Rationale for Including ORVR as a Component within China V to Stabilize and Reduce the Rapidly Increasing VOC Inventory Caused by Evaporative Emissions

EXECUTIVE SUMMARY

- Evaporative emissions consist of diurnal (parking), running loss, permeation, hot soak, and refueling. Combined, these VOC emissions now total 1.1 million metric tons for the 110 million LDVs in China. By 2025, the vehicle population will grow to 300 million LDVs. Unless, more stringent evaporative standards are implemented, evaporative emissions will increase to 2.8 million metric tons.
- The vehicle population is growing in China, because new vehicles are being added to the fleet at a ratio of 3.5:1 relative to older vehicles being scrapped. To keep the evaporative VOC emissions from growing, new evaporative standards need to be implemented that reduce emissions by 72% or more.
- Vehicle testing conducted by Tsinghua University at Beijing CATARC demonstrates the insufficiency of purge and canister capacity on China IV/V vehicles at controlling evaporative emissions. Testing shows that ORVR reduces refueling emissions by 99%, reduces single day parking emissions by 55-96%, and reduces emissions from extended parking events by 98% over the controls now specified on Chinese vehicles. Overall, ORVR will cut total evaporative emissions by 70%, just meeting the target necessary to stabilize and reduce the emissions inventory.
- Euro 6 standards will only cut evaporative emissions by 28%. Even if Stage II was also implemented at 100% of the gas stations across China at the same time Euro 6 standards were implemented, total evaporative emissions would only be reduced by 47%. This level of control is still far below the minimum of 72% reduction necessary to stabilize emissions. Tsinghua's testing at CATARC shows that little to no changes to automobile design would be necessary for automakers to meet a Euro 6 requirement, which explains why it would provide little benefit and why some European automakers are supporting its adoption. If Euro 6 is adopted instead of ORVR, emissions will continue to climb and air quality will continue to decline.
- Adoption of standards similar to US Tier 2 or California LEV II would reduce evaporative emissions by 90%, and adoption of standards similar to US Tier 3 or California LEV III would reduce evaporative emissions by 98%. ORVR can be implemented at a cost of 126 RMB/vehicle and would reduce emissions by 70%. ORVR would be a compromise solution that minimizes cost, yet achieves the emissions reductions necessary to improve air quality. Automakers are already engineering ORVR systems in response to Beijing EPB's communication that ORVR will be necessary by 2017. ORVR could be adopted nationwide in China by 2018.
- ORVR, Tier 2, and Tier 3 are all cost effective. The vehicle owner who invests in these evaporative controls will receive more value in recovering fuel than the cost of the controls. The payback time to the consumer for ORVR is 1.7 years.
- Stage II is not adequately efficient to achieve the needed reductions in refueling emissions and Stage II is not the appropriate long-term vehicle refueling control strategy. Stage II technology is heavily dependent on inspections, testing, and maintenance to perform well. Even though Stage II systems are certified at over 90% efficient, best estimates are that in-use Stage II efficiency is about 70%. Extension of the Stage II requirement throughout China would involve significant costs and burden to the station operators and require the long-term investment of government

resources with great uncertainty about the in-use emission reductions that will be achieved. Stage II systems require annual investment costs for maintenance and upkeep and must be completely overhauled about every seven to ten years, which means costs will have to continually be sunk into stations to achieve only 70% efficiency.

- ORVR has been successfully implemented in the US and Canada for over 15 years. There have been over 1600 tests conducted on in-use ORVR vehicles with an average reduction efficiency of 98%. The odometer readings on a large fraction of these vehicles exceeded 100,000 km. An ORVR program is far less expensive than Stage II and does not involve the broad use of government resources to implement and work effectively.
- There are no significant compatibility issues between ORVR and Stage II technology. When refueling an ORVR vehicle, the current Stage II dispensing nozzles used in China would perform as they do when used with a non-ORVR vehicle. The increase in underground storage tank emissions related to Stage II vacuum assist nozzles is small and not significant until the overall reductions from Stage II become less than 10% of the uncontrolled inventory. Thus, for many years, ORVR and Stage II could both provide meaningful reductions in refueling emissions.
- An in-use dispensing rate limit will help in the design of ORVR systems. Stage II requires that dispensing rates be limited to 38 L/minute and a similar limit would be appropriate for ORVR.

SUMMARY: CONTINUING TO FOLLOW THE EUROPEAN REQUIREMENTS WITH A EURO 6 DIURNAL STANDARD WOULD PROVIDE ONLY MINOR IMPROVEMENT, AND ORVR SHOULD BE IMPLEMENTED INTO CHINA V BY 2018 AS A MINIMUM BUT EFFECTIVE REQUIREMENT TO STABILIZE AND REDUCE THE EVAPORATIVE VOC INVENTORY BEFORE ADOPTING EVEN MORE EFFECTIVE MEASURES THEREAFTER.

By the end of 2014, total evaporative and refueling emissions from combined running loss, refueling, diurnal, permeation, and hot soak emissions will reach 1.1 million metric tons per year across China or 8.8 kg/vehicle·year. The per-vehicle evaporative emissions are over ten times higher than exhaust hydrocarbon emissions from China IV/V vehicles. Over the next ten years, 16-18 million new gasoline vehicles will enter the fleet each year, thus increasing these emissions. New vehicles are entering the Chinese fleet at a ratio of 3.5:1 to older vehicles being scrapped. To keep the emissions inventory at an arbitrary 2018 level of 1.7 million metric tons/year, evaporative emissions will have to be cut by 72%. To reduce the emissions inventory, larger reductions are necessary. Stage II will not come close to meeting the 72% minimum reduction requirement. Refueling emissions comprise only 27% of total evaporative emissions, and Stage II, with a control efficiency of only 70%, can lessen evaporative emissions by only 19% (= 70% x 27%) if Stage II was 100% implemented across China. Continuing to follow the European norms and adopting Euro 6 48-hour standards will also fail to meet this 72% requirement: without Stage II, Euro 6 would reduce emissions by only 28%; with Stage II, the two requirements would add and reduce emissions by only 47% -- still well short of the needed minimum. While measures are available that can provide greater than 90% reductions – such as standards equivalent to US Tier 2 or Tier 3 -- ORVR is a simple, low-cost compromise that is able to cut total evaporative emissions by 69-75%. Adding ORVR to China V is the most reasonable short-term option to reduce the emissions inventory while the vehicle fleet continues to grow.

ORVR would provide 98% control efficiency of refueling emissions and would increase canister capacity by 250% to improve diurnal and running loss control; plus, ORVR would increase purge rates by at least 250%. The benefits that ORVR can provide are demonstrated by recent evaporative emissions vehicle testing conducted by Tsinghua University at Beijing CATARC. Their testing showed that ORVR cuts single day parking emissions by 55-96% and extended three day parking emissions by over 98%. The testing also shows that current Chinese vehicles are purging at insufficient rates, or not purging at all, during low driving speeds that are typical in congested areas like Beijing. ORVR will result in automakers calibrating more purge on their vehicles at certification, which will cut running loss and parking emissions. Testing also shows that vehicles that meet the Euro 6 standards continue to have diurnal emissions 5 to 22 times higher than with ORVR.

ORVR is extremely cost effective. ORVR simply requires routing refueling vapors through an enlarged diurnal canister and recalibrating the engines to increase purge rates. This technology could rapidly be applied onto vehicles. Due to announcements by Beijing EPB, most automakers are currently designing canisters and fuel systems for ORVR on their Chinese platforms, so automakers could accommodate ORVR on their vehicles for a 2018 introduction. The investment cost to the automakers is only 126 RMB/vehicle, but this cost would ultimately be paid for by the consumer. The reduction of over 70% of remaining refueling, running loss, diurnal, and hot soak emissions by ORVR would result in the recovery of 6.6 kg to 9.5 liters of gasoline each year by the vehicle owner that would have otherwise been lost as emissions. This recovered gasoline has a value of 8 RMB/Liter (or 10.8 RMB/kg) and would provide the consumer with 76 RMB/year of value that could be credited against their initial cost for ORVR. The consumer's net present value (NPV) payback time is only 1.7 years. Over a ten year period, the vehicle owner will receive 439 RMB in value above the cost of the 126 RMB investment cost for ORVR.

Almost 200 million vehicles – including micro-cars and very large SUVs and trucks -- have been manufactured and sold with ORVR systems in the United States and Canada since 1998. Over 2,000 of these in-use vehicles have been tested as part of the US EPA's IUVP (in-use verification program) and IUCP (in-use compliance program), and the data show that ORVR reliably provides over 98% control of in-use refueling emissions. In addition, over one million ORVR-equipped vehicles have been sold and are on the roads in China (examples are vehicles from Jeep, Chrysler, Volvo, and Cadillac). There have been no reported problems with the operation or refueling of these vehicles across China. In addition to the recent testing by Tsinghua University, samples of these vehicles have been completed at SGS Environmental Testing Corporation (Aurora, Colorado) and twice at Beijing CATARC (Beijing, China). These tests demonstrate that ORVR provides over 98% control of refueling emissions, under Chinese conditions and using Chinese fuels. Chinese authorities can be confident that ORVR performs reliably, and its implementation can be executed by automakers.

While current Stage II systems provide some emission reductions and could be retained during an ORVR phase-in, it is clear that Stage II is not a viable option when compared with ORVR for the long-term control of refueling emissions. Stage II is at least 25 percentage points less efficient (98% for ORVR and 70% for Stage II) and involves a significant cost burden to station operators for initial installation costs as well as annual costs related to scheduled and unscheduled hardware replacement and inspections and system performance testing. Moreover, the Stage II equipment must be replaced at each gas station about every seven to ten years, which means the high cost cycle will continue indefinitely while the Stage II program is in force. To work effectively Stage II also involves the long-term commitment of government resources to monitor new installations and modifications and assure that the inspections, system testing, and maintenance are conducted. ORVR would involve only the government resources needed to regulate less than 100 manufacturers of gasoline-powered highway vehicles. Stage II would involve the annual oversight of up to 100,000 service stations. There are no functional and no significant emission-related interaction issues between ORVR vehicles and Stage II technology, so current Stage II systems could remain in place and provide added reductions as ORVR phases-in and then be eliminated when ORVR is in widespread use. Furthermore, ORVR systems recover enough fuel vapor that the vehicle owner recovers the cost in less than two years. ORVR requires no maintenance or periodic evaluations as does Stage II, and the larger carbon canister needed for ORVR is a significant piece of the hardware needed for improved evaporative emission controls such as the 48 hour diurnal test.

The fact is that Chinese authorities cannot delay on incorporating ORVR, because the evaporative VOC inventory is continuing to grow. The large amount of VOCs are contributing to haze, PM2.5, and ozone. While the emissions inventory reported here certainly justifies the need to add ORVR, the evaporative emissions inventory is likely much higher. The recent data collected by Tsinghua University suggests that vehicles are probably not purging sufficiently. A tremendous amount of methanol and propane is being added to gasoline in China, which accelerates vaporization and emissions. It is going to quickly become extremely difficult for Chinese authorities to reduce these emissions. For warm cities, like Guangzhou, and for cities with heavy traffic congestion that leads to high running loss and diurnal emissions, like Beijing, the situation is more urgent to add effective evaporative and diurnal controls like ORVR. Otherwise, it could be decades before these cities can see reductions in their evaporative VOC inventory and an improvement to air quality. Also, Chinese authorities should not delay their decision to obtain more precise inventory data. These controls are inexpensive and the value of the recovered gasoline is so great that they will be shown to be cost-effective under any condition. Delaying the decision is not going to improve air quality, but it's going to cause continued degradation. China needs to take action now, before its vehicle population becomes more mature and implementation of new controls becomes less impactful.

I. EURO 6 REGULATIONS WILL NOT REDUCE THE EVAPORATIVE VOC EMISSIONS INVENTORY IN CHINA, AND ORVR WILL BE NECESSARY TO REACH THE MINIMUM 70% REDUCTIONS IN NEW VEHICLE EVAPORATIVE EMISSIONS TO STABILIZE AND REDUCE THE INVENTORY.

Compared with exhaust emissions, evaporative emissions are not well-controlled in China today. Evaporative emissions are a broad classification of emissions that include refueling, diurnal, running loss, permeation, leaks, and hot soak. Using Beijing environmental conditions as an example, each light-duty gasoline vehicle emits about 7 kg of combined evaporative VOCs per year in regions with Stage II and about 9 kg of VOCs per year in the very large number of regions of China without Stage II. The relative fraction of each type of evaporative emissions is shown in Figure 1, which shows that running loss dominates emissions. Refueling and diurnal emissions remain substantial in areas both with and without Stage II. The current vehicle population exceeds 100 million. About 900,000 metric tons of evaporative VOCs are emitted across China each year; 40,000 metric tons of VOCs are emitted each year in Beijing alone. Adopting Euro 6 standards will only reduce emissions on new vehicles by 28-34%. As shown in Figure 2, this relatively minor reduction is not substantial enough to cover the expected increase in the vehicle population and to also achieve a reduction in the evaporative VOC inventory. In order to stabilize and reduce the evaporative VOC inventory, China will have to adopt more effective control measures. The reductions can be achieved by adding ORVR, which will add larger canister capacity, increase purge rates during low-speed driving, and provide near complete refueling emissions control to the vehicle. These improvements will have a major impact in reducing running loss, refueling, diurnal, and hot soak emissions and will result in a combined reduction of 70% or more of evaporative emissions. This substantial reduction can stabilize and reduce the VOC inventory over time while the vehicle population continues to grow. ORVR is necessary to realize meaningful in-use reductions and to improve air quality.

The California Air Resources Board (CARB) and US EPA have shown that four fundamental items are necessary for effectively controlling in-use evaporative VOC emissions: (1) high canister capacity, (2) high purge rates during low speed driving, (3) onboard refueling vapor recovery (ORVR), and (4) a low diurnal SHED (Sealed Housing for Evaporative Determination) limit. Euro 6 requirements alone do little to address these fundamental items.

As a result of US Tier 2 and California LEV II standards, the canister capacity on US vehicles is 250% larger and purge rates are 600% higher than in China today (see Table I). The larger canister capacity and purge rates are needed to regenerate the canister during low speed driving, ensure near-zero emissions during short parking events up to two days, prevent emissions breakthrough during extended parking events of 2-4 days or more, and minimize running loss emissions. Euro 6 standards will only increase canister capacity by 60% and increase purge rates by 115%. Euro 6 will not result in the application of best available technology by automakers and will do little to reduce in-use emissions. Chinese regulators need to take measures to substantially increase canister capacity and low-speed purge air volume.

The United States and California also require ORVR, which is not specified in the Euro 6 standards, to provide reliable, maintenance-free elimination of refueling emissions. Euro 6 relies upon the simultaneous adoption of Stage II vapor recovery to provide refueling control. Studies conducted in the US indicate that at best, Stage II can provide only 70% control of refueling emissions, but this occurs only with regular inspection, testing. and maintenance. To obtain complete reductions, every gas station must be equipped with Stage II. The reality is that only 10% of China's gas stations now have Stage II, and recent studies in China suggest that the working efficiency of Stage II at these stations is much lower than 70%. With time, ORVR can provide much better overall control. Testing of over 2000 in-use vehicles by the US EPA has shown that ORVR provides better than 98% control efficiency over the vehicles' lifetimes. Chinese regulators need to adopt ORVR to address the large amount of refueling emissions that remain and will grow as the Chinese vehicle fleet increases from 100 million vehicles today to over 300 million vehicles by 2025.

Lastly, the Euro 6 standards do not decrease the diurnal SHED limits from the current Type IV 24-hour diurnal level of 2 grams per day. In contrast, US limits now range between 0.5 and 0.65 grams per day (and will soon be 0.30 g/day on LEV III vehicles). To reach these low SHED limits, automakers must use of low permeation fuel system materials and low leak hose connections. Higher limit values, such as the 2 g/day value used in China and Europe, do not necessitate attention to these emission sources or other any significant attention to the other remaining fuel vapor emissions from the vehicle. These emissions are economically controllable, and Chinese regulators should consider adopting lower diurnal SHED limits to encourage better fuel system design and use of low permeation materials.

The most important factor Chinese authorities should consider is the level of evaporative emissions control that will be necessary to reduce the evaporative VOC inventory and improve air quality. Figure 2(a) shows that the Chinese evaporative emissions inventory will continue to climb to almost 3 million metric tons by 2025 unless better controls are implemented. Figure 2(b) shows that evaporative emissions will also continue climbing (and air quality will continue to worsen) if only Euro 6 standards, which provide a 28-34% reduction in emissions, are implemented.

The minimum evaporative emission reduction percentage necessary to maintain the annual evaporative VOC inventory at a constant level was calculated. Each year, new vehicles are sold and added to the vehicle population and older vehicles are scrapped that subtract from the vehicle population. When a vehicle is scrapped, that vehicle no longer contributes to the emissions inventory. When a new vehicle enters the fleet, its emissions add to the inventory but at a lesser amount than the scrapped vehicle. Table II summarizes an analysis that suggests that reductions in the Type IV evaporative emission standards must exceed 71% in 2018 to maintain the emissions inventory at 2017 inventory levels (which will be 1.8 million metric tons of VOCs). China III-V vehicles emit 8,806 g/year of VOCs. According to forecasts by IHS Global Insight, in 2018 gasoline light-duty vehicle (LDV) sales will reach 29.9 million and 7.1 million LDVs will be scrapped, or a 3.5:1 ratio of new vehicles to scrapped vehicles. In order to net zero emissions gain, new cars must emit 72% lower [calculated by (1-1/3.5) = 72%] than the LDVs they are replacing. Obviously, if a Euro 6 48-hour diurnal standard reduces emissions by only 30% (less than half of the minimum level), then the inventory will continue to grow. From Table I we see that the only options that meet or exceed the 72% reduction minimum include: (1) Current China Type IV 24-hour diurnal + ORVR achieving reductions of 69-75%, (2) Euro 6 new Type IV 48-hour diurnal + ORVR achieving 71-76% reductions, and (3) US Tier 2 48-hour diurnal + ORVR achieving 89-91% reductions.

Regulating to achieve the highest reductions will result in the greatest rate of decrease in the evaporative emissions inventory. This analysis demonstrates the trends seen in Figure 2(b) and 2(c), which shows implementing US Tier 2 standards + ORVR in 2018, will result in the most rapid decrease in the evaporative VOC inventory.

The minimum action that Chinese authorities should take is to add an ORVR requirement to the existing China V Type IV 24-hour diurnal standard. This would result in a 250% increase in canister capacity (compared with only 60% for Euro 6) and a 250% increase in purge rate (compared with only 115% for Euro 6). This would also greatly reduce diurnal and running loss emissions plus improve canister regeneration during low-speed driving. It would nearly eliminate refueling emissions both in regions with Stage II and in regions without Stage II. Overall, evaporative emissions would be reduced by 69-75% (see Figure 3); these reductions would be sufficient to reduce the evaporative VOC inventory from 2017 levels in the future. Ideally in the near term (for example China 5.1), Chinese authorities could implement both Euro 6 diurnal standards and ORVR. Canister capacity would increase by 250%, but purge rates would increase by 350%. The standards would be nearly equivalent to the combined US 1996 Enhanced Evaporative and 1998 US ORVR standards, and would provide better canister regeneration and reduced running loss emissions during low speed driving. Evaporative emissions would be reduced by 71-76% from present levels, and would accelerate the rate of evaporative VOC inventory reduction.

The US experience in how Enhanced Evaporative and ORVR controls reduced the VOC evaporative emissions inventory may be informative. By 1999, when the US was beginning to phase-in Enhanced Evaporative and ORVR controls, the VOC inventory for these sources was about 2.087 million metric tons for a population of 205 million gasoline-powered passenger cars and light trucks and an annual gasoline consumption of 492 billion liters. It is estimated that by 2010 the evaporative inventory had dropped to about 0.920 million metric tons even though the gasoline vehicle population had increased by about 13 percent and fuel consumption had increased by 3.8 percent. This was a 55 percent reduction in the evaporative inventory over 10-11 years.

The current Chinese fleet is about 112 million vehicles. For these 112 million vehicles, the current evaporative standards are similar to those in the US that preceded the 1996 Enhanced Evaporative standards. There is also no ORVR on Chinese vehicles. Table II shows that the current VOC inventory for the Chinese vehicle population is 1.1 million metric tons. With the relatively low average vehicle age and the strong demand for new vehicles, a year-to-year net increase of 15 million vehicles or more in this population is likely. By 2020, the Chinese gasoline LDV population will reach 217 million vehicles, and the VOC emissions will reach 2.073 million metric tons. So, by 2020 the Chinese vehicle population and VOC emissions inventory will match the 1999 US vehicle population and VOC inventory levels.

As was discussed above, for a similar sized fleet, Enhanced Evaporative and ORVR standards reduced US evaporative emissions by about 55 percent over 10-11 years. The US experience suggests that Enhanced Evaporative and ORVR standards could reduce emissions by about 50 percent in the first ten years after they were implemented and this could help to offset the increase in the evaporative inventory caused by substantial fleet growth.

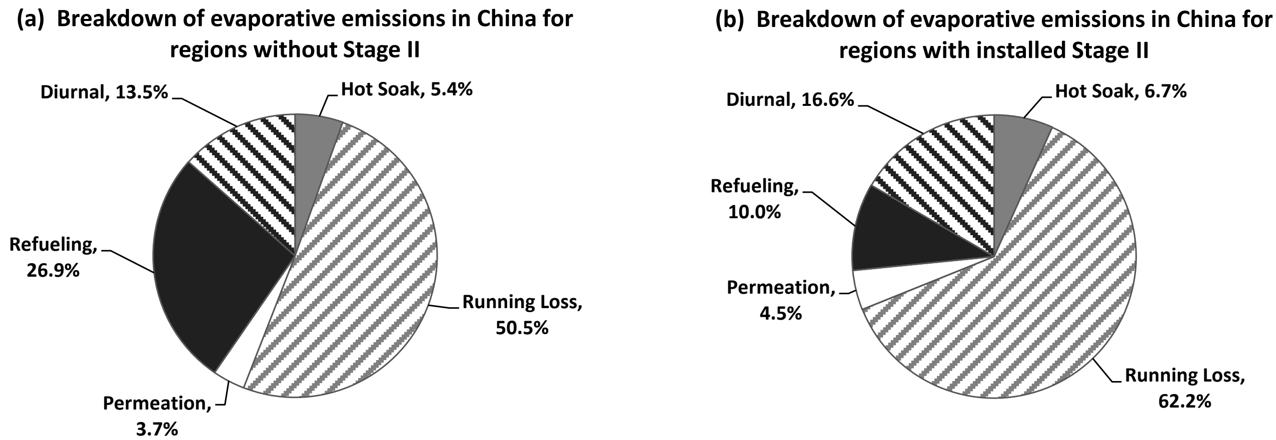

Figure 1. Evaporative emissions are a broad classification of VOC emissions arising from hot soak, running loss, permeation, refueling, and diurnal. In China (on China III-V vehicles) these emissions now total 9 kg/vehicle·year in areas without stage II and 7 kg/vehicle·year in areas where Stage II has been completely installed. Figure 1(a) shows the relative contributions of hot soak, running loss, permeation, refueling, and diurnal in regions of China where there is no installed or operating Stage II; figure 1(b) shows the relative contributions in which Stage II has been installed and is operating. In both cases, running loss emissions are the largest contributor, but diurnal and refueling contributions remain substantial in both regions with and without Stage II.

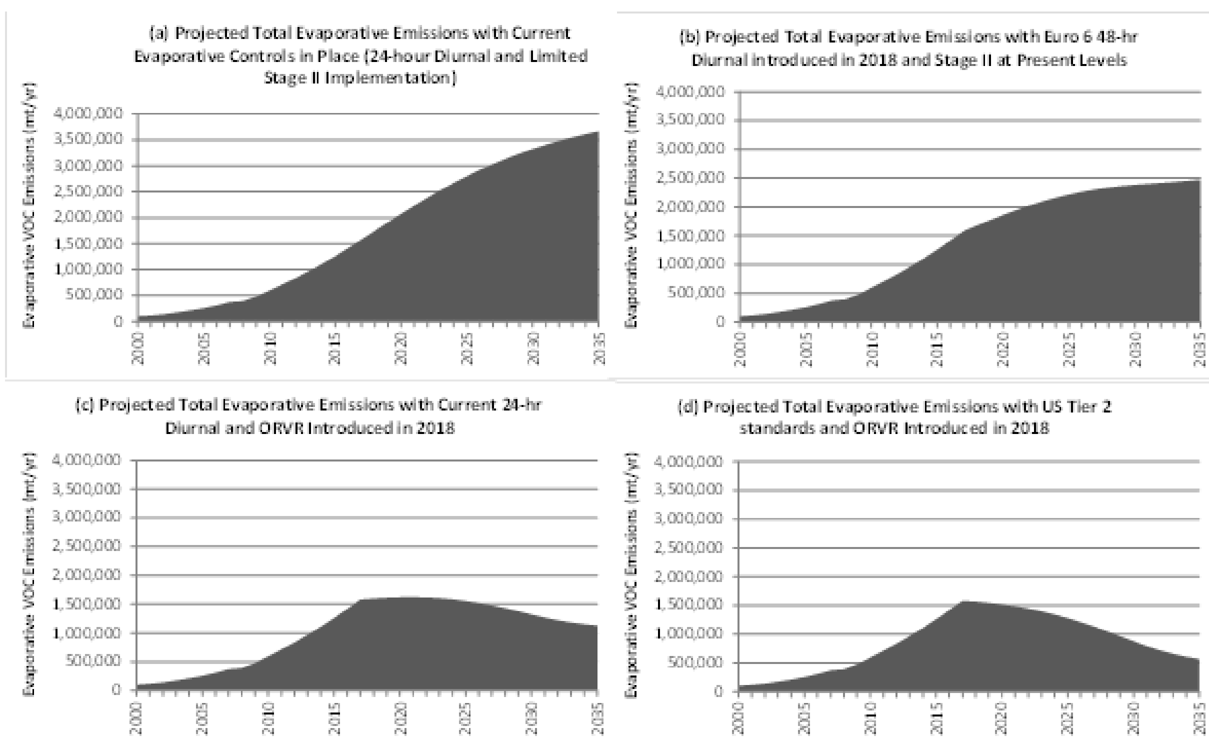

Figure 2. The projected evaporative VOC emissions inventory for China (a) will increase if current evaporative standards are left in place, (b) will continue to increase at a slower rate if only the Euro 6 diurnal standards are introduced in 2018, (c) can stabilize and decrease if ORVR is introduced in 2018, or (d) can be decreased markedly if US Tier 2 and ORVR standards are introduced in 2018.

Table I. Effect of Regulatory Standard on Major Evaporative Control Functions and Emissions

	Current China Type IV 24-hour Diurnal	**Euro 6 new Type IV 48-hour Diurnal**	**Current China Type IV 24-hour Diurnal + ORVR**	**Euro 6 new Type IV 48-hour Diurnal + ORVR**	**US Tier 2 / CA LEV II 48-hour Diurnal + ORVR**
Canister Capacity	20-30 grams of HC	30-50 grams of HC (+60%)	80-100 grams of HC (+250%)	80-100 grams of HC (+250%)	80-100 grams of HC (+250%)
Average Purge Rate	0.8-2.7 LPM, but largely at speeds exceeding 80 km/hr	1.7-5.8 LPM, but will need WLTP to improve at low speeds (+115%)	3.0—8.3 LPM (+250%)	4.4-11.1 LPM (+350%)	6.0-17.0 LPM, uniform over all speeds (+600%)
ORVR	None (with Stage II, only 70% control of refueling)	None (with Stage II, only 70% control of refueling)	Yes (98% control of refueling)	Yes (98% control of refueling)	Yes (98% control of refueling)
Diurnal SHED Limit	2 g/day	2 g/day	2 g/day	2 g/day	0.5-0.65 g/day
Emissions in Regions without Stage II	8.8 kg/vehicle·year	6.3 kg/vehicle·year (-28%)	2.2 kg/vehicle·year (-75%)	2.1 kg/vehicle·year (-76%)	0.8 kg/vehicle·year (-91%)
Emissions in Regions with Stage II	7.1 kg/vehicle·year	4.7 kg/vehicle·year (-34%)	2.2 kg/vehicle·year (-69%)	2.1 kg/vehicle·year (-71%)	0.8 kg/vehicle·year (-89%)

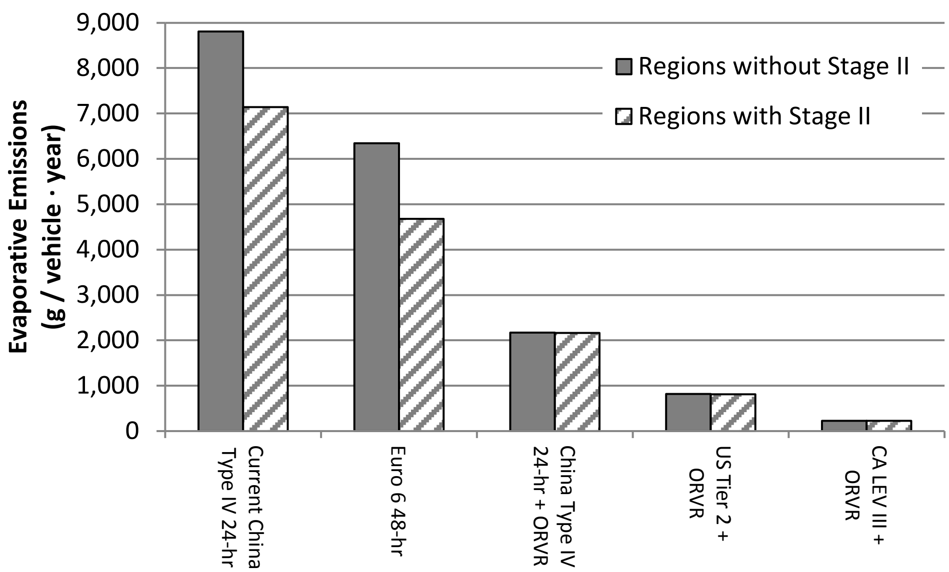

Figure 3. Gasoline vehicles are now emitting 7.1-8.8 kg/year (7,100-8,800 g/year as shown on graph) of evaporative VOC emissions. Euro 6 evaporative standards will still result in emissions of 4.7-6.3 kg/year (a 30% reduction). Adding ORVR can reduce emissions to 2.2 kg/year (a 73% reduction), adding Tier 2 and ORVR can reduce emissions to 0.8 kg/year (90% reduction), or adding California LEV III and ORVR can almost eliminate evaporative emissions.

Table II. Minimum New Vehicle Evaporative Emissions Reductions Necessary to Maintain or Reduce China's VOC Inventory at a Given Year's Level.

Year	Number of New LDVs (million)	Number of Scrapped LDVs (million)	Net Number of New LDVs Entering Fleet (million)	Total LDV Population (million)	Type IV Evaporative Emissions from Scrapped Vehicles (mt/yr)	Emissions Exiting with Scrapped Vehicles (mt/yr)	Evaporative Emissions VOC Inventory for China's LDV Fleet (mt/yr)	Necessary Evaporative Reduction from Type IV Level to Maintain Zero VOC Inventory Growth (%)
2014	19.6	3.9	15.7	112.0	8,806	34,304	1,111,000	80.1%
2015	21.4	4.7	16.7	128.7	8,806	41,299	1,261,000	78.1%
2016	22.8	5.4	17.4	146.1	8,806	47,960	1,419,000	76.2%
2017	24.1	6.2	17.9	164.0	8,806	54,999	1,582,000	74.1%
2018	24.9	7.1	17.9	181.8	8,806	62,350	1,748,000	71.6%
2019	25.5	7.9	17.6	199.4	8,806	69,819	1,911,000	68.9%
2020	26.1	8.8	17.3	216.7	8,806	77,301	2,073,000	66.3%
2021	26.6	9.6	17.0	233.7	8,806	84,832	2,232,000	63.8%
2022	27.1	10.5	16.6	250.2	8,806	92,344	2,386,000	61.3%
2023	27.5	11.3	16.1	266.4	8,806	99,849	2,533,000	58.7%
2024	27.8	12.2	15.6	282.0	8,806	107,345	2,672,000	56.2%
2025	28.2	13.0	15.2	297.2	8,806	114,844	2,802,000	53.8%

II. STAGE II IS NOT ADEQUATELY EFFICIENT TO ACHIEVE THE NEEDED REDUCTIONS IN REFUELING EMISSIONS AND IS NOT THE APPROPRIATE LONG-TERM VEHICLE REFUELING CONTROL STRATEGY.

Refueling emissions involve gasoline hydrocarbons from vapor displacement, spillage, and underground storage tank (UST) vent emissions. Stage II vapor recovery is made up of gasoline dispensing facility (GDF) hardware, comprised of both above and below ground hardware components. These system elements must be designed, installed, and maintained correctly in order for Stage II to significantly reduce refueling emissions. Stage II has gone through at least three generations of development. The Stage II systems installed in most of the US and Europe use the second generation of technology. The Stage II systems required in California, known as Enhanced Vapor Recovery (EVR), represent the third generation. Systems specified for use in China are mostly second generation but those few stations with Stage III processors have some elements of the EVR program.

<u>Efficiency</u>: Stage II systems are certified with efficiencies of 90% or more. Certification is done under controlled conditions with new hardware and with all other parts of the system confirmed to be tight and working properly. Stage II hardware is certified as a system and not as individual components. After a Stage II system is installed and approved, a station cannot switch components, such as nozzles, from the certifying company's model to another and expect the same emission control results as in the certified configuration.

The Stage II technology in China has several limitations which limit its efficiency. First, it is important to know that the CARB certification process uses a prescribed matrix of 100 vehicle types which is intended to represent the in-use fleet mix at the time the equipment is being certified by California. This fleet mix changes over time, so Stage II certifications for future sale must be renewed each four years and meet current requirements. Current Stage II installations do not have to be modified or replaced if the system is recertified by ARB, but otherwise there will be operating and efficiency shortcomings. Past new system certifications used only non-ORVR vehicles. Current certification protocols include both ORVR and non -ORVR vehicles. Second, within the certification protocol there are no test procedure-specific controls on RVP beyond those in place through other regulations nor are there any specifics related to dispensed fuel or vehicle fuel tank temperatures. However, all three of these parameters vary geographically and with time over the course of a year and affect refueling vapor volumes and hydrocarbon concentrations in the vapor. As discussed below, changes in these three parameters affect the system efficiency and impact how well the Stage II system performs.

Furthermore, even though a Stage II system may be certified at 90% refueling control efficiency, this level of control is not achieved in-use. There are several basic reasons for this shortfall:

a) <u>Lack of visual inspections and maintenance</u>: Stage II nozzles and aboveground components wear with use and require periodic repair or replacement. Performance can degrade in two ways: (1) slowly but regularly, starting after the first day of installation or repair, as components wear or calibrations drift, and (2) in a sudden drop, such as when equipment fails or malfunctions (example of vacuum pump breaking). It is often the case that the recommended inspections and maintenance are not conducted in a timely manner or at all.

b) Lack of completion of necessary periodic system testing and follow-on maintenance: Stage II is a system, not just the dispenser-based hardware. There are three tests required periodically (normally annually) to assess the proper functioning of the Stage II system. These include dynamic backpressure, pressure decay, and air-to-liquid (A/L) volume ratio tests. If these tests are not conducted or any indicated maintenance is not performed, the efficiency will be reduced.

c) Dispensed fuel/tank vapor dynamics -- (vapor-to-liquid (V/L) ratio):

    i. Vapor growth: The volume of vapor emitted from the vehicle fuel tank depends on the temperature and vapor pressure of the dispensed fuel. If the temperature of the dispensed fuel is greater than that of the fuel in the vehicle tank, vapor will be created in the vehicle fuel tank as the dispensed fuel evaporates to reach equilibrium in the fuel tank head space. The dispensed fuel vapor pressure is usually greater than the vehicle fuel tank vapor pressure, leading to vapor growth in these situations. The volume of vapor emitted will thus exceed the volume of fuel dispensed. This excess volume may not be captured by the Stage II vacuum assist nozzle. (V/L >1)

    ii. Vapor shrinkage: Conversely, if the dispensed fuel temperature is cooler than the vehicle fuel tank temperature, the cooler fuel will cause the vapor in the vehicle fuel tank head space to condense. The volume displaced from the fill pipe to the Stage II nozzle thus has more air, which could lead to an increase in UST vent emissions when fuel in the UST evaporates into this air. (V/L <1)

d) Vacuum assist nozzle design: Vacuum assist nozzles are designed to draw a specific volume of air for each volume of fuel dispensed. For most of the Stage II vacuum assist nozzles this design value, known as the A/L ratio, varies from 1.0-1.2. These nozzles normally employ boots at the nozzle vehicle interface to contour in-flow streamlines to maximize vapor capture. However, this design approach always results in some fresh air being drawn into the UST and the flow streamlines can further be affected by the direction and speed of ambient wind. The optimum efficiency only occurs when the V/L for the refueling event equals the A/L for the nozzle. If V/L > A/L then control may be lost at the fill pipe interface. If the V/L < A/L then excess air will be drawn into the UST.

e) System tightness: Stage II is a system, not just the dispenser-based hardware observed by the user. For the system to maintain its efficiency, the vapor routed to the UST as well as any vapor created in the UST due to excess air must be retained within the system. This is nearly impossible when the A/L exceeds 1.0; the surplus volume forced back into the UST must be vented. Stage II systems using vacuum assist nozzles employ pressure/vacuum (p/v) valves on the UST vents to maintain a slight positive pressure. However, these p/v valves require inspection and maintenance like other components. Even if the p/v valve is working properly, the valves are designed to vent to atmosphere so these pressure-related emissions are not fully contained. Beyond this, it is often the case that fugitive emissions occur as a result of vapor leaks from underground vapor piping for the Stage II system or UST access points such as the various sumps, the fuel fill port, and the Stage I vapor recovery port.

f) Measurement of Stage II efficiency: Unlike ORVR, there is no direct way to measure the true efficiency of Stage II systems in-use. The certification protocol cannot be repeated on an in-service Stage II system. Successful completion of the three mandated periodic tests are an indicator that the systems are performing well, but there is no way to know at any given time when a system would fail the test. It is good if a system which fails a test is repaired, but for the Stage II systems in China today, the test(s) do not indicate how long a system did not meet the requirements or how long before it may not meet the requirements of that test or another. Also, there are other factors which cannot be replicated such as human factors (the way the attendant uses the nozzle) and the impact of vehicles such as 2-wheeled cycles or heavy-duty vehicles which are not included in the Stage II certification protocol.

Governmental agencies in California have conducted two studies of the efficiency of second generation Stage II systems such as those now installed in China. These studies indicated control efficiencies of 70-75%. This is based on test data and analyses for reasonably well maintained systems. The US EPA uses a value of 70 percent as well. Claims of higher values have been made by other governmental and private entities, but these have not been substantiated.

Sufficiency: Stage II is installed in the municipalities of Beijing, Shanghai, and Tianjin. Stage II is now achieving some control of refueling emissions in these areas, but the in-use efficiency is not known. Looking into the future, one must consider the policy question of whether Stage II should be retained and expanded to other areas as the long term strategy, adopted alongside ORVR in critical areas, or if it should be replaced with ORVR altogether.

a) Stage II Efficiency: As discussed above, the in-use efficiency of Stage II is well below that seen when a new system is certified. Values of approximately 70% are likely the best that can be expected for a reasonably well maintained system. This value is about 25 percentage points below those seen with ORVR in the US. Achieving greater efficiency with Stage II would likely require the adoption of the Enhanced Vapor Recovery regulations now in place in California. No other state in the US has adopted this complex and costly set of technologies. Current California EVR systems may not be compatible with the situation in China, since the EVR certifications are premised on a high penetration of ORVR vehicles.
b) Initial Cost: The installation of Stage II involves substantial investment. For a new station, costs for Stage II as envisioned under the MEP regulations ranges from 500,000 to 600,000 RMB for a moderate size station. For a retrofit installation, the cost of installing underground piping increases costs by an additional 300,000 RMB. These costs are passed on to the vehicle owners (the consumers of gasoline). For an average size station dispensing 500,000 liters/month, if these costs are spread over 5 years, they range from about 0.02-0.03 RMB/L (2-3 FEN/L). The Stage II systems in the three municipalities, with equipment installed in 2007-2009, are soon reaching the life cycle point for the installations. Thus, there will be additional, renewed costs for these stations if Stage II is retained.
c) Operating/maintenance costs and expertise: Achieving even the 70% efficiency for Stage II requires significant attention by the station operator. This involves both daily inspections and

maintenance as needed as well as three annual system tests and any required maintenance. These costs exceed 11,000 RMB per year, assuming no unscheduled recalibration or parts replacements. It will take time for this expertise to be gained in other parts of the nation. Without this level of inspection and maintenance, the control efficiency of Stage II can be expected to be 50% or lower.

d) Annual hardware cost: Aboveground hardware requires annual maintenance. This includes the replacement of the dispensing nozzle and related hardware as well as the p/v valve. Even for a moderate size station these costs exceed 23,000 RMB per year.

e) Phase-in: While Stage II controls may be able to be installed more quickly than fleet phase-in would occur for ORVR, but the differences are not large because of the rapid fleet growth in China. Due to a lack of experienced installers, it is reasonable to project that it would require at least three years to expand Stage II across China if a decision were made to do so. If ORVR was implemented at the same time, it is estimated that ORVR would cover over 30 percent of dispensed fuel in three years if ORVR was implemented in 2018.

f) Government Resources: Government oversight and enforcement is absolutely essential to assure Stage II systems are installed correctly and maintained. This is a recurring annual cost to government which is needed to ensure that inspections, testing, and maintenance are conducted.

g) Small Business: Stage II may have a disproportionately larger impact on small businesses. Current regulations do not allow waivers for small stations, but this may have to be reconsidered if the requirement goes nationwide. Any exemptions would reduce overall effectiveness.

III. WHY HAS ORVR BEEN SO SUCCESSFUL IN THE US?

At the time that the US was considering Stage II and ORVR, many states had a pressing need for VOC reductions to reduce ozone and $PM_{2.5}$. Ultimately, the US implemented Stage II as a near-term strategy for these problem areas and ORVR as the long-term strategy for the whole country. This approach provided quick but relatively expensive control in problem areas but allowed that the higher cost and lower efficiency Stage II technology could be removed at a later time when the more efficient ORVR technology was in widespread use. Combining the two approaches into one national strategy allowed regulators to optimize costs and benefits for the short and long terms. Over the long term, this strategy allowed for the maximum level of control at the lowest overall cost.

There are several technical reasons why ORVR has been successful in the US.

a) ORVR has wide applicability across all gasoline-powered highway motor vehicles. It applies to all gasoline-powered light-duty vehicles, light-duty trucks and complete heavy-duty vehicles. In all it covers 99.5% of all of these vehicles.
b) ORVR in-use efficiency is 98%. This is determined from over 1600 tests conducted on in-use vehicles.
c) ORVR systems are inexpensive. The value of the refueling vapor captured and purged in the engine as fuel offsets the cost to the consumer.
d) ORVR designs are highly durable in-use and require no maintenance.
e) Fuel system designs in response to the ORVR test procedure have reduced in-use gasoline spillage during refueling by 50 percent.
f) After initial purge, the larger activated carbon canister associated with ORVR creates the extra capacity needed for improved evaporative emissions control such as is needed for a 48 hour diurnal requirement.
g) ORVR requires relatively few government resources. Government regulates only the auto manufacturers, not each and every gas station.
h) ORVR technology and efficiency in-use are not sensitive to vapor shrinkage or vapor growth as is Stage II.

IV. THERE ARE NO SIGNIFICANT COMPATIBILITY ISSUES BETWEEN ORVR AND STAGE II.

There are no fundamental technical compatibility issues for Stage II and ORVR. ORVR technology will work effectively with the vacuum assist type Stage II nozzles used In China. In fact, during certification of Stage II equipment in California, including the generation of equipment now used in China, a mixed fleet of ORVR and non-ORVR vehicles were utilized to establish functionality. If there is concern, this can be addressed by a provision in the ORVR test procedure that the ORVR system could be tested and should pass the refueling emission standard with any certified Stage II vacuum assist nozzle or non-Stage II nozzle.

Some have raised a concern that ORVR and Stage II are not compatible from an emissions control perspective. This is simply not the case. The interactions are small and do not become of concern for many years after ORVR phase-in begins. When an ORVR-equipped vehicle with a liquid-seal in the fill pipe is refueled with a vacuum assist Stage II nozzle, the nozzle draws fresh air into the UST. Under some conditions this leads to increased UST vent emissions which affect Stage II system efficiency. This increase is referred to as the compatibility factor (CF). Overall, CF is proportional to the fraction of the total gasoline which is dispensed to ORVR vehicles at a given station over a given time period and the fraction of Stage II that is vacuum assist nozzles. In the case of China this value is essentially 100% for those areas with Stage II.

Figure 1, below, illustrates this interaction. Figure 1 shows ORVR phasing-in (ORVR) and gaining control of 80% of refueling emissions after only 12 years. It also shows Stage II initially controlling 70% of refueling emissions, but control attributable to Stage II (SII) decreasing as ORVR phases-in. The efficiency of Stage II on a per vehicle basis would remain at 70% but the overall reductions attributable to Stage II would decrease due to ORVR phase-in and the increase in CF. While the overall impact of the CF on Stage II control (SII-CF) is very small during the early years of an ORVR phase-in, as ORVR phases in, the reductions attributable to Stage II diminish as CF gets relatively larger. Thus, Stage II and ORVR could be in place simultaneously and both technologies could achieve substantial reductions during the phase-in. The emissions related to CF become important when the control provided by Stage II decreases to the point that CF related emission increases become larger than Stage II emission reductions. At this cross-over point, where CF is greater than Stage II, it would be advisable to remove Stage II or add additional control requirements such as ORVR-compatible nozzles or UST vent post-processors.

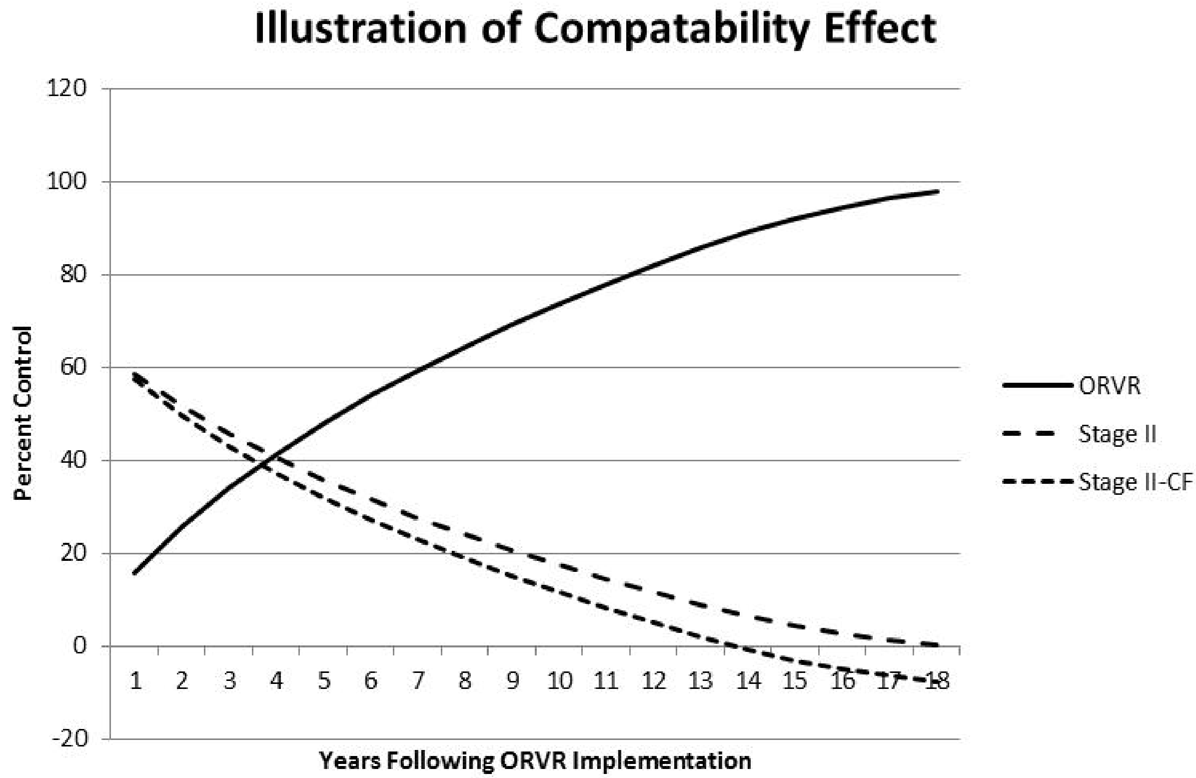

Figure 1. In the early years of ORVR phase-in, both Stage II and ORVR are providing value in reducing refueling emissions from the fleet. After about ten years, ORVR is reducing emissions by about 70% and Stage II is reducing emissions by 15%. The compatibility issues really do not negatively impact total emissions control until 13 years after ORVR is implemented.

V. ARE THERE OTHER ISSUES WITH IMPLEMENTING ORVR?

To optimize the in-use performance of ORVR an in-use dispensing rate limit should be set. This would reduce fuel spillage and allow ORVR system designs to accommodate a reasonable range of vapor flow rates. A limit of 38 liters/minute applies to Stage II and this value is appropriate for ORVR. ORVR has been in place in the US and Canada for over 15 years. There are over 160 million vehicles equipped with ORVR and it has been implemented with no technical issues. Going forward, the only real area of interest is related to keeping test procedures current as hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs) enter the fleet.

VI. ORVR IS A COST-EFFECTIVE MEANS TO REDUCE EVAPORATIVE EMISSIONS IN CHINA BY 6.6 KG/VEHICLE·YEAR AT A COST OF 126 RMB/VEHICLE AND WITH A CONSUMER PAY-BACK TIME OF 1.7 YEARS.

Costs to the automakers will increase as standards become more stringent and new test procedures and limits are applied that: (1) increase the mass of generated fuel vapors that must be controlled and to what extent, (2) affect how vapors must be vented and routed, (3) restrict the amount of permeation and leaks, (4) encourage increased purge rates, and (5) necessitate thermal management of the fuel tank. Table I shows how automakers will generally have to address the four major types of evaporative emissions – diurnal, refueling, permeation & leaks (excluding onboard diagnostic, or OBD, leak detection), and running loss – plus address any in-use standards from a technology perspective. Table I also shows the vehicle technology costs incremental to baseline technology in place to meet the current 24-hour Type IV diurnal standard. The incremental costs were obtained from the US EPA's evaporative program feasibility analyses and put into 2014 US dollars and Chinese RMB. For ORVR, the detailed incremental cost additions are broken down in Table II and total 126 RMB ($21.00 USD).

Ultimately, the control costs to the automakers are passed along to the consumer at the time of automobile purchase. The consumer, however, then benefits financially by the capture and use of otherwise lost gasoline vapors over the lifetime of the vehicle. This captured gasoline vapor currently has a value of 8 RMB/liter in China. The relationship between mass of emissions or recovered vapors (in grams) to its equivalent volume of liquid gasoline can be calculated from the following equation:

$$Recovered\ Liquid\ Gasoline, Liters = \frac{[Mass\ of\ Gasoline\ Vapor\ Captured\ by\ Control\ System, grams]}{(0.74\ kg/L) \times (1000\ g/kg)}$$

Figure 1 shows the total annual evaporative vehicle emissions for Beijing that would result from each of the global evaporative standards, including Stage II, if they were applied to that vehicle. The difference between the uncontrolled emissions and the remaining emissions for the applied standard provides the amount of gasoline captured by the control system as an annual fuel credit to the consumer. This credit is obtained each year of the vehicle's lifetime, assumed to be ten years, and offsets the initial investment cost of the control. Since the time value of money changes, a net present value (NPV) method is used to determine the overall balance between the initial investment cost of the control technology and the annual credit of gasoline that the consumer receives over the ten years of the vehicle's lifetime.

In the NPV analysis, the present value (PV) is equal to the investment – in this case the cost of the control to the automaker that is ultimately paid for by the consumer (for example, 126 RMB for ORVR). The future value (FV) is the anticipated credit value from recovered gasoline vapor that the consumer will receive incrementally as a result of the controls he invested in. The analysis conservatively assumes that gasoline will have constant value of 8 RMB/L. The recovery credit (RC) is based on the NPV at a 5% discount rate of the following calculation RC = (RMB/liter)x(liters/year) assuming a ten year or 124,140 km lifetime or 12.414 km per year. The purpose of the analysis is to determine whether investing in the controls when purchasing the vehicle is a good investment relative to other economic investment opportunities. This analysis is apart from the broader health and environmental costs associated with the pollution effects from the emissions. A common 5% interest rate was used as the basis for the analysis to determine the value of the gasoline credit received over the ten years of the vehicle's lifetime, expressed in present value. The present value of the recovered gasoline can be expressed by:

$$PV = \frac{FV}{(1+r)^n}$$

where r = the rate (set at 5%) and n = number of years. For the ten years of vehicle lifetime, the PV of the cumulative value of annual credits from recovered gasoline can be compared with the cost of the control to obtain the NPV:

$$NPV = Cost\ of\ Control + PV$$

$$NPV = Cost\ of\ Control + \sum_{n=1}^{10} \frac{FV}{(1+0.05)^n}$$

The Cost of Control is an investment, so it has a negative value. The credit from the recovered gasoline has a positive value. Therefore, if the NPV is positive, the investment is good relative to a 5% rate. If the NPV is negative, then the value of the recovered gasoline is insufficient to offset the cost of the investment in the controls relative to a 5% rate.

Figure 2 shows the results of the NPV analyses for five conditions: (1) the status quo condition (current Type IV 24-hour diurnal), (2) applying only the Euro 6 48-hour standard, (3) adding ORVR to the Type IV 24-hour standard, (4) progressing to US Tier 2 + ORVR standards, and (5) progressing to the California LEV III + ORVR standards. Again, a positive NPV means that the consumer has a net economic gain from recovered gasoline that exceeds the initial investment in the controls. An investment in a Euro 6 48-hour diurnal demonstrates a positive NPV in the shortest amount of time, or most rapid investment recovery, because Euro 6 costs automakers only 8 RMB per vehicle to install. But Euro 6 also provides the smallest emissions reduction and the lowest annual gasoline credit to the consumer, which explains why it also provides the lowest economic return over the ten year vehicle lifetime. Tier 2+ORVR produces the highest economic recovery over a 10 year period, but ORVR provides nearly the same emissions reduction but with a smaller investment and only a two year break-even point. These findings are consistent with the US EPA, who found a positive NPV for every rulemaking involving evaporative emissions. Note that for exhaust controls, there is only a negative NPV, because there is no energy recovery during the destruction of the emissions.

The economic cost-effectiveness analysis is performed to show whether a proposed standard is appropriate for the automakers and society. The investment costs for evaporative controls are low relative to exhaust aftertreatment and other regulatory demands and are clearly all a good investment for the consumer and society since fuel recovery credits offset initial costs. The health and environmental implications must also be factored into decision-making and would only make strict regulatory action more attractive. Since all of the analyzed standards have favorable economics and only require moderate investment, the regulatory decision should target the option that can provide the largest environmental and health benefit and can be implemented by the automakers in a short period of time. Table III shows a summary of investment cost, emissions reduction capability, recovered gasoline potential, and NPV for the regulatory options. Making a regulatory decision should weigh all these factors, but, most importantly, should consider the environmental benefit and the feasibility for implementation. Adding ORVR to the current Type IV 24-hour diurnal will provide the greatest environmental benefit in a technology package that can be most readily and quickly applied by industry. This recommendation would reduce vehicle emissions by 66 kg/vehicle or more over a ten year period with an initial investment of only 126 RMB. In contrast, requiring only Euro 6 would reduce emissions by only 25 kg/vehicle over a ten year period. This small reduction from only Euro 6 would not offset new emissions from the growing vehicle population, and air quality would continue to degrade. While a LEV III+ORVR option could be justified from an air quality and economics perspective, this standard would be difficult to implement technologically in the next five years. In summary, the recommendation is to add ORVR and consider also adding a Euro 6 48-hour diurnal standard, as well. These recommendations are not only justified as a sound economic investment for the consumer, but the needed technology is readily available and reasonably simple; plus this minimum level of control is absolutely necessary to achieve improved air quality.

Table I. Technology and Cost Comparison for Regulatory Options for Evaporative Emissions Control

Evaporative Standards	Current Type IV 24-hr	Type IV 24-hr + ORVR	Enhanced + ORVR (or Euro 6 + ORVR)	Tier 2 + ORVR	Tier 3 + ORVR
Diurnal	24-hr SHED and 2 g/day limit	24-hr SHED and 2 g/day limit	48-hr SHED and 2.5 g/day limit	48-hr SHED and 0.65 g/day limit	48-hr SHED and 0.3 g/day limit and 0.020 g/day BETP limit
Drive Cycle	60 minute NEDC	60 minute NEDC	30 minute FTP or WLTP	30 minute FTP or WLTP	30 minute FTP or WLTP
Canister Volume	0.5-0.8 Liters	1.8-2.5 Liters	1.8-2.5 Liters	1.8-2.5 Liters	1.8-2.5 Liters
Canister Design	Conventional single chamber	Single or double chamber	Single or double chamber	Double or triple chamber and low bleed	Double or triple chamber and very low bleed
Bleed Element	Not necessary	Not necessary	Not necessary	Not necessary	Possibly necessary for BETP, but not to meet full vehicle limit
Average Purge Rate Over Drive Cycle (100-200 bed volumes)	0.8-2.7 LPM	3.0-8.3 LPM	6.0-17.0 LPM	6.0-17.0 LPM	6.0-17.0 LPM
Purge Control Valve	Low capacity	High capacity	High capacity	High capacity	High capacity
Air Induction System Control	Not Necessary	Not Necessary	Not Necessary	Not Necessary	Used sometimes to offset other emissions
Refueling	None	ORVR and 0.05 g/L limit over 90 minute NEDC	ORVR and 0.05 g/L limit over 90 minute FTP or WLTP	ORVR and 0.05 g/L limit over 90 minute FTP or WLTP	ORVR and 0.05 g/L limit over 90 minute FTP or WLTP
Routing of tank vapors during refueling	To filler pipe	To diurnal canister	To diurnal canister	To diurnal canister	To diurnal canister
Typical Filler pipe diameter	25-50 mm	25-30 mm	25-30 mm	25-30 mm	25-30 mm
Typical tank vent hose diameter to filler pipe	16 mm	8 mm plus orifice	8 mm plus orifice	8 mm plus orifice	8 mm plus orifice
Typical tank vent hose diameter to canister	8 mm	16 mm	16 mm	16 mm	16 mm
Internal check valve (ICV)	Not necessary	Necessary	Necessary	Necessary	Necessary
Flow Limit Vent Valve (FLVV)	Not necessary	Necessary	Necessary	Necessary	Necessary
Canister Consideration	None	Low pressure drop	Low pressure drop	Low pressure drop	Low pressure drop
Permeation and Leaks	Affected by diurnal SHED limit (2 g/day)	Affected by diurnal SHED limit (2 g/day)	Affected by diurnal SHED limit (2.5 g/day)	Affected by diurnal SHED limit (0.65 g/day)	Affected by diurnal SHED limit (0.3 g/day)
Tank material	Typically monolayer of HDPE, possibly fluorinated or sulfonated	Typically monolayer of HDPE, possibly fluorinated or sulfonated	Typically monolayer of HDPE, possibly fluorinated or sulfonated	Twin sheet with EVOH	Twin sheet with EVOH, possibly blow molded
Hose material	EPDM or NBR/HNBR	EPDM or NBR/HNBR	EPDM or NBR/HNBR	Some use of Nylon-Teflon, THV, or EVOH multilayer	Some use of Nylon-Teflon, THV, or EVOH multilayer
Hose connections	Barbed or clamped	Barbed or clamped	Barbed or clamped	SAE J2044 connections	SAE J2044 connections
Running Loss	No control	No control	0.03 g/km	0.03 g/km	0.03 g/km
Thermal shielding of exhaust system or insulation of fuel tank	Not necessary	Not necessary	Optional	Optional	Optional
Fuel pump type	Recycle and on-demand	Recycle and on-demand	On-demand typical	On-demand typical	On-demand typical
In-Use Standard	None	None	Same as certification limit	Same as certification limit	Same as certification limit
Fuel tank considerations	None	None	Must use multilayer for permeation control	Must use multilayer for permeation control	Must use multilayer for permeation control. May need blow-molded.
Canister considerations	None	None	Should utilize low-aging carbon	Should utilize low-aging carbon	Should utilize low-aging carbon
Total Cost	**Baseline**	**126 RMB ($21.00)**	**170 RMB ($27.00)**	**190 RMB ($31.60)**	**285 RMB ($47.50)**

Table II. Incremental cost to automakers for adding ORVR functionality to a current Chinese vehicle

Part	Non-ORVR System	ORVR System	Remark	Cost Adder, RMB
Canister	0.5-0.8 L	2-2.5 L, pellet carbon, more plastic, and larger mounting bracket	Low pressure drop	60
Fuel Limit Vent Valve (FLVV)	None	New	Control refueling volume	40
Internal Check Valve	Can be incorporated in nozzle receiver	Duckbill or piston with spring and seal	Prevent vapor back-flow when refueling	8
Fuel Pipe	50 mm diameter	Decrease diameter	Produce liquid seal	---
Vapor Recycle Line	15 mm diameter	Decrease diameter	Reduce vapor generation	---
Vapor Outlet Hose	8 mm diameter	15 mm diameter	Reduce pressure drop	18
			TOTAL	126 RMB

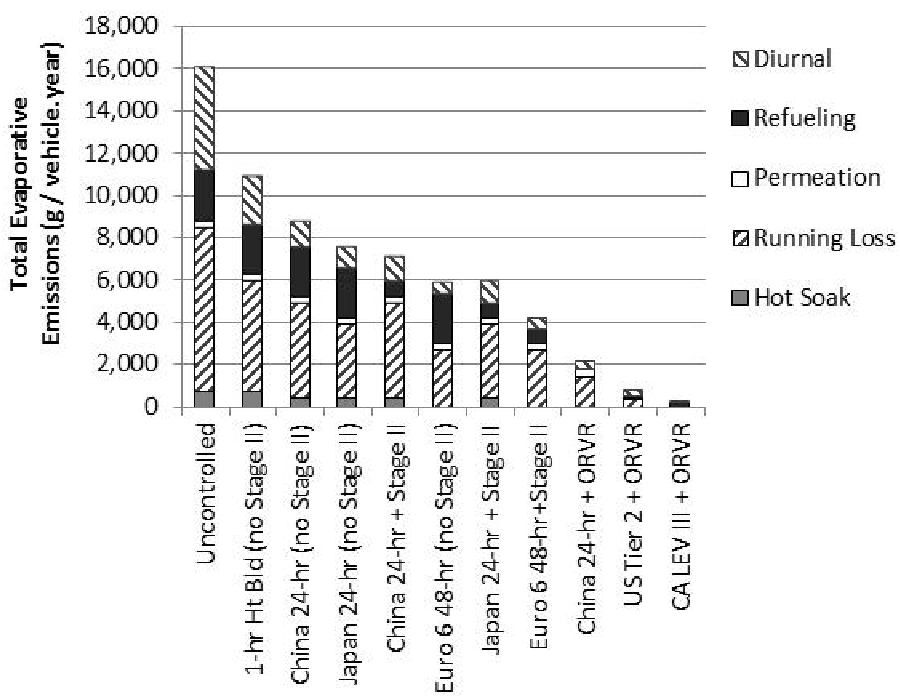

Figure 1. Total evaporative emissions resulting from the applied emissions standard for Beijing environmental conditions and fuels. The total is made up from diurnal, refueling, permeation, running loss, and hot soak emissions. Emissions in China are 10-12 times than in the US. Euro 6 standards would result in emissions still 6-9 times higher than in the US. Adding ORVR to the China Type IV 24-hour standard would reduce emissions by 70%.

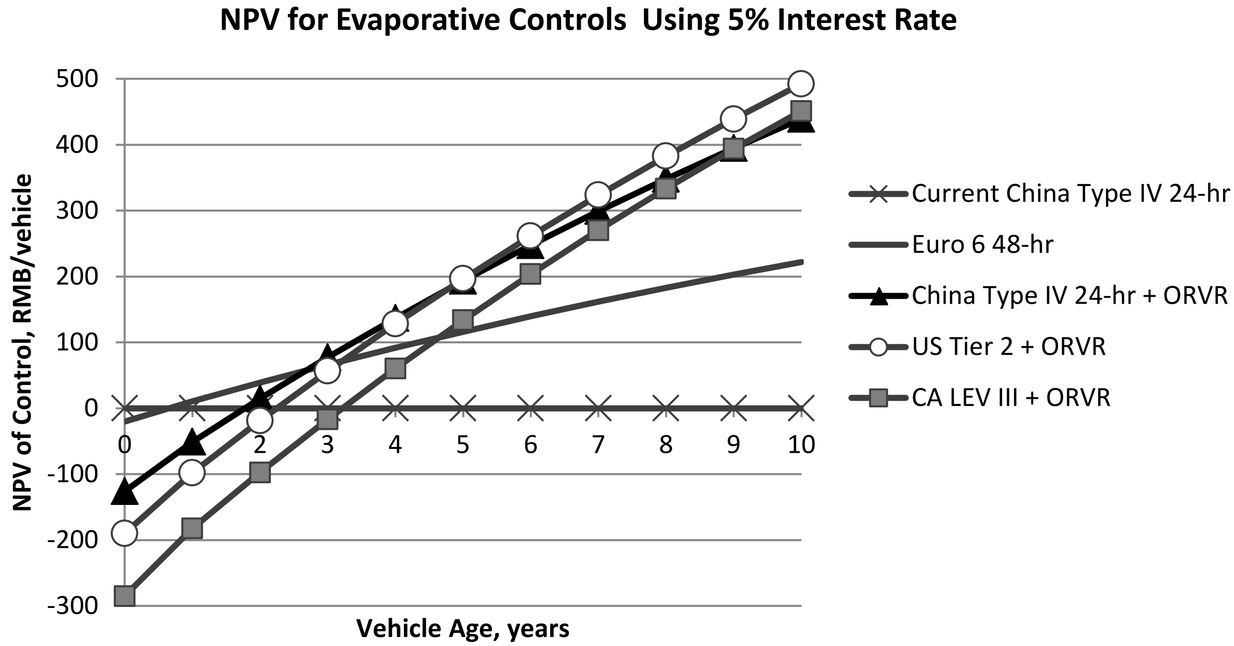

Figure 2. Net Present Value (NPV) analysis for applied evaporative standards and resulting gasoline credit over a vehicle lifetime of ten years and using a 5% interest rate. Positive NPV means that the consumer has a net economic gain from recovered gasoline relative to the initial investment in the controls. ORVR has a break-even point of 2 years. Tier 2+ORVR produces the highest economic recovery over a 10 year period, while the Euro 6 48-hour diurnal has the lowest economic recovery.

Table III. Summary of Cost-Effectiveness of Regulatory Options

	Incremental Cost to Automaker	Annual Emissions Reduction from Present Level (g/vehicle·yr)	Gasoline recovered by control system over ten year vehicle lifetime	Investment break-even time to consumer	NPV to the consumer over ten year vehicle lifetime
Current China Type IV 24-hr	0	0	0	N/A	N/A
Euro 6 48-hour	8 RMB	2,461	24.6 kg (35 L)	< 1 year	188 RMB
China Type IV 24-hr + ORVR	126 RMB	6,638	66.4 kg (95 L)	1.7 years	439 RMB
US Tier 2 + ORVR	190 RMB	7,989	79.9 kg (114 L)	2.3 years	492 RMB
CA LEV III + ORVR	285 RMB	8,576	85.8 kg (123 L)	3.2 years	451 RMB

VII. TESTING AT BEIJING CATARC BY TSINGHUA UNIVERSITY IS DEMONSTRATING THE HIGH EVAPORATIVE EMISSIONS FROM CURRENT CHINESE VEHICLES AND THE EXTENT THEY CAN BE LOWERED USING ORVR

A series of SHED emissions tests are being conducted by Tsinghua University at Beijing CATARC with technical assistance from SGS North America and MeadWestvaco to demonstrate the feasibility and effectiveness of ORVR under Chinese conditions. These data not only demonstrate the ability for ORVR to reduce refueling emissions by at least 98%, but the tests also show that ORVR reduces diurnal emissions by 55-98% over a period of 1-3 days plus increases purge rates by 400-700%. The increased purge rate enables the canister to regenerate and reduces running loss while driving at slow speeds. The ability for Chinese laboratories to conduct the most modern evaporative tests is also shown.

A sizeable evaporative emissions data set was generated for five vehicles: two ORVR vehicles and three non-ORVR vehicles. Although the names of the automobiles are not provided, relevant details such as engine displacement, fuel tank volume, canister volume, and whether or not the vehicle is ORVR-equipped are shown in Table I. The purpose of the study was to provide a side-by-side comparison of emissions during certification and off-cycle conditions, represented by established drive cycles not used for Chinese certification. In addition to SHED emissions, canister purge volumes were monitored to provide an indication of how vehicles may be expected to perform in-use during off-cycle conditions.

Five tests were run on each vehicle:

1. The China III-V Type IV 24-hour diurnal and hot soak test. Every vehicle model sold in China must certify following this test procedure with SHED emissions below a 2 g/test limit. The test procedures include a 60 minute drive that follows the NEDC with speeds reaching 120 km/hr. The specific test procedures are shown in Table II.
2. The US 2-Day diurnal and hot soak test. Each vehicle sold in the United States must certify to these test requirements, including a 0.65 g/day limit. The procedure involves a single 31 minute FTP with speeds reaching 95 km/hr. This short, low-speed cycle is intended to ensure automakers calibrate their engines to purge at low speeds and during short trips.
3. The US 3-day diurnal. Each vehicle sold in the United States must also certify to these test requirements, including a 0.5 g/day limit. The procedure involves a 97 minute drive to purge the canister.
4. The US refueling test. Each vehicle sold in the United States must also certify to these test requirements, including a 0.05 g/L refueling emissions limit. The procedure involves a 97 minute drive to purge the canister.
5. An extra permeation test to measure permeation emissions at a constant 22°C for 24-hours. This test was attached to the US 2-day test procedures.

The results from the study are shown in Table III. Testing found that the ORVR-equipped vehicles had higher absolute and working evaporative canister capacity, maintained higher purge rates, and produced much lower evaporative and refueling emissions than the vehicles engineered to only meet the Chinese Type IV diurnal requirement. The lower evaporative emissions from ORVR vehicles were not only for long parking events, but short parking events as well. The ORVR vehicles produced less than half the emissions of the other vehicles when following the Type IV procedures. More significantly, the diurnal and hot soak emissions from the ORVR vehicle were only 2-12% as high as the non-ORVR vehicles during all the off-cycle (FTP based) conditions. The refueling emissions for the ORVR vehicle were only 1% as high as the non-ORVR vehicles. Moreover, while the purge rates of the ORVR vehicles were four times higher than the non-ORVR vehicles over the NEDC, the purge rates for the ORVR vehicles were seven times higher over the FTP. These findings indicate Chinese vehicles are not purging well during heavy-traffic, low-speed conditions, and ORVR would help overcome this problem. More specific findings are described below.

<u>Refueling Emissions</u>: Refueling vapor generation averaged about 0.848 g/L, which is lower than expected due to the relatively low certification fuel RVP (Reid Vapor Pressure) available at CATARC, which ranged between 49 and 60 kPa, and the loss of resolution with such high SHED vapor concentrations. Nonetheless, as shown in Figure 1 and Table III, refueling emissions for the ORVR-equipped Vehicles A and E were only 0.011 g/L or 1% of the level of the non-ORVR vehicles.

<u>Type IV 24-hour Diurnal and Hot Soak Test Emissions</u>: Vehicles A and E were designed to meet US standards, but were exported for sale in China. The other three vehicles tested were engineered to certify to the Chinese Type IV diurnal standard. Figure 2 shows that all five vehicles easily met the Chinese Type IV 2 g/day limit; however, Vehicles A and E produced less than half the daily diurnal emissions of the other three vehicles. During the NEDC, canister purge was measured, and the cumulative purge during the drive cycle is shown in Figure 3. Over the 60 minutes of driving, Vehicles A and E (with ORVR) purged over 1,000 liters at an average rate of 17.4 L/min. The non-ORVR vehicles purged less than 300 liters, but Vehicle D purged less than 50 liters. The purge rate for the non-ORVR vehicles averaged 3.26 L/min, but this average rate is a little misleading. The majority of purge for the non-ORVR vehicles occurred when the vehicle exceeded 80 km/hr. In areas, such as Beijing, that suffer from heavy traffic congestion, it is unlikely that non-ORVR vehicles are sustaining adequate purge to regenerate their canister to free capacity for subsequent diurnal emissions control when parked and control of running loss.

<u>US 2-Day Diurnal and Hot Soak Test Emissions</u>: Vehicles A and E (with ORVR) show very different capabilities for control than vehicles B, C, and D (without ORVR). Vehicles A and E (with ORVR) maintained emissions below 0.34 g/d for both days. Vehicle B (without ORVR), however, had emissions of 4.3 g/day and 7.8 g/day for day 1 and day 2, respectively; Vehicle C (without ORVR), had emissions of 1.6 g/day and 6.2 g/day; Vehicle D (without ORVR) had emissions of 3.7 g/day and 5.3 g/day. The emissions from Vehicle B, C, and D were 5-28 times higher than Vehicles A and E. The higher emissions for Vehicles B, C, and D were due to two reasons: (1) insufficient canister capacity for two sequential heat builds, which could be addressed by adding ORVR which would increase canister capacity by 250%, and (2) insufficient purge at low speeds and short trips to fully regenerate the non-ORVR canister.

<u>US 3-Day Test Emissions</u>: The US 3-Day test offers a relatively long drive of 97 minutes and 46 km, but speeds are not high when compared with the NEDC. This cycle provides a large amount of time to purge the canister in preparation for three heat builds over a 72-hour period. As shown in Figure 5, the ORVR

vehicles (Vehicle A and E) showed significantly lower emissions than the three non-ORVR vehicles (Vehicles B, C, and D). While Vehicles A and E (with ORVR) maintained emissions below 0.34 g/day for all three days, the non-ORVR vehicles averaged 2.8 g/day for Day 1, 6.1 g/day for Day 2, and 10.8 g/day for Day 3. Vehicle D showed the best results for the non-ORVR vehicle, which is due to its relatively large 0.95 liter canister attached to a 50 liter fuel tank. Note that this same canister has capacity sufficient to meet a Euro 6 48-hour standard, but the emissions are twice as high as the ORVR vehicle on day 1, five times higher on day 2, and 22 times higher on day 3. One should not expect significant reductions in emissions with a Euro 6 48-hour diurnal requirement. In Figure 6, the purge traces for the vehicles over the 97 minute drive cycle are shown. While Vehicle A (with ORVR) and Vehicle E (with ORVR) purged over 1,000 liters at an average of 10.3 L/min, the non-ORVR vehicles purged only 61-268 liters at an average of 3.26 L/min. The ORVR vehicle was calibrated to purge at a rate three times higher than the non-ORVR vehicle. More importantly, Figure 6 shows that Vehicles B, C, and D went very long periods during driving, particularly between 3,500 and 5,500 seconds, without purging. This suggests that running losses were high.

<u>Permeation</u>: Permeation was measured by holding the SHED at a constant temperature of 22°C and venting the canister outside of the SHED. As shown in Figure 7, Vehicles A and E permeated 0.2 g/day while Vehicle B permeated 0.4 g/day and Vehicles C and D permeated 0.7 g/day. The average permeation rate for Vehicles B, C, and D was almost three times as high as that of Vehicles A and E. This higher permeation result for Chinese vehicles is as a result of the high diurnal SHED limit of 2 g/day in China versus the low limit of 0.5 g/day in the US (for the 3-Day test). The SHED limit influences the choice of fuel system materials and design by the automakers. These emissions are easily controlled using low permeation materials, and China should consider reducing its limit.

In summary, ORVR reduces refueling emissions by over 98%. Perhaps more importantly, ORVR results in a canister with very high canister capacity that reduces diurnal emissions by 55-96% for short parking events and over 98% for parking events up to three days. ORVR requires automakers to calibrate their engines to purge at rates 5-8 times higher than Chinese vehicles today. This increased purge is important, because it allows the canister to be regenerated during short or slow driving events and cuts down on running loss emissions. These data demonstrate that evaporative emissions are very high in China today and will continue to be high if the standards remain unchanged or simply evolve to mimic the Euro 6 standards. These data also confirm that ORVR is needed to meet the necessary 72% reductions to reduce the evaporative VOC inventory by 2018 and that ORVR can have a major impact on reducing these emissions.

Table I. Data for Chinese vehicles tested for evaporative emissions

	Engine Displacement, L	Fuel Tank Volume, L	Canister Volume, L	Refueling Control
Vehicle A	2.5 L, 4-cyl	51	2.0	ORVR
Vehicle B	1.6 L, 4-cyl	55	0.7	None
Vehicle C	1.5 L, 4-cyl	50	0.9	None
Vehicle D	1.2 L, 4-cyl	50	0.95	None
Vehicle E	2.0 L Turbo	63	2.1	ORVR

Table II. Evaporative Test Procedures Followed During Analysis

Step in Test Procedure	China Type IV 24-hour diurnal and hot soak test	US 2-Day Diurnal and hot soak test	US 3-Day diurnal test	US Refueling (ORVR) test
Canister Purge	300 BV[1]	300 BV	300 BV	300 BV
Preconditioning Drive	N/A	UDDS	UDDS	UDDS
Canister load to saturation with butane	Load with 50% butane at 40 g/hr to 2 grams breakthrough	Load with 50% butane at 40 g/hr to 2 grams breakthrough	Load with 50% butane at 15 g/hr to 1.5 times EPA BWC	Load with 50% butane at 40 g/hr to 2 grams breakthrough
Drain & Refuel	Drain fuel tank and fill to 40%	Drain fuel tank and fill to 40%	Drain fuel tank and fill to 40%	Drain fuel tank and fill to 40%
Drive cycle to purge canister	Exhaust Portion: 1x Part 1, 2x Part 2 of NEDC (exhaust emissions measured)	N/A	N/A	N/A
Soak	12-36 hours at 20-30°C	12-36 hours at 20-30°C	Soak 12-36 hours at 20-30°C	Soak 12-36 hours at 20-30°C
Drive cycle to purge canister	1x Part 1, 1x Part 2, 1x Part 1 of NEDC (no exhaust emissions measured)	FTP75	FTP75, UDDS, 2xNYCC, UDDS	FTP75, UDDS, 2xNYCC, UDDS
Drain & Refuel	N/A	N/A	N/A	Drain fuel tank and fill to 40%
Hot Soak Test	1 hour in SHED	1 hour in SHED	N/A	N/A
Soak	0-30 hours at 20-30°C	0-36 hours at 20-24°C	0-36 hours at 20-24°C	6-24 hours at 25-29°C
SHED test	24 hours with a 20°C-35°C-20°C heat build	48 hours with two 22°C-36°C-22°C heat builds	72 hours with three 22°C-36°C-22°C heat builds	Refuel tank to at least 95% capacity at 38 LPM.
Relevant limit value	≤ 2 g/day	≤ 0.65 g/day	≤ 0.5 g/day	≤ 0.05 g/L
Extra test for this study	N/A	Vent canister outside of SHED and measure permeation at constant 22°C for 24-hours	N/A	N/A

[1]BV = bed volumes. One bed volume of purge is equivalent to the volume of the canister. So, if a one liter canister is purged 300 bed volumes, then the volume of purge is 300 liters.

Table III. Purge and SHED Emissions Data for ORVR and Non-ORVR Chinese Vehicles

		Average China IV Vehicle	Average ORVR Vehicle	Vehicle A (ORVR)	Vehicle B	Vehicle C	Vehicle D	Vehicle E (ORVR)
Type IV Purge Rate		3.26 LPM	17.4 LPM (+432%)[1]	16.4 LPM (+403%)[1]	4.9 LPM	4.2 LPM	0.8 LPM	18.3 LPM
US 2-Day Purge Rate		0.8 LPM	4.1 LPM (+419%)[1]	4.0 LPM	1.0 LPM	0.8 LPM	0.5 LPM	4.1 LPM
US 3-Day Purge Rate		1.48 LPM	10.3 LPM (+594%)[1]	11.3 LPM (+663%)[1]	0.6 LPM	1.4 LPM	2.5 LPM	9.26 LPM (+525%)[1]
Type IV 24-hour diurnal + Hot Soak	Day 1	0.883 g/d	0.372 g/d (42%)[2]	0.393 g/d (45%)[2]	0.925 g/d	1.089 g/d	0.636 g/d	0.351 g/d (40%)[2]
US 2-Day Diurnal + Hot Soak	Day 1	3.208 g/d	0.329 g/d (10%)[2]	0.316 g/d (10%)[2]	4.300 g/d	1.587 g/d	3.738 g/d	0.341 g/d (11%)[2]
	Day 2	6.418 g/d	0.302 g/d (5%)[2]	0.274 g/d (4%)[2]	7.786 g/d	6.190 g/d	5.277 g/d	0.329 g/d (5%)[2]
US 3-Day Diurnal	Day 1	2.763 g/d	0.286 g/d (10%)[2]	0.344 g/d (12%)[2]	5.867 g/d	1.805 g/d	0.619 g/d	0.227 g/d (8%)[2]
	Day 2	6.072 g/d	0.231 g/d (4%)[2]	0.263 g/d (4%)[2]	8.917 g/d	7.997 g/d	1.302 g/d	0.199 g/d (3%)[2]
	Day 3	10.810 g/d	0.221 g/d (2%)[2]	0.254 g/d (2%)[2]	9.970 g/d	17.082 g/d	5.378 g/d	0.187 g/d (2%)[2]
Refueling		0.848 g/L	0.011 g/L (1%)[2]	0.010 g/L (1%)[2]	0.950 g/L	0.760 g/L	0.835 g/L	0.012 g/L (1%)[2]
Permeation		0.584 g/d	0.213 g/d (36%)[2]	0.212 g/d (36%)[2]	0.375 g/d	0.709 g/d	0.668 g/d	0.214 g/d (37%)[2]

[1]Percentage relative to purge rate of average non-ORVR vehicle. Higher purge rates, particularly during FTP, result in lower running loss emissions and improved canister regeneration during short trips and low speed driving.

[2]Percentage relative to average emissions of non-ORVR vehicle. Lower SHED emissions are indicative of lower in-use emissions.

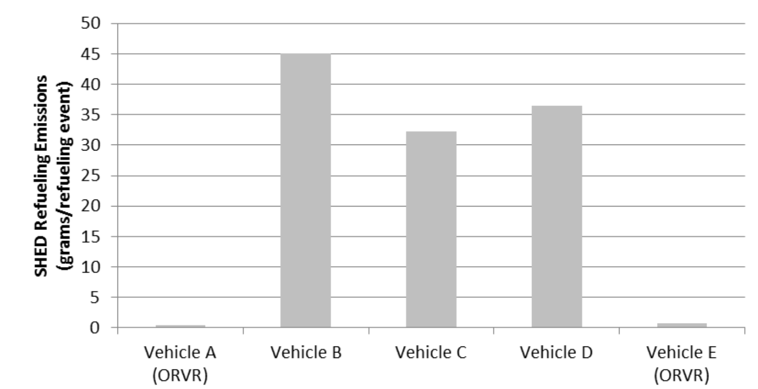

Figure 1. SHED refueling emissions measured for Vehicles A, B, C, D, and E at Beijing CATARC. Vehicles A and E were equipped with ORVR, which provided >99% control of refueling emission (note refueling emissions for vehicle A and E were only 0.5 grams)

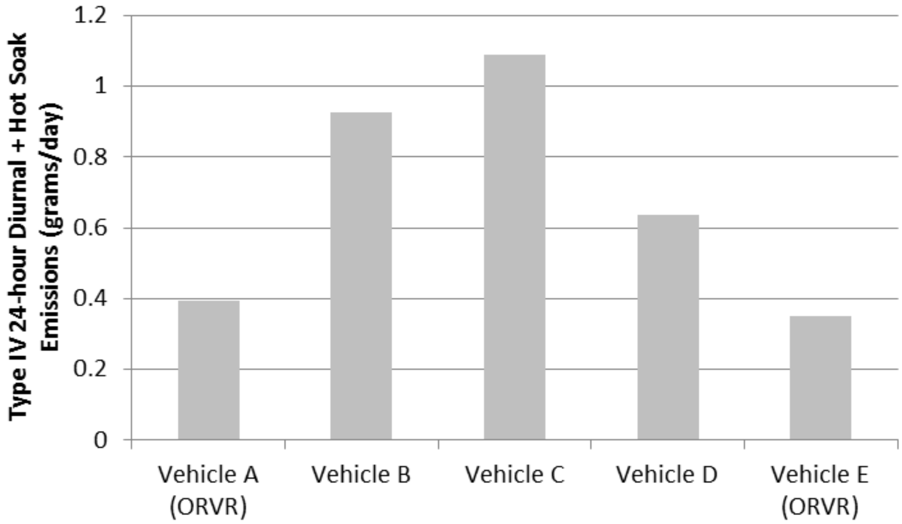

Figure 2. SHED diurnal emissions for Vehicles A, B, C, D, and E following the Chinese Type IV 24-hour diurnal procedures, which has a 2 g/day limit. All vehicles met this requirement, but the ORVR-equipped Vehicles A and E produced half the emissions of the non-ORVR vehicles.

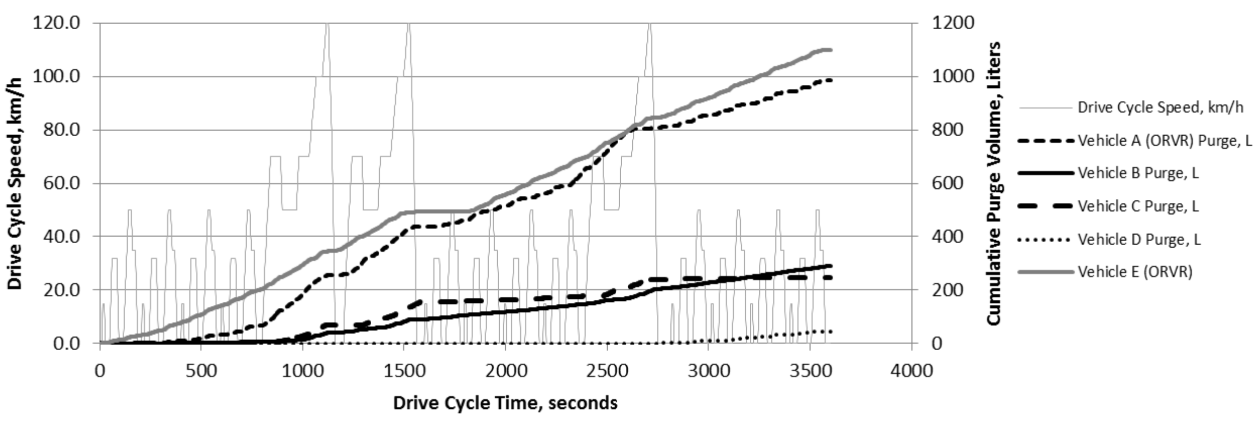

Figure 3. Canister purge traces for Vehicles A, B, C, D, and E showing cumulative purge volumes over the NEDC. The ORVR-equipped Vehicles A and E ingested over 1,000 liters of purge air, while Vehicles B and C ingested 250-290 liters. Vehicle D only ingested 50 liters of purge air. Note that the majority of purge occurred during the highway section of the NEDC. Vehicles B, C, and D purged very little over the low-speed urban portion of the NEDC.

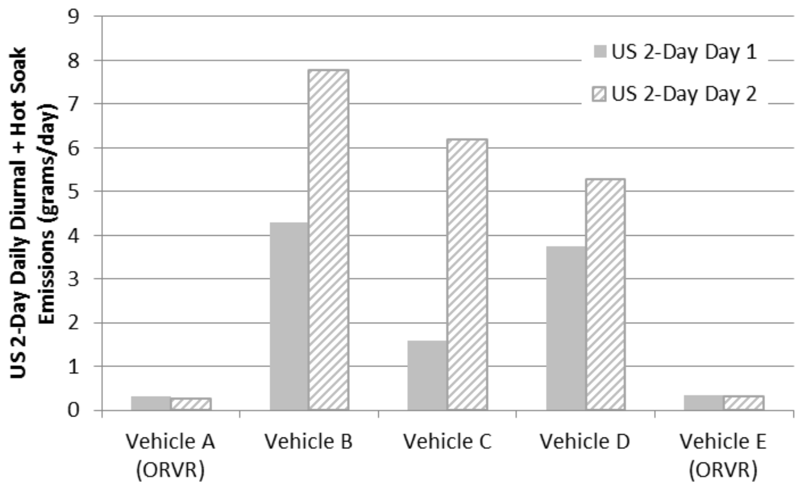

Figure 4. Diurnal SHED emissions for Vehicles A, B, C, D, and E following the US 2-Day diurnal procedures. Vehicles A and E (with ORVR) maintained emissions below 0.32 g/day, while Vehicle B, C, and D had emissions between 6 and 7.8 g/day (or 5-28 times higher). Vehicle B's 0.7 liter canister has insufficient capacity for controlling two days of diurnal heat builds, and its poor purge characteristics resulted in very high Day 1 emissions. Vehicle D's 0.95 Liter canister had similar issues as that of Vehicle B.

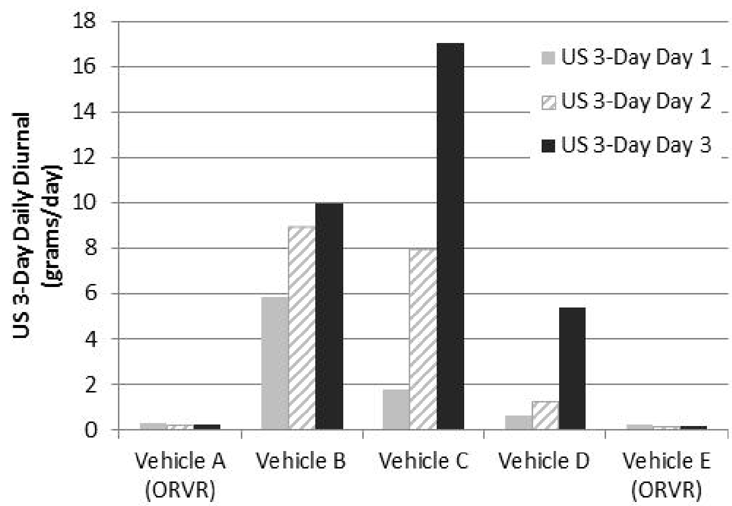

Figure 5. Diurnal SHED emissions for Vehicles A, B, C, D, and E following the US 3-Day diurnal procedures. Vehicle A and Vehicle B (with ORVR) maintained emissions below 0.34 g/day. Emissions from Vehicles B, C, and D (without ORVR) averaged emissions of 2.8 g/d on Day 1, 6.1 g/d on Day 2, and 10.8 g/d on Day 3. These high emissions from Chinese vehicles are due to insufficient canister capacity. High emissions on Day 1 are due to poor purging characteristics. Emissions on Vehicle D were the lowest of the non-ORVR vehicles, but it also has a 0.95 liter canister. This vehicle would easily pass the Euro 6 48-hour test requirements, but its emissions are 2-25 times higher than the ORVR-equipped Vehicle A and Vehicle E. Euro 6 will not lead to significant reductions in evaporative emissions.

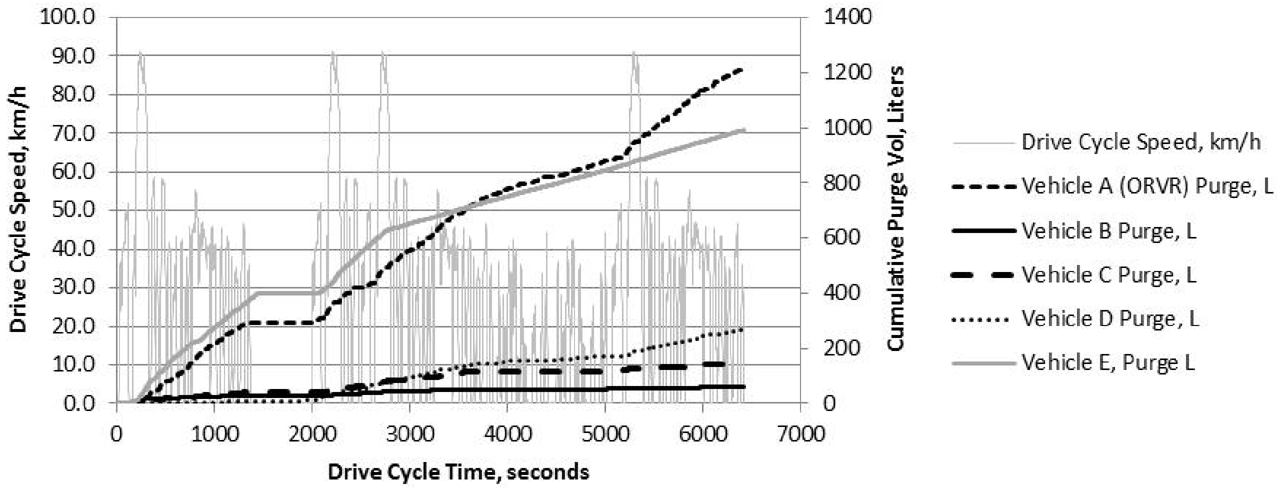

Figure 6. Canister purge traces for Vehicles A, B, C, D, and E showing cumulative purge volumes over the 97 minute FTP of the US 3-Day and Refueling test procedures. The ORVR-equipped Vehicle A and Vehicle E ingested 1,000-1,200 liters of purge air, while Vehicles B and C ingested 60-270 liters. Vehicle B showed little to no purge after 3,000 seconds. In fact, the canister gained 15 grams of weight from running loss over this drive cycle. During the first 30 minutes of driving, Vehicle B purged 29 Liters, Vehicle C purged 40 Liters, and Vehicle D purged 7 Liters. In contrast, Vehicle A purged 293 Liters. These data suggest that Chinese-certified vehicles will not purge well for short driving events.

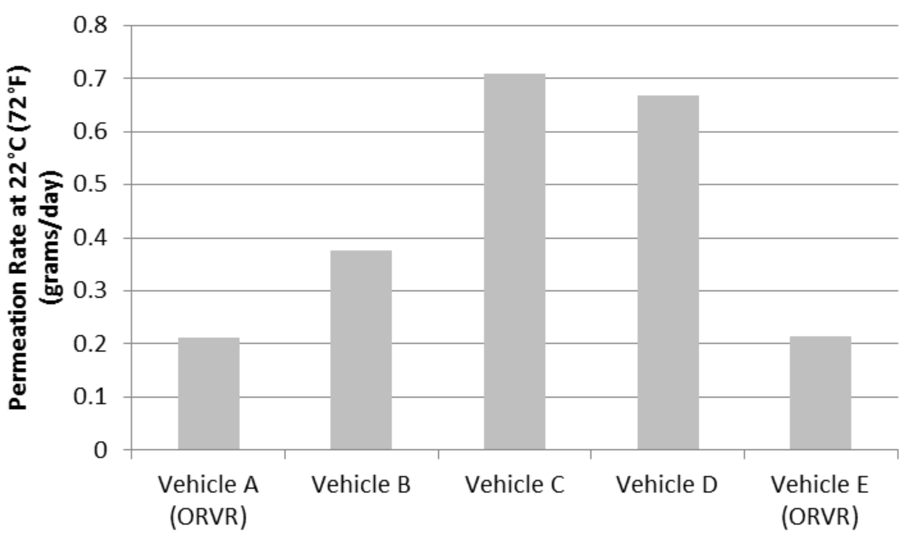

Figure 7. Permeation rates for Vehicle A, B, C, D, and E measured by venting the canister outside of a SHED held constant at 22°C (72°F) for 24-hours. Permeation rates for Vehicles B, C, and D were 2-3 times higher than that of Vehicles A and E that utilize low permeation materials.