A STATUTORY AND REGULATORY HISTORY OF THE U.S. EVAPORATIVE REQUIREMENTS FOR MOTOR VEHICLES AND ANALYSIS OF EUROPEAN EVAPORATIVE EMISSION REQUIREMENTS

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Introduction

Evaporative emission standards and test methods vary widely in stringency and scope across the globe.[1] The most comprehensive and stringent evaporative regulations have consistently been those in the United States. The fundamental goal behind any emission standard is to achieve the emission reductions necessary to improve air quality and protect public health. Air quality standards for the protection of public health and welfare also vary widely across the globe[2] and have historically become more stringent as the research linking air quality and public health has improved. The Clean Air Act's (CAA) statutory requirement for states to meet aggressive National Ambient Air Quality Standards (NAAQS) has driven the need for significant mobile source reductions. As other countries – such as China and Brazil -- get serious on improving urban air quality, and as their understanding of the contribution of evaporative emissions has grown, they have tended to migrate toward alignment with U.S. scope and stringency. Other regions and major countries continue to lag considerably – largely because of a lower priority to reduce urban ground level ozone and $PM_{2.5}$ or a different view of the contribution of evaporative emissions on air quality. By 2025, 55% of the annual gasoline light duty vehicle sales population will have evaporative and refueling emission standards roughly equivalent or better than the U.S. 2010 level. As these remaining regions recognize the role and significance of evaporative emissions on air quality (ozone and with growing ties to secondary organic aerosols [SOAs]) – or simply due to economics – it is expected that stringency and scope will continue converging to that of the U.S. This paper is organized into two sections; the first section provides a general overview of evaporative emissions and summarizes the statutory and regulatory history of the U.S. evaporative requirements for motor vehicles and the general findings of the U.S. EPA and California Air Resources Board (CARB). The second section provides an analysis of European evaporative requirements and the implications on evaporative emissions and air quality in Europe. Based upon these detailed reviews, a set of policy recommendations for Post-Euro6 evaporative requirements is provided below.

Policy Recommendations for Post-Euro 6:

To continue a reduction in evaporative emissions and improve air quality, especially during off-cycle conditions[3], it is recommended that the European Commission consider adding a 3-day diurnal test with a high temperature running loss drive and a high temperature hot soak to its current Euro 6d certification requirements. It is not recommended that a separate running loss standard be included. This test is in addition to the existing 2-day diurnal test with an ambient temperature drive. It is also recommended that the emission limit, without fleet averaging for both tests be reduced to 0.35 grams per day, including hot soak.

Making these changes would:

- Increase canister capacity by about 40-45% and provide proven control for extended parking events, as well as provide better control during off-cycle conditions.
- Increase purge rates by about 60%, which would provide better control during off-cycle conditions (such as driving events less than 30 minutes and during heat waves).

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[1] See Appendix 1 for current evaporative regulations for several countries and regions.

[2] See Appendix 2 for a review of global air quality standards adopted in select countries with respect to World Health Organization (WHO) recommendations.

[3] The concept of "off-cycle" emissions is discussed further below on Pages 6-7.

- Decrease permeation by 70%. Permeation is largely made up of aromatics, which are particularly reactive in forming SOAs.
- Ensure that vehicles are calibrated to provide sufficient purge during hot driving conditions.
- Reduce leaks through greater attention to fittings and connections.

It is also recommended that the European Commission reconsider ORVR as a long-term solution for controlling refueling emissions. ORVR is more effective and less costly than Stage II, and it also adds another 25% to canister capacity and 30% to purge rate. Addition of ORVR technology, in lieu of adding the proposed 3-day diurnal test with a high temperature running loss drive, would provide the extra capacity and purge needed to accommodate a greater proportion of off-cycle conditions leading to excess evaporative emissions.

Section 1: Technology Background and Summary of U.S. EPA and CARB Experience on Evaporative Emissions

1A: Technology Background

Gasoline is a volatile substance and can escape a vehicle's fuel system as emissions via a number of pathways. Left unchecked, losses to the environment can account for several percentage points of the fuel's liquid volume. The largest potential loss of vapor is through a venting process from the fuel tank – either through the tank's vent or through a vapor leak in the fuel system. Gasoline's vapor pressure is exponential with temperature, and an increase in temperature causes gasoline to evaporate to enrich the gas phase of the tank's ullage volume to maintain equilibrium (Figures 1 and 2). This evaporation displaces air in the tank and results in venting of the air-vapor mixture from the tank.

Figure 1: Vapor Pressure and Vapor Fraction of Gasoline at Sea Level

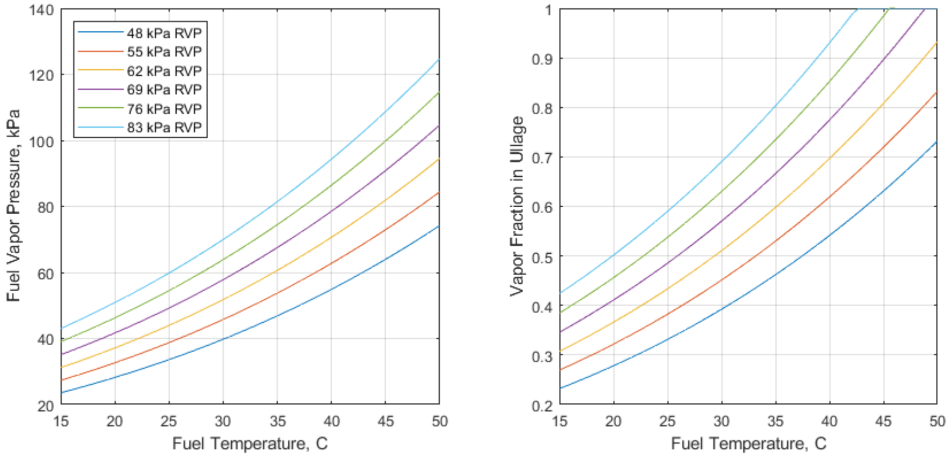
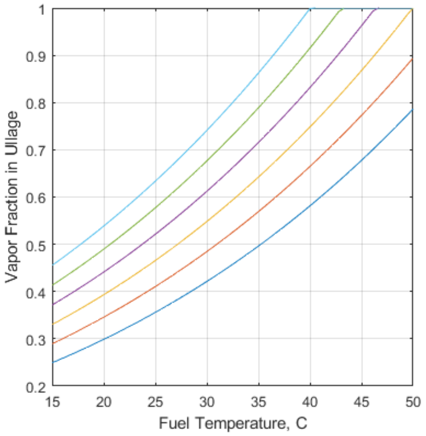


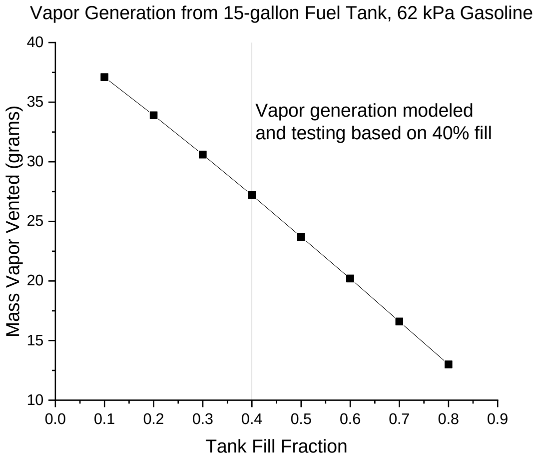
Figure 2: Vapor Fraction of Gasoline in Tank Headspace at 600 meters Elevation



The mass of emissions that vent from the fuel tank, defined as vapor generation, depends upon a number of factors other than simply temperature change and maximum temperature reached. The Reid Vapor Pressure (RVP) is a primary factor and describes the relative volatility of the fuel at 100°F (37.8°C).[4] In most developed regions, caps are placed on the volatility of available fuels, particularly during summer months, to provide some level of control over vapor generation and the extent to which gasoline can reach boiling-point conditions.[5]

Another important factor affecting vapor generation is the relative fill volume of the fuel tank, where vapor generation increases as the amount of vapor volume in the tank increases (Figure 3). Since the 1970s, the U.S. fill volumes averaged 40%[6] of nominal tank capacity, which is considered representative of the in-use fleet. This percentage has been used for testing and modeling purposes around the world ever since.

Figure 3: Vapor Generation from a 15-gallon (~57 Liter) fuel tank with 62 kPa gasoline



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[4] ASTM D4953, D5191, D5482, or D6378

[5] See, for example, ASTM D4814

[6] 41 Federal Register 164, (August 23, 1976).

There are three processes that cause the fuel tank temperature to increase on a vehicle: (1) daily temperature swings, also known as the diurnal heat build, (2) hot soak conditions for the 1-2 hours after a vehicle is turned off and hot exhaust components heat the tank, and (3) running loss conditions in which radiative load from hot pavement and hot exhaust components plus hot air from the engine and radiators are channeled under the vehicle and across the fuel tank.

Diurnal Emission Control:

Most often, tank venting emissions are controlled using an activated carbon filled canister[7] that is placed in the vent line from the fuel tank to the atmosphere. As vapor and air are vented from the fuel tank, this mixture passes through the canister. The hydrocarbon vapors adsorb onto the activated carbon, reducing the amount of hydrocarbon vapor that is released to the environment. The percentage of hydrocarbons that escape as emissions are proportional to the percentage of the canister's capacity that is being utilized to store hydrocarbons at any time.

The canister capacity is sized based upon the highest vapor load challenge in the procedures. A vehicle certified to a 48-hour plus hot soak standard will have almost double the capacity of one designed to meet a 24-hour standard. A vehicle certified to meet a 72-hour diurnal plus hot soak standard will have almost 50% more capacity than one designed to meet a 48-hour standard. A vehicle certified to meet an onboard refueling vapor recovery (ORVR) requirement will have almost 25% more capacity than one certified to only a 72-hour diurnal plus hot soak standard because the same canister must also have the capacity to meet the higher load challenge and a higher load rate of vapor which occurs during refueling.

The canister is regenerated while the vehicle is driven through a process called "purge." The engine's manifold vacuum is used to pull air from the atmosphere, through the canister, and into the engine. The air pulled into the canister desorbs hydrocarbons and delivers them to the engine for use as fuel. The rate at which air is pulled into the canister is a function of the vacuum level in the engine and the calibration of a purge valve used to control airflow. So, the total volume of purge airflow through the canister is a function of the duration of a driving event, the extent to which the purge valve is opened during the driving event (i.e. the size of the purge valve and the conditions in which the valve was calibrated to open or close), and the relative level of manifold vacuum during the driving event. In some cases, a purge pump can be built onto the vehicle to boost purge rates if manifold vacuum is not sufficient to reach target rates.

The vehicle's purge valve is calibrated to open and close in a manner to meet the demands of the test procedures and standards. For diurnal tests, the canister is pre-loaded with butane, and enough capacity must be generated in the canister by the purge to meet the challenge of the hot soak and diurnal load. So, over a 30 minute drive cycle like the WLTC, a vehicle certified to a 72-hour standard will have an average purge rate about 50% higher than one certified to a 48-hour standard.

Running Loss Control: In the U.S., automakers must test for running loss and meet a 0.05 g/mile standard. Fuel tank temperature increases on hot, sunny days can be substantial. As part of the U.S. running loss procedures, auto manufacturers must measure fuel tank temperatures for 70 minutes of driving during sunny conditions at 35°C then duplicate these temperatures during a test. The measured temperature trace of the fuel tank is called the Federal Tank Temperature Profile (FTTP).[8] The FTTPs for two

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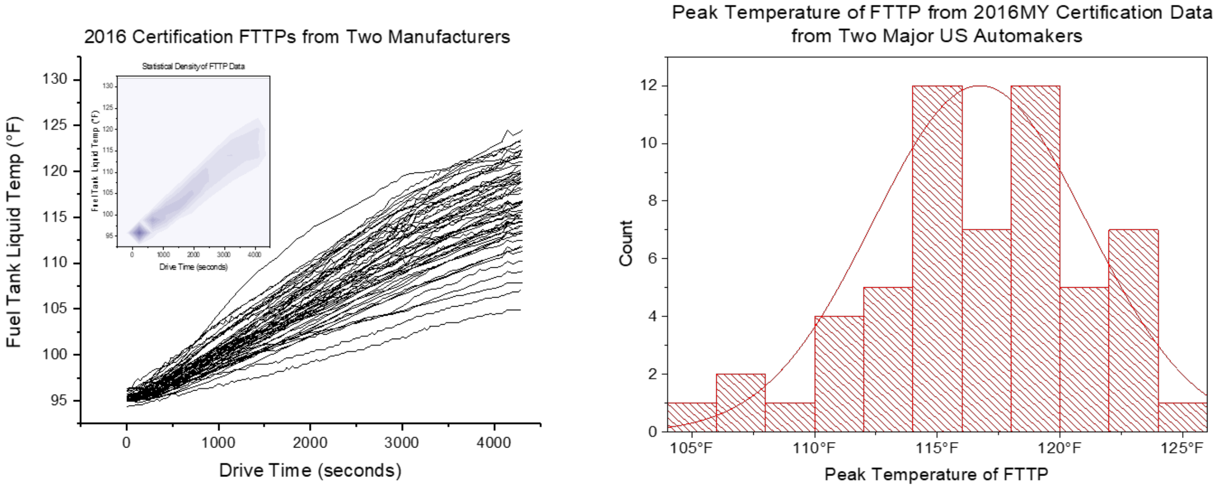
[7] Sealed tank systems can also be used and are exclusively used for Plug-in Hybrid Electric Vehicles (PHEVs).

[8] 40 CFR 86.134-96

manufacturers certifying in the U.S. for the 2016 Model Year are shown in Figure 4 below. Almost 25% of the FTTPs reached temperatures of 49°C or more, indicating the boiling point of a 60 kPa fuel could be neared or exceeded during this type of driving condition. To some degree, vapor generation is reduced by reducing the heat load onto the fuel tank. This is accomplished by using on-demand fuel pumps, adding thermal shielding to reflect radiative load from exhaust components and the road surface, and preventing hot air from the engine and air conditioner condenser from directly impacting the tank. To control the vapors that are generated, automakers rely on maintaining high purge rates at the elevated temperatures. Canister capacity is also important, because spikes of vapor can be generated when fuel sloshes in the tank and contacts a hot portion of the tank. The canister serves to buffer the concentration and mass of vapor to the engine with the purge.

Figure 4: 2016 Federal Tank Temperature Profile (FTTP) certification data for two auto manufacturers



<u>Permeation Control</u>: Hydrocarbons are able to permeate through polymer fuel lines and tanks. Focus on controlling these emissions increase as diurnal emission limits are reduced and as ethanol is introduced into the certification fuel. Permeation rates are temperature dependent and are highly affected by the presence of ethanol in the fuel. Ethylene-vinyl alcohol (EVOH) copolymers are the most prevalently used barrier material to reduce permeation emissions. The amount of EVOH used, if any, as barrier material is largely a function of the diurnal emission limit and whether ethanol is present in the certification fuel.

<u>Off-Cycle Considerations of Test Procedures and Emissions</u>

Since the control efficiency of the canister is proportional to the free capacity of the canister, then two factors are important for highly effective control of tank venting: (1) high canister capacity, and (2) high purge rates. But there are other, very important reasons, why both high canister capacity and high purge rates are needed; it is related to the highly non-linear aspect of the processes governing vapor generation and tank venting and off-cycle conditions.

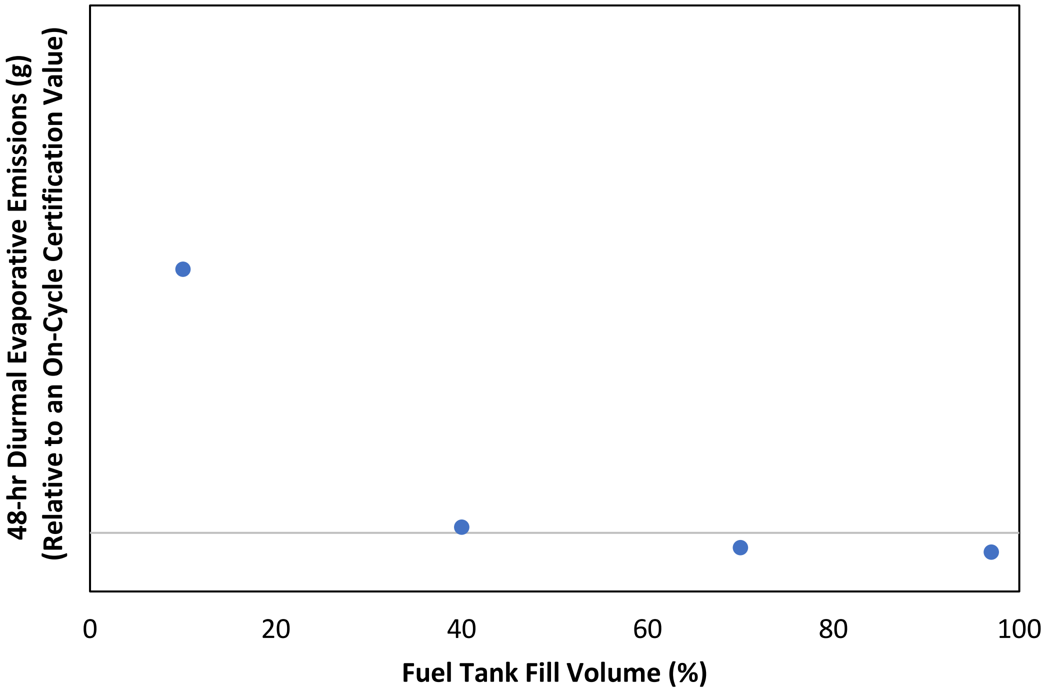
Before discussing evaporative emissions, it is instructive to first look at the regulatory strategy for controlling tailpipe emissions. The general goal is to broadly cover as much of a map of engine torque versus engine speed with the test drive cycle as possible. Automakers will adjust the engine calibration and engine-out emissions as well as the exhaust catalyst treatment technology in response to the technical demands of the test drive cycles and emission limits. Maximizing "on cycle" conditions thus minimizes “off cycle” conditions and ensures that the vehicle is calibrated and designed to minimize emissions during all driving conditions. This includes urban congestion driving as well as high speed driving, high elevation conditions versus low elevation conditions, high temperatures and cold temperatures, low speed and low load to high speed and high load. To achieve acceptably broad coverage, the U.S. has grown to employ a number of exhaust test cycles, including FTP (including low and high altitude), cold FTP, SFTP US06, SC03, and Highway Fuel Economy Test -- all of which focus on separate parts of the engine map and in-use operation. Europe recently increased the broadness of its “on cycle” control strategy by switching to the WLTC and RDE from the limited NEDC.

Just like exhaust control, automakers respond with evaporative controls and vehicle calibration to meet the on-cycle demands of the test procedures. In this regard, “on-cycle” in Europe means a 60 kPa E10 test fuel, a 40% filled tank, a butane-filled canister followed by 30 minutes of ambient temperature driving, and two days of parking with a temperature swing of 20°C to 35°C. Outside of these conditions can be considered off-cycle and can result in a significant increase in evaporative emissions.

Evaporative certification standards are set to be achieved in the laboratory, but – just like exhaust emissions – ‘what are the evaporative emissions in-use?’ With evaporative emissions, there is never an on-cycle condition. That is, the diurnal temperature swing can be less severe or more severe than the test condition, parking events can be shorter or longer than the test condition, gasoline RVP can be higher or lower than the test fuel, the fill percentage of the tank can be lower or higher than 40%, the ambient temperature can be higher or lower than the ambient temperature of the drive cycle, etc. It is in this context that the non-linear properties of gasoline vapor pressure and vapor generation become important. As examples:

- The vehicle is certified using a tank fill percentage of 40%. Using the example above, a 15-gallon tank filled 40% with 60 kPa fuel will vent about 27 grams of vapor over a diurnal. So, a canister designed to meet a 48-hour diurnal will be designed to accommodate on the order of 70 grams of vapor (including hot soak, daily vapor load, back-purge, long-term aging, and engineering surplus). For the 2g standard, the emissions from this canister will be 50-150 mg/day. If the fuel tank is filled to 70% of nominal capacity, then daily vapor generation is reduced to about 17 grams – or 32 grams (including back-purge) over 48 hours. The emissions will be on the order of 30-60 mg lower than the certification value. However, if the fuel tank is filled to only 10% of nominal capacity, then daily vapor generation rates are 37 grams – or 69 grams (including back-purge) over 48 hours, which is about the capacity limit of the canister. When hot soak loading of 5-10 grams and aging is considered, emissions will be on the order of 4-9 grams per 48-hour event. The problem is that the positive and negative emission impacts are not evenly distributed around the average value of the test condition. That is, emission “credits” achieved when fuel tanks are filled more than 40% do not equally offset the “debits” achieved when fuel tanks are filled less than 40%. These higher real-world emissions do not get picked up in the inventory modeling. An illustrative graphic of the non-linearity of off-cycle emissions is provided in Figure 5 below.

Figure 5: Off-Cycle Evaporative Emissions Illustrative Example: Canister Emissions at Variable Fuel Tank Fill Volume Percentages.



- In the U.S. EPA procedures, a 72°F to 96°F (22.2°C – 35.6°C) diurnal heat build is used. The same 15-gallon fuel tank example, filled to 40% of nominal capacity with 62 kPa gasoline, generates 27.2 grams per day of vapor. However, if we look at diurnals with an incremental adjustment, ΔT, of plus or minus 4°F from the minimum and maximum temperature, we find:
    - 68°F to 92°F (20°C – 33.3°C) diurnal vapor generation of: 22.7 grams per day (4.5 grams less than test condition)
    - 76°F to 100°F (24.4°C – 37.8°C) diurnal vapor generation of: 32.9 grams per day (5.7 grams more than test condition)

  Again, the impact on emissions is not equally distributed around the test condition. The higher temperature conditions result in emissions that are not completely offset by more favorable lower temperature conditions.

- A 60 kPa test fuel is used in Europe. However, France has a 65 kPa summertime RVP limit. Using the same 15-gallon tank example filled 40%, a 60 kPa fuel generates 24.8 grams per day of vapor, while a 65 kPa fuel generates 30.8 grams per day of vapor – 24% higher than the test condition. Most of the U.S. has a similar situation, where a federal summertime gasoline RVP cap of 9 psi (62 kPa) exists, but this is on the blender stock fuel. This is also the RVP of the certification test fuel. Most of the U.S.' gasoline pool is E10, and after splash-blending, the in-use RVP is about 9.9 psi. In areas were there are specific limits on in-use RVP, such as ozone nonattainment areas, the gasoline must meet these limits even with E10.

But, unlike developing robust drive cycles or RDE to account for variability of driving conditions on exhaust emissions, there is no practical means to develop evaporative tests that can accommodate all – or even nearly all – the conditions which create in-use variability. California Air Resources Board (CARB) and the U.S. EPA focused on achieving practical in-use control in summertime conditions and settled on three general regimes in which they wanted to ensure that technology on the vehicle would address. They felt that if the technology on the vehicle could address these bounding conditions, then the majority of off-cycle conditions – occurring in summertime conditions when VOC control is needed most – would be contained between the test conditions and become, in effect, on-cycle; the remaining off-cycle conditions that could be reasonably expected would be only a short extrapolation from on-cycle. The critical regimes were:

1. Short driving events followed by moderate parking events: Urban driving often includes short driving events, and the agencies wanted to ensure that purge was calibrated to regenerate the canister during these short driving events. This was needed to minimize emissions from both short and moderate (48-hour) parking events following the short driving event.
2. Lengthy driving events during high temperature (running loss prone driving events) followed by extended parking events: Running losses had been identified as a major emission and canister loading source. Since purge is the primary means to control running losses, the agencies wanted assurance that vehicles would consistently be calibrated to maintain high purge rates at the elevated temperatures. Moreover, higher canister capacities were needed to address a significant portion of three-day parking events and to address other off-cycle issues that could affect emissions.
3. High altitude testing: Venting emissions increase significantly with elevation. Verification testing was needed to ensure the same level of emission control occurred at high elevation.

The U.S. found it was impossible to get robust control with a single certification test. China was able to streamline the number of certification tests by using ORVR to ensure high canister capacity for diurnal control and purge and to provide best available control technology refueling control. China also avoided the need for a separate running loss test by including a 48-hr diurnal test with a 38°C, 38 minute running loss drive to ensure sufficient purge calibration at high temperatures plus a provision requiring that fuel tank emissions be vented only to the canister or engine.

1B: Analysis for the U.S.

For the last 30 years, the U.S. EPA and CARB have concentrated efforts on refining test procedures and standards to reduce VOC emissions and improve air quality. A detailed history behind the U.S. evaporative requirements and the general findings of the U.S. EPA and CARB are presented below. EPA's regulatory approach is best summarized from a statement in EPA's 1993 Enhanced Evaporative Emissions Regulatory Impact Analysis[9]:

> [A] focus on "typical" conditions is not consistent with the statutory mandate, which is to control evaporative emissions to the greatest degree reasonably achievable "under

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[9] "Final Regulatory Impact Analysis and Summary and Analysis of Comments, Control of Vehicular Evaporative Emissions," U.S. EPA, February 1993.

> ozone-prone summertime conditions," including two or more days of nonuse. Any test for evaporative emissions must be judged against this standard.

EPA's goal in designing a test is therefore not to simulate a single, "representative" in-use condition. Clearly, any specific procedure will only simulate one of a multitude of actual in-use patterns of operation. The broader goal of EPA's test design is to develop a test that will result in good emission performance under nearly all conditions that vehicles will experience in use (see Clean Air Act section 202(k)). Designing the test based on average conditions is inappropriate, because the resulting vehicle designs would be incapable of performing well under the temperature and driving conditions when high evaporative emissions are most likely to occur and control is most needed.

EPA's approach has been unique in that it has put tremendous effort into understanding the causes and magnitude of evaporative emissions.[10] For example, its continued cooperation with the Coordinating Research Council (CRC) has contributed greatly to EPA's understanding[11].

Based on good understanding of the specific emissions targeted for reductions, the U.S. EPA drafts its test procedures and emission standards to achieve a desired control technology response which provide the targeted reductions. EPA gauges how that technology response will affect summertime regional inventories, air quality, and public health -- particularly in the specific regions where improvement is needed most. This benefit response is then weighed against the costs to society, burden to the automaker, energy needs and independence, plus any impact on safety, all of which are statutory in the rulemaking process[12]. The bottom line is that the EPA will regulate as necessary to improve air quality, as long as the costs and the needed technology development are reasonable. It is the emphasis on improving air quality that has historically differentiated the U.S. from other regions around the globe.

Factors Leading to Significant Regulatory Progress in the U.S.

During the 1980s, 27 states were having difficulty meeting the 0.12 ppm ozone air quality standards, and days of non-attainment were concentrated in urban areas in summertime conditions. The 1977 Clean Air Act Amendments (CAAA) required states to show progress in meeting the ozone NAAQS, and this required action by EPA to understand the factors affecting ozone formation and to identify sources of ozone precursors, including volatile organic compounds (VOC) and oxides of nitrogen (NOx). EPA and the CARB committed great effort toward understanding the atmospheric chemistry involved with ozone formation, identifying and quantifying the sources of ozone precursors, identifying control technologies, assessing the feasibility of implementation and costs for control options, and then developing comprehensive strategies on how to improve regional air quality. Both EPA and CARB recognized the need to control both VOC and NOx emissions as the only viable means to holistically improve ozone air quality, and they both identified mobile source evaporative emissions as a major source of VOCs. Together, they found that the key to reducing evaporative emissions on hot, summertime days in urban areas was to require test procedures and emission limits which force vehicle technology that would provide emission reductions on the days and in the driving conditions when control is most needed, such as ozone exceedance days. The conclusions were that vehicle evaporative emission control technology would require significantly

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[10] See https://www.epa.gov/moves/mobile-source-emission-factors-research for links to several studies on mobile source emission factors research by EPA.

[11] See appendix 3

[12] 42 U.S.C. §7521(k)(2).

higher purge rates and canister capacities than existed in the control systems on vehicles of the 1980s and early 1990s. In addition, control of running loss emissions, identification of fuel system vapor leaks, and control of refueling emissions were needed.

EPA's attention to evaporative emissions is rooted in its statutory requirement to protect public health and to support states' abilities to reach national ambient air quality standards (NAAQS). The Clean Air Act (CAA) required that EPA develop a deep understanding of the complex atmospheric chemistry underlying the creation of ozone, the relationship between VOC and NOx in ozone formation, as well as the meteorological conditions which are characteristic of ozone prone days and affect regional transport of ozone. It also required that EPA develop an accurate inventory of the sources affecting urban inventories of ozone precursors such as VOCs and NOx.[13] In the 1980s, states were struggling with implementation plans (SIPs) to reach ozone attainment. Attainment was defined when the expected number of days per calendar year, with maximum hourly average concentration greater than 0.12 ppm, is equal to or less than one.[14] EPA found 73 urban areas were exceeding the ambient ozone air quality standard in 1984, and 96% of the exceedances occurred in the summertime months of May through September. For the years 1989-1991, there were 97 areas – affecting 70 million people -- that failed to meet the NAAQS for ozone[15]. Research and future rulemaking activity focused on understanding, quantifying, and controlling the sources of ozone precursors – VOC and NOx – during these summertime months in these urban conditions.

Comprehensive Action to Address Fuel Vapor Emissions by CARB/EPA

As is shown in Appendix 5, prior to 1995/1996, the United States had evaporative requirements that consisted of a hot soak and single heat build in a sealed housing for evaporative determination (SHED) with a standard limit of 2 grams/test. In-use RVP was not regulated, but the ASTM D4814 limits were followed by the gasoline marketing industry. After completion and public review and comment on comprehensive studies[16,17,18,19,20] in August 1987, EPA published its first notices of proposed rulemakings (NPRMs) to address summertime gasoline volatility (Reid Vapor Pressure, [RVP]) limits, refueling emissions using onboard refueling vapor recovery (ORVR), and to improve evaporative emission diurnal test procedures.[21,22] The first final actions, requirements restricting the volatility of summertime gasoline

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[13] Clean Air Act Section 103(c). See Appendix 4.

[14] See https://www.epa.gov/ground-level-ozone-pollution/table-historical-ozone-national-ambient-air-quality-standards-naaqs. In 1997, U.S. measured the fourth-highest daily maximum 8-hour concentration, averaged over three years, to determine attainment. Subsequent U.S. ozone standards were 0.08 ppm (1997), 0.075 ppm (2008), and 0.070 ppm (2015). The current European standard is 0.060 ppm, but it should be noted that compliance is based on the 25th-highest daily maximum 8-hour concentration, averaged over three years. See Appendix 2.

[15] 58 Federal Register 16002, (March 24, 1993).

[16] "Study of Gasoline Volatility and Hydrocarbon Emissions from Motor Vehicles," U.S. EPA, EPA-AA-85-5, November 1985.

[17] Evaluation of Air Pollution Regulatory Strategies for Gasoline Marketing Industry, EPA 450/3-84-012a, July 1984.

[18] Evaluation of Air Pollution Regulatory Strategies for Gasoline Marketing Industry - Response to Public Comments, EPA 450/3-84-012c, July 1987.

[19] Draft Regulatory Impact Analysis, "Control of Gasoline Volatility and Evaporative Hydrocarbon Emissions from New Motor Vehicles," 420D87100, July 1987.

[20] 50 Federal Register 48100, (November 21, 1985).

[21] 52 Federal Register 31273, (August 19, 1987).

[22] 52 Federal Register 31161, (August 19, 1987).

and alcohol blends, were promulgated in March 1989 (Phase I for calendar years 1989-1991) and June 1990 (Phase II for calendar years 1992 and beyond).[23,24,25, 26]

In the same time frame that EPA published the three NPRMs, CARB began to take aggressive action on addressing evaporative emissions. In cooperation with General Motors, a real-time evaporative diurnal sequence was developed which would eventually serve as the basis for all modern, real-time diurnal SHED tests.[27] CARB was generally concerned about the impacts of extended parking events and the need for higher levels of canister capacity and purge that would suitably address off-cycle conditions. In addition, running losses were identified as a major VOC source in the inventory. As a result, the 3-day diurnal sequence and an integrated running loss test and related emission standards were developed. The evaporative emission requirements for CARB's Low Emission Vehicle (LEV) rulemaking was proposed in September 1989[28] and promulgated in September 1990[29] for implementation beginning with the 1995 model year.

During the same rulemaking development period, EPA was highly concerned about achieving adequate purge during urban driving conditions and had developed the 2-day diurnal and hot soak test. In January 1990, EPA issued a supplemental NPRM related to evaporative emissions control and proposed the introduction of a 2-day diurnal that utilized the FTP drive cycle.[30] EPA also proposed addressing running loss emissions by receiving assurance from the automaker at certification, through engineering design, that all vapors generated during driving were routed to the engine or canister. EPA also sought comment on running loss test procedures that could be used as an alternative to that put in place by CARB. EPA agreed with CARB that high canister capacity was needed to address longer parking events and to continue providing needed control when real-world conditions deviated from those in the certification tests (e.g. higher temperatures, higher in-use fuel RVP, extended parking events, slower driving speeds, lower tank fill levels, etc.). But EPA was pursuing a separate ORVR rulemaking,[31] and EPA believed that the canister capacity issue would be suitably, if not better, accomplished with ORVR in combination with its 2-day diurnal test[32].

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[23] "Final Regulatory Impact Analysis on the NPRM Interim Control of Gasoline Volatility," EPA 420R89102, 1989.

[24] 54 Federal Register 11687, (March 22, 1989).

[25] 55 Federal Register 23657, (June 11, 1990).

[26] "Final Regulatory Impact Analysis and Summary and Analysis of Comments on Phase II Gasoline Volatility Control Regulations," EPA 420R90105, 1990.

[27] Haskew *et al.*, "The Development of a Real-Time Evaporative Emissions Test," Journal of Fuels & Lubricants, Vol. 99, Section 4, pp 367-391, 1990.

[28] "A Proposal to Revise the Current Evaporative Emission Test Procedure and Adopt 100,000 Mile Evaporative Emission Standards and Durability Requirements for Passenger Cars, Light-Duty Trucks, Medium-Duty Vehicles and Heavy Duty Vehicles," September 22, 1989, Mailout 89-31; later modified on January 17, 1990 by "Notice of Changes to a Previous Proposal (Mail Out #89-31) to Revise the Current Evaporative Emission Test Procedures and Adopt 100,000 Mile Evaporative Emission Standards and Durability Requirements For Passenger Cars, Light-Duty Trucks, and Heavy-Duty Vehicles and 120,000 Miles Evaporative Emission Standards and Durability Requirements For Medium-Duty Vehicles", Mailout 90-04.

[29] "California Evaporative Emission Standards and Test Procedures For 1978 and Subsequent Model Liquefied Petroleum Gas or Gasoline or Methanol-Fueled Motor Vehicles", September 7, 1990, Mailout 90-59.

[30] 55 Federal Register 1913, (January 19, 1990).

[31] 52 Federal Register 31161, (August 19, 1987).

[32] Draft Regulatory Impact Analysis: Proposed Refueling Emission Regulations for Gasoline-Fueled Motor Vehicles - Volume I Analysis of Gasoline Marketing Regulatory Strategies, EPA-450/3-87-001a, July 1987.

After subsequent discussions with CARB, EPA felt the California 3-day test – with 96 minutes of driving – would not result in adequate purge rates for short trips common in urban areas and could not be substituted for the 2-day test (with 31 minutes of driving). Both agencies agreed that a national program was needed, and EPA agreed that CARB's separate running loss test was an improvement over the engineering design approach and "cap-off" requirement.[33] General Motors had developed and proposed the 70 minute running loss test, and nearly all automakers supported direct testing of running losses over EPA's proposed design review and "cap-off" requirement.[34] So, both the 2-day and 3-day tests with more rigorous diurnal temperature cycles and hot soak requirements and a separate running loss test and standard – together identified as "enhanced evaporative" requirements -- were required by both Agencies for certification. These applied to LDVs, LDTs, and HDGVs. Control of fuel spit back from the vehicle fill pipe during premature shut-offs or at the end of refueling events was also included. CARB promulgated the revised evaporative emission LEV regulations in January 1993[35] and EPA promulgated its "Enhanced Evaporative" regulation in the same month.[36] CARB received its waiver in September 1993.[37] Implementation began with the 1995 model year in California and the 1996 model year for EPA.

As mentioned above, ORVR regulations were first proposed in 1987 and after considerable public review and debate were published by EPA in April 1994.[38] Implementation began with the 1998 model year for LDVs and 2001 for LDTs. ORVR test procedures are based on the drive cycles in the Enhanced Evaporative rule with a standard of 0.20 g/gallon. California adopted ORVR in 1995 with implementation in the 1998 model year.[39] ORVR based on the U.S. EPA test procedures is a nationwide requirement.[40]

Finally, as part of its comprehensive approach to dealing with evaporative emissions, in 1992 CARB adopted an OBD monitoring requirement that fuel system vapor leaks with a cumulative diameter equal to or greater than 0.040" be identified and that a malfunction indicator light (MIL) be illuminated on the vehicle. The requirement was implemented for LDVs and LDTs for the 1994 model year. In 1994, CARB upgraded this OBD evaporative leak threshold to a cumulative diameter of 0.020" or greater effective for the 1996 model year. Following requirements in the 1990 Clean Air Act Amendments (CAAA), EPA adopted similar but not identical evaporative system monitoring requirements in 1993, and these were eventually fully implemented for the 1996 model year.[41] (The difference was in test procedure, not the numerical value monitoring threshold.) In 1998 EPA fully aligned with CARB OBD II evaporative monitoring test procedures. EPA accepted CARB certifications to 0.020" as compliant with the 0.040" Federal standard. EPA eventually adopted the 0.020" value for the 2018 model year.[42] OBD systems also monitor the continued proper operation of the evaporative control system purge valve. Overall, OBD for

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[33] This proposal would have required that the fuel cap be removed in the SHED immediately after the vehicle enters in to the hot soak test and the results would be counted as hot soak emissions.

[34] "Final Regulatory Impact Analysis and Summary and Analysis of Comments, Control of Vehicular Evaporative Emissions," U.S. EPA, February 1993, p.4.

[35] State of California Air Resources Board, Executive Order G-812

[36] 58 Federal Register 16002, (March 24, 1993).

[37] 64 Federal Register 42689, (August 5, 1999).

[38] 59 Federal Register 16261, (April 6, 1994)

[39] CARB mailout 96-31, October 7, 1996.

[40] As can be seen in Appendix 5, ORVR has since been applied to all HDGV up to 14,000 lbs. GVWR (LHDGVs).

[41] See "On-Board Diagnostic (OBD) Regulations and Requirements: Questions and Answers" EPA 420-F-03-042, December 2003 for more detail.

[42] 79 Federal Register 23412, (April 28, 2014).

evaporative control systems are useful as an environmental tool because failure of a purge valve or development of a fuel system vapor leak is an indicator that the vehicle would likely fail the hot soak+diurnal emission standard. It is also a useful tool in screening the performance of vehicles in emission inspection/maintenance programs and to provide data for inventory modeling. However, OBD itself is a monitoring requirement and the illumination of the MIL by OBD itself does not specifically prohibit leaks or purge valve failures.[43]

Role of 1990 Clean Air Act Amendments

The 1990 CAAA made ORVR, evaporative emission standards based on multiday diurnals, and running loss control statutory requirements. However, it is a common misconception that the CAAA served as the basis for EPA to develop and implement these requirements. EPA first proposed ORVR in 1987 and a 2-day diurnal evaporative emission standard in January of 1990. California promulgated the 3-day diurnal and running loss test and standards in September 1990. The 1990 CAAAs were not signed into law until November 1990. What the CAAA did accomplish, in this regard, was to cement a future of certainty that ORVR and multiday diurnals would remain in place, so that states could count on the VOC emission reductions in their implementation plans for air quality attainment. It also provided a statutory basis for applying future regulations with further stringency. In summary, the 1990 CAA required:[44]

> 1. The Administrator shall promulgate (and from time to time revise) regulations applicable to evaporative emissions of hydrocarbons from all gasoline-fueled motor vehicles during operation (i.e. running loss) and over 2 or more days of non-use (i.e. diurnal) under ozone-prone summertime conditions. The regulations shall take effect as expeditiously as possible and shall require the greatest degree of emission reduction achievable by means reasonably expected to be available for production during any model year to which the regulations apply, giving appropriate consideration to fuel volatility, and to cost, energy, and safety factors associated with the application of the appropriate technology.
>
> 2. The Administrator shall promulgate vehicle-based (onboard) systems (i.e. ORVR) for the control of vehicle refueling emissions with a minimum capture efficiency of 95 percent.
>
> 3. The CAA also required that in areas classified as serious or worse ozone non-attainment, owners or operators of gasoline dispensing facilities of more than 10,000 gallons of gasoline per month (50,000 gallons per month for independent small business owners) must install and operate gasoline vapor recovery systems (i.e. Stage II vapor recovery).[45] In total, Stage II for control of ozone precursor emissions was adopted in all or part of 25 states. The CAAA also provided that the requirements for Stage II would not apply once the Administrator determined that ORVR systems reached “widespread use” throughout the motor vehicle fleet.[46] On May 9, 2012, the EPA determined that the use of ORVR was in widespread and waived the requirement that current and former ozone nonattainment areas classified as Serious and above must implement Stage II.[47]

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[43] This was a fundamental rationale in pursuing a separate leak standard as part of the zero evaporative requirements in EPA’s Tier 3 rule.

[44] See Appendix 4 for applicable excerpts from the CAA, codified in 42 U.S. Code §7521

[45] 42 U.S. Code §7511a(b)(3). See Appendix 4.

[46] Clean Air Act, Section 202(a)(6)

[47] 77 Federal Register 28772, (May 16, 2012).

Three other points are important here. First, the 1990 CAAA left in place the general authority of EPA to set emission standards in section 202(a). This was then, and is today, very important since technology developments are frequent and the understanding of air quality science and its effect on health and welfare are increasing each year. The CAA could not be amended as frequently as new information was developed and published by stakeholders in industry, government, and academia, and others. Second, by including the evaporative and ORVR provisions (and others as well related to RVP control) the U.S. Congress acknowledged the need for further progress on meeting the ozone NAAQS and accepted the validity of the modeling work and the technical feasibility of the NPRMs already proposed and, in the case of RVP control adopted, by EPA. Third, while the 1990 CAAAs included other provisions related to vehicles (e.g., OBD and extended lifetime) and fuels (e.g., RFG and benzene control), perhaps most important was the authority in section 202(i) to revisit the existing motor vehicle emission standards and fuel quality requirements in the future in response to air quality needs. This authority would serve as the legal authority for Tier 2 and Tier 3 programs.

Developments After the Completion and Initial Implementation of Rules Related to CAA Provisions

Throughout the 1980s and 1990s, EPA and California invested heavily in research to understand the sources and mechanisms of evaporative emissions and to improve their inventory modeling capabilities. A new 0.08 ppm 8-hour ozone NAAQS[48] was applied nationally in 1997. Further understanding of the need to reduce VOC to address ozone non-compliance led both CARB and EPA to upgrade the motor vehicle emission control programs. Central to these efforts were new requirements for evaporative and refueling emissions. The programs involved were CARB LEV II, EPA Tier 2, HDGV requirements, and the PZEV portion of the California ZEV program.

The CARB LEV II program was formally adopted in November 1999. As is detailed in Appendix 5, the LEV II program reduced the emission limits of the 2-day and 3-day diurnal plus hot soak tests for LDVs, LDTs, and MDVs. This was approximately a 55-75% reduction from the standard levels in the original LEV program, depending on vehicle class. The standards phased-in from model years 2004-2006.[49]

EPA adopted its Tier 2 program in December of 1999, which included evaporative emission standards similar, but not identical to, those in LEV II. The EPA standards, which are termed transitional Tier 2 standards in Appendix 5, phased-in from model years 2004-2007. These transitional Tier 2 evaporative emission standards were about a 50% reduction relative to the Enhanced Evaporative requirements and included the requirement that evaporative and ORVR durability assessments use E10 gasoline.[50] In a subsequent rule promulgated in 2007, the EPA adopted full Tier 2 evaporative emission standards for the 2009/2010 model years for all categories of LDVs, LDTs, and thus were fully aligned with LEV II.[51]

HDGVs were also subject to more stringent standards. In the LEV II program, CARB reduced the HDGV evaporative emissions standards from those in the LEV program. In this case for all HDGVs, the 2- and 3-day hot soak plus diurnal standards were reduced to 1.25 g/test and 1.0 g/test, respectively.[52] In Tier 2,

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[48] 62 Federal Register 38856, (July 18, 1997). 0.08 ppm averaged over 8 hours, annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years.

[49] California Air Resources Board LEV II and CAP 2000 Amendments, Final Regulation Order, see https://ww3.arb.ca.gov/regact/levii/oalfinal/finregor.pdf

[50] 65 Federal Register 6697, (February 10, 2000).

[51] 72 Federal Register 8427, (February 26, 2007)

[52] 13 California Code of Regulations, section 1976, article 2.

EPA adopted a more stringent 2- and 3-day hot soak plus diurnal standards for medium-duty passenger vehicles (MDPVs) and established ORVR requirements for MDPVs. In other later rulemakings, EPA established more stringent 2- and 3-day hot soak plus diurnal standards for all HDGVs for the 2010 model year and expanded the ORVR requirement to all HDGVs under 10,000 GVWR.[53,54]

Finally, as part of its zero-emission vehicle (ZEV) program, California developed the partial-ZEV (PZEV) category of vehicle in 1998, and these vehicles came onto the market beginning in 2003.[55] Two of the requirements to qualify as a PZEV were related to evaporative emissions, with the intent to drive technology to zero fuel-related evaporative emissions ("zero evap"). The first requirement was more stringent 2- and 3-day hot soak plus diurnal standards (350 mg/test - LDV, 500 mg/test - LDT, 750 mg/test-MDV) which were set at the same level for both 2- and 3- day tests. The primary basis in the standard level was to accommodate non-fuel background emissions for the largest vehicles in each category. The second requirement was a new SHED rig test and emission standard to demonstrate zero-fuel emissions from the fuel system.[56,57] While PZEV was optional for the manufacturers, the program was widely accepted. By 2013, there were more than 50 models offered.[58]

New Ozone National Ambient Air Quality Standards (NAAQS) and Modeling

The national 8-hour ozone standard was reduced to 0.075 ppm in 2008[59] and to 0.070 ppm in 2015[60]. By 2010, nationwide air quality had improved substantially, but 50 million people continued to live in areas of ozone non-attainment (Figure 6). Modeling showed that further emission reductions were necessary to bring these urban areas into attainment and to allow other urban areas to remain in attainment with further lowering of the NAAQS.[61]

The U.S. EPA invested to further upgrade its mobile source inventory modeling capabilities and accuracy by introducing MOVES 2010. In 2014, EPA introduced its new Delta Model[62] for calculating diurnal emissions in MOVES 2014. Inventory modeling showed that by 2015, hydrocarbon (VOC and NMHC) emissions from the light duty fleet would bottom out and begin rising again (Figure 7), due to increased vehicle population and vehicle miles traveled (VMT); NOx emissions would remain flat after 2020. Even with the stringency of Enhanced Evaporative and Tier 2 regulations that had been in place since 1996 model year, the U.S. EPA projected that, by 2018, LDVs and LDTs would still contribute 20% of total U.S. NOx emissions, 12% of total VOC emissions, and 4% of total direct PM2.5 emissions.[63] The exhaust NMHC inventory was continuing to drop; the net inventory increase was being caused by evaporative emissions.

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[53] 65 Federal Register 59895, (October 6, 2000).

[54] 66 Federal Register 5001, (January 18, 2001).

[55] See https://www.transportpolicy.net/standard/california-zev/

[56] See California Air Resources Board's "Manufacturers Advisory Correspondence (MAC) 2005-03"

[57] California's rounding convention defined the 0.0 g/day rig test limit as less than or equal to 54 mg/day

[58] "Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards Final Rule, Regulatory Impact Analysis," U.S. EPA, March 2014.

[59] 73 Federal Register 16483, (March 27, 2008).

[60] 80 Federal Register 65292, (October 26, 2015).

[61] "Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards Final Rule, Regulatory Impact Analysis," U.S. EPA, March 2014.

[62] Jarrod Brown *et al.*, "The DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES, DRAFT", U.S. EPA, October 31, 2011

[63] See https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data

Vehicles meeting the Tier 2/LEV II requirements were just phasing in to the overall fleet, but it was quite clear that future reductions in evaporative emissions were necessary to prevent backsliding of ozone air quality.

Figure 6: 2010 8-hour Ozone Air Nonattainment areas for 75 ppb NAAQS

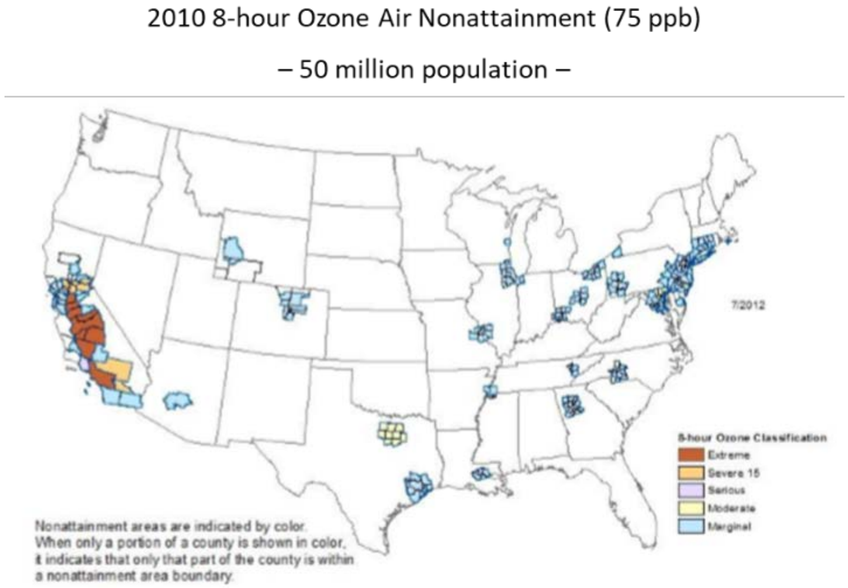
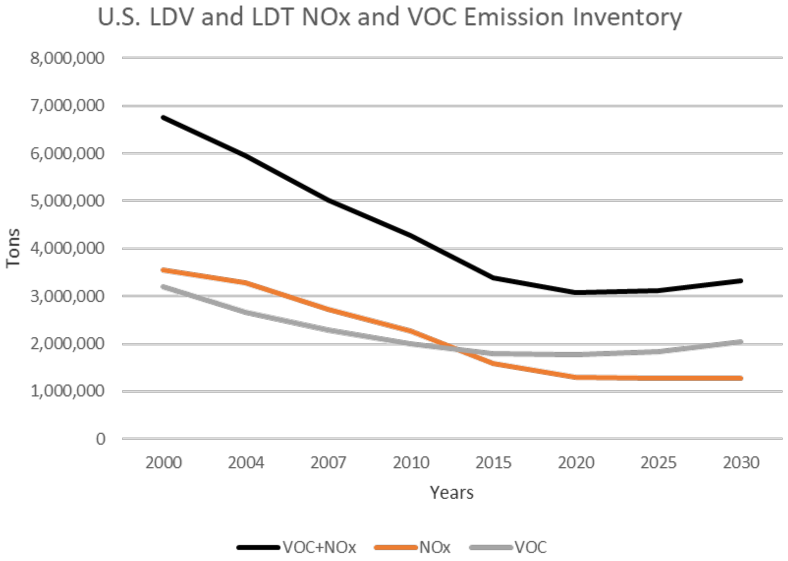


Figure 7: U.S. Light-Duty Vehicle and Light-Duty Truck NOx and VOC Emission Inventory



LEV III/Tier 3

Both California and EPA wanted to ensure that gasoline vapor emissions from the fuel systems would be reduced. In LEV II and Tier 2 technology a substantial portion of SHED emissions under the standard were still fuel vapor. Further increases in stringency were warranted, but because non-fuel hydrocarbon emissions were a significant fraction of emissions measured in the SHED, there were limits on how much the numerical value of the limits could be reduced as a tool to reduce fuel vapor emissions. In developing LEV III and Tier 3 standards, both California and EPA turned to the success of the PZEV program and the "zero evaporative emissions" concept. As is shown in Appendix 5, the LEV III and Tier 3 programs reduced the full vehicle diurnal + hot soak standards by about 50% and allowed for emissions averaging. LEV III and Tier 3 covered LDVs, LDTs, and HDGVs and required the use of E10 gasoline in certification.

The other element of a zero evaporative emissions program was a test and emission standard to minimize fuel vapor emissions. The manufacturers found the SHED rig test contained in the PZEV program to be cumbersome and time-consuming and expressed interest in other options. In considering the best measures to get to zero evaporative emissions, CARB and the manufacturers looked at retaining the SHED rig test, simply reducing the full vehicle SHED standard to 150 mg (a level measured for non-fuel emission levels for many new vehicles), as well as a new simplified Bleed Emissions Test Procedure (BETP) and emission standard.[64] The BETP and bleed emission standard was supported by the OEMs in lieu of the more stringent full vehicle SHED standard or continuation of the SHED rig test. The BETP and bleed standard was ultimately adopted by CARB and EPA.[65] Inventory modeling by EPA showed that, while remaining almost double the magnitude of exhaust NMHC emissions, evaporative emissions would continue declining through 2030 with the introduction of the bleed standard, lower full vehicle hot soak + diurnal limits, and a new leak standard which made a 0.020" vapor leak detected by OBD a violation of a standard and no longer just a monitoring and signaling requirement (Figure 8). California promulgated LEV III in August 2012[66], and EPA promulgated Tier 3 in April 2014[67] with implementation beginning with the 2017 model year.

The U.S. EPA invested to further upgrade its mobile source inventory modeling capabilities and accuracy by introducing MOVES 2010. In 2014, EPA introduced its new Delta Model[68] for calculating diurnal emissions in MOVES 2014. Inventory modeling showed that by 2015, hydrocarbon (VOC and NMHC) emissions from the light duty fleet would bottom out and begin rising again (Figure 7), due to increased vehicle population and vehicle miles traveled (VMT); NOx emissions would remain flat after 2020. Even with the stringency of Enhanced Evaporative and Tier 2 regulations that had been in place since 1996 model year, the U.S. EPA projected that, by 2018, LDVs and LDTs would still contribute 20% of total U.S. NOx emissions, 12% of total VOC emissions, and 4% of total direct PM2.5 emissions.[69] The exhaust NMHC inventory was continuing to drop; the net inventory increase was being caused by evaporative emissions.

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[64] CARB, "Preliminary Discussion Paper – Amendments to California's Low Emission Vehicle Regulations for Criteria Pollutants – LEV III," February 2010.

[65] California Evaporative Emission Standards and Test Procedures for 2001 and Subsequent Model Motor Vehicles, Part III(D)(12) and 79 Federal Register 23412, (April 28, 2014).

[66] https://ww3.arb.ca.gov/regact/2012/leviiighg2012/leviiighg2012.htm

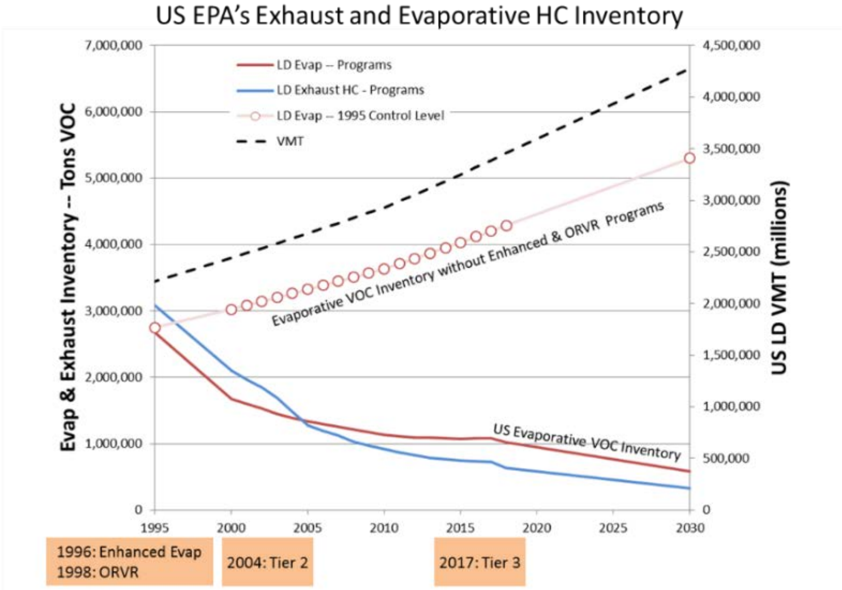
[67] 79 Federal Register 23414, (April 28, 2014).

[68] Jarrod Brown *et al.*, "The DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES, DRAFT", U.S. EPA, October 31, 2011

[69] See https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data

Vehicles meeting the Tier 2/LEV II requirements were just phasing in to the overall fleet, but it was quite clear that future reductions in evaporative emissions were necessary to prevent backsliding of ozone air quality.

Figure 8: U.S. EPA's Exhaust and Evaporative Hydrocarbon Inventory Projections (right panel)



In its work leading up to Tier 3, the EPA began incorporating the effects of VOC on secondary organic aerosol (SOA) formation and its impact on particulate matter (PM) air quality.[70] In its Tier 2 evaluation, only mechanisms involving SO_2, NO_X, and ammonia were considered.[71] EPA identified that in the Southeast and Midwest States, SOAs made up greater than 50 percent of the organic fraction of PM2.5 during the summer. EPA also estimated that mobile source VOCs made up 40% of anthropogenic VOC emissions. Now, there is growing awareness that evaporative emissions and the same photochemistry involved in ozone formation is also significantly tied to $PM_{2.5}$ formation.

Cost and Cost Effectiveness

EPA prepares a draft and final regulatory impact analysis (RIA) as part of each major rule. Central to this analysis is an assessment of the vehicle costs, impacts on operating costs, determination of emission reductions, and calculation of cost effectiveness ($/Mg) for the action. Below are summaries of cost and cost-effectiveness findings for the evaporative requirements in each major rulemaking:

Enhanced Evaporative Requirements: The new regulations were expected to provide reductions of 26 kg, 16 kg, and 68 kg for LDVs, LDTs, and HDGVs, respectively. Total vehicle cost estimates were $9.70/LDV, $13.35/LDT, and $10.70/HDGV, respectively. Based on a weighted projected sales average

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[70] "Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards Final Rule, Regulatory Impact Analysis," U.S. EPA, March 2014, page 7-71

[71] "Draft Regulatory Impact Analysis, Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements," U.S. EPA, April 1999, page VII-12

of each vehicle class and a 10% discount rate, the weighted average cost-effectiveness was estimated to be $500 per Mg. At a 3% discount rate, the weighted average cost-effectiveness was estimated to be $380 per Mg. These cost-effectiveness estimates do not include fuel recovery, which, when factored in, the overall cost-effectiveness is $170 per Mg.[72]

Onboard Refueling Vapor Recovery: In its 1994 RIA for the ORVR rulemaking, EPA estimated the incremental vehicle cost impacts (from an Enhanced Evaporative baseline) to be $6.36/LDV, $7.44/LDT, $8.89 LHDGV, and $25.72/HHDGV.[73] To determine cost effectiveness, EPA examined three scenarios: (1) ORVR in all 50 states and no Stage II control, (2) ORVR in all 50 states and Stage II in all non-attainment, and (3) ORVR in all 50 states and Stage II in all non-attainment areas but phasing out in 2010. In the cases where ORVR and Stage II co-exist, ORVR was attributed only the incremental reduction in refueling emissions. The results were: (1) $27/Mg with Stage II absent, (2) $184/Mg with Stage II present, and (3) $88/Mg with Stage II discontinued in 2010.[74]

Tier 2: As is shown in Appendix 5, EPA's 1999 Tier 2 rule reduced the 2- and 3-day hot soak plus diurnal standards by about 50%. This rule, which is here-in termed the transitional Tier 2 rule was implemented from 2004-2007 model years. The standards were not as stringent as those in CARB's LEV II program. The incremental cost of the evaporative standards was estimated to be $4.10 per vehicle, less the fuel recovery credit for all vehicle classes. The added cost included moving to low permeability materials, improved designs or low-loss connectors and canister/purge improvements. The cost effectiveness of these controls was calculated to be $2400 per ton ($2600/ Mg).[75]

In 2007, EPA upgraded its hot soak + diurnal standards to align with those in LEV II.[76] The RIA for that rule did not include an assessment for these standards because manufacturers were selling their LEV II systems nationwide and there would be no added cost to the consumer. However, information in the 1999 RIA can be used to calculate the costs, fuel savings, emission reductions, and cost effectiveness of the full Tier 2 evaporative program.[77] Using a mix of more evaporative emissions hardware for progressively larger vehicles (LDV/LDT1, LDT2, LDT3/4) incremental to that identified for transitional Tier 2, the hardware cost of the full Tier 2 evaporative program would be about $7.20, less $0.80 for fuel savings. The emission reductions would be 2.13 Kg yielding a cost effectiveness of $3000/Mg.

Tier 3: The Tier 3 evaporative emission standards are phasing-in over the 2017-2022 model years. The 2025 incremental cost of the evaporative standards was estimated at $12/LDV, $11/LDT, $9/LHDGV, and $15/HHDGV. These costs were due to the expected application of improved evaporative emissions

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[72] "Final Regulatory Impact Analysis and Summary and Analysis of Comments, Control of Vehicular Evaporative Emissions," U.S. EPA, February 1993.

[73] "Final Regulatory Impact Analysis: Refueling Emission Regulations for Light Duty Vehicles and Trucks and Heavy Duty Vehicles," U.S. EPA, January 1994, Chapter 5.

[74] "Final Regulatory Impact Analysis: Refueling Emission Regulations for Light Duty Vehicles and Trucks and Heavy Duty Vehicles," U.S. EPA, January 1994, Chapter 7.

[75] Regulatory Impact Analysis, "Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements," Chapter V and VI, US EPA, EPA 420-R-99-023, December 1999.

[76] 72 Federal Register 8427, (February 26, 2007).

[77] Regulatory Impact Analysis, "Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements," Chapter V and VI, US EPA, EPA 420-R-99-023, December 1999.

technology such as air induction system scrubbers, canister bleed emission control elements, greater use of more permeation-resistant materials, and improved fuel system architecture. ORVR was also required for LHDGVs. Accounting for the lifetime fuel savings per vehicle from recovered fuel vapor at a projected value of $3.75 per gallon, the fuel savings per vehicle are $2.93/LDV, $3.07/LDT, $3.65/LHDGV, and $3.26/HHDGV. Thus, the net costs are $9.07/LDV, $8.93/LDT, $5.35/LHDGV, and $11.74/HHDGV. Using the lifetime per vehicle emission reductions (2.13 Kg/LDV, 2.23 Kg/LDT, 2.65 Kg/LHDGV, and 2.38 Kg /HHDGV), these yield cost effectiveness values of $4250 per Mg/LDV, $4000 per Mg/LDT, $2000 per Mg/LHDGV, and $4900 per Mg/HHDGV.[78]

The cost effectiveness values presented above were calculated using the dollar value for hardware and other costs and the price of gasoline for recovery credits during the time frame when the rule was being developed. Thus, direct comparisons among the values presented above may not be the best way to evaluate this information. To facilitate this comparison, the key values could be brought to that which would occur in a given year using the U.S. government price index (CPI) and gasoline price information.[79,80] For comparison purposes, presented below is a table for LDVs which shows the cost effectiveness values for 2011 since that was the dollar basis for the Tier 3 analysis.

VOC Cost Effectiveness (C/E) for LDVs ($/Mg) 2011$ and 2011 Gasoline Price					
Program	Enhanced Evaporative	ORVR	Tier 2	Tier 3	Overall
Base Year $	1992	1993	1999	2011	2011
2011 Cost $	$15.42	$9.79	$6.36	$12	$47
Discounted Lifetime Fuel Savings (2011 fuel price)	-$29.06	-$10.08	-$2.11	-$2.39	-$44
Net	- $13.64	- $0.29	$4.25	$9.07	$3
Discounted Reduction (Mg)	0.026	0.0212	0.00126	0.00213	0.0506
C/E with fuel savings ($/Mg)	Savings (-$525)	Savings (-$14)	$3370	$4250	$60

While all the elements of the Tier 3 evaporative program yield about the same emission reductions as the Tier 2 evaporative program, the hardware cost values are higher than for Tier 2, so the cost effectiveness value increases. This should be expected because complexity increases as zero emissions is approached. Even so, the cost effectiveness value for Tier 3 is quite attractive given that it represents the technologies needed for a zero evaporative emission program.

Taken as an entire program, for LDVs, the hardware cost is about $47, the fuel savings are a bit less than $44 and the lifetime emission reduction per vehicle is 0.0506 Mg. Overall cost effectiveness is about $60/Mg.

Section 2: Analysis for Europe

European evaporative standards and test procedures have historically been significantly less demanding than in the United States. A 24-hour and hot soak SHED test with a 2 gram standard and 60 minute NEDC

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[78] Regulatory Impact Analysis, “Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards,” Regulatory Impact Analysis, Chapter2, US EPA, EPA 420-R-14-005, March 2014.

[79] https://www.bls.gov/data/inflation_calculator.htm

[80] https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=emm_epmr_pte_nus_dpg&f=a

was introduced with the Euro 3 standards in 2000, five years after the enhanced evaporative standards were first implemented in the United States. There were no full useful life or in-use standards, no OBD leak detection requirements, no spit-back requirements, and no consideration for hot driving conditions. ORVR has never been seriously considered in Europe; refueling control was managed through Directive 2009/126/EC, that required implementation of Stage II across all EU Member States. In September 2019, Euro 6d standards were implemented and included four improvements to its evaporative emissions program:

1. The number of diurnals increased from one to two, which increased the canister capacity by about 80%;
2. The drive cycle, embedded in the evaporative test procedures, was decreased from 60 minutes (NEDC) to 32 minutes (WLTP Low, Medium, High, Medium Speed Elements). The decrease in drive cycle time about doubled average purge rate; the 80% larger canister capacity increased purge rates by about 80% further. So, the net effect on purge rate is a 240% increase. Moreover, switching from the NEDC to the WLTP decreased the net speed of the tests, added more accelerations/decelerations, and reduced top speeds. These will result in more low-speed, urban condition purging.
3. The SHED test limits dropped from 2 g/day to 2 grams per two days – or about 1 g/day. This effect results in lower day 1 and day 2 canister emissions, as well as a reduction in permeation emissions.
4. Some level of canister aging was accounted for by pre-aging the canister with gasoline vapor at certification.

There are still aspects of the European evaporative program that continues to lag the U.S. significantly. Addressing these matters would further reduce VOC inventories across Europe.

- Identifying vapor leaks with OBD has not been addressed. EPA found that 39% of pre-enhanced vehicles (pre-1996, with no OBD leak detection) leaked at a rate greater than 0.3 grams per hot soak. 2.6% of the vehicles leaked more than 20 grams per hot soak, and 4.2% leaked more than 10 grams per hot soak. After the introduction of leak detection in OBD II, the percentage of leaking vehicles reduced to 6.4% at rates of 0.3 grams per hot soak or higher and 2% at a rate of 10 grams per hot soak. Leak rates dropped further with Tier 2 and further again with Tier 3.
- Canister capacity is significantly lower in Europe than in the U.S. Manufacturers in the U.S. must report canister capacity for certification, and the EPA reports that U.S. canister capacity averages 137.5 grams and tank volume averages 19.1 gallons, or 1.90 g/L.[81] In comparison, the BWC of Euro 6d canisters, sized to meet the 48-hour and hot soak requirement, average about 1.02 grams per liter of nominal fuel tank capacity. European canisters have about 46% less capacity than U.S. canisters. The higher canister capacity of U.S. canisters provide four benefits: (1) reduced emissions for short parking events, (2) reduced emissions from parking events following very short driving events, (3) better control in parking events of 3 days or more, (4) improved control during off-cycle conditions (e.g. heat waves, fuel RVP higher than 60 kPa, higher elevation, high running loss driving conditions), and (5) results in higher purge rates – because more butane must be purged off of the canister during the evaporative test drive cycle (this also improves the previous three emission conditions).

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[81] Measured using butane, according to EPA method. "Evaporative Emissions from On-road Vehicles in MOVES2014," EPA-420-R-14-014, U.S. EPA, September 2014, page 21

- Europe has only a single certification test for evaporative emissions, which involves a short, ambient temperature drive. Evaporative emissions are most severe, and the photochemical reactions involving VOCs are most problematic, when temperatures are high. The U.S. requires a 3-day diurnal test -- that includes a 70 minute drive at high temperatures – to ensure the vehicle is properly calibrated to properly purge the fuel tank and canister during these conditions. Not including this same test in Europe makes these high temperature conditions "off cycle," and the Commission runs the risk that vehicles are not properly calibrated for these conditions.
- Europe has a diurnal test limit of 2 grams over two days plus a hot soak, which is equivalent to about 1 g/day. This value is similar to the 2004 U.S. EPA Transitional Tier 2 standards[82]. Currently, the U.S. is phasing in Tier 3 standards, which are 0.300 g/day for the fleet average. Reducing the European standard to 0.300 g/day (fleet average) or 0.350 g/day (vehicle) would reduce permeation rates to about 0.003 g/h (from 0.010 g/h) and reduce canister emissions and leaks.[83]
- Europe relies entirely upon a Stage II program to control refueling emissions. CARB found that the average in-use control efficiency of Stage II was no better than 71%[84]. Enforcement of compliance requires dedicated local government oversight of every regulated single gas station, so compliance checks are limited. Both the equipment certification requirements for Stage II systems and annual equipment inspection requirements in Europe are much less demanding than in the U.S. Moreover, underground storage tank (UST) vent stack emissions are not included in the determination of control efficiency at certification in Europe, like it is in the U.S. So, it should be fully expected that actual in-use efficiency is lower in Europe than in the U.S. The U.S. relies upon ORVR, proven through the EPA's in-use verification program to provide 98% average control efficiency, to control refueling emissions. ORVR technology also adds another 25% to canister capacity and 30% to purge rates, which further reduces off-cycle emissions.

Implications for Europe

In combination with its light-duty and heavy-duty tailpipe programs, as well as stationary source requirements and SIPs, the improvement in urban air quality in the United States has been tremendous. In aggregate across the United States, 8-hour ozone concentrations have decreased 21% since 1990 and 24-hour $PM_{2.5}$ has decreased 34% since 2000. These improvements are despite an increase in GDP of 175%, an increase in vehicle miles traveled (VMT) of 111%, an increase in population of 44%, an increase in energy consumption of 30%, and an increase in CO_2 emissions of 12% since 1980.[85] EPA has the statutory obligation to control evaporative emissions to the greatest degree reasonably achievable under ozone-prone summertime conditions, including two or more days of nonuse, and the measures EPA has taken to reduce evaporative emissions is one reason for the improvement in air quality. Over the three decades that EPA has focused on evaporative emission causes and controls, its efforts have concentrated on ensuring high canister capacity, high purge rates in urban and in summertime driving conditions, controlling refueling emissions with ORVR, minimizing leaks, and minimizing permeation rates. These areas are further explained below:

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[82] See Appendix 5

[83] See Table 22 of U.S. EPA, "Develop of Evaporative Emissions Calculation for MOVES2014, September 3, 2013.

[84] California ARB, Revised Emission Factors for Phase II Vehicle Fueling at California Gasoline Dispensing Facilities, December 2013.

[85] See https://www.epa.gov/air-trends/air-quality-national-summary

High Canister Capacity: In the development of enhanced evaporative requirements, both CARB and the EPA recognized that in-use conditions were highly variable and could not be simulated by one or two laboratory tests. Vapor generation from the fuel tank varies markedly by temperature, gasoline vapor pressure, elevation above sea level, and tank fill percentage. Air quality tends to suffer on hot days when vapor generation rates can tend to be highest. Getting good control on average days was not the objective; the agencies needed to ensure that control technologies were robust to provide significant control during off-cycle conditions in hot, urban environments. For example, vapor containment is needed more when temperatures rise to 95°F or 96°F (35-35.6°C), which are the running loss test and upper diurnal test temperatures. Also, more capacity is needed when vehicles remain parked for an extended period of time, when vehicles are driven infrequently, or when driven over very short drives. During the development of the Enhanced Evaporative Emissions regulations, EPA believed that ORVR would provide the canister capacity necessary to provide robust control. CARB was so concerned with the matter, that they wanted a specific 3-day test in addition to ORVR to provide the capacity needed to demonstrate control for extended parking events. Ultimately, EPA agreed with CARB, and both agencies settled on both a 2-day test (to ensure purge during urban driving) and a 3-day test (to ensure control over extended diurnals), in addition to ORVR. Moreover, one of the reasons to develop tests that demand high canister capacity is as an indirect means to force the calibration of higher purge rates onto the vehicle. For example, if a drive cycle time of 30 minutes is available to purge a canister following a butane load step, the automaker will have to double the purge rate to purge a canister with 100 grams of capacity versus one with 50 grams of capacity.

Two examples in Europe from the summer of 2019 explain the need for high capacity and high purge rates. The first is Paris, where a series of heat waves affected air quality (Figure 9). There were thirteen days in which the 8-hour 120 $\mu g/m^3$ ozone threshold was exceeded, and all of these occurred during heat waves that hit the city at the end of June, July, and August. $PM_{2.5}$ concentrations also spiked during the heat waves. Some of the higher than normal pollution concentrations are explained by high pressure systems typically associated with heat waves, but evaporative vapor generation and emissions and permeation are also much higher during the heat waves. Hourly permeation and canister emissions were estimated for Paris, over the summer of 2019, using hourly temperature data and the driving and parking activity data from COPERT (Figure 10).[86] [87] Calculations show that daily canister and permeation rates, for Euro 6d vehicles with canisters sized to meet the 48-hour diurnal and hot soak requirements, were 3-4 times higher than average summertime levels during the heat waves and exceeded 1-2 grams per day. Higher canister capacity would buffer these emission spikes during the heat waves and when air quality has the potential to be the worst.

One problem for regulators in addressing these types of conditions is that they are not typically accounted for in inventory models. For example, COPERT assumes daily high and low temperatures, based on monthly averages, to calculate diurnal emissions. These temperatures are May 10.4°C – 22.0°C, June 12.1°C – 21.7°C, July 14.3°C – 26.4°C, August 14.9°C – 27.4°C, and September 10.9°C – 22.2°C. When compared with real hourly temperatures, there are significant deviations, particularly during heat waves (see Figure 11). Gasoline vapor pressure is exponential with temperature, so deviations below the

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[86] "Evaporative Emissions from On-road Vehicles in MOVES2014," EPA-420-R-14-014, U.S. EPA, September 2014

[87] Xinyi Dong *et al.*, "Modeling cold soak evaporative vapor emissions from gasoline-powered automobiles using a newly developed method," Journal of the Air & Waste Management Association, Vol. 68, No. 12, pp 1317-1332, 2018

average temperatures do not offset vapor generation and emissions from deviations above the average. Based on Paris heat wave conditions, real emissions can be 2-7 times higher than expected from modeling based on average conditions (Figure 10).

Figure 9: Paris ozone and PM2.5 hourly data from the summer of 2019 (AirParif)

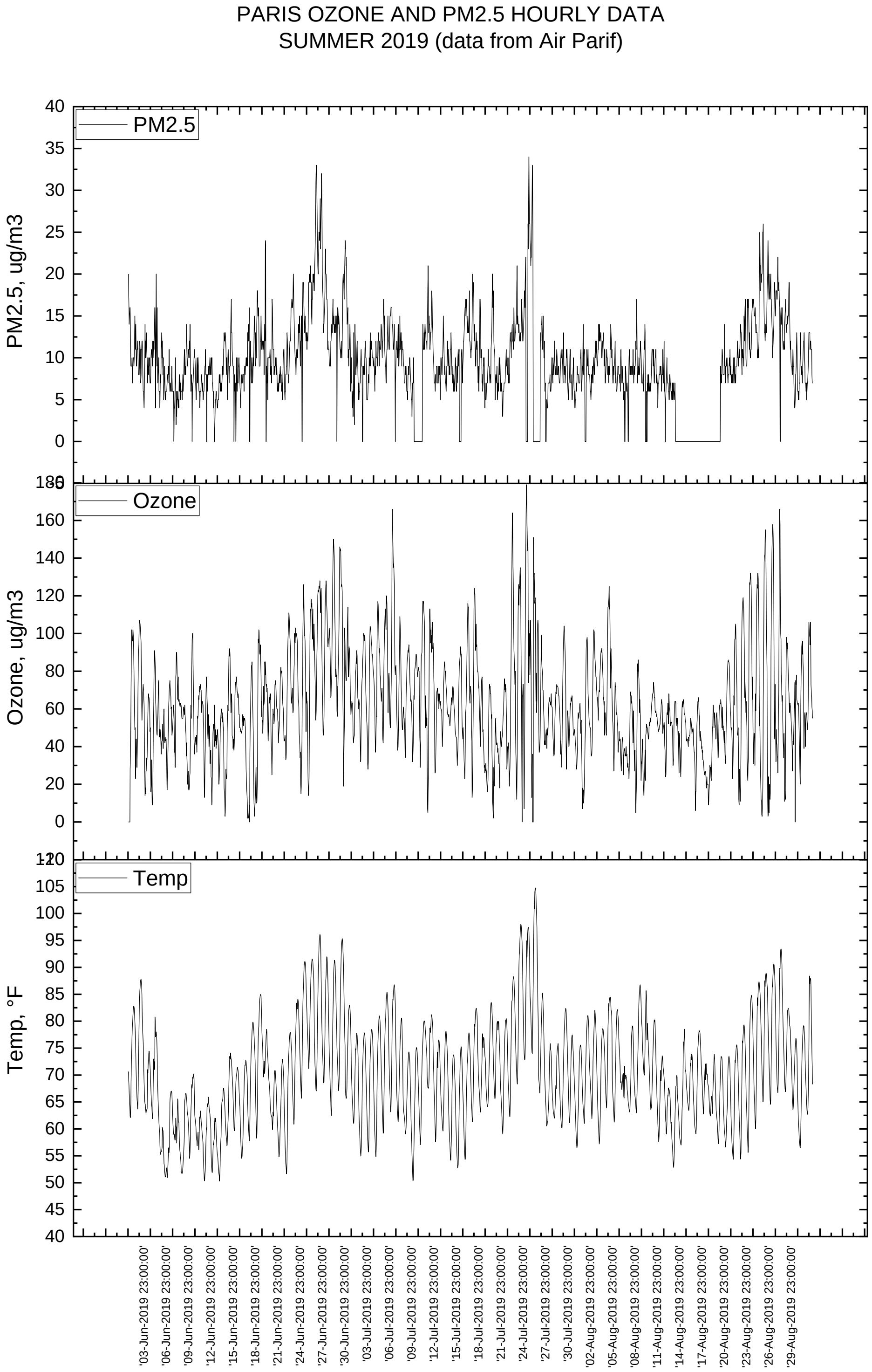


Figure 10: Modeled daily canister and permeation emissions in Paris from the summer of 2019

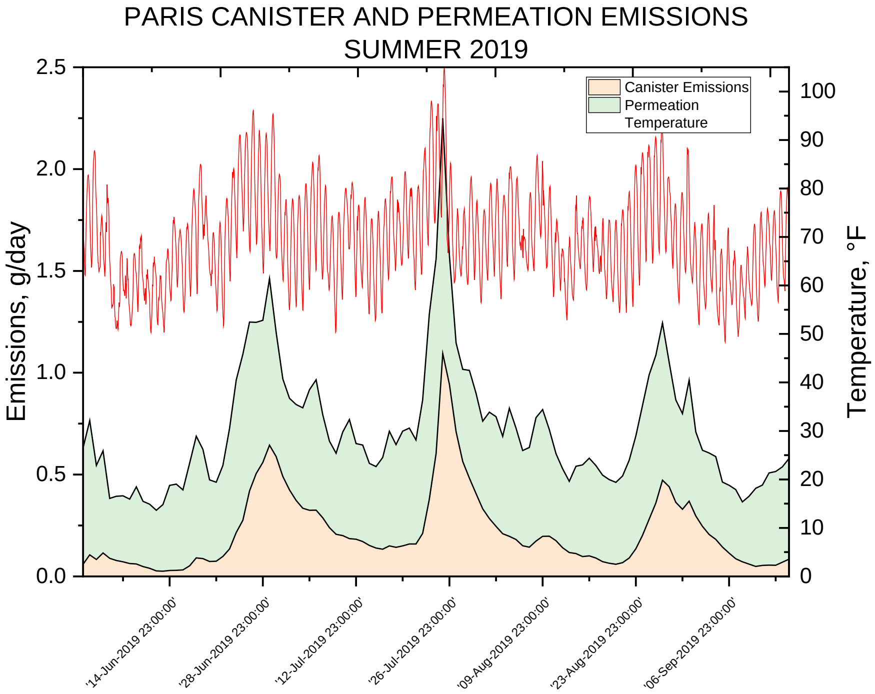
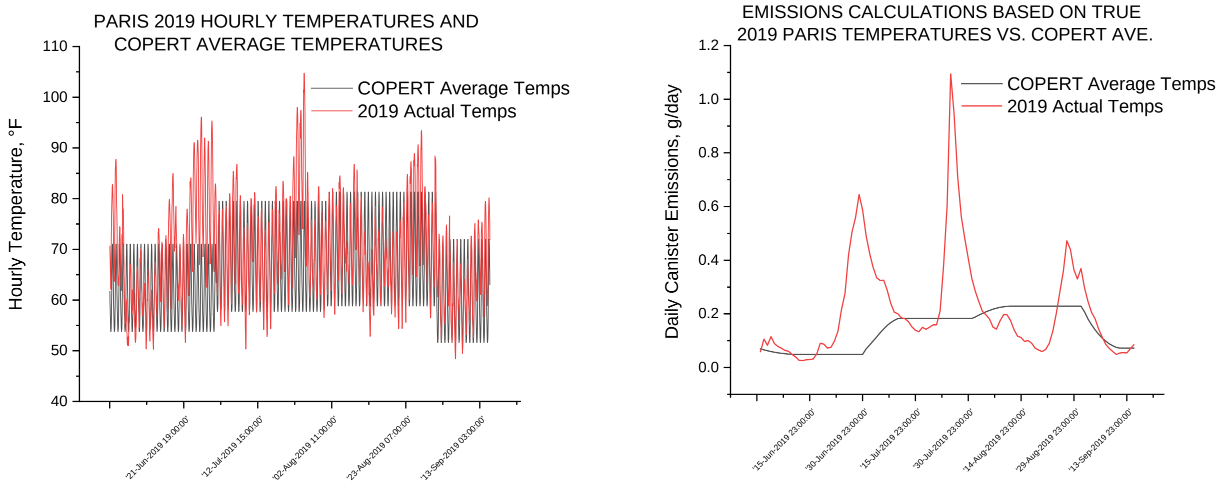
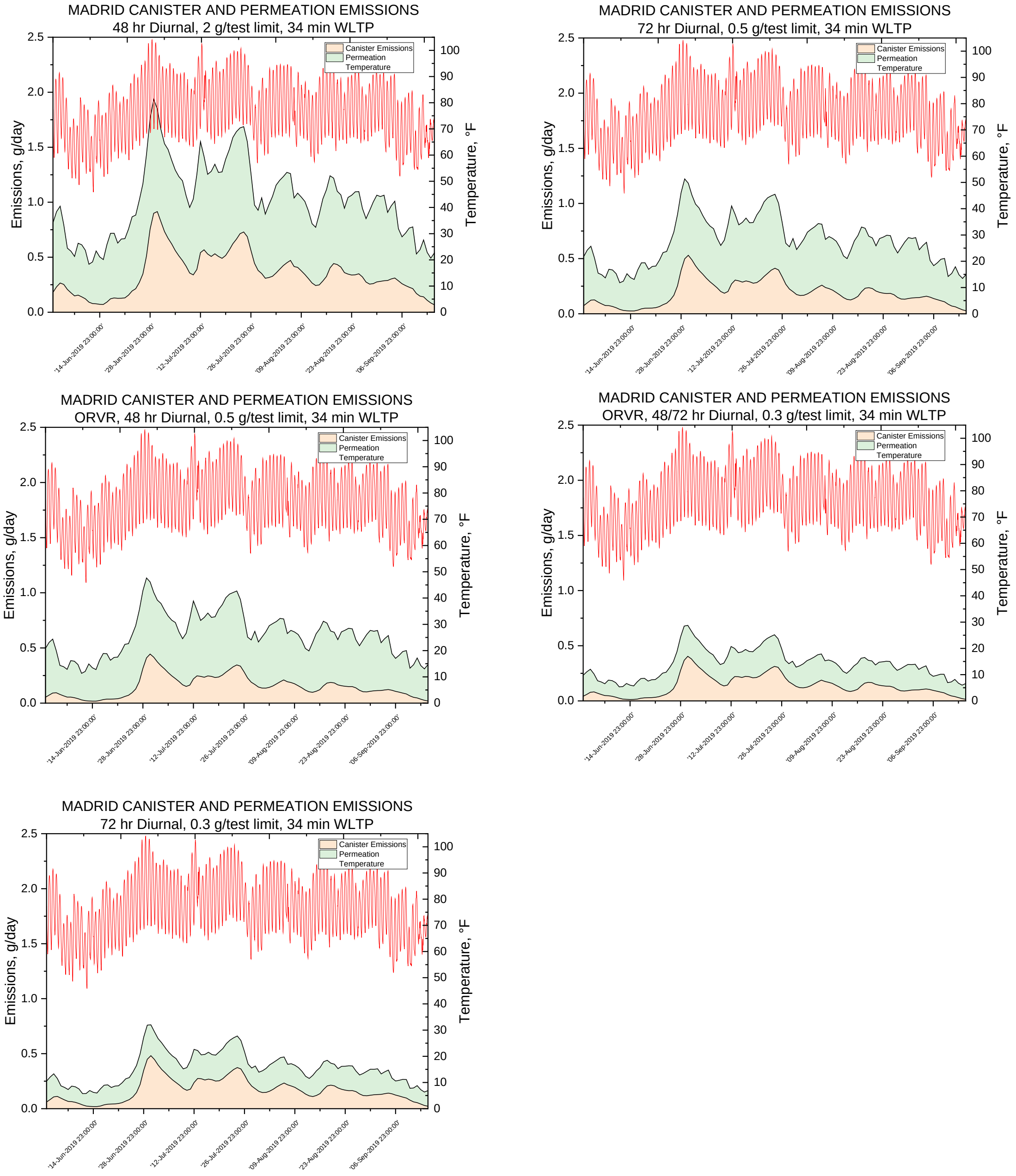


Figure 11: Comparison of 2019 hourly temperature values in Paris and COPERT modeled average temperatures (left panel) and the corresponding impact of the difference in actual vs. modeled temperature on daily canister emissions (right panel)



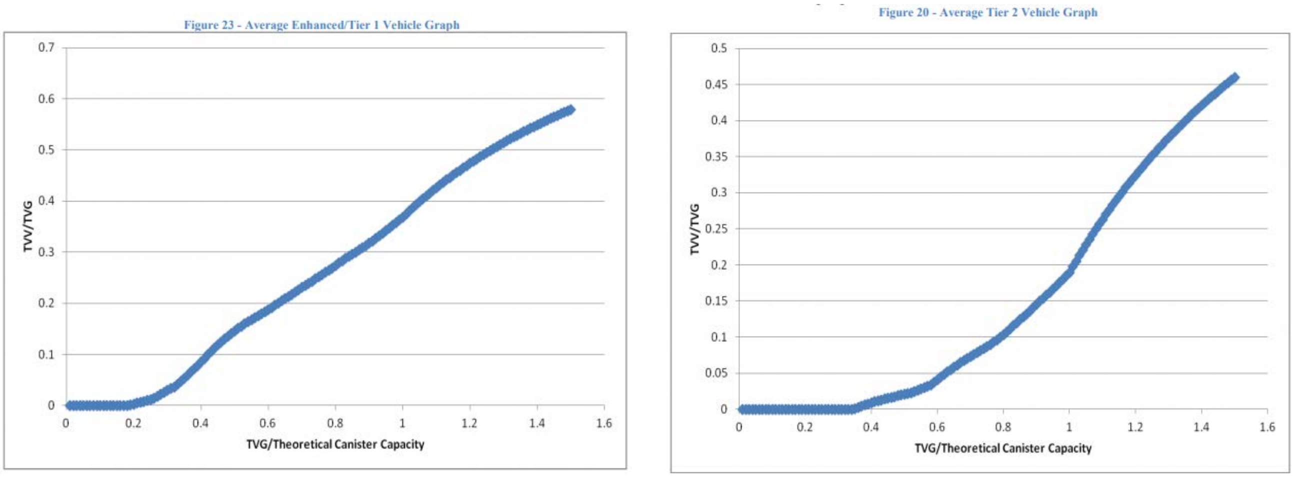
A second example is Madrid, Spain. During the summer of 2019, temperatures in the city exceeded 35°C (95°F) on a number of occasions, particularly in late June and late July. Madrid is also at an elevation of 667 meters above sea level, and vapor generation rates are amplified at increased elevation. Calculations show that average daily vapor generation rates exceeded 1.5 grams per day during these periods of higher temperature (Figure 12). Increasing the canister capacity to that equivalent needed to meet a 72-hour requirement or ORVR would cut the canister emission contribution in half. Reducing the diurnal emission limit to a U.S. Tier 2 or Tier 3 standard would reduce both permeation and canister emissions even further.

Figure 12: Modeled daily canister and permeation emissions for Madrid, Spain using 2019 daily summer temperatures. Each panel represents a different model result for a different evaporative emission standard, as noted above each panel.



EPA found that, not only does higher canister capacity provide more robust control during off-cycle conditions, but higher canister capacity also reduces emissions when vapor generation and canister loading is only a fraction of a canister's total capacity. During development of the Delta model and using data from the E-77 study, EPA quantified the effect for Enhanced Evaporative and Tier 2 canisters.[88] Breakthrough was found to occur prior to the theoretical capacity of the canister for most vehicle systems. The breakthrough curves were aggregated for all vehicles and normalized to vapor generation and canister capacity. The results, used by EPA in the Delta model and MOVES 2014 inventory calculations, are shown below in Figure 13. So, even for short parking events, increased canister capacity reduces emissions in addition to the effects from a reduced emission limit.

Figure 13: Breakthrough curves aggregated for all vehicles and normalized to vapor generation and canister capacity



<u>High Purge Rates</u>: EPA revised the new evaporative test procedures in its Enhanced Evaporative rulemaking to include three basic elements: an initial loading of the evaporative canister with butane, a period of driving to provide an opportunity to purge the canister, and a simulation of repeated hot days of parking. By following this sequence, the test ensures that the vehicle can quickly regain canister storage capacity during driving, and that the canister's total capacity is sufficient. An additional test element that measures evaporative emissions during vehicle operation (running losses), provides further assurance that vehicles can control fuel vapors generated in use by ensuring they are all purged to the engine.[89] The 2-day test was designed to ensure that vehicles would purge during short, urban driving conditions. The 3-day test, in addition to ensuring needed canister capacity, was meant to replicate vehicle operation in ozone-prone summertime conditions: the running loss test element corresponds to sustained operation on a hot day and ensured the canister remained purged during this operation prior to the high temperature hot soak and 3-day diurnal event.[90] During discussions between CARB and EPA, CARB acknowledged that its 3-day procedure – with the total of 100 minutes of driving – could lead to

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[88] Jarrod Brown *et al.*, The DELTA Model: Improved Evaporative Emissions Modeling for EPA MOVES, U.S. EPA, October 13, 2011

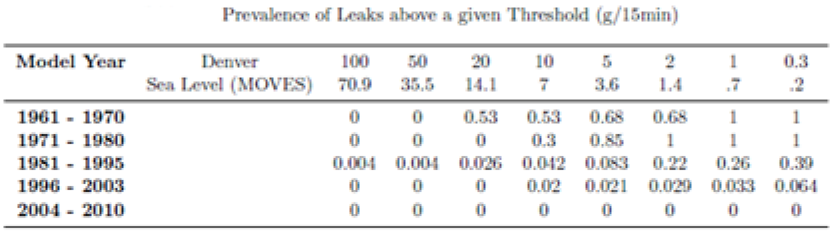
[89] 58 Federal Register 16002, (March 24, 1993).

[90] 58 Federal Register 16007, (March 24, 1993).

inadequate purge during short trips; the 3-day test was needed in combination with the 2-day test that used a 30 minute FTP75. Even for heavy duty vehicles that could not be chassis-certified, EPA was concerned about purge. Engine manufacturers were required to exhaust test the engine with a loaded canister and demonstrate a sufficient level of purge during engine testing.[91] EPA was also concerned that some purge strategies used to pass emission tests could be ineffective over a wide range of in-use driving patterns. To help preclude this, the Agency evaluated purge strategies in the certification process to identify vehicle designs that, though capable of passing emission tests, may not function effectively in use. EPA also considered designs that purged at substantially higher rates during high speed operation than during low-speed operation to be defeat devices.

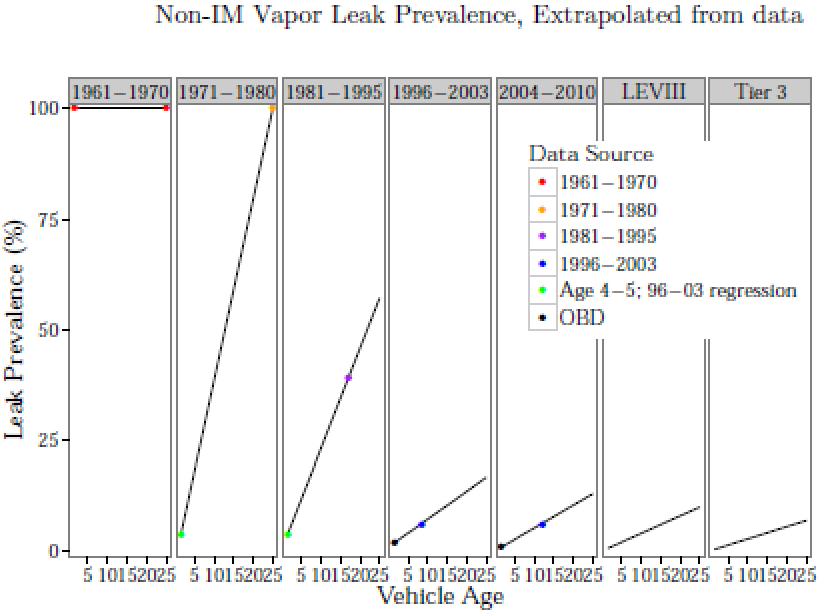
Leaks: OBD leak detection, first introduced by CARB in 1994, has had a large effect on reducing leaks.[92] The prevalence of leaks increase as the vehicle ages (Figure 14). EPA estimated that about 10% of 1995 vehicles that were five years old experienced leaks. That percentage dropped to just a couple percent by 2004. Tier 3 has dropped that value by another 30%, due to the introduction of the leak test and a reduction of the leak detection limit to 0.020 inches cumulative diameter. Leaks are caused by corroded fuel lines, filler neck, cracked hoses, etc.

Figure 14: EPA leak data used in MOVES2014



Prevalence of Leaks above a given Threshold (g/15min)

Model Year	Denver Sea Level (MOVES)	100 70.9	50 35.5	20 14.1	10 7	5 3.6	2 1.4	1 .7	0.3 .2
1961 - 1970		0	0	0.53	0.53	0.68	0.68	1	1
1971 - 1980		0	0	0	0.3	0.85	1	1	1
1981 - 1995		0.004	0.004	0.026	0.042	0.083	0.22	0.26	0.39
1996 - 2003		0	0	0	0.02	0.021	0.029	0.033	0.064
2004 - 2010		0	0	0	0	0	0	0	0



Non-IM Vapor Leak Prevalence, Extrapolated from data

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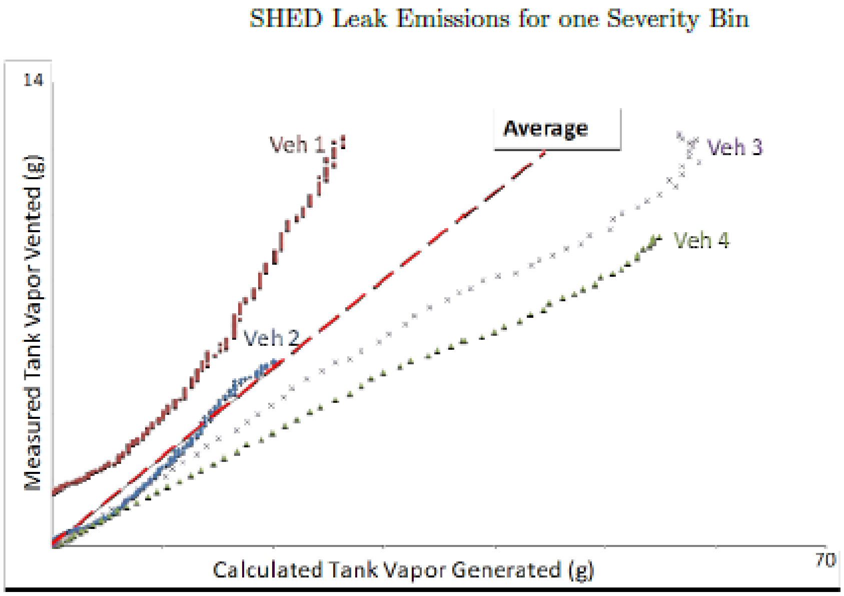
[91] 58 Federal Register 16005, (March 24, 1993).

[92] "Evaporative Emissions from On-road Vehicles in MOVES2014," EPA-420-R-14-014, U.S. EPA, September 2014.

The severity of leaks was established by EPA in the E-77 studies and in portable SHED studies on the in-use fleet in Denver (Figure 15). It was found that the magnitude of leaks varied and increased with vapor generation in the fuel tank. On average, it was found that about 20% of vapor generated escaped the vehicle if a leak was present.

Figure 15: SHED Leak Emissions for One Severity Bin



Permeation: Permeation through hoses and plastic fuel tanks is dependent upon materials used, the thickness of permeation barriers (such as EVOH), temperature, and the prevalence of ethanol in gasoline. The use and amount of use of low permeation materials is largely a function of the diurnal test limit and whether ethanol is included in the certification fuel. EPA models permeation rates based upon a standard permeation rate by model year (associated with a standard and phase in percentage). This base rate is then adjusted by temperature according to the formula:

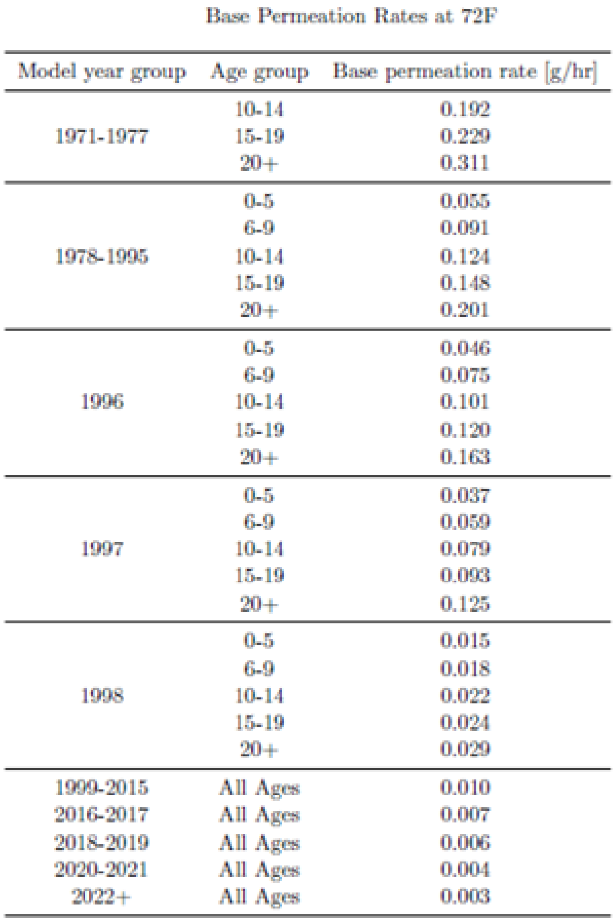
$$P_{adj} = P_{base} e^{0.0385(T_{Tank} - T_{base})}$$

where P_{base} is base permeation rate, T_{Tank} is the in-use tank temperature, and T_{base} is 72°F. Prior to enhanced evaporative standards, base permeation rates were 0.055 to 0.201 g/hr. The base permeation rate dropped to 0.010 g/hr for enhanced and Tier 2 vehicles. The base permeation rate has dropped to 0.003 g/hr for Tier 3 vehicles (Figure 16).

SUMMARY

The United States EPA and California Air Resources Board (CARB) have led the world in their ability to identify the sources of evaporative emissions and to quantify those emissions. This understanding, along with statutory requirements to improve air quality, has led to regulatory requirements for gasoline powered vehicle certification and in-use compliance that are significantly more demanding than in Europe and Japan. From its first enhanced evaporative emissions control and ORVR proposal in 1987, test procedures have expanded and emission limits have been reduced to provide needed control of precursors to ozone and $PM_{2.5}$ on summertime days. The foundational philosophy of the agencies is that the test procedures themselves are not a surrogate for real-world operation but are rather a mechanism by which to obtain a needed control technology response onto the vehicle to improve air quality on summertime days in urban communities. The identified technology response includes: (1) high canister capacity, obtained by a 3-day diurnal requirement or ORVR; (2) high purge rates during all driving conditions and across the range of vehicle temperatures; (3) low permeation rates; (4) identification and minimization of vapor leaks; (5) 95+% control of refueling emissions using vehicle controls; and (6) minimization of fuel spillage. Moreover, all of the control must be achieved, not only at certification, but for the lifetime of the vehicle. The result has been a continuous decline in the inventory of evaporative emissions, even as the number of vehicles and miles traveled have continuously increased. China and Brazil now also recognize the significance of evaporative emissions on air quality in their countries and have taken regulatory measures that begin to align with those of the United States. The US Tier 3 regulations, currently phasing in, continue reductions towards a goal of zero emissions. Remarkably, even with this best achievable control technology needed for Tier 3, the total evaporative program cost is less than \$100/Mg. As European regulators evaluate post-Euro 6 options, they should consider lessons learned in the United States and elsewhere.

Figure 16: Base Permeation Rates for U.S. Light-Duty vehicle by Model Year Group and Age Group



Base Permeation Rates at 72F

Model year group	Age group	Base permeation rate [g/hr]
1971-1977	10-14	0.192
	15-19	0.229
	20+	0.311
1978-1995	0-5	0.055
	6-9	0.091
	10-14	0.124
	15-19	0.148
	20+	0.201
1996	0-5	0.046
	6-9	0.075
	10-14	0.101
	15-19	0.120
	20+	0.163
1997	0-5	0.037
	6-9	0.059
	10-14	0.079
	15-19	0.093
	20+	0.125
1998	0-5	0.015
	6-9	0.018
	10-14	0.022
	15-19	0.024
	20+	0.029
1999-2015	All Ages	0.010
2016-2017	All Ages	0.007
2018-2019	All Ages	0.006
2020-2021	All Ages	0.004
2022+	All Ages	0.003

APPENDIX 1

Global Evaporative Standards		Europe	United States & California	China	Brazil	South Korea	India	Japan
Latest Standard		Euro 6d-TEMP-EVAP-ISC	Tier 3/LEV III	China 6a/6b	PROCONVE L7	KLEV III	Bharat III-VI	PPNLT
Implementation Dates		2019	2017-2022	2019-2020/2023	2022-2025	2018-2022	2020	2020
Diurnal + Hot Soak	24-hr SHED	-	-	-	-	-	2.0 g/test	-
	48-hr SHED	2.0 g/test	0.300 g/day	0.70 g/day	0.50 g/day	0.350 g/day	-	2.0 g/test
	48-hr Zero Evap	-	0.020 g/test	-	-	-	-	-
	72-hr SHED	-	0.300 g/day	-	-	-	-	-
Refueling	Stage II Recovery (controls on gasoline pump)	Phased-in	U.S. Phased-out; California Only (EVR)	Phased-out	-	Minimal	Future Limited (Delhi)	Limited
	ORVR (controls on vehicle)	No	0.20 g/gal	0.05 g/L	0.05 g/L	No	No	No
Running Loss		No	0.05 g/mile	38°C drive cycle	No	No	No	No
Sealed Tank Requirement		Puff loss Test (0.5 g limit)	Design based Requirement	Design based Requirement	Design based Requirement	No	No	Puff loss Test (0.5 g limit)
In-Use Standard (In-Use Verification Program, In-Use Compliance Program)		In Service Conformity; 5 yrs, 100,000 km; Type 4 EVAP test is optional	In-use Verification, Low and High Mileage	In-use Survelliance ; Low, Medium and High Mileage	Full Useful Life Standard	-	In Service Conformity; 5 yrs, 100,000 km	No
Useful Life /Durability Requirement		160,000 km	150,000 miles (~242,000 km)	160,000 km / 200,000 km	160,000 km	240,000 km	160,000 km	80,000 km
Certification Fuel Specifications		E10, 56-60 kPa	E10, 62 kPa (US) 48 kPa (CA)	E0, 56-60 kPa	E22, 60-63 kPa; E100	E0, 48 KPa	E10, 56-60 KPa	E0, 56-60 kPa
OBD Leak Monitoring		EOBD	OBDII (Leak) + Leak Standard	OBDII (Leak)	OBD BR3	KOBD	EOBD	Yes
Drive Cycle		NEDC/WLTP	FTP	WLTP	FTP	FTP-75	MIDC	WLTP

APPENDIX 2

Global Air Quality Standards

Pollutant	WHO	E.U.	China	U.S.	Canada	Japan
Ozone Standard (ppb)	50	60	80	70	62	60
Compliance Statistical Form		Maximum daily 8 hour average not to exceed on more than **25 days per year**, averaged over 3 years	Maximum daily 8 hour average not to exceed 80 ppb for Class II (urban) areas	3-year average of annual **4th highest** maximum daily 8 hr. average (MDA8)	3-year average of annual **4th highest** of the daily maximum 8 hr. average	Hourly values shall not exceed
PM2.5 24-hr Standard (µg/m^3)	25	N/A	75	35	27	35
Compliance Statistical Form		N/A		3-year average of the annual 98th percentile of the daily 24-hr average concentrations	3-year average of the annual 98th percentile of the daily 24-hr average concentrations	Annual 98th percentile values
PM2.5 Annual Standard (µg/m3)	10	25	35	12	8.8	15
Compliance Statistical Form		Annual mean		Annual mean, averaged over 3 years	3-year average of the annual average of 1 hr. concentrations	
NO2 Annual Standard (µg/m3)	40	40	40	100	32	N/A
Compliance Statistical Form		Annual mean	Annual mean	Annual mean	Annual mean	
NO2 1-hr Standard (µg/m3)	200	200	200	188	113	75-113
Compliance Statistical Form		Not to be exceeded on more than 18 times in a calendar year		3-year average of the annual 98th percentile of the daily maximum 1 hr. average concentrations	3-year average of the annual 98th percentile of the daily maximum 1 hr. average concentrations	Daily average of hourly values shall be within or below zone

APPENDIX 3

- A 300 vehicle “Auto-Oil Hot Soak Pilot Study” (1993),
- A 150 vehicle “CRC E-9 Real-Time Diurnal Study” (1996),
- A 150 vehicle “CRC E-35 Running Loss Study” (1997),
- A 422 vehicle, “CRC VE 11-7 Assessment of Non-Tailpipe Hydrocarbon Emissions from Motor Vehicles” (1997): This study also examined inspection/maintenance data from over 69,000 vehicles,
- A 50 vehicle “CRC E-41 Late Model In-Use Evap Emissions” Study (1998),
- A ten vehicle “CRC E-65 Fuel Permeation from Automotive Systems”,
- A nine vehicle “CRC E-77 Vehicle Evaporative Emission Mechanisms: A Pilot Study” (2008),
- An eight vehicle “CRC E-77-2 Enhanced Evaporative Emission Vehicles” (2010),
- An eight vehicle “CRC E-77-2b Evaporative Emissions from In-Use Vehicles: Test Fleet Expansion” (2010),
- A nine vehicle “CRC E-77-2c Study to Determine Evaporative Emission Breakdown, Including Permeation Effects and Diurnal Emissions, Using E20 Fuels on Aging Enhanced Evaporative Emissions Certified Vehicles” (2010).

APPENDIX 4

APPENDIX 1: US EVAPORATIVE and REFUELING EMISSION CONTROL REQUIREMENTS

		ORVR[1]		
	LDV	LLDT	HLDT[2]	LHDGV
phase-in	1998-2001	2001-200	2004-2006	2018
std(g/gal)	0.20	0.20	0.20	0.20

[1] test procedure also addresses fuel spitback

[2] also includes MDPVs and complete 2bs

		EPA Pre-enhanced SHED (1981-1995)			
		LDV	LDT	LHDGV	HHDGV
	MY	1981	1981	1985	1985
Diurnal+Hot Soak					
24 hr (1 hr heat build)		2.0	2.0	3.0	4.0

		EPA Enhanced Evap			
	LDV	LLDT	HLDT	LHDGV	HHDGV
	phased-in 1996-1999				
Diurnal+Hot Soak					
LA 2-day (g/test)	2.5	2.5	2.5	3.5	4.5
LA 3-day (g/test)	2.0	2.0	2.0	3.0	4.0
HA 2-day (g/test)[1]	2.5	2.5	2.5	3.5	4.5
HA 3-day (g/test)[1]	2.0	2.0	2.0	3.0	4.0
Running loss (g/mi)	0.05	0.05	0.05	0.05	0.05
Spitback (g/test)	1.0	1.0	1.0	1.0	

[1] HA tested at 7.8 RVP gasoline

US EPA and California ARB Useful Life Requirements

Program	Vehicle Category	EPA Yrs/Miles	ARB Yrs/Miles
Pre-enhanced SHED	LDV/LDT	5 yrs/50,000 miles	5 yrs/50,000 miles
Enhanced Evaporative	LDV/LDT1	10 yr/100,000 miles	10 yr/120,000 miles
	LDT 2,3,4	11 yr/120,000 miles	11 yr/120,000 miles
	MDV	----	10 yr/120,000 miles
LEV II	LDV	----	15 yr/150,000 miles
	LDT	----	15 yr/150,000 miles
	MDV	----	15 yr/150,000 miles
Tier 2	LDV, LDT 1, 2	10 yr/120,000 miles	----
	LDT 3,4, MDPV	11 yr/120,000 miles	----
PZEV	LDV	----	15 yr/150,000 miles
	LDT	----	15 yr/150,000 miles
ORVR	LDV/LDT 1	10 yr/100,000 miles	10 yr/120,000 miles*
	LDT 2,3,4	11 yr/120,000 miles	
	MDPV	11 yr/120,000 miles	----
	MDV	----	11 yr/120,000 miles*
Tier3/LEVIII/ORVR	LDV/LDT 1	10 yr/120,000 miles*	15 yr/150,000 miles
	LDT 2,3,4	15 yr/150,000 miles	15 yr/150,000 miles
	MDPV	15 yr/150,000 miles	----
	MDV	----	15 yr/150,000 miles

* useful life could be 15 yr/150,00 miles depending on useful life for exhaust standards

		Tier 2/LEV II				Optional PZEV			Tier 3/LEV III			
	LDV	LLDT	HLDT[5]	LHDGV	HHDGV	LDV	LDT	MDV	LDV/LDT1	LDT2	HLDT/MDPV	L/HHGDV	EtoH
LEV II and Full Tier 2 (phased-in 2004-2006 for LEV II and 2009-2010 for Full Tier 2)						thru 2017: CA & 177 states				phase-in 2017-2022			Correction
Diurnal+Hot Soak				CA/EPA	CA/EPA								
LA 2-day (g/test)	0.65	0.85	1.15	1.25/1.75	1.25/2.3	0.35	0.50	0.75	0.300	0.400	0.500	0.600	yes
LA 3-day (g/test)	0.50	0.65	0.90	1/1.4	1/1.9	0.35	0.50	0.75					
HA 2-day (g/test)[1]	1.20	1.20	1.50	1.75	2.30				0.65	0.85	1.15/1.25	1.75/2.3	yes
HA 3-day (g/test)[1]	0.95	0.95	1.20	1.40	1.90								
Bleed (g/test)[2]									0.020	0.020	0.020	0.030	no
SHED rig (g/test)[3],[6]						~0	~0	~0	~0	~0	~0	~0	yes
Running loss (g/mi)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	yes
ORVR (g/gal)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	no

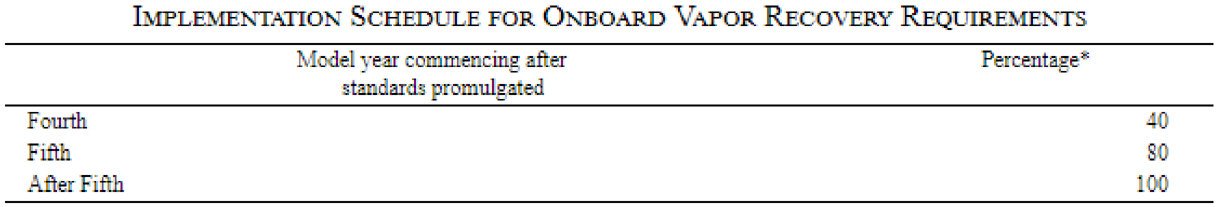
EPA Transitional Tier 2 (phased in 2004-2007)					
Diurnal+Hot Soak	LDV	LLDT	HLDT[5]	LHDGV	HHDGV
LA 2-day (g/test)	1.20	1.20	1.50	3.5	4.5
LA 3-day (g/test)	0.95	0.95	1.20	3.0	4.0

[1] EPA only, [2] low altitude only, [3] CA only, [4] available as an option to bleed standard in Tier 3 through 2019, [5] includes MDPVs

APPENDIX 5

42 U.S.Code §7521(a)(6)

(6) Onboard vapor recovery.—Within 1 year after November 15, 1990, the Administrator shall, after consultation with the Secretary of Transportation regarding the safety of vehicle-based (“onboard”) systems for the control of vehicle refueling emissions, promulgate standards under this section requiring that new light-duty vehicles manufactured beginning in the fourth model year after the model year in which the standards are promulgated and thereafter shall be equipped with such systems. The standards required under this paragraph shall apply to a percentage of each manufacturer’s fleet of new light-duty vehicles beginning with the fourth model year after the model year in which the standards are promulgated. The percentage shall be as specified in the following table:



IMPLEMENTATION SCHEDULE FOR ONBOARD VAPOR RECOVERY REQUIREMENTS

Model year commencing after standards promulgated	Percentage*
Fourth	40
Fifth	80
After Fifth	100

*Percentages in the table refer to a percentage of the manufacturer’s sales volume.

The standards shall require that such systems provide a minimum evaporative emission capture efficiency of 95 percent. The requirements of section 7511a(b)(3) of this title (relating to stage II gasoline vapor recovery) for areas classified under section 7511 of this title as moderate for ozone shall not apply after promulgation of such standards and the Administrator may, by rule, revise or waive the application of the requirements of such section 7511a(b)(3) of this title for areas classified under section 7511 of this title as Serious, Severe, or Extreme for ozone, as appropriate, after such time as the Administrator determines that onboard emissions control systems required under this paragraph are in widespread use throughout the motor vehicle fleet.

42 U.S.Code §7521(k) Control of evaporative emissions

The Administrator shall promulgate (and from time to time revise) regulations applicable to evaporative emissions of hydrocarbons from all gasoline-fueled motor vehicles—

(1) during operation; and

(2) over 2 or more days of nonuse;

under ozone-prone summertime conditions (as determined by regulations of the Administrator). The regulations shall take effect as expeditiously as possible and shall require the greatest degree of emission reduction achievable by means reasonably expected to be available for production during any model year to which the regulations apply, giving appropriate consideration to fuel volatility, and to cost, energy, and safety factors associated with the application of the appropriate technology. The Administrator shall commence a rulemaking under this subsection within 12 months after November 15, 1990. If final regulations are not promulgated under this subsection within 18 months after November 15, 1990, the Administrator shall submit a statement to the Congress containing an explanation of the reasons for the delay and a date certain for promulgation of such final regulations in accordance with this chapter. Such date certain shall not be later than 15 months after the expiration of such 18 month deadline.

42 U.S.Code §7511a(b)(3)

(3) Gasoline vapor recovery

(A) General rule

Not later than 2 years after November 15, 1990, the State shall submit a revision to the applicable implementation plan to require all owners or operators of gasoline dispensing systems to install and operate, by the date prescribed under subparagraph (B), a system for gasoline vapor recovery of emissions from the fueling of motor vehicles. The Administrator shall issue guidance as appropriate as to the effectiveness of such system. This subparagraph shall apply only to facilities which sell more than 10,000 gallons of gasoline per month (50,000 gallons per month in the case of an independent small business marketer of gasoline as defined in section 7625–1 [2] of this title).

(B) Effective date

The date required under subparagraph (A) shall be—

(i) 6 months after the adoption date, in the case of gasoline dispensing facilities for which construction commenced after November 15, 1990;

(ii) one year after the adoption date, in the case of gasoline dispensing facilities which dispense at least 100,000 gallons of gasoline per month, based on average monthly sales for the 2-year period before the adoption date; or

(iii) 2 years after the adoption date, in the case of all other gasoline dispensing facilities.

Any gasoline dispensing facility described under both clause (i) and clause (ii) shall meet the requirements of clause (i).

CAA Section 103(c)

(c) AIR POLLUTANT MONITORING, ANALYSIS, MODELING, AND IN- VENTORY RESEARCH.—In carrying out subsection (a), the Administrator shall conduct a program of research, testing, and development of methods for sampling, measurement, monitoring, analysis, and modeling of air pollutants. Such program shall include the following elements:

(1) Consideration of individual, as well as complex mixtures of, air pollutants and their chemical transformations in the atmosphere.

(2) Establishment of a national network to monitor, collect, and compile data with quantification of certainty in the status

and trends of air emissions, deposition, air quality, surface water quality, forest condition, and visibility impairment, and to ensure the comparability of air quality data collected in different States and obtained from different nations.

(3) Development of improved methods and technologies for sampling, measurement, monitoring, analysis, and modeling to increase understanding of the sources of ozone precursors, ozone formation, ozone transport, regional influences on urban ozone, regional ozone trends, and interactions of ozone with other pollutants. Emphasis shall be placed on those techniques which—

(A) improve the ability to inventory emissions of volatile organic compounds and nitrogen oxides that contribute to urban air pollution, including anthropogenic and natural sources;

(B) improve the understanding of the mechanism through which anthropogenic and biogenic volatile organic compounds react to form ozone and other oxidants; and

(C) improve the ability to identify and evaluate region specific prevention and control options for ozone pollution.

(4) Submission of periodic reports to the Congress, not less than once every 5 years, which evaluate and assess the effectiveness of air pollution control regulations and programs using monitoring and modeling data obtained pursuant to this subsection.