Onboard Refueling Vapor Recovery Systems
Analysis of Widespread Use

By Eric Skelton and Lisa Rector
NESCAUM
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101 Merrimac Street, 10th Floor
Boston, MA 02114
Tel (617) 259-2000
Fax (617) 742-9162

Introduction

Beginning in the mid-1970s as states began developing ozone attainment plans in response to requirements of the federal Clean Air Act (CAA), gasoline refueling was identified as a candidate area source category for controlling volatile organic compound (VOC)[1] emissions. Considering that millions of gallons of gasoline were dispensed daily into motor vehicles, it was readily apparent that gasoline refueling was one of the most significant VOC area source categories and therefore one of the highest priority categories to be controlled as part of an overall ozone attainment strategy.

Gasoline is a relatively volatile liquid that readily vaporizes to saturate air in a confined space, such as the space above the liquid level in a motor vehicle fuel tank. When the fuel tank is subsequently refilled with liquid gasoline, this air-vapor mixture is displaced out of the tank and through the fill pipe. Without some means of capture, the vapors escape to the ambient air, ultimately contributing to photochemical processes that form ozone and other oxidants.

Early on, states and the U.S. Environmental Protection Agency (EPA) identified two basic conceptual approaches to capturing gasoline vapors. The first approach (Stage II Vapor Recovery, or “Stage II”) was first implemented in the late 1970s and ultimately became a requirement under CAA § 182(b)(3) for areas classified as moderate, serious, severe, and extreme ozone nonattainment areas. Stage II allows the vapors to continue to pass through the motor vehicle fuel tank fill pipe but retains the vapors at the gasoline service station, capturing them at the interface between the fill pipe and the dispensing nozzle.

In a typical Stage II installation, a flexible rubber bellows surrounds the nozzle spout, forming a partial seal around the lip of the fill pipe. The vapors are forced by displacement through a chamber in the nozzle, into a second hose or into the annular space between dual hoses, and into underground piping connected to the vapor space in the underground storage tank. Once in the underground tank, the vapors remain in a gaseous state within the tank’s head space where they may partially convert to a liquid phase as the tank re-establishes equilibrium between liquid and vapor phases, or partially escape through the tank vent or leaks in the system. Ultimately, most of the vapors are displaced out of the underground tank into a cargo tank (Stage I Vapor

[1] In the atmosphere, VOCs along with nitrogen oxides in the presence of sunlight and heat promote formation of ozone and other photochemical oxidants. Thus, attainment strategies for reducing tropospheric ozone levels focus on reducing emissions of VOCs, nitrogen oxides, or a combination of the two.

Recovery) and transported to a gasoline terminal, either to be condensed into liquid or thermally destroyed. According to data compiled in 2006 by EPA's Office of Transportation and Air Quality and illustrated in Figure 1 below, there are 27 states and the District of Columbia involving 275 counties nationally that have implemented various levels of Stage II programs. In some states, Stage II programs are required state-wide. Other states limit the coverage of their Stage II programs to their ozone nonattainment areas.

Figure 1 – Stage II Vapor Recovery Areas – 275 Counties

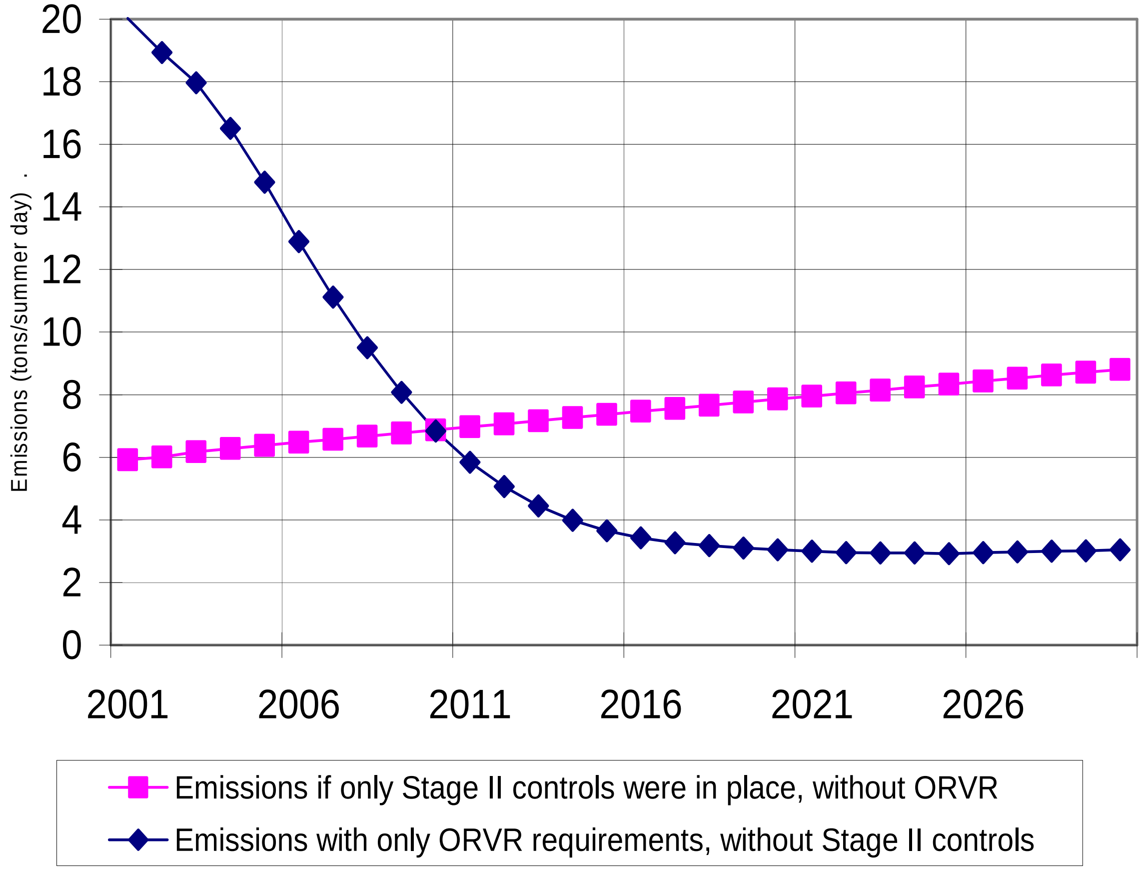
The second approach (Onboard Refueling Vapor Recovery, or "ORVR"), also required under CAA § 202(a)(6), began with certain 1998 model year new gasoline-powered light duty motor vehicles (passenger cars and light trucks), with full phase in by model year 2006 for other classes of gasoline powered motor vehicles.[2] The approach involves creating a mechanical or liquid seal around the dispensing nozzle, redirecting the vapors away from the fuel tank fill pipe, and forcing the vapor stream to pass though a canister filled with activated carbon. The vapors are then adsorbed onto the carbon for temporary storage. Upon engine restart, air is pulled through the canister to purge the vapors from the carbon and route them to the engine where they are combusted. Approved Stage II and ORVR systems both are certified to be 95 percent efficient in capturing VOC emissions from refueling gasoline powered motor vehicles. In theory, the choice of one system type versus the other is emissions neutral. In practice, there are a number of factors that affect the efficiency of each system type.

The decision by Congress to require new motor vehicles to be equipped at some point with ORVR was also a decision ultimately to cease requiring Stage II at gasoline service stations. As increasing numbers of ORVR-equipped motor vehicles replace the aging fleet of motor vehicles without ORVR, there is a continually diminishing mass of displaced gasoline vapors available for capture by Stage II. Using Massachusetts as an example, Figure 2 illustrates how ORVR as a

[2] The ORVR requirements apply to light-duty vehicles, light-duty trucks, medium-duty passenger vehicles, and complete heavy-duty vehicles. For specific phase-in dates and definitions of vehicle classes, see Appendix A.

stand-alone technology ultimately achieves significantly greater emissions reductions compared to a hypothetical scenario whereby Stage II is maintained as a stand-alone technology for capturing gasoline refueling vapors (i.e., ORVR never implemented). If Stage II were the sole program for controlling emissions from gasoline refueling, emissions would continue to increase as gasoline throughput increases. In contrast, the emissions benefits of ORVR as the sole program will extend out until virtually all light-duty gasoline vehicles (as defined in Appendix A) are ORVR equipped.

Figure 2 – Emissions from ORVR & Stage II as Stand-Alone Programs (Massachusetts)



Most Stage II programs will reach a point where the continually diminishing emissions benefit will no longer justify the cost of installing new systems or maintaining existing ones. In fact, there is an eventual emissions disbenefit associated with continuing to employ many of the Stage II systems. CAA § 202(a)(6) authorizes the EPA Administrator to waive the Stage II requirements for areas classified as serious, severe, or extreme when the Administrator determines that ORVR systems are in "widespread use" throughout the motor vehicle fleet.[3] The CAA appears to give the Administrator considerable discretion in defining widespread use.

[3] CAA § 202(a)(6) also states that Stage II controls no longer apply to moderate ozone nonattainment areas after EPA promulgates regulations implementing ORVR. These regulations were promulgated on April 16, 1994 (59 FR 16262).

However, for purposes of this analysis, it is assumed pursuant to the anti-backsliding requirements in CAA § 110(l) that EPA would not authorize a state to discontinue a Stage II program if the result would be to worsen air quality in the state or nonattainment area(s) within a state where the Stage II equipment is installed.

Using this approach, a strong argument can be made that ORVR is in "widespread use" when ORVR by itself achieves the same or a better emissions benefit compared to maintaining Stage II requirements in the state or applicable nonattainment areas, as ORVR-equipped vehicles phase into the fleet. When states are able to project the year in which ORVR by itself achieves the same or a better emissions benefit as compared to maintaining Stage II requirements and subsequently submit amendments to their ozone attainment or maintenance plans to discontinue Stage II programs, such amendments should meet the no-backsliding test.

Stage II Programs in the Ozone Transport Region (OTR)

The OTR was created under CAA § 184 to address regional transport of ozone and ozone precursors in the northeastern U.S.[4] Among other provisions, § 184(b)(1) prescribed specific control requirements[5] to be incorporated into ozone implementation plans for states in the OTR. Additionally, in accordance with § 184(b)(2), all areas in the OTR, regardless of their ozone attainment status, had to adopt Stage II or alternative measures capable of achieving comparable emissions reductions. The CAA required EPA to complete a study identifying such control measures.[6] States with ozone nonattainment classifications of serious and above had no other option but to adopt and implement Stage II programs in these areas. However, areas in the OTR with classifications of moderate or below had the option of adopting comparable measures. States in the OTR that are now contemplating discontinuing Stage II programs at some future date face an additional hurdle of addressing the comparable measures requirement in § 184(b)(2).

Factors Affecting the ORVR Emissions Benefit

There are many factors affecting when the state-wide or nonattainment area-wide collective emissions benefits achieved with ORVR become superior to the benefits of a Stage II program and therefore when states may discontinue their Stage II programs without adversely affecting air quality. We discuss the principal factors in the following paragraphs.

In-Use Efficiency of Stage II Programs. Although Stage II programs have been important components of the suite of controls for ozone attainment purposes, they do not perfectly capture and control gasoline vapors. The in-use efficiency of Stage II as a control technology or strategy varies from station to station and locality to locality. These variations affect emissions and therefore affect when ORVR becomes the better choice as a stand-alone state-wide or area-wide control strategy. Areas with very effective Stage II programs will continue to benefit from a combination of Stage II and ORVR for several years beyond the point at which areas with less effective Stage II programs determine that a stand-alone ORVR program achieves a better result.

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[4] The OTR covers the entire states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont, along with the District of Columbia consolidated metropolitan statistical area (CMSA), which includes a portion of northern Virginia.

[5] The specific requirements were for enhanced vehicle inspection and maintenance programs and reasonably available control technology for all VOC sources covered by control techniques guidelines,

[6] Stage II Comparability Study for the Northeast Ozone Transport Region, EPA, January 1995.

The following is a summary of the primary factors which influence the effectiveness of Stage II programs.

1. Rule penetration. Typically, Stage II is not required at every gasoline service station in every state. Many states limit the application of Stage II to ozone nonattainment and maintenance areas as part of their federally approved plans. Within these areas, Stage II often is required only at commercial service stations with larger underground storage tanks and/or with annual or monthly average gasoline throughputs above specified thresholds. Decreased rule penetration within the geographical area where Stage II is required translates into more emissions from Stage II equipment and a nearer date by which ORVR is determined to be the superior stand-alone strategy.

2. Rule effectiveness. Stage II systems, in particular the dispensing nozzles and hoses, require regular and consistent maintenance to optimize emission reductions. The best maintained systems typically are inspected regularly by station personnel who are able to identify maintenance problems (e.g., damaged bellows or hoses) and expeditiously complete the necessary repairs. The certainty of frequent inspections by state and local regulatory personnel tends to deter postponement of critical repairs by station personnel. As is the case with rule penetration, decreased rule effectiveness translates into more emissions from Stage II and a nearer date for a determination for reliance solely on ORVR.

In its Stage II Technical Guidance,[7] EPA developed in-use efficiency factors for Stage II programs based on a combination of exemption levels (rule penetration) and inspection frequency (rule effectiveness). Table 1 lists the various efficiency factors. The table shows, among other things, that in-use efficiency decreases significantly from certification levels when the inspection frequency is minimal. In addition, the table shows that even though individual Stage II systems are certified to be 95 percent efficient, an overall Stage II program likely will not control 95 percent of an affected area's gasoline refueling emissions.

Table 1 – Program In-Use Efficiency Factors (% Efficiency)

Inspection Frequency	Minimal	Annual	Semiannual	Certification
Exemption Level (gal/mo)				
None	62	86	92	95
2000	61	84	90	93
10,000	60	84	89	92
10,000 & 50,000	56	77	83	86

3. System integrity. The plumbing connecting the gasoline dispenser to the underground storage tank is intended to provide an unrestricted and vapor-tight passage for collecting gasoline vapors. Likewise, other tank plumbing fixtures, such as vent pipes, pressure vacuum valves, fill pipes, and Stage I Vapor Recovery Systems, are intended to be installed and maintained in a vapor-tight condition and to function properly at all times. In reality, connections and fixtures do not always

[7] Technical Guidance – Stage II Vapor Recovery Systems for Control of Vehicle Refueling Emissions at Gasoline Dispensing Facilities, EPA-450/3-91-022a, November 1991.

function properly or are not always vapor-tight. Additionally, if the plumbing from the dispenser does not properly slope all the way to the underground tank, condensed liquid may collect in low spots, partially or completely obstructing vapor return lines, and creating back-pressure in the system. Pressure vacuum valves also may not close completely after venting or may stick in a closed position, forcing pressure to be relieved at weak points in the system. Cargo tank drivers may fail to properly connect vapor return hoses to the Stage I system during tank filling. These are the types of factors, tied to inspection frequency, that contribute to the fugitive emissions of gasoline vapors, thereby adversely affecting the efficiency of Stage II , relative to ORVR.

4. System type. There are two general types of Stage II systems; balance and vacuum-assist. Typically, both types are in use in any given state program, and the propensity to favor one system type over another varies by state. The balance system is the simpler of the two. It relies on the draw-down of gasoline from the underground storage tank during refueling to create a slight vacuum in the vapor return lines that is sufficient to draw most of the vapors dispensed from the motor vehicle fuel tank into the vapor return system. The dispensing nozzle bellows and the seal it creates against the lip of the motor vehicle fill pipe help to maintain the slight vacuum necessary to "balance" the volume of gasoline vapors displaced from the motor vehicle fuel tank against the volume of liquid extracted from the underground tank.

The vacuum-assist type of system employs a mechanical vacuum pump or a venturi[8] to actively draw the displaced vapors into the Stage II system. Typically, the degree of vacuum is set by adjusting the volume of air drawn into the Stage II system against the volume of liquid dispensed. This setting is known as the Air-to-Liquid Ratio (A/L). If the A/L is greater than 1, a greater volume of air is drawn into the Stage II system, relative to the volume of liquid drawn from the underground storage tank. Drawing excess air increases the capture of vapors displaced out of the motor vehicle fill pipe. These systems often are more acceptable to consumers because the nozzles look and operate more like those from the pre-Stage II era. They are equipped with less bulky reduced-tension bellows or may not be required to have a bellows.

A higher A/L ratio is beneficial only to a point. If too much excess air enters the system, the head space pressure in the underground storage tank may increase. At some point, this pressure may have to be relieved by opening the pressure vacuum valve, allowing vapors to escape to the ambient air. Vapors may also leak to soil, groundwater, and the atmosphere through plumbing connections that are not leak resistant to pressurization. In addition, excess air introduced into the headspace of an underground storage tank upsets the equilibrium at the interface between gas and liquid. To re-establish equilibrium, more liquid gasoline must convert to a vapor phase and occupy the tank head space. This phenomenon, known as vapor growth, increases pressurization of the Stage II system and increases the mass of vapor that is released through the pressure vacuum valve or via system leaks, or requires collection by the Stage I system. In theory, greater vacuum at the nozzle, resulting from a higher A/L ratio, also may cause more liquid gasoline, otherwise destined for the motor vehicle fuel tank, to vaporize inside the fill pipe and be captured by the Stage II system.

[8] A venturi is a tube with tapered constriction in the middle, designed to cause an increase in the velocity of flow of a fluid and a corresponding decrease in fluid pressure to create a vacuum.

The increased vapor collection efficiency of vacuum-assisted Stage II systems, partially offset by the effects described above of excess air on leakage and vapor growth, affects overall emissions from Stage II and thereby affects when stand-alone ORVR becomes the more effective choice for controlling emissions. Vacuum-assist Stage II systems also exhibit certain incompatibility problems with ORVR. This will be discussed later.

Motor Vehicle Fleet Characteristics. The overall attributes of a motor vehicle fleet, within a state or nonattainment area that utilizes Stage II systems, likewise have a significant effect on refueling emissions. The following is a summary of the primary fleet characteristics which will influence state decisions regarding when to discontinue their Stage II programs.

1. Fleet turnover. At some point, as older vehicles are retired from the fleet and replaced by newer vehicles, virtually all light-duty motor vehicles will be ORVR-equipped. However, the fleet turnover rate varies from state to state, depending on such factors as personal disposable income, weather, road conditions, and accident rates. As the analysis illustrates later in this report, it is unnecessary for states to wait until 100 percent of the vehicle fleet is ORVR-equipped before discontinuing Stage II programs. However, states with a higher fleet turnover rate are likely to see stand-alone ORVR effectiveness surpass Stage II at an earlier date, compared to states with a relatively lower turnover rate.

2. Vehicle type. Differences in consumer preferences for vehicle types also affect ORVR penetration and overall control of refueling emissions by Stage II. ORVR was first introduced in lighter light-duty new gasoline vehicles and phased in over time into the fleet of heavier light-duty new vehicles (see Appendix A). If there is a preference by consumers in a particular state for purchasing heavier vehicles, the percentage of ORVR-equipped vehicles registered in that state will be lower[9] compared to a state where the preference is for lighter vehicles. The resulting lower ORVR penetration rate tends to postpone the date by which ORVR surpasses Stage II.

3. Fuel efficiency. There is a contributing factor to be considered that is associated with a higher percentage of heavier vehicles (e.g., light-duty trucks) in the fleet and their concomitant lower fuel efficiency. Consider two hypothetical fleets; one heavier, with an average fuel efficiency of 15 miles per gallon (mpg), and the other considerably lighter with an efficiency of 30 mpg. The heavier fleet must consume 100,000 gallons of fuel to travel a collective 1.5 million miles. In contrast, the lighter, more fuel efficient fleet consumes only 50,000 gallons of fuel to travel the same distance. Over the span of time in which it takes to travel the 1.5 million miles, the heavier fleet, upon refueling, displaces 100,000 gallons of a saturated mixture of air and gasoline vapors and the lighter fleet only 50,000 gallons. Assuming near identical degrees of saturation in the displaced air/fuel mixtures between the two fleets, the heavier fleet displaces twice the mass of gasoline vapor per distance traveled compared to the lighter fleet. Thus, having a higher percentage of heavier vehicles in a fleet will result in more emissions from gasoline refueling, both from ORVR and Stage II. Depending on the comparative in-use efficiency between ORVR and Stage II, fleet-wide fuel efficiency could have the effect of either moving forward or postponing the date by which ORVR surpasses Stage II.

[9] This heavier vehicle effect began to diminish in model year 2006 when ORVR was required for 100 percent of new heavy light-duty trucks, medium-duty passenger vehicles, and complete heavy-duty vehicles.

4. Vehicle miles traveled (VMT). VMT differences from state-to-state depend on a number of factors, including population, average commute distance to work, availability of transportation alternatives, personal disposable income, severity of traffic congestion, and personal preference. Higher state-wide VMT means more fuel is dispensed and consumed and therefore more emissions per unit of time from gasoline refueling and Stage II systems. Similar to the fuel efficiency concept described above, the effect of higher VMT on refueling emissions will affect the date for moving to a stand-alone ORVR program.

Other Factors Affecting Refueling Emissions. In addition to Stage II and motor vehicle fleet characteristics, other miscellaneous factors affect VOC concentrations in gasoline vapors and affect refueling emissions. Some of the more significant factors are discussed below.

1. Gasoline volatility. Gasoline is a complex mixture of organic compounds, including lighter species that readily evaporate. The propensity for gasoline to evaporate from motor vehicles and refueling operations is a function of its Reid vapor pressure (RVP), measured in pounds per square inch (psi). Prior to RVP controls, typical summertime gasoline RVP in the northeast U.S. ranged from 10.8 to 11.7 psi. Phase I RVP controls took effect in 1989, limiting RVP to a range of 9.0 to 10.5 psi, with the most stringent limits applying to ozone nonattainment areas. Phase II RVP controls became effective in 1992, capping summertime RVP at 9.0 psi with a more stringent cap of 7.8 psi applying in ozone nonattainment areas. Further, reformulated gasoline (RFG), required in ozone nonattainment areas, typically has much lower summertime RVP levels, on the order of 6.8 psi. Higher RVP will tend to elevate the VOC concentration in the vapor stream and increase emissions from Stage II systems and from ORVR-equipped motor vehicles.

2. Temperature. Gasoline volatility also is affected by temperature. On hot summer days, refueling emissions tend to increase both from ORVR-equipped motor vehicles and from Stage II systems simply because gasoline's evaporation increases with temperature. There is an offsetting effect related to the difference in temperature between the cooler dispensed fuel temperature and the warmer motor vehicle fuel tank. As the cooler dispensed fuel enters the motor vehicle fuel tank, it has a condensing effect in the vapor head space, effectively reducing the mass of vapor to be routed to the carbon adsorber.

Also, increased sunlight and heat, typically associated with elevated ambient temperature events, favor formation of tropospheric ozone and other photochemical oxidants. For these reasons, widespread use analyses focus on the hottest days of the summer or the days in which ozone levels are highest. These factors will of course vary considerably from one area to another.

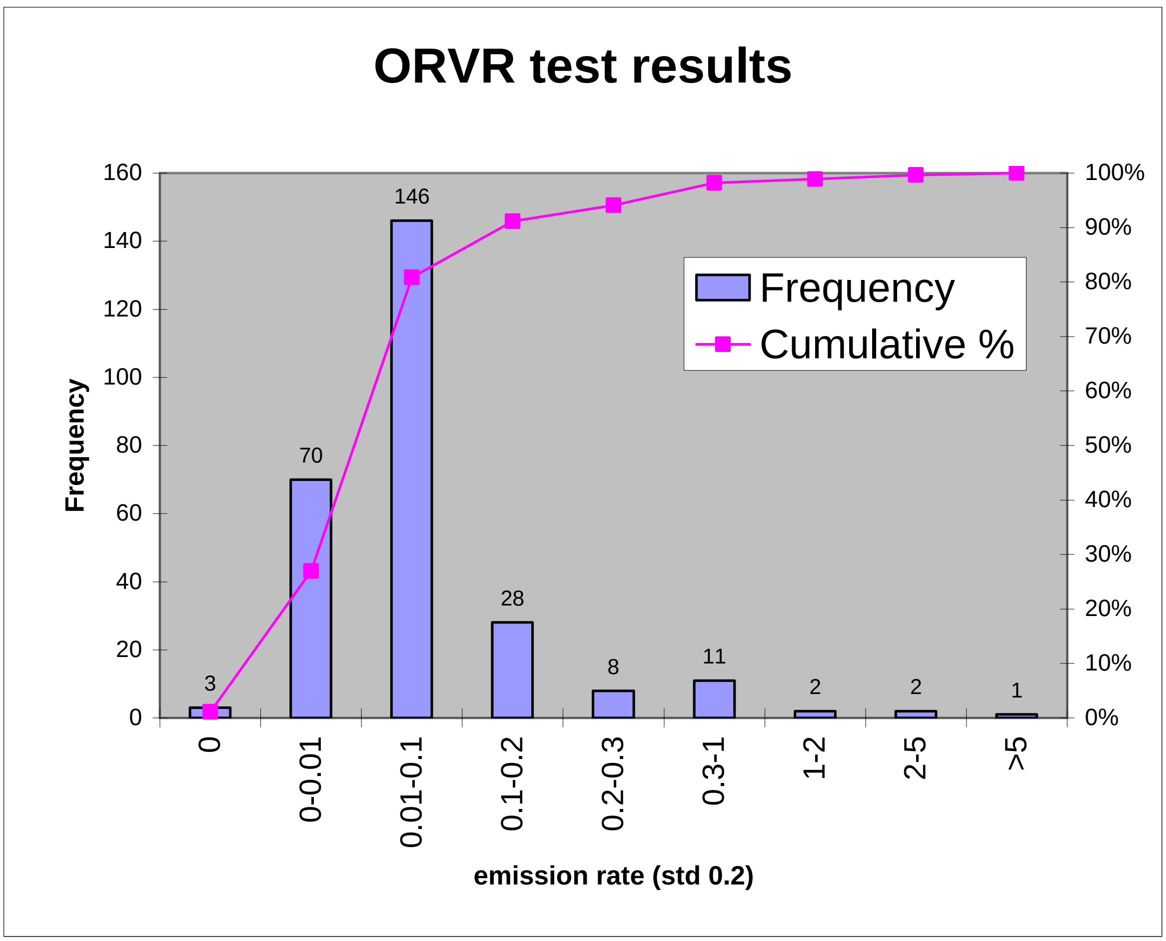
3. Refueling Activity. The activity level at gasoline service stations with high-volume throughputs tends to minimize the opportunity for the underground storage tanks and the Stage II system to establish equilibrium conditions. Consequently, pressure vacuum valves may open and vent to the atmosphere more frequently in response to build-up of pressure in the system. The VOC concentration of the vapor stream also will vary, thereby affecting the VOC emissions rate during the release event.

Effectiveness of ORVR Systems

As previously stated, ORVR systems are certified to be 95 percent efficient in capturing VOC emissions during refueling operations. However, in-use efficiency is influenced by other factors, as described below.

Reliability and Durability. In concept, an ORVR system is quite simple. Organic vapors are displaced during refueling to a sealed canister where they adsorb onto activated carbon. Following engine start up, air is pulled through the canister to purge the vapors, which are then routed to the engine and combusted. The vehicle's On-Board Diagnostic (OBD) System monitors the function of critical components of the system. However, there are limited in-use data available on the reliability of ORVR systems, particularly systems that have been in operation for many years. The available data have been provided to EPA by automobile manufacturers.

Figure 3 – ORVR Test Data Submitted to EPA as of April 2006



Preliminary information compiled in April 2006 on 288 vehicles showed that 24 (8.8 percent of the total) did not meet the standard of 0.20 grams of VOC per gallon of fuel dispensed.[10]

[10] The 0.20 gram per gallon standard is equivalent to the required 95 percent efficiency for ORVR systems.

However, of the vehicles that passed the test, more than 80 percent showed results that were half the standard or less. Therefore, although an 8.8 percent failure rate may seem high, the average emission rate overall was well within the standard, suggesting that the ORVR program as a whole achieves better than a 95 percent control efficiency. In fact, EPA's MOBILE6 model assumes that ORVR systems are 98 percent efficient in controlling the portion of refueling emissions that does not include spillage.[11] Figure 3 (above) illustrates the frequency of compliance with the standard for this limited data set.

There is no information available regarding the effectiveness of OBD systems to detect an ORVR malfunction. Lacking sufficient data, the assumption in this analysis is that ORVR systems retain the same high degree of effectiveness for the life of the vehicle.

Gasoline Spillage. Spillage of gasoline during vehicle refueling is a common event, involving both vehicle design and human factors. To account for spillage, EPA's ORVR certification includes a requirement that any spillage occurring during the certification test is counted in the emission results. This requirement had the effect of discouraging use of fill pipe designs prone to cause spitback spillage. Each cubic centimeter of gasoline spilled weighs about 0.67 grams, so spillage of even a small volume of gasoline during the refill, required in the test, likely will result in failure to meet the 0.2 gram per gallon refueling emission standard. Based on the refueling emission test procedure requirement and the results of the field tests displayed in Figure 3 above, it seems clear that ORVR, in conjunction with fill pipe redesign, has reduced gasoline spillage. The emissions modeling used in the widespread use analysis accounts for the reduced spillage benefit by incorporating a spillage emission factor for ORVR which is one-half of that for non-ORVR vehicles using conventional nozzles.

Compatibility with Stage II Systems. As previously explained, the ORVR system minimizes or prevents the escape of gasoline vapors from the fill pipe of the motor vehicle fuel tank by directing the vapors to a canister. Thus, when an ORVR-equipped vehicle is refueled at a gasoline service station equipped with Stage II, there is little to no vapor to be captured and routed to the underground storage tank.[12] If the Stage II system is a balance system, the slight negative pressure created during draw-down of liquid fuel in the underground tank will cause an equivalent volume of fresh air to be drawn into the Stage II system. This air may enter by way of one or more refueling nozzles that are in use at the time but for which the interface between the bellows and the fill pipe is imperfectly sealed. Air also may enter from leaks in the system plumbing or through a defective or missing vacuum vent valve. If the system is perfectly sealed, a slight negative pressure will be established in the head space of the underground storage tank. In either circumstance, the gasoline dispensing action upsets equilibrium, and liquid gasoline will vaporize at the liquid-vapor interface in the tank until equilibrium is re-established.

If the Stage II system is vacuum-assisted, air in excess of the volume of gasoline dispensed is drawn into the system. When fueling an ORVR-equipped vehicle, this air likely contains no gasoline vapors. If the seal formed in the fill pipe is a liquid seal, the slight vacuum at the nozzle may cause some liquid gasoline to vaporize and be drawn into the Stage II system. The volume

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[11] Frequently Asked Questions on Mobile6, EPA, January 16, 2002.

[12] This is the case regardless of whether the ORVR system is functioning properly to capture and retain the vapors in the canister.

of air entering the system in excess of the volume of gasoline dispensed creates a slight positive pressure within the head space of the tank. Since the newly introduced air likely contains little to no gasoline vapor, gasoline inside the underground storage tank converts from liquid to vapor phase (vapor growth) to re-establish equilibrium. Multiple fillings of ORVR-equipped vehicles further increase pressure in the Stage II system, causing vapors to escape though system leaks or causing the pressure-vacuum valve to open. Emissions created by this interaction between ORVR-equipped vehicles and vacuum-assisted Stage II systems are referred to as Incompatibility Excess Emissions (IEE).

Table 2 – Comparison of Test Data for Determining IEE Factors[13]

Test Data	Incompatibility Excess Emissions Factor (lbs/1000 gal)			
	Gilbarco vacuum-assist VRS (Certified A/L ratio is 1.0 to 1.2)	**Wayne-Dresser vacuum-assist VRS (Certified A/L ratio is 0.9 to 1.1)**	**ORVR – Vehicle fuel tank fill pipe savings (reduction)**	**Overall (Gilbarco) excess emissions factor**
CARB TEST (1999)	0.86 [a]	0.06 [a]	N/A	0.86
API analysis of CARB IEE factor	0.78 [b]	0.08 [b]	N/A	0.78 [b]
API Phase 1 Report (2004)	N/A	N/A	0.31	0.55 [c]
API Phase 2 Report (2004)	0.72	N/A	0.39	0.33

[a]The CARB report provides average emissions for baseline and ORVR-simulated refueling; the IEE factors were calculated by EPA's contractor from these values and the percent of ORVR vehicles simulated; for the Wayne-Dresser system, only the test with the P/V valve intact was used.
[b]API used a linear regression of the CARB test results to determine the emission factor at 100 percent ORVR vehicle simulation and adjusted the factors for a lower Reid vapor pressure (assumed uncontrolled emissions of 7.6 lbs/1000 gal versus 8.4 lbs/1000 gal).
[c]API calculated 0.55 lbs/1000 gal based on the CARB factor of 0.86 lbs/1000 gal (0.86 – 0.31 = 0.55).

The magnitude of IEE has been the subject of debate for several years, with the American Petroleum Institute (API) and the California Air Resources Board (CARB) as primary participants in the debate. API and CARB have each overseen testing projects and have come to different conclusions regarding IEE. Table 2 (above) summarizes the results and analyses of data from recent studies involving Stage II systems manufactured by Gilbarco and Wayne-Dresser.

When evaluating emissions during refueling of an ORVR-equipped vehicle with a vacuum-assisted gasoline dispensing nozzle, the primary difference between the CARB and API factors is explained according to how each accounts for emissions at the interface between the nozzle and the motor vehicle fill pipe. In arriving at the 0.86 lbs/1000 gal factor, CARB focused solely on vapor growth due to excess air in the underground tank. However, API contends there is a significant emissions savings with an ORVR-equipped vehicle because essentially no fugitive vapor emissions occur at the nozzle-fill pipe interface. API quantified this emissions savings in

[13] Stage II Vapor Recovery Systems Issue Paper (and references therein), EPA, August 12, 2004.

its phase I report at 0.31 lbs/1000 gal for a net IEE factor of 0.55 lbs/1000 gal. Further in its phase II report, API arrived at an even lower vapor growth emissions factor (0.72 lbs/1000 gal) and a higher fugitive emissions benefit (0.39 lbs/1000 gal) for a net factor of 0.33 lbs/1000 gal.

A decision on the most appropriate IEE factor to use in an analysis will have a significant effect on determining when ORVR surpasses Stage II as the better stand-alone technology. A lower IEE factor, exemplified by the Wayne-Dresser vacuum-assist data (Table 2) and likely related to the reduced A/L ratio, will extend the life of effective Stage II programs. California, for example, now requires all Stage II systems to be ORVR-compatible. Pursuant to the California regulation, balance and vacuum-assist Stage II systems are required to meet a VOC emissions standard of 0.38 pounds per 1000 gallons dispensed, based on an uncontrolled emission factor of 7.6 pounds per 1000 gallons gasoline dispensed. As shown by the data in Appendix C, the result of this requirement is to project a continued emissions benefit from maintaining Stage II programs in California for more than a decade beyond what other states are likely to achieve without ORVR-compatible equipment..

For the time being, EPA recommends states use the 0.86 lbs/1000 gal emission factor for non-ORVR compatible equipment when performing widespread use analyses.[14] At the same time, EPA affirms that additional emissions monitoring is needed in order to better characterize IEE. Results from subsequent studies ultimately may suggest using a different emission factor, perhaps closer to what was demonstrated for Wayne-Dresser systems, particularly if lower limits are stipulated for A/L ratios. The table in Appendix E, using the metropolitan Atlanta data as an example, illustrates how varying the IEE factor affects the date when an ORVR-only program yields a better emissions result, compared to maintaining Stage II in conjunction with ORVR.

Widespread Use Analysis

A state's decision to amend its implementation plan to discontinue Stage II and for ORVR to become the exclusive means for controlling gasoline refueling emissions will be facilitated by findings that when the change occurs, it will be emissions neutral at a minimum, and preferably achieve an emissions benefit. Emissions-based analyses for all states, however, may be unnecessary if it is possible to identify surrogates that reliably project nearly the same timeframe for making the change as what would be projected from comparing emissions between the two programs.

In 2002, API commissioned an independent assessment of the relative importance of the above factors and how, in combination, they affect the efficacy of ORVR relative to Stage II. Many of API's members are responsible for implementing Stage II and therefore have an economic and regulatory stake in the Stage II program. API contracted with a consultant to develop a spreadsheet-based model to project emissions and enable comparisons between varying ORVR and Stage II scenarios. API's consultant modeled emissions scenarios for several states, and API shared the model and the results with EPA.

In 2004, EPA's Emissions Monitoring and Analysis Division within OAQPS published its Stage II Vapor Recovery Systems Issues Paper as a means to promote discussion of EPA's preliminary ideas regarding ORVR widespread use and to solicit comments from stakeholders. The Issues

[14] Stage II Vapor Recovery Systems – Options Paper (Draft), EPA-OAQPS, February 7, 2006.

Paper listed four definitions (labeled (a), (b), (c), and (d)) under consideration for defining widespread use. In response, API suggested a variant of Definition (c), referred to as (c2).[15]

The emissions-based definitions of widespread use are:

- *Definition (c):* Widespread use of ORVR is achieved when VOC emissions (tons per summer day) under an ORVR-only scenario equal VOC emissions under a Stage II-only scenario.
- *Definition (c2):* Widespread use of ORVR is achieved when VOC emissions (tons per summer day) under a prospective ORVR-only scenario equal VOC emissions under a real world combination scenario in which (1) Stage II controls are in place, (2) both ORVR and non-ORVR equipped vehicles are fueling at Stage II equipped stations, and (3) fueling of the ORVR equipped vehicles is creating incompatibility excess emissions (IEE) between the two systems.

The surrogate definitions of widespread use are:

- *Definition (a):* Widespread use of ORVR is achieved when a specified percentage of the in-use light-duty vehicle fleet is equipped with ORVR systems. The 2005 analysis highlighted 85 percent, 90 percent, and 95 percent scenarios. For comparison purposes, this report also highlights the 80 percent scenario in addition to the other three scenarios.
- *Definition (b):* Widespread use of ORVR is achieved when a specified percentage of the vehicle miles traveled (VMT) by the in-use light duty fleet is attributable to ORVR equipped vehicles. The 2005 analysis and this analysis highlight 90 percent and 95 percent scenarios.
- Known as *Definition (d)*, widespread use of ORVR is achieved when a specified percentage of the gasoline throughput is attributable to ORVR equipped vehicles. The 2005 analysis and this analysis highlight 85 percent, 90 percent, and 95 percent scenarios.

In 2005, EPA and its own consultant expanded upon the API analytical tool, building in further assumptions and worked through NESCAUM to gather data and perform similar analyses for three of the NESCAUM states: Massachusetts, New Hampshire, and Vermont. Stage II is required state-wide in Massachusetts and Vermont and in the more populous Merrimack Valley and seacoast areas of southern New Hampshire. The results of these analyses[16] are in Appendix B and summarized in Table 3. EPA has stated its preferred definition is Definition (c2). Therefore, Table 3 shades the Definition (c2) results to identify these as EPA's preferred emissions-neutral scenario for when Stage II may be discontinued. For comparison purposes, Table 3 has similar shading in the rows for Definitions (a), (b), and (d) to identify which results under these definitions yield dates that most closely match the dates derived from EPA's preferred Definition (c2). For example, under Definition (b), the closest match to Definition (c2) occurs when 90 percent of the VMT in each state is by ORVR-equipped vehicles.

[15] For a fuller comparison of Definition (c2) versus Definition (c), see Appendix D.
[16] Source: Stage II Vapor Recovery Systems - Options Paper (Draft), EPA-OAQPS, February 2006.

Table 3 – Summary of 2005 Analysis for Three NESCAUM States

Definition	Description	Massachusetts Effective Date	New Hampshire Effective Date	Vermont Effective Date
(c)	Emissions from ORVR-only equal emissions from Stage II-only	2010	2008	2008
(c2)	Emissions from ORVR-only equal emissions from combination of ORVR and Stage II plus IEE	2013	2013	2015
(a)	80% of fleet with ORVR			2013
	85% of fleet with ORVR			2015
	90% of fleet with ORVR			2017
	95% of fleet with ORVR			2023
(b)	85% of VMT from ORVR-equipped vehicles	2011	2012	2013
	90% of VMT from ORVR-equipped vehicles	2012	2013	2015
	95% of VMT from ORVR-equipped vehicles	2015	2016	2019
(d)	85% of gasoline dispensed to ORVR-equipped vehicles	2011	2012	2013
	90% of gasoline dispensed to ORVR-equipped vehicles	2013	2014	2016
	95% of gasoline dispensed to ORVR-equipped vehicles	2016	2018	2021

At the same time, EPA recognized that decisions affecting determination of widespread use would have national implications. Therefore, it was important to have data from similar analyses for states outside of the NESCAUM region to support policy decisions. In 2007, EPA contracted with NESCAUM to perform the expanded analyses. With assistance from the National Association of Clean Air Agencies (NACAA), NESCAUM solicited participation in the expanded study from states outside the NESCAUM region. Four states expressed interest and a willingness to provide data (California, Delaware, Georgia, and Pennsylvania) and all were selected to participate. The results of the expanded analysis are in Appendix C and summarized in Table 4.

Table 4 – Summary of 2007 Analysis for Four Additional States

Definition	Description	California[17] Effective Date	Delaware Effective Date	Georgia Effective Date	Pennsylvania Effective Date
(c)	Emissions from ORVR-only equal emissions from Stage II-only	2012	2011	2010	2009
(c2)	Emissions from ORVR-only equal emissions from combination of ORVR and Stage II plus IEE	N/A	2013	2012	2013
(a)	80% of fleet with ORVR	2014	2012	2012	2012
	85% of fleet with ORVR	2015	2014	2013	2013
	90% of fleet with ORVR	2018	2016	2015	2015
	95% of fleet with ORVR	2022	2019	2018	2018
(b)	85% of VMT from ORVR-equipped vehicles	2014	2012	2011	2012
	90% of VMT from ORVR-equipped vehicles	2016	2013	2013	2014
	95% of VMT from ORVR-equipped vehicles	2022	2016	2016	2017
(d)	85% of gasoline dispensed to ORVR-equipped vehicles	2014	2012	2012	2013
	90% of gasoline dispensed to ORVR-equipped vehicles	2017	2014	2013	2015
	95% of gasoline dispensed to ORVR-equipped vehicles	2021	2018	2017	2018

Of the four additional states, Delaware was the only one where the analysis addressed a program covering the entire state. The analysis for California covered only the South Coast Air Basin

[17] Data are for California's South Coast Air Basin only.

(metropolitan Los Angeles). In Georgia and Pennsylvania, Stage II programs are only in effect in the major metropolitan areas. These analyses therefore were confined respectively to metropolitan Atlanta and metropolitan Philadelphia.[18] NESCAUM subcontracted with EPA's consultant from the 2005 study (RTI International) to perform the modeling. Effective dates for California are presented in the table but for reasons discussed below, no California dates are highlighted.

Options for Establishing ORVR Widespread Use Dates

As indicated previously, CAA § 202(a)(6) authorizes EPA to waive the requirements for Stage II once it is determined that ORVR systems are in widespread use throughout the motor vehicle fleet. Consistent with EPA's preferred Definition (c2), it is expected that when ORVR by itself achieves the same or a better emissions benefit compared to the benefits achieved in the present situation (i.e., Stage II systems operating in conjunction with ORVR on most light-duty vehicles), Stage II programs can be discontinued without causing refueling emissions to increase. NESCAUM has identified several possible options upon which to base such decisions. The options are presented in this section.

Require every state to conduct an emissions-based (Definition (c2)) analysis. This approach would best ensure that emissions will not increase when Stage II programs are discontinued. However, it is the most complex of the various approaches.

Require ORVR-compatible Stage II systems. California adopted a regulation, effective March 1, 2006, requiring all Stage II systems to be ORVR-compatible. With the use of a processor, vacuum-assist systems are able to contain the vapor growth problem discussed above and thereby meet the California standard. As indicated by the graph in Appendix C, the South Coast Air Basin will continue to realize an emissions benefit from the ORVR-compatible Stage II requirement until essentially 100 percent of the light-duty vehicles in the fleet are equipped with ORVR. Even as late as 2030, the emissions benefit over ORVR as a stand-alone program will be almost 0.8 tons per summer day. Other states could consider requiring Stage II equipment to meet the California certification for ORVR compatibility, and thereby extend the benefits achieved by Stage II and ORVR programs in tandem for many years.

Establish a single national date for authorizing discontinuation of Stage II programs. According to the analyses conducted for six states (excluding California), Stage II programs could be discontinued without an emissions increase in five of the states on or before 2013. Vermont was the only state that projected a later date (2015). According to the analysis, if Vermont were to discontinue Stage II in 2013, there would be an emissions increase of 0.08 tons per summer day. Based on these results, EPA could establish 2013 as the widespread use date for all states. States that have concerns about potential emissions increases associated with removing Stage II in 2013 could delay the change to a later date. Alternatively, EPA could establish a later date (e.g., 2015) and allow individual states the option of preparing technical analyses to justifying an earlier date.

[18] Stage II is also in effect in metropolitan Pittsburgh, Pennsylvania, but this area was not included in the analyses.

Use ORVR fleet penetration as a surrogate. According to the analyses for four of the states,[19] the Definition (a) date either matches the Definition (c2) date or exceeds it by no more than one year when 85 percent of the state fleet of light-duty vehicles is ORVR-equipped.

Use ORVR VMT penetration as a surrogate. According to the analyses of six states (excluding California) in five of the six scenarios, the Definition (b) date either matches the Definition (c2) date or exceeds it by no more than one year when 90 percent of the vehicle miles traveled (VMT) are attributed to ORVR-equipped light-duty vehicles. In the case of Massachusetts, the Definition (b) date (2012) precedes the Definition (c2) date (2013) by one year. If Massachusetts were to discontinue Stage II in 2012, the analysis indicates that there would be an emissions increase of 0.23 tons per day. In reality, the 2012 date for Massachusetts reflects an 88 percent VMT threshold, so when the 90 percent threshold is achieved sometime between 2012 the 2013 summer seasons, there is actually a small emissions benefit from discontinuing Stage II.

Use ORVR gasoline throughput penetration as a surrogate. According to the analysis of six states (excluding California), the Definition (d) date will match the Definition (c2) date when somewhere between 85 percent and 90 percent of the gasoline is dispensed to ORVR-equipped light-duty vehicles. At 85 percent throughput, the result is the same as projected by Definition (c2) for Georgia and Pennsylvania. At 85 percent throughput for the other four states, the Definition (d) date occurs one to two years earlier than the date predicted by Definition (c2), meaning emissions will increase somewhat in those states if Stage II is discontinued according to Definition (d). At the 90 percent throughput threshold, only Massachusetts achieves the same result (2013) under both definitions. The other five states are delayed from one to two years under Definition (d) beyond the Definition (c2) date.

Stakeholders Meetings

In May 2007, NESCAUM hosted a stakeholders meeting in Manchester, NH, to discuss transitioning from Stage II programs to exclusively ORVR programs. At the meeting, there was general support among the participating states for ensuring that the result of Stage II removal was emissions neutral and would properly address soil and groundwater contamination and the potential for on-going fugitive emissions from discontinued Stage II systems. At least one state favored retaining discretion to remove Stage II in advance of a date strictly imposed under the Definition (c2) approach as long as excess emissions were offset by other measures. States also favored having the option to use alternative metrics.

State Workgroup Recommendations

There was general agreement among the states that EPA should allow use of alternative metrics for states to establish their widespread use dates. In particular, the states favored the following:

- 85 percent of ORVR fleet penetration (Definition (a))
- 90 percent of VMT attributed to ORVR-equipped vehicles (Definition (b))

In addition, there was agreement that states should not be precluded from establishing dates other than those predicted by the metrics, provided states are able to demonstrate through technical analyses that a chosen date does not cause emissions to increase. Further, states may choose to

[19] California is excluded because of its ORVR-compatibility requirements for Stage II. No data on ORVR penetration were generated for Massachusetts or New Hampshire in the 2005 study.

perpetuate their Stage II programs while requiring exclusive use of ORVR compatible equipment in lieu of earlier termination of the program.

Conclusions and Recommendations

As increasing numbers of ORVR-equipped motor vehicles replace those without ORVR, most SIP-approved Stage II programs are approaching a point where the incremental emissions benefit disappears. When states perform analyses to project the year in which this point is attained, they will be poised to prepare amendments to their ozone attainment or maintenance plans to discontinue Stage II programs and at the same time meet the no-backsliding requirements pursuant to the Clean Air Act.

The level of the Incompatibility Excess Emissions (IEE) factor to use in these analyses will have a significant effect on determining when ORVR surpasses Stage II as the better stand-alone technology. A lower IEE factor will have the effect of extending the life of effective Stage II programs. A higher factor will have the opposite effect. EPA previously affirmed that additional emissions monitoring was needed to better characterize IEE and that the results from subsequent studies may suggest using an emissions factor that is different from the one used in this analysis. It will be helpful to states that are soon to embark on preparing SIP amendments to receive updated guidance in the short term from EPA regarding the appropriate IEE factor to use and related guidance on appropriate A/L ratios for vacuum-assist Stage II systems.

States choosing to follow the California example by requiring all Stage II systems to be ORVR-compatible may be able to extend the effective life of their Stage II programs. Alternately, EPA can facilitate the efforts of states choosing to establish a closer date for discontinuing their Stage II programs, based on the technology in place, by allowing use of alternative metrics, such as those based on ORVR fleet penetration or vehicle miles traveled by ORVR-equipped vehicles. At the same time, EPA may wish to consider allowing states to establish dates other than those predicted by the metrics, provided states are able to demonstrate through technical analyses and possibly substitute control measures that a chosen date for discontinuing Stage II will not result in an emissions increase.