EMISSION CONTROL, VEHICLE

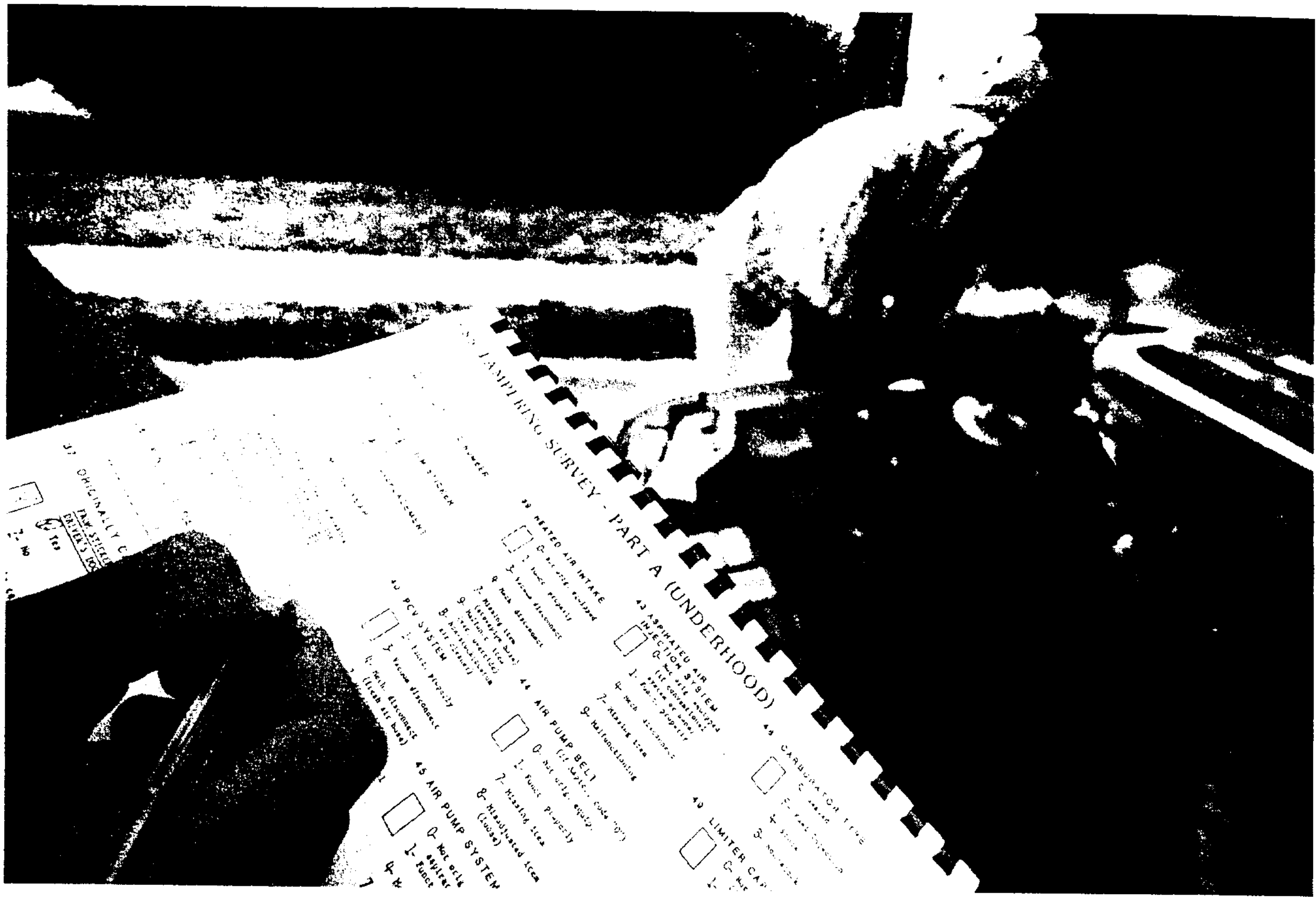
Researchers linked automobile use to air pollution in the early 1950s when A. Haagen-Smit of the California Institute of Technology and fellow researchers began to unravel the complex atmospheric chemistry that leads to the formation of photochemical smog (ozone). Ozone is a strong lung and throat irritant that decreases lung function, increases respiratory problems, and complicates heart disease. Moderate ozone concentrations also damage materials and crops, increasing the cost of living. Ozone forms in the atmosphere when oxides of nitrogen (NO_x) and hydrocarbons (HC) mix and react in the presence of sunlight. Because onroad automobiles, trucks, passenger vans, and sport utility vehicles are typically responsible for about 30 percent of a region's HC and NO_x emissions, transportation is a significant contributor to smog problems in urban areas.

Onroad transportation sources are also responsible for more than 60 percent of regional carbon monoxide emissions. Carbon monoxide is a colorless, odorless gas that interferes with oxygen transfer in the bloodstream. With a higher affinity than oxygen to bind with red blood cell hemoglobin, with continual exposure, CO gradually displaces oxygen in the bloodstream. Because CO disperses well, it tends to be a hotspot pollutant, with troubling concentrations occuring in areas of high vehicle activity and poor air circulation, such as urban street canyons. When transportation facilities are constructed, engineers model the microscale air quality impacts to ensure that the highway design will not result in unhealthy CO levels downwind from the facility.

Carbon monoxide (CO) and hydrocarbon (HC) emissions arise from incomplete combustion, when petroleum hydrocarbons (gasoline or diesel fuel) do not completely oxidize to carbon dioxide and water. Hydrocarbon emissions also result from gasoline evaporation (liquid leaks, daily heating of fuel and tank vapors, seepage from fuel lines and other components, and displacement of fuel vapors during refueling). A number of toxic air contaminants, such as benzene and 1,3-butadiene are also associated with unburned and partially burned fuel hydrocarbons. Oxides of nitrogen (NO_x) form in the high temperature and pressure environment of the engine cylinder when the elemental nitrogen in air reacts with oxygen. Higher levels of NO_x form at the higher engine temperatures, which unfortunately correspond to peak fuel efficiency.

Given the health impacts that arise from exposure to vehicle emissions and their byproducts, regulatory agencies have focused on motor vehicle emissions control in their efforts to clear the air. Five basic strategies are employed for reducing onroad vehicle emissions: (1) reducing the emissions from new vehicles that displace the older high-emitting vehicles that are scrapped, (2) accelerating vehicle fleet turnover to get new vehicles into the fleet more quickly, (3) reducing emissions from in-use vehicles, (4) reducing travel demand to reduce vehicle activity, and (5) improving traffic flow to reduce emission rates.

The primary focus of federal environmental policy over the past 30 years has been on reducing the emissions from new vehicles. Strategies to enhance vehicle fleet turnover have not prove cost effective over the long term, but such strategies can provide useful short-term emissions reductions. Strategies aimed at limiting in-use vehicle emissions began around 1983 and continue today. Strategies designed to reduce travel demand and improve traffic flow, generically classified together as transportation control measures, have achieved mixed results to date. While demand management measures do work for individual large employers, regional demand management programs have failed to garner public support and have not provided cost-effective emissions reductions. On the other hand, technology-based traffic flow improvement programs, such as traffic signal optimization, can still provide significant emissions reductions at the regional level.



Surveyors from the Environmental Protection Agency inspect the engines and exhaust systems of volunteers' cars for emission control tampering and fuel switching. (Corbis Corporation)

VEHICLE STANDARDS AND EMISSION CONTROLS TECHNOLOGY

In 1963, new cars emitted nearly eleven grams per mile of hydrocarbons (HC), four grams per mile of oxides of nitrogen (NO_x), and eighty-four grams per mile of carbon monoxide (CO). Public pressure to reduce vehicle emissions began to mount in the early 1960s. Manufacturers responded to the general public pressure (and a few specific emissions control regulations) by adding positive crankcase ventilation (PCV) systems to new vehicles. A PCV valve prevents the release of unburned fuel from the crankcase by sending these vapors back to the intake air for combustion. With the passage of the Clean Air Act of 1970, the U.S. Environmental Protection Agency (EPA) began implementing a series of comprehensive regulations limiting the gram-per-mile emissions from new motor vehicles. Manufacturers must produce vehicles that comply with the EPA standards, as measured in the laboratory on EPA's federal test procedure, but manufacturers are free to develop and implement any combinations of control systems they choose. Assembly-line testing and in-use surveillance testing and recall ensure that manufacturers comply with the certification standards.

Emissions standards in 1970 and 1972 were designed to reduce HC and CO emissions by 60 percent and 70 percent, respectively. In response to evaporative emissions standards, manufacturers developed onboard charcoal canisters in the early 1970s to capture gasoline vapors driven from the gas tank (and from the carburetor fuel bowl) by the daily rise and fall of ambient temperature. Exhaust emissions control strategies generally focused on de-tuning the engine to increase exhaust manifold temperature and adding a smog pump that delivered fresh air into the exhaust manifold to oxidize unburned CO and HC.

Manufacturers added exhaust gas recirculation (EGR) systems to counter the increased in-cylinder NO_x formation associated with higher operating temperatures. The EGR recycles a portion of the exhaust stream back into the engine intake air. The relatively inert exhaust gas, containing carbon dioxide and water but little oxygen, serves as a combustion buffer, reducing peak combustion temperatures.

By 1975, new cars were required to meet a 1.5 gram-per-mile HC standard, a 15 gram-per-mile CO standard, and a 3.1 gram-per-mile NO_x emissions standard. In response to the regulatory requirements, the automotive industry added new innovative emissions control technologies. Vehicles came equipped with oxidation catalysts (platinum and palladium on an alumina honeycomb or pellet substrate) designed to convert the CO and partially burned HC in the exhaust stream to CO_2 and water. The catalytic converter allows oxidation to occur at temperatures as low as 300°C, so that oxidation of the exhaust stream can continue downstream of the exhaust manifold. In 1975, lead was eliminated from the gasoline supply for these new vehicles, not because of lead's known harmful health effects, but because lead would foul the new catalytic converters of the new vehicles. A single tank full of leaded gasoline is enough to significantly and permanently reduce the efficiency of the catalytic converter. To reduce contamination of catalysts on new vehicles, the size of the opening to the gasoline tank fill neck was narrowed so that only the nozzles from unleaded gasoline pumps could be inserted into the fill neck during refueling.

Reduction catalysts that convert NO_x back to nitrogen and oxygen under conditions of low oxygen concentration began to appear in the late 1970s. At this time, vehicles began to employ dual-bed catalyst systems. These dual-bed systems employed a reduction catalyst followed by an oxidation catalyst, with fresh air (and thus additional oxygen) injected between the two catalyst beds. Dual-bed systems were capable of controlling NO_x, CO, and HC in a sequential mode.

The emissions reductions provided by the catalytic converter also allowed engineers to re-tune their engine designs and add an improved proportional EGR system. By modifying the EGR that recycles exhaust in proportion to intake air (as a function of engine speed) rather than at a constant rate, emissions could be better controlled over a wider range of operating conditions. The new EGR systems provided the added bonus of improved vehicle performance, balancing some of the efficiency losses associated with the use of catalytic converters.

Probably the most significant control technology breakthrough came in 1977, when Volvo released a computer-controlled, fuel-injected vehicle equipped with a three-way catalyst. The new catalytic converters employed platinum, palladium, and rhodium to simultaneously reduce NO and oxidize CO and HC emissions under carefully controlled oxygen conditions. The new Bosch fuel injection system on the vehicle provided the precise air/fuel control necessary for the new catalyst to perform effectively. The combined fuel control and three-way catalyst system served as the foundation for emissions control on the next generation of vehicles.

By 1981, exhaust emissions standards had tightened to 0.41 grams-per-mile HC, 3.4 grams per mile CO, and 1.0 gram-per-mile NO_x. Manufacturers turned from carburetors, to single-point throttle-body injection, and then to multi point fuel injection systems. With each shift in technology, better control over the air and fuel mixture and combustion was achieved. Better control over the delivery and mixing of air and fuel provided significant emissions and performance benefits. New computer-controlled variable EGR significantly reduced NO_x formation. Smog pumps had also given way to lightweight, inexpensive, pulse air injection systems, significantly improving engine performance. Using the natural pressure variations in the exhaust manifold, fresh air flows in to the manifold through a one-way reed valve and helps to oxidize CO and HC. Finally, many of the new vehicles now came equipped with the improved three-way catalytic converters (TWC) that debuted in 1977.

The new three-way catalytic converters required precise control of fuel/air ratio, so onboard computers became necessary to monitor the combustion process and rapidly adjust the air/fuel mixture through closed loop control. The goal of the computer program is to keep combustion at stoichiometric proportions, where there is just enough air (and therefore oxygen) delivered to completely oxidize the fuel. The stoichiometric ratio for an average fuel is roughly 14.7 kilograms of air per kilogram of fuel. An oxygen sensor in the exhaust manifold monitors the oxygen concentration of the exhaust gases to determine if the combustion mixture contained sufficient oxygen. A reading of zero oxygen in the exhaust gas probably indicates that too much fuel was mixed with the intake air (consuming all of the oxygen before combustion was completed) while a high oxygen concentration in the exhaust gas indicates that too little fuel was mixed with the intake air. The computer processes and evaluates multiple readings each second making minute adjustments to the amount of fuel delivered to the intake air (closing the loop between computer action, sensor reading, and computer response). The computer never achieves a perfect stoichiometric mixture; the air and fuel mix instead alternates between slightly rich and slightly lean. However, the extremely rapid measurement and computer response minimizes emissions formation by responding rapidly to changes in engine operation.

The efficiency of the three-way catalytic converter is also a function of air/fuel ratio. At the stoichiometric air/fuel ratio of 14.7 kilograms of air per kilogram of fuel, the relative air/fuel ratio known as λ equals 1.0. Figure 1 illustrates catalytic converter efficiency for each pollutant as a function of relative air/fuel ratio λ (where a positive λ indicates a lean mixture and a negative λ indicates a rich mixture). The closer the mixture stays to stoichiometric, the more efficient the catalyst at reducing the combined emissions of the three pollutants.

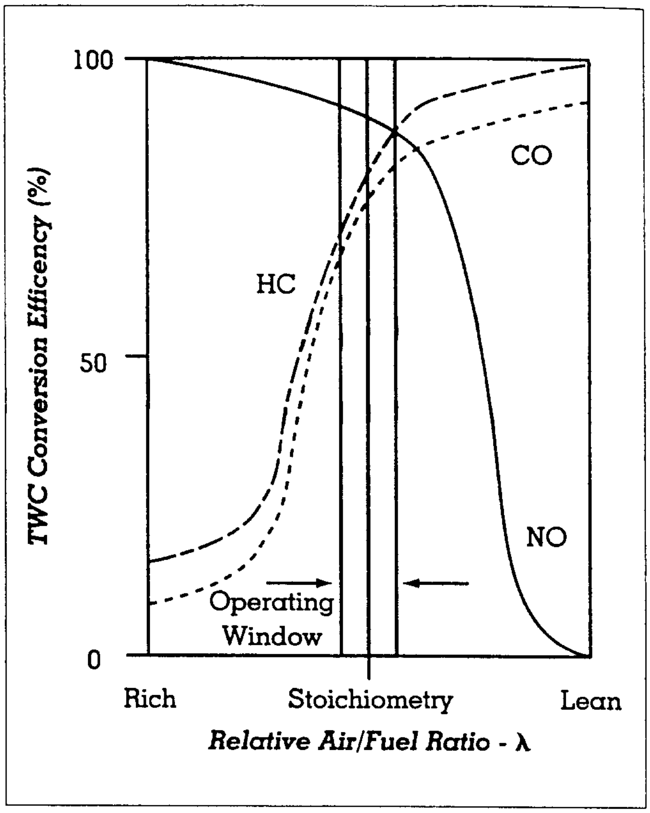


Figure 1.

SOURCE: Chowanietz, 1995.

By 1994, EPA had further tightened the standards to 0.25 grams-per-mile for HC and 0.4 grams per mile for NO_x. Hence, new vehicle HC emissions had now dropped nearly 98 percent and NO_x emissions had dropped 90 percent compared to the level of the 1960s. Manufacturers were also required to ensure that the emissions control systems would endure for at least 100,000 miles. To meet the stringent 1994 standards, manufacturers relied on improved technology and materials, and more advanced computer systems to monitor combustion and rapidly adjust a variety of operating parameters (fuel metering, spark timing, and EGR) to optimize vehicle performance and minimize emissions. Advanced exhaust treatment systems (such as electrically heated or close-coupled catalysts), that manufacturers originally believed in the 1980s would be necessary to comply with these standards, have not been needed.

In 1999, the EPA proposed stringent standards applicable to model year 2004 vehicles. Thus, the EPA continues to implement technology-forcing regulations, in which EPA tasks manufacturers with an emissions standard, and industry must develop technologies to enable the vehicles to comply. When these standards are in place, new vehicles will emit less than 1 percent of the HC and NO_x emissions of their 1960s counterparts (see Figure 2). Advanced computer controls, variable valve timing, and improved catalysts will continue to provide significant reductions. New control systems are also likely to focus on reducing emissions immediately following the engine start. Advances in diesel emissions control technologies may yield viable light-duty diesel vehicles.

Vehicles powered by alternative fuels have yet to make significant inroads into public ownership. Battery technology has not advanced sufficiently to deliver low-cost electric vehicles capable of providing comparable vehicle performance and more than 100 miles between recharging. However, new hybrid electric vehicles that perform on a par with current vehicles and never require recharging began entering the marketplace in 2000. These hybrid electric vehicles are achieving emissions levels as low as 10 percent of 1999 emissions levels, qualifying well below the

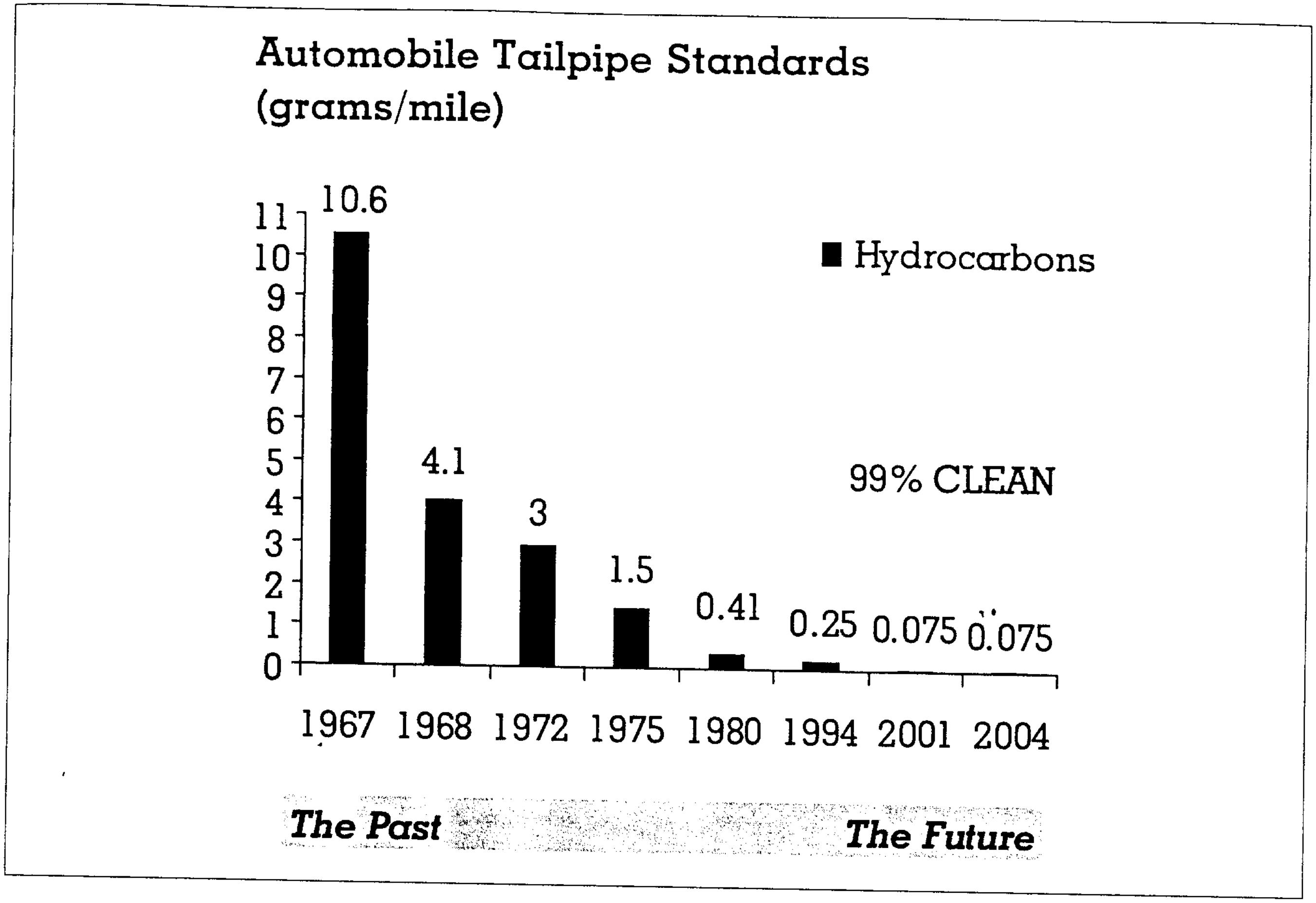


Figure 2.

SOURCE: Alliance of Automobile Manufacturers (2000)

2004 standards. Fuel cell vehicles, which convert the chemical energy of a fuel into electricity, are expected to provide near-zero emissions within the decade.

LIGHT-DUTY TRUCKS AND SPORT UTILITY VEHICLES

Sales of sport utility vehicles and light-duty trucks have topped 45 percent of the new vehicle sales market in the late 1990s, and shares are still climbing. In some months, light-truck and SUV sales exceed those of automobiles. Current emissions regulations are currently less stringent for the vast majority of these light-duty trucks (LDTs) and sport utility vehicles (SUVs) than they are for automobiles. These vehicles are heavier than automobiles, employ larger engines, and the drivetrain (engine, transmission, rear differential, and tire diameter) is designed to handle heavier loads. As such, the emissions from these vehicles are naturally higher. New and in-use LDTs and SUVs exhibit much higher emissions levels than do automobiles (roughly 30 percent more HC and CO, and 85 percent more NO_x per mile traveled). Light-duty trucks also have a significantly longer lifespan in the fleet than do automobiles, compounding the emissions impact over time.

The environmental community has argued, for some time, that the actual onroad duties of the vast majority of LDTs and SUVs are not significantly different from the duties performed by automobiles. That is, most of these vehicles are simply making commute, shopping, and recreation trips that do not require enhanced performance. This issue, combined with the availability of emissions control systems to significantly lower emissions from LDTs and SUVs, led the EPA to harmonize the two standards under the new Tier 2 program. Beginning in 2004, through a phase-in schedule, LDTs and SUVs are required to meet the same emissions standards as automobiles.

Although the lightest of current onroad trucks already meet the same standards as automobiles, the new certification requirement will bring the remaining 80 percent of light-duty truck sales into alignment with the more stringent emissions standards.

HEAVY-DUTY VEHICLES

Onroad and off-road heavy-duty vehicles (greater than 8,500 pounds gross vehicle weight rating) contribute significantly to emissions of NO_x, which in turn participate in ozone formation. As one would expect, heavy-duty engines are large, and the engine load for a vehicle carrying a 60,000-pound payload is extremely high. Most heavy-duty trucks operate on the diesel cycle, an engine cycle that produces much higher temperature and pressure conditions, leading to the formation of significantly greater NO_x levels per mile traveled. Given the stringent controls implemented for light-duty vehicles, it is not surprising that the heavy-duty vehicle contribution as a percentage of regional emissions has been increasing. Projections for the Los Angeles basin in 2010 indicate that without further controls, heavy-duty vehicles will contribute more than 55 percent of onroad NO_x emissions.

According to industry experts, the state of emissions control for heavy-duty engines in the 1990s was at the level of technical advancement that we were achieving for light-duty vehicles in the 1970s. In the last few years, new, highly effective diesel particulate trap and catalyst systems have been developed for heavy-duty diesel vehicles. Many of these new system designs are currently on the road undergoing performance and durability testing. All of the new technologies that are forthcoming were developed in response to new EPA heavy-duty vehicle certification standards that are affective as of 2004. Significant reductions in heavy-duty vehicle emissions are on the horizon.

ENGINE START EMISSIONS

Exhaust emissions are high during the first one to three minutes of engine operation, until combustion stabilizes and the catalytic converter reaches approximately 300°C (known as light-off temperature, when the catalyst begins controlling emissions). Peak catalyst efficiency occurs between 400°C and 800°C. A vehicle that sits more than an hour is usually considered to be starting in a cold-start mode, because the temperature of the catalytic converter has dropped significantly since the vehicle was last used. The average vehicle on the road in 2000 emitted 2 to 4 grams of HC, 1 to 3 grams of NO_x, and 30 to 50 grams of CO for each cold engine start. Vehicles starting in warm-start mode (less than one hour of parking time) produce significantly lower emissions than a cold start, but still contribute significantly to overall trip emissions. Hot starts after 10 minutes or parking time still produce nearly 0.5 gram of HC, 0.5 gram of NO_x, and 20 grams of CO per start for the average vehicle. New emissions models are forthcoming that estimate engine start emissions as a continuous function of park-time distributions.

Because gram/mile emissions from modern vehicles are so low, engine start emissions have become a large fraction of the emissions associated with a vehicle trip. For a typical twenty-mile commute trip in a 1994 vehicle, roughly 30 percent of the CO and 10 percent of the NO_x and HC can be attributed to the cold start. For a ten-mile trip, the overall emissions are about 35 percent lower, but the cold start contributions rise to approximately 50 percent of the CO and 20 percent of the NO_x and HC. On very short trips, total trip emissions are lower still, but the cold start contribution dominates the total. For a half-mile trip, most vehicles never achieve catalyst light-off, and more than 95 percent of the CO and 80 percent of the HC and NO_x trip emissions can be attributed to cold-start operation (as compared to the same trip made by a fully-warmed-up vehicle). It is important to note that a single trip of twenty miles will result in significantly lower emissions than ten trips of two miles each. Trip chaining, where the end of one trip serves as the beginning of the next trip after a short parking period, also results in significantly lower emissions than if each trip results in a cold engine start.

Given the importance of engine start emissions in urban areas, new emissions control systems are likely to focus on achieving instant catalyst light-off. Catalyst manufacturers will increase catalyst surface area and use materials and designs that are resistant to damage from high-temperature exhaust gas. Such designs will allow placement of catalysts closer to the exhaust manifold where higher temperatures will help the catalyst reach light-off much more quickly.

ENRICHMENT EMISSIONS

In recent years, research has demonstrated that real-world vehicle emissions under typical onroad operating conditions can differ significantly from the emissions observed in the laboratory under standard federal test procedures. The occurrence of enrichment, when the air/fuel mixture becomes rich for a few moments, results in orders of magnitude increases in CO and HC emissions rates for short periods. N. Kelly and P. Groblicki (1993) first reported indications that enrichment conditions were likely to be causing a significant portion of vehicle emissions not captured during standard laboratory certification tests. Numerous studies since then have identified enrichment as a widespread concern.

Carbon monoxide emissions rates (grams/second) under enrichment conditions for the very cleanest of vehicles can soar as high as 2,500 times the emissions rate noted for stoichiometric conditions. Although most vehicles spend less than 2 percent of their total driving time in severe enrichment, this can account for up to 40 percent of the total CO emissions (LeBlanc et al., 1995). Hydrocarbon emissions rates can rise by as much as a factor of a hundred under enrichment conditions. Enrichment activity is usually associated with high power demand and engine load conditions, such as high-speed activity, hard accelerations, or moderate accelerations under moderate to high speeds. However, enrichment also occurs during hard deceleration events. When the throttle plate snaps shut during a rapid deceleration event, the rapid decrease in intake manifold pressure vaporizes liquid fuel deposits, causing the fuel mixture to become rich.

All vehicles undergo some enrichment. Fuel enrichment sometimes results from malfunctions of vehicle sensors and control systems. When engine and exhaust gas sensors fail to provide appropriate data to the onboard computer under certain operating conditions, the computer sends inappropriate control commands to fuel injectors and spark advance units. Depending upon the type and extent of component failure, such malfunctions can result in a super-emitter, with significantly elevated emissions rates under all operating conditions. It is interesting to note that engine manufacturers have engineered occurrences of enrichment through the onboard vehicle computer software. Because peak engine torque develops when the air/fuel mixture is slightly rich, manufacturers sometimes use enrichment to improve vehicle performance. Enrichment can increase acceleration rates, improve engine performance while hill-climbing or running accessories such as air conditioning, and can be used to control cylinder detonation. In addition, the cooling properties associated with vaporizing and partially combusting excess fuel lowers peak combustion temperatures, protecting cylinders, valves, and catalysts from high-temperature damage during high RPM activity.

When enrichment episodes occur in the real world, but not in the laboratory under federal certification tests, real-world emissions are significantly higher than predicted. Further complicating emissions prediction is that aggressive driver behavior and complex traffic flow characteristics play a large role in enrichment occurrence. Current vehicle activity simulation models can predict average speeds and traffic volumes very well, but poorly predict the hard-acceleration events that lead to enrichment.

The federal test procedure for new vehicle certification is limited to a maximum acceleration rate of 3.3 mph/second and a maximum speed of 57 mph (and even that speed is for a very short duration). Based upon extensive data collected in Baltimore, Spokane, and Atlanta, more than 8.5 percent of all speeds exceeded 57 mph, and more than 88 percent of trips contained acceleration activity exceeding 4 mph/second. In fact, more than one-third of the trips monitored included an acceleration rate at some point during the trip of more than 7 mph/second. Similarly, more than 15 percent of the deceleration activity exceeded -3.5 mph/second. Hence, enrichment events are significant in real-world emissions inventories.

To counter the elevated emissions associated with enrichment, the EPA has adopted supplemental federal test procedures. The new laboratory test procedures contain higher speeds, higher acceleration and deceleration rates, rapid speed changes, and a test that requires the air conditioning to be in operation. These tests increase the probability that vehicles will go into enrichment under laboratory test conditions. Hence, manufacturers have an incentive to reduce the frequency of enrichment occurrence in the real world. Future catalytic converters and emissions control systems will be resistant to the high-temperature conditions associated with engine load, and will be less likely to require enrichment for protection. Thus, enrichment contributions to emissions will continue to decline.

IN-USE VEHICLE EMISSIONS

New vehicle emissions standards have served as the primary means for reducing vehicle emissions over the last thirty years. However, urban areas must wait for years before the purchase of new vehicles significantly reduces onroad emissions. Meanwhile, daily motor vehicle emissions remain dominated by the small fraction of very high-emitting vehicles. The average car on the road emits three to four times more pollution than new standards allow, and minor control system malfunctions greatly increase emissions. Numerous research studies conclude that a small fraction of onroad vehicles contribute a large fraction of fleet emissions. Some researchers argue that as few as 5 percent of the vehicles are causing 40-50 percent of onroad emissions, but published estimates of super-emitter contribution estimates vary widely. These research studies rely upon laboratory data collected on certification tests, field data collected using portable testing systems, data from remote sensing devices that estimate pollutant concentrations in vehicle tailpipe exhaust plumes, or laboratory or roadside inspection and maintenance data. The controversy surrounding the wide range of super-emitter contribution estimates stems from significant differences in the vehicles sampled, data collected, and the analytical methods and assumptions employed in the various analyses. Although the contribution percentage is uncertain, it is clear that a small fraction of super-emitting onroad vehicles contribute disproportionately to emissions.

To reduce emissions from onroad vehicles, urban areas have turned to inspection and maintenance (I/M) programs. By 1983, sixty-four cities nationwide had established I/M programs, requiring passenger vehicles to undergo a visual inspection and a two-speed idle test to detect severely malfunctioning emissions control systems. Many areas are now adopting advanced I/M programs, which require vehicle testing on a garage treadmill to better identify problem vehicles. Enhanced I/M programs achieve greater emissions reductions than standard I/M programs. However, other states are beginning to restructure and sometimes eliminate statewide inspection and maintenance programs, because the annual fees and testing hassle are not popular with the public. Furthermore, some studies indicate that the emission reduction benefits of I/M programs, while still significant, may be achieving only half of their current modeled emissions reductions. When a state eliminates or scales back an I/M program, the state is responsible for identifying other sources of emissions reductions.

New onboard diagnostics (OBD) systems bridge the gap between new vehicle certification and the in-use compliance verification of I/M. Onboard diagnostics systems detect failures of the engine sensors and the control actuators used by the onboard computer to optimize combustion and minimize emissions. Federal and California OBD programs introduced in 1994 detect component failures (such as an oxygen sensor) by continuously monitoring and evaluating the network of sensor readings to detect erroneous or illogical sensor outputs. Such OBD systems employ detailed computer programs that can change the control logic, discard the inputs from bad sensors, and ensure that emissions remain low even when failures do occur. A malfunction indicator lamp (MIL), or Check Engine light, illuminates on the dashboard when the OBD system identifies problems. Engine computers facilitate repair by reporting trouble codes to mechanics through handheld diagnostic tools that interface with the engine computer. Under I/M programs, vehicles with OBD-reported malfunctions cannot be re-registered until the problem is diagnosed and repaired. The new OBD systems are designed to improve the effectiveness of I/M and minimize lifetime emissions from the vehicle.

Super-emitters behave differently than their normal-emitter counterparts. Whereas normal-emitting vehicles may exhibit high emissions under a hard acceleration or high speeds, vehicles classified as super-emitters tend to exhibit elevated emissions under almost every operating condition. New emissions models will likely track the activity of high-emitting vehicles separately, applying different emission rate algorithms to this activity. Similarly, these new emissions models will also model the effect of I/M programs as decreasing the fraction of onroad high-emitting vehicles.

CLEANER FUELS

Numerous fuel properties affect evaporative and exhaust emissions. Refiners can modify fuel vapor pressure, distillation properties, olefin content, oxygen content, sulfur content, and other factors to reduce emissions. In 1989, the EPA set fuel volatility limits aimed at reducing evaporative emissions. In 1992, manufacturers introduced oxygenated gasoline into cities with high wintertime CO levels. By 1995, the EPA's reformulated gasoline (RFG) program required the sale of special gasoline in nine metropolitan areas that do not meet national clean air standards for ozone. RFG yielded a 15 percent reduction in HC emissions without increasing NO_x emissions, at a cost of somewhere between four and seven cents per gallon. Fuels had to include 2 percent oxygenate by weight (ethanol or MTBE), but manufacturers could adjust a variety of other gasoline properties to achieve the mandated emissions reduction.

Proposed fuel regulations associated with EPA's 2004 vehicle standards program (Tier 2) will substantially reduce the allowable sulfur content of fuel, significantly enhancing the effectiveness of advanced catalytic converters. Sulfur in gasoline temporarily deactivates the catalyst surface, thereby reducing catalyst efficiency. The sulfur reductions are critical for enabling the vehicle emissions control technology to meet Tier 2 standards. By 2006, Tier 2 regulations will require an average fuel sulfur level of 30 ppm, with an 80 ppm cap. This is a substantial decrease from current average sulfur levels of 340 ppm. Vehicle manufacturers estimate that the 90 percent reduction in fuel sulfur will reduce NO_x emissions from the new, low-emitting vehicles by 50 percent, at a marginal cost of between two and four cents per gallon. Vehicle manufacturers argue that further reducing sulfur levels from 30 ppm to 5 ppm will provide additional emissions benefits at a cost somewhere between two and three additional cents per gallon.

FUEL ECONOMY IMPROVEMENTS AND EMISSIONS

In the 1970s, manufacturers requested and received some delays in the implementation of new vehicle certification standards. EPA granted these delays to help manufacturers balance emissions reduction efforts with their efforts to increase corporate average fuel economy. At that time, almost every control system (smog pumps, EGR, and catalytic converters) resulted in a fuel economy penalty. The direct relationship between increased emissions control and decreased fuel economy was broken in the late 1980s with the widespread adoption of advanced computer-controlled fuel injection and spark timing systems. Smog pumps were removed and other devices that reduced fuel economy were improved with computer control. Today, the same technologies that reduced motor vehicle emissions (electronic fuel injection, spark timing, and computer control) have improved fuel economy (or provided improved engine power output in lieu of fuel economy improvements). In general, reduced fuel consumption results in emissions reductions from the vehicle, and reduced vehicle refueling minimizes evaporative emissions. Improving fuel economy is sometimes referred to as the forgotten emissions control strategy.

CONCLUSION

Despite the emissions rate reductions achieved during the last thirty years from new and in-use vehicles, rapid growth in vehicle use has offset a good portion of the total potential reductions. Population growth continues at a rate between 1 percent and 2 percent per year, but the number of trips per day and vehicle miles of travel are increasing at double or triple that rate in many areas. More people are making more trips and driving farther each day. As vehicle miles of travel continue to increase, so do congestion levels. The net effect is that more people are making more trips and driving farther under conditions that increase emission rates. Manufacturers sell nearly 16 million vehicles per year in the United States. More importantly however, the average vehicle lifespan of nearly fourteen years continues to increase. Given the tremendous growth in vehicle use and the emissions rate increases that come with congestion and an aging onroad fleet, reducing onroad vehicle emissions remains extremely important for air quality. Without the previous 30 years of transportation emissions controls, urban air quality would have continued to degrade. Instead, the most polluted areas of the United States have experienced significant air quality improvements.

Randall Guensler

See also: Traffic Flow Management.

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