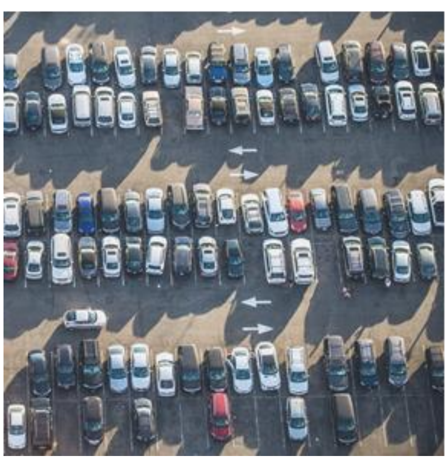
California Transportation Policy Leadership

How California Led the World Toward Cleaner, Advanced Vehicles



MJB & A

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Acknowledgements

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M.J. Bradley & Associates, LLC (MJB&A), founded in 1994, is a strategic consulting firm focused on energy and environmental issues. The firm includes a multi-disciplinary team of experts with backgrounds in economics, law, engineering, and policy. The company works with private companies, public agencies, and non-profit organizations to understand and evaluate environmental regulations and policy, facilitate multi-stakeholder initiatives, shape business strategies, and deploy clean energy technologies.

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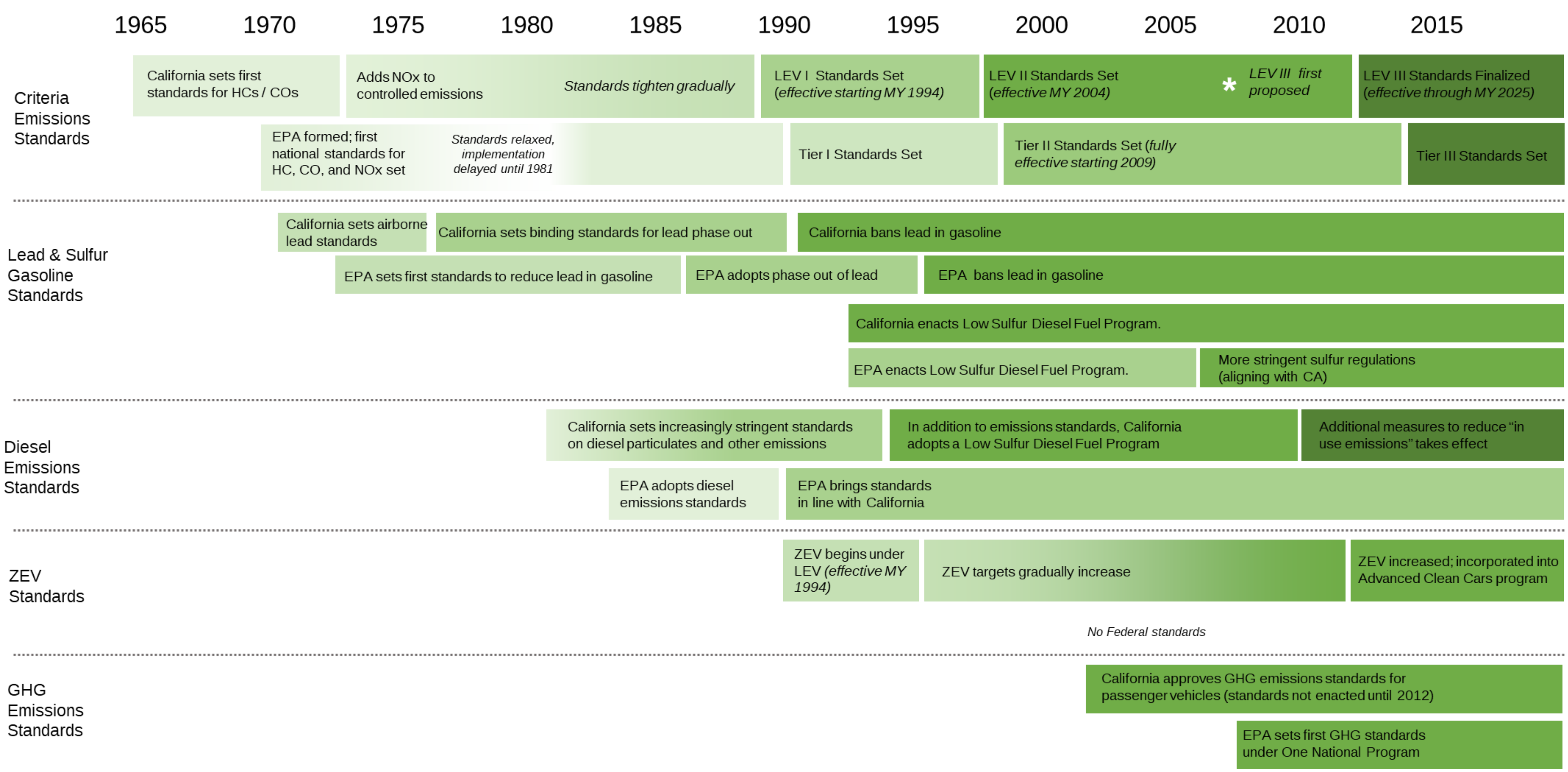
Introduction

California has long led the U.S. in establishing innovative, technology-driving, and effective emissions-reducing regulations in the light- and heavy-duty vehicle sector. As explored in this report, California has achieved significant reductions in emissions due to these programs, leading to healthier air and meaningful steps toward state contributions to climate change and serving as an incubator for technological development. Just as importantly, California has also served as a proving ground for policy and technological innovations that have since been adopted across the country and world. The environmental and economic gains of these policies have thus been multiplied as state actors, investors, technology developers, and industry apply lessons learned, ultimately improving the efficiency, affordability, and effectiveness of environmental initiatives across the country and beyond.

In 1947, California Governor Earl Warren signed into law the Air Pollution Control Act, authorizing the formation of county air pollution control districts.[1] In 1957, these control boards were given the authority to prescribe standards for emission control devices.[2] California's first vehicle tailpipe emissions standards were promulgated in 1966, establishing the nation's first tailpipe emissions standards for hydrocarbons and carbon monoxide. In 1967, two important pieces of federal legislation, the Mulford-Carrel Act and the Federal Air Quality Act, preserved California's authority to set its own air quality rules and emissions standards because of the state's leadership and the value that policy innovations in California delivered for the rest of the country.

This report highlights key examples of California's leadership role in setting technology-driving standards later adopted by other states, EPA, and countries around the world. Figure 1 below summarizes key policies, showing with darkening colors how standards have increased over time, with federal programs largely following California's lead. This begins with the first tailpipe standards, which, then and today, pushed forward technical innovations. Since then, California has implemented standards for gasoline and diesel emissions standards, mandatory targets for zero emissions vehicles and, most recently, tailpipe standards for greenhouse gases. Each of these policies is explored in turn. As context alongside key policies referenced, this report also includes a brief background on the development and requirements of these policies.

Figure 1 California Vehicle Standards Leadership



California Leadership: Stimulating Market and Policy Developments

The policies and innovations in this report are organized largely chronologically by the time of first promulgation. California has subsequently amended and strengthened many of the policies described here over the past 50 years leading to greater innovation and adoption of these refined policies at the state, federal, and international levels.

Mandatory Tailpipe Emissions Standards: Criteria Pollutants

When California issued standards for hydrocarbon (HC) and carbon monoxide (CO) emissions from passenger vehicles in 1966, it was the first jurisdiction—subnational, national, or otherwise—to introduce tailpipe emissions standards for new vehicles. California continued its leadership in developing vehicle emissions standards for criteria pollutants throughout the 1970s and 1980s, continuing to regulate CO and particulates and establishing mandatory regulations on oxides of nitrogen (NOx) in 1971. The first comprehensive policy that combined these separate standards into one program that allowed increased flexibility for vehicle manufacturers was the Low Emissions Vehicle (LEV) Program (see box to right).

Additional states soon thereafter adopted these standards. In 1991, the 13 northeastern states that comprised the Ozone Transport Region pledged to adopt California's new LEV program and its stricter multi-pollutant vehicle emissions standards.[*] In 1994, the region's Ozone Transport Commission (OTC) officially resolved to adopt the LEV standards on a regional basis because "regional ozone modeling to date has shown the need for emission reductions beyond those which will be realized through the strategies specifically included in the [CAA; and]…based on the technical analysis done by the states of the OTC to date, LEVs provide substantial and cost effective emissions reductions." The Commission also noted that implementation of the LEV program in the "Northeast will result in substantially greater emission reductions than provided by the Federal Motor Vehicle Control Program not only of ozone precursors but of airborne toxics, acid rain producing gases and to prevent air pollution in general."[3]

The California LEV program also drove technology development and adoption that facilitated the tightening of national standards (these technological improvements are discussed in more detail below). In some cases, automakers decided to certify their vehicles for all 50 states instead of only for California. By doing this, they put California emission controls on all of their vehicles in order to simplify their

Low Emissions Vehicle (LEV) Program

In 1990, building off a nearly 25-year history of establishing tailpipe emissions standards, the California Air Resources Board (ARB) adopted the Low Emissions Vehicle (LEV) program which, among other things, set criteria pollutant emissions standards for passenger vehicles for model years (MY) 1994 through 2003. These standards required each automaker to calculate a "fleet" average emissions rate—an average rate of all new vehicles sold by that automaker. In addition, the program was carefully crafted to balance how the individual pollutant standards were met. For example, compared to the federal standards, LEV I allowed for higher CO emissions in order to implement a lower NOx standard.

This fleet-based approach, the first of its kind, granted manufacturers flexibility in how to meet the new standards that would regulate five non-greenhouse gas pollutants: nonmethane organic gas (NMOG), NOx, CO, particulate matter (PM), and formaldehyde. ARB continued to make changes to these regulations including increasing the stringency of the emissions requirements under the subsequent LEV II and LEV III programs.

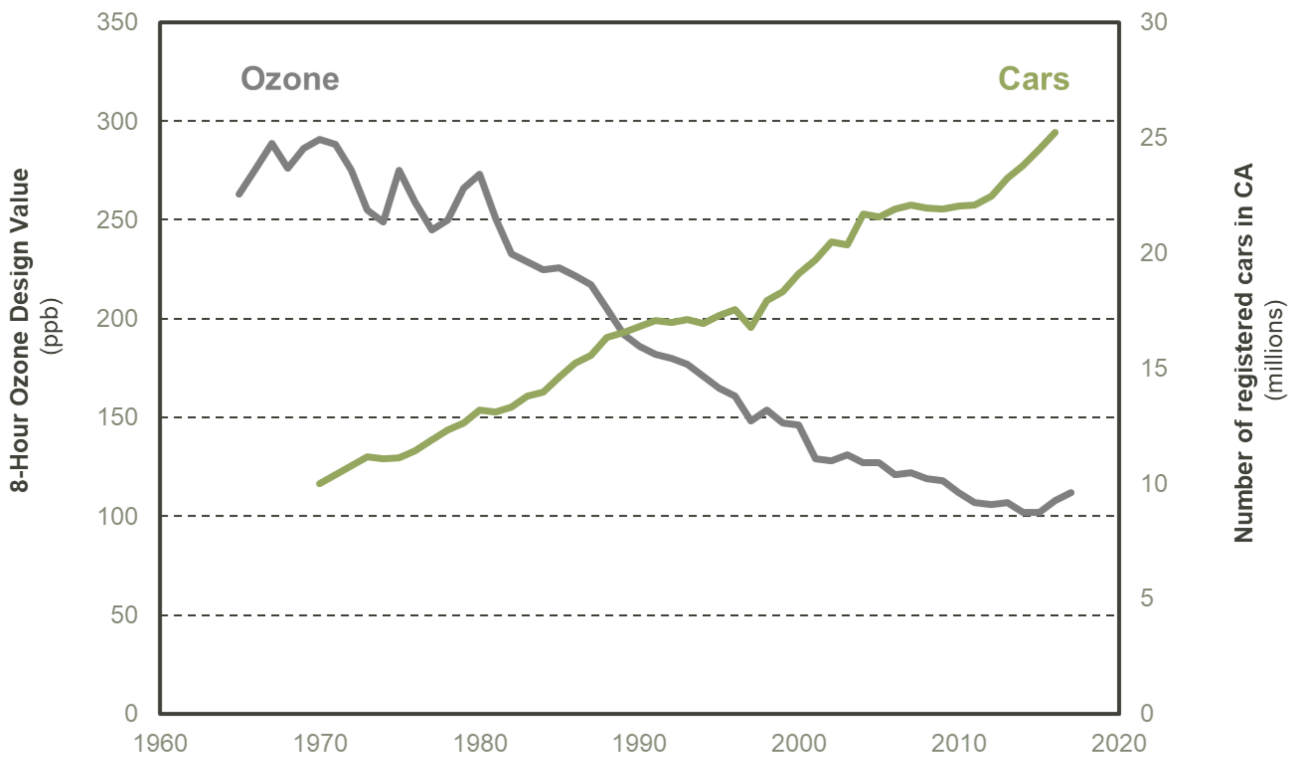
[*] Original member states of the Ozone Transport Region were Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, parts of Virginia and the District of Columbia.

production and distribution. For example, in 1997, Honda announced that it would distribute its low emitting, redesigned Accord in all 50 states, becoming the first automaker to sell a vehicle throughout the United States that met California's low-emission vehicle standard.[4] Starting in 1998, additional competition among the 'Big Three' U.S. auto manufacturers and major Japanese companies pushed each company to pledge voluntarily to market low emitting vehicles in all states, even in the 45 states that had not mandated California cars at that time.[5]

When EPA finalized its Tier 2 vehicle emissions standards in February 2000, it wrote that its standards were "aimed at improving the implementation efficiency of the program by better aligning the federal Tier 2 program with the [voluntary federal] NLEV program and with California's [LEV II] program."[6] However, it also noted that "many current production vehicles are already certified at or near the Tier 2 standards."[7] EPA also wrote at the time that "[e]mission control technology has evolved rapidly in recent years…some vehicles currently in production are well below [required] levels…The reductions have been brought about by ongoing improvements in engine air-fuel management hardware and software plus improvements in catalyst designs."[8]

Since implementing criteria standards and the LEV programs, California has experienced significant improvements in air quality, even as the number of cars on the road has increased (see Figure 2). The LEV program not only led to cleaner air within the state, but California's actions have also benefitted the rest of the nation: as of 2018, 13 states have adopted California's emissions standards under Section 177.[*] More recently, Colorado's Executive Order B 2018 006 committed to establishing a state LEV program that would incorporate the requirements of California's LEV program. Governor John Hickenlooper's Executive Order states that by adopting LEV standards Colorado can continue its history of "adopting and implementing strategies to protect and improve our air quality."[9]

Figure 2 Ozone in California



Source: Adapted from the California Air Resources Board[10]

[*] These states are: Colorado, Connecticut, Delaware, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington.

Emissions Control Technologies Stimulated by California Standards

In order to meet California standards, auto manufacturers accelerated research and development of advanced technologies. This technology forcing function is a long-recognized feature of vehicle emissions standards. For example, a study of patents for new engine and vehicle emissions control technologies found that the automotive industry introduced new emission control technologies in each period of phasing in more stringent standards: oxidation catalysts in 1975; three-way catalysts in 1980, and thermal management and onboard diagnostic systems in 1994.[11] These technologies, often pioneered in the California market, made their way throughout the U.S. and international markets where they contributed to reducing emissions, improving associated health and environmental outcomes, and easing compliance with subsequent federal emissions standards. Below, we highlight some of the more prominent examples of this California leadership.

Catalytic Converters

A chief example of this technological development is the catalytic converter, a device installed in the exhaust system to significantly reduce tailpipe emission levels. The two-way catalytic converter, more commonly known as an oxidation catalyst, was first introduced commercially in the 1970s and controlled for CO and HC engine emissions. Modern three-way catalytic converters also control for NOx emissions. The technology has reduced emissions from a range of sources: cars, trucks, buses, and motorcycles as well as vehicles fueled with alternative fuels like propane and natural gas.

When California first established standards for NOx, catalytic converters utilized two-way technology. However, California's NOx standards pushed the industry to further advance research and development—and industry rose to the occasion by developing a range of technologies to improve emissions performance. Chief among these was the advancement of three-way technology, which started being placed in vehicles by 1976. These catalytic converters were enabled only through the application of other critical technologies discussed in more detail below, such as electronic fuel injection controlled by on board diagnostics and computers.

A federal Congressional vehicle technology assessment in 1979 noted that "the 1982 California NOx standard of 0.4 gram per mile introduces a more difficult technical problem than the 1981 Federal standard of 1.0 gram per mile," and that while "no method has been demonstrated to meet the California standard with typical large U.S. spark ignition engines,…Volvo, Saab, and GM have shown, however, that they can meet the 0.4 gram per mile requirement with a three-way catalyst system on a four-cylinder engine."[12] This same report noted that Volvo had installed a three-way catalyst and electronic feedback control on some of its 1977 cars, and that Ford and General Motors introduced this system on a limited number of their 1978 new cars in California. This allowed these automakers to "comply with the tighter California emission standards and to gain operating experience prior to full-scale use."[13] Advanced catalytic converter technology also was applied in the heavy duty and diesel fleet thanks to California-driven technological development: in its 1993 rulemaking on emissions standards for heavy duty vehicles, EPA noted that "close coupled catalytic converters will be available for the 1994 model year due to the California LEV standards."[14]

The three-way catalytic converter is widely recognized as one of, if not the, best technologies to reduce criteria air pollution from mobile sources. According to the National Resource Council of the National Academies, "[t]he primary success of the [California] LEV program has been in achieving near-zero levels of tailpipe emissions from gasoline-fueled vehicles, exceeding the expectations of experts in both industry and government."[15] Studies have found that "[a]mong all the types of technologies developed so far, use of catalytic converters is the best way to control auto exhaust emission," and EPA considers it to "be one of the great environmental inventions of all time."[16] The Society of Automotive Engineers and the magazine *Car and Driver* called the catalytic converter one of the top ten automotive breakthroughs of the 20^{th} century.[17] A Swedish study found that passenger cars with catalysts have substantial emissions reductions compared to cars without the technology: 95 percent lower CO emissions, 90 percent lower NOx, 95 percent lower HC, and 70 percent lower methane.[18]

Although first used in the U.S., the catalytic converter has had a global impact. Catalytic converters first were adopted in Europe, with the European Union mandating their use in the early 1990s.[19] Since then, the technology has been adopted across countries where car ownership is rapidly increasing—such as China, Brazil, India, and Russia—as a result of regulations that require catalytic converters on all new passenger cars. As of 2011, more than 750 million vehicles with catalytic converters have been sold worldwide.[20] A report from the United Nations cited the catalytic converter as an example of how "[t]he United States has often set technology-forcing standards, advancing emissions control technology worldwide."[21] Likewise, a European Union report notes that because German car manufacturers had been required to develop vehicle models with catalytic converters to meet California's standards, they were prepared to address the growing public pressure from Europeans in the 1980s to address air quality issues.[22] Now, a technology that was developed in response to California's standards is used in almost all light duty vehicles globally.[23]

Onboard Diagnostic (OBD) Technologies

Manufacturers began utilizing electronic means to control and diagnose engine functions in the 1970s and 1980s.[24] These "on board diagnostic" (OBD) systems control, monitor, and assist in diagnosing electronic component problems, including monitoring and assisting many emission-related components. For example, OBD systems are critical for controlling the precise fuel injection necessary for the operation of three-way catalysts. California introduced OBD regulation that specifically required manufacturers to enable these and other important emissions-controlling functions as well monitor some of the emission control components on vehicles. In more advanced forms, OBD systems monitor all the vehicle components that can affect emissions performance, ultimately ensuring that the vehicle is operating as designed to comply with emissions standards. The California Air Resources Board (ARB) states that "[w]hile the new vehicles in California may start out with very low emissions, improper maintenance or faulty components can cause vehicle emission levels to sharply increase," citing studies that concluded that approximately 50 percent of total criteria emissions from late-model vehicles are the result of malfunctions.[25] California first imposed requirements for OBD systems for models released in 1988 in order to ensure all vehicles complied with state, and subsequently national, emissions standards.[26]

California has consistently demonstrated leadership in OBD systems and requirements, especially relating to emissions reducing technology. As OBD technology rapidly improved, in 1992 ARB published their "OBD II" requirements that incorporated the emerging technologies, such as tracking catalyst efficiency.[27] In 1993, EPA followed, publishing its first version of regulations called "Federal OBD." Over time EPA and ARB harmonized these requirements, though, as EPA noted, "ARB OBD II requirements tend to focus on OBD system design and, as a result, are more technology forcing and provide greater detail for each required OBD monitor."[28] The advanced OBD system developed for compliance with OBD II was much more sophisticated; it monitored nearly all emission related functions of the engine and specifically targeted emissions performance.[29] OBD II also results in improvements in fuel efficiency, reduced maintenance costs, and increased engine power. Because EPA accepts compliance with ARB's more comprehensive design requirements, most manufacturers prefer to certify to ARB OBD II design requirements,[30] ensuring that this technological development extends throughout the U.S. vehicle market.

After development and implementation in the U.S., other countries began to incorporate OBD II technology. Even though Japan officially required OBD II system integration in 2000, Japanese manufacturers—who also sell vehicles in the U.S. market—had been producing cars with the technology since 1996. The European Union's Directive 1999/96/EC followed California's lead and mandated that "[f]rom 1 October 2005, new types of vehicles, and from 1 October 2006, all types of vehicles, should be equipped with an OBD system or an On-Board Measurement (OBM) system to monitor in-service exhaust emissions."[31] After Europe mandated in 2005 that OBD II systems must be used on heavy-duty vehicles as well, countries like Brazil and China followed suit.[32] An *OECD Journal: Economic Studies* report tracking the effects of environmental policy on innovation finds that ultimately "the forerunner in development and implementation of both OBD legislation and OBD systems was the United States" with its technology-forcing standards.[33] And, California led developments in the U.S.

Fuel Injection: Electronic, Throttle Body, and Direct

Similarly, electronically controlled, throttle body, and direct fuel injection (DFI) began in California to meet local standards and spread throughout the industry. Fuel injection modifications began in the 1950s to replace the less efficient and dirtier carburetors that were at the time standard in the industry. These standard carburetors used the pressure drop in an engine air intake system to pull fuel into the air stream. Electronically controlled injection, on the other hand, injects fuel from an electronically controlled valve directly into the air intake, and in smaller discrete amounts, allowing for better control of combustion within the cylinder. It can also be directly injected into single or multiple ports within the engine. Because this process is controlled by the vehicle's computer, it is much more precise and results in more efficient fuel use, reduced fuel consumption, and fewer emissions.[34]

Electronically controlled injection first got a boost from California's tightening NOx standards to 0.4 grams per mile starting with model year 1982, since three way catalytic converters needed precisely controlled injection of fuel to function appropriately. To achieve this, the auto industry adopted throttle body injection, which injects fuel into the engine using an electric pump. The technology continued to improve in concert with advancements in OBD technology, which controlled the injection and made it more feasible to achieve more accurate fuel metering and to control the complex and precise injection. This included "multi-port" fuel injection, which adjusts fuel injection for each cylinder using improving computers. By the mid-1980s, virtually every European carmaker used an electronic fuel injection system or its components, and the carbureted vehicle died out in the early 1990s.[35] However, in 2008, prior to the establishment of California's Advanced Clean Car Program, only two percent of gasoline fueled vehicles used gasoline *direct* injection, a more efficient but also more complex process that involves spraying fuel directly into the cylinder. After the Advanced Clean Car standards took effect, however, this penetration rapidly increased: by 2014, 38 percent of vehicles utilized DFI. This "diffusion" of technology was spurred only when "stimulated by emissions standards," standards which California drove.[36]

By allowing for more precise control of combustion, electronically controlled and direct fuel injection has led to more powerful engines with improved fuel efficiency and lower emissions. A study done by the U.S. Department of Health, Education and Welfare during the early transition toward electronically controlled injection in the 1960s found that switching from a carburetor to a timed port fuel injection reduced on road emissions of CO by 50 to 60 percent and HC by 25 to 50 percent.[37] DFI has a further significant improvement on emissions by reducing fuel consumption, leading to a 14.5 percent decrease in CO_2 emissions in one recent study.[38]

Additional Technological Developments

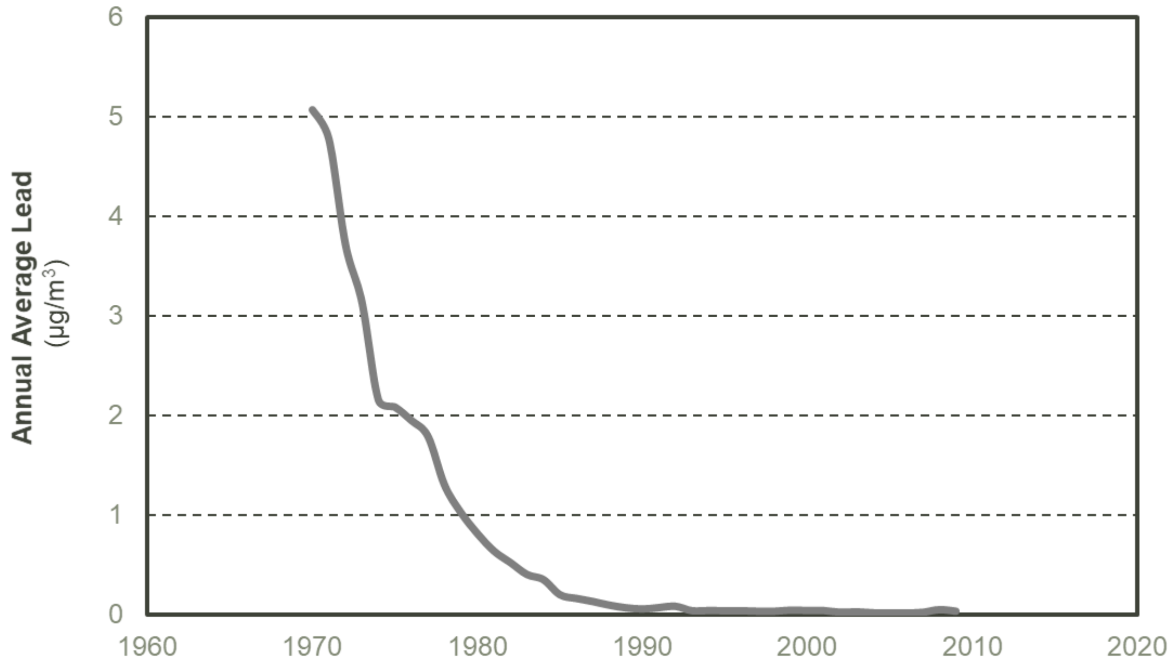
Auto manufacturers developed myriad other technologies to reduce emissions and improve performance. For example, in 1972 Honda released a passenger vehicle with a compound vortex controlled combustion (CVCC) engine in response to California's pending NOx emissions standards. This helped drive forward the rest of the industry, especially domestically, where it "dispelled the myth in Detroit that stiffer new [California] emissions standards could not be met."[39]

Gasoline Requirements: Unleaded, Low Sulfur, and Reformulated Gasoline

Starting in the early 1920s, gasoline refiners began including various additives in their fuels to improve engine performance. One of the first—and most common—was lead in various forms. Emissions of lead from this gasoline, however, created new environmental problems. In addition, lead in gasoline significantly harmed the operations of catalytic converters. As these devices became more necessary to meet other emissions standards for NOx, CO, and other pollutants and health concerns grew, California increasingly turned its focus to regulations to reduce lead content in gasoline.

In 1970, California set the first standard for airborne lead (from all sources, including vehicles), at 1.5 $\mu g/m^3$, laying the groundwork for and creating pressure for EPA to develop a federal standard.[40,41] Although EPA set standards to reduce lead from gasoline in 1973, EPA showed a reluctance to enforce the regulations and litigation continued for multiple years.[42] Indeed, although refiners such as Texaco had begun manufacturing unleaded or low-lead fuels by 1970, these fuels were only initially offered for sale in California.[43] California, meanwhile, established binding regulations in 1976 to phase out lead from gasoline over several years. According to one study, California's requirements corresponded with a significant decrease in California average ambient air lead levels between 1976 and 1980 (see Figure 3), precipitating a 37 percent drop in average blood lead levels during the same period.[44] California ultimately banned leaded gasoline in 1992 and the federal government followed in 1996.[45]

Figure 3 Ambient Air Lead in Los Angeles



Source: Adapted from the California Air Resources Board[46]

In addition to the health benefits of reducing ambient lead, reducing the amount of lead in gasoline was important to avoid damaging catalytic converters. By damaging and reducing the effectiveness of catalytic converters, leaded gasoline can increase emissions of HC, CO, and NOx by as much as a factor of eight.[47] EPA,[48] industry,[49] and academic literature[50] cite this negative interaction with catalytic converters as a critical reason for the reduction in leaded gasoline. As California emissions standards tightened and catalytic converters became necessary to meet those and subsequent federal emissions standards, the demand for unleaded gasoline that was compatible with these devices grew. For example, ARB found that while leaded gasoline constituted around 75 percent of gasoline produced in California in 1977, it fell to only 15 percent in 1989.[51]

Similarly, sulfur in gasoline has been shown to inhibit the emission control performance of catalyst technology. California recognized the need to reduce sulfur in gasoline in order to meet LEV II vehicle standards, [52] and, in setting its reformulated gasoline requirements to take effect in 1992, set an average sulfur level in gasoline of 300 ppm.[53] The ARB has continued to make these standards more stringent, imposing the current standard of 20 ppm.[54] ARB lists reducing sulfur to “enabl[e] catalytic converters to work more effectively and further reduce tailpipe emissions” as the first goal of clean gasoline standards.[55] When EPA established its Tier 3 sulfur standards, it noted that these “vehicle standards are intended to harmonize with California’s Low Emission Vehicle program, thus creating a federal vehicle emissions program that will allow automakers to sell the same vehicles in all 50 states.”[56] It also noted that “the experience in California demonstrates that commercial technologies already exist to permit refiners to produce low sulfur gasoline.”[57] The European Union has also followed in establishing a two phase reduction in gasoline sulfur to 150 ppm in 2000 and 50 ppm in 2005.

Finally, California has also led the developments of a reformulated gasoline program, with its standards serving as the template for federal action. The California reformulated gasoline program (CaRFG) sets stringent standards for California gasoline that produce “cost-effective emission reductions from gasoline-powered vehicles” and focus largely on reducing ozone-causing pollutants. The CaRFG program has been implemented in three phases. Phase

1, in 1991, eliminated lead (as discussed above) and set regulations on other additives and volatile compound emissions. This program is a critical component of California's State Implementation Plan (SIP) to reduce air pollution and also was formulated such that the state would meet the requirements of the federal RFG program three to four years earlier than that mandated.[58] Phase 2, implemented in 1996, set standards for pollutants such as sulfur and other volatile compounds, including the carcinogen benzene. Phase 3, implemented in 1999, eliminated a common additive that had replaced lead in gasoline to increase octane but had been found to pose a cancer risk through groundwater contamination. EPA has since adopted federal reformulated gas requirements similar to Phase 2 standards for areas not in compliance with federal ozone national ambient air quality standards.

Statewide Clean Diesel Strategy

California first established limits on diesel particulates from mobile sources in 1982. Building from these regulations and upon additional findings of the health harm of diesel particulates,[59] ARB approved a comprehensive plan in 2000 to reduce diesel PM emissions from new and existing diesel-fueled engines and vehicles. This "Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles" set goals to reduce diesel PM emissions and the associated health risk by 75 percent in 2010 and 85 percent by 2020.[60] The plan identified fourteen measures that ARB recommended be developed to further reduce diesel PM emissions, with a particular emphasis on measures to reduce emissions from in-use diesel engines. ARB stated that the measures were meant to "comprise a comprehensive program to be implemented in California to control and reduce potential cancer risk from exposure to diesel particulate matter from mobile sources."[61]

California, unlike any other state in the U.S., currently uses a multi-pronged regulatory approach to reduce diesel emissions from both in-use and new engines. Since 1990, when the stringency of federal standards tightened to mostly align with California's program,[*] the two have had matching emissions requirements for emissions of PM, NOx, CO, and HC from new heavy-duty diesel engines.[62] However, California has also implemented various innovative programs to reduce emissions from in-use engines. These regulations are generally based on three types of control:

1. Retrofitting engines with emission control systems, such as diesel particulate filters or oxidation catalysts;
2. Replacement of existing engines with new technology diesel engines or natural gas engines; and
3. Restrictions placed on the operation of existing equipment.[63]

In total, the state's regulations for both new and in-use engines require diesel PM levels of less than 0.01 g/bhp-hour, equivalent to the 2007 PM emission standard for new heavy-duty highway engines.[64] While the regulations are mandatory, operators have a degree of flexibility in the how they approach compliance.[65]

Additionally, ARB encouraged EPA to adopt a nationwide low sulfur diesel fuel standard, as well as other diesel-related emissions reduction programs. California's Low Sulfur Diesel Fuel Program, in effect since 1993, sets limits on aromatic HC content (10 percent by volume) and on sulfur content (15 parts per million by weight) to reduce emissions from diesel engines and equipment.[66]

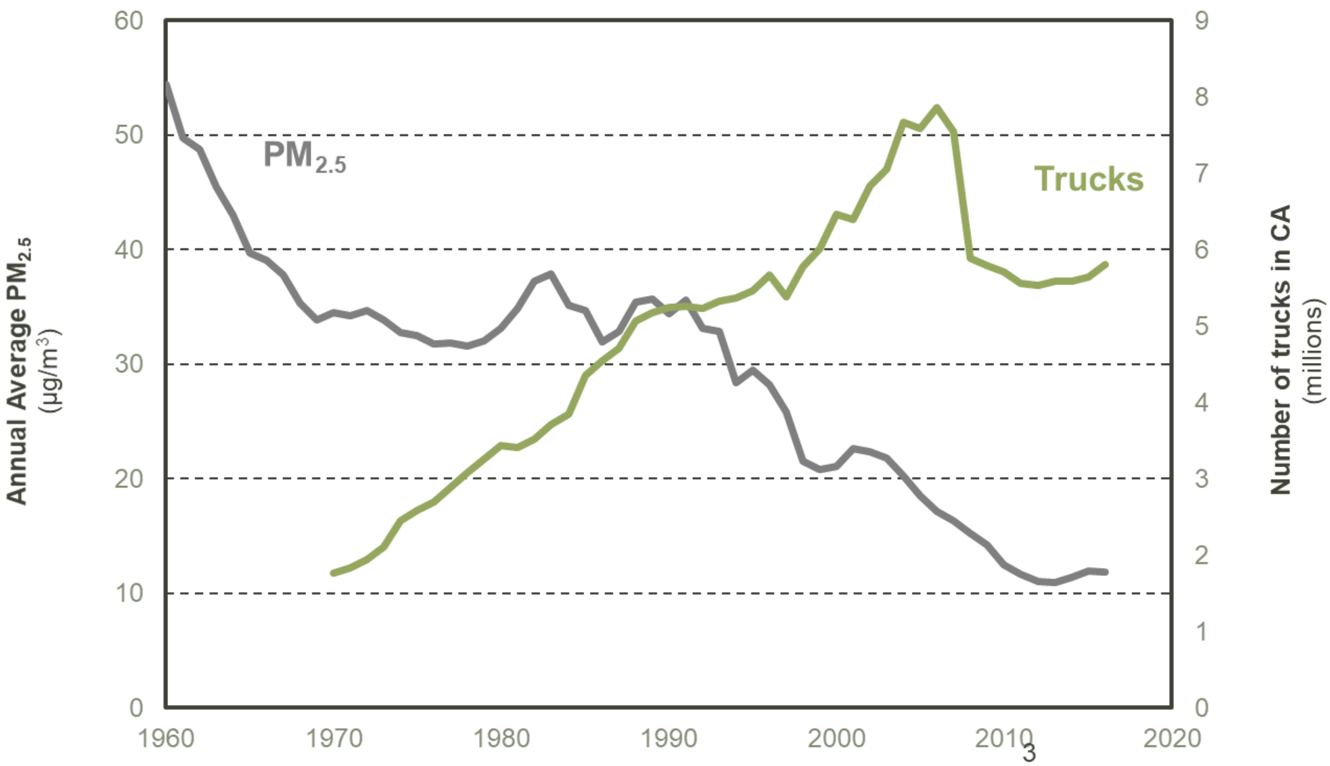
EPA began regulating diesel fuel sulfur levels in 1993. Beginning in 2006, EPA phased in more stringent regulations limiting sulfur in diesel fuel to 15 ppm (known as ultra-low sulfur diesel), bringing these standards more in line with California's. Several states, such as Oregon and New Jersey, have formed their own clean diesel plans and programs. [67] In listing acceptable retrofit devises, the New Jersey Department of Environmental Protection's Mandatory Diesel Retrofit Program incorporates both California's and EPA's list of verified retrofits by reference.[68]

Diesel engines emit both solid PM and gaseous material, including volatile organic compounds and NOx. ARB regulations have had a major impact in particular on PM reductions: since 1990, statewide PM emissions from diesel engines have decreased by 68 percent.[69] Figure 4 shows this drastic decrease in the Los Angeles area. ARB expects diesel PM levels to continue to decline as additional controls are adopted, including the use of cleaner-

[*] California does still impose more stringent standards for certain classes of vehicles, such as diesel buses.

burning diesel fuel and increasing use of alternative fuels, retrofitting engines with particle-trapping filters, and integrating new, advanced technologies.[70]

Figure 4 Fine Particulate Matter (PM2.5) in Los Angeles



Source: Adapted from the California Air Resources Board[71]

Most recently, China, the country with the largest diesel vehicle fleet in the world (largely heavy trucks and off-road vehicles), has launched a similar comprehensive strategy to reduce emissions, including PM and NOx, from diesel on- and off-road vehicles. Nationwide implementation of the current standard was completed in 2016.[72] The International Council on Clean Transportation stated that the regulations combine "best practices from the latest emissions regulations in the EU, the State of California, and the U.S."[73]

Zero Emissions Vehicle Requirements

In 1990, California first adopted a "zero emissions vehicle" (ZEV) mandate as part of its LEV I program, effective starting MY 1994. The initial regulations required two percent of new vehicle sales by major manufacturers to be ZEVs by 1998 and 10 percent by 2003. Over time, California has modified the ZEV through biennial reviews to evaluate the status of ZEV technology and make regulatory modifications.

Today, California's ZEV program requires increasing deployment of electric vehicles in California. The regulation is imposed on automakers, who earn credits for the deployment of electric vehicle technology, including fully electric vehicles as well as plug-in hybrid vehicles. In MY 2018, large volume vehicle manufacturers must meet a ZEV credit requirement of 4.5 percent. By 2025, the sale target increases to 15.4 percent.

Mandatory Requirements for Zero Emissions Vehicles

The Zero Emissions Vehicles (ZEV) program has long been viewed by both its designers and compliance entities as a technology forcing mechanism. When ARB first imposed the program in 1990, it stated that "without the mandate, it is uncertain whether manufacturers would be willing to commit the resources needed to accelerate the commercialization of ZEVs."[74] And certainly, at the time of the mandate's initial enactment, electric vehicle and battery technology was relatively immature.[75]

Results from the first ten years of the program demonstrate its success in advancing technological development. Battery developers have stated that the ZEV mandate was a crucial component to obtaining outside investment in early stages of the industry.[76] A study interviewing 134 automakers, fleet managers, and policy agencies found that 80 percent said that between 1990 and 1998, the program was very or somewhat important to the success of their business, and an even greater percentage—90 percent—viewed the policy as very or somewhat important to the *future* success of their business.[77] A 2000 ARB report concluded that the ZEV requirements had been "instrumental in promoting battery, fuel cell, component and vehicle research and development…[and] spawning a large variety of extremely low emission vehicle technologies,"[78] including not only electric vehicles and battery technologies but also "gasoline vehicles with zero evaporative emissions, exceedingly clean exhaust…and emission control systems that are twice as durable than their conventional forebearers."[79]

This development has only accelerated since. As of January 2018, global carmakers' investments in batteries and electric cars surpassed $90 billion.[80] Automakers are continuing this investment and have committed significant resources toward electric vehicles. A few examples of recent commitments include:

- General Motors CEO Mary Barra has stated, "we believe in an all-electric future;" the company will launch 20 new all-electric vehicles globally by 2023.[81]
- Daimler Group, owner of Mercedes and the SmartCar brands, has said that it is "all systems go" on an electric future, bringing more than ten different all-electric vehicles to market by 2022 and electrifying the entire Mercedes-Benz portfolio, leading to more than 50 electric options for customers overall.[82]
- Volkswagen Group is going to make everything electric "in some shape or form" by 2030.[83]
- Ford is investing $11 billion to bring 40 total EVs to market by 2022, including seven to the U.S. market. [84]
- Finally, Volvo Cars has announced that every Volvo it launches from 2019 will have an electric motor, in its words "marking the historic end of cars that only have an internal combustion engine (ICE) and placing electrification at the core of its future business."[85]

The ZEV program also fostered improvements and greater efficiency in the research and development process. For example, the program increased public-private partnerships and research efforts.[86] In 1990, prior to implementation of the ZEV mandate, government funding to support electric vehicle technology improvements totaled $18 million. By 2000, related funding had increased to $100 million.[87] In addition, prior to the ZEV program, research and development efforts were fragmented between industry and federal programs.[88] After its implementation, a variety of U.S-based partnerships emerged to support technological development to meet the ZEV standard, most notably the U.S. Advanced Battery Consortium (USABC), which was formed to leverage private research and development with federal resources.[89] In 1991, shortly after the finalization of the ZEV mandate, members of the USABC matched $130 million in Department of Energy research funds.[90] In addition, a variety of other supportive U.S policies and programs have ramped up since the ZEV mandate. Today, investments in electric vehicle and charging infrastructure development continue to grow. In May 2018 alone, New York and California authorized almost $1 billion in spending on electric vehicles, with the California Public Utilities Commission approving $738 million in transportation electrification projects and New York dedicating $250 million to the launch of Evolve NY, a new electric vehicle expansion initiative in partnership with the New York Power Authority.[91]

Other states have been able to take advantage of and contributing to these technological improvements. Directly, nine states have adopted California's ZEV requirements.[92] Together, these ten states represent more than a quarter of total annual light-duty vehicle sales in the United States.[*] Potential benefits of adopting California's standards include facilitating state air quality goals and/or more readily meeting federal air quality standards through reduced vehicle emissions.[93] These standards have also inspired international action. For example, China's New Energy Vehicle (NEV) mandate, finalized in September 2017, is modeled off of California's ZEV mandate, setting required fleet ZEV requirements and a crediting mechanism, scaled based on electric range, for automakers to track compliance.[94]

GHG Emissions Regulation and the Advanced Clean Cars Program

In 2002, the California Legislature passed Assembly Bill 1493, sponsored by Assemblywoman Pavley, directing ARB for the first time to establish GHG emissions standards for passenger vehicles. As part of the LEV II program updates in 2004, ARB approved the "Pavley standards," ultimately put into place for MY 2009 through 2016. ARB developed standards for both light-duty cars and trucks as well as heavy-duty trucks, with near-term (2009-2013) and mid-term (2013-2016) standards for both vehicle subcategories. The standards required carmakers to reduce GHG emissions from their vehicle fleets by approximately 30 percent by 2016. As well as establishing CO_2 standards, the program required automakers to control two other GHGs, nitrous oxide (N_2O) and methane (CH_4), measured in equivalent emissions of CO_2.

In addition, the regulations included the option for manufacturers to receive credit for the inclusion of systems demonstrated to mitigate fugitive emissions of hydrofluorocarbons (HFCs), a GHG with a high global warming potential, from vehicle air conditioning (AC) systems. AC systems contribute to GHG emissions through the direct release of HFC emissions (AC direct emissions) and through tailpipe emissions due to increased load on the system (AC indirect emissions) associated with AC operation. The regulations provided that automakers could earn credit toward compliance with GHG standards through both indirect and direct AC emissions reduction.

In 2012, in coordination with EPA and NHTSA, ARB adopted the Advanced Clean Cars program. ARB began with this phase of vehicle emissions standards "a new approach to passenger vehicles," that combined "the control of smog-causing pollutants and greenhouse gas emissions into a single coordinated package of standards." This package of regulations under the Advanced Clean Cars umbrella included the latest criteria emissions (the LEV III program), the GHG standards, and the ZEV program.

[*] Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Vermont

Mandatory Tailpipe Emissions Standards: Greenhouse Gases

A similar trajectory can be seen with California's development of GHG tailpipe standards. Currently, thirteen states have adopted California's GHG standards.* In California alone, ARB estimated that the standards would reduce GHG emissions by approximately 30 million metric tons by 2020 and by over 50 million metric tons by 2030, equating to an 18 percent overall reduction in GHG emissions from passenger cars in 2020 and a 27 percent reduction in 2030.[95] In addition, ARB estimated that the regulation would reduce "upstream" smog-forming emissions of HCs and NOx by approximately six tons per day in 2020 and 10 tons per day in 2030.[96] ARB estimated that emissions reductions from the twelve total states adhering to California's vehicle standards† would reduce greenhouse gas emissions by 74 million metric tons per year by 2020.[97] While much of these regulations were focused on reducing CO_2 emissions, these regulations also transitioned from the LEV II optional standards for non-CO_2 GHGs to mandatory standards.

The federal government looked to California's standards upon determining that federal vehicle GHG emissions standards were needed to mitigate the danger to human health and welfare posed by these emissions.[98] In order to avoid the creation of two different sets of standards across the country, EPA, the U.S. Department of Transportation, ARB, and vehicle manufacturers began collaborating on the creation of one harmonized fuel economy and GHG standards program for cars and light-duty vehicles at the federal level.[99]

In 2009, the Obama Administration announced "One National Program," a harmonized national standard on GHG emissions and light-duty vehicle fuel economy for model years 2012 through 2016.[100] As part of the program, California agreed to allow compliance with the national standards in order to satisfy its own requirements, even though its existing criteria and GHG emissions standards as finalized in 2004 were more stringent than the proposed federal standards. In 2009, as "part of California's commitment toward a nation-wide program," and with the intent to "prepare California to harmonize its rules with the federal rules for passenger vehicles," ARB amended its Pavley regulations for MYs 2012 through 2016 such that compliance with the new federal GHG standards would be deemed to be in compliance with California's GHG standards.[101]

The new harmonized Federal and California standards, covering model years 2012 to 2016, ultimately required light-duty vehicles to meet an estimated combined average emissions level of 250 grams/mile of CO_2 in model year 2016 and were projected to achieve a reduction of approximately 900 million metric tons in GHG emissions.[102] EPA's standards were finalized in April 2010 and were further strengthened for model years 2017 through 2025 in a separate rulemaking.[103]

One example of this harmonization under EPA's One National Program standards was the incorporation of California's standards by allowing manufacturers to generate and use credits for improved AC systems that reduced leakage of non-CO_2 GHGs to comply with the CO_2 fleet average standards.[104] Indirect credits were awarded for the use of a range of approved technologies.[105] In the final rule's Regulatory Impact Analysis, EPA found both the reduction of AC system leakage and increasing efficiency of the technology to be highly cost-effective and technologically feasible.[106] EPA and ARB also aligned their standards for N_2O and CH_4 under this program.

In 2011, regarding One National Program, President Obama stated, "[t]his agreement on fuel standards represents the single most important step we've ever taken as a nation to reduce our dependence on foreign oil."[107] California and major automakers showed their support for the continuation of One National Program for light-duty GHG and fuel efficiency standards by sending letters to the agencies in July 2011.[108] In 2012, EPA and ARB issued emission standards for model year 2017 to 2025 light-duty vehicles that further strengthened these criteria and GHG emissions standards.[109]

Other countries have also since implemented GHG standards. For example, the European Union (EU) had imposed voluntary standards and various downstream policies (e.g., registration fees and labelling requirements) since the

* These states are: Colorado, Connecticut, Delaware, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington.

† Note that this does not include Colorado, which has since adopted these standards.

early 2000s[110] but in 2011 first proposed direct binding standards for CO_2 from vehicles.[111] The EU finalized these standards in 2014.[112] Today, ten governments have established fuel economy or GHG emission standards for light duty vehicles: Brazil, Canada, China, the European Union, India, Japan, Mexico, Saudi Arabia, South Korea, and the United States. These ten locations are all within the top 15 vehicle markets worldwide.[113] California's leadership in putting mandatory GHG standards in place has started to spread around the world.

Conclusion

California's transportation policy leadership has resulted in cleaner air and more efficient vehicles across the country. It has spurred growth in new and exciting markets such as electric transportation. And it has provided policy certainty for automakers to make investments in innovative technologies for cars and trucks—innovations that have since been adopted around the world. The environmental and economic gains of these policies have thus been multiplied as state actors, investors, technology developers, and industry apply lessons learned, ultimately improving the efficiency, affordability, and effectiveness of environmental initiatives across the country and beyond.

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