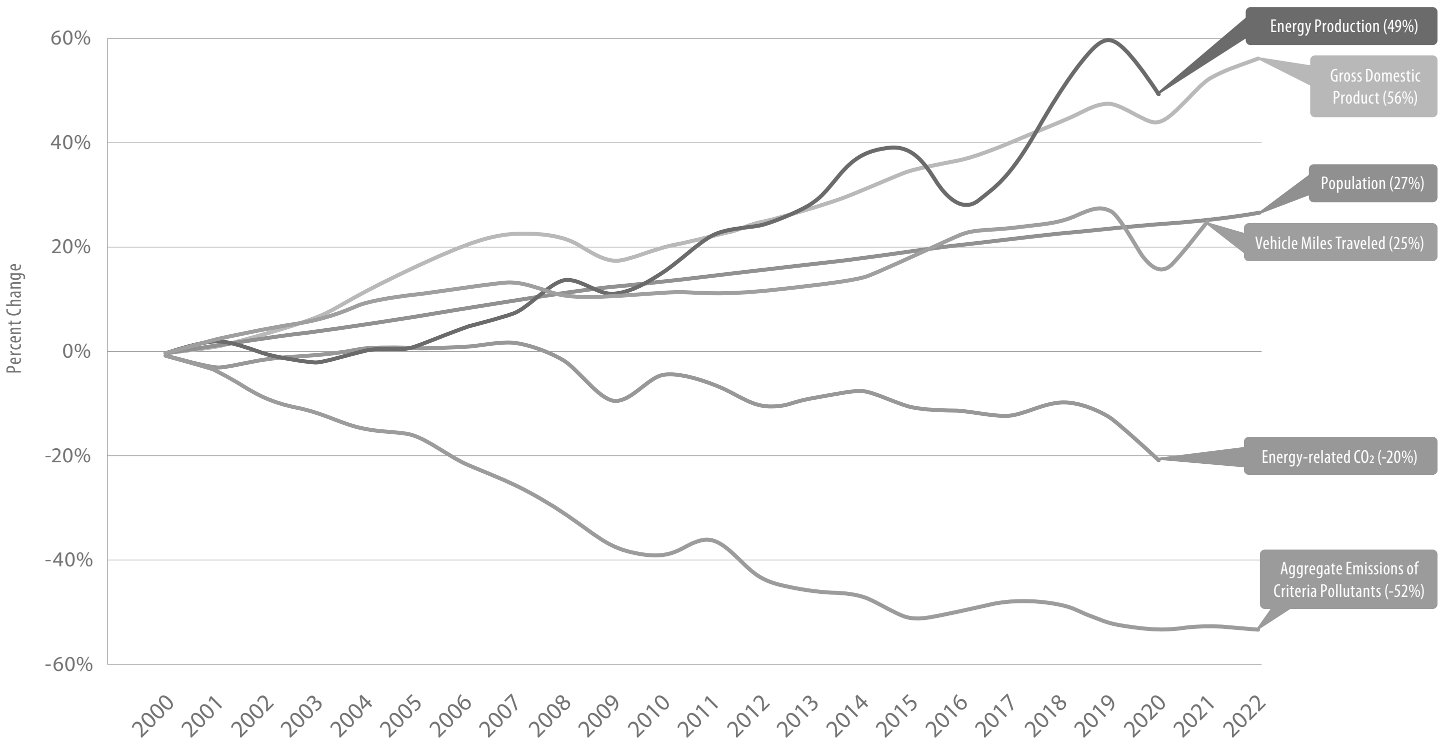
Source: U.S. EPA, ***FY 2022–2026 EPA Strategic Plan***, March 2022.

Economic Growth and Air Quality in AAPCA Member States

Since 2000, AAPCA Member States have overseen a 52 percent decrease in the combined emissions of the pollutants (or pollutant precursors) for which there are national ambient air quality standards, or NAAQS, while also experiencing significant economic and social growth over the last two decades[15]:

- AAPCA Member States saw a total increase in Gross Domestic Product (GDP) of 56 percent from 2000 to 2022, and contributed about 38 percent of the total U.S. GDP in 2022[16];
- States in the Association reported a 25 percent increase in vehicle miles traveled from 2000 to 2021[17];
- By 2022, AAPCA's membership represented more than 145 million people, or 44 percent of the total U.S. population, an increase in population of 27 percent from 2000[18]; and,
- From 2000 to 2020, the 21 states in AAPCA's membership were responsible for a 20 percent reduction in energy-related carbon dioxide (CO_2) emissions.[19] In 2020, energy production in AAPCA Member States grew by 49 percent compared to production levels in 2000. AAPCA's Member States produced 61 percent of total U.S. energy in 2020.[20]

AAPCA Member States | Comparison of Growth Indicators and Emissions Since 2000



Sources: U.S. Bureau of Economic Analysis, data available here; U.S. Energy Information Administration, State Energy Data System (SEDS): 1960–2020; U.S. Federal Highway Administration Office of Highway Policy Information, data available here; U.S. Census Bureau, data available here; U.S. EIA, Energy-Related CO_2 Emission Data Tables, Table 1. State energy-related carbon dioxide emissions by year (1970–2020); U.S. EPA, Air Pollutant Emissions Trends Data (Data file: "State Tier 1 CAPS Trends, Criteria pollutants State Tier 1 for 1990–2022").

Air Quality | Fine Particulate Matter

U.S. EPA's online Green Book "provides detailed information about area National Ambient Air Quality Standards (NAAQS) designations, classifications, and nonattainment status."[21] According to the database, a total of 39 areas were initially designated non-attainment for the 1997 fine particulate matter ($PM_{2.5}$) annual NAAQS of 15.0 micrograms per cubic meter (µg/m^3), measured by the three-year average annual mean concentration.[22]

U.S. EPA develops design values[23] based on monitoring data from the Agency's Air Quality System (AQS).[24] Of the designated areas, 23 are located partially or completely in AAPCA Member States, with the table below detailing the percent change in design values over two decades, a period in which AAPCA Member States averaged a 47 percent reduction in $PM_{2.5}$ ambient air concentrations.[25] Furthermore, all of the designated areas within AAPCA Member States are now classified as in attainment or maintenance for the current 2012 $PM_{2.5}$ NAAQS of 12.0 µg/m^3.[26]

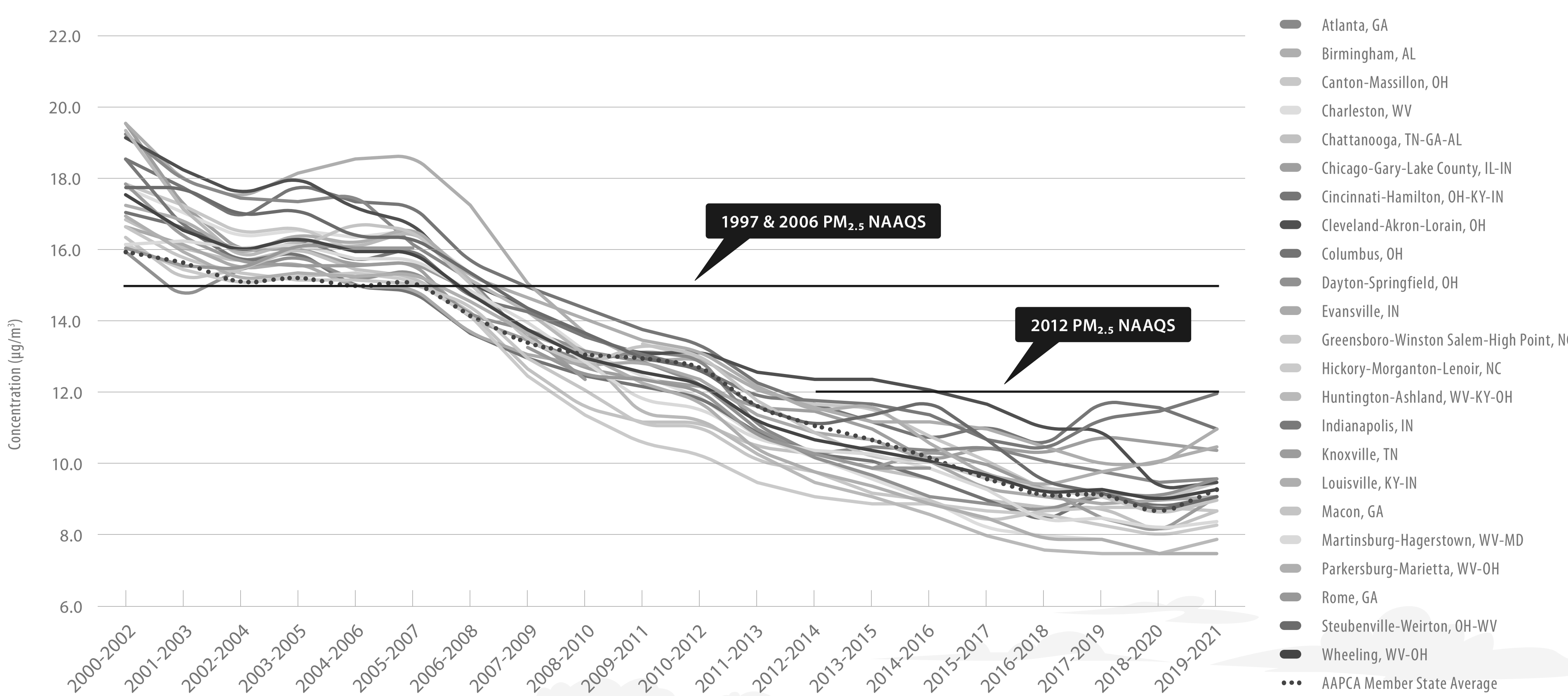
Designated Area	Percent Reduction in $PM_{2.5}$ Concentrations (2000–2002 through 2019–2021 Design Values)
Atlanta, GA	-50.26%
Birmingham, AL	-43.88%
Canton-Massillon, OH	-46.93%
Charleston, WV	-57.87%
Chattanooga, TN-GA-AL	-48.52%
Chicago-Gary-Lake County, IL-IN	-46.94%
Cincinnati-Hamilton, OH-KY-IN	-40.86%
Cleveland-Akron-Lorain, OH	-50.52%
Columbus, OH	-46.78%
Dayton-Springfield, OH	-40.00%
Evansville, IN	-45.51%
Greensboro-Winston Salem-High Point, NC	-47.90%
Hickory-Morganton-Lenoir, NC	-48.77%
Huntington-Ashland, WV-KY-OH	-59.28%
Indianapolis, IN	-35.48%
Knoxville, TN	-49.16%
Louisville, KY-IN	-39.31%
Macon, GA	-45.12%
Martinsburg-Hagerstown, WV-MD	-48.15%
Parkersburg-Marietta, WV-OH	-55.88%
Rome, GA*	-38.51%
Steubenville-Weirton, OH-WV	-48.88%
Wheeling, WV-OH	-41.88%

**Data ends in designation year 2014–2016*

Source: U.S. EPA, **Air Quality Design Values** (Data file: "$PM_{2.5}$ Design Values, 2021").

Air Quality | Fine Particulate Matter

AAPCA Member States | Design Value History for Areas Previously Designated Nonattainment for the 1997 $PM_{2.5}$ Annual NAAQS, 2002–2021



Source: U.S. EPA, Air Quality Design Values (Data file: "$PM_{2.5}$ Design Values, 2021").

Air Quality | Ozone

According to U.S. EPA's online Green Book, 47 areas in the United States were previously designated as nonattainment for the 2008 ozone annual national ambient air quality standard (NAAQS) of 0.075 parts per million (ppm), determined using the annual fourth-highest daily maximum 8-hour concentration, averaged over three years.[27]

The table below lists the percent change in design values over the last twenty years for the 13 previously designated nonattainment areas for the 2008 ozone NAAQS that are partially or fully within AAPCA Member States, which averaged over a 26 percent reduction in ambient concentrations of ozone.[28]

Designated Area	Percent Reduction in Ozone Concentrations (2000-2002 through 2019-2021 Design Values)
Atlanta, GA	-31.31%
Baton Rouge, LA	-19.77%
Charlotte-Rock Hill, NC-SC	-35.29%
Chicago-Naperville, IL-IN-WI	-25.00%
Cincinnati, OH-KY-IN	-27.08%
Cleveland-Akron-Lorain, OH	-27.27%
Columbus, OH	-26.67%
Dallas-Fort Worth, TX	-23.23%
Houston-Galveston-Brazoria, TX	-28.04%
Knoxville, TN	-36.73%
Memphis, TN-MS-AR	-27.66%
Phoenix-Mesa, AZ	-5.88%
Upper Green River Basin, WY*	2.78%

**Upper Green River Basin, WY is calculated from the first year that data was available, design value year 2005–2007. This area is excluded from average calculations.*

Source: U.S. EPA, **Air Quality Design Values** (Data file: "Ozone Design Values, 2021").

Implementing the National Ambient Air Quality Standards (NAAQS)

U.S. EPA and delegated programs at state, local, and tribal air agencies work together to implement the NAAQS, as directed by the federal Clean Air Act. U.S. EPA provides the below timeline for designations and implementation following a new or revised standard:

Promulgation of NAAQS

Within 2 years after a final NAAQS
With input from the states and tribes, EPA must "designate" areas as meeting (attainment areas) or not meeting (nonattainment areas) the final NAAQS based on the most recent set of air quality monitoring or modeling data characterizing an area.

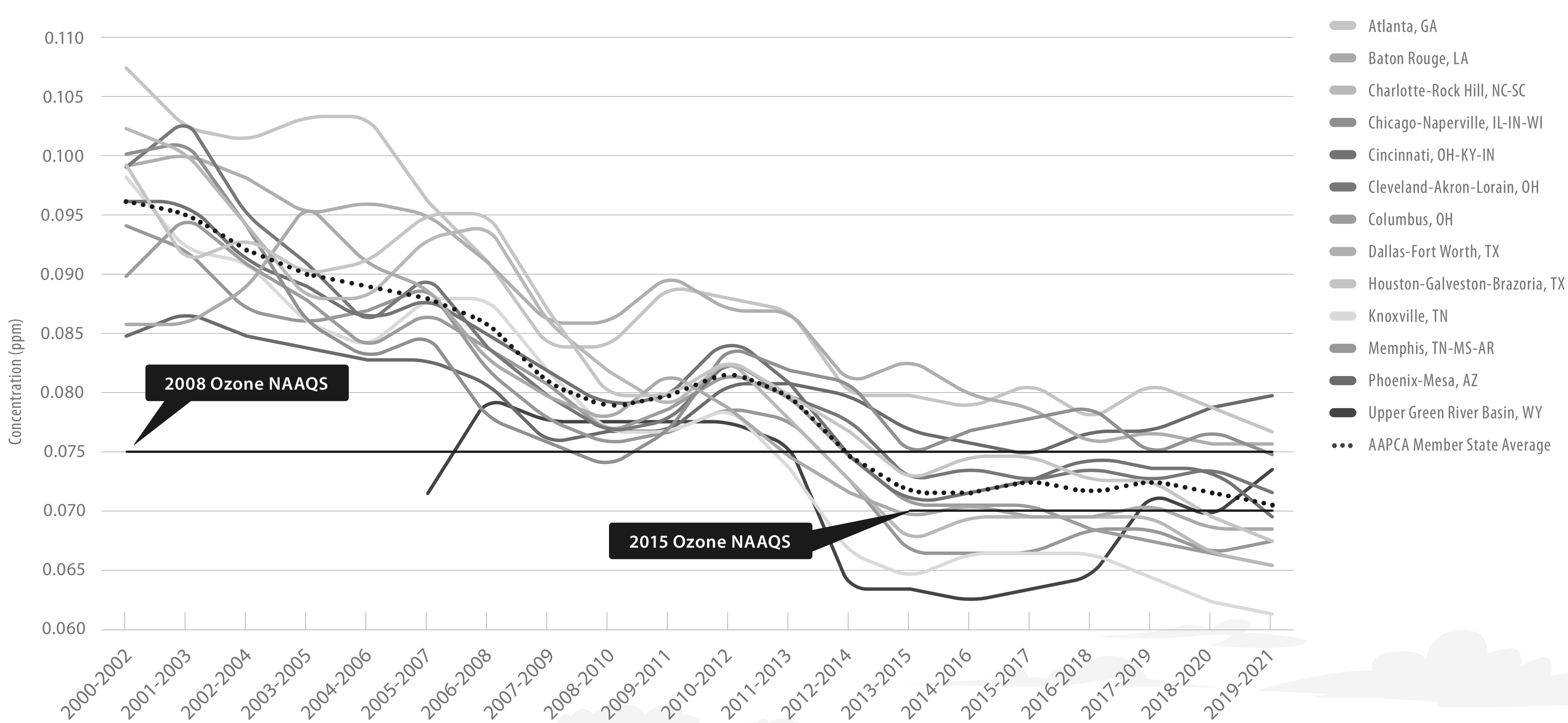
Within 3 years after a final NAAQS Clean Air Act Section 110 requires all states to submit "infrastructure" state implementation plan (SIP) revisions to show they have the basic air quality management program components in place to implement the final NAAQS.

Within 18–24 months after the effective date of designations Nonattainment area SIPs are due.

Source: U.S. EPA, "**NAAQS Implementation Process**," last updated July 8, 2022.

Air Quality | Ozone

AAPCA Member States | Design Value History for Areas Previously Designated Nonattainment for the 2008 Ozone Annual NAAQS, 2002–2021



**Upper Green River Basin, WY is calculated from the first year that data was available, design value year 2005–2007. This area is excluded from average calculations.*

Source: U.S. EPA, **Air Quality Design Values** (Data file: "Ozone Design Values, 2021").

AAPCA **Best Practices** in Air Pollution Control

Each year, AAPCA designates Best Practices that identify ground-breaking technology, innovative approaches, and exemplary operations in the field of air pollution control, with particular focus on activities that are directly transferable to the operation of an air pollution control agency. Below are recipients of AAPCA's Best Practices in Air Pollution Control since 2018:

2022

Open Burn Permit Program
Arizona Department of Environmental Quality

2022 Air Quality Workshop
Oklahoma Department of Environmental Quality

Environmental Trainee Mentoring Program
Pennsylvania Department of Environmental Protection

Wyoming Environmental Audit Process
Wyoming Department of Environmental Quality

Air Quality Action Partners Program
Louisville Metro Air Pollution Control District (Local Government Best Practice)

Streamlined Communication and Collaboration for Air Monitoring Programs via Microsoft Teams
Mecklenburg County Air Quality (Local Government Best Practice)

Residential Woodsmoke Reduction Strategy
San Joaquin Valley Air Pollution Control District (Local Government Best Practice)

2021

COVID-19 Air Quality Inspection/Compliance Determinations
Arizona Department of Environmental Quality

Efficiencies in the Data Quality Review of Ambient Air Monitoring Data
Georgia Environmental Protection Division

NESHAP 6H Reg Nav Tool
North Carolina Division of Environmental Assistance & Customer Service

Shiny Dashboard for Remote Monitoring of Air Quality Data
Tennessee Department of Environment & Conservation

2020

Georgia PSD Emissions Inventory
Georgia Environmental Protection Division

2019

Data Verification Procedures
Georgia Environmental Protection Division

Ozone Design Value Predictor Tool
North Carolina Division of Air Quality

Louisville Community Workshop Series
Louisville Metro Air Pollution Control District (Local Government Best Practice)

2018

Georgia State Implementation Plan Processing Procedures
Georgia Environmental Protection Division

Toxicity Factors Database
Texas Commission on Environmental Quality

Inventory, Monitoring, Permitting, and Compliance Tracking (IMPACT) Web-based Data System
Wyoming Department of Environmental Quality

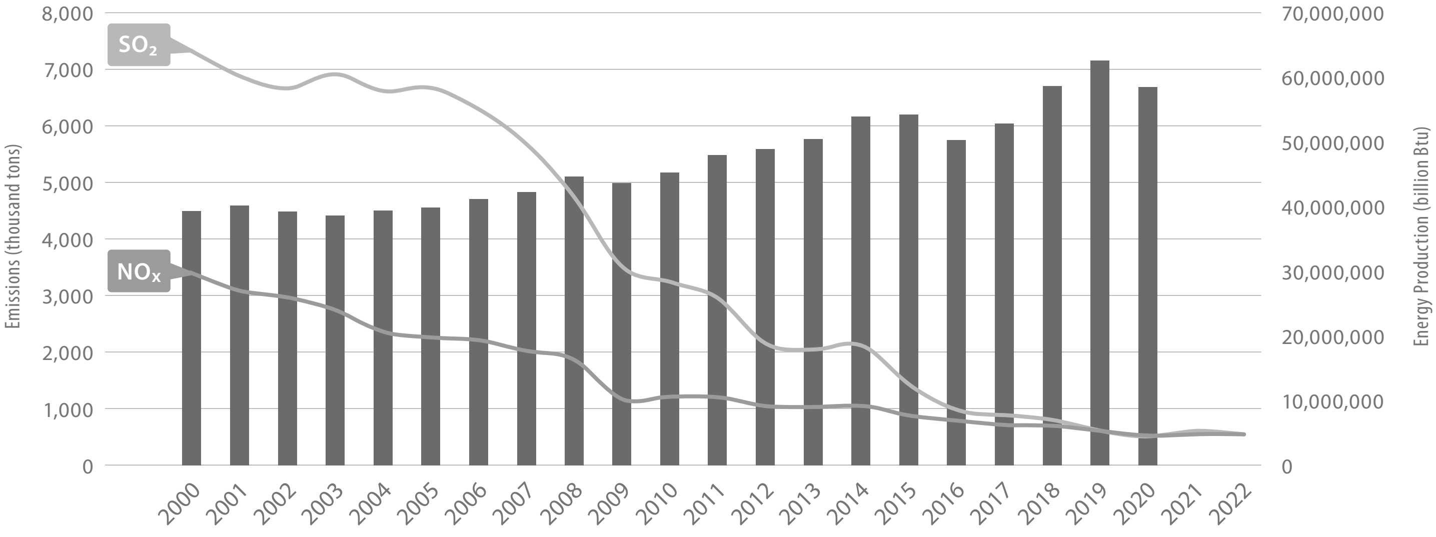
Presentations from all past recipients can be found on AAPCA's website: **www.cleanairact.org**

Emissions Reductions in the Electricity Sector

From 2000 to 2022, AAPCA Member States oversaw significant reductions in the emissions of sulfur dioxide (SO_2) and oxides of nitrogen (NO_X) from the electricity sector. Specifically, SO_2 emissions went from 7,322,232 tons in 2000 to 551,533 tons in 2022, a decline of 92 percent; NO_X emissions went from 3,405,187 tons in 2000 to 544,863 tons in 2022, a decline of 84 percent.[29]

Meanwhile from 2000 to 2020, energy production in AAPCA Member States increased by 49 percent, to a total production in 2020 exceeding 58,500 trillion British thermal units (trillion Btu) of energy.[30]

AAPCA Member States | Energy Production Compared to SO_2 and NO_X Emissions from the Electricity Sector, Since 2000



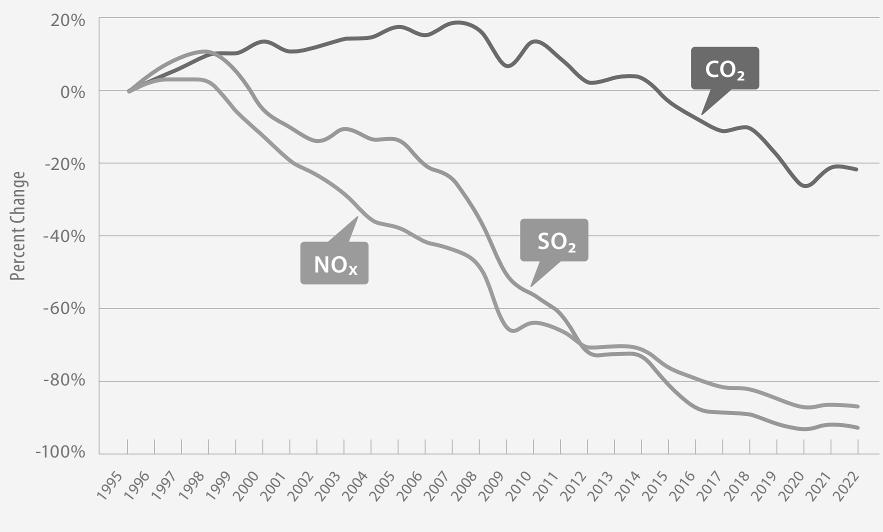
Source: U.S. Energy Information Administration, **State Energy Data System (SEDS): 1960–2020**; U.S. EPA, **Air Pollutant Emissions Trends Data** (Data file: "State Tier 1 CAPS Trends, Criteria pollutants State Tier 1 for 1990–2022").

U.S. Power Plant Emissions Trends | Annual Percent Change of Emissions From Power Plants, 1995–2022

In February 2023, U.S. EPA released the 2022 annual emissions data for power plants across the United States, highlighting the following trends compared to 2021:

- A 10 percent decrease in sulfur dioxide (SO_2) emissions, a 93 percent reduction from 1995 levels;
- A 4 percent decrease in nitrogen oxides (NO_X) emissions, down 87 percent from 1995 levels; and,
- A 1 percent decrease in carbon dioxide (CO_2) emissions, 22 percent below 1995 levels.

Source: U.S. EPA, "**EPA Releases 2022 Power Plant Emissions Data**," February 24, 2023. Data available **here**.



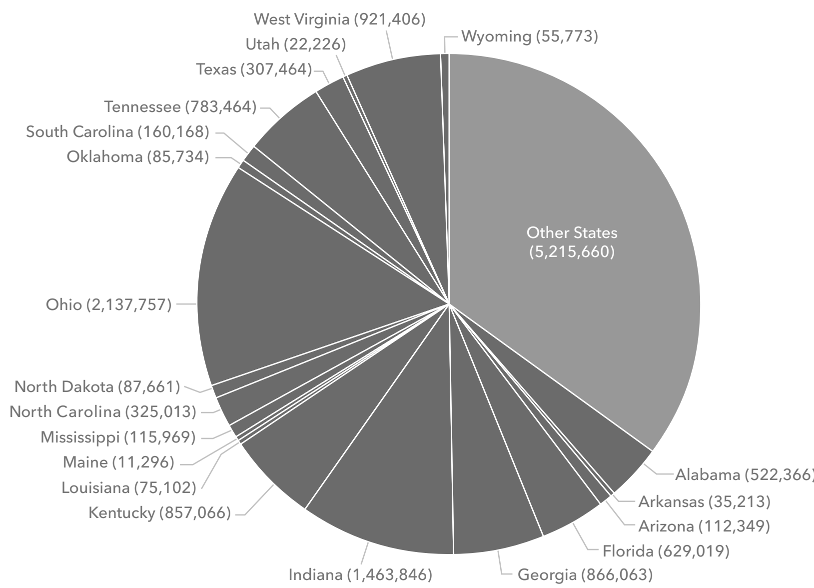
Emissions Reductions in the Electricity Sector

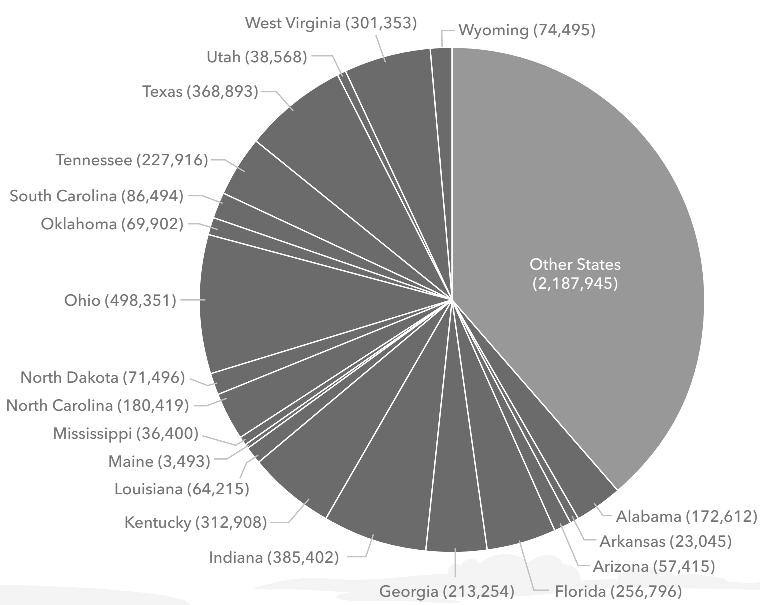
Data from U.S. EPA's Clean Air Markets Programs[31] show that nationally from 1990 to 2021, the United States electricity sector reduced sulfur dioxide (SO_2) emissions by 94 percent — from 15,733,106 tons to 942,491 tons — and nitrogen oxides (NO_X) emissions by 88 percent — from 6,410,541 tons to 779,169 tons.

AAPCA Member States accounted for nearly 65 percent of the total 14,790,615-ton national reduction in SO_2 emissions, lowering SO_2 emissions from 10,152,009 tons in 1990 to 577,054 tons in 2021.[32] Of the national 5,631,372-ton decrease in NO_X emissions, AAPCA Member States accounted for 61 percent, or 3,443,427 tons, reducing emissions from 3,938,966 tons in 1990 to 495,539 tons in 2021.[33]

AAPCA Member States | Share of SO_2 Emissions Reductions in the Electricity Sector
(tons of SO_2 reduced)

Source: U.S. EPA, "**State-by-State SO_2 Emissions from CAIR and ARP Sources, 1990–2021**," July 2022.





AAPCA Member States | Share of NO_X Emissions Reductions in the Electricity Sector
(tons of NO_X reduced)

Source: U.S. EPA, "**Annual NO_X Emissions from CSAPR and ARP Sources, 1990–2021**," July 2022.

Regional Haze | Breton Wilderness Area

Figure: Harvard College Library, Theodore Roosevelt Collection, Breton National Wildlife Refuge, photograph from *www.fws.gov/media/president-teddy-roosevelt-breton-island-1915*

Established in 1904 through executive order of President Theodore Roosevelt, Breton National Wildlife Refuge (NWR) is the second oldest refuge in the National Wildlife Refuge System and the only refuge the president ever visited when he traveled to the islands in June 1915. As Louisiana's only Class I area, Breton NWR is comprised of a sixty-mile-long crescent of barrier islands, including Breton Island and the Chandeleur Islands. Breton NWR is located in the Gulf of Mexico, south of Gulfport, Mississippi and east of New Orleans and is accessible only by boat or seaplane.

The exposed islands are composed of open sand, shell beaches, and are partially covered with dune grasses and other shrubby vegetation. As nature takes its course, some parts of the islands are washed away while sand is deposited in other areas. Breton NWR also has some of the largest seabird colonies in the nation and has been identified as a Globally Important Bird Area by the American Bird Conservancy and The Nature Conservancy. Twenty-three species of seabirds and shorebirds frequently use the refuge, and thirteen species nest on the islands. The most abundant nesters are brown pelicans, laughing gulls, and royal, Caspian, and sandwich terns. Over 10,000 brown pelicans have been recorded nesting on the refuge. Waterfowl winter nearby and use the shallows, marshes, and sounds for feeding and shelter. Additionally in 2022, Kemp's ridley sea turtle nests have been observed on the islands for the first time in 75 years!

While the birds use the islands as a safe harbor, Louisiana must not become complacent with emissions reductions that push us firmly under the uniform rate of progress (glideslope). Through the collaborative efforts of state, local, and federal entities, visibility has improved and will continue to improve in Breton NWR under the Regional Haze Rule. The rule requires that each Class I area achieve natural conditions for visibility by the year 2064 by steadily improving the number of most impaired days and keeping the number of clearest days from decreasing. Point source sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions were collectively reduced some 32 percent (134,965 tpy) from 2011 to 2017. These reductions have allowed Louisiana to exceed the uniform rate progress goals and remain below the glideslope established in the original state implementation plan (SIP) submittal.

More on the Louisiana Department of Environmental Quality can be found at *www.deq.louisiana.gov/subhome/air*.

Figure: U.S. Fish & Wildlife Service, Breton National Wildlife Refuge, photograph from *www.fws.gov/refuge/breton*.

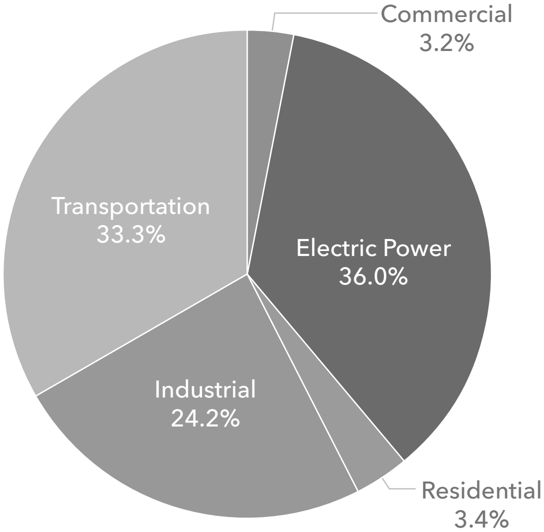
Greenhouse Gases and Energy

AAPCA Member States | Energy-Related Carbon Dioxide Emissions by Sector, 2020

The profile of energy-related carbon dioxide (CO_2) emissions from AAPCA Member States in 2020 was attributable to the following primary economic sectors[34]:

- 36.0 percent from electricity generation;
- 33.3 percent from transportation;
- 24.2 percent from industry;
- 3.4 percent from residential; and,
- 3.2 percent from commercial.

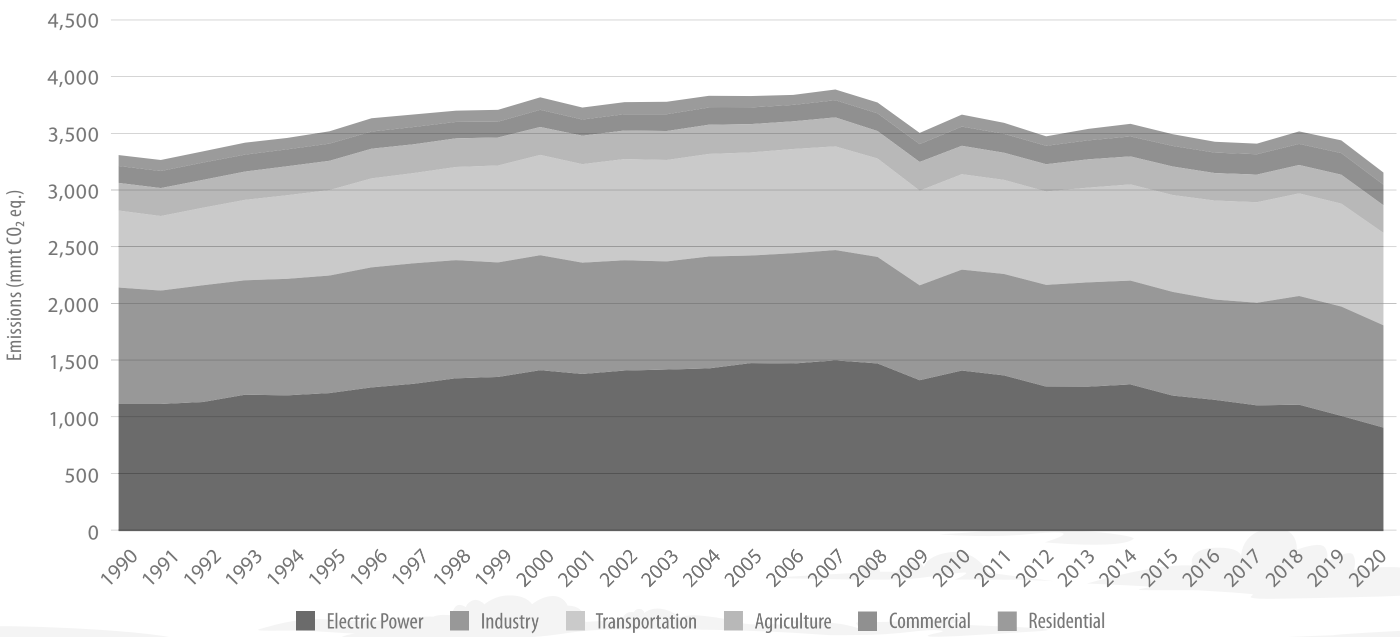
Source: U.S. Energy Information Administration, **Energy-Related CO_2 Emission Data Tables**, Table 3. State energy-related carbon dioxide emissions by sector.



U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks by State* provides estimated greenhouse gas (GHG) data at the state level, consistent with the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.[35] From 1990 to 2020, estimated GHG emissions in AAPCA Member States followed these trends:

- Electric power sector emissions decreased 19 percent;
- Industry sector emissions decreased 12 percent;
- Transportation sector emissions increased 20 percent;
- Agriculture sector emissions decreased 1 percent;
- Commercial sector emissions increased 21 percent; and,
- Residential sector emissions increased 15 percent.

AAPCA Member States | Greenhouse Gas Emissions by Economic Sector, 1990–2020

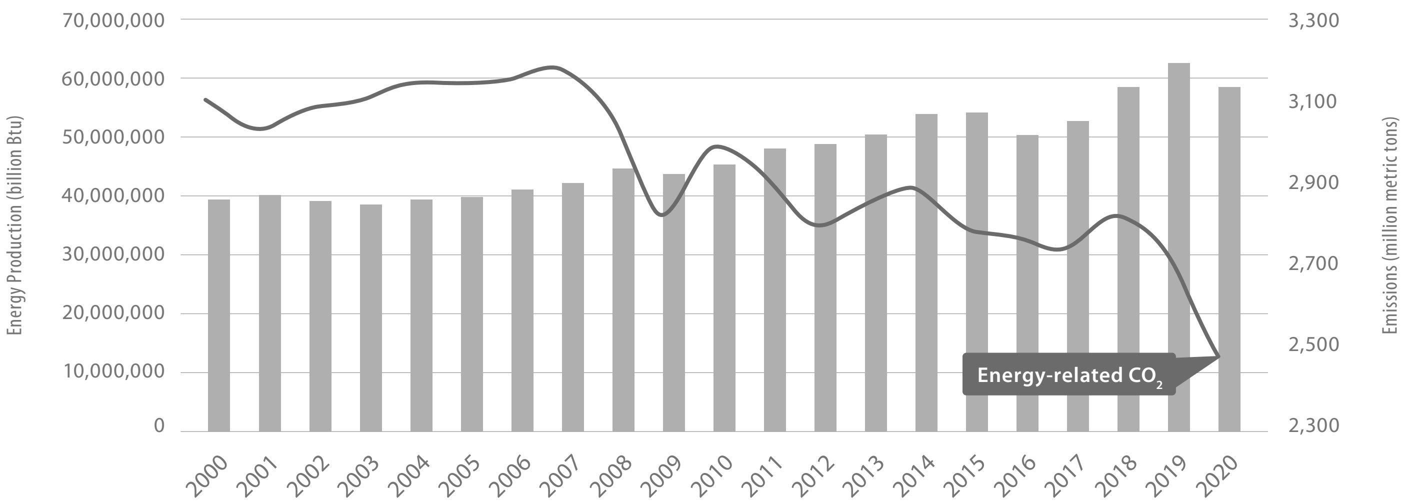


Source: U.S. EPA, ***Inventory of U.S. Greenhouse Gas Emissions and Sinks by State: 1990–2021***, April 2023. See U.S. EPA's **Greenhouse Gas Inventory Data Explorer**.

Greenhouse Gases and Energy

From 2000 to 2020, energy-related carbon dioxide (CO_2) emissions in AAPCA Member States declined 20 percent, from 3,106 million metric tons in 2000 to 2,479 million metric tons in 2020, while energy production increased 49 percent.[36]

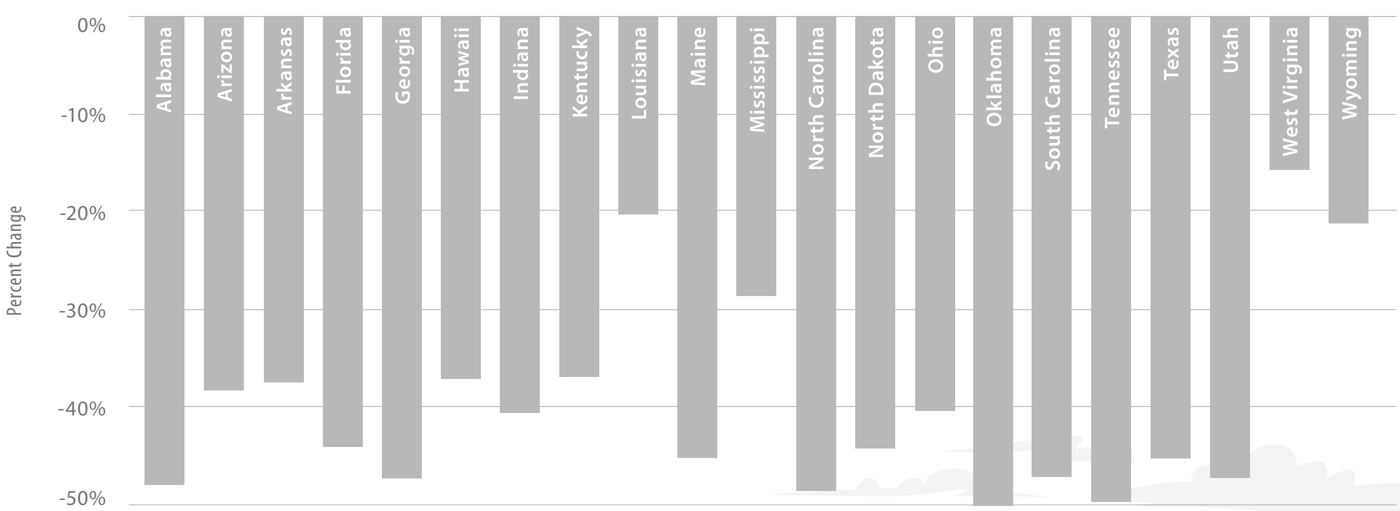
AAPCA Member States | Total Energy Production Compared to Energy-Related Carbon Dioxide Emissions, 2000–2020



Source: U.S. Energy Information Administration (EIA), **State Energy Data System (SEDS): 1960–2020**; U.S. EIA, **Energy-Related CO_2 Emission Data Tables**, Table 1. State energy-related carbon dioxide emissions by year (1970–2020).

Furthermore from 2000 to 2020, states in AAPCA's membership oversaw an average reduction of nearly 40 percent in the carbon intensity of their economies.[37]

AAPCA Member States | Percent Reduction in Carbon Intensity of the Economy, 2000–2020



Source: U.S. Energy Information Administration, **Energy-Related CO_2 Emission Data Tables**, Table 7. Carbon intensity of the economy by state (1997–2020).

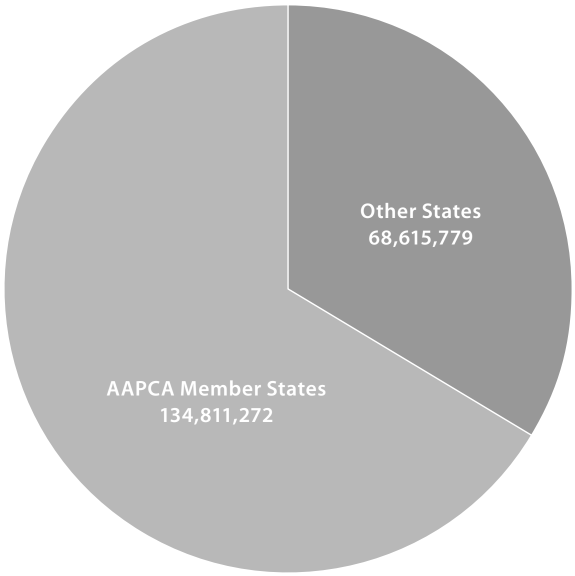
Air Toxics

AAPCA Member States | Share of Total Reduction of Reported Toxic Air Releases, 2012–2021 (pounds reduced)

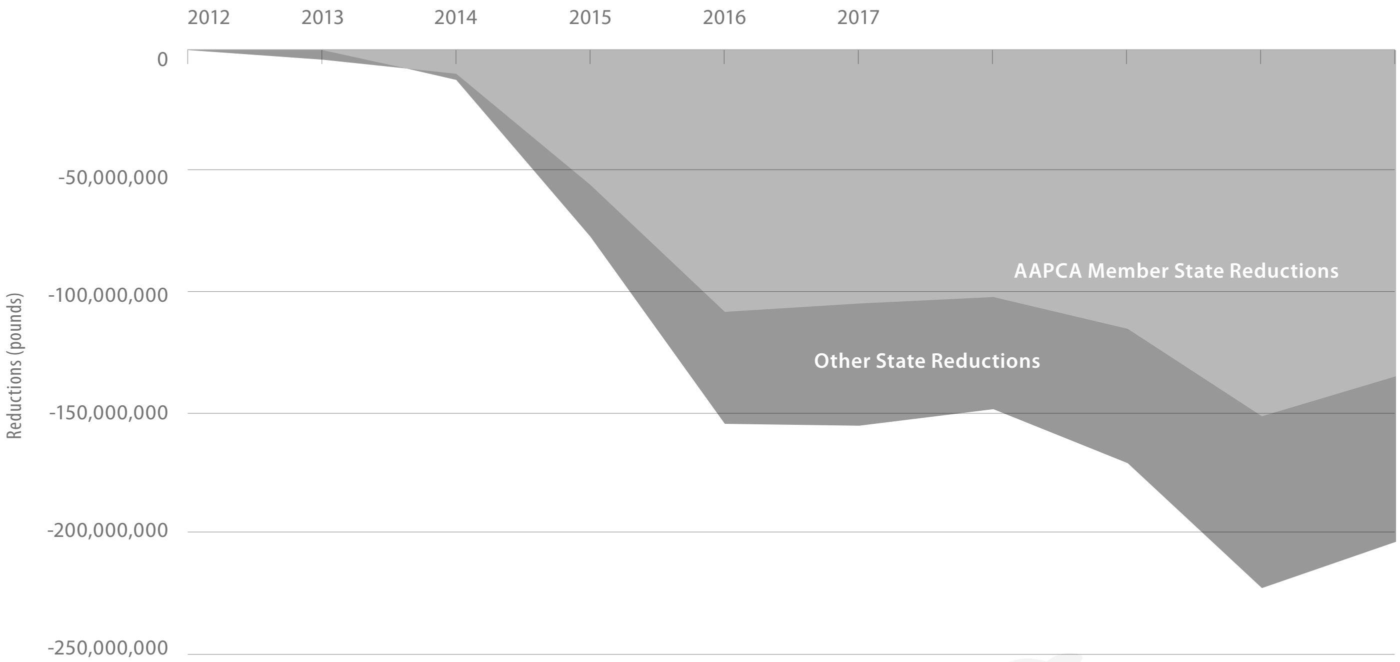
U.S. EPA's *2021 Toxic Release Inventory (TRI) National Analysis* revealed a 26 percent reduction in reported toxic air releases compared to 10 years ago, from 774.6 million pounds in 2012 to 571.2 million pounds in 2021.[38]

Of the 203.4-million-pound decrease in reported releases over the past decade, AAPCA Member States oversaw roughly 66 percent, or 134.8 million pounds.[39]

Source: U.S. EPA Toxic Release Inventory Explorer, **2021 TRI Factsheets**.



AAPCA Member States | Annual Share of National Reduction in Reported Toxic Air Releases, 2012–2021



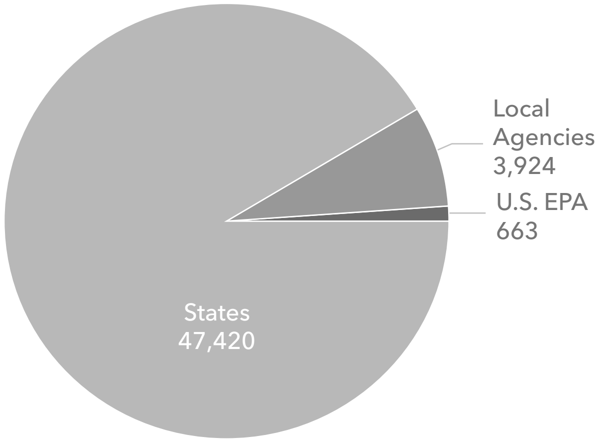
Source: U.S. EPA Toxic Release Inventory Explorer, **2021 TRI Factsheets**.

State Compliance and Enforcement Activity

Number of Facilities Permitted Under Clean Air Act, 2022

U.S. EPA's Enforcement and Compliance History Online (ECHO) documents compliance monitoring activities that are undertaken by state and local air agencies and U.S. EPA, such as compliance evaluations, compliance determinations, and enforcement actions. U.S. EPA's ECHO Dashboard notes that "EPA delegates much of its [Clean Air Act] authority to state, local, and tribal agencies."[40]

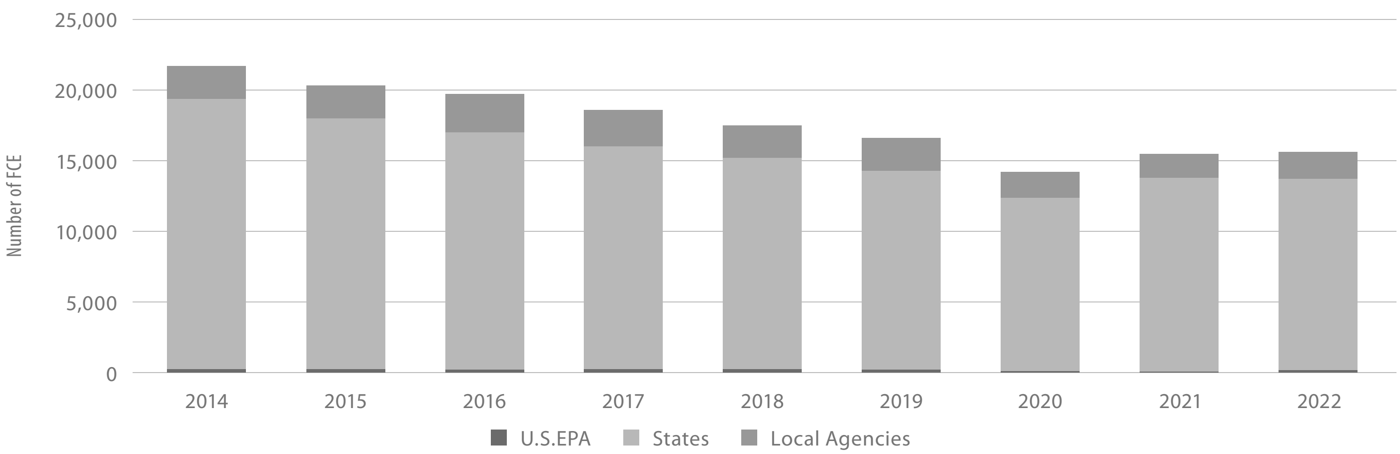
The ECHO Air Dashboard shows that of the 52,007 facilities permitted under the Clean Air Act in federal fiscal year (FY) 2022, states were the permitting agency on 47,420 facilities, local agencies on 3,924, and U.S. EPA for 663 facilities.[41]



The ECHO Air Dashboard also provides data on Full Compliance Evaluations (FCE) performed by U.S. EPA and state and local agencies. U.S. EPA defines an FCE as "a comprehensive evaluation of the compliance status of the facility. It looks for all regulated pollutants at all regulated emission units, and it addresses the compliance status of each unit, as well as the facility's continuing ability to maintain compliance at each emission unit."[42] In federal FY 2022, ECHO details the following FCE lead agency distribution:

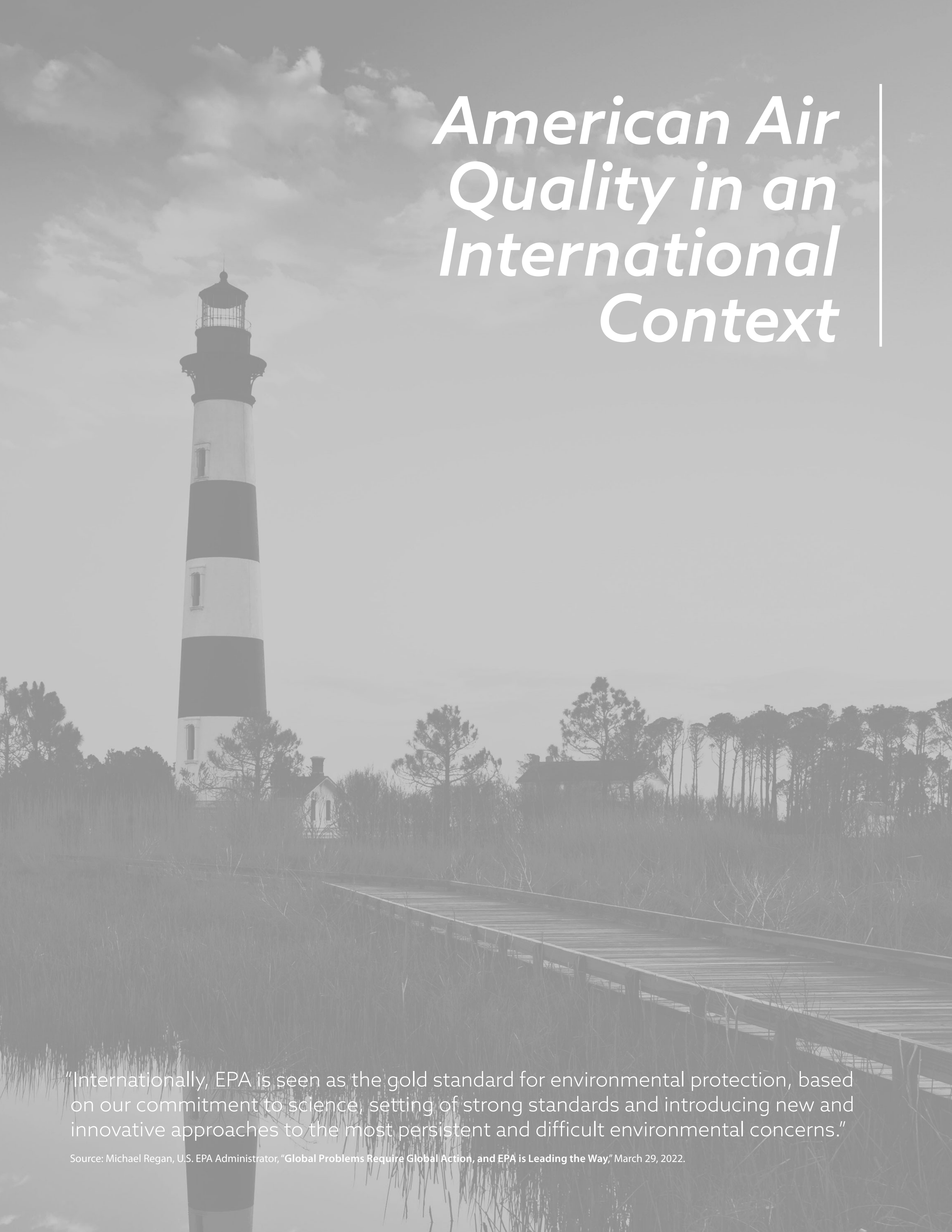
- States were the lead agency for 13,551 FCE, averaging more than 15,300 FCE annually from 2014 through 2022;
- Local programs were the lead agency for 1,872 FCE, averaging above 2,200 FCE annually from 2014 through 2022; and,
- U.S. EPA was the lead agency for 178 FCE, averaging about 200 FCE from 2014 through 2022.[43]

Full Compliance Evaluations under Clean Air Act by Lead Agency, 2014–2022



Source: U.S. EPA, **Analyze Trends: State Air Dashboard**.

Additionally, U.S. EPA's ECHO Air Dashboard also shows that states averaged about 86,200 Clean Air Act compliance monitoring activities per year from 2014 through 2022, while local programs averaged above 22,500 per year from the same period. In 2022, AAPCA Member States were the lead agency for 44,997 out of the 75,678 state-led compliance monitoring activities, or 59 percent of the state lead agency total.[44]



American Air Quality in an International Context

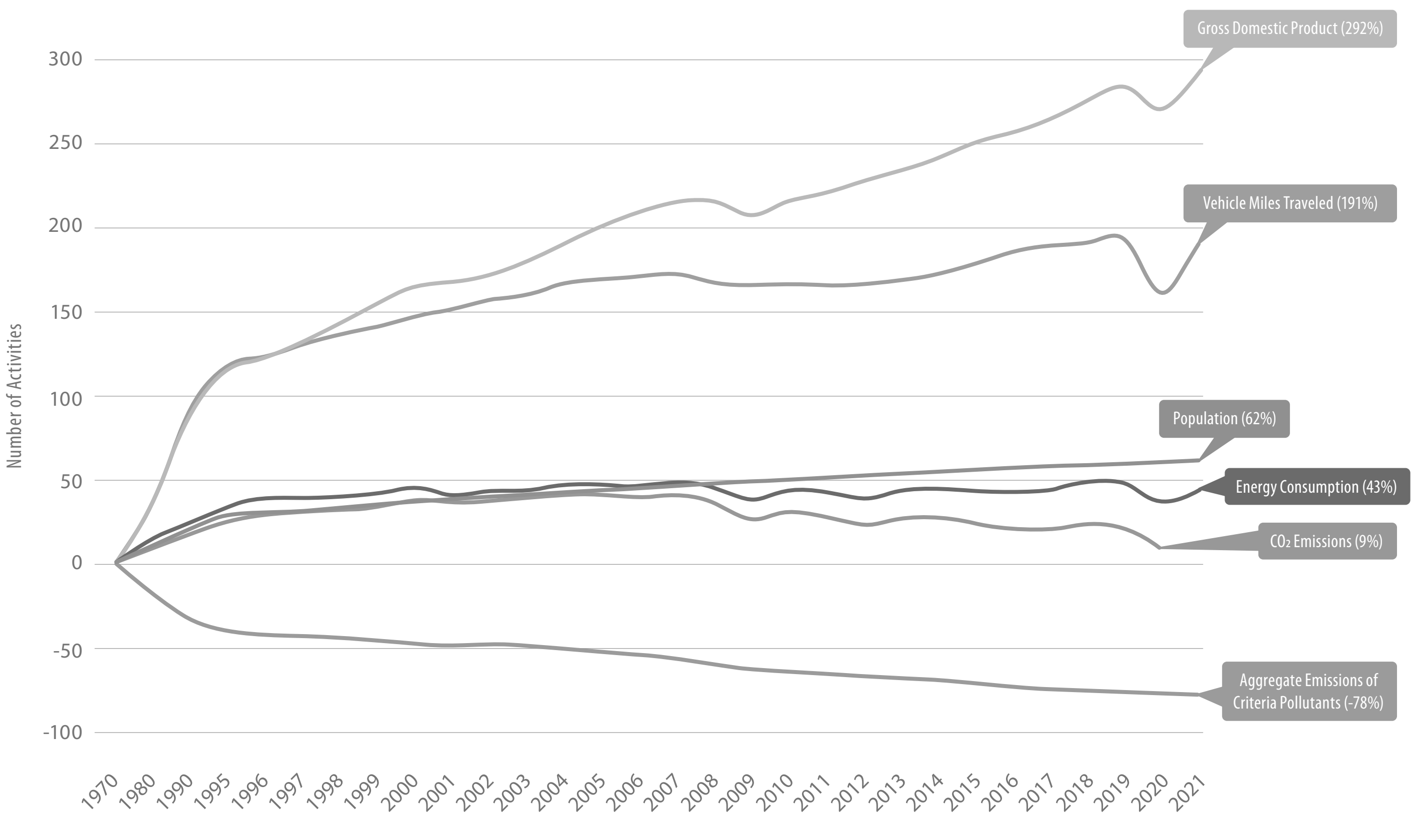
"Internationally, EPA is seen as the gold standard for environmental protection, based on our commitment to science, setting of strong standards and introducing new and innovative approaches to the most persistent and difficult environmental concerns."

Source: Michael Regan, U.S. EPA Administrator, "**Global Problems Require Global Action, and EPA is Leading the Way**," March 29, 2022.

Air Quality and Growth Indicator Trends in the United States

According to U.S. EPA's June 2022 report, *Our Nation's Air: Trends Through 2021*, the United States has reduced aggregate emissions of the six criteria air pollutants by 78 percent since 1970.[45] The substantial, sustained decline in emissions have led to improved air quality in the United States while Gross Domestic Product (GDP) rose 292 percent, Vehicle Miles Traveled increased 191 percent, population grew 62 percent, and energy consumption went up 43 percent.[46]

Growth Indicators and Emissions Reductions in the United States, 1970–2021



Source: U.S. EPA, ***Our Nation's Air: Trends Through 2021*** (Section: "Economic Strength with Cleaner Air"), June 2022.

Internationally, the United States ranks:

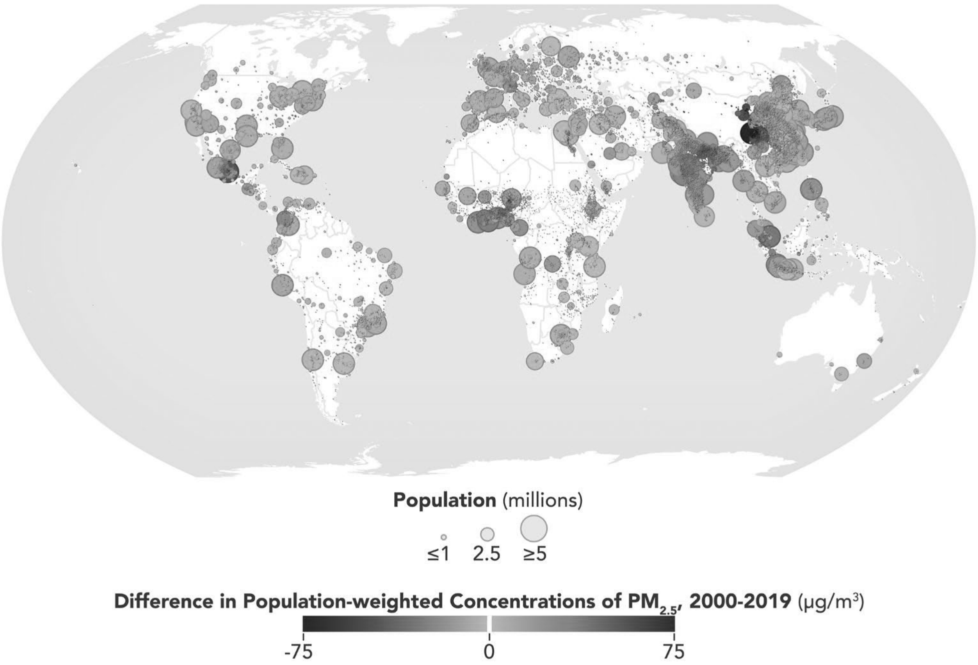
- First in GDP, at $23.32 trillion in 2021, representing 24 percent of gross world product[47] and up by 127 percent from 2000 levels.[48]
- Second in energy production, behind China, according to International Energy Agency (IEA) data.[49] From 1960 to 2020, United States energy production increased from approximately 42,591 trillion British thermal units (Btu) to 95,711 trillion Btu, or 125 percent.[50]
- Third in total population, behind China and India,[51] growing from approximately 203.4 million people in 1970 to 331.9 million people in 2021.[52]

International Trends | Air Quality

Global Change in Population-Weighted Concentrations of $PM_{2.5}$, 2000–2019

Using satellite data,[53] the National Aeronautics and Space Administration's (NASA) Earth Observatory mapped the mean population-weighted ambient fine particulate matter ($PM_{2.5}$) concentration globally across all urban areas. The change in population-weighted $PM_{2.5}$ concentration trends from 2000 to 2019 varied widely between regions, with consistent decreases across North America, including the United States, and Europe while increasing across southeast Asia.[54]

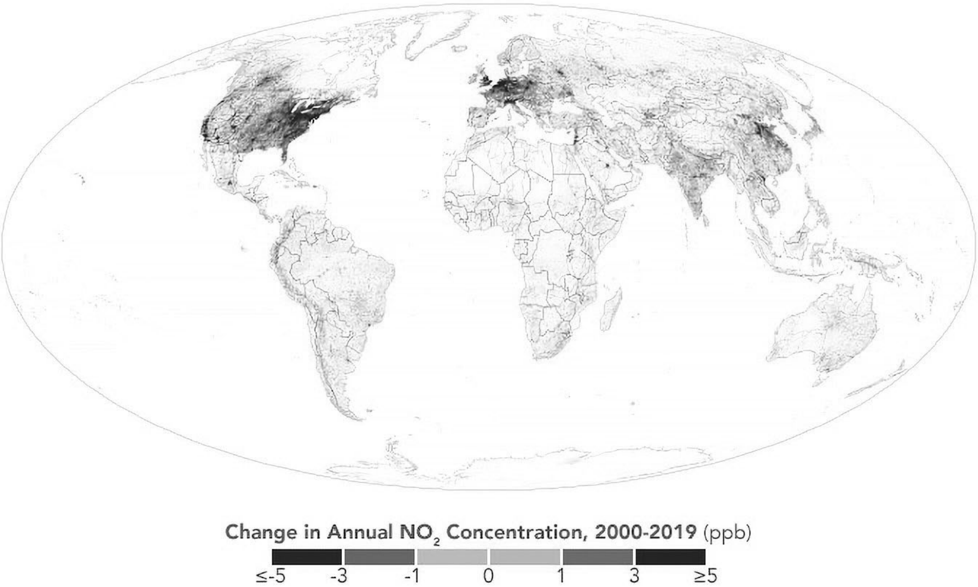
Source: NASA Earth Observatory, "No Breathing Easy for City Dwellers: Particulates," March 15, 2022.



Global Change in Concentrations of NO_2, 2000–2019

Data from NASA's Ozone Monitoring Instrument on the Aura satellite shows a similar global pattern for the change in annual average nitrogen dioxide (NO_2) concentrations between 2000 and 2019.[55]

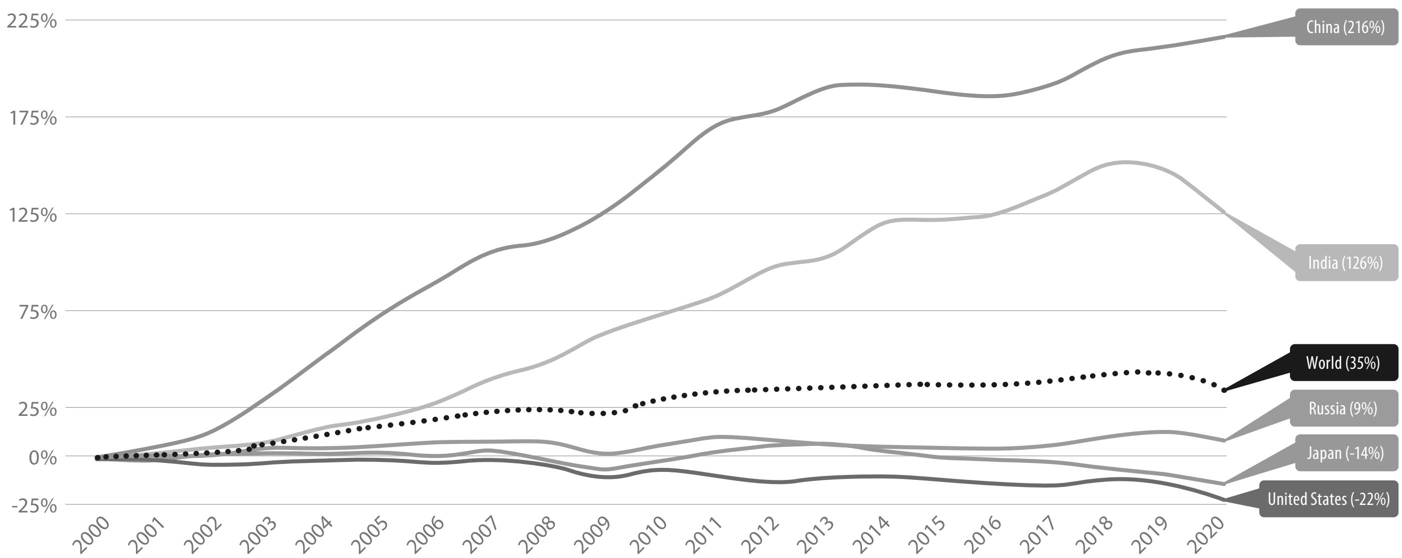
Source: NASA Earth Observatory, "No Breathing Easy for City Dwellers: Nitrogen Dioxide," March 14, 2022.



International Trends | Greenhouse Gas Emissions

The International Energy Agency's (IEA) database, *Greenhouse Gas Emissions from Energy*, includes annual estimates of total greenhouse gas (GHG) emissions from the energy sector for over 190 countries and regions.[56] From 2000 to 2020, the United States achieved the largest reductions among the five highest emitting nations, decreasing energy-related GHG emissions from 6,070 million tonnes of carbon dioxide equivalent (CO_2e) in 2000 to 4,744 million tonnes CO_2e in 2020. Data from IEA shows that GHG emissions from energy in the United States in 2021 were 18 percent lower than 2000 levels.[57]

Annual Percent Change of Greenhouse Gas Emissions from Energy by Country, 2000–2020



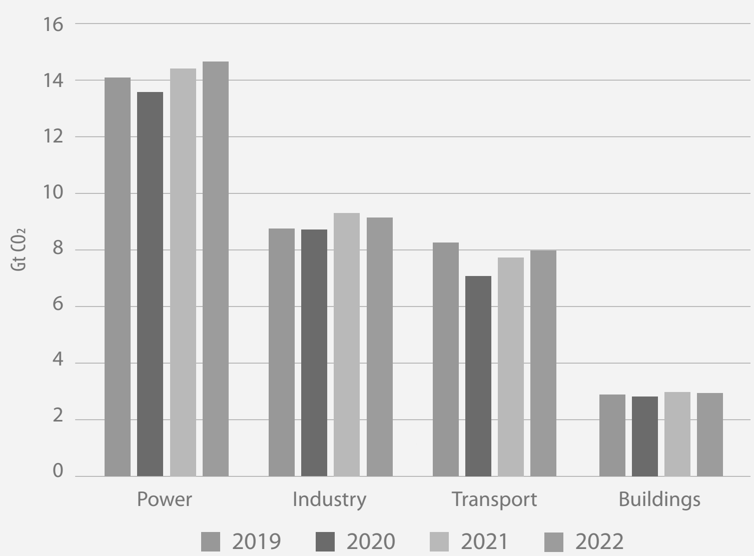
Source: International Energy Agency, ***Greenhouse Gas Emissions from Energy* Highlights**, September 16, 2022.

International Energy Agency | Global CO_2 Emissions by Sector, 2019-2022 (Gt CO_2)

In March 2023, IEA released the report, *CO_2 Emissions in 2022*, highlighting the following global carbon dioxide (CO_2) emissions trends:

- Global energy-related CO_2 emissions reached 36.8 gigatonnes (Gt) in 2022, a 0.9 percent increase from 2021;
- United States emissions grew by 0.8 percent (or 36 megatonnes) from 2021, to total 4.7 Gt in 2022;
- Total energy-related greenhouse gas emissions increased by 1.0 percent from 2021, to an all-time high of 41.3 Gt CO_2-equivalent; and,
- Global electricity demand increased by 2.7 percent, and overall carbon intensity of electricity generation declined by 2.0 percent.

Source: International Energy Agency, ***CO_2 Emissions in 2022***, March 2023.



Air Quality Trends in the United States

"Cleaner air provides important public health benefits, and we commend our state, local, community and industry partners for helping further long-term improvement in our air quality."

Source: U.S. EPA, ***Our Nation's Air: Trends Through 2021*** (Section: "**Introduction**"), June 2022.

Criteria Air Pollutants | Concentration Trends

U.S. EPA's national-level analysis of 2021 monitoring data show the substantial reductions in ambient concentrations of all criteria pollutants over the past several decades. As the below chart indicates, the United States has seen at least a 29 percent decline in the ambient levels of carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2) since 1980. Available data show that fine and coarse particulate matter ($PM_{2.5}$ and PM_{10}) ambient concentrations have declined by at least a third of 2000 levels. And more recent data point to a sustained trend of meaningful improvements, with monitored concentrations of all criteria pollutants continuing to decline over the last ten years.[58]

Ambient Concentrations	1980 vs 2021	1990 vs 2021	2000 vs 2021	2010 vs 2021
Carbon Monoxide	-87%	-79%	-65%	-26%
Lead	-98%	-98%	-93%	-85%
Nitrogen Dioxide (annual)	-67%	-61%	-53%	-29%
Nitrogen Dioxide (1-hour)	-64%	-54%	-40%	-22%
Ozone (8-hour)	-29%	-21%	-16%	-5%
PM_{10} (24-hour)	---	-32%	-36%	-5%
$PM_{2.5}$ (annual)	---	---	-37%	-14%
$PM_{2.5}$ (24-hour)	---	---	-33%	-2%
Sulfur Dioxide (1-hour)	-94%	-91%	-85%	-74%

Source: U.S. EPA, **Air Quality—National Summary: Air Quality Trends** (updated June 1, 2022).

Criteria Air Pollutants | Emissions Trends

In coordination with state and local air agencies, tribes, and industry, U.S. EPA develops annual nationwide emissions estimates, which are "based on actual monitored readings or engineering calculations of the amounts and types of pollutants emitted by vehicles, factories, and other sources."[59] U.S. EPA's most recently published estimates, show that the emissions of all criteria pollutants and precursors declined by at least a third (33 percent) from 1990 through 2021, and at least 21 percent since 2010.[60]

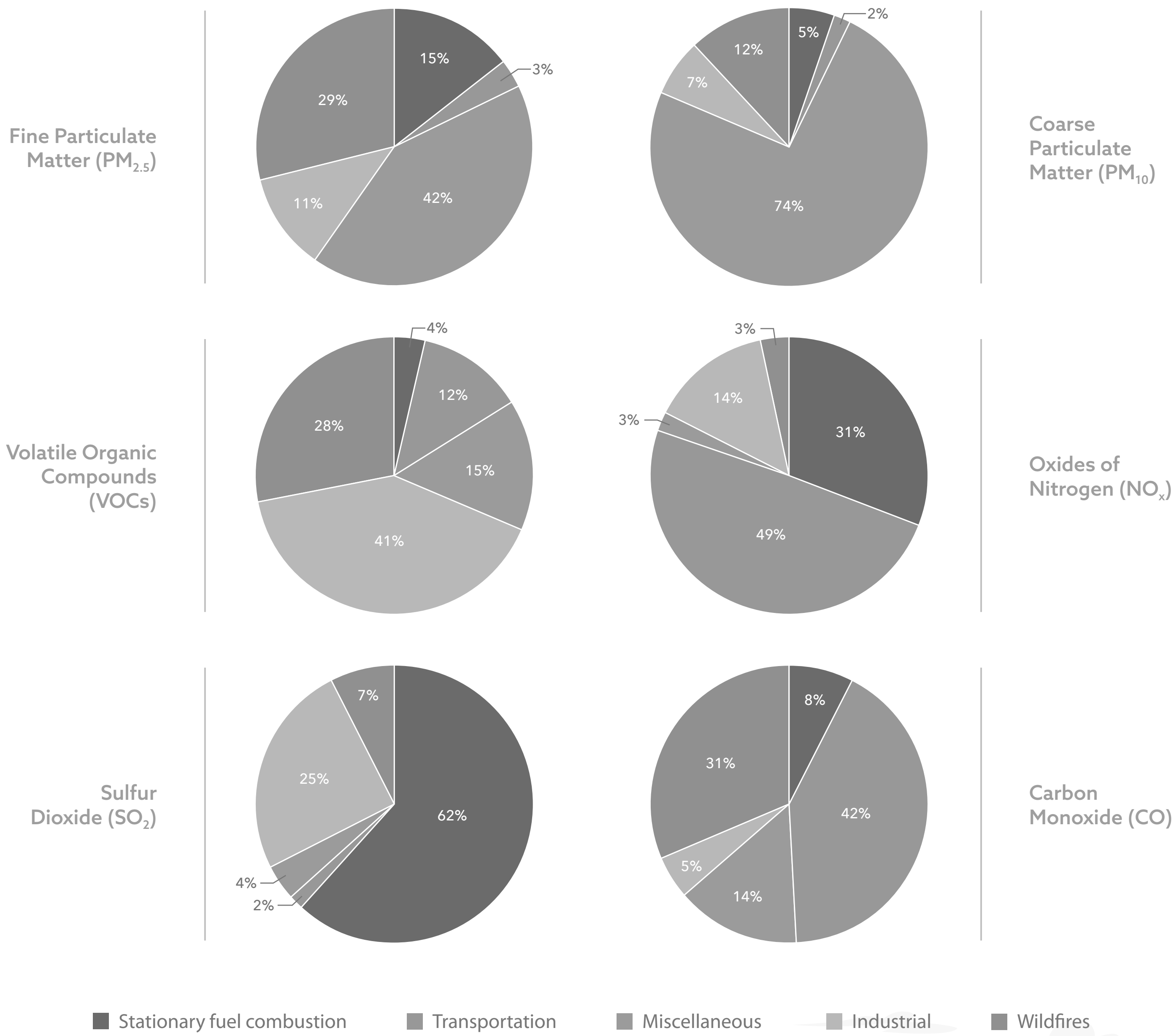
Emissions	1980 vs 2021	1990 vs 2021	2000 vs 2021	2010 vs 2021
Carbon Monoxide	-75%	-70%	-57%	-29%
Lead	-99%	-87%	-76%	-30%
Nitrogen Oxides	-72%	-70%	-66%	-48%
Volatile Organic Compounds	-61%	-49%	-30%	-21%
Direct PM_{10}	-65%	-33%	-30%	-22%
Direct $PM_{2.5}$	---	-40%	-46%	-25%
Sulfur Dioxide	-93%	-92%	-89%	-76%

Source: U.S. EPA, U.S. EPA, **Air Quality—National Summary: Emissions Trends** (updated June 1, 2022).

Criteria Air Pollutants | Emissions Sources

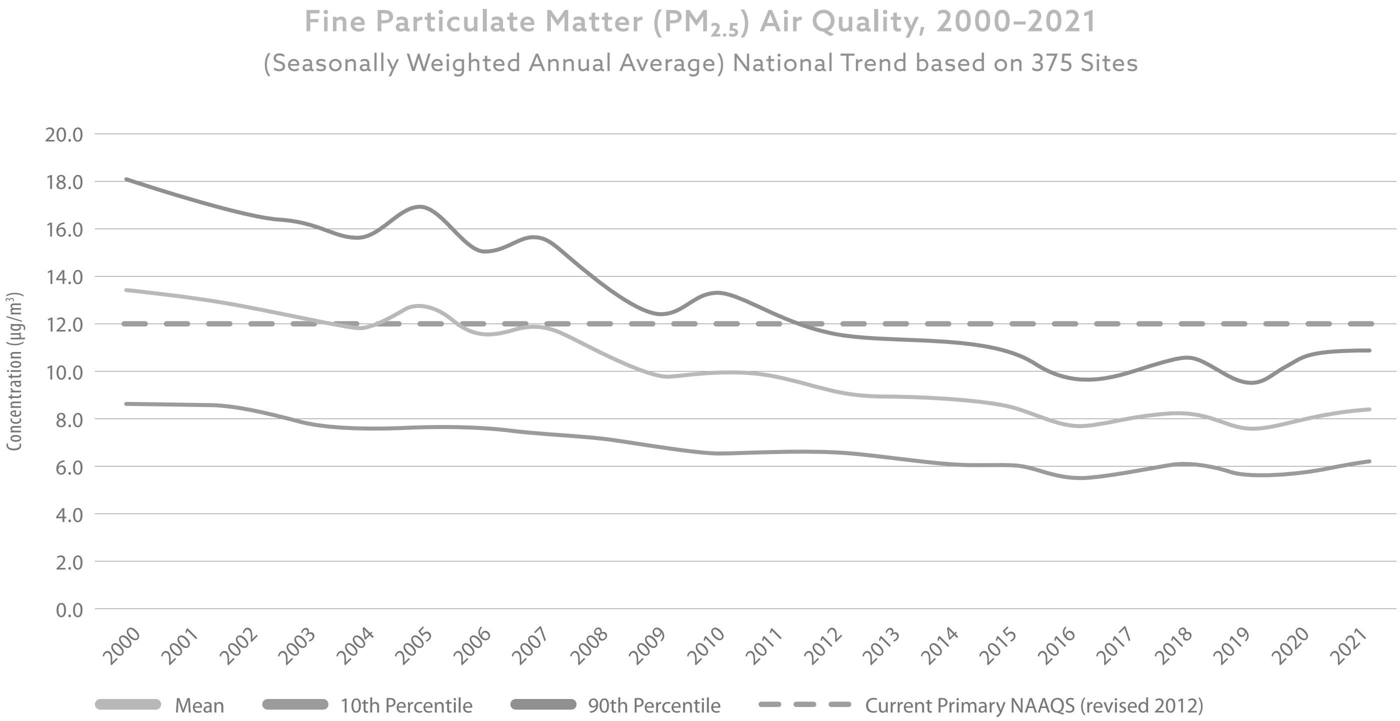
U.S. EPA tracks emissions from the following source categories: Stationary Fuel Combustion, Industrial, Transportation, Wildfires, and Miscellaneous. Included below are the sources of criteria air pollutant and precursor emissions for the year 2022.[61]

Criteria Air Pollutant Sources, 2022

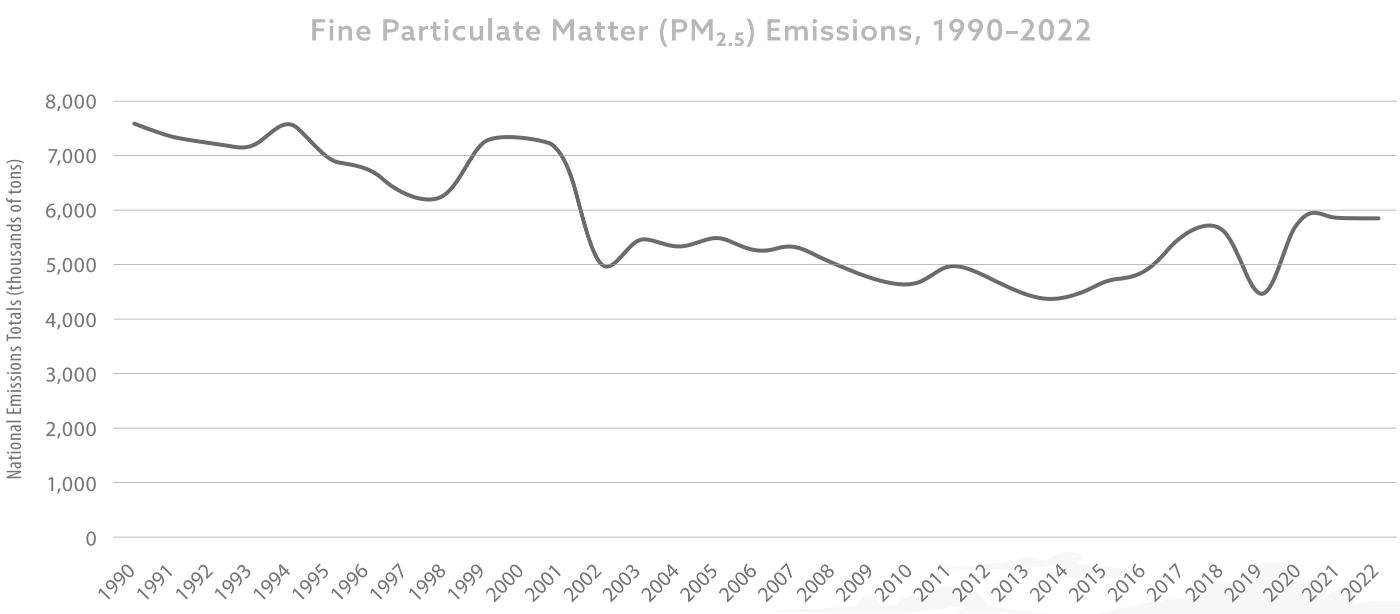


Source: U.S. EPA, **Air Pollutant Emissions Trends** (Data file: "National Tier 1 CAPS Trends, Criteria pollutants National Tier 1 for 1970–2022").

Criteria Air Pollutant Trends | Fine Particulate Matter

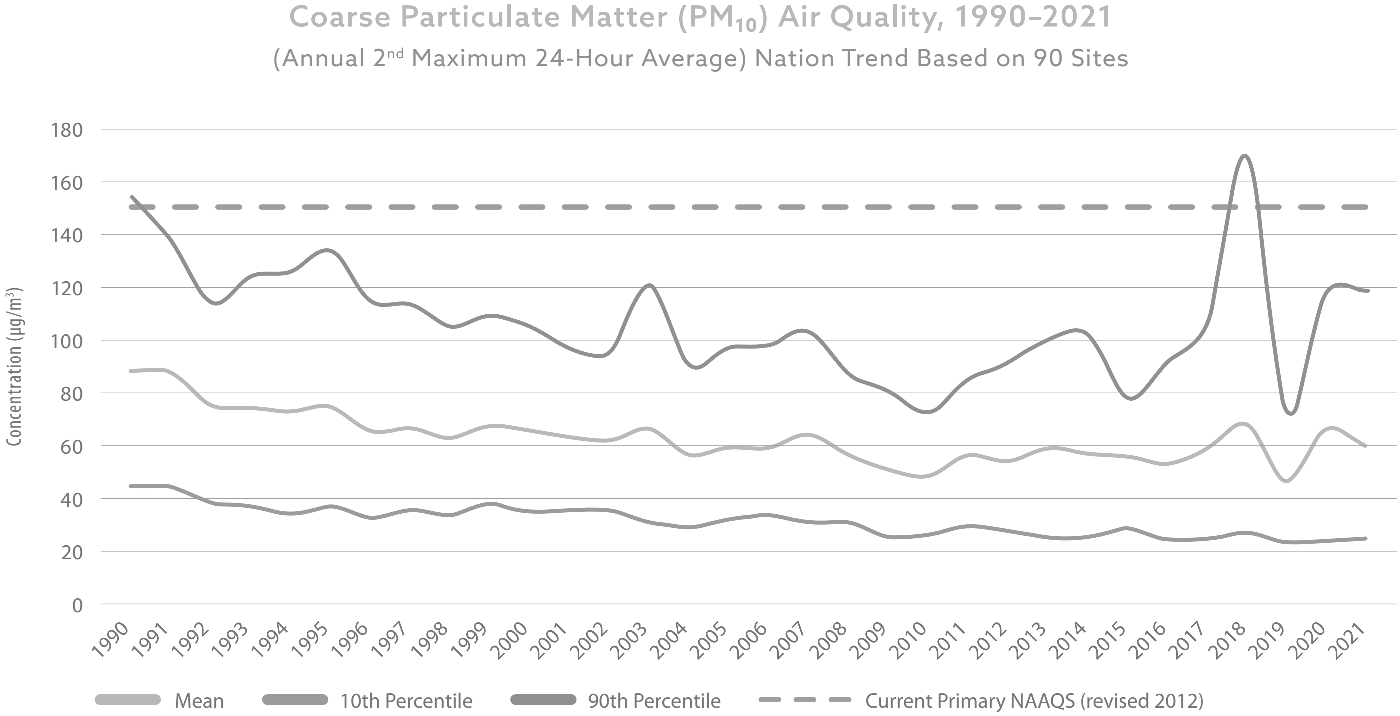


Source: U.S. EPA, **Particulate Matter ($PM_{2.5}$) Trends**, August 2022.

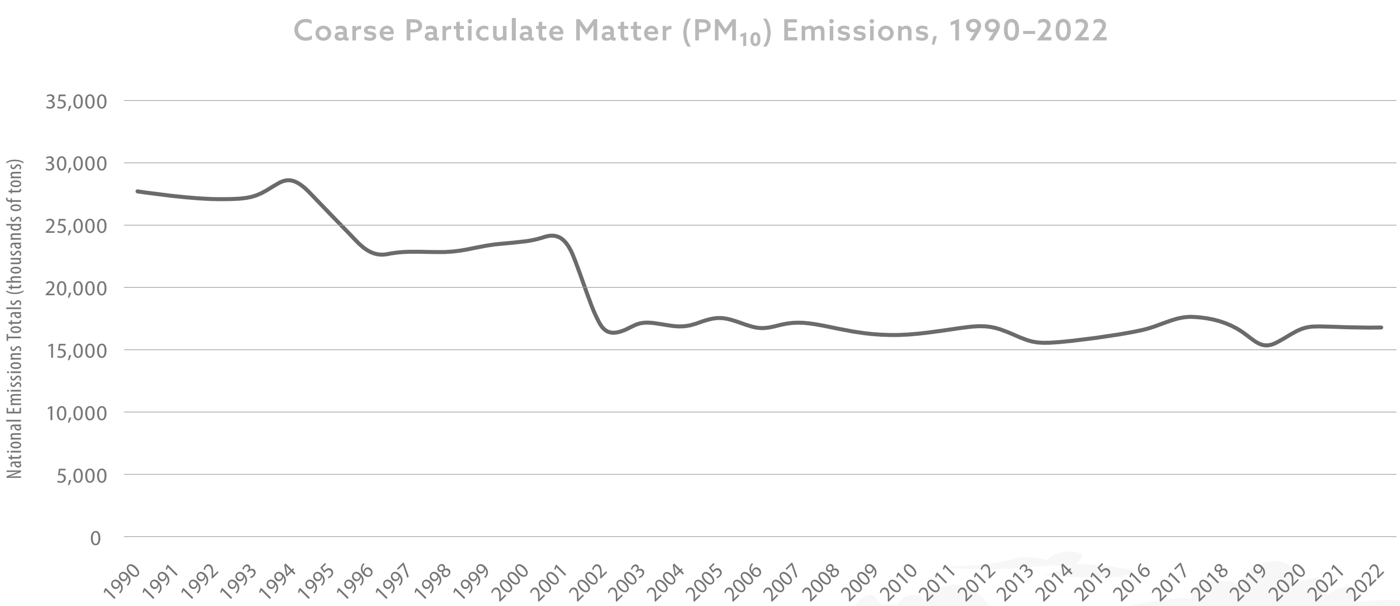


Source: U.S. EPA, **Air Pollutant Emissions Trends** (Data file: "National Tier 1 CAPS Trends, Criteria pollutants National Tier 1 for 1970–2022").

Criteria Air Pollutant Trends | Coarse Particulate Matter



Source: U.S. EPA, **Particulate Matter (PM_{10}) Trends**, August 2022.

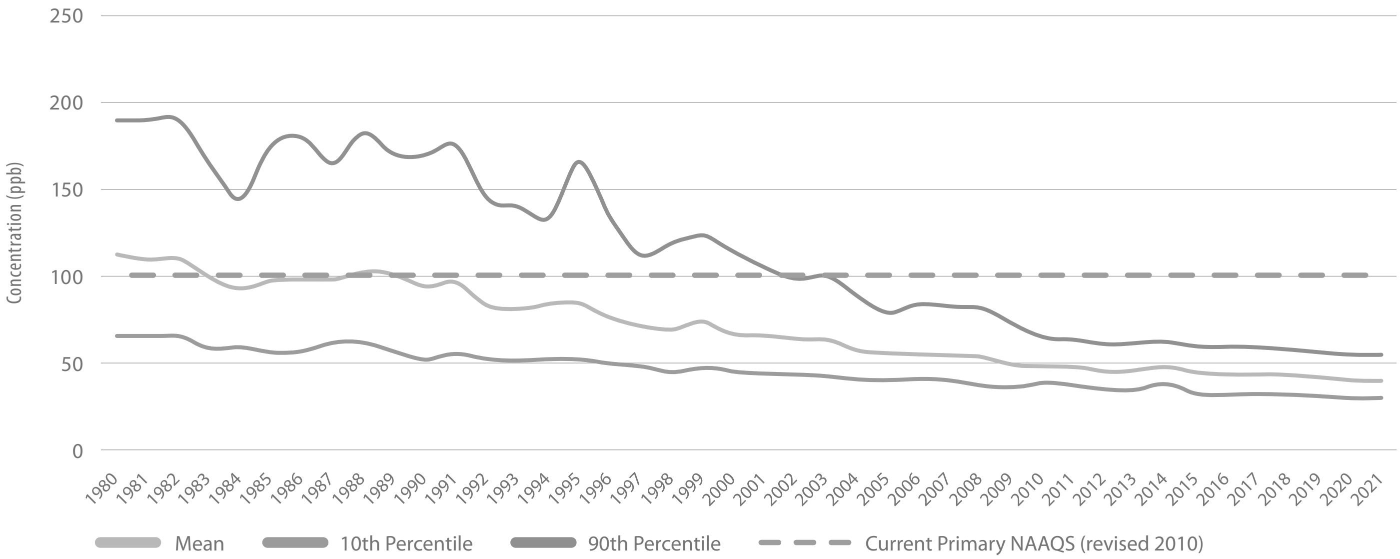


Source: U.S. EPA, **Air Pollutant Emissions Trends** (Data file: "National Tier 1 CAPS Trends, Criteria pollutants National Tier 1 for 1970–2022").

Criteria Air Pollutant Trends | Nitrogen Dioxide

Nitrogen Dioxide (NO_2) Air Quality, 1980–2021

(Annual 98th Percentile of Daily Max 1-hour Average) National Trend based on 20 Sites

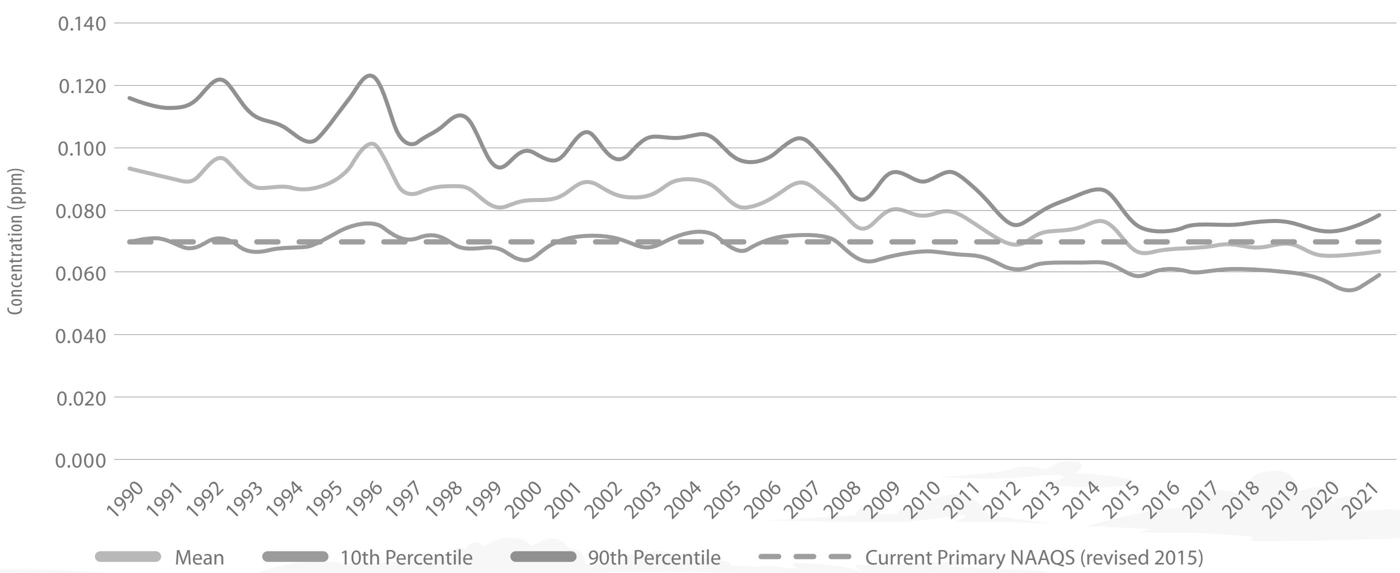


Source: U.S. EPA, **Nitrogen Dioxide Trends**, August 2022.

Criteria Air Pollutant Trends | Ozone

Ozone (O_3) Air Quality, 1980–2021

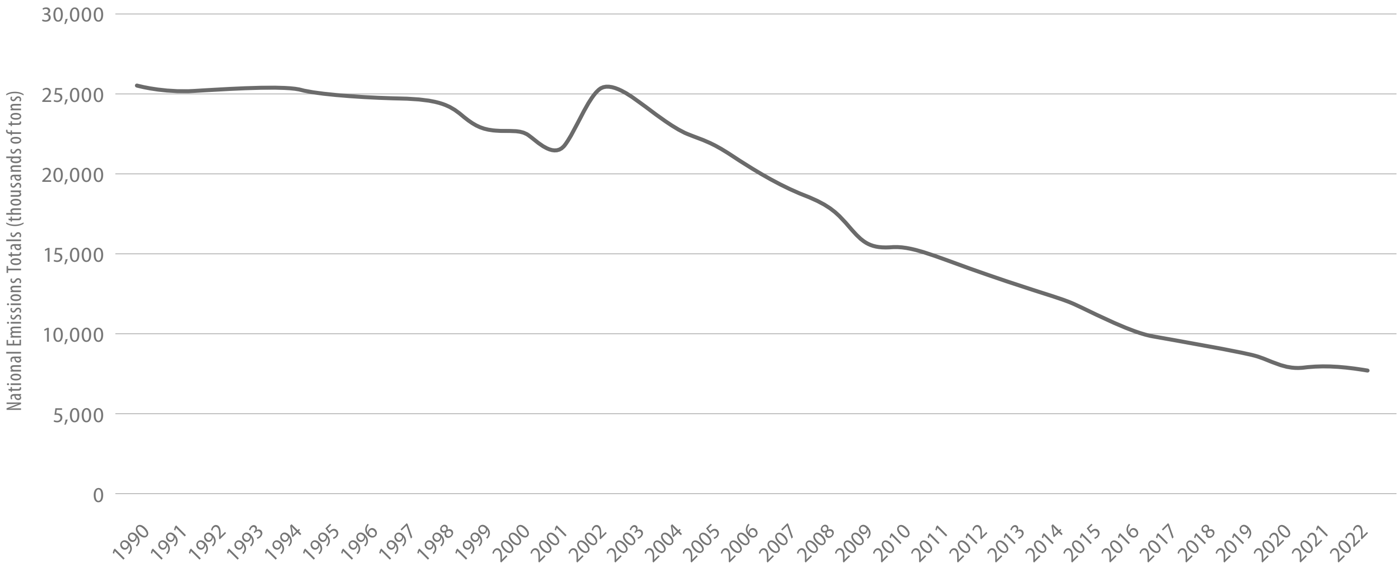
(Annual 4th Maximum Daily Max 8-Hour Average) National Trend based on 135 Sites



Source: U.S. EPA, **Ozone Trends**, August 2022.

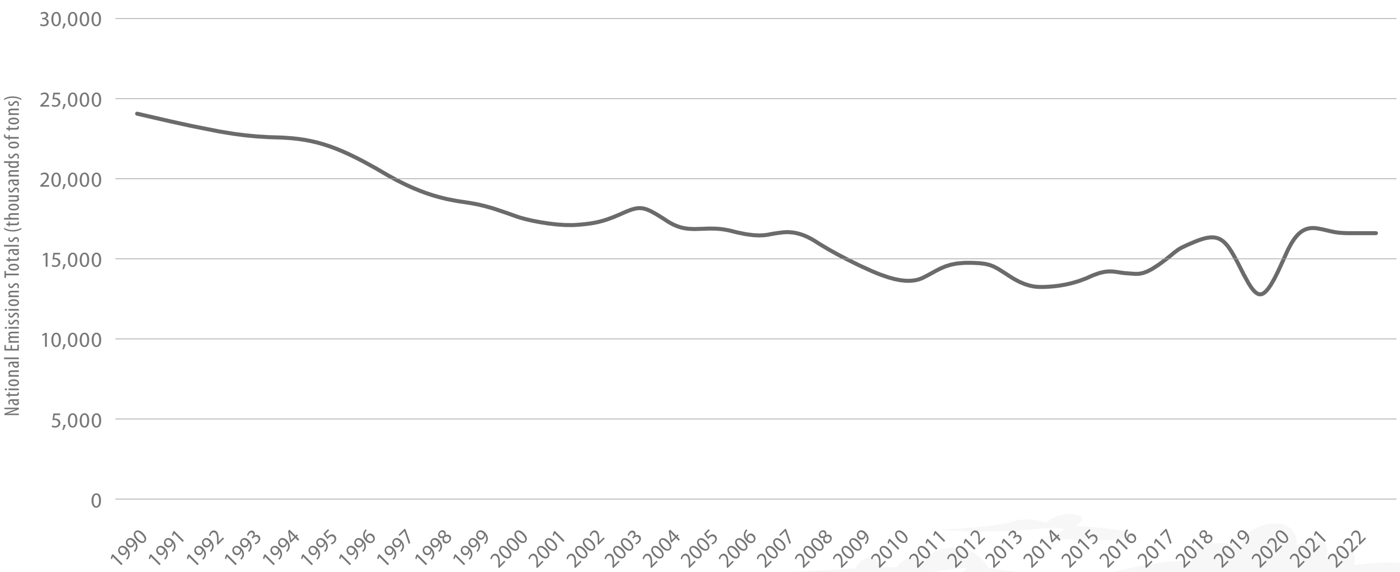
Criteria Air Pollutant Trends | Ozone Precursor Emissions

Oxides of Nitrogen (NO_X) Emissions, 1990–2022



Source: U.S. EPA, **Air Pollutant Emissions Trends** (Data file: "National Tier 1 CAPS Trends, Criteria pollutants National Tier 1 for 1970–2022").

Volatile Organic Compound (VOC) Emissions, 1990–2022

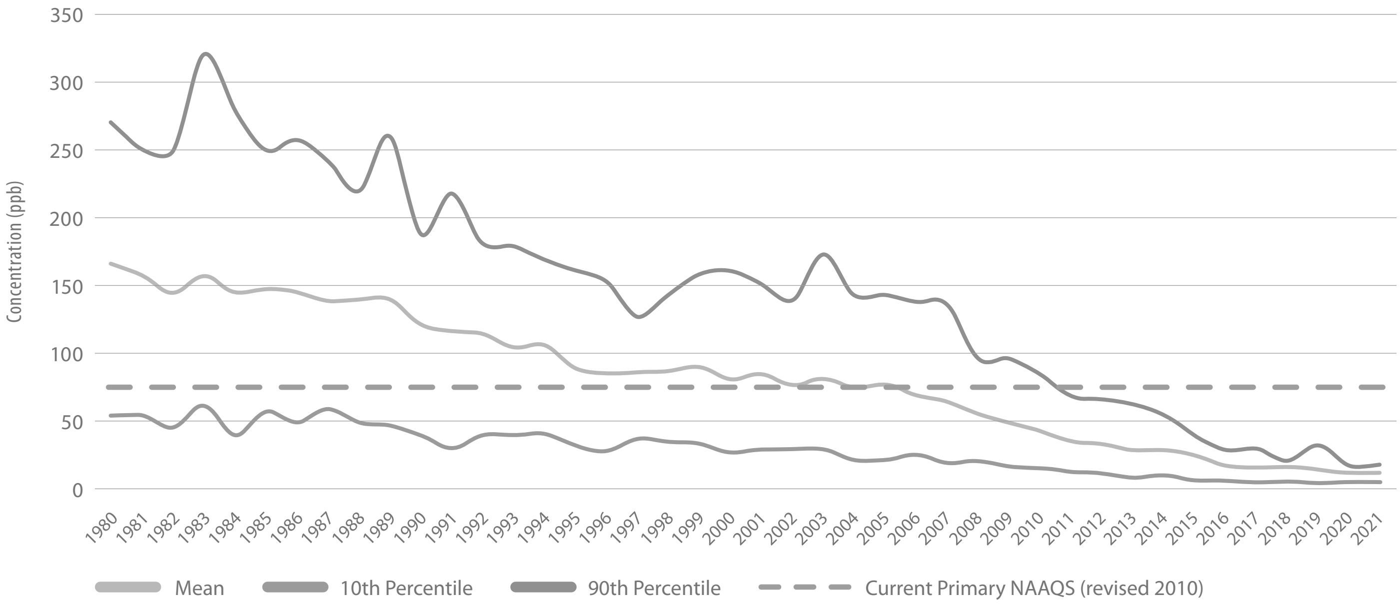


Source: U.S. EPA, **Air Pollutant Emissions Trends** (Data file: "National Tier 1 CAPS Trends, Criteria pollutants National Tier 1 for 1970–2022").

Criteria Air Pollutant Trends | Sulfur Dioxide

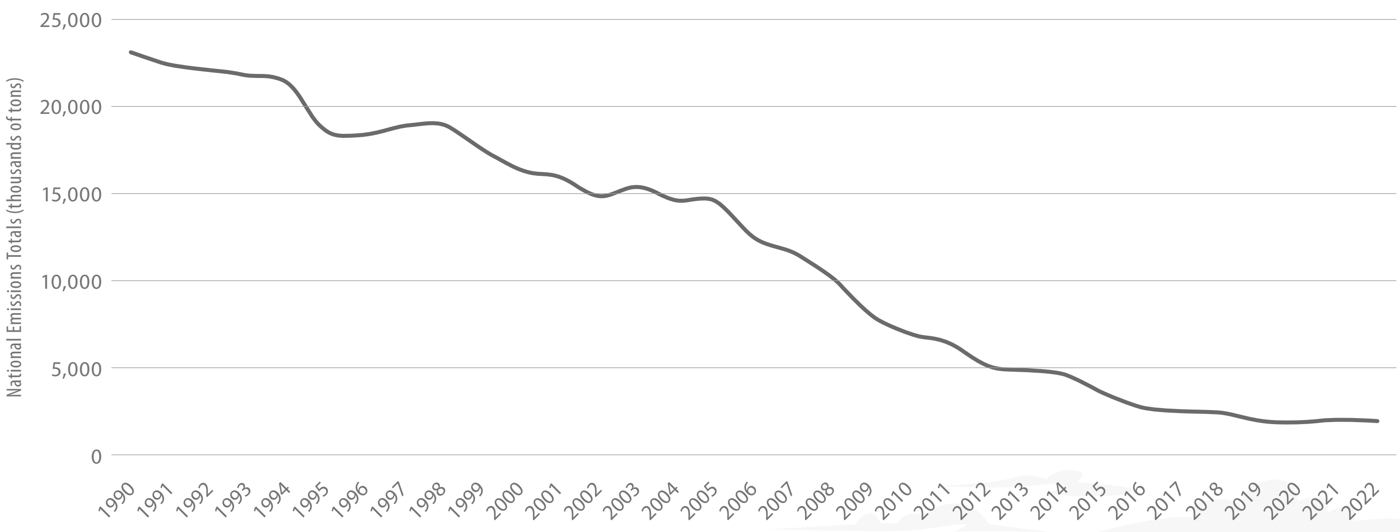
Sulfur Dioxide (SO_2) Air Quality, 1980–2021

(Annual 99th Percentile of Daily Max 1-Hour Average) National Trend based on 31 Sites



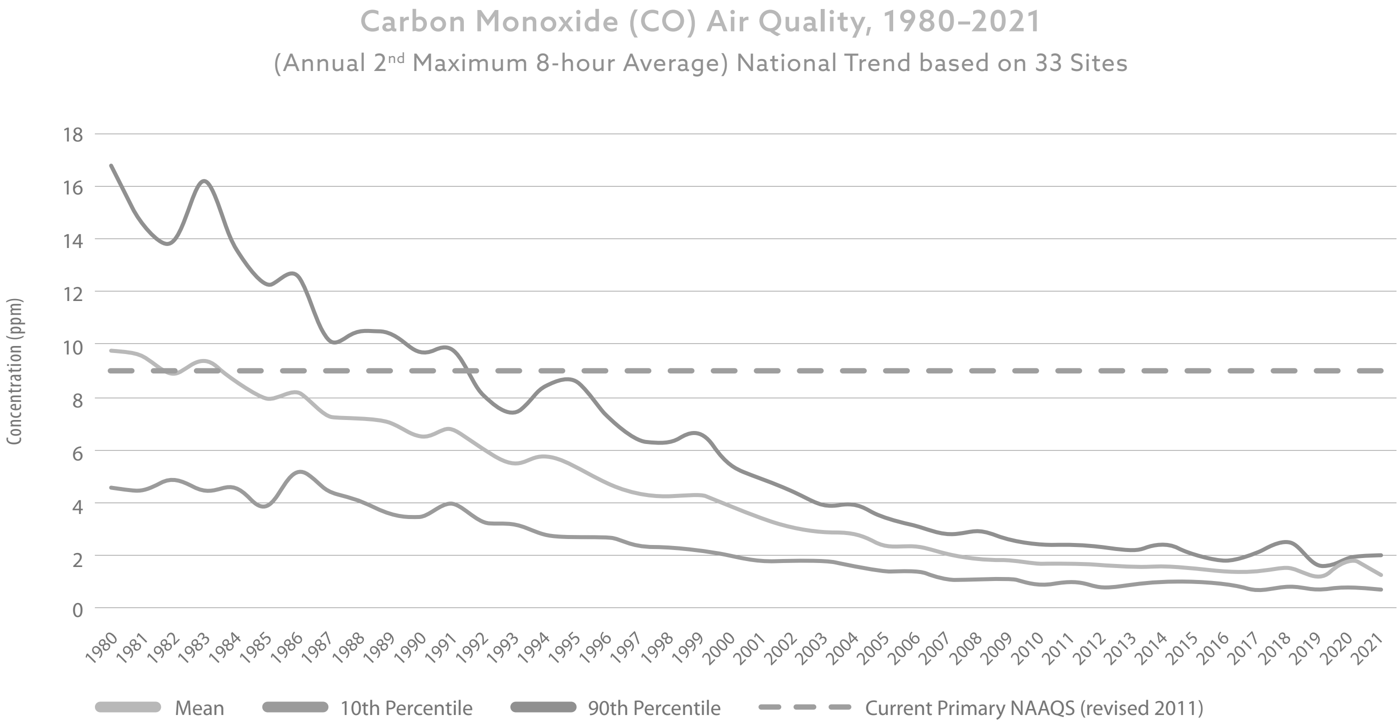
Source: U.S. EPA, **Sulfur Dioxide Trends**, August 2022.

Sulfur Dioxide (SO_2) Emissions, 1990–2022

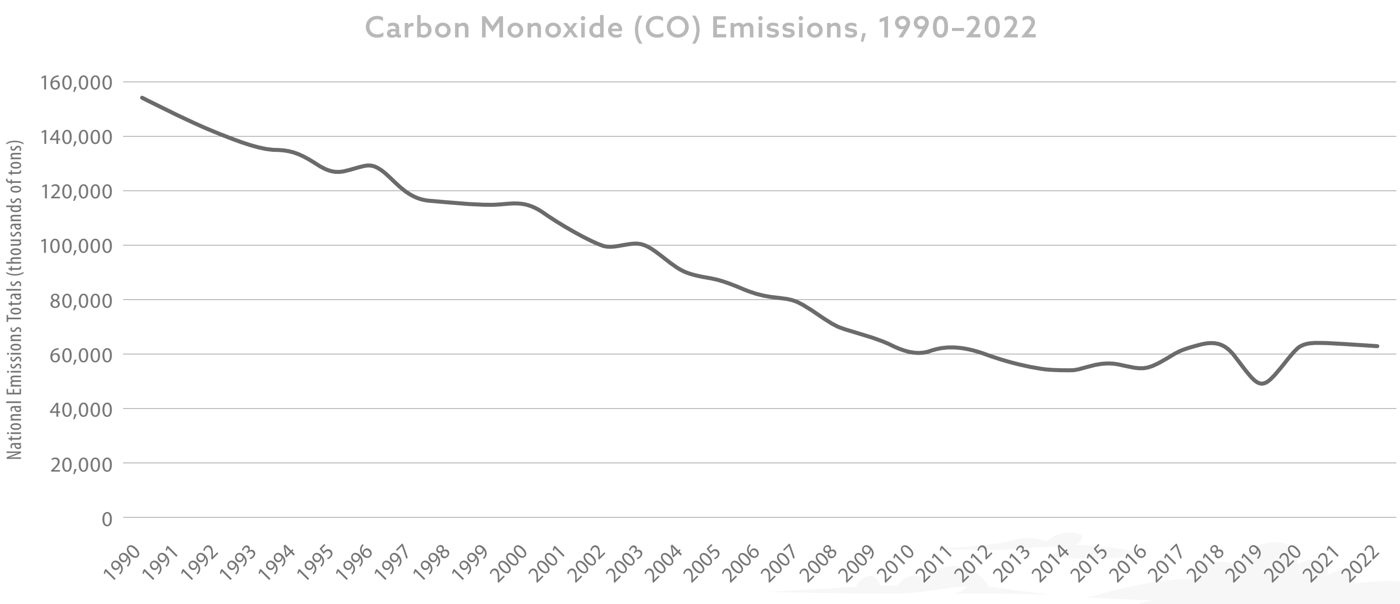


Source: U.S. EPA, **Air Pollutant Emissions Trends** (Data file: "National Tier 1 CAPS Trends, Criteria pollutants National Tier 1 for 1970–2022").

Criteria Air Pollutant Trends | Carbon Monoxide

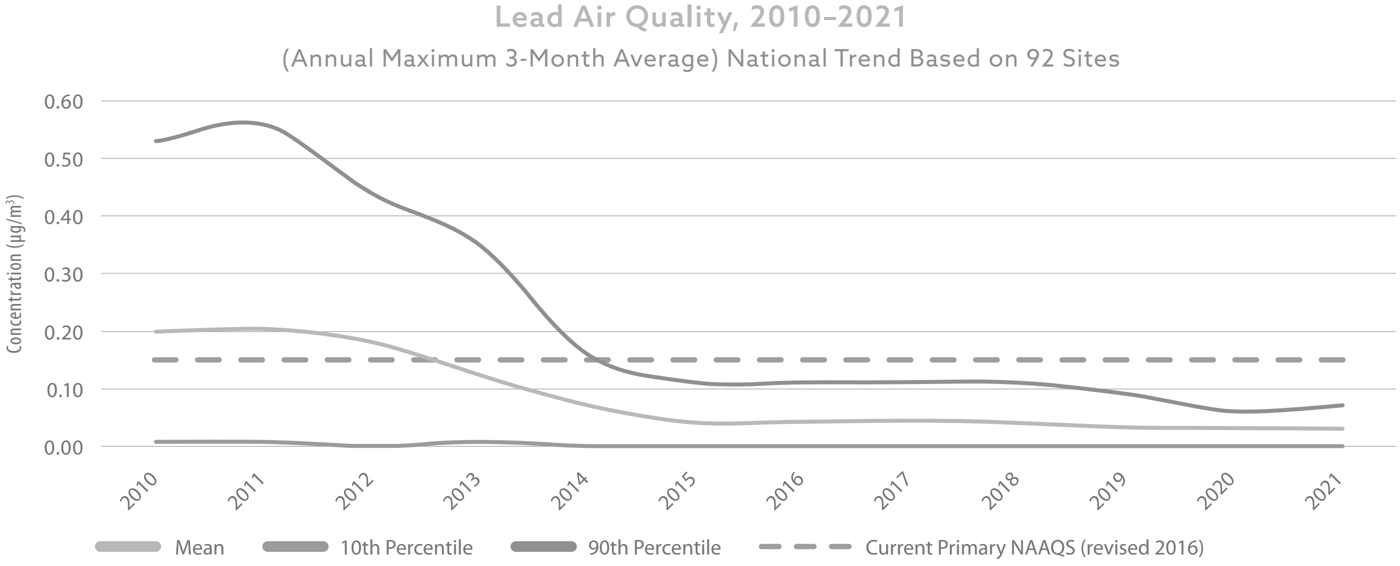


Source: U.S. EPA, **Carbon Monoxide Trends**, August 2022.



Source: U.S. EPA, **Air Pollutant Emissions Trends** (Data file: "National Tier 1 CAPS Trends, Criteria pollutants National Tier 1 for 1970–2022").

Criteria Air Pollutant Trends | Lead

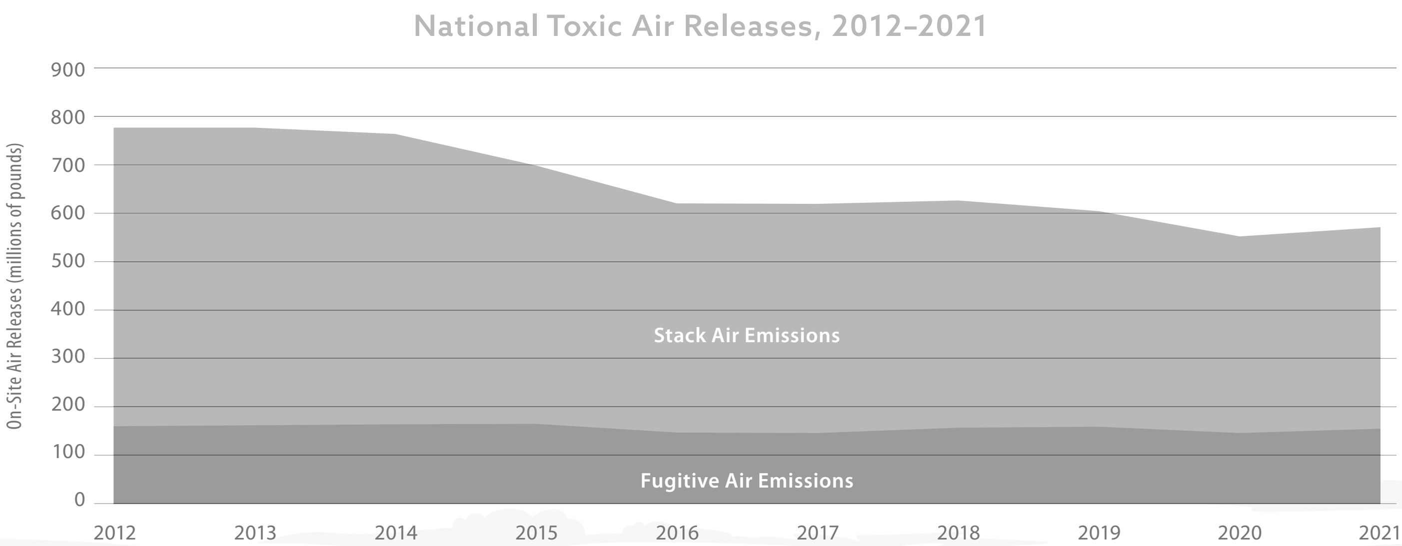


Source: U.S. EPA, **Lead Trends**, August 2022.

Hazardous Air Pollutants

As reported to U.S. EPA's *2021 Toxic Release Inventory National Analysis*, emissions of hazardous air pollutants, or air toxics, have continued to trend downward over the past decade. From 2012 to 2021, reported on-site toxic air releases decreased by 26 percent, from approximately 774.6 million pounds in 2012 to 571.2 million pounds in 2021, for a total reduction of about 203.4 million pounds.

Compared to 2020, national toxic air releases increased in 2021 by 3 percent. Sectors contributing the largest quantities of air releases during 2021 included chemical manufacturing (168.0 million pounds, or 29 percent), paper manufacturing (115.8 million pounds, or 20 percent), and electric utilities (64.5 million pounds, or 11 percent).[62]

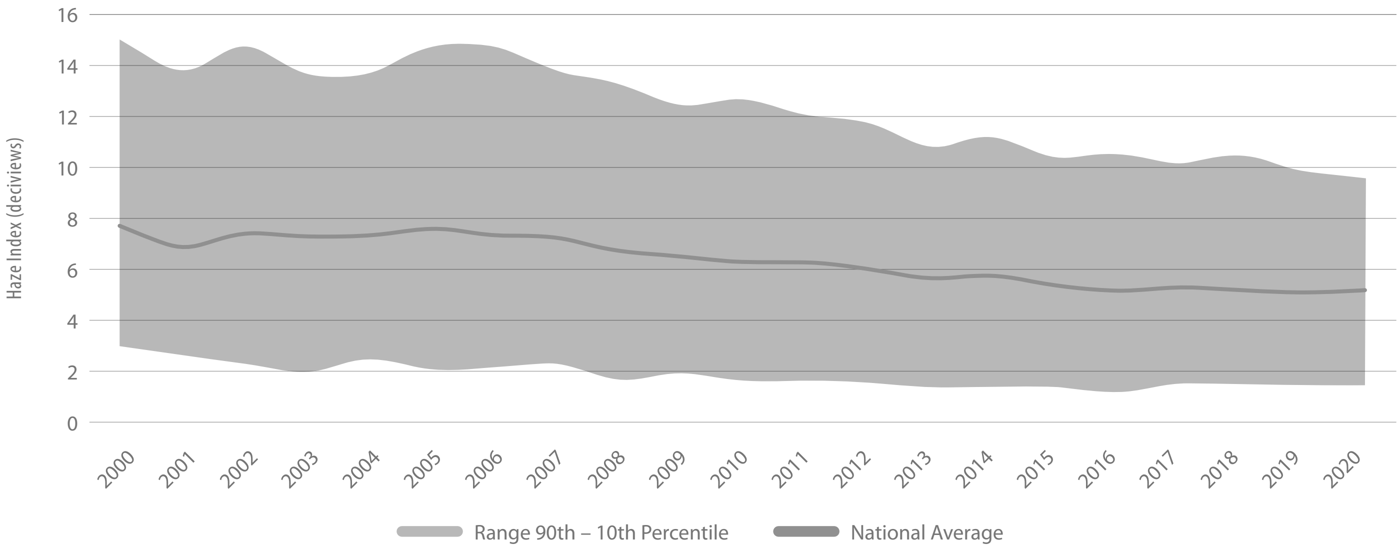


U.S. EPA, *2021 Toxic Release Inventory National Analysis*, March 16, 2023.

Visibility Improvements

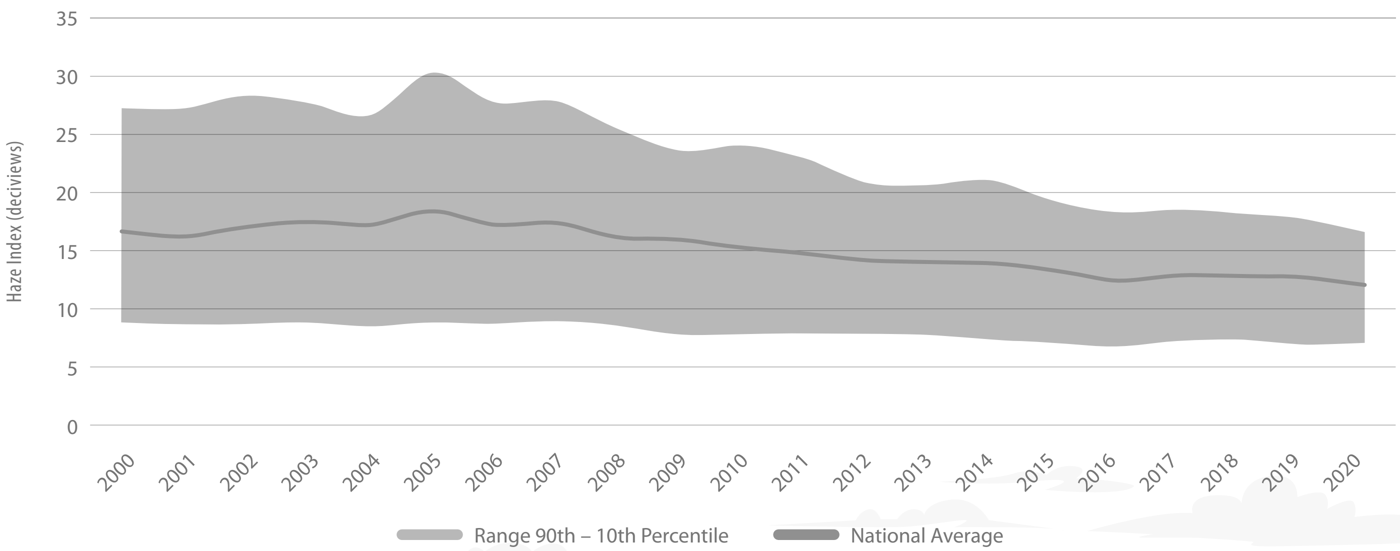
Under the Regional Haze Program, state and federal agencies monitor visibility in 156 national parks and wilderness areas, or Class I areas. U.S. EPA's 2021 report on air trends provides visibility data for Class I areas through 2020. Since 2000, visibility on the 20 percent clearest days has improved by nearly 33 percent, while there has been a 28 percent improvement in visibility during the 20 percent most impaired days.[63]

National Visibility Trends on Clearest Days, 2000–2020



Source: U.S. EPA, *Our Nation's Air: Trends Through 2021* (Section: "Visibility Improves in Scenic Areas"), June 2022.

National Visibility Trends on Most Impaired Days, 2000–2020



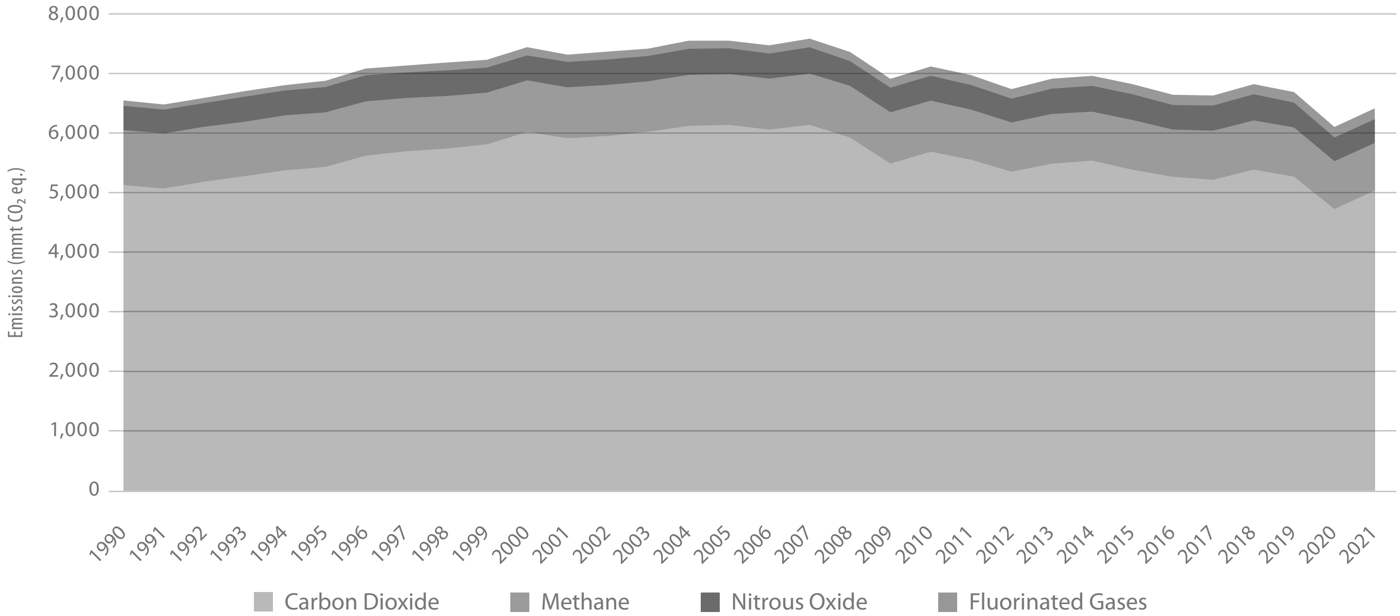
Source: U.S. EPA, Our Nation's Air: Trends Through 2021 (Section: "Visibility Improves in Scenic Areas"), June 2022.

Greenhouse Gas Trends

Released in April 2023, U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021* documents that gross greenhouse gas emissions in the United States totaled 6,340.2 million metric tons of carbon dioxide equivalents (mmt CO_2 eq.) in 2021, a 2.3 percent decrease from 1990 levels.

In 2021, after accounting for sequestration from the land sector, U.S. EPA's *Inventory* finds that the nation's greenhouse gas emissions totaled 5,586.0 mmt CO_2 eq., an increase of 6 percent from the prior year and 17 percent below 2005 levels.[64]

U.S. Greenhouse Gas Emissions by Gas, 1990–2021



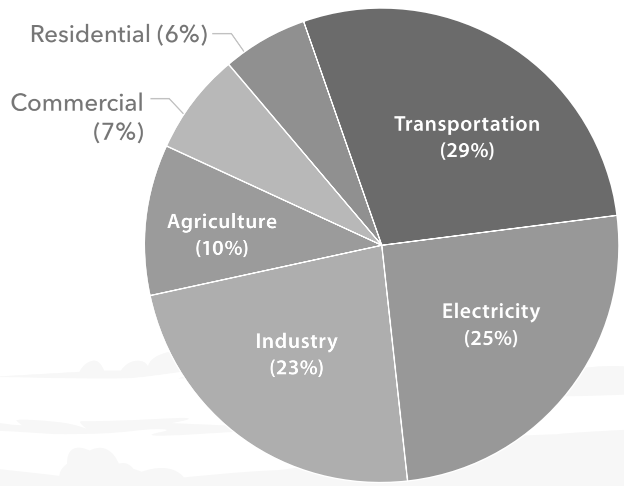
Source: U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*, April 2023. See U.S. EPA's **Greenhouse Gas Inventory Data Explorer**.

U.S. Greenhouse Gas Emissions by Economic Sector, 2021

Greenhouse gas (GHG) emissions in 2021 were from the following primary economic sectors:

- 29 percent from transportation, up 18.6 percent from 1990;
- 25 percent from electricity generation, down 15.7 percent from 1990;
- 23 percent from industry, down 11.3 percent since 1990;
- 10 percent from agriculture, up 7.2 percent since 1990;
- 7 percent from commercial, down 1.8 percent from 1990; and,
- 6 percent from residential, up 5.8 percent from 1990.

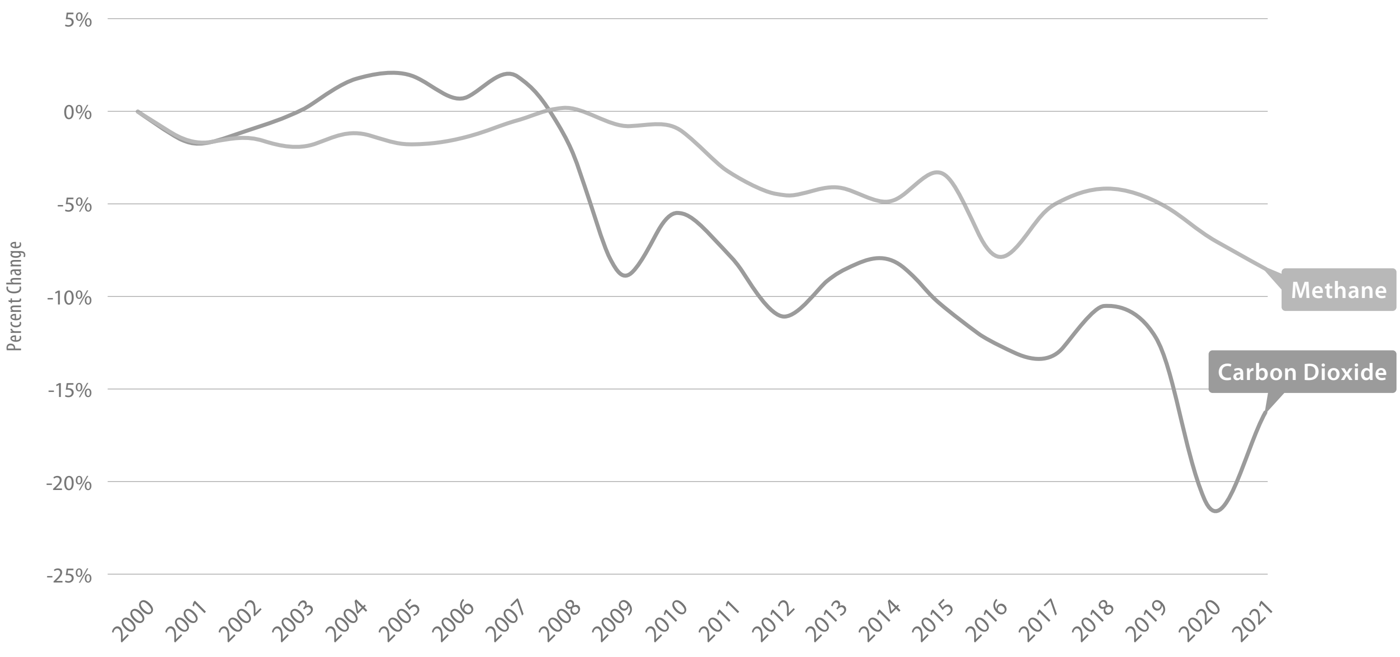
Source: U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*, April 2023. See U.S. EPA's **Greenhouse Gas Inventory Data Explorer**.



Greenhouse Gas Trends

U.S. EPA's *Inventory* also shows that, from 2000 to 2021, the United States reduced annual carbon dioxide emissions from 6,010.1 million metric tons of carbon dioxide equivalents (mmt CO_2 eq.) to 5,032.2 mmt CO_2 eq., a 16 percent decline.[65] Annual U.S. emissions of methane went from 867.8 mmt CO_2 eq. in 2000 down to 793.4 mmt CO_2 eq. in 2021, equivalent to a 9 percent decline.[66]

Percent Change of U.S. Emissions of Carbon Dioxide and Methane, 2000–2021



Source: U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*, April 2023.

Recent Headlines from the U.S. Energy Information Administration (EIA)

U.S. coal shipments increased slightly in 2022 as power plants replenished stockpiles | April 26, 2023

U.S. natural gas production grew by 4% in 2022 | March 29, 2023

Renewable generation surpassed coal and nuclear in the U.S. electric power sector in 2022 | March 27, 2023

Coal was the largest source of electricity generation for 15 states in 2021 | December 7, 2022

Nearly a quarter of the operating U.S. coal-fired fleet scheduled to retire by 2029 | November 7, 2022

U.S. natural gas production set a new record in 2021 | October 12, 2022

Carbon intensity of U.S. power generation continues to fall but varies widely by state | September 13, 2022

In the first half of 2022, 24% of U.S. electricity generation came from renewable sources | September 9, 2022

Energy production declined by record amounts in several states in 2020 | August 8, 2022

Energy use fell during 2020 in all U.S. states except Alaska | July 21, 2022

Fossil fuel sources accounted for 79% of U.S. consumption of primary energy in 2021 | July 1, 2022

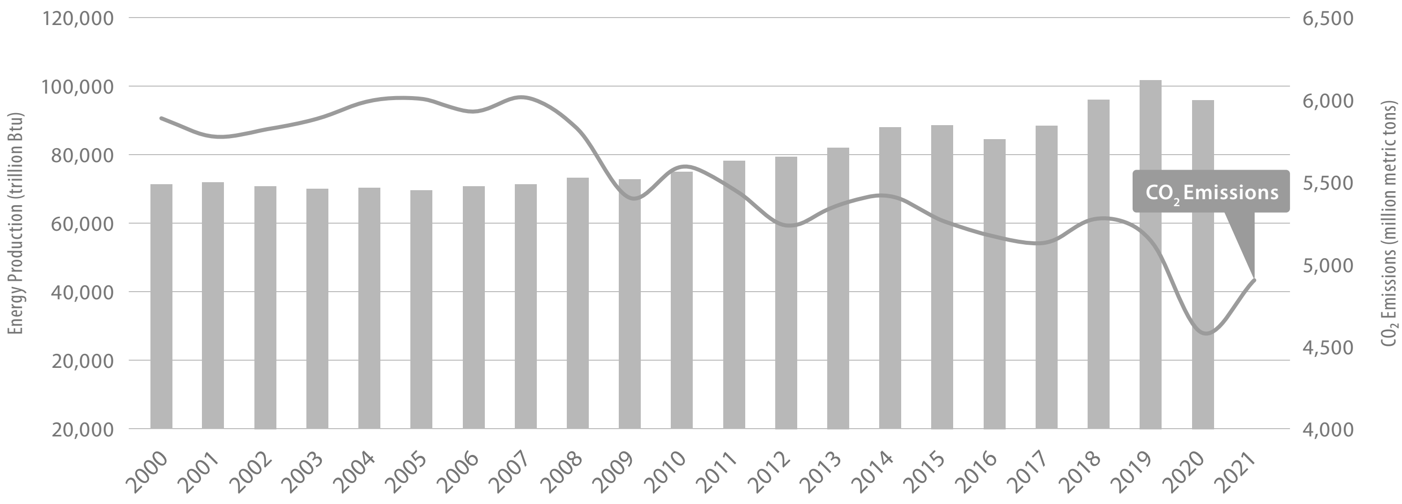
U.S. energy-related CO2 emissions rose 6% in 2021 | May 13, 2022

Greenhouse Gas Trends | Energy-Related Carbon Dioxide Emissions

According to recent data from the U.S. Energy Information Administration, or EIA, United States energy-related carbon dioxide (CO_2) emissions fell by almost 17 percent from 2000 to 2021, from 5,888.6 million metric tons in 2000 to 4,902.5 million metric tons in 2021.[67]

U.S. EIA data also shows that total U.S. energy production increased by 34 percent from 2000 to 2020, from 71,238 trillion British thermal units (Btu) in 2000 to 95,711 trillion Btu in 2020.[68]

U.S. Total Energy Production Compared to Energy-Related CO_2 Emissions, 2000–2021

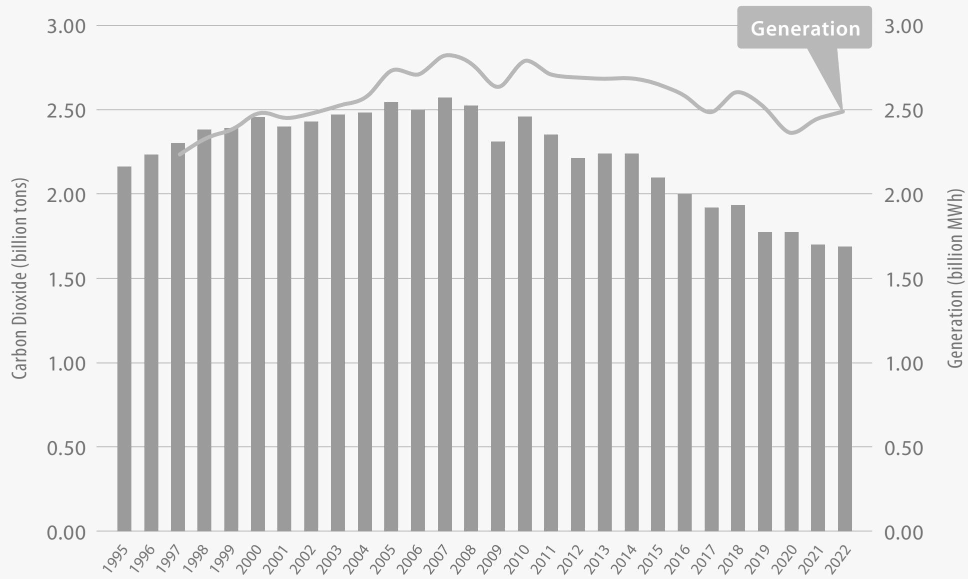


Source: U.S. EIA, **Annual Energy Outlook 2023** (Section: "Emissions"), March 16, 2023; U.S. EIA, **State Energy Data System (SEDS): 1960–2020**.

U.S. Power Plant Emissions Trends | Annual CO_2 Emissions, 1995–2022

U.S. EPA's annual progress report on emissions from the power sector documents that CO_2 emissions from electricity generation declined by 21 percent from 1995 to 2021, during which time gross generation grew nearly 7 percent. From 2021 to 2022, U.S. CO_2 emissions decreased slight by 1 percent, while generation rose by 2 percent.

Source: U.S. EPA, **Power Plant Emission Trends**, February 2023.



Sources

Types of Air Quality Data and Metrics

[1] **42 U.S.C. §7409(b)**.

[2] U.S. EPA **states**: "Units of measure for the standards are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air ($\mu g/m^3$)."

[3] A chart of the primary and secondary NAAQS by pollutant, which includes averaging time, level, and form, can be found **here**.

[4] **42 U.S.C. §7409(d)**.

[5] U.S. EPA, **Air Quality System**. U.S. EPA notes that the AQS "also contains meteorological data, descriptive information about each monitoring station (including its geographic location and its operator), and data quality assurance/quality control information."

[6] Links to data summary files for national criteria pollutant trends can be found **here.**

[7] Data can be found **here**. U.S. EPA notes: "The latest version of the 1970 – 2022 data show the trends for Tier 1 categories which distinguish pollutant emission contributions among major source types… As inventory methods are improved over time, for some emission sources an improved estimation method may be applied 'backwards' to previous year trend estimates."

[8] More information on the NEI can be found **here**. U.S. EPA states: "The NEI is built using the Emissions Inventory System (EIS) first to collect the data from State, Local, and Tribal air agencies and then to blend that data with other data sources."

[9] U.S. EPA, **Air Quality Design Values**.

[10] U.S. EPA, **Toxics Release Inventory (TRI) Program**. Annual TRI National Analysis **here**. U.S. EPA notes that the TRI "is a resource for learning about toxic chemical releases and pollution prevention activities reported by industrial and federal facilities. TRI data support informed decision-making by communities, government agencies, companies, and others. Section 313 of the *Emergency Planning and Community Right-to-Know Act* (EPCRA) created the TRI Program."

[11] U.S. EPA, **Air Quality – National Summary**. See also: U.S. EPA, ***Our Nation's Air: Trends Through 2021***, June 2022 (Section: "**Visibility Improves in Scenic Areas**").

[12] U.S. EPA, **Power Sector Programs – Progress Report**.

[13] U.S. EPA releases the Inventory of ***U.S. Greenhouse Gas Emissions and Sinks*** each April. See also: U.S. EPA, **Greenhouse Gas Inventory Data Explorer**.

[14] U.S. EIA, ***Annual Energy Outlook 2023***, March 16, 2023.

AAPCA Member State Air Trends & Successes

[15] U.S. EPA, **Air Pollutant Emissions Trends Data** (Data file: "State Tier 1 CAPS Trends," Criteria pollutants State Tier 1 for 1990–2022).

[16] U.S. Bureau of Economic Analysis, "**Gross Domestic Product by State, 4th Quarter 2022 and Year 2022 (Preliminary)**," released March 31, 2023.

[17] U.S. Office of Highway Policy Information, data available **here**.

[18] U.S. Census Bureau, data available **here**.

[19] U.S. EIA, **Energy-Related CO_2 Emission Data Tables**. Table 1. State energy-related carbon dioxide emissions by year.

[20] U.S. EIA, **State Energy Data Systems (SEDS): 1960–2020**.

[21] U.S. EPA's Green Book can be found **here**.

[22] U.S. EPA's listing of areas designated nonattainment or maintenance for the 1997 annual $PM_{2.5}$ NAAQS can be found **here**. In 2012, the NAAQS for $PM_{2.5}$ was lowered to 12.0 $\mu g/m^3$, based on an annual arithmetic mean averaged over three years (the 2006 review maintained the 1997 NAAQS). In 2020, U.S. EPA **retained** the 2012 standard of 12.0 $\mu g/m^3$. In June 2021, U.S. EPA announced the **reconsideration** of the 2020 decision to retain the 2012 $PM_{2.5}$ standards. On January 6, 2023, U.S. EPA announced the **proposed decision** for the reconsideration of the NAAQS for PM.

[23] U.S. EPA defines a design value as "a statistic that describes the air quality status of a given location relative to the level of the [NAAQS]." More information is available **here**.

[24] U.S. EPA's **Air Quality System** "contains ambient air pollution data collected by EPA, state, local, and tribal air pollution control agencies from over thousands of monitors."

[25] U.S. EPA, **Air Quality Design Values** (Data file: "$PM_{2.5}$ Design Values, 2021"). Data for this chart is based on overlapping three-year averages beginning with 2000–2002 and ending with 2019–2021.

[26] U.S. EPA's listing of areas designated nonattainment or maintenance for the 2012 $PM_{2.5}$ NAAQS can be found **here**.

[27] U.S. EPA's listing of areas designated nonattainment or maintenance for the 2008 ozone NAAQS can be found **here**. In 2015, U.S. EPA lowered the NAAQS for ozone to 0.070 parts per million (ppm), based on the annual fourth-highest daily maximum 8-hour average concentration, averaged over three years. In 2020, U.S. EPA **retained** the 2015 standard of 0.070 ppm. In October 2021, U.S. EPA announced the **reconsideration** of the 2020 decision to retain the 2015 ozone standards.

[28] U.S. EPA, **Air Quality Design Values** (Data file: "Ozone Design Values, 2021"). Data for this chart is based on overlapping three-year averages beginning with 2000–2002 and ending with 2019–2021.

Sources *(continued)*

[29] U.S. Energy Information Administration, **State Energy Data System (SEDS): 1960–2020**.

[30] U.S. EPA, **Air Pollutant Emissions Trends Data** (Data file: "State Tier 1 CAPS Trends," Criteria pollutants State Tier 1 for 1990–2022).

[31] More information on U.S. EPA Clean Air Markets Programs can be found **here**, and include the **Acid Rain Program** (ARP), the **Cross-State Air Pollution Rule** (CSAPR), and the **CSAPR Update**.

[32] U.S. EPA, "**State-by-State SO_2 Emissions from CSAPR and ARP Sources, 1990–2021**," July 2022.

[33] U.S. EPA, "**State-by-State NO_X Emissions from CSAPR and ARP Sources, 1990–2021**," July 2022.

[34] U.S. Energy Information Administration, **Energy-Related CO_2 Emission Data Tables**. Table 3. State energy-related carbon dioxide emissions by sector.

[35] U.S. EPA recognizes that there will be differences between the EPA's state-level GHG estimates and some inventory estimates developed independently by individual state governments. Inventory data presented **here** should not be viewed as official data of any state government. More information is available here, including official state greenhouse gas inventories **here**.

[36] U.S. Energy Information Administration (EIA), **State Energy Data System (SEDS) 1960–2020**; U.S. EIA, **Energy-Related CO_2 Emission Data Tables**. Table 1. State energy-related carbon dioxide emissions by year.

[37] U.S. Energy Information Administration, **Energy-Related CO_2 Emission Data Tables**. Table 7. Carbon intensity of the economy by state.

[38] U.S. EPA, ***2021 Toxic Release Inventory (TRI) National Analysis***, March 2023.

[39] U.S. EPA Toxic Release Inventory Explorer, **2021 TRI Factsheets**.

[40] See U.S. EPA's **State Air Dashboard**, part of **Enforcement and Compliance History Online (ECHO)**.

[41] See U.S. EPA's **State Air Dashboard**, part of **Enforcement and Compliance History Online (ECHO)**. Data accessed April 27, 2023.

[42] U.S. EPA's ECHO **Air Dashboard** reports the following as Clean Air Act compliance monitoring activities: Full Compliance Evaluation (FCE), Partial Compliance Evaluation (PCE), Stack Test, and Title V Annual Compliance Certification (TVACC) Reviews.

[43] See U.S. EPA's **State Air Dashboard**, part of **Enforcement and Compliance History Online (ECHO)**. Data accessed April 27, 2023.

[44] See U.S. EPA's **State Air Dashboard**, part of **Enforcement and Compliance History Online (ECHO)**. Data accessed April 27, 2023.

American Air Quality in an International Context

[45] U.S. EPA, ***Our Nation's Air: Trends Through 2021***, June 2022.

[46] U.S. EPA, ***Our Nation's Air: Trends Through 2021***, June 2022.

[47] World Bank, **GDP Listings by Country**, March 30, 2023.

[48] World Bank, **GDP Listings by Country**, March 30, 2023.

[49] IEA maintains country profiles on key energy statistics, including energy production. More information on the United States can be found **here**, and China **here**.

[50] U.S. Energy Information Administration, **State Energy Data System (SEDS): 1960–2020**, June 24, 2022.

[51] U.S. Census Bureau, **Current Population**.

[52] U.S. Census Bureau, **Population and Housing Estimates**.

[53] Synthesized measurements of aerosol optical depth acquired by the National Aeronautics and Space Administration (NASA) **Moderate Resolution Imaging Spectroradiometer** (MODIS), **Multi-angle Imaging SpectroRadiometer** (MISR), and **Sea-viewing Wide Field-of-view Sensor** (SeaWiFS).

[54] Southerland, V. et al., "Global urban temporal trends in fine particulate matter ($PM_{2.5}$) and attributable health burdens: estimates from global datasets," *The Lancet Planetary Health*, January 05, 2022. Available at: **https://doi.org/10.1016/S2542-5196(21)00350-8**.

[55] Anenberg, S. et al., "Long-term trends in urban NO_2 concentrations and associated pediatric asthma incidence: estimates from global datasets," *The Lancet Planetary Health*, January 2022. Available at: **https://doi.org/10.1016/S2542-5196(21)00255-2**.

[56] More information on IEA's *Greenhouse Gas Emissions from Energy* database and methodology can be found **here**.

[57] International Energy Agency, ***Greenhouse Gas Emissions from Energy Highlights***, September 2022.

Air Quality Trends in the United States

[58] U.S. EPA, **Air Quality—National Summary: Air Quality Trends** (updated June 1, 2022).

[59] U.S. EPA, **Air Quality—National Summary: Emissions Trends** (updated June 1, 2022). Note: "EPA estimates nationwide emissions of ambient air pollutants and the pollutants they are formed from (their precursors). These estimates are based on actual monitored readings or engineering calculations of the amounts and types of pollutants emitted by vehicles, factories, and other sources. Emission estimates are based on many factors, including levels of industrial activity, technological developments, fuel consumption, vehicle miles traveled, and other activities that cause air pollution."

Sources *(continued)*

[60] U.S. EPA, **Air Quality—National Summary: Emissions Trends** (updated June 1, 2022).

[61] U.S. EPA, **Air Pollutant Emissions Trends Data** (Data file: "National Tier 1 CAPS Trends," Criteria pollutants National Tier 1 for 1970–2022).

[62] U.S. EPA, ***2021 Toxic Release Inventory National Analysis***, March 2023.

[63] U.S. EPA, ***Our Nation's Air: Trends Through 2021***, June 2022 (Section: "**Visibility Improves in Scenic Areas**"). A full listing of Class I Areas under U.S. EPA's Regional Haze program can be found **here**.

[64] U.S. EPA, ***Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021***, April 2023. U.S. EPA's *Inventory* "provides a comprehensive accounting of total greenhouse gas emissions for all man-made sources in the United States."

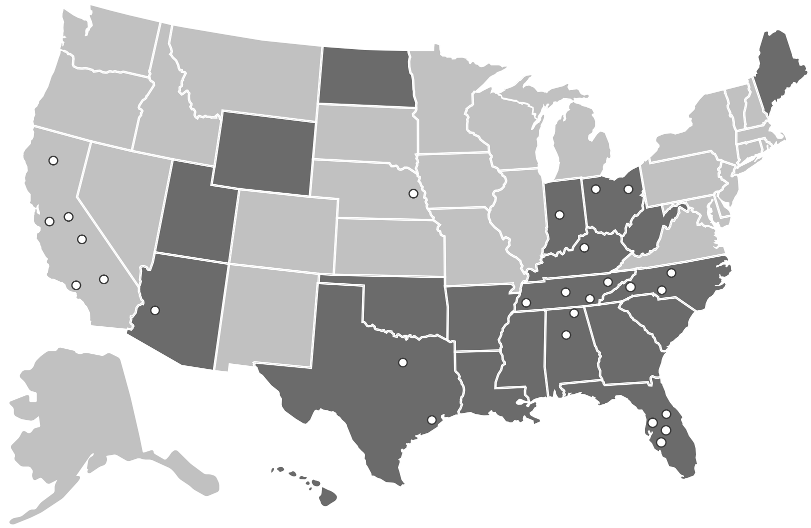
[65] U.S. EPA, ***Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021***, April 2023.

[66] U.S. EPA, ***Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021***, April 2023.

[67] U.S. EIA, **State Energy Data System (SEDS): 1960–2020**, June 24, 2022.

[68] U.S. Energy Information Administration, ***Annual Energy Outlook 2023***, March 16, 2023 (Section: "Emissions"). Includes the following sectors: transportation, industrial, electric power, residential, and commercial.

Air Quality Resources



AAPCA State Agencies

- Alabama Department of Environmental Management
- Arizona Department of Environmental Quality
- Arkansas Division of Environmental Quality
- Florida Department of Environmental Protection
- Georgia Environmental Protection Division
- Hawaii Department of Health
- Indiana Department of Environmental Management
- Kentucky Division for Air Quality
- Louisiana Department of Environmental Quality
- Maine Department of Environmental Protection
- Mississippi Department of Environmental Quality
- North Carolina Department of Environmental Quality
- North Dakota Department of Environmental Quality
- Ohio Environmental Protection Agency
- Oklahoma Department of Environmental Quality
- South Carolina Department of Health & Environmental Control
- Tennessee Department of Environment & Conservation
- Texas Commission on Environmental Quality
- Utah Department of Environmental Quality
- West Virginia Department of Environmental Protection
- Wyoming Department of Environmental Quality

AAPCA Local Agencies

- Asheville-Buncombe Air Quality Agency (NC)
- Butte County Air Quality Management District (CA)
- Canton City Health Department Air Pollution Control Division (OH)
- Chattanooga-Hamilton County Air Pollution Control Bureau (TN)
- City of Fort Worth Environmental Quality Division (TX)
- City of Huntsville Natural Resources Office (AL)
- City of Indianapolis (IN)
- El Dorado County Air Pollution Control District (CA)
- Environmental Protection Commission of Hillsborough County (FL)
- Forsyth County Office of Environmental Assistance & Protection (NC)
- Galveston County Health District, Air & Water Pollution Services (TX)
- Jefferson County Department of Health, Air & Radiation Protection Division (AL)
- Knox County Air Quality Management (TN)
- Louisville Metro Air Pollution Control District (KY)
- Manatee County Environmental Protection Division (FL)
- Maricopa County Air Quality Department (AZ)
- Mecklenburg County Air Quality (NC)
- Mojave Desert Air Quality Management District (CA)
- Nashville-Davidson Metro Public Health Department (TN)
- Omaha Air Quality Control Division (NE)
- Orange County Air Quality Management (FL)
- Pinellas County Air Quality Monitoring Program (FL)
- San Joaquin Valley Air Pollution Control District (CA)
- Shelby County Health Department (TN)
- Toledo Division of Environmental Services (OH)
- Ventura County Air Pollution Control District (CA)
- Yolo-Solano Air Quality Management District (CA)

Additional Air Quality Resources

- U.S. EPA Air Quality Trends Website
- U.S. EPA Nonattainment Areas for Criteria Pollutants (Green Book)
- U.S. EPA Report on the Environment (ROE)
- U.S. EPA Air Quality Index (AQI)
- U.S. EPA Power Plant Emissions Trends
- Environmental Council of the States ECOS Results
- Western Regional Air Partnership (WRAP) Regional Haze Storyboard

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ACT OHIO
AFFILIATED CONSTRUCTION TRADES

Chairman Riordan McClain
Ohio House Transportation Committee
41 S. High Street
Columbus, OH 43215

Chairman McClain, Vice Chair Dobos, Ranking Member Grim, and members of the House Transportation Committee:

Please be advised that the Affiliated Construction Trades Ohio Foundation ("ACT Ohio") is a 501(c)(5) organization created to help foster economic and industrial development opportunities, and to promote industry-best practices for Ohio's public and private construction. ACT Ohio currently has 141 local affiliates across the state, who in the aggregate represent more than 97,000 building trades members.

ACT Ohio supports an all-of-the-above energy strategy for the state of Ohio. For decades, Building Tradespeople have built and have maintained our state's oil refineries, oil and gas pipelines, coal- and natural gas-fired power plants, and nuclear energy facilities. In addition, Ohio's Building Trades unions are leading the state in training construction workers to build and maintain the infrastructure required to incorporate wind, solar, hydropower, and alternative fuels infrastructure into Ohio's energy portfolio. Finally, we are proud to partner with Ohio's automotive and advanced manufacturing leaders to ensure that the construction of their plants results in world-class quality and efficiency for their future operations.

The electrification of motor vehicles is a growth area for our members. We support investment in the modernization of Ohio's electric grid and generation infrastructure. ACT Ohio supports policies that ensure Electric Vehicle Supply Equipment is installed by tradespeople with an Electric Vehicle Infrastructure Training Program (EVITP) certification or another EVSE-specific training course offered through an electrical Registered Apprenticeship Program. With continued investment in the coming decades, Ohio's EV infrastructure can provide industry and the public with increased sustainable transportation options.

However, EV mandates and vehicle emissions standards that exceed federal EPA standards have the potential to cause economic harm should such requirements be imposed on industries, governmental bodies, and consumers.

ACT Ohio supports the protections that HB 201 provides to industry and consumers by prohibiting the restriction on the use or sale of motor vehicles based on power/fuel source.

Thank you to the members of the House Transportation Committee for considering ACT Ohio's support for HB 201. If you have any questions, please do not hesitate to contact me at (614) 795-3164 or mszollosi@actohio.org.

June 20, 2023

Chairman McClain, Vice Chairman Dobos, Ranking Member Grim and Members of the House Transportation Committee, I wish to thank you for allowing Consumer Energy Alliance (CEA) the opportunity to offer proponent testimony on House Bill 201. My name is Chris Ventura, and I am the Executive Director of Consumer Energy Alliance-Midwest.

On behalf of CEA, I wish to share our strong support for HB 201 that has been introduced by Representatives Hillyer and Demetriou. We believe this legislation will offer important consumer protections for all Ohioans with mobility requirements, especially those struggling to get by and those living on fixed incomes.

CEA is the nation's leading consumer energy and environmental advocate – ensuring families, farmers, and local businesses have access to sustainably produced, affordable, reliable and environmentally responsible energy. Our diverse membership represents a cross-section of the economy, all of whom have been impacted by rising inflation and higher energy prices.

We support a rational, all-of-the-above energy policy that provides the options to utilize all our domestic natural resources – both traditional and renewable – while ensuring robust environmental protections are in place. And, quite simply, HB 201 is commonsense legislation that ensures consumers can continue to have options and choose vehicles that meet their mobility needs.

As consumers become more accepting of electric vehicles (EV), taxpayer-funded incentives expand, and automobile manufacturers produce a greater variety of models, EV purchases are expected to keep growing. Despite this, policymakers in several states have embarked on a regulatory regime designed to prematurely force a market transition without holistically examining the impacts these mandates will have on consumers.

Our latest report, *Freedom to Fuel: Consumer Choice in the Automotive Marketplace* reviewed several fundamental questions which policymakers in other states failed to consider – questions which must be asked to ensure consumer acceptance, reduce negative economic and societal impacts, and mitigate against consumer backlash against EVs. Some of these questions include:

- What is the true cost to consumers of moving from internal combustion engine-powered vehicles to electric vehicles?
- What electric generation requirements and transmission investments are necessary to power a move to electric vehicles?
- How does a transition and vehicle affordability affect equitable job growth in the United States?

Unfortunately, by not addressing these questions, consumers are driven to purchase products they aren't ready to accept, they can't afford to purchase, and that face significant supply-chain bottlenecks.

Looking at total cost of ownership, there is a $16,360 upfront price difference between EV and ICE vehicles - more than two times the federal tax credit. As a result, the break-even point for families in the United States would be close to 24 years.

While the push to transition to EVs from ICE vehicles is an effort to shift to a low-carbon economy, the shift from a transportation system based on liquid fuels to one based on electricity is far more complicated and costly than most decision-makers in other states – and the federal government – have considered.

Nationally, there are about 250 million light-duty vehicles, clocking over 2.8 trillion miles every year. This would require over 1 trillion Kwh/year of new generation. To account just for the increase in electricity usage to power light-duty vehicles, over the next decade we would need to build the equivalent of 122 new nuclear stations, or almost 284,000 MW of onshore wind capacity.

More than generation, investments in transmission and distribution would also be required. Brattle identified $15-$25 billion in required upgrades for transmission and distribution systems, and another $30-$50 billion for charging infrastructure as automobiles to transition just 7% of the US light-duty vehicle fleet.

Some in the policy debate over EV mandates believe that the benefits of shifting the public to EVs is helpful to working-class and lower-income families. Typically, this focuses exclusively on lowering vehicle emissions which have indirect health benefits associated with environmental improvement. But, often ignored are the direct impacts on the practical use of EVs for a working-class family and how the benefits of an EV transition mostly flow to the wealthier segments of the population.

Charging infrastructure is a critical component for EV usage with access to chargers (and specifically fast chargers) a major consideration in purchasing an EV. Wealthier users are far more likely to live in single family homes where installation of a fast charger costing thousands of dollars is simply a matter of fact. Lower income families who are more likely to reside in apartments or rental properties do not have the option of installing their own personal dedicated fast chargers.

In fact, a recent MIT study on EVs and equity noted, "Black and Hispanic neighborhoods only had 0.7 times the access to public chargers." The researchers further posited that public charging, when available to lower income communities, typically costs more than home charging stating, "This higher cost would disproportionately affect low-income households who already pay a higher proportion of their income towards transportation."

Electric vehicles will play an important role in diversifying our vehicle mix, and, if integrated correctly, can help meet our shared environmental goals. Yet, it is increasingly clear that public officials and regulators in several states and at the federal level are either willfully ignoring or failing to fully consider all the implications of aggressively mandating EVs and banning ICE vehicles. Without adequately considering the impact this will have on consumers, acceptance of EVs will suffer as overall negative impacts on low- and middle- income earners will increase.

This is why HB 201 is critically important for consumers and why we urge the committee to pass this legislation.

Thank you, again, for the opportunity to provide comments on House Bill 201. I am happy to answer any questions the committee may have.

PBF HB 201 Testimony

- I'm Scott Hayes, Midwest GR Director for PBF Energy, which owns 6 oil refineries in the country, including the Toledo Refining Company. We are proud of our 130 year history of bringing high quality and affordable products to the market place.
- I'm here to support HB 201, which would prevent Ohio from adopting attempts to literally ban gasoline and diesel powered vehicles, as is sadly occurring in other states.
- While the federal government is the predominant entity that can set vehicle efficiency standards, there is a carve out in the Clean Air Act that allows California to set its own standards and then allows states to opt into California's requirements.
- Unfortunately, California is now looking to grossly abuse this provision of the law to literally ban the sale of all gasoline and diesel powered vehicles in 2035; just over 10 years from now. If successful, electric vehicles will be the only cars auto dealers can sell come that date.
- Several states are already trying to "opt in" to California's car ban, despite auto manufacturers all indicating such mandates are unachievable. These mandates are often being advanced with the stroke of a Governor's pen or pursuant to prior laws that automatically adopt any new standard California advances.
- Simple consideration of these mandates can have unintended consequences for consumers and the economy; specifically as it pertains to tradition fuel supplies and refining jobs.
- Refineries plan out a timeline for major maintenance and capital projects, which entail hundreds of millions of dollars of investment, over the span of up to five years.
- Major turnarounds occur every 1 to 2 years and cost between $50–250 million, but these projects are planned for three to five years in advance.
- Banning traditional vehicles sends a message that refineries are not wanted, which can lead investors to advocate forgoing capital projects and, in some cases, premature asset closures rather than waiting to see if aspirational mandates, coupled with adverse market cycles, prevent a return on massive expenditures.
    - Such circumstances could similarly threaten biofuel production, since electric vehicles obviously cannot run on ethanol or renewable diesel.
- California's announced EV mandate, coupled with other costly regulations in the state, have been frequently cited for the net loss of over 218,000 barrels per day of fuel supply and more than 1,000 direct job losses, leaving the state short fuel relative to demand, without sufficient electric vehicle penetration to compensate for lost fuel supplies.
- Diminished fuel supplies, coupled with extensive regulatory costs, are why California persistently has the nation's highest fuel prices and is now becoming dependent on foreign gasoline and diesel fuel imports.
- Ohio's fuel supply and consumers cannot run the risk of these policies proliferating.

- HB 201 is important to send the opposite policy signal from what is being advanced in California and other states. It prevents any state agency or Administration from trying to limit consumer choice and threaten the state's energy security by advancing gasoline and diesel powered vehicle bans.
- In doing so, it will protect consumer choice, jobs and Ohio's energy security.
- Finally, I'd also like to note that the current supply chain for electric vehicles is almost completely reliant on foreign minerals, often mined with child and slave labor, and Chinese manufacturing.
- Current federal incentives can hopefully start to re-shore some elements of these supply chains, but that will not happen in a decade. We have seen the adverse impacts of ceding our energy security to foreign powers and should not look to advance new policies that will erode American energy security even more extensively.

OHIO AUTOMOBILE DEALERS ASSOCIATION

OADA

June 20, 2023

Chairman McClain, Vice Chairman Dobos, Ranking Member Grim and members of the Ohio House Transportation Committee, on behalf of our over 800 franchised dealer members, we are writing to express our support for House Bill 201, which would prohibit government entities from restricting the sale or use of a motor vehicle based on the vehicle's energy source. The bill would also prohibit a state agency from adopting the California emissions standards for motor vehicles.

Our member dealers sell vehicles that run on a variety of energy sources – gas, diesel, hydrogen, electricity, or a combination of these sources (hybrid). Having options is what our customers want and expect from us. Some of the factors that our customers consider when purchasing a vehicle include price, vehicle features, work commute, family size, rural or urban location, electric charging infrastructure availability, and a host of others. We believe that the proposed legislation protects and ensures that customers have the full range of options when purchasing their next motor vehicle. Having a market driven 'menu' of different types of vehicles to choose from is helpful to our customers.

It is also important to note that our manufacturers are investing significantly to make vehicles more fuel efficient. They will continue to respond to market changes and expectations, which includes producing cleaner vehicles that our customers want to drive. Manufacturers are responding to consumer demand, and we support providing options to our customers to meet their needs and expectations.

We appreciate joint sponsors Hillyer and Demetriou for bringing this issue before you for debate.

Please contact us with any questions.

Zach Doran
President
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VP, Government Relations
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June 20, 2023

Ohio House of Representatives
Transportation Committee
1 Capitol Square
Columbus, OH 43215

RE: Support for House Bill 201

Dear Chairman McClain, Vice Chair Dobos, Ranking Member Grim, and members of the House Transportation Committee:

The American Fuel & Petrochemical Manufacturers (AFPM) supports HB 201 and respectfully urges members of this Committee to support its passage. AFPM is a national trade association representing nearly all U.S. refining and petrochemical manufacturing capacity. Our members are also leading producers of renewable fuels such as renewable diesel and Ohio's farmers are an important part of the renewables supply chain. Ohio's four refineries support more than 80,000 jobs statewide and contribute $17 billion the state's economy each year.

AFPM supports reducing the carbon intensity of transportation, but policies must encourage competition and innovation to among fuel and vehicle technologies. Unfortunately, California is going in the wrong direction and exceeding its authority in an attempt to ban the sale of new combustion engines.

In August 2022, the California Air Resources Board (CARB) voted to adopt new emissions standards ("Advanced Clean Cars II") for light duty vehicles for model years 2026 through 2035. As a part of these new standards, a certain percentage of new vehicles sold within California – and the other participating states – must be either zero-emission vehicles (ZEV) or plug-in hybrid electric vehicles (PHEV); for model year 2026, 35 percent of new cars must be ZEVs or PHEVs, increasing to 100 percent by 2035, representing a total ban on the sale of new internal combustion engine vehicles powered by gasoline, diesel, or other liquid fuels.

Adopting California's regulations to ban the sale of new internal combustion engines would undermine consumer choice, harm Ohioans on low and fixed incomes, and present new national security and other challenges that have not yet been adequately considered or addressed. Motorists should be empowered to utilize the vehicular technologies that best suit the needs and desires of themselves and their families.

HB 201 would protect Ohioans by explicitly disallowing any state agency from adopting California's unrealistic emissions standards and vehicle mandates as Ohio's own. Federal emissions standards remain in place to ensure new cars sold in Ohio can be operated in a manner that ensures public health, safety, and environmental quality.

AFPM would like to thank Representatives Hillyer and Demetriou for their leadership on this matter and respectfully requests that members of the House Transportation Committee join them in supporting HB 201.

Thank you for the opportunity to provide these comments and for your consideration. For more information or if you have any questions, please do not hesitate to contact me at (202) 844-5526 or dthoren@afpm.org.

Sincerely,

Don Thoren
Vice President
State Government Affairs

Ohio Oil and Gas Association
Proponent Testimony
House Bill 201

House Transportation Committee
Chairman Riordan McClain
June 20, 2022

Mr. Chairman and members of the committee, my name is Stephanie Kromer, and I am the Director of Legislative & Regulatory Affairs of the Ohio Oil and Gas Association (OOGA). OOGA is a 75-year-old statewide trade association representing both independent conventional producers and large independent horizontal operators exploring Ohio's shale play. OOGA membership also consists of midstream companies, large-scale transmission line companies, contractors, oilfield service and supply providers, manufacturers, gas utilities and various other professional entities.

Thank you for the opportunity to offer proponent testimony in support of House Bill 201. House Bill 201 does two things; prohibits a state agency, township, or county from restricting the use or sale of a motor vehicle based on its energy source and prohibits the Ohio EPA or any other state agency from adopting any motor vehicle emissions standards that are established by California as a result of California having received a waiver to adopt stricter standards than those required by the federal Clean Air Act.

The bill ensures that Ohio will continue follow the Clean Air Act's strict emissions guidelines, while at the same time reinforcing that Ohio's elected officials and not unelected bureaucracies, will have the decision-making authority in regard to alternative emissions standards.

The bill smartly protects consumer choice by preventing local governments from developing a cumbersome patchwork of local ordinances under potentially unattainable guidelines.

A collection of states have adopted the California standards. These efforts in states to ultimately eliminate the internal combustion engine. There are too many undetermined variables to risk putting Ohio on such a path. A great example is in Maryland. The state's leadership recently announced their intentions to take an aggressive path on mandating electric vehicles that has backfired with the voters indicated by a recent poll in Maryland Matters[1].

By prohibiting state agencies and local governments from interfering in consumer choice, House Bill 201 will protect our state's overall economic competitiveness by preventing a patchwork of regulatory schemes and allowing Ohioans to decide what types of vehicles best suit their needs. For these reasons, the Ohio Oil and Gas Association respectfully asks the committee to favorably report House Bill 201.

Mr. Chairman and members of the committee, thank you for the opportunity to offer proponent testimony today. I would be happy to try and answer questions from the committee.

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[1] https://www.marylandmatters.org/2023/06/12/poll-about-60-of-marylanders-oppose-plan-to-mandate-electric-car-sales-by-2035/

CONSUMER ENERGY ALLIANCE
THE VOICE OF THE ENERGY CONSUMER

Freedom to Fuel:

Consumer Choice in the Automotive Marketplace

2023

Executive Summary

As consumers become more accepting of electric vehicles (EV), taxpayer-funded incentives expand, and automobile manufacturers produce a greater variety of models, EV purchases are expected to keep growing. The public and policymakers, however, should be increasingly mindful not to put the cart before the horse when it comes to centrally planned mandates that attempt to drive consumers to purchase products they aren't ready to accept, they can't afford to purchase, and that face significant supply-chain bottlenecks that are already limiting supply and increasing costs.

Substantial infrastructure investment — in both the EV charging network and the electric generation, transmission, and distribution systems — is needed before widespread adoption can occur. Banning gasoline and diesel-powered vehicles and forcing consumers to purchase EVs before states have the requisite infrastructure needed to support this will imperil the electric grid. Such policies will also be disadvantageous for consumers and the economy in terms of electric grid reliability and cost considerations.

During the last decade, as public policy action on climate and the environment has migrated from the federal to the state level, the automotive sector has found itself the subject of new regulations that could shake up the industry, and American vehicle choice, as never before. Where once it was incremental increases in Corporate Average Fuel Economy (CAFE) standards at the federal level that had the most impact on the industry, we now have EV mandates in place in several states and under consideration in quite a few more. Many of these mandates have been handed down without adequate cost-benefit or market impact analyses.

Massachusetts and New York have both enacted legislation banning new registrations of internal combustion engine light-duty vehicles starting in 2035.[1] California has pursued an EV mandate through an Executive Order and regulatory restrictions put into effect by the California Air Resources Board (CARB) that will ban sales of internal combustion engine vehicles as soon as 2035. Other states are opting into the California ICE ban or setting informal goals and targets. New Mexico recently set a goal of having 7% of all new vehicle sales be EVs by 2025. Michigan has set a goal of 2 million EVs on the road by 2030. Another half dozen states have set more modest targets, mostly by 2030 or 2035.

Most recently, the U.S. Environmental Protection Agency (USEPA) has released two new emissions rules that require 60% of all new vehicles sold to be only electric vehicles by 2030 and 67% by 2032.[2]

While there are clearly many reasons to pursue EV as a mobility option, the push by elected officials toward mandates or target EV sales goals by a certain date, often fail to take into account many of the real-world economic, social, and practical problems created by these sorts of regulations. Too often, the consumer is completely left out of the discussion.

What is also frequently left out of the discussion are the advances in new technologies – lower carbon fuels, hybrid electric vehicles, and fuel cells – that are moving us towards a lower-emission future while also offering families and businesses multiple, and sometimes better, choices to meet their driving needs and continue our march toward meeting our environmental goals.

It is becoming increasingly clear that policymakers are not fully considering all the implications of aggressively mandating EVs. This risks near- and long-term consumer acceptance of EVs and increases the likelihood of unintended consequences causing an overall negative reaction to the increased utilization of EVs. To avoid this possible outcome, policymakers should more carefully consider several critically important issues.

In an effort to ensure consumer acceptance for EVs and reduce negative economic and societal impacts, this paper raises many important topics that should be considered and poses questions that lawmakers and regulators should address before imposing mandates which will have a significant impact on the U.S. economy—and especially those living on low and fixed incomes.

Some of these questions include:

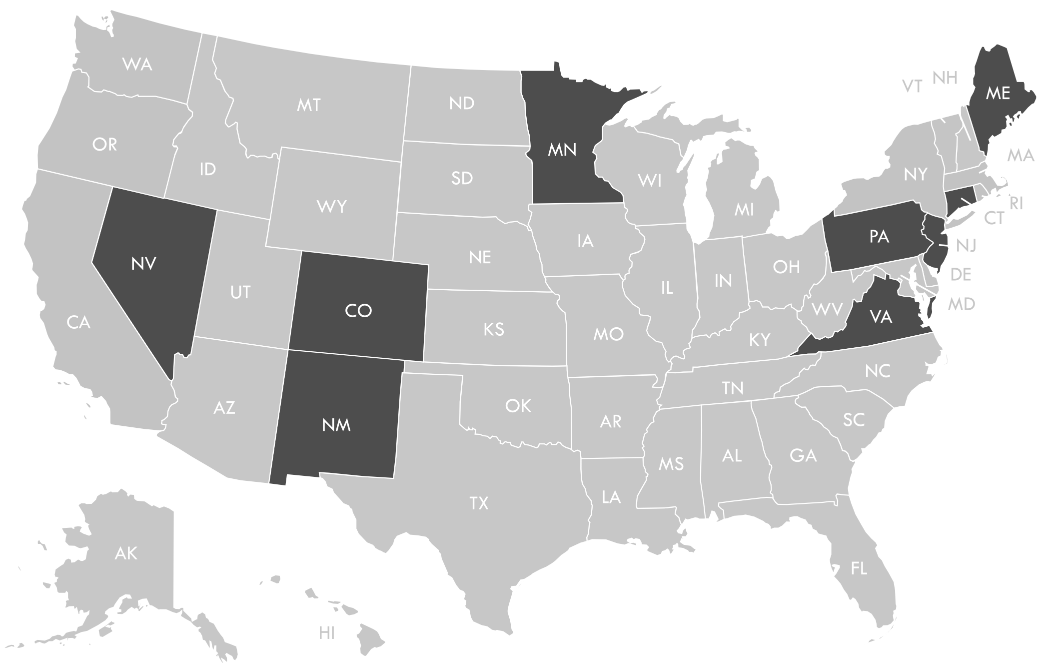
- What is a realistic timeframe for the United States to move its fleet to all-electric vehicles?
- What is the true cost to consumers of moving from internal combustion engine-powered vehicles to electric vehicles?
- What electric generation requirements are necessary to power a move to electric vehicles?
- What transmission investments are required to ensure consumers are able to conveniently charge electric vehicles?
- Is the supply chain for electric vehicles more or less advantageous to the national security prospects of the United States in comparison to ICE vehicles?
- With state transportation budgets primarily financed by gas and diesel fuel taxes, how will governments ensure our transportation infrastructure is adequately maintained?
- How does a transition and vehicle affordability affect equitable job growth in the United States?
- Is due consideration being given to EV affordability and current taxpayer-funded incentives, which at present can only be availed by higher-income earners and not the majority of Americans?

The EV Transition **by the Numbers**

Many states are considering mandates that force the transition from ICE vehicles to EVs either through executive orders or more likely, through the adoption of California's Advanced Clean Cars II regulations.[3] Unfortunately for many consumers, some states which have adopted California's regulations have triggers that automatically opt them into any future California regulatory regime for which the U.S. EPA provides a waiver. This denies residents and businesses of the affected states from having an opportunity to comment or provide meaningful input on policies that may greatly impact their everyday lives.

California's ZEV Rules Effects Beyond It's Borders

New CA rule Requires 100% zero emission vehicle sales by 2035



States that Follow CA standards and announced commitments to new rule

States that follow CA standards but not committed to new rule

Source: California Air Resources Board

Whether the result of legislation or regulation, EV mandates and ICE bans are often imposed on consumers because of statutes or executive orders laying out NetZero goals to be met by 2030, 2035, 2040 or 2050. With the transportation sector responsible for 28% of the carbon dioxide emissions in the U.S., most states currently considering a move toward NetZero are likely to consider, among other options, attempting to shift from ICE vehicles to EVs for mobility to have any hope of meeting these goals — ignoring advances in the development of lower carbon liquid fuels and other technologies.[4]

Decision-makers in those states are starting to realize that while EV adoption has been accelerating over the last few years, especially among wealthier families who can afford the higher average purchase price of an EV, the general public has been far more reluctant to adopt them. In order to stay on a path that makes NetZero commitments possible, several states are now considering or have adopted EV mandates. Typically, these mandates take the form of banning sales of new ICE vehicles after a certain date or dictating what percentage of sales on the free market should be EVs.

As is often the case, it appears many decision-makers have failed to consider the real-world implications of the mandates they are imposing. To appreciate the enormous changes these mandates will usher in, it is more helpful to look at this on a smaller scale than the national level.

Let's consider Massachusetts. The state enacted a regulatory framework at the end of 2020 which imposes a NetZero emissions limit by 2050. This includes a mandate which, "will require (zero-emission vehicle) sales to ramp up to 100% of new (light-duty vehicle) sales by 2035."[5]

In 2021, there were about 5.4 million light-duty vehicles (passenger cars, SUVs and light trucks) registered in Massachusetts.[6] Of these, 191,500 were EV, Plug-In Hybrid EV (PHEV), or Hybrid EV (HEV). There were about 275,000 new light duty vehicles sold in MA in 2022.[7] Let's assume a 1% overall growth rate, and that 20,000 EVs will be sold in the state in 2023 (vs 9,000 sold in 2021). This projects to about 7.2% of all new vehicle sales in Massachusetts in 2023 will be EVs. Further assuming about 230,000 vehicles (virtually all ICE) will be retired in Massachusetts, we will see EVs making up about 3.9% of the total registered vehicles in Massachusetts in 2023. This would put the state in the top 5 of the 50 states according to data from the U.S. Department of Energy. Certainly, this would make the state among the leaders in shifting from ICE vehicles to EVs.

If we extrapolate that new car and retirement trends continue, and EV sales in 2024 can jump to 10% of new car sales, and then increase market share of new cars by 50% for the next several years, what percentage of the registered automobiles in Massachusetts would be EVs by the start of 2028? It would be only 10.8%.

Given the current adoption of EVs in a state that is among the leaders, it seems unreasonable to think that under current market conditions this kind of pace will be achievable. Yet even under these very generous adoption rates, less than 11% of the Massachusetts fleet of light-duty vehicles would be electric by 2028.

State	Net Zero Target Date	InterimTargets
California (executive order)	2045	(Statute) 40% below 1990 levels by 2030
Hawaii (statute)	2045	26-28% below 2005 levels by 2025; 40-50% by 20302050
Louisiana (executive order)	2050	(Statute) 45% below 1990 levels by 2030; 80% by 2050
Maine (executive order)	2050	60% below 2006 levels by 2031
Maryland (statute)	2045	50% by 2030; 75% by 2040
Massachusetts (statute)	2050	26-28% below 2005 levels by 2025
Michigan (executive order)	2050	
Montana (executive order)	2050	28% below 2005 levels by 2025; 45% by 20302045
Nevada (statute)	2050	40% below 1990 levels by 2030; 85% below 1990 levels by 2050
New York (statute)	2050	50% below 2005 levels by 2030
North Carolina (executive order)	2050	10% below 1990 levels by 2020; 45%below 1990 levels by 2030; 80% below 1990 levels by 2040
Rhode Island (statute)	2050	
Virginia (statute)	2045	45% below 1990 levels by 2030; 70% by 2040; 95% by 2050
Washington (statute)	2050	

Source: Council of State Governments

Going further, if theoretically more than 50% of all new light-duty vehicles sold in Massachusetts were EVs in 2028, 80% were EVs in 2029 and 100% of all new vehicles were EVs from 2030 onward, then by 2035 less than half of all vehicles on the road in Massachusetts would actually be EVs. This is a conservative estimate, as it is highly likely that under this type of mandate ICE owners would hold onto their vehicles longer and the used ICE market would become more robust, lowering the number of vehicles retired in the later years while sustaining the number of ICE vehicle registrations overall.

Again, even with Massachusetts' robust adoption rate, it will fall short of hitting its EV target – and that assumes that the conservative assumptions here are actually met.

Massachusetts Vehicle Fleet Transition Projection

	% of New Sales as EV	Non-EV	EV	Total	New Cars	New EVs	New Non-Evs	Retired	Net	EV / Total
2022		5,200,900	191,500	5,392,400	275,000					
2023	7.2%	5,225,900	211,500	5,437,400	276,375	20,000	256,375	231,375	45,000	3.9%
2024	10.9%	5,241,186	241,664	5,482,850	277,757	30,164	247,592	232,307	45,450	4.4%
2025	16.3%	5,241,617	287,137	5,528,755	279,146	45,473	233,673	233,241	45,905	5.2%
2026	24.4%	5,219,431	355,688	5,575,118	280,541	68,550	211,991	234,178	46,364	6.4%
2027	36.7%	5,162,918	459,027	5,621,945	281,944	103,340	178,605	235,117	46,827	8.2%
2028	55.0%	5,054,429	614,811	5,669,241	283,354	155,784	127,569	236,058	47,295	10.8%
2029	82.5%	4,867,353	849,656	5,717,009	284,771	234,845	49,926	237,002	47,768	14.9%
2030	100.0%	4,629,404	1,135,851	5,765,255	286,194	286,194	-	237,948	48,246	19.7%
2031	100.0%	4,390,507	1,423,476	5,813,984	287,625	287,625	-	238,897	48,729	24.5%
2032	100.0%	4,150,660	1,712,540	5,863,200	289,064	289,064	-	239,848	49,216	29.2%
2033	100.0%	3,909,859	2,003,049	5,912,908	290,509	290,509	-	240,801	49,708	33.9%
2034	100.0%	3,668,103	2,295,010	5,963,113	291,961	291,961	-	241,756	50,205	38.5%
2035	100.0%	3,425,389	2,588,431	6,013,820	293,421	293,421	-	242,714	50,707	43.0%

Source: Calculations based on Massachusetts Vehicle Registration

This type of hyper-growth adoption is unrealistic and unlikely to occur, even if mandated, as there are many aspects of EV adoption, as outlined in this report, that are extremely difficult or impossible to overcome. Otherwise, we would be seeing EVs represent much more than their current 4% share of new vehicle sales in the state. What is clear is that officials in Massachusetts (and any other state enacting EV mandates) either have not considered what a realistic path to an all-electric transportation system looks like, or they believe that the public will give up on what is best for their livelihoods and give in on a timetable that adheres to the mandates.

Policy Consideration #1: **Cost of ICE vs EV**

One of the expected drivers of EV adoption cited by proponents is the Total Cost of Ownership (TCO), which factors in all vehicle-related costs including purchase price, fuel cost, insurance, and maintenance for the vehicle's lifespan. Numerous studies have been conducted over the last decade arguing that while the upfront cost of an EV may be substantially higher than that of an ICE vehicle, the low cost of charging versus the cost of gasoline gives EVs an advantage.

This is a very important consideration as proponents of EV mandates attempt to accelerate their mainstreaming. In order for the EV adoption math to come close to working in a state like New York for example, EVs will have to become more affordable for middle-income families. The economics matter much less for wealthy early-adopters than for those on fixed- or low-incomes. When decisions need to be made by families where discretionary spending is more limited, total cost of ownership becomes a very important issue. When states are mandating EVs, at a certain point it becomes imperative to understand how these economics impact low- and middle-income earners.

Looking at New York, it certainly appears that the total cost of ownership in reality is higher than the claims made by advocates of EV mandates.

According to the U.S. Department of Transportation Federal Highway Administration the average annual mileage for a light vehicle in New York State in 2020 was 8,404 miles.[8] Considering the average ICE vehicle achieves 25.4 MPG, this would equal 331 gallons of gasoline per year.[9] The average cost of regular unleaded gasoline in New York in 2021 was $3.028/gallon, which results in $1,002 per year in fuel costs for the average ICE vehicle.[10]

If we assume an average EV efficiency of 0.364 kWh/mile, 8,404 miles would require 3,059 kWh/yr of electricity for an EV in New York.[11] At an average residential electric rate of $0.1948/kWh[12] in 2021, we get $596 in "fuel" costs for the average EV, clearly an advantage for EVs over ICE vehicles. To the consumer, gasoline prices may appear more volatile because they move higher and lower on an almost daily basis. Electricity prices, however, are far more volatile in reality. Consumers do not see this volatility because their utility rate is regulated and subject to change only once or twice a year. From 2006 to 2021, residential electricity prices increased by over 30%, with only one year marginally lower than the prior year.[13] Over that same time period, regular gasoline prices increased 17%, with five of those years (2009, 2015, 2016, 2017, and 2020) having lower prices than 2006.[14] As will be examined, electricity generation shortfalls and electric grid reliability may also send electric rates much higher as NetZero policies and mandates to all electric transportation are imposed – making any current fuel advantage EVs possess a potential disadvantage over the long-term.

Consumers, however, must consider more than just the cost of fuel for their vehicle. They must also consider the price of the vehicle they plan to purchase or lease. The average EV cost $65,041 in 2022 while the overall average automobile (including those higher-priced EVs) cost only $48,681, according to Kelly Blue Book data.[15] This is a $16,360 upfront price difference to begin with, and assuming a five-year loan at current 6% interest rates, borrowing the price difference would add another $3,059 in interest costs over the first five years of ownership. Furthermore, according to Quadrant Information Services data as reported in Forbes, the average EV costs an additional $103 per year to insure versus a comparable ICE vehicle.[16]

The final item to consider is maintenance costs, however there is not yet any reliable data or consensus on whether ICE maintenance costs are higher than EV maintenance costs over the life of the vehicle. There are dozens of studies with conflicting conclusions as to which costs more, and many of them recognize that the long-term durability of EVs is an open question, especially regarding battery life. This is due to the fact EVs have not been mass-market vehicles for more than a decade. For consideration here, we will assume that there is no benefit for either ICE or EVs with respect to regular maintenance.

So how long would it take for a middle-income family in New York to break even on buying an EV versus a comparable ICE vehicle? With the annual benefit of $303 (the $406 annual energy benefit less the $103 disadvantage in insurance costs), it would take over 64 years to recover the $19,419 of the initial purchase price plus higher interest costs. Even considering the current $7,500 federal tax credit, there is still a 39-year payback period. This makes purchasing an EV not only unattractive economically, but it turns a mandate into a substantial economic burden on working-class families.

Even on a national level, when you consider the average price for residential electricity in 2021 was $0.1366/kWh and the cost of gasoline was $3.10/gallon, the break-even point for the average family in the United States would take almost 24 years. This level of payback is not economically viable for most families, except for those where cost considerations are secondary to other factors. State and national EV mandates ignore the financial realities for most people while imposing fewer choices, limiting transportation options, and harming working families.

Car Insurance Rates: Electric Vehicles vs. Gas Vehicles

Model	Average annual car insurance cost (electric model)	Average annual car insurance cost (gas-powered model)
Chrysler Pacifica	$1,986	$1,891
Ford Fusion	$2,041	$1,865
Ford Escape	$1,831	$1,663
Honda Accord	$1,888	$1,988
Honda CR-V	$1,831	$1,574
Toyota Camry	$1,970	$1,899
Toyota Corolla	$1,823	$1,909
Toyota Highlander	$1,904	$1,757
Toyota RAV4	$1,776	$1,704
Subaru Crosstrek	$1,843	$1,606
Average	**$1,889**	**$1,786**

Source: Quadrant Information Services / Forbes Advisor

Total Cost of Ownership

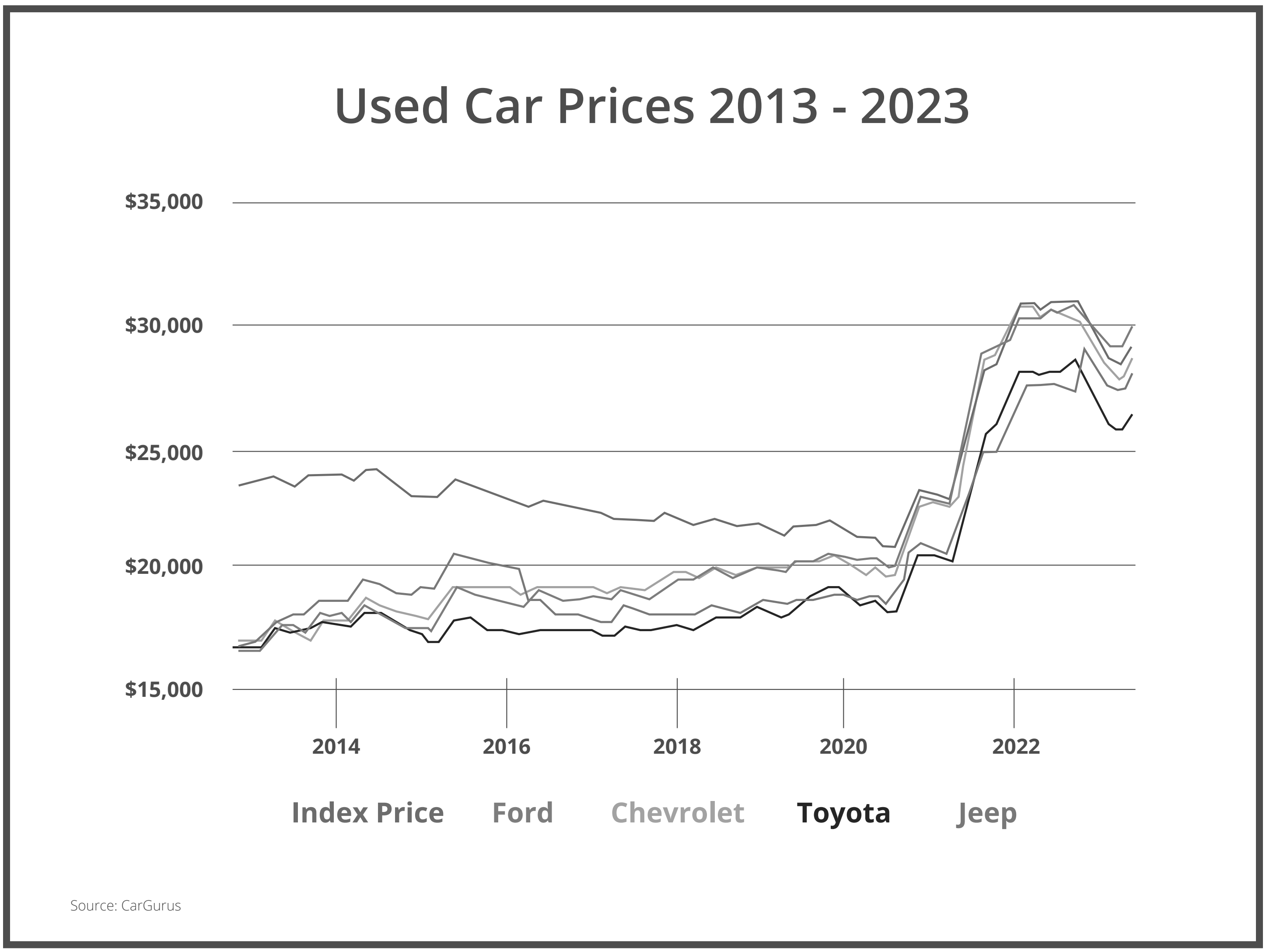
Upfront Costs	$16,360
Interest Costs	$3,059
Annual Energy Cost	($406)
Annual Insurance Cost	$103
Annual Maintenance Cost	-
Upfront Cost Benefit to ICE	$19,419
Annual Benefit to EV	($303)
Payback Period (years)	**64.1**

Source: Calculations based on purchase price, fuel cost, insurance, and maintenance for life of vehicle

An important factor for consideration in the TCO calculation which was not addressed here is the question of battery replacement. Typical battery replacement costs can reach $15,000 or more, in contrast to an ICE engine rebuild at $2,500-$4,000. This can dramatically affect the long-term and resale value of an EV versus an ICE vehicle. This cost differential will become better understood over time as EVs begin to mature beyond the typical 10-year/100,000-mile warranty periods. The results will not only affect the ownership cost calculations but also the used car market viability of EVs.

While the used car market may have second order impacts on new car pricing, it is far more important for low- and middle-income families who are more reliant on this market for their second vehicle or vehicles for their children. A National Automobile Dealers Association study on the cost of ownership estimated that after five years, EVs depreciate $43,515 in value, while ICE vehicles average only $27,883 in depreciation.[17] This depreciation almost eliminates any residual value advantage of the higher-priced EVs after only a short period of usage. If EVs become a non-viable option as used cars due to substantial depreciation and cost of battery replacement, used car markets operating under EV mandates will see very constrained supply despite sustained demand, eventually making even used cars too expensive for many working-class families.

Looking at the trends over the past decade, used car prices had dropped about 10% between 2014 and 2020, ensuring affordable vehicles were accessible to the middle class.[18] Since 2020 though, used car prices have risen nearly 50% in less than 3 years. With EVs priced much higher than ICE vehicles, and the potential for greater supply constraints as discussed above, used car prices could continue their recent upward trend and put used cars out of reach for millions of American families. Add to this the concerns that new cars are already out of reach for many, access to transportation could become a serious issue with additional EV mandates.[19]



Policy Consideration #2:
Generation Requirements

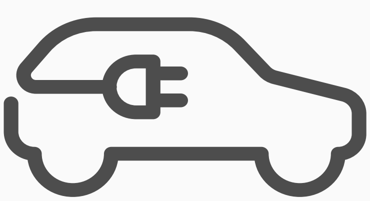
While the push to transition to EVs from ICE vehicles is an effort to shift to a low-carbon economy, the shift from a transportation system based on gasoline to one based on electricity is far more complicated and costly than most decision-makers consider. Set aside for a moment the costs of upgrading an energy distribution system that cannot currently handle the projected loads an all-EV fleet would require. The cost of supplying the necessary energy for hundreds of millions of EVs via electrical generation is vastly underappreciated.

Consider the fact that a few years ago, Virginia decided to opt into California's 100 percent EV mandate by 2035. The state currently has 7.6 million light-duty vehicles. Assume for a moment that Virginia achieves its goal and switches all its 7.6 million vehicles from using gasoline to electricity. Using the current U.S. Department of Energy standard of 0.364 kWh/mile, and the average miles travelled in Virginia of 12,879 miles per year, then the state would need 35.5 billion kWh of generation to cover the almost 100 billion miles traversed annually by its light-duty vehicle fleet.

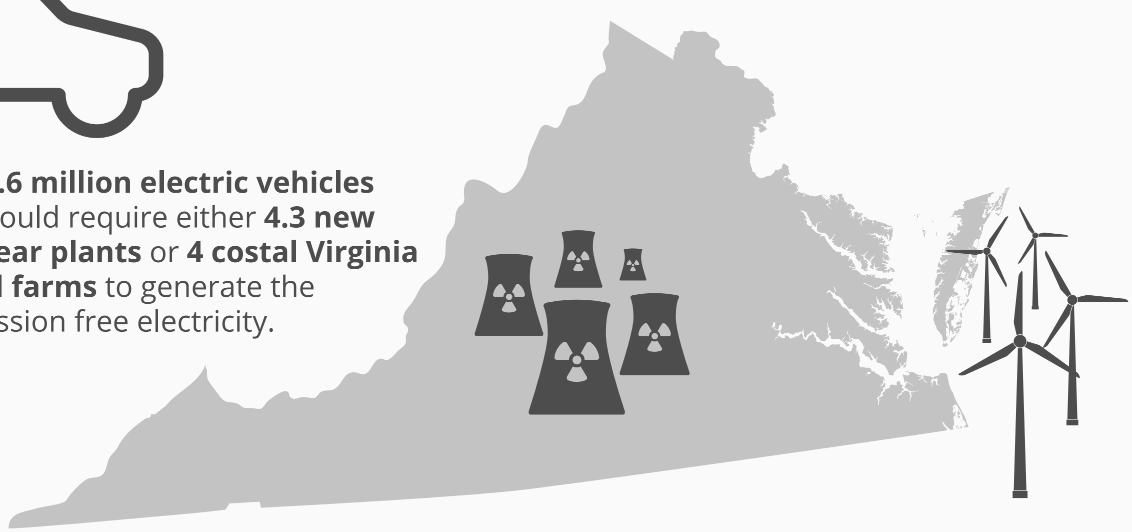
Let us further suppose we discount transmission losses and assume a single 1,000 MW nuclear plant could be built with a 95% capacity factor, which is enough electricity to power 600,000 Virginia homes – over 16% of the households in the state.[20] For Virginia to operate an all-EV automotive fleet without just shifting emissions from tailpipe to smokestack, it would require 4.3 new nuclear generating units of that size – equivalent to the generation needed to power almost 70% of all the homes in Virginia.

Recognizing that it is rare for a new nuclear unit of that size to be built in the United States, never mind more than four within a decade. How many Coastal Virginia Offshore Wind Farms would be needed to provide the electricity demanded by an all-EV fleet? At 2,587 MW and assuming a 40% capacity factor (comparable to major offshore wind capacity factors in the United Kingdom), each wind farm would only be able to supply 25% of the needed power.[21] Thus, in order to fuel the state's fleet of light-duty vehicles under a 100% EV scenario, four offshore wind farms of comparable size to Coastal Virginia Wind – which itself will cover more than 451,200 acres or about three times the land area of Virginia Beach) – would need to be built.[22]

This is merely the incremental generation needed to power only passenger vehicles and not the entire transportation sector. For that, we would need to consider heavy-duty vehicles including semi-trucks, buses, and construction vehicles.



For a fleet of **7.6 million electric vehicles** in Virginia, it would require either **4.3 new 1000MW nuclear plants** or **4 costal Virginia offshore wind farms** to generate the necessary emission free electricity.



Source: Calculations based on U.S. Department of Energy data

Given the major hurdles in permitting just one large-scale (>500MW) generation facility either onshore or offshore in almost any jurisdiction in the United States, advocates for EV mandates need to be more forthcoming and realistic with how they believe the incremental electricity required will be sited and subsequently generated to support any substantial move to EVs. This may explain the argument being advanced in some states that wind and solar projects should be given preferential permitting treatment.

Policy Consideration #3: **Electrical Grid Infrastructure**

Elected officials and policy makers rarely consider the substantial changes that will have to be made to the existing electrical grid under an EV mandate. EVs will require major transmission and distribution system upgrades, along with upgrades to charging locations, and it is likely that these costs will be borne by consumers.

A recent study by the Brattle Group looked at the cost of "Getting to 20 million EVs by 2030" in the United States, specifically as it related to the required capital costs of upgrading the electrical grid.[23] On a national level, Brattle identified $30-$50 billion of additional costs to increase the amount of generation and storage for the incremental electricity demanded as automobiles move from ICE to EV. There was a further $15-$25 billion in required upgrades for transmission and distribution systems, and another $30-$50 billion for charging infrastructure. That's a total of $75-$125 billion in costs just to get to 20 million EVs, representing only about 7% of the US light vehicle fleet.

While there are likely some variations based on economies of scale, we can consider these costs on a more local level so that decision-makers can better understand what it may mean for a typical family that will have to pay for these additional costs added to their electric bill.

Using New Mexico as an example, there are currently 1.9 million ICE vehicles in the state. If we consider the infrastructure requirements to shift those vehicles to EVs implied by the Brattle Group model, then New Mexico would have to invest $2.8-$4.7 billion in generation, $1.4-$2.3 billion in transmission and distribution, and $2.8-$4.7 billion in charging infrastructure, for a total investment of $7.0-$11.7 billion.

As noted above, the costs for these types of expenditures have typically been passed on to consumers through their electric bill. Residential rates in New Mexico according to the EIA averaged 14.1 cents/kWh in 2022.[24] Assuming the costs for this infrastructure will be passed through to customers over the next 20 years, with the average household using 9,175 kWh/yr, and ignoring any rate of return for the utilities, the cost to upgrade the state's electrical grid could result in a 1.3 to 2.1 cent increase per kWh which equates to $117 to $195 per year.[25] Considering that nearly half of Americans don't even have $500 in savings, elected officials and other decision-makers need to consider how these policies impact average Americans living paycheck-to-paycheck.[26]

How much of this infrastructure has been rolled out to date? Per the Brattle Group study, New Mexico has provided no state funding for charging infrastructure. This is a far cry from the billions necessary as the state moves to an ICE-free future. And, almost nothing has been done for transmission and distribution system upgrades as they relate to EV adoption. With respect to generation, the state has yet to transition away from having most of its electricity generated from fossil fuels (over 63% per the EIA), with the current shift to renewable generation only focused on lowering its dependence on fossil fuels.[27] Once the low-hanging renewable generation fruit has been picked to update the current generation mix, it is likely the incremental generation needed for a shift to EVs will be even more expensive. Where will the additional funds come from and when? More importantly, will elected officials be upfront with the public and explain to them that there will be permanent 6-10% increases in their electric bills just to pay for the energy infrastructure required by EVs?

Beyond these costs that will certainly be imposed on working families, there are growing concerns about the reliability of the electric grid without even considering the challenges associated with electrifying our transportation system. Both federal agencies and Independent System Operators, which are responsible for maintaining the electric grid and ensuring just and reasonable rates for consumers, have voiced much concern and issued numerous warnings over the past several years.

Several Federal Energy Regulatory Commissioners recently testified before the U.S. Senate, stating, "We face unprecedented challenges to the reliability of our nation's electric system."[28] The Commissioners didn't even focus on the large additional demands which will be imposed under EV mandates over the next 5-10 years. The North American Electric Reliability Corporation (NERC) has also put out warnings over the past several years, including its most recent report which assessed the country's electric grid reliability for the upcoming summer season.[29] Seven of the 20 regions, "face risks of electricity supply shortfalls during periods of more extreme summer conditions" this year. These areas include New England, the Midcontinent, and every region west of the Mississippi River. Coincidentally, most of the states imposing new EV mandates, including California, New England, and New York, are the ones with the highest electricity prices in the country. And, they are in regions with growing reliability concerns. If EV mandates are continued in these states without consideration of the stresses placed on the electric grid, there could be critical problems for both the electric grid and the transportation systems.

While the experts at the Federal Energy Regulatory Commission and NERC can warn the country about these looming problems, it requires state and local officials to acknowledge them and craft sensible policy solutions to address them. It is clear that many officials seeking to impose EV mandates have not sufficiently considered the detrimental impacts on grid reliability, let alone the cost of grid modernization to families and businesses, their mandates will bring.

Policy Consideration #4: **Supply Chain of Critical Materials**

On a broader level, while many officials in the United States and globally are mandating EV usage, the question arises as to whether the world can supply the copper, lithium, cobalt and other critical materials required to build enough EVs. Consider, EVs require six times the amount of minerals than traditional cars.[30] Given the current state of the global supply chain for these raw materials and the requirements to bring additional supply to market, it is likely that the mandated goals are unachievable even over several decades.

> "Amounts vary depending on the battery type and model of vehicle, but a single car lithium-ion battery pack (of a type known as NMC532) could contain around 8 kg of lithium, 35 kg of nickel, 20 kg of manganese and 14 kg of cobalt, according to figures from Argonne National Laboratory."[31]

The U.S. Geological Survey estimates that in 2022, there was approximately 130,000 tons of lithium mined globally.[32] The quantity of lithium mined would be able to produce just under 14 million EV batteries. This doesn't account for the lithium used in other products, including laptop batteries, phones, residential power packs, and utility scale storage.

Lithium production also typically requires substantial water use, which carries the potential for large-scale and long-term environmental damage in certain regions.

Permitting also has been a hurdle to bringing any mining project online. Lithium mines coming online between 2010-2019 took an average of 16.5 years to develop into producing mines according to the IEA.[33]

Under EV mandates, the demands to eliminate ICE vehicles may rapidly run into the reality of lithium battery supply. With global annual light-duty vehicle sales of over 66 million and a global fleet of over 1.3 billion vehicles, it is going to be very difficult to practically achieve EV mandates anytime in the next several decades.

California alone would require almost 15% of current global battery supply if a theoretical 1.67 million new EVs were sold (100% of current annual light-duty vehicle sales) in the state in 2030.[34] It is highly unlikely that a material portion of the world's lithium supply will be committed in this manner, yet state elected officials and regulators are assuming that this type of allocation will take place without any deleterious economic impacts, such as higher costs, for EVs.

Unfortunately, this is not only a problem for the supply of lithium. An IEA review of critical minerals assessed global demand for copper, lithium, and cobalt. Under the current "Stated Policy Scenarios," by 2040 the world will require 12 times more lithium, six times more cobalt and nine times more copper just for EVs.[35] These forecasts would result in primary demand for these minerals outstripping supply for cobalt and lithium by 2028, and copper by 2026.[36]

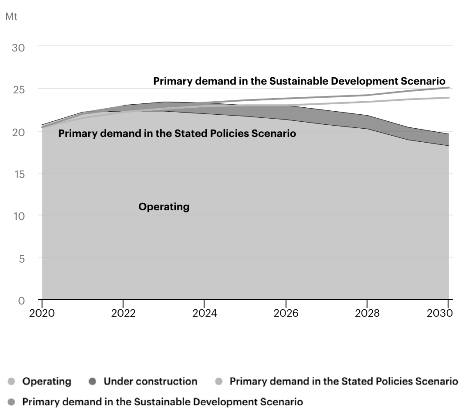
Yet, mining is only one part of the critical mineral supply chain which must be considered. After minerals are mined, they must also be processed. Of the critical minerals necessary for EV production, China controls the processing and refinement of 58% of lithium, 65% of cobalt, and 87% of rare earths.[37]

Although the United States can become less reliant on foreign supply chains for critical minerals to build a cleaner energy future, there is no strategic planning to ensure access to these resources. In January of 2022, the Biden Administration canceled leases for copper and nickel mining that had been held for more than 50 years.[38] And, in January 2023, the Administration paused mineral leasing on over 200,000 acres of land in the Superior National Forest, enacting a 20-year prohibition on mining.[39]

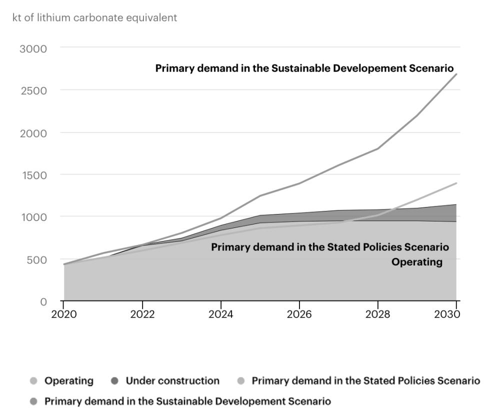
Restricting mining operations in the United States is not only counterintuitive to the promotion of electric vehicle adoption. It has additional global impacts. Gillian Caldwell, Chief Climate Officer and Deputy Assistant Administrator for the Center for Environment, Energy, and Infrastructure at the United States Agency for International Development (USAID) said USAID is seeing evidence that mining for the transition away from fossil fuels is tied to “increased corruption, human rights violations, environmental destruction and conflict.”[40]

Once again, the supporters of EV mandates are not considering the real-world consequences of these policies. The projected shortfalls of lithium, copper and cobalt are very likely to dramatically raise battery costs, which would stall or reverse progress on reducing the price of this key EV component, keeping EVs much more expensive than traditional ICE vehicles.

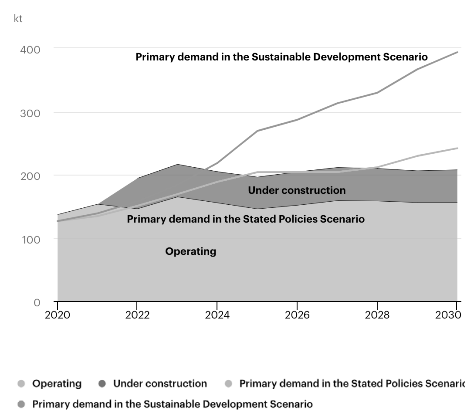
Committed mine production and primary demand for copper, 2020-2030



Committed mine production and primary demand for lithium, 2020-2030



Committed mine production and primary demand for cobalt, 2020-2040



Source: International Energy Agency

Policy Consideration #5: **Fuel Tax Revenue Impacts**

With EV adoption still accounting for single-digit percentages of any state light-duty passenger vehicle fleet, the impact of moving from ICE to EVs on state budgets has historically been a relatively minor consideration. However, if and when more states implement EV mandates, officials will be forced to evaluate how this will lower fuel tax revenues.

Historically, most fuel taxes (both gasoline taxes and diesel excise taxes) have been dedicated to spending on highways and road infrastructure. In 2020, states brought in over $52.7 billion in motor fuel tax revenue.[41] On top of those collections, the federal government collected and distributed over $43 billion in federal highway-related excise taxes, most of which is returned to the states through federal highway grants.[42]

If EV adoption increases materially, with a push from EV mandates, fuel-base tax revenue will begin to dry up at both the state and federal level. States will have to either dramatically reduce spending on maintaining highways, find new sources of revenue to maintain state and local roads, or increase taxes in other areas to replace the lost revenue.

How big an impact would that be? Let's consider Colorado as an example, which collected almost $677 million in 2019 (pre-COVID baseline) and received $589 million in 2020 Federal Highway Funding.[43] If Colorado reaches its goal of 100% EV adoption, the state will need to replace over $1.25 billion in highway and road spending that comes from taxes on gasoline and diesel, a number that will only increase with inflation over time. That amounts to over $560 per household annually.[44] Nationally, an elimination of ICE vehicles would represent a fuel tax revenue loss of $741 per household annually. Whether at the state or federal level, that is a significant amount of lost tax revenue that will need to be recouped from somewhere. EV mandate advocates have for the most part remained silent on how this tax revenue problem should be addressed.

FY 2020 FEDERAL-AID HIGHWAY PROGRAM APPORTIONMENTS UNDER FIXING AMERICA'S SURFACE TRANSPORTATION (FAST) ACT

	National Highway Performance Program	Surface Transportation Block Grant Program	Highway Safety Improvement Program[1]	Railway-Highway Crossings Program	Congestion Mitigation & Air Quality Improvement	Metropolitan Planning	National Highway Freight Program	Apportioned Total
Alabama	492,134,217	245,432,298	48,837,668	5,030,652	12,233,496	3,316,382	28,788,785	835,773,498
Alaska	311,449,135	155,857,612	32,861,826	1,225,000	29,510,597	2,445,667	19,017,598	552,367,435
Arizona	444,770,886	222,967,580	45,708,482	2,966,959	55,631,678	6,311,543	27,652,981	806,010,109
Arkansas	333,002,634	166,181,866	32,309,619	4,139,566	13,205,084	1,853,154	19,660,713	570,352,636
California	2,078,188,513	1,048,137,089	210,661,318	16,727,512	497,658,600	53,965,333	137,926,316	4,043,264,681
Colorado	321,396,882	161,270,563	31,505,959	3,666,390	45,357,082	5,704,498	20,171,449	589,072,823
Connecticut	299,029,572	150,166,240	31,340,232	1,383,449	47,442,976	4,977,836	18,959,974	553,300,279
Delaware	102,772,834	51,523,301	10,022,376	1,225,000	12,505,645	1,921,968	6,376,902	186,348,026
Dist. of Col.	97,491,778	48,852,942	9,444,590	1,225,000	10,832,815	1,914,382	6,011,421	175,772,928
Florida	1,230,552,474	613,629,270	125,049,915	9,645,070	14,581,543	22,332,190	71,396,176	2,087,186,638
Georgia	802,729,658	401,678,890	79,023,613	8,832,059	72,865,342	8,380,145	48,898,593	1,422,408,300
Hawaii	103,668,547	51,934,683	10,120,681	1,225,000	11,108,307	1,886,318	6,377,228	186,320,764
Idaho	179,413,341	89,712,341	17,695,492	1,941,086	13,741,061	1,746,334	10,835,702	315,085,357
Illinois	854,148,369	428,610,365	82,096,255	11,378,101	118,061,702	18,404,231	53,516,633	1,566,215,656
Indiana	594,777,804	297,524,632	57,135,272	7,961,587	50,525,029	5,645,449	36,104,102	1,049,673,875
Iowa	316,132,458	157,761,587	28,906,320	5,696,331	12,112,591	2,139,447	18,649,117	541,397,851
Kansas	242,235,322	120,917,351	20,004,259	6,509,648	10,204,923	2,100,918	14,323,658	416,296,079
Kentucky	428,567,666	213,825,070	42,886,877	4,022,841	14,690,724	2,732,368	25,218,395	731,943,941
Louisiana	453,696,920	226,324,212	45,222,096	4,438,479	12,274,696	4,637,158	26,576,703	773,170,264
Maine	113,877,380	57,018,934	11,152,460	1,310,716	11,042,240	1,986,927	6,962,687	203,351,344
Maryland	356,318,933	178,997,233	36,489,672	2,502,896	57,581,191	7,479,531	22,630,742	662,000,198
Massachusetts	352,553,814	177,426,422	35,923,007	2,655,165	68,009,774	9,695,577	22,796,269	669,060,028
Michigan	639,192,348	320,467,515	61,753,764	8,198,781	79,361,076	11,169,405	39,719,065	1,159,861,954
Minnesota	406,390,112	203,313,740	37,920,917	6,557,215	34,557,941	4,931,718	24,669,848	718,341,491
Mississippi	311,202,267	155,297,492	30,354,640	3,708,399	12,030,939	1,834,157	18,362,236	532,790,130
Missouri	606,806,615	302,902,609	60,376,693	6,041,419	25,277,065	5,606,369	35,870,641	1,042,881,411
Montana	260,101,310	129,949,324	26,410,791	2,057,799	15,964,596	1,939,123	15,563,794	451,986,737
Nebraska	183,111,794	91,489,420	16,141,946	3,899,958	11,032,465	1,787,676	10,949,321	318,412,580
Nevada	215,824,563	108,397,813	22,372,849	1,245,351	34,926,363	3,540,715	13,709,470	400,017,124
New Hampshire	101,199,080	50,700,532	9,850,396	1,225,000	11,098,102	1,705,104	6,234,662	182,012,876
New Jersey	581,246,558	292,446,674	59,618,357	3,985,031	111,625,812	13,427,554	37,565,516	1,099,915,502
New Mexico	234,104,595	116,909,344	23,782,027	1,841,556	12,238,985	1,736,084	13,930,085	404,542,676
New York	968,878,443	487,836,077	99,317,842	6,699,842	196,450,213	26,935,869	62,998,269	1,849,116,555
North Carolina	651,177,859	325,731,113	64,091,626	7,178,118	54,960,959	6,273,979	39,514,654	1,148,928,308
North Dakota	155,961,136	77,976,284	13,130,490	3,939,339	11,281,607	1,810,940	9,394,944	273,494,740
Ohio	813,767,125	407,992,546	79,622,819	9,435,011	102,686,164	12,494,647	50,627,736	1,476,626,048
Oklahoma	409,868,698	204,464,769	39,128,799	5,734,415	12,605,902	2,788,852	24,065,103	698,656,538
Oregon	315,048,840	157,473,486	30,670,517	3,811,656	20,804,470	3,904,366	18,905,395	550,618,730
Pennsylvania	1,005,576,239	503,765,944	102,849,149	7,202,976	112,063,118	13,990,442	62,017,204	1,807,465,072
Rhode Island	136,340,569	68,208,344	13,697,064	1,225,000	11,185,141	2,002,995	8,261,506	240,920,619
South Carolina	432,006,055	215,537,181	42,522,566	4,763,532	14,047,633	3,397,425	25,392,750	737,667,142
South Dakota	177,035,582	88,517,870	16,645,755	2,730,620	13,154,614	1,906,023	10,677,248	310,667,712
Tennessee	530,606,460	265,298,313	52,780,497	5,293,911	39,722,613	5,185,028	32,012,474	930,899,296
Texas	2,284,681,927	1,142,841,937	229,571,159	20,481,394	187,158,067	27,986,441	138,429,943	4,031,150,868
Utah	218,770,623	109,353,917	22,095,746	1,848,723	13,854,695	3,495,247	13,106,163	382,525,114
Vermont	124,798,788	62,503,850	12,433,336	1,225,000	12,703,195	2,261,098	7,652,518	223,577,785
Virginia	630,756,761	315,701,430	64,143,588	4,889,748	58,893,491	8,154,467	38,482,756	1,121,022,241
Washington	418,430,054	209,500,895	41,303,106	4,491,549	39,626,396	7,897,746	25,548,842	746,798,588
West Virginia	278,229,316	138,959,136	28,350,728	2,102,357	15,359,219	1,836,025	16,585,526	481,422,307
Wisconsin	476,081,816	237,891,534	45,855,013	6,252,793	29,380,173	4,931,298	28,493,221	828,885,848
Wyoming	161,332,135	80,645,720	16,432,799	1,225,000	11,174,403	1,705,234	9,700,318	282,215,609
Apportioned Total	**24,237,436,805**	**12,137,825,290**	**2,407,622,968**	**245,000,000**	**2,496,402,513**	**358,213,383**	**1,487,293,352**	**43,369,794,311**

[1]Amount is net of the $3,500,000 takedown for safety-related programs.

Source: Federal Highway Administration

Policy Consideration #6: **State Employment Impacts**

Industry disruptions are often accompanied by substantial shifts in employment, whether the disruption is caused by market forces or mandated government policy. This can be either movement within a particular industry or significant job losses as a particular "losing" industry is forced out of existence. Under normal market conditions, these changes would be prompted by shifting consumer preferences, leading to relatively gradual changes in capital allocation and eventually, employment patterns. With abrupt mandates from government, often there is far less time and rapid, dramatic action by companies to adhere to new realities. This can result in far more volatile employment changes and far more disruption for working-class families in particular industry segments.

Again, the consequences of these employment shifts are rarely considered when EV mandates are imposed. One of the most obvious businesses at risk under EV mandates are gas stations and their associated convenience stores. While there may be some shift to adding electric charging stations at existing fueling stations, the bulk of the funding for expanded charging is not going to installations at gas stations. Rather, it is being allocated for more public charging facilities, utility-owned locations, hotels, restaurants, shopping centers, and similar locations. Industry statistics indicate that there are over 64,000 gas stations with convenience stores in the United States, employing 890,000 individuals.[45] These jobs are typically entry level employment providing younger workers with job skills and experience that can lead to more gainful employment. Under an EV mandate and a forced transition away from ICE vehicles, these jobs will be, in effect, mandated away by the government.

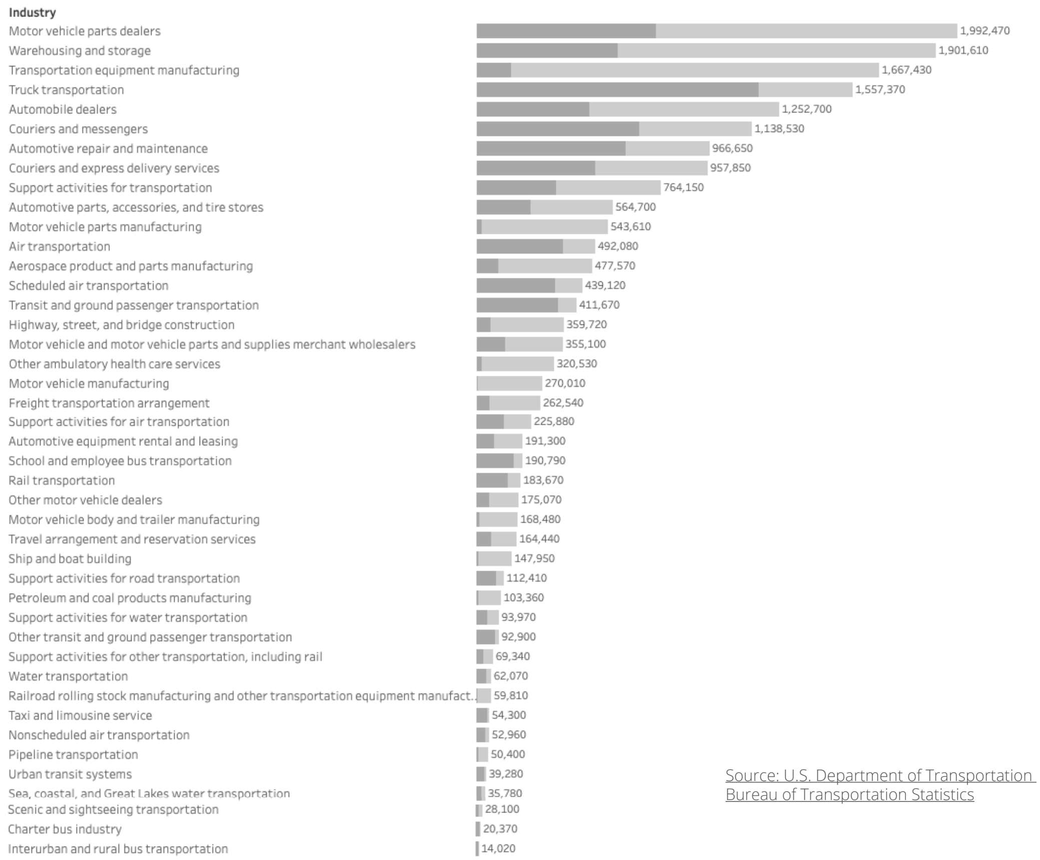
Moving further upstream, there are over 113,000 workers in the oil and gas extraction industry whose employment will be at risk as governments force the elimination of ICE vehicles from the roads.[46] The refining industry is highly dependent on road transport industry demand for liquid petroleum products to sustain its business. One recent study of refining employment in Washington State indicated that the refineries were directly responsible for 2,246 workers in the region, with average wages and benefits per worker over $200,000 per year.[47] The indirect employment effects of this industry were estimated to support an additional 22,000 to 30,000 workers.

More recently, the University of California Berkeley Labor Center examined the economic and employment effects of a refinery closure on workers in the Bay Area.[48] More than a year after the shutdown of the refinery in Contra Costa County, California, one in five workers remained unemployed. Those who were successful at finding new employment saw earnings decline sharply, with the median hourly wage decreasing from $50 to $38. Some workers reported earning as little as $14 an hour. In addition, workers reported worse working conditions at their post-layoff jobs than at the refinery.

There are currently over 1.5 million truck drivers in the United States and while segmentation data of the market is difficult to obtain, crude petroleum and petroleum product trucking activity is one of the largest and most ubiquitous segments of the markets.[49] The tank truck market as a whole represents $49 billion of economic activity. And, there are a variety of other industry segments which could also be substantially impacted, including:

- Motor Vehicle Parts Dealers – 1.926 million employees
- Automobile Dealers – 1.22 million employees
- Automotive Repair and Maintenance – 917 thousand employees
- Automotive parts and accessories retail – 542 thousand employees
- Automotive parts manufacturing – 244 thousand employees
- Motor Vehicle and Parts Wholesalers – 339 thousand employees
- Motor Vehicle Manufacturing – 244 thousand employees[50]

Employment in the Transportation and Warehousing Sector and in Transportation-related Industries by Type of Occupation - 2022



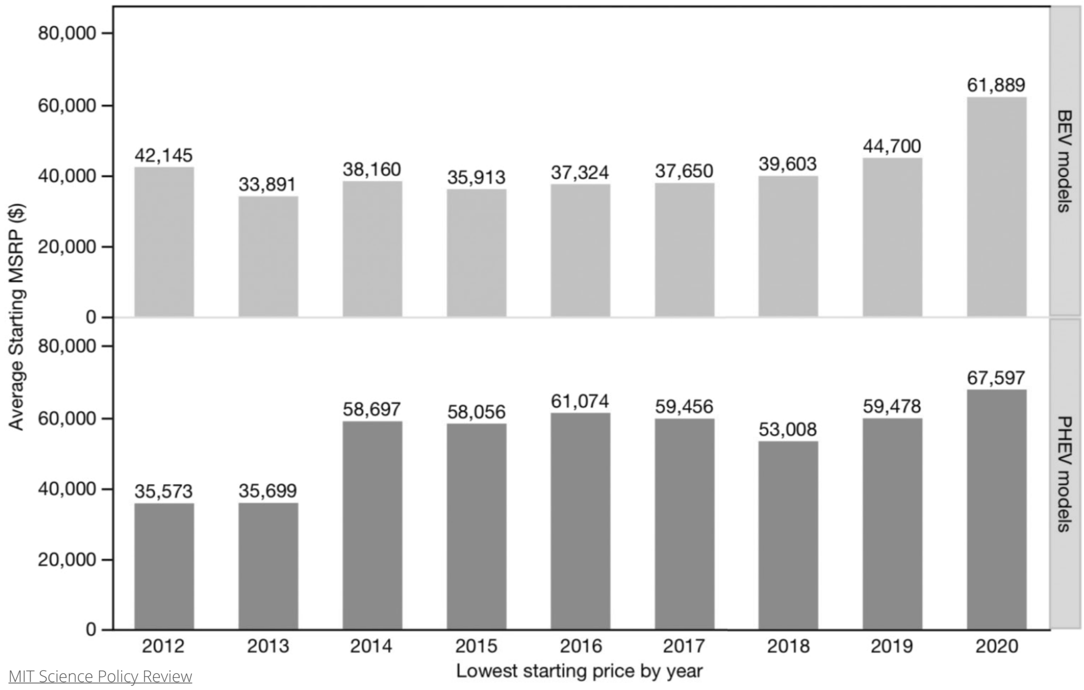
If these industry disruptions and associated employment impacts were driven by natural consumer adoption of EVs, the transition periods would likely be much more gradual and much more easily absorbed by the affected companies and their workers. Disruption imposed by mandate is likely to have much more significant, rapid, and harmful impacts on employees and their families. It is incumbent on elected officials to understand and assess the risks to their constituents as they consider these policies.

Policy Consideration #7: **Benefit Shift from Working Class to Wealthy**

There is often a component of the debate over EV mandates that declares that the benefits of shifting the public to electric vehicles is helpful to working-class and lower-income families. Typically, this is raised in the context of lowering vehicle emissions and the indirect health benefits associated with decreasing that externality. But, often ignored are the direct impacts on the practical use of EVs for a working-class family and how the benefits of an EV transition mostly flow to the wealthier segments of the population.

The initial purchase of an EV is not one that working-class families can often consider. As noted earlier, the price differential between an EV and a comparable ICE vehicle is often on the order of $15,000 or more. And contrary to popular opinion, the cost of EVs have been steadily increasing since 2015.[51] Today, the average EV costs well over $60,000, a price which can only be considered affordable by the upper quintiles of income earners. The idea that EVs can currently be an option for the average family cannot be taken seriously.

Average Starting MSRP of BEV Models and PHEV Models Available Between 2012 and 2020



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This then exposes the current federal and state EV tax credits as a substantial cost shift from middle-class families to the wealthy. In 2022, there were over 800,000 EVs sold in the United States.[52] Assuming the $7,500 federal tax credit was available for most of these purchases, this represents over $6 billion of tax benefits that are paid for by the average American but flow mostly to wealthier families. This does not even account for state incentives.

Looking at state-by-state EV sales for 2021 (2022 data is not available yet) in the 14 states that provide tax credits of $1,000-$4,000, we calculate an additional $600 million or more (depending on type of EV and income level) that mostly flowed to wealthier families.[53] However, some states are providing larger incentives for low-income families to purchase an EV. Yet, even with these generous federal and state incentives, the average EV purchase price of $50,000 or more is out of reach for most low-income earners.

Beyond the immediate financial benefits, the practical use of EVs benefit wealthier users as well. Charging infrastructure is a critical component for EV usage, with access to chargers (and specifically fast chargers) a major consideration in purchasing an EV. Wealthier users are far more likely to live in single family homes where installation of a fast charger costing thousands of dollars is simply a matter of fact. Lower income families who are more likely to reside in apartments or rented properties do not have the option of installing their own personal dedicated fast chargers.

Currently there are an estimated 52,510 public charging stations in the United States, with 134,697 Level 2 or better charging ports associated with them.[54] There are only 30,417 DC, Level 3, fast charger ports which allow for much more rapid charging, but at a higher cost.[55] Contrast this with the 145,000 fueling stations in the United States and while there are no reliable numbers on the amount of gasoline pumps per station, if we assume an average of 8 per location, there are likely over 1 million pumps, with refueling times on the order of five minutes to put over 350 miles of range or more in a tank.[56] Contrast that with costly DC fast chargers, which require approximately 30 minutes to obtain the same mileage, and Level 2 chargers that require hours. The time advantage of ICE fueling versus EV charging is dramatic.

Even the location of charging infrastructure tends to benefit the wealthier, whiter, male demographic that makes up 75% of the individuals who purchase EVs.[57] A recent MIT study on EVs and equity noted that:

> "According to Hsu and Fingerman [43], Black and Hispanic neighborhoods only had 0.7 times the access to public chargers as the no-majority reference group in California. They also determined that even when income, proximity to the nearest highway, and multi-family housing were controlled for, White-majority census block groups were 1.5 times more likely to have access to public charging stations compared to Black- and Latino-majority census block groups."[58]

They also noted that public charging, when available to lower income communities, typically costs more than home charging stating:

> "This higher cost would disproportionately affect low-income households who already pay a higher proportion of their income towards transportation."[59]

One additional aspect of income disparity that is often ignored when considering EV mandates is the fact that the used car market is the major resource for transportation options for low- and middle-income families. EV mandates are likely to have a substantial direct and indirect impact on the used automobile supply. As noted earlier, the life of EV batteries before replacement is an open question which the used car industry will soon be facing at a much greater scale.

With replacement costs estimated in the range of $15,000 or more, there is high likelihood that high mileage EVs will be "totaled" as battery replacement costs will be higher than the value of the car in the used car market. Under such a scenario, EV mandates will lower the number of ICE vehicles over time, winnowing the number of automobiles available in the used car market and driving up used vehicle prices and disproportionately affecting low- and middle-income families. Once again, the unintended costs and consequences of an EV mandate are likely to fall disproportionately onto the individuals and families who can least afford it.

None of these economic disparities are addressed under EV mandates, and very little of these concerns are typically raised in the debate before enacting these policies. Yet EV mandates are likely to burden working-class families with the costs of incentives while rarely enabling them to enjoy those benefits themselves. And, by creating disparities in access to the "fuel" through charging network realities and economics this further exacerbates the differences in transportation equity between rich and poor.

Conclusion

Electric vehicles will play an important role in diversifying our vehicle mix, and, if integrated correctly, can help meet our shared environmental goals. It is increasingly clear that public officials and regulators are not fully considering all the implications of aggressively mandating EVs and banning ICE vehicles. Without adequately considering the impact this will have on consumers, acceptance of EVs will suffer as overall negative impacts on low- and middle- income earners will increase.

While it is fair to say there is much to debate on how best to tackle these questions, it is incumbent on policy makers to be proactive and transparent about the implications of the policies they are advocating for, and to ensure consumers understand the costs and benefits of EV mandates and bans on ICE vehicles. The following are some questions for policy makers to consider:

- How impactful would an EV mandate be given the current fleet of passenger cars and the uptake of EVs as a percentage of new car sales? Will the presumed benefits be justified by the real and upfront costs?
- Given the economics of the Total Cost of Ownership, will EV mandates lower household discretionary income and raise the cost of transportation for working families?
- How much increased electricity generation will be required for an all-electric vehicle fleet? Where will that generation come from? At what cost?
- How much additional capital needs to be invested into the existing electrical grid to allow it to reliably provide the necessary electricity to homes and businesses with an all-electric fleet? Who will pay for this (ratepayers?) and how much will the average family pay in higher utility bills?
- Will global supply chains be able to support a rapid EV transition, and if not, will that hurt the families and businesses that are being forced to buy EVs?
- How will states compensate for the loss of billions of dollars of fuel tax revenue?
- How will an EV mandate impact the substantial number of workers whose jobs are supported by the current transportation system? What will the states do to address this potentially large economic impact?
- How do elected officials and decision makers justify the disproportionate impact an EV mandate has on low-income and working-class families, burdening them with higher costs while wealthier families can more easily benefit from the current taxpayer-funded incentives?

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About Consumer Energy Alliance

Since 2006, Consumer Energy Alliance (CEA) has been the leading voice for sensible energy and environmental policies for families, farmers, small businesses, distributors, producers and manufacturers in support of America's environmentally sustainable energy future. We are committed to leading the dialogue around energy and the environment to ensure continued access to affordable, reliable, and resilient energy for all consumers.

CEA believes it is not a question of when we evolve our energy mix, but rather how that evolution occurs to create the maximum benefit to communities across the country. Propelling our country forward are technological innovation, energy diversity, and improved efficiency to help the U.S. continue to lead the world in enhanced environmental protections with reduced emissions.

Done right, we can ensure everyone has access to affordable, reliable, and resilient energy, a cleaner environment, and a sustainable economic future.

We hope you'll join the energy conversation at **www.consumerenergyalliance.org**.