CARB RESEARCH IN REVIEW

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Each issue of Research in Review presents a brief description of completed projects and results along with the CARB Contract Number that you can use to look up the full project description. Find more details about these projects from their final reports, public seminars, scientific articles, and more by visiting *arb.ca.gov/research*.

INSIDE THE ISSUE

1 Vehicle Monitoring & Measurement
4 Clean Vehicle Demand
5 Clean Fuels
7 Sustainable Communities
11 Atmospheric Monitoring & Modeling

DON'T MISS

3/27/2018

Upcoming Research Seminar, Real-World Activity of Heavy-Duty Tractors Hauling Container Chassis, Flatbed Trailer, and Tank Trailer

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arb.ca.gov/research/seminars/durbin/durbin4.htm

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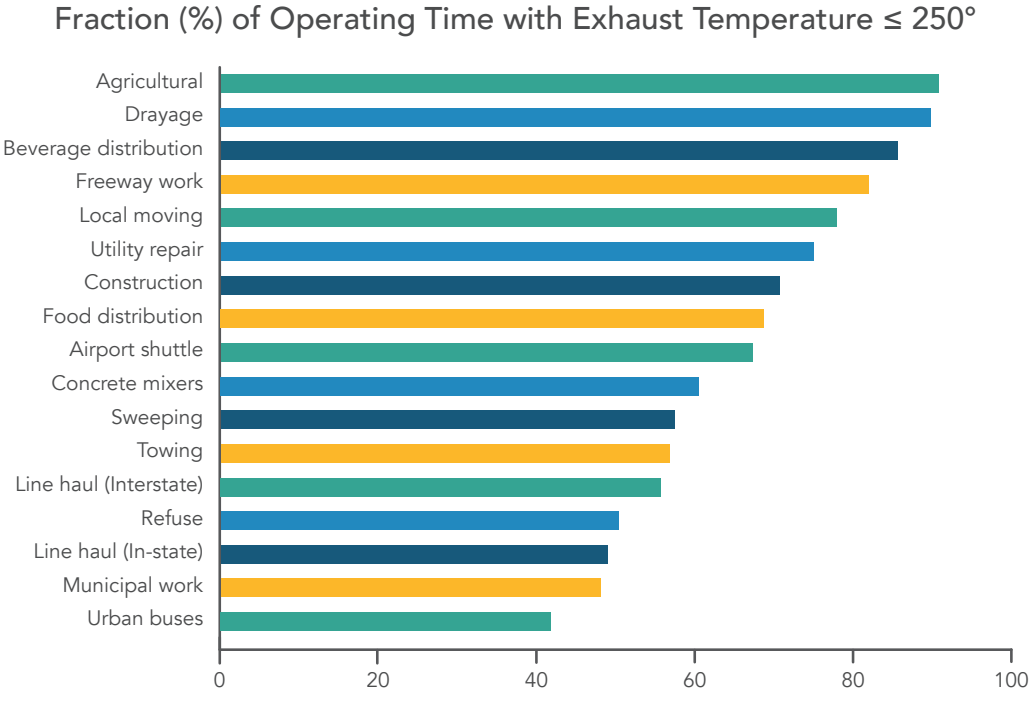
VEHICLE MONITORING & MEASUREMENT

CARB's Mobile Sources research includes forward-thinking projects to update emission inventories and track the progress of regulations aimed at reducing transportation-related emissions.

One for the Road: Big Trucks, Big Data, Big Difference

Exhaust temperature profiles for heavy-diesel vehicles will help fine-tune emission control programs.

California's efforts to reduce particle pollution from heavy-duty diesel vehicles have been very effective, but those same vehicles remain California's largest source of oxides of nitrogen (NO_x), the main contributors to smog. Modern exhaust treatment systems work best for NO_x when the exhaust is very hot, above 250 degrees Celsius (250˚C). When the exhaust is cooler – just after the truck starts, or when idling or crawling through traffic, the exhaust treatment is less effective, so the trucks emit more NO_x. University of California, Riverside, researchers found that the exhaust of many types of large trucks and buses is below 250˚C for at least half of their working hours (*Figure*). Because the researchers collected both location and exhaust temperature data from 19 types of heavy-diesel vehicles, CARB will be able to estimate where and when each type of vehicle emits the most pollution. These results, and additional analysis of collected data, will enable CARB to improve vehicle emission control programs, and help achieve emissions reductions vital to reaching long-term air quality goals outlined in California's Mobile Source Strategy. *CARB Contract 13-301*



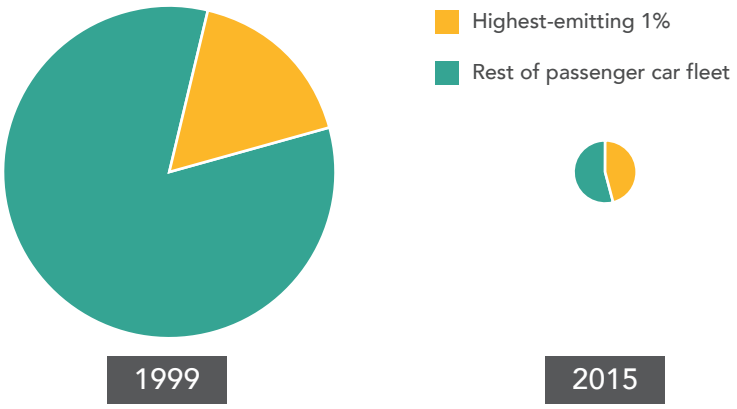
Tracking Real-World Passenger Car Emissions

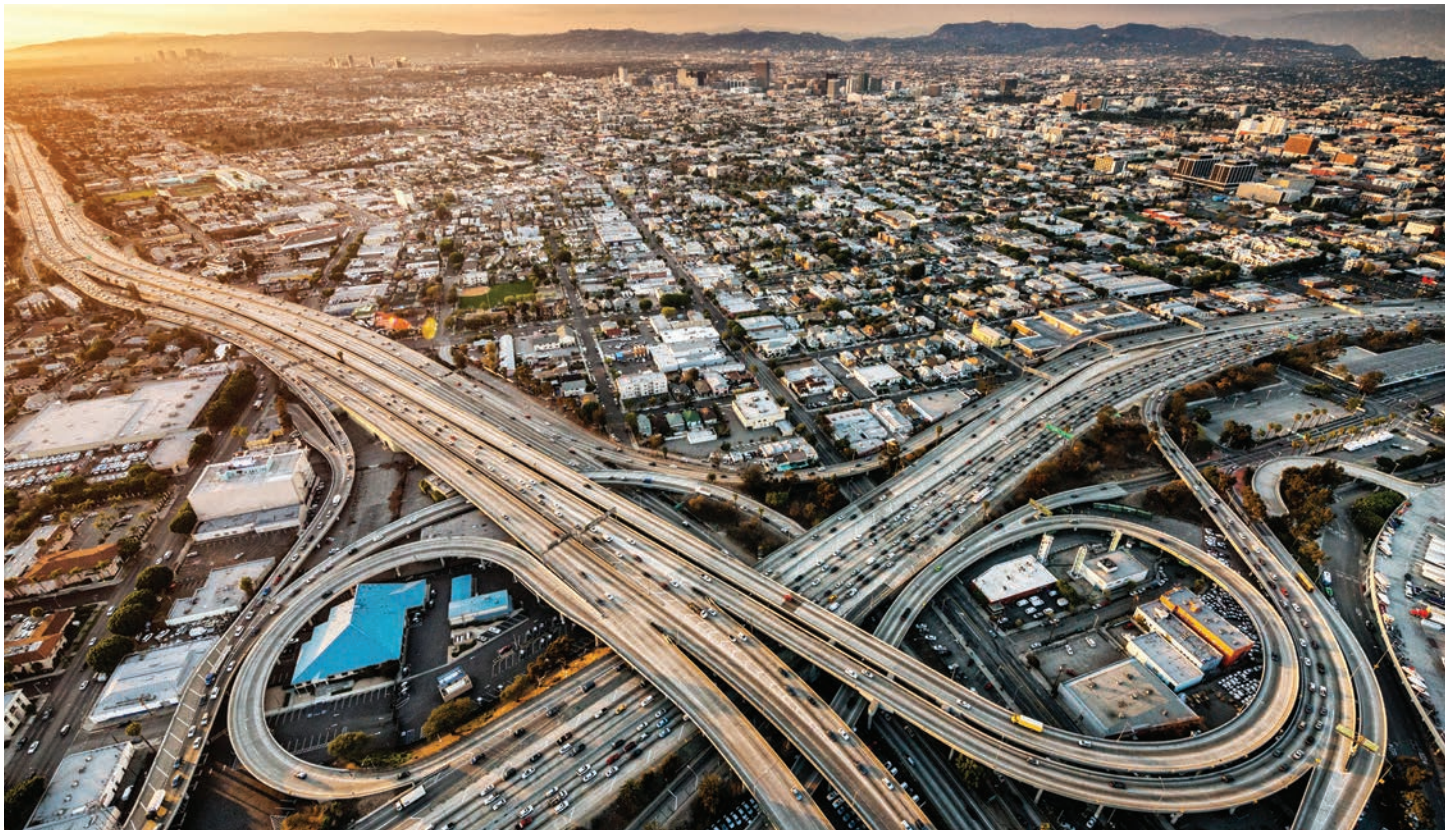
Greening of California fleet stalled by "Great Recession".
Tailpipe emissions decline, but dirtiest vehicles' share jumps.

How have decades of evolving emissions standards affected real-world emissions from California's light-duty vehicle fleet? To find out, University of Denver researchers regularly sampled passenger vehicle emissions on a West Los Angeles freeway between 1999 and 2015. They found that California's emissions control programs have reduced real-world emissions of carbon monoxide, hydrocarbons (HC), and oxides of nitrogen from light-duty vehicles by 70-80% between 1999 and 2015. They also detected an abrupt increase in average vehicle age – from 7.4 years in 2005 to 9.1 years in 2015 – reversing the prevailing trend. The explanation? California new car sales dropped 45% from 2007 to 2009 due to the "Great Recession," keeping more 10-to-20-year-old vehicles in circulation longer, meaning that 2013 passenger cars' emissions were as much as 28% higher than they would have been without the recession. Since 2009, new light-duty vehicle sales have rebounded to pre-recession levels, but even at this rate it will take more than 20 years to return to the 2008 average vehicle age of 7.4 years. Meanwhile, the share of emissions from the dirtiest 1% of passenger cars soared between 1999 and 2015. The highest-emitters' share of fleet HC emissions, for example, grew from 17% in 1999 to 46% in 2015 (*Figure*). This research verifies that CARB's mobile source emission control programs are performing as expected, and underscores the value of vehicle scrappage programs that get the highest-emitting vehicles off the road (such as CARB's Enhanced Fleet Modernization Program).
CARB Contract 12-303

Share of Hydrocarbon Emissions from the Highest-Emitting Passenger Vehicles, 1999 & 2015

(Circle size is scaled to total emissions.)



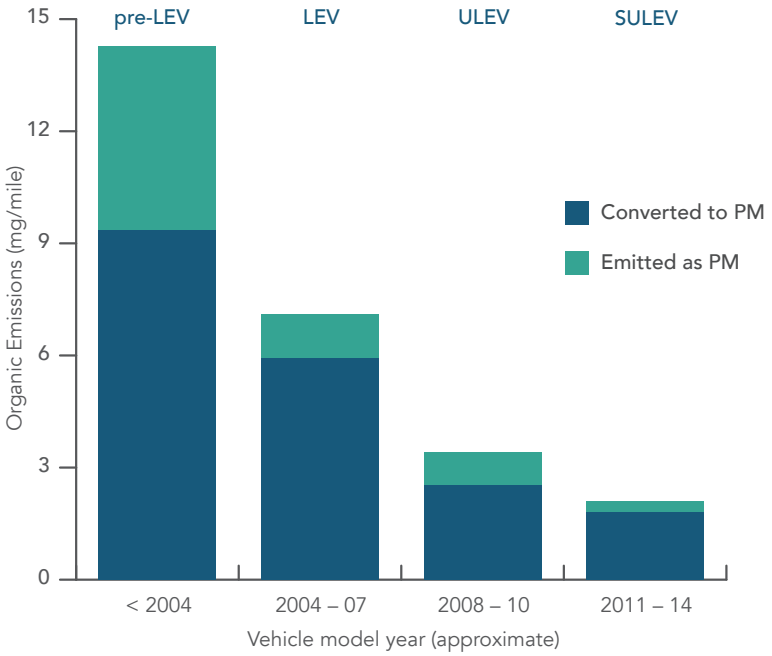


CARB Tailpipe Standards Drive Down Light-Duty Fleet Emissions

LEV standards prove effective at reducing direct vehicle emissions. Lower NOx emissions may impact secondary pollution.

CARB's Low-Emission Vehicle (LEV) standards are designed to reduce light-duty vehicle emissions that contribute to the formation of fine particulate matter ($PM_{2.5}$) and smog. Laboratory analysis of tailpipe exhaust from 1990-2014 model-year cars and light-duty trucks by UC Berkeley, Carnegie Mellon and MIT scientists confirm that more stringent LEV standards dramatically reduce tailpipe emissions of smog precursors, including oxides of nitrogen (NO_X) and volatile organic compounds (VOCs). The team also combined exhaust samples with a mix of chemicals typically present in the air to simulate atmospheric processes that convert tailpipe exhaust to secondary air pollution. Progressively cleaner LEV standards have produced sharp drops in total net (primary and secondary) pollution from California's light-duty fleet, (*Figure*), proving the effectiveness of the LEV regulatory program. The scientists also found that as the ratio of emitted NO_X to atmospheric VOCs falls, the rate at which secondary $PM_{2.5}$ is formed by car exhaust rises. Understanding how the NO_X-to-VOC ratio affects the rate at which secondary pollutants form will be valuable as CARB develops strategies to further reduce $PM_{2.5}$ in California's most polluted areas. *CARB Contract 12-318*

Pollutant Exhaust and Secondary Pollutant Yield for a Range of Emission Standards[1]



1 LEV, ULEV (Ultra-low-emission vehicle) and SULEV (Super-ultra-low-emission vehicle) are increasingly stringent California light-duty vehicle emission standards.

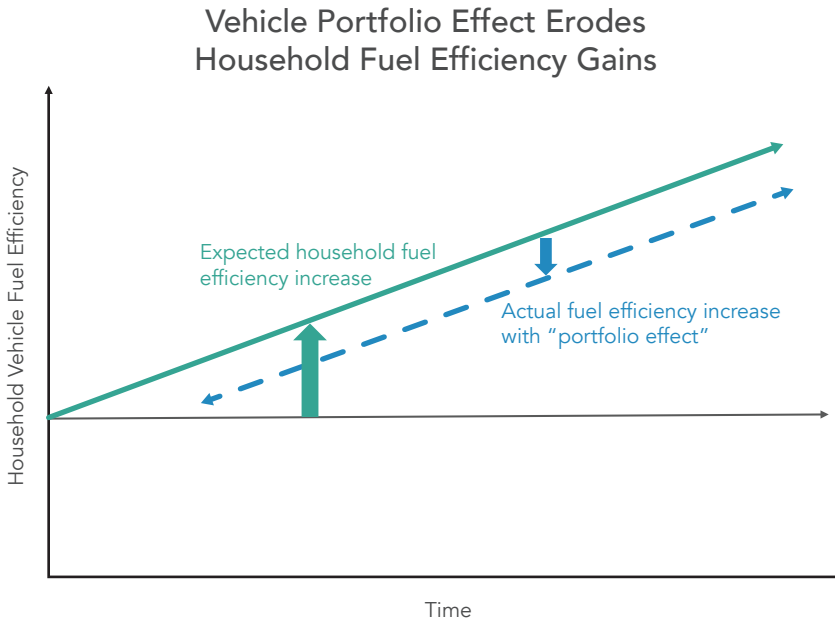
Clean Vehicle Demand

CARB's Mobile Sources research assesses factors that modulate consumer response to regulatory and incentive programs supporting clean vehicle sales and use, to help predict the effectiveness of clean vehicle policies.

Gas Sipper or Gas Guzzler? Two-car Households Want...Both.

Analysis of household vehicle holding patterns helps CARB predict light-duty fleet composition and emissions.

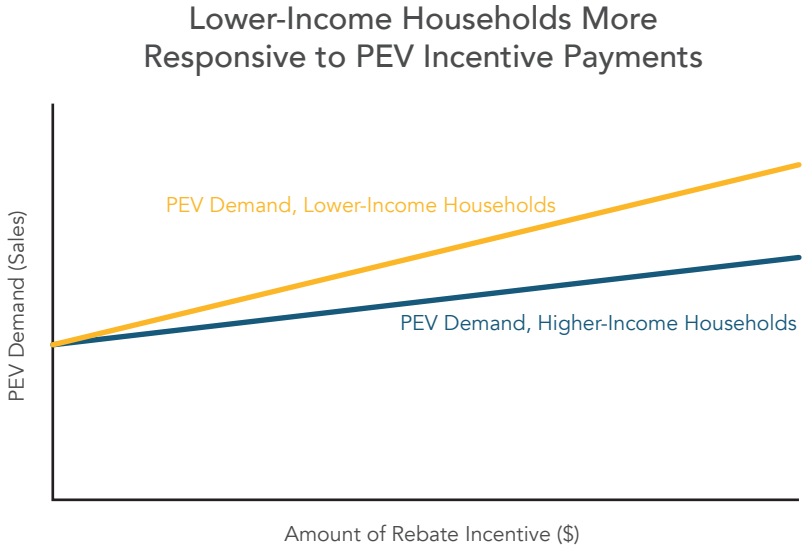
To better understand how vehicle owners respond to policies aimed at improving fuel efficiency and reducing tailpipe emissions from passenger cars, University of California, Davis, researchers tracked the vehicle holdings of California households from 2001 to 2007. They found that two-car households' preference for vehicle diversity – the "portfolio effect" – erodes the fuel savings achieved by rising fuel economy standards. (*Figure*) When a two-car household replaces a car, the fuel economy of the kept car pulls the fuel economy of the new car in the opposite direction. If the kept car is highly fuel-efficient, for example, the new car is more likely to be larger and more fuel-intensive. However, as gas prices increase, the portfolio effect's drag on fuel savings declines, since high gas prices nudge more drivers to purchase more fuel-efficient vehicles and discourage driving of the oldest, most polluting vehicles. This research helps CARB more accurately predict what California vehicle emission standards will need to accomplish in order to meet air quality goals. *CARB Contract 11-322b*



Solving the Clean Vehicle Incentive Puzzle

Results point way to equity, cost-effectiveness improvements for clean vehicle rebates.

How big a rebate should be offered – and to whom – to maximize additional plug-in electric vehicle (PEV) sales? UCLA researchers surveyed new-car buyers to assess their level of interest in PEVs, and analyzed rebate data to estimate how PEV demand varies with income. They found that rebate dollars are more effective at nudging low-income households toward buying a new PEV than they are for higher-income households with similar vehicle preferences (*Figure*). They also found that – among households with similar income – rebate dollars are more effective at swaying buyers with lower initial preference for PEVs. The research confirmed the wisdom of offering bigger rebates for all-electric vehicles – which car buyers found less appealing than other PEVs. It also supports recent changes to eligibility guidelines for CARB's Clean Vehicle Rebate Project (CVRP), capping applicant income and increasing rebate amounts for lower-income households. *CARB Contract 13-303*



Clean Fuels

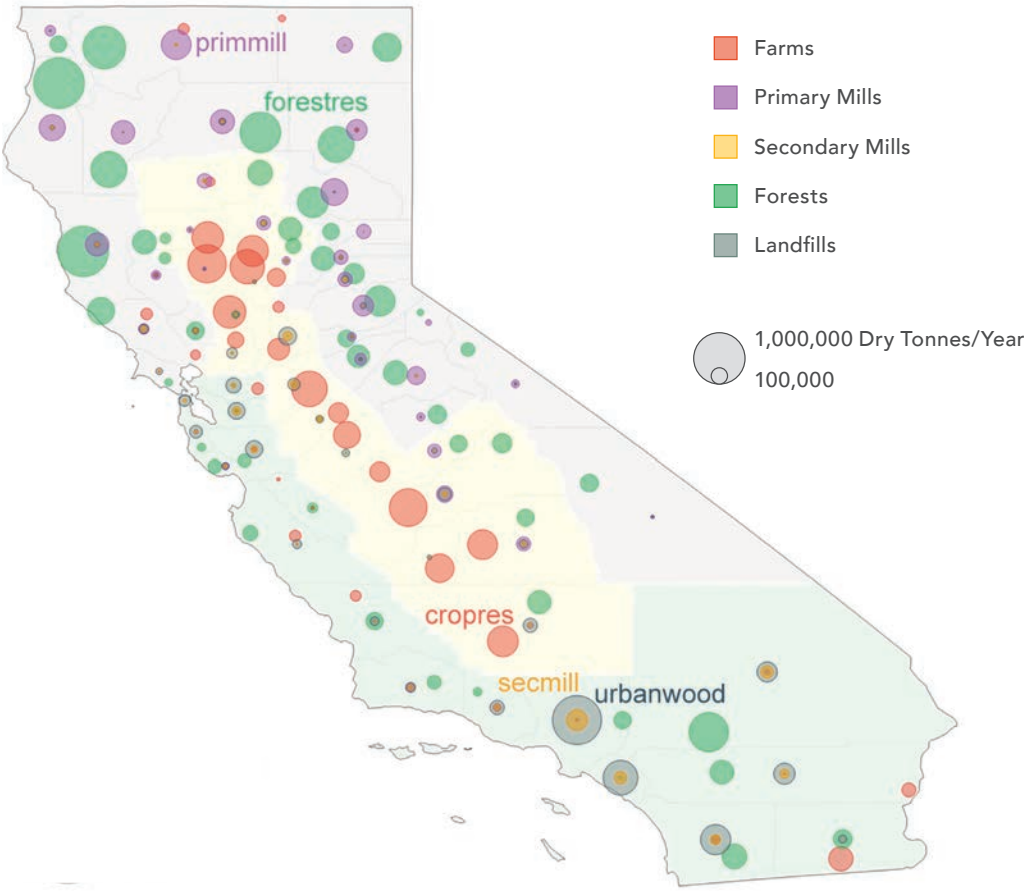
Cleaner burning alternative transportation fuels are a key component of CARB's mobile source emissions strategy. CARB research in this area explores the feasibility of emission reductions achieved through production and use of renewable fuels.

Converting California's Woody Biomass into "Drop-In" Fuels

Biorefineries can convert California's biomass into lower-carbon diesel and gasoline for today's vehicle fleets.

As California moves toward a carbon-free transportation sector, it needs transitional, lower-carbon fuels that can displace conventional fossil fuels without requiring costly replacement of vehicles or infrastructure. Today's gasoline and diesel fuels already contain 10-15% renewable biofuel – mainly ethanol produced outside the state. University of California, Berkeley, scientists evaluated the potential for converting California's own renewable resources into diesel or gasoline that can be dropped directly into today's truck and car engines. Of all available feedstocks and conversion methods, they found that California's waste biomass – woody leftovers from forests, mills, landfills, and farms (*Figure*) – could replace up to 58% of diesel fuel and 8% of gasoline sold in the state while reducing both carbon and criteria pollutant emissions. Renewable electricity generated as a by-product of the biomass-to-fuel conversion process would enable drop-in fuel refineries to achieve negative net carbon emissions. Drop-in diesel for heavy-duty trucks is the most attractive supply opportunity, the study finds, due to the near-term challenges of electrifying heavy trucks. This research helps planners assess the potential of renewable drop-in fuels to meet greenhouse gas emission and fossil fuel use reductions targeted by California's Sustainable Freight Strategy. *CARB Contract 13-308*

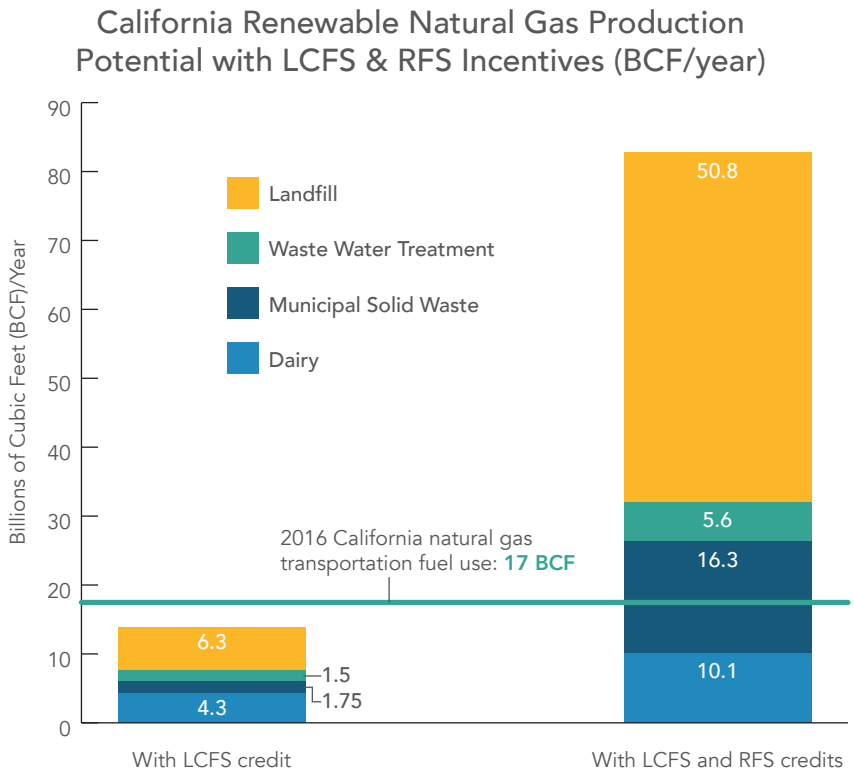
Distribution of California's Solid Biomass Resources



With Low-Carbon Incentives, Homegrown RNG Can Fuel California's Heavy-Duty Natural Gas Fleet

Renewable natural gas can be used in conventional natural gas equipment and vehicles.

As California's fleet of natural gas-powered trucks and buses grows, capturing renewable natural gas (RNG) that might otherwise be flared or vented to fuel that fleet can reduce net carbon emissions. But can locally-produced RNG compete with fossil natural gas on price and quality? And can RNG replace fossil natural gas in existing pipelines and vehicles? UC Davis researchers found that the combined value of Low Carbon Fuel Standard (LCFS) and Renewable Fuel Standard (RFS) credits earned by supplying fuel-grade RNG make it profitable to produce enough renewable fuel to supply California's entire heavy-duty natural gas fleet. (*Figure*). The incentives are needed to make RNG produced by California's dairy farms, landfills, waste water treatment and municipal solid waste plants competitive with low-priced fossil natural gas. The study team also found that RNG can be processed to share the same pipelines, station equipment and vehicles now used for fossil natural gas. LCFS credits alone could incentivize the supply of enough California RNG in the coming decade to replace 85% of fossil natural gas fuel now burned by California's heavy-duty vehicles. *CARB Contracts 13-307 & 14-317*



Sustainable Communities

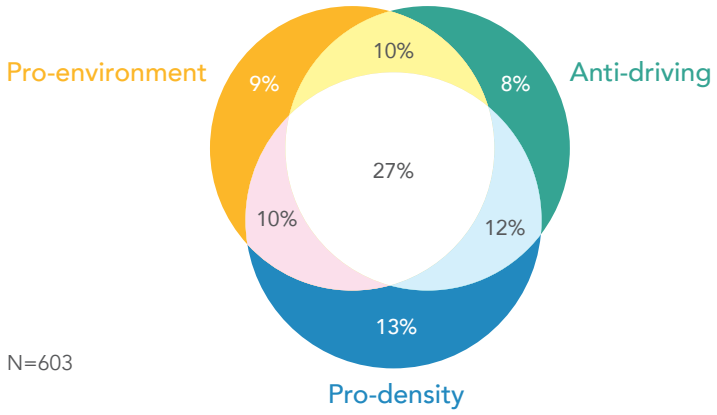
Sustainable communities are neighborhoods with equitable and affordable transportation choices and housing options, and access to quality employment, education and other services. CARB's sustainable communities research program supports the implementation of Senate Bill 375 and helps pave the way for the 2050 climate goal.

Who *Chooses* to Own Fewer Cars, Drive Less?

Renters in high-density urban areas where active transportation and rail transit are viable options are more likely to say "No" to driving.

What type of household *chooses* to own fewer cars and drive them less? Analysis of travel and attitude surveys by UC Davis researchers found that positive attitudes toward the environment and residential density, along with a preference for transit, biking or walking over driving are more common among those choosing not to own a car (*Figure*). Households abstaining from car ownership are also more racially diverse, have fewer children and are more likely to rent homes in high-density urban neighborhoods where needed services are accessible on foot or by transit. Rail transit plays a key supporting role; in the highest-density neighborhoods, access to rail is linked to larger reductions in driving. Planners hoping to reduce private vehicle travel may be able to help Californians travel sustainably by crafting policies that improve access to rail transit and encourage positive attitudes to the environment, urban density and active transportation. *CARB Contract 11-322a*

Three Attitudes Overlap More Often Among Those Choosing to Own Fewer Vehicles[1]

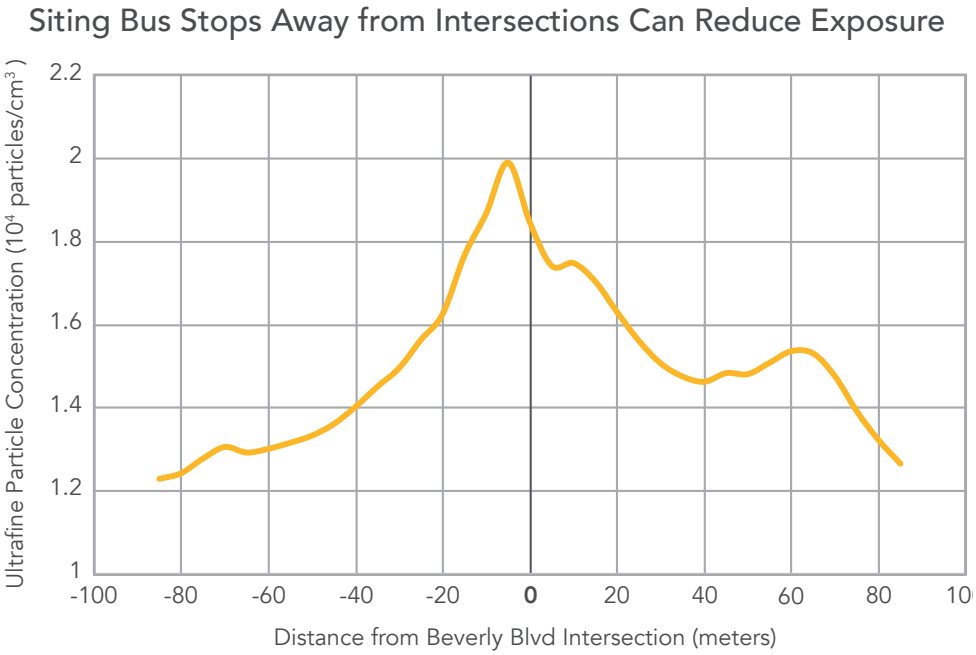


1 Percentages are the share of high-income individuals without mobility restriction who score higher than the sample median for these attitudes.

Preserving California's Most Endangered Species: Pedestrians

Analysis of seven Los Angeles transit-oriented developments highlights urban design approaches that can reduce roadside exposure.

Transit-oriented developments (TODs) are designed to foster active transportation, but walking and bicycling along busy streets can also increase exposure to traffic-related air pollution for pedestrians. Roadside exposure to air pollution in TODs can be reduced if planners organize buildings, streets, and traffic to improve air circulation and reduce the buildup of air pollution. Analysis of seven Los Angeles TOD sites by scientists from the University of California, Los Angeles, and Riverside, identified design techniques that can greatly reduce pedestrian exposure. Researchers found that air pollutants are more concentrated near intersections due to idling traffic as well as emission spikes from accelerating vehicles. By analyzing street-level air samples, the study team found that siting bus stops at least 40 meters away from intersections can significantly reduce transit users' exposure (Figure). Similarly, zoning to avoid street canyons is an effective strategy at the city block scale. At the neighborhood scale, reducing building volume, diversifying building size, and adding open space in the built environment can reduce street-level exposure by a factor of three. This research helps urban planners reduce pedestrian exposure to air pollution as California's cities and towns implement sustainable community strategies to meet SB 375 greenhouse gas reduction targets. *CARB Contract 12-308*

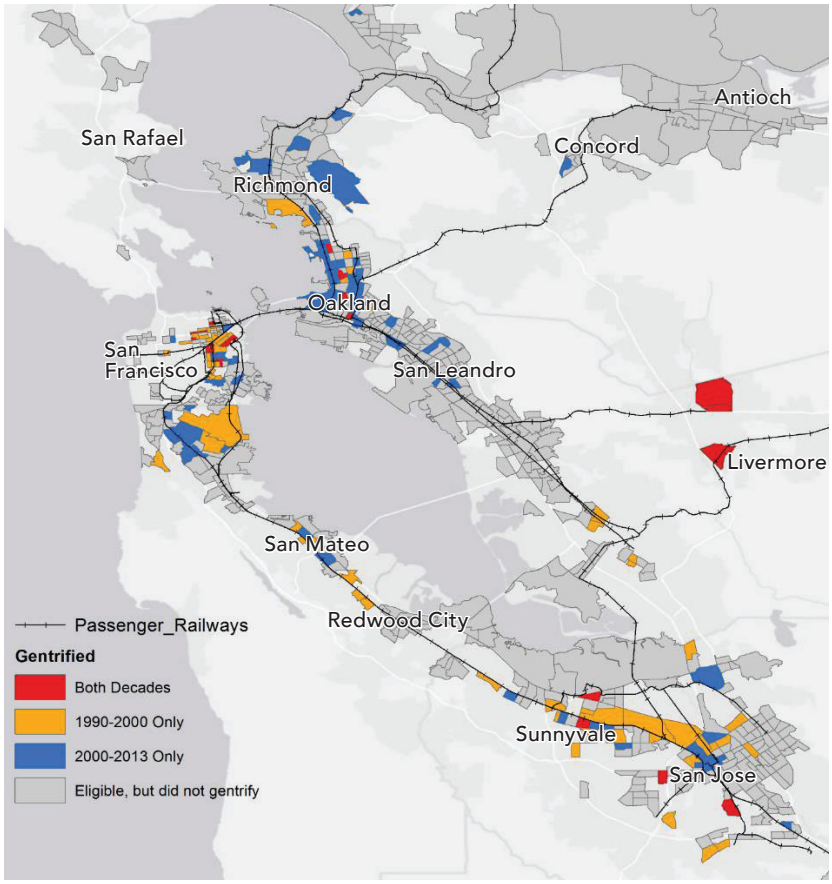


Low-income Households Displaced from Transit-Oriented Neighborhoods

Research underscores affordable housing need in high-density housing developments near transit.

With a nudge from Senate Bill 375, urban and transportation planners in California have been improving transit access for more Californians to help reduce climate-changing emissions from private vehicle travel. But transit-oriented, more walkable neighborhoods also are more desirable and therefore more expensive places to live. Researchers from the University of California at Berkeley and UCLA found more people moved to and from transit-accessible neighborhoods, and those moving in were more likely to be higher-income, college-educated, and white: a process called 'gentrification.' In contrast, the displaced households tend to be lower-income, less educated, and nonwhite. Displacement is occurring in many neighborhoods near rail stations in California's major metropolitan areas, especially older neighborhoods near downtowns (*Figure*). This research underscores the need for more affordable housing near transit to ensure that California's housing equity and greenhouse gas reduction goals can both be met. *CARB Contract 13-310*

S.F. Bay Area 1990-2013: 149 Transit Neighborhoods Gentrified

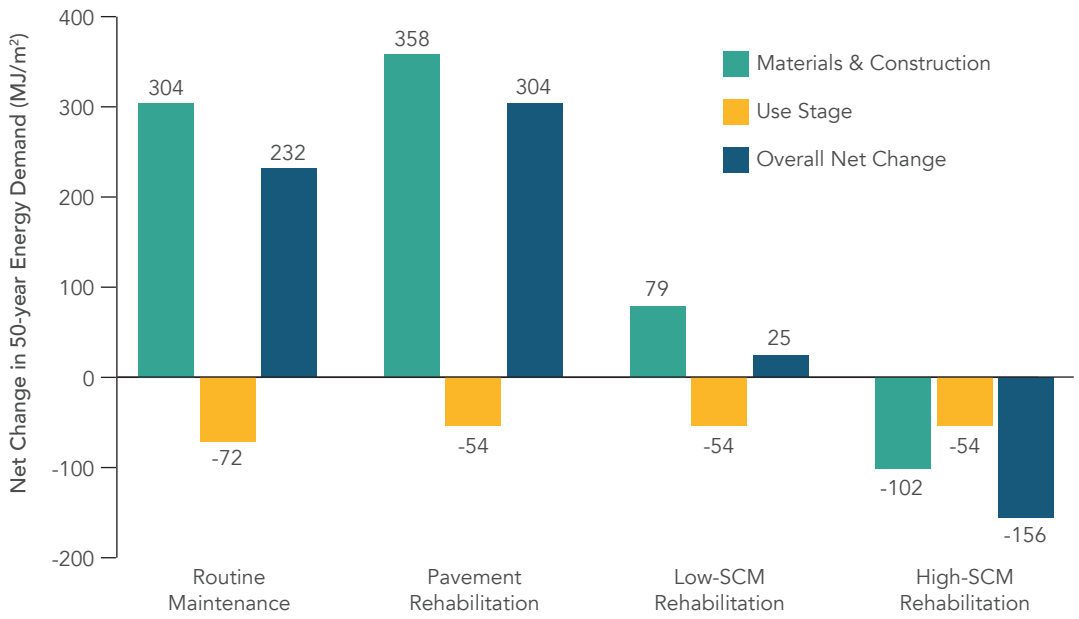


Are Cool Pavements Cooler? It's Not All Black and White.

Cool pavements are cooler, but the materials used to make them are more energy and carbon-intensive than conventional surfaces.

Urban planners look to "cool pavements" to combat the "urban heat island" effect and shrink their cities' carbon footprints, but until now there were no clear answers about the aggregate environmental benefits of cooler, more reflective pavement options. A research team led by Lawrence Berkeley National Laboratory created a life-cycle assessment tool that calculates the energy and environmental impacts of cool pavements over a 50-year life cycle. The tool estimates energy impacts across all phases of a pavement's life cycle, from materials extraction and construction to roadway use, maintenance, and end-of-life recycling. The bottom line? Under most replacement scenarios, the energy and climate-change benefits of using cool pavements are outweighed by the impacts of pavement material manufacture, transport and construction (*Figure*). Estimated energy savings from cool roofs, meanwhile, are 15 times greater – per square meter – than those from cool pavements.
CARB Contract 12-314

Energy Demand Estimates for Cool Pavement Replacement Scenarios:[1] Los Angeles



1 The figure shows how energy demand differs for different pavement practices when "cool" pavement treatments are chosen over typical pavement treatments (over a 50-year life cycle). Supplementary cementitious materials (SCM) used in "cool" pavement – such as fly ash, slag cement, and silica foam – are by-products of other industrial processes and thus have lower environmental impacts than conventional cement production.

Atmospheric Monitoring & Modeling

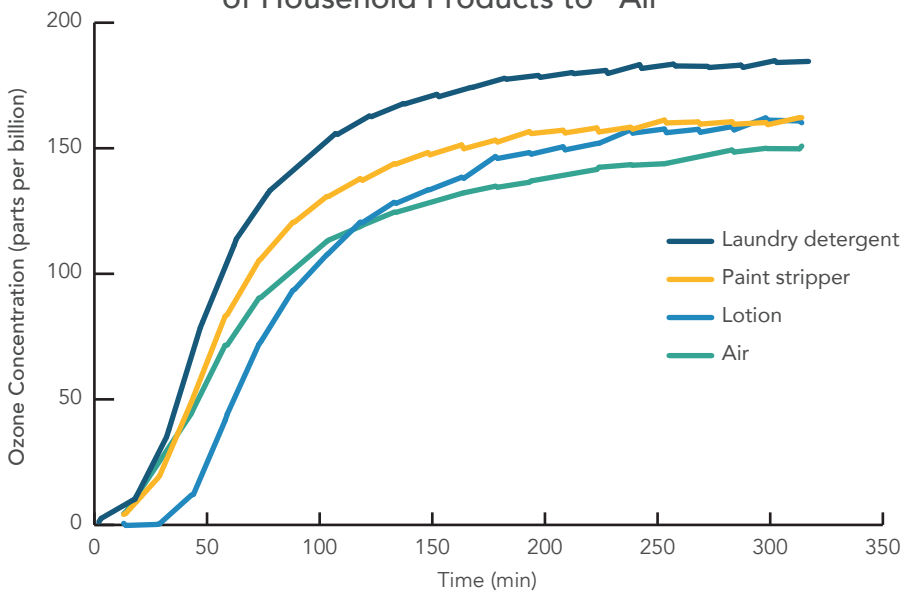
CARB's atmospheric monitoring and modeling research program provides a better understanding of the influence of emissions, meteorology, and long-range transport on surface ozone and $PM_{2.5}$, and the nexus between air quality and climate change in California.

Charting VOC Emissions from Consumer Products

Household and personal care products receive renewed attention as regulators seek additional air quality improvements.

To help California meet federal air quality standards in the coming decades, new regulations will be needed to reduce emissions of volatile organic compounds (VOCs) from consumer products. In 2012, on-road vehicles were the largest source of VOC emissions in the South Coast Air Basin – double the emissions of consumer products. But as existing regulations reduce VOC emissions from on-road vehicles, unregulated VOC emissions from consumer products will grow with the region's population. By 2031, consumer products are expected to become the largest controllable source of VOC emissions in South Coast – double the emissions of on-road vehicles. To support new regulatory efforts, UC Riverside researchers evaluated VOC emissions from an array of consumer products containing less volatile "low vapor pressure VOCs" (LVP-VOCs) that had been exempted from 2008 rules limiting the products' VOC content. To assess their potential impact on smog formation, researchers measured changes in ozone concentration, (a smog indicator), as selected household products evaporated in the laboratory (*Figure*). Test results will guide the development of new air quality rules to protect the health of millions of Californians living in areas of the state that do not yet meet federal air quality standards. *CARB Contract 13-302*

Ozone Levels Resulting from Exposure of Household Products to "Air"[1]



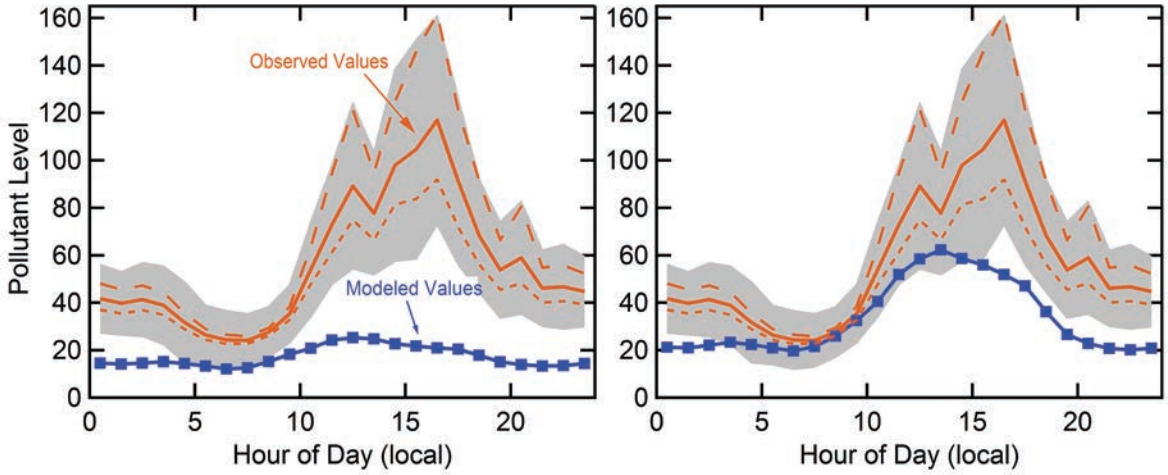
1 Experiments compared the background ozone level of laboratory-simulated "ambient air" to ozone levels resulting from exposure of household products containing LVP-VOCs to that air.

Taming Smog Formation by Thinking *Inside* the Box

Adjusting for differences between chemical reactions in laboratory smog chambers and the open air improves CARB's smog modeling capacity.

Programs to improve California's air quality rely on air pollution models to predict regional smog formation so that regulators can effectively plan how to reduce it. To calibrate these models, UC Davis scientists reviewed laboratory chamber studies and tested alternative modeling methods, comparing the results to observed values. By adjusting their models to account for the differences between smog formation in the open air and inside lab chamber walls – an effect known as "vapor wall loss" – researchers were able to significantly improve model accuracy. When models adjust for "vapor wall loss" they do a much better job of predicting daily smog levels – as seen in the figure below comparing observed and modeled levels of smog-related pollutants on a summer day in Riverside, Calif. Adding this wrinkle to air pollution models will improve CARB pollution control programs designed to implement California's long-term plans to meet federal air quality standards in California's most polluted areas. *CARB Contract 12-312*

Estimates of smog formation (blue line) more closely track observed pollutant levels (orange line) when "vapor wall loss" is included in the model (right).



About the California Air Resources Board's Research Program

California's progress on addressing environmental problems is guided by a strong scientific knowledge base. The California Air Resources Board sponsors a comprehensive program of research into the causes, effects, and solutions of the air pollution problem, supporting its regulations on cars, trucks, fuels, power plants, and other sources. The research is done under the guidance of CARB's Research Screening Committee and in partnership with the University of California system and other research institutions.