

REFUELING VAPOR RECOVERY:
A HISTORY OF U.S. EXPERIENCE WITH ORVR AND STAGE
II, A DISCUSSION ON REFUELING EMISSION GENERATION
AND EMISSIONS FROM GASOLINE DISPENSING
FACILITIES, AND A SYNOPSIS OF ORVR AND STAGE II
IMPLEMENTATION, IN-USE EFFICIENCY, AND COST-
EFFECTIVINESS

February 2020



Manufacturers of Emission Controls Association

2200 Wilson Boulevard | Suite 310 | Arlington, VA 22201 | (202) 296-4797 | www.meca.org

Introduction:

The objective of this White Paper is to provide a detailed global review of refueling vapor recovery, including Stage II vapor recovery and On-board Refueling Vapor Recovery (ORVR). The paper is organized into three sections: (1) A Review of the U.S. EPA experience with ORVR and Stage II, (2) A discussion of how refueling dynamics influence fuel vapor emissions from gasoline dispensing facilities (GDF), and (3) A synopsis on the adoption of ORVR and Stage II vapor recovery, including data on efficiency and cost-effectiveness of the two control technology options.

Summary of Key points:

- After more than 20 years of experience with ORVR and Stage II technology, information from the U.S. indicates that ORVR is the preferred control strategy from an environmental perspective. Even if Stage II had been implemented on a nationwide basis, the much greater in-use efficiency of ORVR over the full vehicle life results in 27% greater reductions in refueling emissions (98% efficiency for ORVR vs. 71% for Stage II with strong enforcement).
- When assessing the control efficiency of fuel vapor recovery options (Stage II, ORVR, ORVR + Stage II), the release, capture, and containment of air and gasoline vapors must be viewed across the entire gasoline dispensing facility (GDF) as a system, including the vehicle's tank and canister, gasoline dispensing unit (nozzles, hoses and pumps), gasoline transfer lines, the underground storage tank (UST), and the UST vapor vent line and pressure/vacuum (P/V) valve. Loss of containment and release of gasoline vapors from any point in this interconnected system negatively impacts the overall in-use control efficiency.
- While the European Directives call for "Stage II vapor recovery", the actual requirements fall far short of those prescribed in U.S. Federal and state regulations and related directives. Across Europe, a reliance on certification data alone has led to the view that 85% (or greater) of refueling emissions are captured by Stage II vapor recovery. However, comparatively weak certification provisions, limited in-use testing, an apparent lack of prescribed requirements for routine inspections at the GDF, and the disregard for UST vent pipe emissions in the Stage II Directive all undermine the validity of this view. The Stage II certification program in the EU directive focuses on emissions at the nozzle/fill pipe interface. For vacuum assist type Stage II equipment, the system's A/L is calibrated to achieve a capture efficiency of 85% based upon ideal certification conditions. However, changes in the refueling emission generation rates resulting from changes in UST and vehicle tank fuel temperatures, fuel volatility, and vehicle-to-vehicle differences result in an average in-use efficiency often well below the certification value of 85%. Beyond this, equipment malfunctions and vapor leaks go undetected or unaddressed due to the lack of rigorous inspection and maintenance programs. Experience in the U. S. shows that this inattention to the condition of the equipment at the GDF further diminishes in-use efficiency. Finally, while a few member states have voluntarily adopted more comprehensive requirements, it is very important to emphasize that the European Directive focuses only on the capture at the nozzle/fill pipe interface. It does not address containment of vapor when it reaches the UST. Relative to the Stage II system program that was established in the U.S., the program in the European Directive could better be described as partial Stage II requirement. From an overall GDF perspective, it is likely that the in-use efficiency falls far short of the claimed 85% value.
- The concern of ORVR + Stage II compatibility only affects the net Stage II efficiency, it does not affect ORVR efficiency. Since ORVR captures 98% of refueling vapor emissions onboard the

vehicle's canister, the compatibility issue is associated with Stage II vacuum assist-systems return of excess air into the UST when refueling an ORVR-equipped vehicle. Excess air ingestion into the UST results in vapor growth and a release of excess vent emissions from the UST vent pipe. Data from the U.S. has shown that the magnitude of these excess vent emissions is small, less than a 1% impact on control efficiency for the A/L ratios specified in Europe. The combined effect of the increased control efficiency of ORVR (98%) relative to Stage II (71%) results in a significant reduction in emissions from the GDF, even when accounting for the excess vent emissions.

- ORVR should be viewed as a complement or replacement for Stage II vapor recovery at service stations. As the penetration of ORVR vehicles in a fleet increases, there comes a point where the emission reduction benefits from Stage II are *de minimis*.
- ORVR provides added benefits to an evaporative emissions vehicle control program, by providing extra capacity and increasing vehicle purge rates. Both the extra capacity and increased purge rates would provide additional control of diurnal and running loss emissions during off-cycle and/or extreme climate conditions, such as during heat-waves.
- After many extensive analyses on the cost-effectiveness of Stage II and ORVR, the U.S. EPA determined that the ORVR program is the most cost-effective strategy for the control of refueling emissions in all vehicle classes, even when Stage II controls were in place. Using EPA estimates of the incremental costs for ORVR hardware and the savings realized from ORVR fuel recovery credits and 2019 dollar values for hardware and fuel recovery credits, the addition of ORVR technology results in a net savings to the consumer. Compared with the most recent estimates of Stage II cost-effectiveness from the EU (~\$2,600-\$2,900 per tonne VOC controlled) and information derived from past U.S. EPA analyses (~\$2,800 per tonne VOC controlled) updated to reflect the latest technical and cost information, ORVR is both a more efficient and cost-effective long-term solution to the control of refueling vapor emissions at a GDF. The EU and U.S. have estimated the lifetimes of aboveground Stage II equipment to be only 5-8 years, so ongoing testing, inspection, maintenance, and capital replacement costs for Stage II must be considered and included when considering the adoption, expansion, or retention of Stage II.

Section 1: U.S. EPA Experience with ORVR and Stage II

The following section is a historical review of the U.S. EPA's experience with ORVR and Stage II as drawn from U.S. EPA, California Air Resources Board (CARB), and related public records.

Introduction:

In the U.S., it is the joint responsibility of the EPA and the States to develop plans and control programs to reduce the emissions of ozone precursor compounds such as volatile organic compounds (VOCs). The EPA takes the lead on national emission control requirements for motor vehicles such as exhaust, evaporative and refueling emission standards. For local emission sources, the U.S. Clean Air Act (CAA) authorizes EPA to issue control technique guidelines (CTGs) to help states develop control regulations for their State Implementation Plans (SIPs).¹ While states other than California are prohibited from implementing their own vehicle control requirements, there are generally no such prohibitions for stationary sources.

¹ US Clean Air Act 1970, sections 108 and 110.

In 1971, the EPA had only been in existence for one year, the ambient air quality standard for photochemical oxidants (later ozone) had just been established, and there were only very simple standards for exhaust and evaporative emissions for passenger cars and smaller light commercial vehicles. Discussions on refueling emission control (ORVR) began at EPA in 1973.² Areas in the state of California had the worst ozone air quality in the U.S. in the 1970s. In 1974-1975, using their local legal authority, San Francisco and San Diego California which already had required Stage I, now required early versions of Stage II control.³ This program included controlling refueling emissions at the vehicle fill pipe/nozzle interface and at the UST vent. In 1973, EPA proposed requiring Stage II in portions of 8 states with the worst ozone air quality, but this initiative was delayed in 1974 and then deferred in 1977 when the viability of ORVR as an option to Stage II became clear and the U.S. Congress was working on amendments to the CAA.^{4,5}

Statutory Provisions and Regulatory Assessments:

The 1977 CAA amendments contained two provisions which were significant to the implementation of refueling emission controls.⁶ The first was the requirement for an extensive study comparing virtually all aspects of Stage II and ORVR for control of refueling emissions and the requirement for a proposed regulation after the study was completed and reviewed. The second requirement was for the States with high ozone concentrations (non-compliant with the ozone standard) to implement measures to show progress toward meeting the ozone standard.⁷ This, of course, would be done through control programs to reduce the magnitude of the inventories of ozone precursors.

The Stage II and ORVR study began in 1978 and after much internal deliberation and a public review, ended with a decision by EPA to propose nationwide ORVR.⁸ Data and analysis showed ORVR to have higher in use efficiency, lower costs, wider coverage, and easier implementation.^{9,10} The proposed rule for ORVR was published in 1987.¹¹ However, during this time (1978 to 1987) states with the worst ozone air quality problems were required to show progress in meeting the ozone standard. This resulted in Stage

² Control of Refueling Emissions with an Activated Carbon Canister on the Vehicle – Performance and Cost Analysis, Interim Report Project EF-14, October 1973, API, Washington DC and Vehicle Refueling Emissions Seminar, API Publication 4222, December 1973.

³ Evaluation of Air Pollution Regulatory Strategies for Gasoline Marketing Industry, EPA 450/3-84-012a, July 1984 and Stage II Vapor Recovery Systems for Control of Vehicle Refueling Emissions at Gasoline Dispensing Facilities, Vol II, November 1991.

⁴ SAE Technical Paper 750905, “Control of Refueling Emissions with an Activated Carbon Canister on the Vehicle”.

⁵ US Federal Register, 39 FR 4880 (February 8, 1974), 39 FR 21049 (June 18, 1974), 40 FR 47668 (October 9, 1975), 40 FR 54436 (November 24, 1977), 41 FR 48043 (November 1, 1976), 42 FR 27674 (May 31, 1977).

⁶ US Clean Air Act, section 202(a)(6).

⁷ US Clean Air Act, section 182.

⁸ Evaluation of Air Pollution Regulatory Strategies for Gasoline Marketing Industry, EPA 450/3-84-012a, July 1984.

⁹ 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.

¹⁰ Evaluation of Air Pollution Regulatory Strategies for Gasoline Marketing Industry - Response to Public Comments, EPA 450/3-84-012c, July 1987.

¹¹ US Federal Register, 52 FR 31161 (August 19, 1987) and Draft Regulatory Impact Analysis: Proposed Refueling Emission Regulations for Gasoline-Fueled Motor Vehicles -Volume II: Additional Analysis of Onboard Controls, EPA-450/3-87-001b, July 1987.

II being implemented in parts of three states before the proposed rule for ORVR and three more in the following two years (see Table 1). These areas already had Stage I controls in place.

As EPA worked toward completing its final ORVR regulation in 1988 and 1989, the CAA was once again raised for amendment by the U.S. Congress and a final rule for ORVR was delayed. As a compromise with environmental, oil, and auto interests, the 1990 CAA amendments included three major provisions affecting refueling emissions control: (1) a requirement for ORVR nationwide, (2) a requirement that 18 States containing areas classified as serious or worse for ozone air quality (including the six already with Stage II) implement Stage II in areas not meeting the ozone standard, and (3) an allowance for these States to remove Stage II when ORVR was in widespread use in the U.S. motor vehicle fleet.¹² Even with these requirements, a few States classified as moderate for ozone and a few states whose pollution affected ozone compliance in neighboring states also implemented Stage II.¹³ In total, Stage II for control of ozone precursor emissions was adopted in all or part of 25 states. Stage I controls were already in place in all these areas.

Table 1: Year of Initial Adoption of Stage II Program and Initial Administrative Action to Remove Stage II Requirement					
	Adopt Stage II	Remove Stage II		Adopt Stage II	Remove Stage II
California	1974-75	EVR 2001	Arizona	1992	2015
District of Columbia	1976	2019	Illinois	1992	2014
Missouri	1987	2013	Wisconsin	1992	2015
New Jersey	1988	2017	Tennessee	1993	2015
New York	1988	2012	Kentucky	1993	2016
Massachusetts	1989	2013	Indiana	1993	2013
Louisiana	1992	2019	Ohio	1993	2014
Maine	1992	2012	Virginia	1993	2014
New Hampshire	1992	2012	Rhode Island	1993	2013
Pennsylvania	1992	2016	Maryland	1993	2014
Texas	1992	2014	Delaware	1993	2015
Connecticut	1992	2013	Vermont	1999	2013
Georgia	1992	2014			

EPA completed its final regulations requiring ORVR in 1994 and the requirements began to phase-in for the 1998 model year.¹⁴ The 18 States with serious or worse ozone problems implemented Stage II in the areas required during 1993-1995.¹⁵ Those states with moderate ozone problems which chose to

¹² US Clean Air Act sections 182 (b)(3) and 202(a)(6).

¹³ Under the Clean Air Act section 182(b)(3) states classified as marginal or moderate could adopt Stage II even after EPA adopted ORVR and under section 184(a) states whose emissions affected ozone compliance in other states could implement Stage II in lieu of other measures. Stage II Comparability Study for the Northeast Ozone Transport Region, January 1995, EPA-452/R 094-011.

¹⁴ US Federal Register, 59 FR 16261 (April 6, 1994).

¹⁵ The phase-in schedule for Stage II for these areas is contained in section 182(b)(3) of the Clean Air Act.

implement Stage II and those states whose ozone-precursor pollution transported to other states implemented the controls more slowly, with all completed by 1999.

In the following years there were two significant developments. First, as expected, ORVR vehicles captured an increasing portion of refueling emissions at service stations as ORVR vehicles phased-in to the fleet. By 2007, ORVR controlled more than one-half of refueling emissions at service stations nationwide and surpassed control provided at service stations with Stage II installed. The overall control provided by Stage II decreased each year and by 2012 the fraction of all refueling emissions controlled by ORVR had grown to 75%.¹⁶

The second development was a shift in the fundamental understanding of the operation of Stage II and what factors affect its in-use efficiency. Prior to 2000, there seemed to be a relatively simplistic view that Stage II involved capturing vapor at the vehicle fill pipe and routing it to the UST where it would be contained by negative tank pressure achieved using a pressure-vacuum (P/V) valve on the UST vent pipe. This approach relied on three and in many cases four periodic sub-system operational tests as a surrogate for evaluation of overall efficiency evaluations (see below). Maintenance would be required if a test indicated that the sub-system did not meet the pass/fail criteria. In the early 1980s, initial information from the California Air Resources Board (CARB) indicated in-use efficiencies of 80-92% depending on the frequency of the testing and follow-up maintenance.¹⁷ EPA reported a Stage II efficiency value of 62% for stations in an area where there was minimal enforcement.¹⁸ Based on CARB's data and approach, EPA settled on an in-use efficiency value of 86% with requirements for (1) operator training, (2) daily equipment inspections, (3) annual testing, and (4) follow-up maintenance if the 86% value was applied in the areas ozone SIP.^{19,20} These requirements are discussed further below.

In 1999 CARB released two reports indicating performance problems with Stage II hardware.^{21,22} The data showed that instead of an in-use efficiency of 80-92%, the value was about 71%.²³ The root cause of the problem was related to the inability of the UST and its piping and valves to contain vapor when UST pressures were above atmospheric. Depending on the situation, this includes vapor returned from the vehicle during refueling and/or vapor generated in the UST when excess air was entrained into the UST either during the refueling event or in times of negative pressure in the UST. This ultimately led California to abandon its Stage II approach in favor of a more comprehensive program termed Enhanced Vapor Recovery (EVR).²⁴ This program required development of controls which would treat refueling vapor

¹⁶ EPA Memorandum, "Onboard Refueling Vapor Recovery Widespread Use Assessment," June 2011.

¹⁷ Report to the Legislature on Gasoline Vapor Recovery Systems for Vehicle Fueling for Service Stations, California ARB, March 1983.

¹⁸ 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.

¹⁹ "Technical Guidance – Stage II Vapor Recovery Systems for Control of Vehicle Refueling Emissions at Gasoline Dispensing Facilities, Volume I" US EPA, 450/3-91-022a, November 1991.

²⁰ Enforcement Guidance for Stage II Vehicle Refueling Control Programs, US EPA, December 1991.

²¹ ARB/CAPCOA Vapor Recovery Test Report, April 1999.

²² Performance of Balance Vapor Recovery Systems at Gasoline Dispensing Facilities, San Diego Air Pollution Control District, May 2000.

²³ California ARB, Revised Emission Factors for Phase II Vehicle Fueling at California Gasoline Dispensing Facilities, December 2013.

²⁴ California ARB, Enhanced Vapor Recovery, Initial Statement of Reasons, February 2000 and Final Statement of Reasons, February 2001.

capture and vapor storage in the service station UST as a system rather than as parts. Not only would refueling emission capture be required at the vehicle fill pipe, but there is substantial emphasis on maintaining UST tank pressures within specific ranges to avoid vapor leaks or venting in normal operating conditions.²⁵ Central to the keeping tank pressures negative (and optimizing in-use efficiency of EVR in controlling refueling emissions) is the presence of a significant number of ORVR-equipped vehicles in the fleet. As discussed further in Section 2 below, ORVR vehicles do not return vapor to the UST. With the presence of an ORVR-compatible nozzle required in the EVR program (which allows for some air flow from the vacuum assist nozzle to the UST), a properly operating UST vent valve, and the absence of UST leaks, it is possible to accommodate vapor growth in the UST and still maintain negative tank pressures.

CARB completed the implementation of the six modules of the EVR program in 2009. No other state in the U.S. has adopted the EVR program in lieu of Stage II, due to its cost and complexity and the diminishing need for new regulations with the continually increasing control provided by ORVR. In subsequent regulatory assessments EPA adopted CARB's 71% in-use efficiency for Stage II.²⁶

As it became evident that ORVR control was replacing that provided by Stage II, EPA began work on its rule to remove the Federal requirements for state Stage II regulations. This rule, which was based on the concept that ORVR technology was in "widespread use," relied on data which showed that ORVR vehicles were controlling 75% of refueling emissions by 2012, and that this percentage would continue to increase in the future.²⁷ The EPA "widespread use" rule was published in May of 2012, and almost immediately the states with Stage II began actions to allow for the removal of the technology. Table 1 shows when states adopted Stage II regulations and when administrative action was first taken to remove Stage II requirements from the state regulations. In most cases the Stage II controls had a 3-year phase-in from when first adopted and a 3-year decommissioning requirement. Figure 1 shows how coverage by Stage II has decreased since 2012. Today, only CARB has not acted to remove Stage II. CARB replaced their Stage II program with EVR.

It has been demonstrated and documented that ORVR technology achieves 98% control in-use.²⁸ Since ORVR was first adopted for light-duty vehicles and light-duty trucks in 1994, the requirement has been expanded to cover heavy-duty gasoline vehicles (HDGVs) less than 14,000 lb. Gross Vehicle Weight Rating (GVWR) and EPA is now developing a rule to apply the ORVR requirement to vehicles heavier than 14,000 lbs. GVWR.^{29,30,31,32} As of 2019, ORVR vehicles now provide control of 91% of all gasoline-powered motor vehicle refueling emissions in the U.S.³³

Issues Raised When Implementing ORVR with Stage II in Place

²⁵ California ARB certification procedure CP 201 and test procedure TP 201.2B.

²⁶ EPA Memorandum, "Onboard Refueling Vapor Recovery Widespread Use Assessment," June 2011.

²⁷ US Federal Register, 77 FR 28772 (May 16, 2012).

²⁸ SAE Technical Paper 2017-01-5008, "Summary and Analysis of 2000-2015 Model Year IUVP Evaporative and Refueling Emission Data".

²⁹ US Federal Register, 65 FR 6697 (February 10, 2000).

³⁰ US Federal Register, 65 FR 59895 (October 6, 2000).

³¹ US Federal Register, 79 FR 23412 (April 28, 2014).

³² US Federal Register, 85 FR 3306 (January 21, 2020).

³³ EPA Memorandum, "Updated Data for ORVR Widespread Use Assessment," February 2012.

If both ORVR and Stage II are in place at the same time, when an ORVR-equipped vehicle is refueled with a Stage II nozzle, all the refueling emission vapor is captured on the vehicle. If the Stage II nozzle is the vacuum assist type design, then only air would be returned to the UST and this would enhance evaporation of gasoline in the UST and thus increase the amount of vapor the UST vents to the atmosphere. Not all of this excess vapor is vented, because, in some cases, the vapor fills the void in the UST created when the next refueling event draws fuel from the UST. Excess vapor generation would not occur with a system using a balance type nozzle design since air is not returned to the UST from the vehicle fill pipe area.

a. Emissions Impact: In the U.S., both ORVR and Stage II were required at the same time for about 15 years. A field study was done by CARB to quantify the increase in emissions with vacuum assist type designs as the number of ORVR vehicles in the fleet increased.³⁴ EPA took this data and developed an equation which allows the calculation of the reduction in Stage II efficiency from the increased venting from the UST.³⁵ This EPA analysis shows that at 100% ORVR penetration, the increase in tank vent emissions at a station equipped with a vacuum assist type Stage II system using nozzle A/L of 0.9-1.1 would be about 1%, or less at any lower ORVR penetration value. This represents only 1-2% of the uncontrolled refueling emission rate. Any increase in vent emissions would be more than offset by the superior in-use efficiency of ORVR. The presence of Stage II does not impact the operation of ORVR or its efficiency.

b. Safety Assessment: The EPA adopted ORVR in 1994 with implementation required for the 1998 model year. The U.S. already had Stage II in about 30% of all private and public service stations at that time. Of these stations, about 80% used balance type designs and 20% used vacuum assist type designs. With vacuum assist type designs, a vacuum pump in the dispenser creates a suction at the end of the nozzle which pulls vapor from the fill pipe as the vehicle is refueled. However, with an ORVR system, there is no vapor flow from the fill pipe, because a seal at the bottom of the fill pipe blocks vapor from escaping, and thus a traditional vacuum assist nozzle routes only air back to the UST.

In 1996, a question was raised by Stage II manufacturers to the CARB about whether the mix of refueling of ORVR and non-ORVR cars at a service station during ORVR phase-in could be a safety issue. There is always a flammable concentration somewhere in the vapor space above the liquid level in the UST. However, the question was about whether the vacuum assist type Stage II technology, returning air and not vapor during the refueling of an ORVR vehicle, could create a flammable concentration in the vapor return hoses and lines and increase the size of the flammable concentration zone within the UST. It was then postulated that these flammable concentration zones could create a safety risk if an ignition source found its way into the vapor return hose. (Such a concern does not exist for balance type Stage II systems since they return no air or vapor to the UST from the vehicle tank during the refueling of an ORVR vehicle.) A similar question was expressed by the Canadian Petroleum Products Institute in 1995 when Canada was considering adopting Stage II and ORVR. An independent study of this issue concluded that there was no reason for concern.³⁶ Canada adopted only ORVR.

³⁴ California ARB, Preliminary Draft Test Report, Total Hydrocarbon Emissions from Two Phase II Vacuum Assist Vapor Recovery Systems During Baseline Operations and Simulated Refueling of Onboard Refueling Vapor Recovery (ORVR) Equipped Vehicles, Project Number ST-98-XX, June 1999.

³⁵ US EPA, "Guidance on Removing Stage II Gasoline Vapor Control Programs from State Implementation Plans and Assessing Comparable Measures," EPA-457/B-12-001 August 7, 2012.

³⁶ "A Comparative Characterization of Gasoline Dispensing Facilities With and Without Vapor Recovery Systems," Sierra Research, Inc. for the Province of British Columbia Ministry of Environment, Lands, and Parks, October 1995.

In response to these questions, engineers from CARB conducted field measurements on hydrocarbon concentrations at the nozzle and fill pipe interface on a matrix of Stage II vacuum assist nozzles and ORVR vehicles. They found that under some test conditions flammable concentrations could exist briefly at the nozzle/fill pipe interface.³⁷ No problems were found for balance type Stage II vapor recovery systems since the fill pipe is blocked by the nozzle boot.

Based on this information, CARB and the California State Fire Marshall contracted with Southwest Research Institute (SwRI) to assess the ignitability and propagation behavior of this vapor for vacuum assist Stage II systems when refueling ORVR vehicles.³⁸ A vehicle spark plug was used at the fill pipe opening to simulate a charge capable of igniting the vapor. This spark provided 5-6 orders of magnitude more energy (Joules) than needed to ignite gasoline vapor.

After the completion of this testing, the California State Fire Marshall sent a letter to CARB concluding that the introduction of ORVR with Stage II does not create a fire hazard.³⁹ It has now been over 20 years since ORVR vehicles were required in the U.S. and Canada and there have been no safety problems at service stations when ORVR-equipped vehicles are refueled with Stage II vapor recovery.

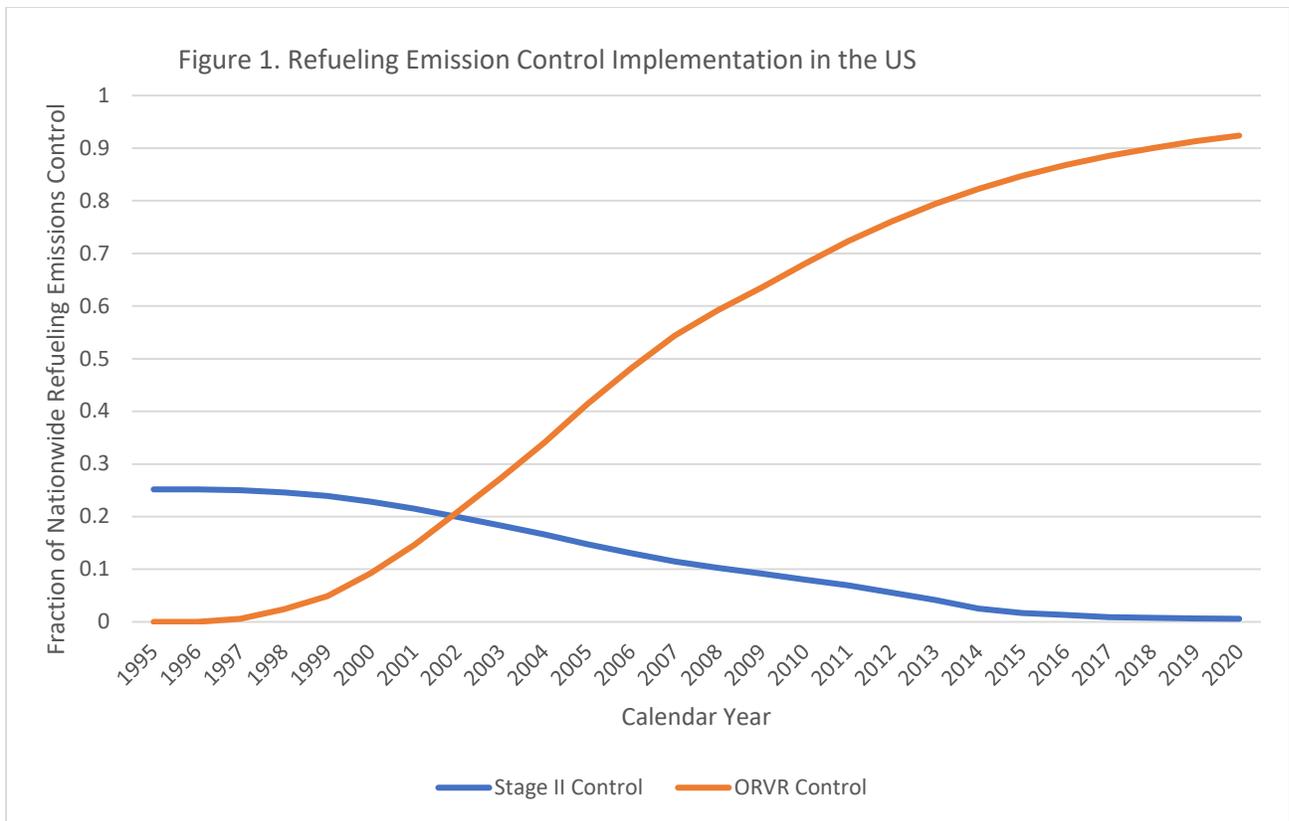
Program Comparison:

Figure 1 depicts the U.S. experience in implementing refueling emission control. The analysis covers both Stage II and ORVR and begins in 1995 when the Stage II program completed implementation. Stage II covered about 35% of nationwide gasoline consumption with an in-use efficiency of 71%. ORVR is a nationwide program which phased-in over the 1998-2006 model years. Its in-use efficiency is 98%. The control from ORVR increased as the requirement phased-in and the fleet turned over. The nationwide control from Stage II was steady until ORVR began and then decreased as ORVR vehicles entered the fleet and then when Stage II controls were removed. On a nationwide basis, control from ORVR surpassed that from Stage II in 2002. Control from ORVR reached 50% of the refueling emission inventory in 2007 and 75% in 2012. It was in 2012 that the U.S. EPA permitted removal of Stage II by the States.

³⁷ "Vapor Return Path Hydrocarbon Concentrations in Vacuum Assist Vapor Recovery Systems Dispensing Gasoline to Onboard Refueling Vapor Recovery (ORVR) Equipped Vehicles," CARB, MLD, Project C-97-024, March 1998.

³⁸ "Fire Safety Evaluation of Onboard Vapor Recovery (ORVR) Fill Neck," SwRI, Project No. 01-1267, March 1988.

³⁹ Letter, Hugh Council, California State Fire Marshall's Office to James Morgester, California Air Resources Board Compliance Division, May 29, 1998.



Inspections, Testing, and Maintenance

It is not economically or otherwise possible or practical to determine the in-use efficiency of Stage II installations using the methods prescribed for certification.⁴⁰ As a means to try to maximize in-use efficiency, regulators, GDF equipment manufacturers, and gasoline marketers have developed a series of measures to identify and address known or potential problems which would degrade performance.^{41,42,43} Each of these is described below.

Training and Inspections:

Taken together, the Recommended Practices of both API and PEI contain comprehensive recommendations and checklists to address the effectiveness of daily operation of Stage II equipment. State regulations incorporated many of these as requirements.

⁴⁰ “Technical Guidance – Stage II Vapor Recovery Systems for Control of Vehicle Refueling Emissions at Gasoline Dispensing Facilities, Volume II: Appendices” US EPA, 450/3-91-022b, November 1991, Appendix C.

⁴¹ “Owner/Operator’s Guide to Operation and Maintenance of Vapor Recovery Systems at Gasoline Dispensing Facilities,” API Recommended Practice 1639, July 2003.

⁴² “Recommended Practices for Inspection and Maintenance of Motor Vehicle Fuel Dispensing Equipment,” Petroleum Equipment Institute, PEI RP500-11.

⁴³ “Recommended Practices for Installation and Testing of Vapor Recovery Systems at Vehicle-Fueling Sites,” Petroleum Equipment Institute, PEI RP300-09.

As presented in sections 5 and 6 of API RP 1639, the purpose of regular inspections of vapor recovery equipment is to look for visible signs of damage or deterioration that might prevent the vapor recovery system from functioning properly and to correct problems when they are discovered. Inspectors should familiarize themselves with the vapor recovery system being inspected and with the operation of all components and be able to recognize when the components are not in good operating condition. The API RP goes on to recommend that operators follow manufacturers' recommendations for inspections and maintenance of equipment, that all GDF supervisory personnel should familiarize themselves with inspection procedures and the follow-up actions if they discover problems requiring correction, that personnel performing equipment inspections should have proper training to conduct effective inspections, and all such training should be documented. Finally, regarding record keeping and retention, the API RP goes on to state that all inspections should be documented in writing when performed and that a record of all training, equipment inspections, maintenance, or repairs should be maintained at the station, be accessible within 24-hours, or as required by local or state regulations, but otherwise for a minimum of two years. Appendix A of the API document provides comprehensive inspection checklists.

Section 6 of PEI RP500-09 specifically provides that a Level 1 Qualified Person should always be on duty when the GDF is in operation and describes the training needed for Level 1. It also discusses daily inspection requirements. Very detailed daily inspection and operating checklists for hanging hardware for vacuum-assist and balance Stage II systems, respectively are provided in Appendices B-2 and B-3. Additional items for monthly and annual inspections for Stage II vapor recovery hanging hardware are provided in Appendices B-4 and B-5.

Testing:

In a U.S. Stage II installation, three or perhaps four operational tests must be conducted and pass manufacturer and state requirements for the GDF to be permitted. These tests are prescribed in CARB regulations and have been almost universally incorporated into the regulations of other states with Stage II. These tests, which are listed below, are described in detail in either PEI RP300-09, the CARB regulations or both.⁴⁴

Pressure Decay Test: An integrity test of the ullage portion of a gasoline storage system equipped with Stage II vapor recovery. To conduct the test, all the vapor-containing portions of the storage system, including the vent lines, vapor manifold, vapor piping, and riser pipes, are pressurized slightly by adding nitrogen gas. Pressure changes in the system are monitored for a specified period of time, and the final pressure is compared to an allowable value. This is the test which identifies vapor leaks within the system.

A/L Volume Ratio Test (A/L): A test procedure that measures the volume of air returned to a storage tank when a specified volume of gasoline is dispensed from a vacuum-assist vapor-recovery nozzle. The ratio of the volume of air returned to the tank and the volume of gasoline dispensed is a measure of the effectiveness of the vapor-recovery system. The A/L ratio measured during a test is compared with the specifications for a specific vacuum-assist system to determine if the equipment is operating properly. This test applies only to vacuum-assist type systems. A/L is not the same as the V/L ratio, which is discussed in Section 2 below.

⁴⁴ These tests are described in detail in CARB test requirements for Stage II: TPs 201.1E, 201.3, 201.4, and 201.5.

Dynamic Backpressure Test: A test of Stage II vapor-recovery piping that measures the resistance to flow in the vapor path between the nozzle or dispenser riser and the storage tank. The purpose of the test is to verify that there are no physical or liquid blockages obstructing the flow of vapors in the piping system.

Pressure/Vacuum Valve (P/V) Test: The purpose of this procedure is to determine the pressure and vacuum at which a P/V valve actuates, and to determine the volumetric leak rate at a given pressure as specified in CARB CP-201, Certification Procedure for Vapor Recovery Systems at GDFs.⁴⁵ Typical cracking pressures are +3.00" H₂O and -8.00" H₂O.

Any time a test reveals that the system does not meet the requirement(s) prescribed in the permit, either during inspections or testing, maintenance, repairs, or replacement parts as needed are required. As was mentioned above, records are to be kept, and made available for review by government agencies with enforcement authority.

Much more detail could be gleaned from the documents identified in the references. The important point here is that even though systems are required to be certified at 95% (including vehicle displacement and vent emissions) and the Federal and state regulations require training, inspections, testing and maintenance, the overall efficiency in the U.S. was only about 70%. The efficiency values seen were even lower when conditions of the permit were not met.

Closing:

After more than 20 years of experience with ORVR and Stage II technology, information from the U.S. indicates that ORVR is the preferred control strategy from an environmental perspective. Even if Stage II could be implemented on a nationwide basis, the much greater in-use efficiency of ORVR over the full vehicle life results in 27% greater reductions in refueling emissions (98% efficiency for ORVR vs. 71% for Stage II with strong enforcement). Finally, as discussed in Section 3, the economic impact and cost-benefit clearly favor ORVR.

Section 2: Overview of Refueling Dynamics

The following section includes a detailed review on how refueling dynamics influence the fuel vapor emissions from a gasoline dispensing facility. A summary of the dynamics of uncontrolled refueling, Stage II, ORVR, and Stage II combined with ORVR are presented.

Overview of a Gasoline Dispensing Facility (GDF)

Figure 2 provides a general schematic of a gasoline dispensing facility (GDF). When assessing the control efficiency of fuel vapor recovery options (Stage II, ORVR, ORVR + Stage II), the release, capture, and containment of air and gasoline vapors must be viewed across the entire GDF system, including the vehicle's tank and canister, gasoline dispensing unit (nozzles, hoses and pumps), gasoline transfer lines, the underground storage tank (UST), and the UST vapor vent line and pressure/vacuum (P/V) valve. Loss of containment and release of gasoline vapors from any point in this interconnected system negatively impacts the overall control efficiency.

Gasoline fuel dispensers are connected by fuel lines to the UST. A vapor vent line is attached to the UST for stabilizing the tank pressure. In some cases, a P/V valve is added to the top of the vent line to better

⁴⁵ CARB, TP-201.2B, "Determination of Flow vs. Pressure for Equipment in Phase II Vapor Recovery Systems of Dispensing Facilities," 1996.

control the tank pressure and prevent uncontrolled releases of gasoline vapor. If the tank pressure falls either below or above the P/V setting the valve will open and allow air to flow into the UST in the event of negative tank pressure or allow air and fuel vapors to vent to the atmosphere in the event of positive tank pressure. If there is no P/V valve the UST is vented to atmosphere and draws in air or vents vapor to maintain atmospheric pressure.

During a refueling event, gasoline is drawn out of the UST, creating a negative pressure in the UST. Air can be ingested through the vent line to maintain tank pressure. Air ingested into the UST from either the UST vent line or during refueling will cause the vapor concentration in the UST to become diluted below the equilibrium concentration and vapor pressure. In response, gasoline in the UST vaporizes until equilibrium is reestablished and UST pressure will increase. If the pressure in the UST increases above the P/V valve setting (or at atmospheric pressure if there is no P/V valve), the air and fuel vapor mixture will vent to the atmosphere. These emissions are commonly referred to as UST breathing/emptying loss emissions. Fugitive emissions from the UST are sometimes included in estimates of these emissions.

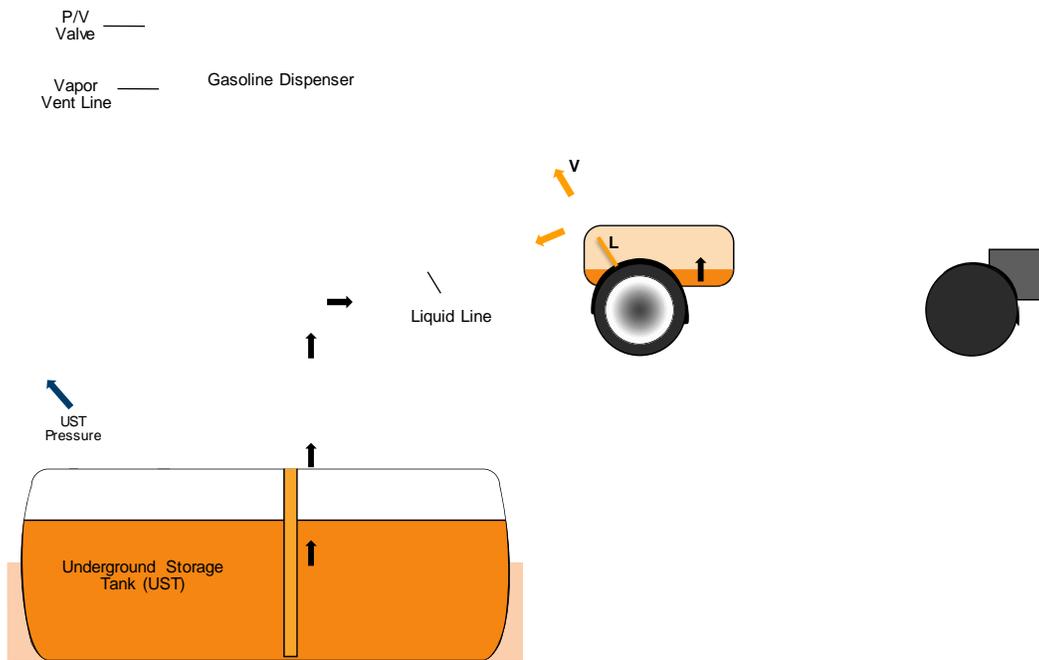


Figure 2: Gasoline Dispensing Facility with Uncontrolled Refueling Event

Uncontrolled Refueling Event

As shown in Figure 2, when a car is refueled, a fuel dispenser activates a pump, sending gasoline out of the storage tank, through a flowmeter in the dispenser, through a nozzle, and into the fuel tank of the vehicle. The rate of gasoline dispensed (liters per minute) is referred to as **L**. In a refueling event where there is no vapor emission control (no Stage II nor ORVR), as the vehicle tank fills, a mixture of air and gasoline vapor in the tank headspace is forced out of the filler neck (along the path of least resistance) and into the atmosphere. The amount of vapor generated and released from the vehicle tank during a refueling event is referred to as **V**. Gasoline is a volatile substance, with volatility being a measure of the tendency of a substance to vaporize (vapor generation). Gasoline volatility, and thus **V**, is strongly affected

by changes in temperature, by addition of ethanol, and/or fuel compositional changes which impact RVP. As temperature increases, vaporization increases. A storage tank filled with gasoline can have a gasoline vapor concentration of 35% in the headspace at 22°C and 59% at 36°C. Addition of ethanol into gasoline increases the volatility. If equal volumes of E10 and E0 gasoline are mixed, the vapor pressure increases up to 15%. Winter grade gasoline may have a more volatile chemical composition and a higher RVP than summer grade gasoline, which often has a lower RVP due to government limits on RVP to prevent excessive evaporative emissions caused by higher temperatures.

During a refueling event, the volume of vapors displaced (**V**) often does not equal to volume of liquid transferred (**L**). Temperature variations between the liquid fuel dispensed and the vapors in the tank can cause either an expansion or contraction of the vapors, resulting in the V/L ratio varying from 1. When warm liquid fuel enters a cooler tank, the temperature in the tank increases, increasing the volume of vapors in the tank and increasing the volume of vapors displaced. This results in a volume of displaced vapors that is greater than the volume of liquid dispensed ($V/L > 1$), which is called vapor growth. The opposite occurs when the liquid fuel being dispensed is cooler than the vehicle tank's temperature. The cooler temperature of the fuel reduces the vapor volume displaced ($V/L < 1$), which is called vapor shrinkage. Either vapor growth or vapor shrinkage is a common occurrence when transferring liquids from a service station UST into vehicle fuel tanks, which can be at a wide variety of temperatures due to different driving and ambient conditions. Figure 3 provides a summary of experimental data⁴⁶ on the V/L ratio as a function of different vehicle tank and fuel dispensing temperatures (ΔT) and dispensing rates (**L**). As show in Figure 3, because vapor growth and vapor shrinkage can occur so often, errors in emission estimates occur if it is assumed that the volume of vapors displaced equals the volume of liquid dispensed ($V=L$).

⁴⁶ Stanford Research Institute, "A Study of Variables that Effect the Amount of Vapor Emitted During the Refueling of Automobiles", 1975.

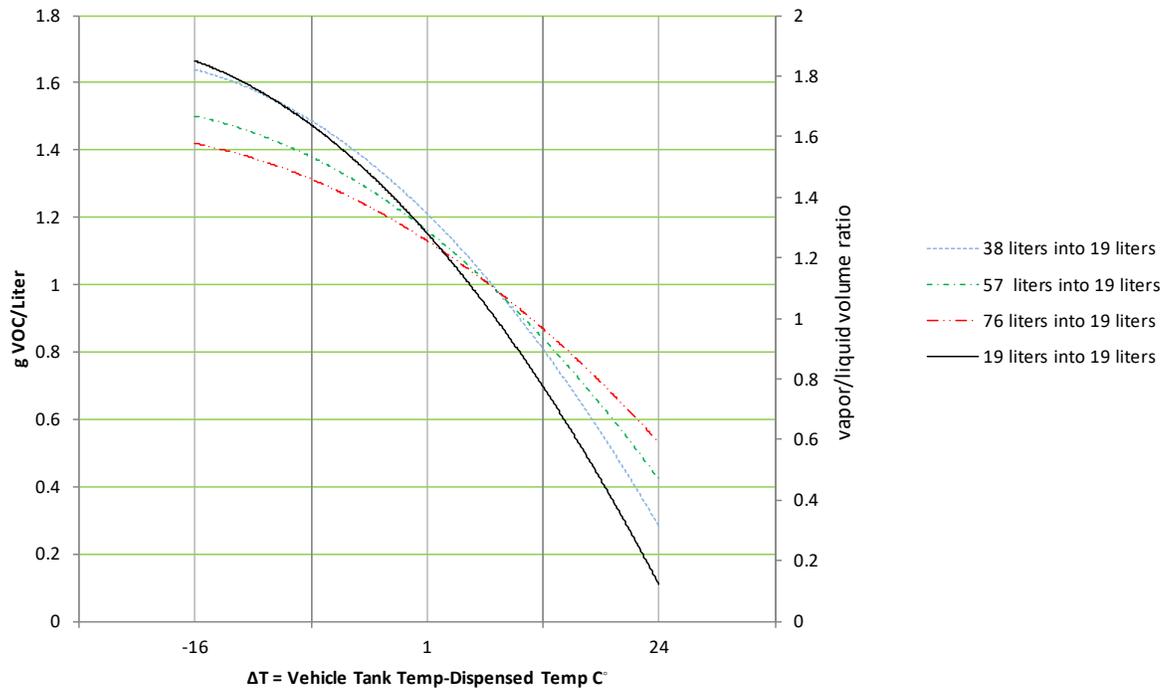


Figure 3: V/L versus initial ΔT (initial tank temperature – dispensed fuel temperature)

Conventional Refueling Nozzle

During refueling, gasoline flows through a venturi in the nozzle, creating a vacuum. This vacuum draws air through a small hole (sensing port) located at the end of the refueling nozzle (Figure 4). The air is routed through a small pipe in the refueling nozzle towards the venturi and a diaphragm of air before becoming mixed into the fuel being dispensed. As the fuel tank becomes full, the increased pressure forces liquid fuel to move up the fill pipe, displacing the air with liquid fuel, which deflates the diaphragm and triggers the auto shut-off valve to stop refueling. Air entrainment rates are typically 10-15%,⁴⁷ but the net amount of outside air delivered to the tank can be reduced through a vent line routed to the top of the fill pipe. The net amount of air entrained into the fuel at the nozzle is important, as it directly impacts (increases) the amount of fuel vapor generated from the tank during refueling. Ingestion of air into the vehicle tank upsets

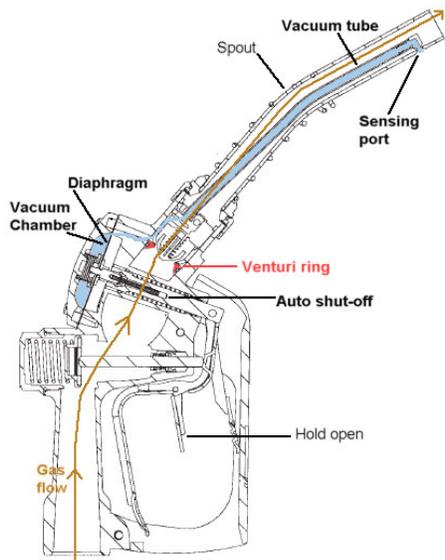


Figure 4: Conventional Refueling Nozzle

⁴⁷ SAE Technical Paper 970311, "Methodology for Evaluating Fuel Dispenser Nozzle Characteristics", February 1997.

the vapor pressure equilibrium in the tank and gasoline will evaporate to reestablish equilibrium, resulting in $V > L$.

On-board Refueling Vapor Recovery (ORVR)

Vehicles equipped with ORVR have a few notable design changes onboard the vehicle and no changes are needed for the GDF;

- The diameter of the filler neck is reduced – this change is designed to create a liquid seal during refueling.
- Fuel spit-back and well-back must be prevented and is accomplished using a check valve at the bottom of the fill pipe.
- An upgraded, four-function, low-pressure drop valve is added to the tank.
- The vent line leading to the carbon canister is replaced with a larger diameter hose – this change results in less resistance and allows the vapors displaced from the tank during refueling to more easily flow to the canister. This change is offset by reducing the diameter of the hose to the top of the fill pipe.
- The canister capacity is increased to accommodate the vapor load and load rate from refueling (V), in addition to multiple days of diurnal evaporative emissions. The canister must have a low pressure drop to prevent premature shutoff during refueling and fuel well-back in the fill pipe after refueling.
- The vehicle must be recalibrated to increase purge rates to accommodate the higher vapor capacity of the canister.

Essentially all ORVR vehicles use a liquid seal at the bottom of the fill pipe to block vapor from escaping to the atmosphere through the fill pipe during refueling. Another option is to use a mechanical seal. In a liquid seal, liquid gasoline backs up slightly near the bottom of the fill pipe as fuel is dispensed, blocking the escape of any vapors. Liquid seals are almost always used due to lower cost and higher durability relative to mechanical seals. As shown in Figure 5, with ORVR-equipped vehicles, the air and fuel vapor mixture vented from the vehicle tank is routed to a canister where the gasoline vapors are adsorbed onto the activated carbon and purified air exists the canister vent. When the vehicle is operated, engine vacuum creates purge flow and gasoline vapors are removed from the canister and routed along the vapor purge line to the engine for combustion. During refueling with ORVR-equipped vehicles, the UST pressure may become slightly negative as fuel is withdrawn and no vapors are returned from the vehicle tank to the UST. ORVR systems have a demonstrated in-use efficiency of 98%⁴⁸ and require no maintenance over the lifetime of the vehicle.

⁴⁸ Passavant, G., "Summary and Analysis of 2000-2015 Model Year IUVP Evaporative and Refueling Emission Data," SAE Technical Paper 2017-01-5008, 2017, <https://doi.org/10.4271/2017-01-5008>.

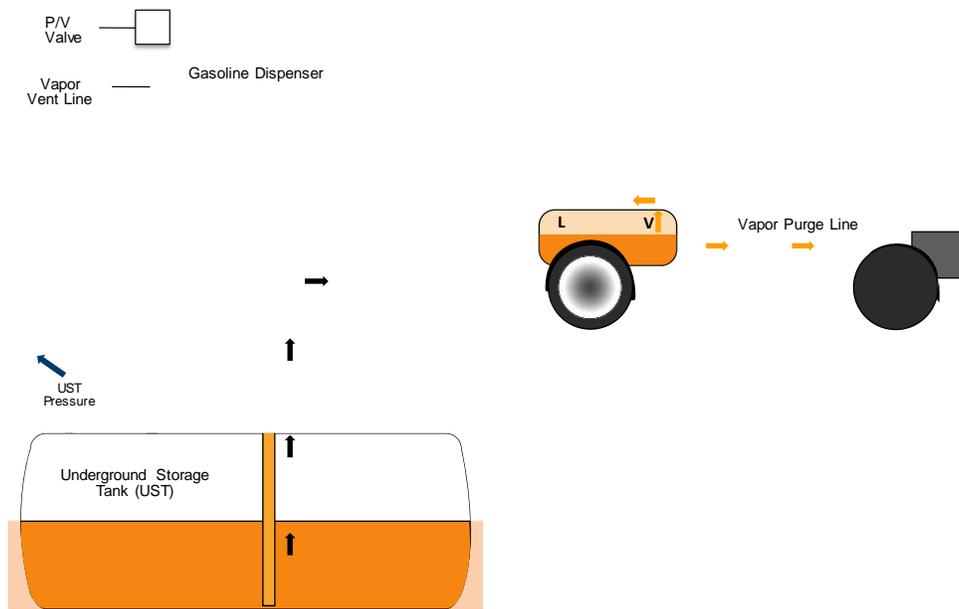


Figure 5: Gasoline Dispensing Facility with ORVR-equipped vehicle

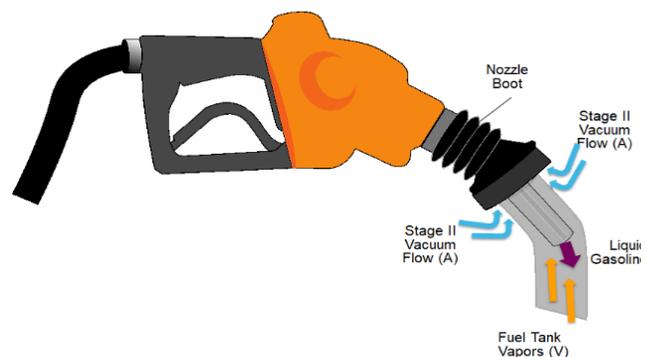
Stage II Vapor Recovery Systems with non-ORVR vehicles

A Stage II system is integrated into a GDF by replacing the existing fuel dispensers with new units and Stage II nozzles and adding vapor return lines to the underground storage tank. New hanging hardware is required, which includes coaxial hoses, break-away valves, and fuel dispensing rate limiters. Stage II nozzles are designed to draw in the mixture of air and gasoline vapors as they escape the vehicle fill neck during refueling and return them back to the UST. Stage Ia and Ib programs must also be in place for Stage II to be worthwhile. Otherwise, a large amount of the collected vapors is lost when the UST is fueled or when the fuel tanker is reloaded.

There are two primary designs for Stage II systems – balance and vacuum assist.

Balance systems include a tight-fitting bellow attached to the dispensing nozzle designed to make a complete seal at the point of the vehicle during refueling. A balance system relies on the pressure differential between the fuel tank and the UST to move gasoline vapors out the fill pipe through the bellows and route them back to the vapor dome of the UST. Balance systems must make a complete seal at the vehicle and the tank system needs to be leak free and maintain a vacuum in the UST. A properly functioning P/V valve on the vent pipe is also required.

Figure 6: Stage II Vacuum Assist Nozzle



Vacuum assist systems (Figure 6) physically

pump the vapors as they exit the fuel pipe through a vacuum created at the end of the nozzle spout. The

vacuum flow is calibrated and controlled by use of an **A/L ratio**, or the volume of air (vapor) drawn into the nozzle spout and routed to the UST (**A**) for every liter of gasoline dispensed (**L**). A schematic of a vacuum assist nozzle is shown in Figure 6. Vacuum assist nozzles cannot make a complete seal at the vehicle, otherwise you can disrupt fuel delivery.

Under European Directive 2009/126/EC (VOC-II),⁴⁹ the vapor/petrol ratio (A/L) shall be equal to or greater than 0.95 but less than or equal to 1.05, which is designed to ensure that the vapor collection element of the Stage II system operates as certified. Under European CEN Standard 16321-2, the A/L should be verified at least once each year.⁵⁰ However, the use of a fixed A/L ratio is based on the incorrect assumption that the volume of the gasoline vapor mixture generated (**V**) is equal to the amount of liquid gasoline dispensed (**L**). As illustrated in Figure 3, for the vapor generated in the tank (**V**) to perfectly match the volume of liquid dispensed (**L**) and thus be completely captured by the Stage II vacuum flow (**A**): The temperature, Reid Vapor Pressure (RVP), and ethanol content of the gasoline being dispensed must perfectly match the temperature, RVP, and ethanol content of the gasoline in the vehicle tank. This can only occur during certification tests. Real-world, in-use deviations between gasoline temperature, RVP, and ethanol content changes the gasoline volatility, which affects the volume of vapor that vents from the vehicle during refueling (**V**). This results in either over-collection ($A > V$) or under-collection ($A < V$) of vapors from the Stage II nozzle. It is also difficult to maintain a negative UST pressure with a Stage II vacuum-assist system. A positive UST pressure above the P/V setting will vent emissions to the atmosphere if a P/V valve is present.

Scenario A: Stage II Over-collection: In a Stage II over-collection scenario, air is ingested into the Stage II nozzle and deposited into the UST. This scenario can occur if the A/L ratio of the nozzle is set greater than 1. While in this scenario nearly 100% of vapors are collected at the vehicle, the amount of air being deposited into the UST is larger than the volume of liquid fuel dispensed. The pressure in the UST increases and the excess volume is vented out the UST vent line (Figure 7). Over-collection can also occur if the dynamics of the refueling result in air ingestion into the UST which has a vapor concentration below the equilibrium vapor concentration of the fuel in the UST. This scenario results in vapor growth in the UST (additional evaporation of fuel vapor into the air to reestablish equilibrium), increasing the pressure in the UST, and release of gasoline vapors out of the vent line.

⁴⁹ <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0126&from=EN>

⁵⁰ CEN, European Standard 16321-2, Petrol Vapor recovery during refueling of motor vehicles at service stations – Part 2: Test methods for verification of vapor recovery systems at service stations, September 2013.

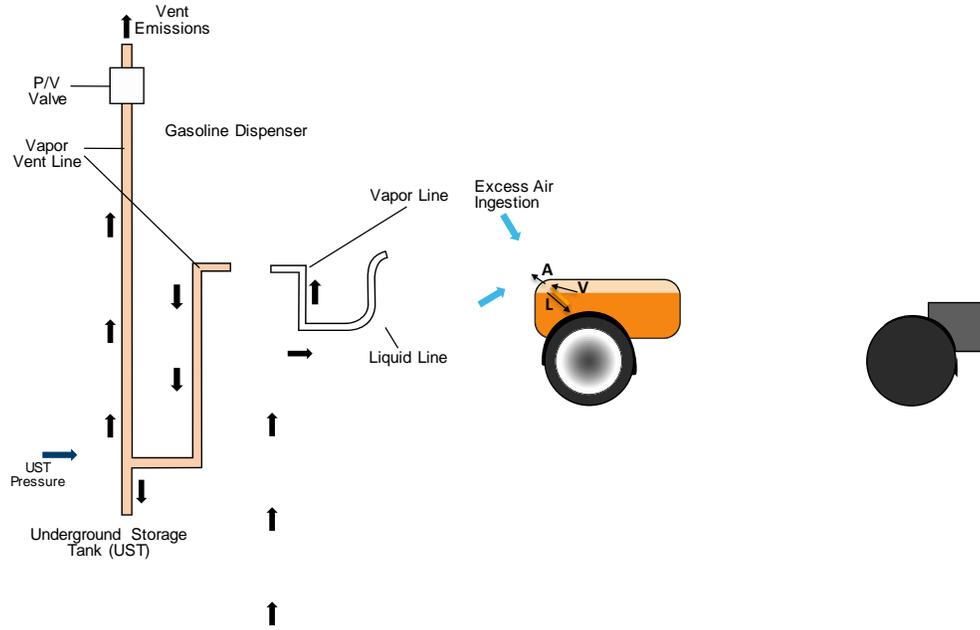


Figure 7: Gasoline Dispensing Facility with Stage II Vacuum Assist operating with $A > V$

Real-world Stage II over-collection example: If the UST is 22°C and the vehicle tank is 36°C, the gasoline entering the tank quickly cools the gasoline in the vehicle tank. As the tank re-establishes equilibrium, a portion of the vapor in the tank headspace condenses back into the liquid gasoline. In this instance, for every liter of gasoline that enters the tank, on average a little over 0.5 liters of vapor exists the vehicle. Since the Stage II pump is set to collect 1 liter of the vapor mixture per liter of gasoline dispensed, the Stage II nozzle is able to collect 100% of the emissions that escape the vehicle. However, the Stage II nozzle is also drawing in 0.5 liters of additional air to make up the difference. When the additional air mixes with the vapor mixture emitted from the vehicle, the vapor concentration is diluted below the equilibrium concentration and vapor pressure in the UST. In response, gasoline in the UST vaporizes until equilibrium is reestablished. The newly created vapor increases the pressure in the UST and excess air and gasoline vapors are pushed out of the vent pipe. The benefit of collecting 100% of emissions at the vehicle is offset by the release of emissions further down the line.

Scenario B: Stage II Under-collection: In a Stage II under-collection scenario, excess gasoline vapors are being released at the fill neck (Figure 8). This scenario can occur if the A/L ratio is less than 1 or if the dynamics of the refueling event are such that $A < V$.

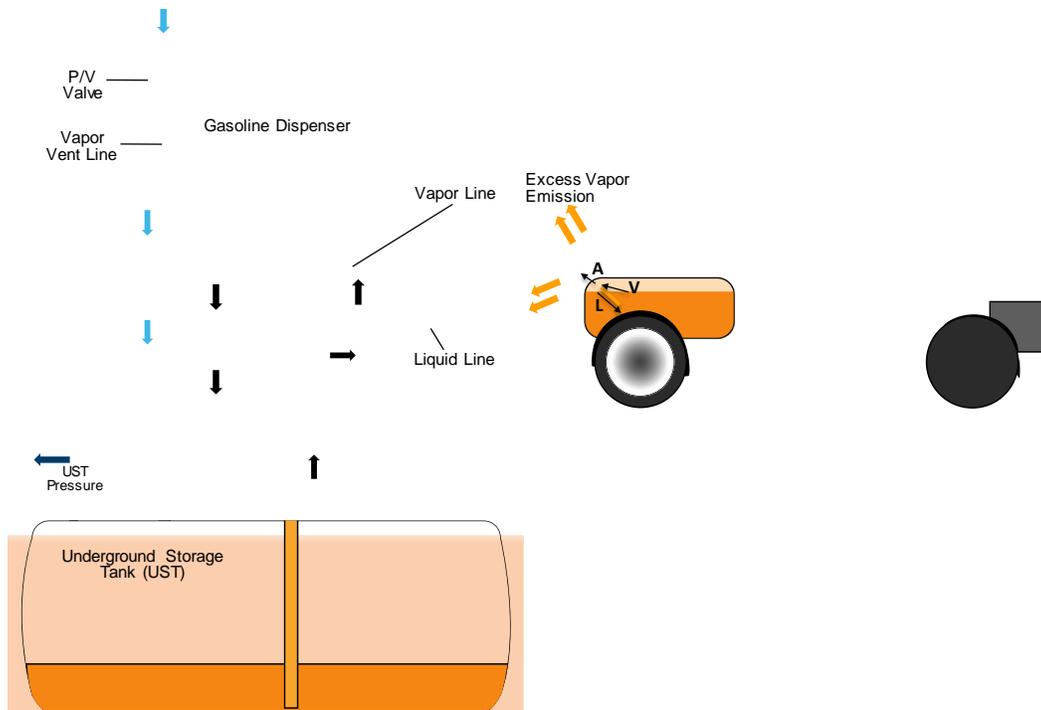


Figure 8: Gasoline Dispensing Facility with Stage II Vacuum Assist operating with $A < V$

Real-world Stage II under-collection example: If the UST is 25°C and the vehicle tank is 10°C, then the vapor concentration in the UST is higher than the vapor concentration in the vehicle tank. As gasoline enters the vehicle tank, equilibrium conditions change. The gasoline temperature in the vehicle tank rises and gasoline vaporizes to maintain equilibrium as warm gasoline enters the vehicle tank. The newly created volume of vapor is then pushed out of the filler neck along with the original volume of vapor mixture of the tank. In this scenario, for every liter of gasoline that enters the tank, an average of 1.3 liters of air and gasoline vapor are pushed out. If the Stage II vacuum pump is set to draw in 1 liter per liter of gasoline dispensed, the surplus vapor mixture, 0.3 liters per liter, escapes to the atmosphere. In this scenario, the best efficiency that Stage II could provide is only 75%.

ORVR + Stage II Compatibility

The concerns with ORVR + Stage II compatibility only affects the net Stage II efficiency, it does not affect ORVR efficiency. When an ORVR vehicle is refueled, essentially all the vapor generated from the refueling event is captured on the vehicle within the carbon canister (98% control efficiency of ORVR). The concern for compatibility between ORVR and Stage II systems arises only for vacuum-assist Stage II systems, where the Stage II refueling nozzle is calibrated to a fixed A/L ratio. When refueling an ORVR vehicle with a vacuum-assist Stage II system, little to no gasoline vapor is captured by the Stage II nozzle and only air is routed to the UST. The excess air ingested into the UST can result in vapor growth as gasoline in the UST evaporates into the air to re-establish equilibrium. Any excess volume generated from vapor growth within the UST will be released from the P/V valve on the UST vent pipe. The dynamics of the process is similar to the Stage II over-collection scenario presented in Figure 7.

The emissions created by the interaction between ORVR-equipped vehicles and vacuum-assist Stage II systems are referred to as excess vent emissions. These are incremental to the normal breathing loss emission from UST's, which can be partially controlled through a properly functioning P/V valve on the UST vent pipe. Excess vent emissions are essentially zero for balance nozzles, ORVR compatible nozzles, and stations with UST vent post processors. For balance-type Stage II systems, there is no compatibility concern because there is no active vacuum to draw in excess air, and thus no excess vent emissions. ORVR-compatible vacuum-assist Stage II nozzles can be added to reduce excess vent emissions. These operate to detect when refueling an ORVR vehicle and decrease the A/L ratio, thus decreasing the amount of excess air ingestion into the UST.

The excess emission rate for vacuum-assist Stage II systems depends on four factors: (1) The fraction/throughput of fuel going into ORVR vehicles; The larger the fraction of total gasoline throughput from a UST which is dispensed into ORVR vehicles, the greater the total volume of air ingested by the Stage II nozzles, and greater potential for vapor growth. (2) The design and operating A/L of the Stage II nozzle; the higher the A/L ratio, the greater the volume of air ingested relative to the amount of gasoline dispensed. (3) The RVP of the gasoline in the UST; evaporation of fuel into air increases with increasing RVP. (4) The temperature of gasoline in the UST; evaporation of fuel into air increases exponentially with fuel temperature.

It is important to note the magnitude of excess vent emissions arising from the compatibility between Stage II vacuum-assist systems and ORVR are small. Data generated by CARB indicates less than 1% loss of control efficiency at full vehicle fleet turnover of ORVR vehicles refueled at Stage II systems with A/L 0.9-1.1.⁵¹ The combined effect of the increased control efficiency of ORVR (98%) relative to Stage II (71%) results in an overall reduction in emissions from the GDF, even when accounting for the excess vent emissions. As the penetration of ORVR vehicles in a fleet increases, there comes a point where the benefits from Stage II are *de minimis*. In 2011, the U.S. EPA made this determination in their ORVR Widespread Use Assessment⁵² and provided guidance⁵³ to states on removal of Stage II vapor recovery programs. CARB switched from Stage II to a more comprehensive EVR program designed to address GDF emissions as a system, which as discussed above in Section 1, was only possible because of ORVR penetration.

Section 3: Global literature review on the adoption of ORVR and Stage II vapor recovery, including data on efficiency and cost-effectiveness of the two control technology options.

Table 2 provides a summary of the status of Stage II and ORVR adoption in global automotive markets. ORVR has been implementing in the United States since 1998, China since 2019, and will be implementing in Brazil starting in 2023. As shown in Table 1, the U.S. states are progressing with the decommissioning of Stage II, except for California, where Stage II was replaced with EVR. Following Directive 2009/126/EC, Europe is progressing with the implementation of Stage II across all EU Member States. A 2017 report

⁵¹ California ARB, Preliminary Draft Test Report, Total Hydrocarbon Emissions from Two Phase II Vacuum Assist Vapor Recovery Systems During Baseline Operations and Simulated Refueling of Onboard Refueling Vapor Recovery (ORVR) Equipped Vehicles, Project Number ST-98-XX, June 1999.

⁵² <https://www.federalregister.gov/documents/2012/05/16/2012-11846/air-quality-widespread-use-for-onboard-refueling-vapor-recovery-and-stage-ii-waiver>

⁵³ https://www3.epa.gov/ttn/naaqs/aqmguide/collection/cp2/20120807_page_stage2_removal_guidance.pdf

from the European Commission⁵⁴ reported 72% of all service stations in the EU are currently fitted with Stage II vapor recovery nozzles. Essentially full implementation was expected by 2020. China partially implemented Stage II in Beijing and Shanghai, but China MEE and Beijing EPB realized Stage II would not meet the reductions needed for their air quality objectives and adopted ORVR with China 6. As shown in Figure 9, by 2025, 55% of annual global automotive sales will be equipped with ORVR.

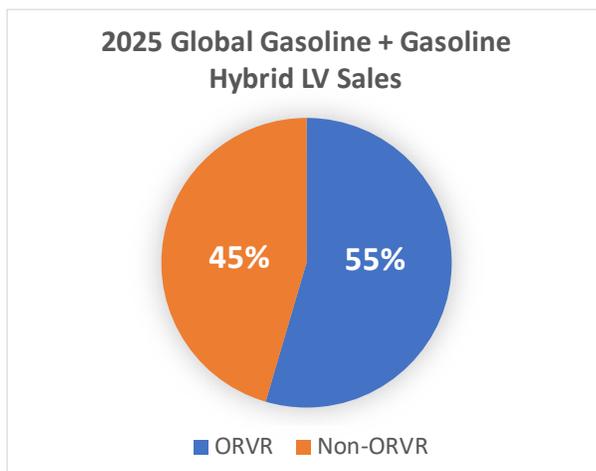


Figure 9: 2025 Global Light-Duty Gasoline and Gasoline Hybrid Vehicles with (blue) and without (orange) ORVR. Data Source: IHS Markit Rivalry

In-use Efficiency of Stage II:

The emission sources for a Stage II system are comprised of the interface between the vehicle and nozzle, connections and access points in the UST, and the UST vent stack. When looking at the in-use refueling efficiency, one must include leaks and UST vent stack emissions. California addressed this through the Enhanced Vapor Recovery (EVR), which consists of vent stack emission and UST pressure requirements. To maintain a negative pressure in the UST with EVR, there must be no leaks and a sizable fraction of ORVR-equipped vehicles is needed in combination with ORVR-detectable nozzles.

a. Europe: European Directive 2009/126/EC does not regulate UST vent pipe emissions, despite this being an important emission source for Stage II systems as described in Section 2. The certification efficiency of 85% in European Directive 2009/126/EC only includes the control of emissions at the interface between the vehicle and nozzle and requires only an annual verification that the vapor/petrol ratio (A/L) shall be equal to or greater than 0.95 but less than or equal to 1.05. In the Final Evaluation Report for Directive 2009/126/EC, the European Commission acknowledged that vent pipe emissions occur, and that implementation of Stage II will make them worse by stating:⁵⁵

⁵⁴ <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52017DC0118&from=EN>

⁵⁵ <https://publications.europa.eu/en/publication-detail/-/publication/2fce37c3-d154-11e5-a4b5-01aa75ed71a1>, See page 78.

“Defra (2008)⁵⁶ also notes that where Stage II systems transfer the recovered petrol vapour to a storage tank at the service station, experience across the EU has shown that there is a risk of excessive pressure building up in the storage tank if these systems are fitted with vapour-tight pressure vacuum relief valves. This leads to the consequent VOC release through the pressure vacuum relief valves or the tank lid fittings (PELG, 2014).”⁵⁷

Despite this acknowledgement, in 2016, the European Commission chose to disregard and postpone the issue of vent pipe emissions associated with Stage II, stating (emphasis added)⁵⁸:

“It is noted that this issue was already acknowledged during the adoption process of the VOC-II Directive as well as during the approval of CEN Standard EN 16321:2013. **However, the final decision was to not regulate this aspect in the Directive on the grounds that it would be difficult for manufacturers of Stage II systems to meet the 85% recovery criterion if this included additional emissions from the vent pipe which might not be related to the functioning of the Stage II equipment.** Similarly, during negotiation of the CEN Standard EN 16321:2013, **it was decided to postpone the issue**, though it could ultimately form an additional or complementary part to the CEN standard. Alternatively, it could constitute a subject to be covered by EU Guidance.”

The issues of leaks and vent stack emissions remain unaddressed in the Directive.

Across Europe, a reliance on certification data, an absence of in-use testing, and the disregard for UST vent pipe emissions has led to the general belief that 85% (or greater) of refueling emissions are captured by Stage II vapor recovery. However, changes in fuel temperatures and volatility complicate Stage II efficiency because the system A/L is calibrated based upon ideal conditions. Variable fuel composition and temperatures make it extremely challenging to test in-use Stage II efficiencies at a GDF. Conditions can change daily or even with every vehicle. The lack of in-use testing has led to the general acceptance of the certification values, values measured under conditions that will rarely occur naturally. In the JRC’s 2012 Review of European Test Procedure for Evaporative Emissions: Main Issues and Proposed Solutions,⁵⁹ the JRC acknowledged Stage II system efficiency can be as low as 55% in-use due to the inability to match the A/L ratio with V/L ratio and to poor maintenance. Typical in-use efficiencies of 50-60% for Stage II have been recently provided by the CLOVE consortium.⁶⁰

Furthermore, the failure to view the GDF as a system by ignoring vapor leaks and UST vent emissions is a significant shortfall in the program. Another significant shortfall of the program is that the certification of Stage II systems in the EU is based on a single tank system performance test, whereas CARB requires a system performance test on a 100-vehicle matrix representing the current vehicle population (see Table 3 for detailed comparison of EU and CARB certification requirements). CARB determined that failure to

⁵⁶ Defra (2008) AQ05(08) Petrol Vapour Recovery at service stations: explanatory notes on the use of orifice vent devices, pressure vacuum relief valves and applications for Stage II.

⁵⁷ PELG (2014) Petrol Filling Stations Guidance on Managing The Risks of Fire & Explosion (the Red Guide) updated 2014; Petroleum Enforcement Liaison Group (PELG); Energy Institute.

⁵⁸ <https://publications.europa.eu/en/publication-detail/-/publication/2fce37c3-d154-11e5-a4b5-01aa75ed71a1>, See page 79.

⁵⁹ https://publications.jrc.ec.europa.eu/repository/bitstream/JRC77061/final_evap_report_online_version.pdf

⁶⁰ CLOVE Consortium, “Study on post-EURO 6/VI emission standards in Europe – Part A, Draft Report, October 2019.

test a vehicle matrix representing the vehicle population may bias the test toward either compliance or noncompliance.⁶¹ Certifying a Stage II system in the EU against a single tank creates an extra layer of uncertainty on how these Stage II systems will perform on a whole fleet of vehicles with different refueling system designs.

b. U.S. and CARB: The U.S. EPA and CARB have extensively studied the in-use efficiency of both balance and vacuum assist Stage II systems.⁶² Even with the most advanced certification requirements resulting in 95% certification efficiency (Table 3) and significant investment in inspection, testing, maintenance and government oversight, CARB estimates the in-use efficiency of Stage II to be 71%.⁶³ To overcome the limitations with the typical Stage II systems, CARB developed Enhanced Vapor Recovery (EVR) procedures.⁶⁴ A summary of current GDF emissions factors utilized by CARB⁶⁵ is included in Table 4. In developing these emission factors, CARB estimates the control for Stage II systems to be ~71% prior to EVR, a 95% efficiency for ORVR and a 98% efficiency for Stage II + ORVR. Connecticut also conducted extensive Stage II GDF inspections and found that Stage II systems quickly develop leaks and other malfunctions and determined actual Stage II efficiency may actually be 60% or less.⁶⁶

c. Japan: Japan's 59th Experts Committee on Motor Vehicle Emissions issued a draft report⁶⁷ on cost effectiveness of fuel evaporative emission reduction measures in Japan where a median efficiency of 55% was utilized for Stage II vapor recovery systems. The technical approach for the Japan Stage II system is different than U.S. and Europe as it relies upon a condensation process to return liquid fuel to the tank.⁶⁸ While the technology is interesting, a 55% in-use efficiency is not competitive with the existing refueling vapor recovery options of ORVR and existing Stage II systems.

Cost-Effectiveness of Stage II vs. ORVR

Cost-effectiveness studies for Stage II and ORVR are sensitive to the underlying assumptions of recovery efficiency, capital component costs, maintenance costs, and system lifetime. It is often difficult to directly compare between studies due to the different assumptions utilized. The following section provides a review of existing data from Europe and the U.S.

a. Europe Stage II and ORVR: The European Commission has not conducted a full cost-benefit analysis of ORVR, but the JRC has evaluated ORVR component costs and recommended ORVR be evaluated. In the JRC's 2012 Review of European Test Procedure for Evaporative Emissions: Main Issues and Proposed Solutions,⁶⁹ the JRC acknowledged that "no detailed analysis of technical feasibility, performance, and costs of the ORVR was undertaken" for the Commission's 2008 Impact Assessment for Directive 2009/126/EC, where ORVR was discarded as an option at an early stage of the assessment. JRC

⁶¹ https://ww3.arb.ca.gov/testmeth/vol2/tp201.2_april2013.pdf

⁶² Barnard R. McEntire, Performance of Balance Vapor Recovery Systems at Gasoline Dispensing Facilities, San Diego Air Pollution Control District, May 18, 2000

⁶³ <https://ww3.arb.ca.gov/vapor/gdf-emisfactor/gdfumbrella.pdf>

⁶⁴ https://www.arb.ca.gov/testmeth/vol2/cp201.pdf?_ga=2.87634330.323969504.1578687804-1352500858.1570019936

⁶⁵ <https://ww3.arb.ca.gov/vapor/gdf-emisfactor/attachment1.pdf>

⁶⁶ https://www.ct.gov/deep/lib/deep/air/siprac/2011/gasoline_dispensing_facility_vapor_control.pdf

⁶⁷ https://www.env.go.jp/council/07air-noise/y072-59/mat02_2.pdf

⁶⁸ <https://tatsuno-corporation.com/jp/products/139/>

⁶⁹ https://publications.jrc.ec.europa.eu/repository/bitstream/JRC77061/final_evap_report_online_version.pdf

recommended at least two different options should be evaluated in a cost/benefit analysis: (1) Introduction of ORVR and Stage II discontinuation and (2) Introduction of ORVR and Stage II retention. The JRC estimated the incremental vehicle component costs for ORVR at 16.1 – 29 Euros (~\$18-\$32), which included changes to fill pipe, valves, hoses, and the canister. In the Commission’s 2008 Impact Assessment for the Stage II Directive,⁷⁰ the Commission stated: “If and when such a tightening of the regulated limits on evaporative emissions is considered, the incremental step of proceeding to “full” ORVR could also be considered as a complement or replacement for Stage II PVR controls at service stations.”

A 1996 study prepared by Chem Systems for the U.K. Department of the Environment estimated the cost-effectiveness for an active Stage II system at £1,060 (~\$1,377) per tonne of VOC recovered for 74.6% control and the cost-effectiveness for ORVR as £1,441 (~\$1,873) per tonne of VOC recovered for 95% control.⁷¹ A 2005 DG Environment study provided by Entec UK Limited⁷² estimated the costs per ton of VOC for implementation of Stage II in 2010, including saving from recovered petrol, within a range of €2,080 – €3,175 (~\$2,305 - \$3,519) per tonnes at stations ranging from >3000m³ to >500m³ of annual fuel throughput, respectively. This study assumed an investment lifetime of 5 years on aboveground Stage II equipment.⁷³ The 2016 European Commission Final Evaluation Report for the Stage II Directive⁷⁴ provided a cost-effectiveness value for Stage II (VOC-II) ranging from €2,314 (~\$2,565) to €2,610 (~\$2,894) per tonne VOC abated, which excluded administrative and compliance costs.

b. U.S. EPA Stage II: The most comprehensive study of Stage II cost-effectiveness in the U.S. is provided in a 1991 U.S. EPA Technical Guidance Document.⁷⁵ The EPA used a unit cost estimate approach based on model station sizes and equipment specifications for all components in a Stage II system. Capital cost estimates are converted to annualized costs using an eight-year life on aboveground equipment and 35-year life on below-ground equipment. The program cost-effectiveness for multi-product dispensers, excluding stations < 10,000 gal /month,⁷⁶ was estimated to be \$1,310 per metric ton.⁷⁷ It is important to note that this cost-effectiveness value was based on two key assumptions that have changed since 1991: (1) The capital and maintenance costs were only for balance-type Stage II systems and (2) the fuel recovery credits were estimated using an in-use Stage II efficiency of 86%. Since 1991, most Stage II systems are now vacuum-assist. U.S. EPA has estimated the capital and maintenance costs for Stage II vacuum-assist

⁷⁰ See Page 14 of Commission Staff Working Document, Accompanying document to the Proposal From the Commission to the European Parliament and Council for a directive proposal for Stage II petrol vapour recovery during the refueling of petrol cars at service stations, Impact Assessment, 2008.

⁷¹ U.K. Department of the Environment, Final Report, “Further Research into the Costs of the Proposed Stage II Controls and On-Board Vapour Recovery”, April, 1996.

⁷² https://ec.europa.eu/environment/air/pdf/entec_report.pdf

⁷³ See Table 4.1, https://ec.europa.eu/environment/air/pdf/entec_report.pdf

⁷⁴ European Commission, “Final Evaluation Report, Evaluation of Directive 1994/63/EC on VOC emissions from petrol storage & distribution and Directive 2009/126/EC on petrol vapor recovery”, 2016.

⁷⁵ US EPA, “Technical Guidance – Stage II Vapor Recovery Systems for Control of Vehicle Refueling Emissions at Gasoline Dispensing Facilities, Volume I: Chapters”, EPA-450/3-91-022a, November, 1991.

⁷⁶ This exemption level is approximately equivalent to the 500m³/yr exemption provided in European Directive 2009/126/EC

⁷⁷ See Table 5-13, US EPA, “Technical Guidance – Stage II Vapor Recovery Systems for Control of Vehicle Refueling Emissions at Gasoline Dispensing Facilities, Volume I: Chapters”, EPA-450/3-91-022a, November, 1991.

systems to be approximately 31% higher than balance systems.⁷⁸ As more experience and data from CARB on the in-use efficiency of Stage II has become available, EPA has reduced the in-use efficiency used in Stage II emission reduction and fuel recovery credit calculations to 71%. Accounting for the increased costs of vacuum-assist systems, the reduction in Stage II efficiency to 71%, and adjusting for inflation (increase in costs by factor of 1.86 since 1991) and the increase cost of gasoline (increase in cost by factor of 2.5 since 1991), a current estimate of Stage II cost-effectiveness using the U.S. EPA Stage II cost data is \$2,727 per metric ton VOC reduced. Even though the EU program does not address UST vent emissions, the values presented above for the EU (~\$2,600-\$2,900 per tonne) and the U.S. (~\$2,800 per tonne) are remarkably similar.

It is important to also note that the EU and U.S. have estimated the investment lifetimes for aboveground Stage II equipment to be 5-8 years, so recurring testing, inspection, maintenance, and hardware replacement costs for Stage II must be considered and included when considering the adoption, expansion, or retention of Stage II. Annual testing and inspection costs include the training and certification of operators, GDF compliance monitoring and recordkeeping, and fees associated with daily, monthly, and annual inspections. In 2012, U.S. EPA estimated annual costs of \$1700 associated with Stage II vacuum pump maintenance, training and certification of operators, and GDF compliance costs.⁷⁹ Annual testing costs are dependent upon the number of different tests conducted and their frequency. As mentioned above, annual U.S. EPA and CARB Stage II testing requirements are more comprehensive than those required in Europe, where an annual test of A/L is the only requirement in European Directive 2009/126/EC. In the U.S., annual testing could include A/L volume ratio verification, pressure decay tests, dynamic backpressure tests, and verification of P/V valve functionality. In-use testing experience suggests that the A/L and pressure decay tests are the most likely to fail.⁸⁰ Costs of these tests have been estimated to range from \$1,350 - \$1,950 depending on the number of dispensers and USTs at the station. Annual recurring maintenance costs per station were estimated in the 2016 evaluation of Directive 2009/126/EC by the European Commission to range from €257-€738 (\$285-\$818) depending on the size of the station. Finally, hardware replacement costs can be annualized using the estimated lifetime of aboveground equipment (5-8 years) and below-ground equipment (14-35 years), which are the range of lifetimes based on EU and U.S. estimates of Stage II capital investment lifetime. U.S. EPA estimated these annual capital recovery costs to be ~\$6,100 (2019 dollars) for stations ranging from 50,000 – 100,000 gallons/month.

c. U.S. EPA ORVR: The cost-effectiveness of ORVR implementation has been assessed by the U.S. EPA in its 1987 and 1994 Regulatory Impact Assessments (RIAs).^{81,82} The 1987 RIA includes incremental costs for an ORVR system prior to the adoption of U.S. Enhanced Evaporative emission standards (2-day, 3-day, elevated diurnal and hot soak temperatures, and running loss control). Since the U.S. Enhanced

⁷⁸ See Table 2-19, US EPA, "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.

⁷⁹ US EPA, "Final Regulatory Support Document, Widespread Use for Onboard Refueling Vapor Recovery and Stage II Waiver, Decommissioning Stage II Vapor Recovery Financial Benefits and Costs", May 2012.

⁸⁰ "Stage II Vapor Recovery Systems – Options Paper," U.S. EPA, Office of Air Quality Planning and Standards, pp. 59-60, February, 2006.

⁸¹ US EPA, "Draft Regulatory Impact Analysis: Proposed Refueling Emission Regulations for Gasoline-Fueled Motor Vehicles – Volume II – Additional Analysis of Onboard Controls, EPA-450/3-87-001b, July 1987.

⁸² US EPA, "Final Regulatory Impact Analysis: Refueling Emission Regulations for Light Duty Vehicles and Trucks and Heavy-Duty Vehicles," January 1994.

Evaporative emission standards provided some elements of design and hardware which would be needed for an integrated ORVR/evaporative system,⁸³ the 1994 RIA provided updated incremental hardware costs for an ORVR system excluding those costs associated with the U.S. Enhanced Evaporate standards.

- In the 1987 RIA, the long-term hardware costs were estimated to be \$12.87 for light-duty vehicles and \$17.85 for light-duty trucks.⁸⁴ To quantify the net costs in 2019 dollars, these costs estimates were multiplied by a Retail Price Equivalent (RPE) factor of 1.26⁸⁵, multiplied by a factor of 2.25 to adjust for inflation, and fuel recovery credits were updated based on current gasoline prices.⁸⁶ The resulting incremental net costs in 2019 dollars for an ORVR system prior to the U.S. Enhanced Evaporative Emission standards is \$27.24 and \$36.56 for light-duty vehicles (LDVs) and light-duty trucks (LDTs), respectively.
- In the 1994 RIA, the long-term hardware costs were estimated to be \$4.28 and \$4.79 for light-duty vehicles and light-duty trucks, respectively.⁸⁷ These costs already include an RPE of 1.26. To quantify the net costs in 2019 dollars, these cost estimates were multiplied by a factor of 1.76 to adjust for inflation and fuel recovery credits were updated based on current gasoline prices.⁸⁸ The resulting incremental net costs in 2019 dollars for an ORVR system after the adoption of U.S. Enhanced Evaporative Emissions standards is -\$4.21 and -\$13.52 for LDVs and LDTs, respectively. Following the adoption of Enhanced Evaporative Emission standards, the economics for ORVR became a net cost savings.

The U.S. EPA determined from the results that the ORVR program is a cost-effective strategy for the control of refueling emissions in all vehicle classes nationwide, even with Stage II controls in place.

⁸³ US Federal Register, 58 FR 16001 (March 24, 1993).

⁸⁴ Refer to Table 5 in Reference 78.

⁸⁵ Refer to Page 5-10 in Reference 79.

⁸⁶ The cost in the RIA was updated based on DoE EIA website for January 13, 2020.
<https://www.eia.gov/petroleum/gasdiesel/>

⁸⁷ Refer to Table 5.8.2 in Reference 79.

⁸⁸ The cost in the RIA was updated based on DoE EIA website for January 13, 2020.
<https://www.eia.gov/petroleum/gasdiesel/>

Table 2: ORVR and Stage II adoption in global automotive markets

Type		Japan	EU	US	China	Brazil
ORVR	Fuel Vapor Recovery in Vehicle	x	x	✓	✓	✓
		Decided to not adopt in 2017	ORVR option was discarded in 2008 without any detailed analysis of technical feasibility, performance and costs of ORVR	Required by 1990 Clean Air Act Amendments. Adopted in 1994. Implementation into light-duty fleets began with the 1998 model year.	Adopted with China 6 in December 2016. Implementation into light-duty fleets required by July 1, 2020. Several provinces announced early implementation for 2019.	Adopted with PROCONVE L7/L8 (CONAMA Resolution 492/2018) in December 2018. ORVR phases in 2023-2025.
Stage II	Fuel Vapor Recovery at Nozzle	✓	✓	✓ ⇒ x	✓ ⇒ x	x
		Promoting introduction on a voluntary basis	Required by Directive 2009/126/EC.	Required by 1990 Clean Air Act Amendments in Serious, Severe, and Extreme ozone nonattainment areas. In 2012, U.S. EPA determined ORVR was in "widespread use" and provided a pathway for states to decommission Stage II systems.	Limited adoption in major cities since 2007	No requirements

Table 3. Stage II Certification Requirements

Criterion	EU Stage II	U.S. EPA Stage II	U.S. CARB EVR	Comments
Preliminary Application				Demonstrates system meets basic performance standards before starting test protocol
- 30-day operational test			✓	
- 50-vehicle operation observation				
200 spillage observations				
Boundary conditions for petrol and ambient temperatures	✓	✓	✓	
Component bench testing			✓	Testing if required to verify individual component performance
180-day hands-off equipment durability demonstration before performance test			✓	Normal station operation. Can perform only specified maintenance
Back pressure standard	✓	✓	✓	Limits system pressure
Single vehicle tank system performance test	✓			Representative tank or vehicle
100-vehicle system performance test		✓	✓	Representative fleet vehicles in specified matrix
Refueling emissions measured at fill neck	✓	✓	✓	
Determination of storage tank emissions		✓	✓	Vent line emissions
Determination of pressure-related fugitives			✓	Losses from unintended openings
Nozzle spitting, spillage and liquid retention requirements			✓	Limits fugitive refueling emissions and efficiency degradation
P/V volume ratio specification	✓ (if used)	✓	✓	
Proportionality specification	✓	✓	✓	
A/L ratio specification	0.95-1.05	0.95-1.05	N/A	
Stage II emission certification efficiency	85%	95%	95%	

Table 4. California 2013 emission factors:

California Air Resources Board (CARB) GDF Emission Factors		
Category	Emission Factor (lbs/kgal)	Control Efficiency (Relative to Uncontrolled)
Uncontrolled Emission Factor (No ORVR, No Stage II)	8.4	-
Stage II Only (pre-EVR) - no ORVR	2.4	71.4%
ORVR Only - No Stage II	0.42	95.0%
ORVR with Stage II (pre-EVR)	0.12	98.6%
ORVR with Stage II EVR	0.021	99.8%