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Combined Regulatory Assessment of PROCONVE L7 Improved Evaporative and Refueling Emission Control Requirements for Light Vehicles

Cost-Effectiveness and Cost/Benefit

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Summary:

PROCONVE L7 includes new evaporative and refueling emission control requirements for E22, E100 and flex fuel passenger cars and light commercial vehicles (light vehicles) based on US EPA test procedures. The improved evaporative requirements begin in January 2022 and the refueling requirements (based on ORVR technology) phase-in from 2023/2024/2025 at 20/60/100% as proposed by the industry during CONAMA discussions. This paper is a regulatory assessment of the upcoming improved evaporative and refueling emission control requirement. It is designed to examine the cost effectiveness of improved evaporative and ORVR technologies and the cost/benefit of these technologies in addressing the health and economic welfare effects of photochemical ozone caused by volatile organic compounds (VOCs) such as those in gasoline and ethanol vapor.[a] The São Paulo Metropolitan Area (SPMA)[b] has been taken as the urban airshed example to examine the ozone air quality impact, because it has the most comprehensive monitoring system and scientific studies available. In addition, the SPMA has 21 million inhabitants and more than 15% of all light vehicles in Brazil. This concentration of vehicle activity alone justifies the implementation of improved evaporative and ORVR technologies as a significant step toward meeting Brazil's current and future ozone air quality standards. This analysis is equally applicable to other urban regions, where, in total, more than 50% of light vehicle fleet is concentrated.

This paper addresses the combined effects of the improved evaporative an refueling emission control requirements of PROCONVE L7. There are two earlier papers addressing related to this analysis. The first, addresses improved evaporative incremental to PROCONVE L6 evaporative control requirements and the second paper addresses refueling emissions control incremental to the improved evaporative control of PROCONVE L7.

The key findings are summarized below:

- The VOCs in evaporative and refueling emissions are significant contributors to the formation of photochemical ozone. Of the 20 VOCs identified as presenting the greatest concern in the formation of ozone, gasoline vapor emitted during refueling contains on average 10 of them.
- Light vehicles will integrate their evaporative and their refueling (ORVR) controls into one technology package which shares common hardware, the same on-vehicle packaging, and one set of engine calibrations. This integrated technology package allows the control system to serve multiple purposes, which makes the system more efficient and cost-effective. This reduces engineering, tooling, hardware, and assembly costs.
- Improved evaporative emission control technology captures 80% of hot soak, diurnal and permeation evaporative emissions not captured by PROCONVE L6.

[a] The terms volatile organic compound (VOC) and hydrocarbon are used interchangeably in the professional literature.
[b] The São Paulo Metropolitan Area (SPMA) is comprised of 39 contiguous municipalities in the state of São Paulo, including the State Capital. It is sometimes referred to as the RMSP.

- ORVR technology captures 98% of refueling emissions and an additional 45% of running loss evaporative emissions not covered by the improved evaporative control technology used for the new PROCONVE L7 evaporative emission control requirements.
- Since the evaporative and refueling emission tests share many elements of the test methods and facilities, the improved evaporative and refueling emission standards do not meaningfully add to the laboratory, instrumentation, or facilities overhead or test equipment requirements. Furthermore, the certification requirements fit well within the current emissions certification protocol used by CETESB and thus does not add to government overhead to run the program.
- The PROCONVE L7 improved evaporative emission standard modernizes the Brazilian automotive sector to align technology requirements with those of Europe, China, Canada and the U.S., which concentrate more than 70% of the automotive global market. For refueling, the PROCONVE L7 for refueling aligns with the U.S., Canada, and China which concentrate almost 60% of the automotive global market. Both the improved evaporative and refueling emission standards will bring technology to Brazil which makes Brazilian suppliers and manufacturers more competitive in the world market.
- Incremental to PROCONVE L6 evaporative requirements, improved evaporative emission control technology will add $22 to the cost of a new light vehicle. For refueling emission control through ORVR technology, it will add an additional cost of $23 to the cost of a new light vehicle.
- The value of the fuel vapor captured by improved evaporative and ORVR technology and burned as fuel by a light vehicle over an average vehicle life for all Brazil is 2.6 times greater than the cost of installing the new hardware ($118/$45). The cost-effectiveness value is -$750/Mg of VOCs control. This is a net savings to the consumer.
- Improved evaporative and ORVR technology can reduce the SPMA VOC inventory by about 49%.
- The VOC reductions from improved evaporative and ORVR technology can reduce mean ozone concentrations by about 50% (18 ug/m^3) in the most critical ozone period and the highest measured ozone values by 61-91 ug/m^3. This has the potential to significantly increase compliance with the ozone air quality standard (140 ug/m^3) in the SPMA and these reductions are essential for meeting the programmed intermediate ozone standards of 130 ug/m^3 and 120 ug/m^3. Over the long term improved evaporative and ORVR technology will greatly enhance efforts to meet 100 ug/m^3 WHO ozone standard.
- Annually these ozone reductions lead to 112 avoided hospitalizations related to respiratory distress and 296 avoided premature deaths annually in the SPMA. The annual societal benefit is at least $429 million USD based health saving and the value of avoided premature death.
- The annual economic welfare benefits of the ozone reductions in the SPMA are about $15.6 million. This covers crop and materials damage as well as ecosystem effects. Also, annual CO_2 emissions are reduced by 69,000 Mg in the SPMA.
- There is an elevated risk of cancer related to benzene exposure for service station attendants. The risk today is about 1.33 cases per year for the estimated 332,000 service

station attendants in Brazil. This risk, four in one million, is four times that considered acceptable by public health professionals. At a 98% control efficiency, ORVR reduces the annual incidents to 0.03 or a risk of 0.08 in a million.

- Significant co-benefits from a reduction of $PM_{2.5}$ will occur due to a reduction in the atmospheric emission of fuel vapor aromatics in refueling, evaporative and running loss emissions, which are known precursors and contributors to creation of Secondary Organic Aerosols.
- The fuel vapor captured by improved evaporative and ORVR technology and used as fuel on the vehicle, reduces annual petroleum gasoline use by 14,100 m^3 and ethanol use by 24,500 m^3 in the SPMA and 84,100 m^3 of petroleum gasoline and 96,000 m^3 of ethanol for all of Brazil.
- Overall, the benefit/cost analysis concludes the following for the SPMA:

Cost/savings category	Million USD
Fleet hardware	$12
Fuel savings	-$46.6
Health savings*	-$429 (VSL)
Economic welfare savings	-$15.6

* Based on value of statistical life (VSL) metric for premature deaths avoided

In the SPMA the societal benefit/cost is 37:1. Each $1 of expense for improved evaporative/ORVR technology returns $37 to society.

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Introduction and Overview

Brazil uses two fuels for motor vehicles: gasoline C which is a blend of 73-75% gasoline and 25-27% anhydrous ethanol by volume and hydrated ethanol (E100). The market shares are approximately 66% gasoline C and 34% E100 for Brazil. Whether it uses gasoline C, E100, or some other gasoline/ethanol blend, the diurnal, hot soak, running loss, permeation and refueling emissions from the fuel systems on light vehicles are very important sources of the volatile organic compounds (VOCs) which contribute to the formation of ozone in urban areas of Brazil. The purpose of this paper is to present an analysis of the technology, the effectiveness, the costs of control, the cost-effectiveness and the cost/benefit of the PROCONVE L7 provisions related to reducing evaporative and refueling emissions. This is the third of three papers addressing these requirements combined. The first addressed the impacts of the improved evaporative emission control requirements for 2022 and later model year light vehicles incremental to the PROCONVE L6 evaporative requirements.[1] The second paper addressed control of refueling emissions for light vehicles through onboard refueling vapor recovery (ORVR) phasing in at 20/60/100% for the 2023-2025 model years.[2] This analysis was done incremental to the improved evaporative control for 2022. This paper combines these two analyses and examines the impacts of both programs together.

A. Gasoline Vapor and Ozone Reactivity

The base-gasoline used in gasoline C is a mixture of classes of organic compounds referred to as paraffins, olefins, naphthenes, and aromatics blended with ethanol at 25-27% to give the fuel the properties needed as a motor vehicle gasoline and to meet other consensus specifications or regulatory standards. The fractions of these hydrocarbon classes and the individual hydrocarbon vary from batch to batch of refinery product. Brazilian fuels have a maximum of 35% aromatics, and 25% olefins by volume with ethanol set at values based on national legislation.[3] Also, the fuel formulation must have some compounds with higher vapor pressure to meet the Reid Vapor Pressure and distillation temperature requirements.

For assessing the air quality impacts of refueling emissions three factors are important. First, is the vapor mass emission rate during refueling. Data from numerous studies show an emission rate of about 1.25 grams VOC per liter dispensed for fuels such as gasoline C.[4] For E100, the rate is about 0.35 grams ethanol per liter, due to the lower vapor pressure of ethanol. These include both vapor displacement from the tank and any spit back spillage from the fill pipe opening at the nozzle shut-off.[5]

Second, is the hydrocarbon composition of the gasoline vapor emitted to the atmosphere during refueling. Almost every hydrocarbon compound in gasoline C will be found in the refueling vapor, but the vaporized mass of each component will depend on the liquid concentration, as well as the specific vapor pressure of the individual compounds, the temperature of the gasoline in the tank, and the temperature of the dispensed gasoline. Calculating these mass fractions is relatively easy for traditional gasolines because they are ideal solutions. Gasoline/ethanol blends such as gasoline C are not ideal solutions.[6] For gasoline/ethanol blends the best data on concentrations of individual compounds in the vapor are based on in-tank headspace vapor measurements.

The third concept is related to the propensity of a given VOC to react in the atmosphere to create ozone. This is often referred to as the maximum incremental reactivity (MIR) and is expressed as grams of ozone per gram of VOC (g ozone/g VOC). It has been studied extensively for hundreds of VOC species, and the information needed for VOC compounds in evaporative and refueling emission is readily available.[7]

Table 1 shows the major VOCs in the vapor found in the headspace of a vehicle fuel tank for a gasoline/ethanol blend.[8,9] Column 1 lists 40 separate compounds. The mass liquid fraction of the compounds is shown in column 2, the mass vapor fraction is in column 3, and the MIR value is in column 4. The product of the vapor mass fraction and the MIR is in column 5. Column (5) illustrates that controlling a compound with a relatively low MIR and a high mass vapor fraction can be as valuable as controlling a compound with a relatively high MIR but a small mass fraction.

One might argue that emission control programs should focus solely on the VOCs with the greatest MIR values, but this is not practical for two reasons. First, vehicle emission control technologies such as catalytic converters and activated carbon canisters used in evaporative/refueling control systems are very efficient at reducing emissions of virtually all VOC compounds. The emissions of some compounds may be reduced to de-minimis levels or even below measurable levels. However, neither a catalyst nor an activated carbon canister is 100% efficient and neither selectively reduces only a given compound or set of compounds. Second, ozone photochemistry is complex, and the inventories of low MIR compounds are large enough that aggregate contributions to ozone formation are significant. Furthermore, low-MIR compounds can be transformed in the atmosphere to high-MIR compounds.

These facts are well understood, and the general approach implemented in regulatory programs is to reduce the emissions of ozone precursors (VOCs) without regard to the specific MIR values and to use the ozone reductions that are provided as part of the strategy for meeting the ozone standard.

Table 1 Ethanol/Gasoline Blend					
(1)	(2)	(3)	(4)	(5)	
	Fuel	Fuel	MIR	MIR	%
VOC Compound	Wt%	Emission Wt%	g O_3/g VOC	weighted	reactivity
Isopentane	6.75	20.44	1.68	34.34	12.94
Ethanol	25.00	19.00	1.45	27.55	10.38
n-butane	1.79	14.14	1.08	15.27	5.76
n-pentane	3.90	8.55	1.23	10.52	3.96
m- and p-Xylene	5.68	3.26	7.61	24.81	9.35
2-Methylpentane	3.46	2.84	1.41	4.00	1.51
Isobutane	0.20	2.18	1.17	2.55	0.96
Toluene	7.32	2.13	3.88	8.26	3.11
2-Methyl-2-butene	0.94	1.71	13.72	23.46	8.84
3-Methylpentane	2.16	1.47	1.70	2.50	0.94
2-Methyl-1-butene	0.52	1.29	6.23	8.04	3.03
trans-2-Pentene	0.63	1.28	10.25	13.12	4.94
n-hexane	2.42	1.28	1.15	1.47	0.55
1,2,4-Trimethylbenzene	2.95	1.24	8.64	10.71	4.04
2-Methylheptane	0.86	1.17	0.99	1.16	0.44
o-Xylene	2.24	0.91	7.44	6.77	2.55
2,3-Dimethylbutane	1.01	0.90	0.91	0.82	0.31
1-Pentene	0.32	0.85	6.97	5.92	2.23
1-Methyl-3-ethylbenzene	1.74	0.84	2.43	2.04	0.77
Ethylbenzene	1.58	0.81	6.39	5.18	1.95
cis-2-Butene	0.11	0.74	13.89	10.28	3.87
cis-2-Pentene	0.35	0.70	10.07	7.05	2.66
2,4-Dimethylpentane	1.46	0.70	1.46	1.02	0.39
Benzene	2.15	0.70	0.69	0.48	0.18
trans-2-Butene	0.09	0.63	14.79	9.32	3.51
3-Methyl- 1-butene	0.11	0.61	6.76	4.12	1.55
2-Methyl-2-pentene	0.98	0.51	10.70	5.46	2.06
Cyclopentane	0.40	0.49	2.25	1.10	0.42
2,2-Dimethylbutane	0.32	0.41	1.11	0.46	0.17
1,3,5-Trimethylbenzene	0.85	0.38	11.44	4.35	1.64
1-Methyl-4-ethylbenzene	0.81	0.36	2.43	0.87	0.33
1-Methyl-2-ethylbenzene	0.78	0.31	6.39	1.98	0.75
1,3-Dimethyl-5-ethylbenzene	0.66	0.30	9.80	2.94	1.11
1,4-Diethylbenzene	0.55	0.29	6.39	1.85	0.70
Indane	0.38	0.27	3.20	0.86	0.33
Propylbenzene	0.57	0.27	1.95	0.53	0.20
1,2,3-Trimethylbenzene	0.74	0.25	1.66	0.42	0.16
1-Butene	0.03	0.24	9.42	2.26	0.85
n-octane	0.57	0.23	0.82	0.19	0.07
Cyclopentene	0.14	0.20	6.55	1.31	0.49

Ethanol vapor is a significant source of air pollution in Brazil due to the use of gasoline C and E100.[10] As can be seen in Table 1, ethanol is the largest source contributor to vapor emissions in gasoline/ethanol blends and is probably among the top two or three in ambient concentrations due to fuel distribution, evaporative, refueling, and exhaust emissions.[11] Four comments are needed regarding ethanol vapor emissions. First, on a gram per liter basis the VOC emission rate of E100 is only 28% that of gasoline C, but the ethanol specific emission rate for E100 is about 40% greater (0.35 g/liter for E100 versus 0.25 g/liter for the ethanol fraction in the vapor of gasoline C). Second, with its relatively low MIR value (1.45), the ethanol molecule itself is not a major contributor to ozone, but this is partially offset by the fact that there is a relatively large amount in the atmosphere.[12] Third, there is an atmospheric transformation pathway for ethanol emissions to acetaldehyde to ozone[13] (acetaldehyde has a MIR of 6.34). Finally, in some cases ethanol can transform to another reactive compound known as peroxyacetyl nitrate (PAN) which is an oxidant more stable than ozone and transports longer distances but upon decomposition can cause ozone.[14]

Section D., below, presents a cost/benefit analysis which focuses on the São Paulo Metropolitan Area (SPMA). The atmospheric chemistry of ozone formation varies seasonally, with meteorology, and as the relative concentrations of the ozone precursors in the atmosphere change over various time scales. Studies published in 2010[15], 2017[16], and 2018[17] each listed what their research identified as the top VOC ozone precursor compounds for the time periods in the study (2006, 2006/2008, and 2011/2012, respectively). Looking at the top 20 VOC precursor compounds identified in the atmosphere, in the 2010 study fuel vapor had 10 of 20, in the 2017 study it was 13 of 20, and in the 2018 study it was 8 of 19. For the three studies the average was about 10 of 20 VOCs were found to participate in the formation of ozone in the atmosphere. Clearly, fuel vapor is an important contributor to VOC ozone precursor concentrations.

In addition to the VOCs in evaporative and refueling emissions, the compounds identified by the researchers are found as products of combustion from motor vehicles and industrial processes and in some cases arise from natural sources. There are already relatively strict hydrocarbon-related exhaust emission standards for light vehicles, motorcycles, and heavy trucks and buses in PROCONVE and PROMOT. The reduction in these VOCs with gasoline and ethanol vapor emissions control will be very helpful in addressing the ozone problem, especially since evaporative and refueling emissions control have not been addressed in more than 15 years and, presently, they are 10 fold higher than the exhaust emission in a new vehicle. The history of evaporative and refueling emissions control within PROCONVE is discussed next.

B. Background on Evaporative Emission and ORVR regulations

1. Evaporative and Refueling Controls in PROCONVE

Brazil first adopted evaporative emission standards (diurnal + hot soak) for light vehicles for the 1990 model year (PROCONVE L1). These were based on U.S. EPA emission standards, test procedures, and drive cycles in place at that time. The stringency of the evaporative emission standard under these test procedures was reduced from 6.0 g/test for the 1990 model year to 2.0 g/test for January 2005 (PROCONVE L4). This change did not affect vehicle technology, since most vehicles had certified evaporative emissions below this level since 1990.[18] Other than a small change in stringency in 2015 related to an allowance for alternative measurement technology (PROCONVE L6), the test procedures are the same and the vehicle control technology used is basically unchanged for 30 years. PROCONVE L6 does not include multi-day diurnal, running loss, or refueling emission control requirements.

In 2018, CONAMA adopted PROCONVE L7 which included two sets of requirements related to vehicle evaporative and refueling emissions. The first set of requirements, termed "improved evaporative" controls involved a substantial upgrade to the hot soak + diurnal test procedures and a more stringent emission standard effective for the 2022 model year. The hot soak+diurnal standard was set at 0.5 g/test for a 48-hour test (two 24-hour diurnal test cycles in series; the standard must be met on each 24-hour test cycle instead of the previous requirement of 2 g/test in a 1-hour cycle). The second, is a vehicle refueling emission standard of 0.05 g/liter using what is now termed as Onboard Refueling Vapor Recovery (ORVR) technology which phases in over model years 2023-2025 (20%/60%/100%). The test procedures for these new standards has been completed and is now being processed by ABNT for publication as NBR standard test procedures.

Relative to the technology used for compliance with PROCONVE L6 evaporative requirements, the technology response to the new requirements would come in two phases. The first would be for the 2022 improved evaporative requirements and the second would be for 2023-2025 phase-in of control of refueling emissions. As discussed below, we expect manufacturers to use "integrated evaporative/refueling control system" designs when refueling emission control phases-in starting for the 2023 model year. We expect some manufacturers will begin to use some or all elements of this approach in 2022, thus reducing engineering burden and costs.

One final note here is related to certification test fuels and in-use fuels. The evaporative and refueling emission certification test procedures require a gasoline flex vehicle to meet emission requirements on both a blend containing E22 and a separate set of tests using E100. For dedicated ethanol fuel vehicles only, certification on E100 is required. A gasoline flex vehicle can operate on gasoline C (currently 27% ethanol and 73% gasoline), E100, or any blend in between these as a result of commingling in the fuel tank. The actual in-use demand varies by region. In this analysis we used data from ANP indicating that for Brazil overall, the in-use mix is 66% gasoline C and 34% E100, but for Sao Paulo it is about 50% gasoline C and 50% E100.

<u>Improved Evaporative Control Technology</u>: As is illustrated in Figure 1, an improved evaporative emission control system for PROCONVE L7 uses the same basic hardware as the current evaporative system. To incorporate improved evaporative control requires a few technology changes: (1) an upgrade to the canister capacity to better capture the fuel tank diurnal and hot soak emissions, (2) an upgrade to the purge valve to improve its ability to more precisely meter purge air flow to the canister during the various driving conditions, (3) a modified purge

calibration, and (4) improved fuel vapor permeation control for the fuel tank and fuel lines. In most cases the evaporative control system configuration on the vehicle will be the same as for the PROCONVE L6 system including canister location as well as the vapor and purge line routings. This system would work equally well for gasoline C and E100 and any other gasoline/ethanol blend. The gasoline/ethanol vapor captured by the evaporative control system canister is purged to the engine during vehicle driving and this vapor is used by the vehicle as fuel.

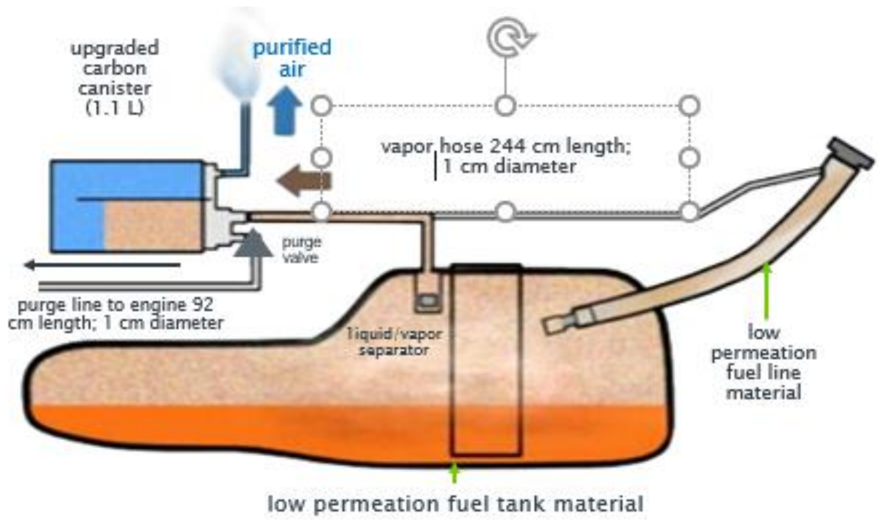

Figure 1: Improved Evaporative Control System for PROCONVE L7

<u>Onboard Refueling Vapor Recovery (ORVR)</u>: For refueling emissions control we would expect that manufacturers will use an integrated evaporative/ ORVR emission control system which uses much of the same component hardware and technology to control both evaporative and refueling emissions. As is illustrated in Figure 2, an integrated evaporative/ORVR emission control system uses many of the same basic components as the improved evaporative system. This design moves the canister from the front of the vehicle to mid-body or nearer the rear. This change leads to a much shorter, but slightly larger diameter vapor line from the tank to the canister. The canister is larger than that for the improved evaporative system because of the greater vapor load in total grams during a refueling and the greater load rate (grams/minute). The purge valve is the same or slightly upgraded from the improved evaporative system, the purge valve calibration is modified for the refueling test requirements, and the purge line to from the canister to the engine is longer since the canister has moved farther back on the vehicle. What is new is a liquid seal in the fill pipe to block vapor flow (created by changing the fill pipe dimensions), an anti-spit back valve at the bottom of the fill pipe to help fuel shut off and reduce spills, and an upgraded fuel tank valve to allow for greater vapor flow rates to the canister during refueling and to incorporate a fill limiter function. This integrated evaporative/ ORVR emission control system works equally well for gasoline C and E100 and any other gasoline/ethanol blend and is commonly used in the U.S, Canada and China.

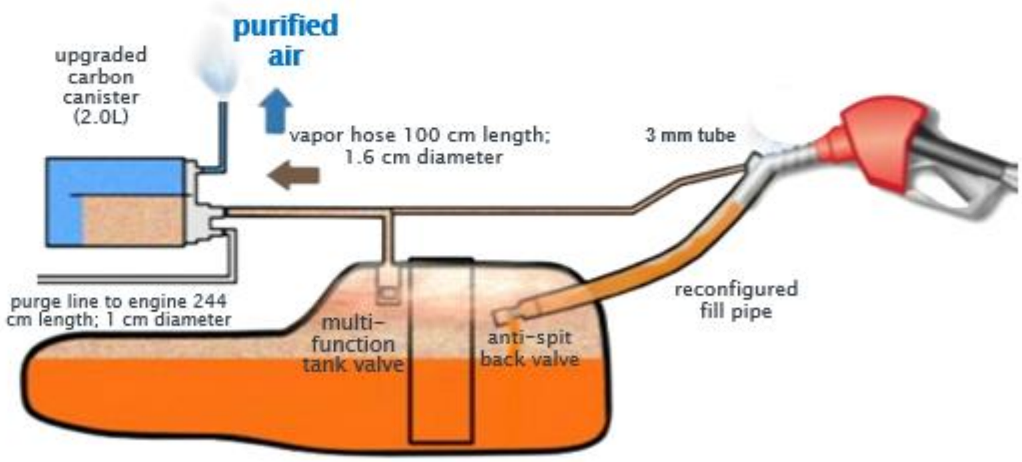

Figure 2: Integrated Evaporative/ Refueling (ORVR) Control System

Thus, the costs for upgrading to an integrated evaporative/refueling control system from the current design are shared across the new PROCONVE L7 48-hour hot soak+diurnal standards for 2022 and the refueling standards (ORVR) for 2023-2025.

2. <u>Why Has Europe Not Yet Adopted ORVR</u>

Initially, it is important remove the myth that Europe's automotive emission control program for evaporative emissions should be used as a benchmark. Europe did not adopt any evaporative emission standards until two years after Brazil and for the most part, the program focused more on permeation than fuel system vapor emissions such as diurnal and hot soak. There were no significant upgrades in the evaporative emission requirements until 2019, and even now the European standards are a total of 2 grams VOC over 48 hours (or about 1 gram per 24-hour). This is two times the Brazilian standard for 2022 and three times the current US standard. Also, it should be noted that Europe has no standards for heavy-duty gasoline vehicles (HDGVs). The first US first standards for HDGVs took effect in 1985 and since 2018 the US standards for HDGVs are more stringent than the 2019 European standards for cars.

Nonetheless. with ORVR requirements in the world's two largest automotive markets, it is puzzling why Europe has not harmonized their automotive fuel system platforms for ORVR and offered this control in Europe. Every European auto manufacturer and auto manufacturers who only export from Europe offer ORVR in the Chinese market, the North America market, or both. Retrospectively, there are five reasons why this has not occurred.

- <u>Climate</u>: Generally, the EU does not view itself as having an ozone air quality problem and does not view itself needing VOC control. Europe is a climatically diverse region. What ozone problems are acknowledged are more in the warmer southern regions. Brazil's climate falls into this warmer and sunnier regime.

- Structure of the ozone air quality limit values (AQLV). The maximum daily 8-hour mean ozone AQLV is 120 ug/m^3 in the EU, which is numerically quite stringent, but compliance in any member state is based on a 3-year averaging period where the ozone standard cannot be exceeded on average more than 25 days per year. This allows for many days exceeding the ozone AQLV without going in to noncompliance. This situation is further confused by the way the EU defines its compliance measurement boundaries. Other than the requirement that the ozone standard applies to any city with a population above 250,000, the EU directives leave it to each member state to define its areas. This leads to a great disparity among the square km covered by each area, ranging from 0.19 - 11, 000 km^2. With large areas, exceedances of the daily 8-hour ozone AQLV are probably not observed.

- Air Quality Need Assessment Is Based on Average Conditions: The European motor vehicle emissions model, air quality impact analyses, and cost-effectiveness assessments are based on how a potential regulatory program affects the average in-use concentrations for a given pollutant. With regard to ozone, refueling emissions control is most critical in the summer months when days are longer, air is more stagnant, and there is more direct sunlight. The use of an annual average set of environmental conditions greatly discounts the value of evaporative emissions control including ORVR in the summer months when it is needed most to reduce ozone.

- Dominance of Diesels: There are technology differences between North America, Brazil, and Europe. European automobiles are predominantly powered by diesel fuel, not gasoline or gasoline/ethanol blends. There are relatively few diesel passenger cars and light commercial vehicles in North America and Brazil. Diesel fuel has a very low vapor pressure, so fleet average refueling and evaporative emission rates are low. Europe is now moving away from diesels, so evaporative and refueling emission control may become more important.

- Political Decision Making for Automotive Policy: The policy decision-making process for motor vehicle emission standards in the EU is different than in North America or Brazil. While any proposed policy is developed by technical experts and representatives from government and industry on various committees within the European Commission (EC), final requirements must be approved by the European Parliament. The 28 member states of the EU have diverse interests with some being heavily influenced by auto manufacturing. Reaching consensus for meaningful action on evaporative controls is not easy. The difference between North American and EU requirements have been identified and evaluated by EC technical staff, and recommended the ORVR to be implemented by the EU, but progress is slow toward these new requirements.

- Decentralized Authority for Local Sources: Individual member states have much more independence in addressing local sources. Several member states implemented Stage II vapor recovery to address air toxics such as the benzene in gasoline vapor in the mid-1990s. This slowly spread to other member states and in 2009 an EC directive was implemented for Stage II implementation by the end of 2019. It is not clear that ORVR was ever evaluated seriously at the policy level, but it is clear that the EC has overstated the in-use efficiency of Stage II.

C. Cost-Effectiveness of Improved Evaporative and ORVR Technology in Brazil

Cost- effectiveness, presented as cost per Mg (metric ton) of emission control achieved, is the most common parameter used to assess regulatory efficiency and to compare between or among competing regulatory options. Of course, the lower the cost-effectiveness value, the more attractive the control option becomes, but to achieve the environmental goal the options considered should be roughly equivalent in the emission reductions they could provide. In assessing the cost-effectiveness of motor vehicle emission control options, an analysis involves three elements: the initial cost increase for the vehicle (which includes overhead and profit), any changes in cost of ownership over the vehicle life, and the emission reductions over the vehicle life. To put the monetary values on a common basis, costs of ownership are discounted to the year of vehicle purchase using a net present value (NPV).

Improved Evaporative Control Technology: In this analysis we took a bottom-up approach to assessing what incremental technology changes would be needed for an improved evaporative control system for PROCONVE L7 relative to that used for PROCONVE L6. Our estimate is that the incremental per vehicle cost for the technologies discussed above and shown in Figure 1 for improved evaporative controls is $22 (incremental to the cost for the PROCONVE L6). The vehicle's improved evaporative control system would capture 80% of the hot soak+diurnal evaporative emissions not controlled by PROCONVE L6 technology. Data for similar technologies used in the U.S. since 2004 shows that over 96% of vehicles with improved evaporative control technology meet the emission standard over the full vehicle life. The average in-use emission rate is 0.32 g/test for 48-hour test cycle similar to the test cycle required in PROCONVE L7 where the emission standard is set at 0.5 g/test.[19] There is no required maintenance.

Furthermore, the modified purge calibration and greater capacity of the activated carbon canister needed for improved evaporative control has a very positive added benefit in that it also captures a 45% of running loss evaporative emissions which are controlled in the U.S. (by a separate regulatory test and emission standard), but not controlled using the technology to meet the PROCONVE L6 24-hour hot soak+diurnal standard.[c]

Overall, these captured evaporative emission vapors (diurnal, hot soak, running loss) are burned as fuel over the vehicle life, resulting in a fuel savings to the consumer of about $69 NPV.[d,e]

[c] A reduction in running losses using a specific running loss test procedure and emission standard would require the same technology as is used for improved evaporative controls: a larger capacity canister and upgraded purge.
[d] A net present value discount factor of 3% is commonly used in US EPA regulatory analyses.
[e] This calculation is based on 66% gasoline C and 34% E100.

Thus, the consumer achieves $47 of net savings because of the fuel vapor captured by the technology.

From an emissions control perspective, the diurnal, hot soak, permeation and running loss emissions captured by improved evaporative control technology are calculated on a per vehicle basis using its kilometers traveled annually and its average vehicle lifetime in days and years. The reductions in these four sources of emission taken together result in emission reductions of 0.057 Mg[f] VOC per vehicle. This is based on a 30 year fleet life in which the average vehicle survives for 15-16 years and is driven 12,725 kilometers per year.

The overall cost effectiveness for the improved evaporative controls as required for PROCONVE L7 is ($22-$69)/0.057 Mg = - $800/Mg[g]

As mentioned above, the CONAMA process created two regulatory provisions to reduce fuel vapor emissions. The first, a 48-hour hot soak plus diurnal emission standard takes effect for 2022. The second, that leads to the use of ORVR technology, phases in from 2023-2025. Thus, all vehicles installing ORVR systems will already have technology for the improved evaporative control requirement. For integrated evaporative/ refueling ORVR systems this will lead to lower incremental hardware costs for ORVR as compared to if only ORVR was required.

Refueling Emission Control Technology (ORVR): For ORVR, we analyzed what incremental changes would be needed to the improved evaporative control system to make it an integrated evaporative/refueling ORVR system. Our estimate is that the per vehicle cost for the ORVR technology as discussed above and shown in Figure 2 is $23 incremental to the cost for the improved evaporative requirement. . In addition, the Joint Research Center - JRC[20], the technical organization of the European Commission, estimated that the ORVR system total cost of the by € 16 to € 29, integrated to the European system of diurnal evaporative emission control which is equivalent to the current Brazilian one. The vehicle's ORVR technology would capture 98% of the refueling emissions. The average in-use emission rate is 0.02 g/liter for a vehicle using ORVR and certified using refueling emission test like that required in PROCONVE L7. [21] There is no required maintenance.

Furthermore, as was the case for improved evaporative controls, the improved purge calibration and greater capacity of the activated carbon canister needed for ORVR technology has a very positive added benefit in that it also captures an extra 45% of running loss evaporative emissions incremental to that captured by improved evaporative emission control technology.[h] These captured refueling and evaporative emission vapors are burned as fuel over the vehicle

[f] One Mg equals one metric ton.

[g] In the U.S., a general threshold value is about $3000/Mg. A negative value such as calculated here means that there is a net savings.

[h] A further reduction in running losses using a specific running loss test procedure and emission standard would require the same technologies used in ORVR: a larger capacity canister and improved purge.

life, resulting in a fuel savings to the consumer of about \$49 NPV.[i,j] Thus, the consumer achieves \$26 of net savings because of the fuel vapor captured by ORVR technology.

From an emissions control perspective, the refueling and extra evaporative emissions captured by ORVR technology are calculated on a per vehicle basis using its fuel economy and kilometers traveled annually and over the average vehicle lifetime. These terms taken together (refueling and extra evaporative control) result in emission reductions of 0.041 Mg per vehicle, considering 30 year fleet life in which the average vehicle survives for 15-16 years and is driven 12,725 kilometers per year.

The overall cost effectiveness for ORVR is (\$23-\$49)/0.041 Mg = - \$600/Mg

With such an attractive cost-effectiveness value, one may ask why the auto manufacturers do not just apply ORVR anyway? We think it comes down to four points. First, consumers do not innately recognize the economic losses they incur from evaporative and refueling losses. Second, the auto manufacturers are not inclined to add hardware and increase vehicle price if they do not think it will help them sell vehicles, even if it is only \$23 per vehicle. Third, in a broad sense, citizens do not understand the link between fuel vapor emissions and air quality, nor do they necessarily understand the adverse health effects of ozone or particulate matter. However, a study published for São Paulo in 2011 indicates some "willingness to pay" for prevented health outcomes for adults and children (hospital admissions, emergency room visits).[22] Fourth, in the case of refueling emissions, service station attendants and those citizens living near service stations are the only ones who feel the direct effects of exposure to refueling vapor, not the driver or the vehicle owner.

<u>Combined Improved Evaporative and ORVR</u>: Taking improved evaporative and ORVR technology together, the total per vehicle cost is \$45. The combined NPV (at 3%) of the fuel savings is \$118, yielding a net savings of \$73 per vehicle over its life. Using the two values presented above, the sum of the VOC emission reductions over a vehicle life is 0.12 Mg.

The overall cost effectiveness for ORVR is (\$45-\$118)/0.098 = - \$750/Mg.[k]

D. <u>Cost/benefit of Improved Evaporative and ORVR Technology in Brazil</u>

Cost/benefit analysis considers the desirability of a regulation from a broader societal perspective. In a cost/benefit analysis, the costs of the regulation are compared with the societal benefits. Costs of a regulation are normally evaluated applying the same categories used in a cost-effectiveness analysis but on a full fleet basis in a given year. The benefits fall

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[i] This calculation is based on 66% gasoline C and 34% E100.

[j] A net present value discount factor of 3% is commonly used in U.S. EPA regulatory analyses.

[k] In the U.S., a general threshold value is about \$3000/Mg. A negative value such as that shown here means that there is a net savings.

broadly in to two categories. The first is health effects, that being an assessment of positive impacts on morbidity and mortality.[23] Morbidity is usually expressed as hospital admissions and emergency room visits to assure the accuracy of data (as represented by the "SUS" costs in Brazil). However, this approach does not capture costs associated with items such as lost work days, lower productivity, and homebound illness.[24] Mortality is expressed as premature deaths avoided and is quantified as either a value of a life year (VOLY) or value of a statistical life (VSL).[25] VOLY is the economic value used to quantify the benefit of avoiding a fatality that can reduce one year in someone's life expectancy. VSL is an economic concept used to estimate how much people are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused by environmental pollution. It is used mostly in regulatory impact analyses and scientific research. It summarizes the value society places on preventing death for any particular person. Both approaches have value in understanding and quantifying the economic value of reducing or eliminating premature death. However, the VOLY covers only one year, and one must know the average life years saved to calculate a full value. The VSL is the preferred value since it better addresses the economic value full elimination risk.

The second benefit is economic welfare effects, that being an assessment of positive impacts in areas such as crop production, materials damage, flora (trees/plants) in ecosystems, and climate change.[26] There is usually little specific data on the monetary value of the economic welfare benefits, so general estimates are applied.

Researchers and government organizations in Brazil have been evaluating the ozone air quality problem in Brazilian cities for quite some time. Even with the data and time constraints related to this assessment, information is available to use a "backcast" method to evaluate the cost/benefit of improved evaporative and ORVR technology.[l] In this case, the data for the analysis are limited to the SPMA, but as is discussed below, should generally be applicable to other smaller urban areas in Brazil which have ozone air quality problems. The SPMA is the urban area with the greatest population, the greatest activity (vehicle population, driving, and fuel use), and the most significant ozone air quality problem for Brazil. SPMA has 15.6% of all light vehicles in Brazil.[27] In addition, another study showed that the 20 most populated metropolitan regions concentrate 40% of Brazil's population and vehicle fleet.[28]

In this "backcast" approach an analysis year is selected, and all the factors that impact ozone air quality, except the program(s) being analyzed, are set as they existed in that year. This includes items such as fleet characteristics, VOC and oxides of nitrogen (NOx) emission inventories, and meteorology. This is important because these factors all affect the atmospheric chemistry which create ozone and fixing them at values as existed in the analysis year allows the use of a

[l] The "backcast" approach used here is a retrospective method where the effects of one regulatory change or set of changes can be isolated and all other elements of the VOC inventory and factors affecting ozone formation are fixed. A prospective method requires that the effect of all changes affecting the inventory and ozone formation be identified and quantified for some future year. For a prospective analysis, the accuracy of the results is heavily dependent on the accuracy of the input values, which is too uncertain for a forecast 20 or 30 years ahead.

tool to predict the effects of improved evaporative and ORVR technology on VOCs and subsequent ozone concentrations. As will be discussed further below, we have elected to analyze the effect of improved evaporative and refueling emission control technology using 2018 data since that is the latest complete year for CETESB VOC inventory and ozone air quality data for the SPMA.

In this modeling, the only terms which are different from the baseline CETESB VOC inventory are the PROCONVE L6 evaporative and refueling emission values. Instead of using the CETESB's 2018 values for SPMA for evaporative and refueling emissions, the inventory for 2018 is calculated based on the more representative values developed for the 2018 CONAMA process.[m] This baseline inventory does not include the emission reduction benefits of either improved evaporative or ORVR technology. The emission reduction values for improved evaporative and refueling emission control technology (ORVR) were also taken from those prepared for deliberative process at the CONAMA technical group.

Under this "backcast" method for assessing cost/benefit, the modeling is based on the approach that full fleet turnover has occurred. Furthermore, all gasoline, flex fuel, and E100 vehicles in the fleet are certified to the improved evaporative and refueling emission standards and certification life requirements using both gasoline C and E100 or just E100 for a dedicated ethanol vehicle.

The final step in this backcast methodology is to determine the effects of improved evaporative and ORVR technology on the VOC emission inventory in the SPMA. The VOC emission reductions from improved evaporative and ORVR technology divided by the baseline VOC inventory yields the percent reduction in the inventory. This is used to determine the effect on ozone concentrations.

Six pieces of information are needed to conduct the cost/benefit analysis. Each is discussed and presented below.

1. <u>Fleet costs of control for all improved evaporative and ORVR-equipped vehicles in 2018</u>.

a. The in-use light vehicle fleet in 2018 is a mixture of vehicles ranging in age from 1-30 years. The mixture by model year in the fleet depends on the sales in that model year and the survival fraction of that model year's fleet in 2018. The costs of control for the entire 2018 in-use fleet of vehicles requires calculations covering control hardware costs for the purchaser and operating costs.

[m] The evaporative and refueling inventory in the analysis should be aligned with those presented to the CONAMA technical group and be consistent with the test procedures and emission standards of the new requirements. The PROCONVE program for light vehicle evaporative and refueling emission control is based on US EPA test procedures and standards and are reflected in EPA's MOVES emissions model. The CETESB inventory uses emission factors adapted from the European Guide for emission inventory (the COPERT model), thus is not the best approach for Brazil.

a. Control Hardware: For purchase cost there are two calculations. The first is the annualized cost for improved evaporative and ORVR hardware. This is based on the cost of purchase for each vehicle (incremental cost of $45) annualized over a 30-year vehicle life. The annualized cost is used because the analysis is for one year of the vehicle operating life (2018), not its entirety. The second calculation is the future value term. This is based on a compound 3% per annum rate from the model year of purchase to 2018. The cost for the fleet for 2018 is then equal to the sum of the products of (the annualized cost x the model year sales x the survival fraction for that model year in 2018 x future value term for that model year)[n] for model years 1989 to 2018. Using this approach, the cost for improved evaporative and ORVR control hardware in 2018 for all light vehicles in the SPMA fleet would be about $12 million USD.

b. Operating Costs: Improved evaporative and ORVR technology do not increase maintenance costs, but as was the case in the cost-effectiveness discussion above, the vapor captured in the control system is recovered and burned as fuel by the vehicle. For the 2018 calendar year, data from IHS estimated light vehicle kilometers traveled in Brazil at 483 billion kilometers.[29] This would be 75.3 billion kilometers in the SPMA. This value multiplied by the fuel recovered on a g/km basis, the appropriate conversion factors, and the weighted price of fuel for 2018 yields a fuel recovery credit from improved evaporative and ORVR technologies of $46.6 million USD in 2018 for the SPMA.[o,p] This value reflects the savings for 2018 for the entire in-use fleet, not for just one vehicle over its individual life time.

2. Information on the VOC ozone precursor inventory for 2018 for SPMA:

The anthropogenic VOC ozone precursor inventory for 2018 for the SPMA is the sum of emissions from stationary sources and mobile sources. Stationary sources include activities such as light and heavy industry, petroleum refining, power generation, fuel storage and distribution, the production and use of chemicals and solvents, and food processing. Mobile sources include exhaust and evaporative and refueling emissions from light vehicles, medium and heavy trucks and buses, and motorcycles.

Table 1 is a summary of the VOC inventory for SPMA for 2018. This includes the adjustments discussed above to incorporate the PROCONVE L6 and PROCONVE L7 evaporative and refueling emission programs using the approach developed in the CONAMA process, except based on fuel use of 50% gasoline C and 50% E100. The magnitude of the light vehicle exhaust emission inventory is small relative to that for evaporative for 2018. While there may be some updates needed in the exhaust estimate, this difference is mostly because the exhaust NMHC and aldehyde standards have become progressively more stringent with time, but there have been

[n] The annualized cost is $1.5 ($45/30 years), gasoline, FFV and E100 light vehicle sales from 2018-1989 are from IHS Markit and the ANFAVEA website. The survival fraction by age is from CETESB, and the future value term is 1.03^{age} where a 2018 vehicle is zero years old.

[o] For the SPMA, gasoline C and E100 were both modeled at 50% of annual consumption for 2018.

[p] (75.3×10^9 km/yr.) (0.414 g/km)(1lb./453.59 g)(1 gallon/6.76 lb.)($4.56 /gallon)

no real changes in the technology required for the evaporative standards and running losses and refueling emissions are uncontrolled.

	Table 1: 2018 SPMA VOC Emission Inventory (metric tons/yr.) for Backcast Model									
		E100, Gasoline, Gasoline Flex						Diesel		
	Stationary Source [30,q]	Light Vehicle					Motor Cycle	Truck	Bus	
		Exhaust[31]	Evaporative				Exhaust	Exhaust		
	HC	NMHC+ aldehyde	Parked[r]	Hot Soak	Running Loss	Refueling	NMHC	NMHC		Total
2018 with PROCONVE L6 evaporative	9280	9580	7343	935	25504	6172	2933	790	472	63009
2018 with improved evaporative	9280	9580	1231	450	13669	6172	2933	790	472	44577
2018 with improved evaporative and ORVR	9280	9580	1148	450	7036	124	2933	790	472	31813

Notes:
Scenario 1: 2018 inventory with evaporative emissions measured in a 2-h test, according to phase L6
Scenario 2: 2018 inventory with evaporative emissions measured in a 48-h test, according to phase L7 / 2022
Scenario 3: same scenario 1 with the addition of ORVR technology

The reductions in the inventory are very large. For improved evaporative control technology the reduction is 18,432 metric tons/yr. of VOC. For ORVR technology incremental to improved evaporative the reduction is 12,764 metric tons/yr. of VOC. Overall, the combined reduction for the PROCONVE L7 improved evaporative and ORVR requirements is 31,196 metric tons/yr. of VOC. This is a 78% reduction in light-duty evaporative and refueling emissions and a 49% reduction in the overall anthropogenic VOC inventory modeled for the SPMA. Such large reductions cannot be achieved from exhaust emissions.

3. <u>Information on the ozone air quality for the SPMA for 2018:</u>[32]

The current ozone (O_3) standard for Brazil is 140 micrograms/cubic meter (ug/m^3) for an 8-hour average. This is both the primary standard (health) and the secondary standard (welfare). In 2018 there were 18 days with violations of the standard in the SPMA at 23 different monitoring sites. There was a total of 44 8-hour periods above the ozone standard.[33] Table 2, below, shows a decline in violations over the four preceding years, but CETESB's report indicates that the 2018 values were significantly less than the preceding five years due partially to favorable

[q] Stationary sources include VOCs (gasoline C and E100) from loading of tanker trucks at terminals, delivery to underground storage tanks (USTs) at service stations, and storage in the (USTs). It does not include dispensing to the vehicle.
[r] Parked includes diurnal and permeation emissions.

meteorological conditions and that this does not necessarily signal a favorable trend.[34] In addition, the economic crisis reduced transportation and industrial activities in the same period and thus reduced emissions, which also favors the ozone levels to decrease. However, this trend might reverse with economic recovery, as appears to be the case based on preliminary 2019 data.

Table 2: Ozone Violations in the SPMA.

Tabela 20 – Número de dias com ultrapassagem do padrão estadual de ozônio na RMSP

	Ano	Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez	Total
PQAr-8h	2013	0	5	1	1	1	0	0	0	2	0	2	1	13
	2014	8	8	1	1	0	0	0	1	3	13	4	4	43
	2015	12	2	3	0	0	0	0	3	6	6	3	1	36
	2016	4	3	2	6	0	0	0	1	0	4	5	7	32
	2017	1	3	0	0	0	0	0	2	12	5	1	4	28
	2018	2	2	2	1	1	0	1	0	0	0	0	9	18

Fonte: CETESB (2019)

The above figures come from comparison of ozone concentrations and the 140 ug/m3 standard presently in place. However, it is already programed that two new intermediate and a final standard are to be implemented in Brazil to comply to the World Health Organization ozone standard of 100 ug/m3. Comparing the daily ozone levels from QUALAR (CETESB databank) to the different ozone standards (as shown in Table 3), it is clear that this negative trend is a problem for compliance with the future ozone standards as the numbers of violations increase significantly (up to 50% for each ozone season).

Table 3 - Ozone Violations Trends in the SPMA According to Future Ozone Standards

2013	2014	2015	2016	2017	2018	2019	STD (ug/m3)
13	43	36	32	28	18	41	PQAr - 140 ug/m3
30	63	57	47	47	29	64	M_{I2} - 130ug/m3
55	84	82	67	63	47	91	M_{I3} - 120ug/m3
91	135	125	121	111	114	148	M_{Final} - 100ug/m3

Note: 2019 data and violations according to intermediate ozone standards were calculated from CETESB databank hourly ozone concentrations in each monitoring station

Three other sets of information are important here and they are shown in Table 4 (below), which is derived for information provided by CETESB for the 23 monitoring stations in the SPMA.[35] Column 2 of the table lists the average daily 8-hour average ozone concentration at each station in the SPMA. The average for all 23 stations is 37 ug/m^3. Columns 3-6 present the 1st, 2nd 3rd, and 4th largest 8-hour average ozone readings at each station. Finally, columns 7 and 8 present the number of exceedances of the 140 ug/m^3 Brazil standard for ozone, and for comparison and later discussion exceedances of the 100 ug/m^3 WHO standard for ozone. The 100 ug/m^3 ozone standard is programmed to be implemented in Brazil at some future date according to Resolução CONAMA 491/2018.

4. <u>An assessment of how the regulation would change the inventory and ozone air quality</u>

Several researchers have conducted extensive studies on the relationship between the magnitude of the ozone precursor inventory and ozone concentrations in São Paulo. Through this work they have developed a general tool to predict how reductions in the VOC inventory in São Paulo would impact ozone concentrations.[36,37,38] The results of the three studies vary, but there are four common outcomes: (1) the results are dependent on the meteorology for the years studied, (2) Brazilian Spring and Summer (calendar October-March) are the dominant months for ozone formation (also see Table 3 above), (3) some VOCs are more reactive than others in creating ozone, but a broad reduction in VOCs including those with greater and lesser reactivity will reduce ozone concentrations in the urban area, and (4) reductions in NOx will increase ozone concentrations in the urban area unless there are also VOC reductions.

In this analysis, we have elected to use the results of the study published by Orlando et al in 2010 which favors broad VOC reductions as an ozone control strategy. It relied on the CETESB inventory for its modeling and covered all four seasons. Also important is that it covers all VOCs including ethanol which is a major constituent in urban air. Figure 3 taken from the Orlando et al. paper published (page 1617) presents a relationship depicting how much ozone concentrations would decrease as a function of a decrease in the VOC inventory for each of the four seasons. In the previous section on inventory impacts, we estimated that when improved evaporative and ORVR technology vehicles are fully phased-in to the SPMA fleet, it would reduce the SPMA VOC inventory by about 49%. The presentation in Figure 3 does not extended to a 49% VOC changes, but the relationship is clearly linear. Therefore, the predicted ozone reduction would be about 50% for Spring and Summer, when ozone problems are most common and 64% during fall and winter when the ozone concentrations are lower.

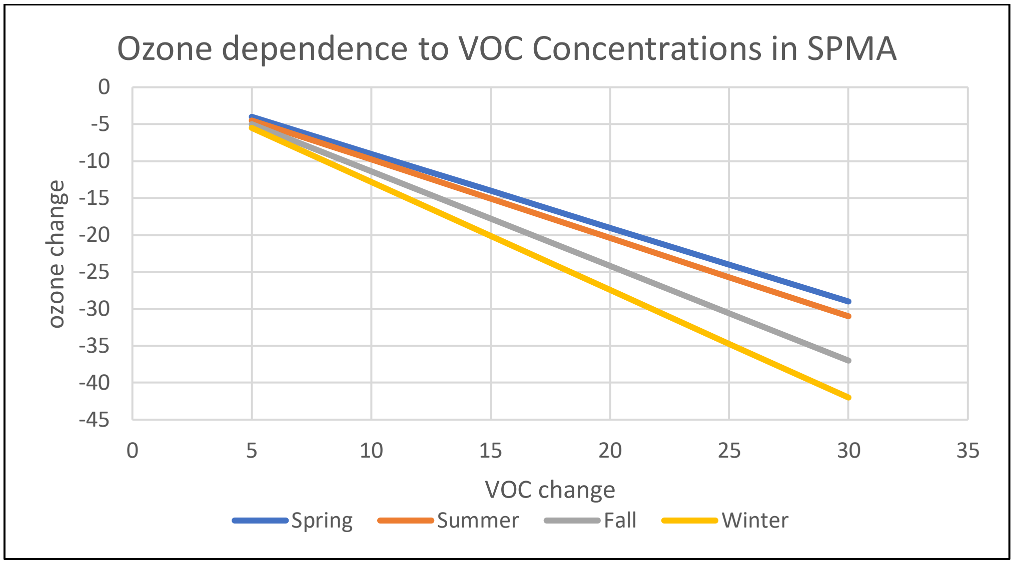

Figure 3 – O_3 percent change as a function of VOC reductions for the four seasons of the year (source: Orlando et al.)

5. <u>How much would the improved ozone air quality positively impact health and economic welfare</u>

Table 4 presents the ozone air quality picture for the SPMA.[39] The inventory analysis presented in Table 1 indicates that improved evaporative and ORVR technology would reduce the VOC inventory by about 49% and using this information, the modeling analysis discussed in the immediately preceding section indicates an ozone reduction of about 50% during the most critical Spring and Summer period. Applying this reduction percentage to the 2018 ozone information in Table 4, yields an assessment of the ozone profile for a scenario where light vehicles using improved evaporative and ORVR technology are fully in place in the fleet.

Table 4 – SPMA Ozone Air Quality Data – 2018 8- hour average values (ug/m3) – and Projections

Monitoring Station	2018 Avg (ug/m³)	SPMA Ozone Air Quality Data – 2018 8- hour average values (ug/m3) – and Projections 2018 Maximum Values (ug/m³) 1st	2nd	3rd	4th	> Level (ug/m³) 140	100	New Avg (ug/m³)	New Maximum Values (ug/m³) 1st	2nd	3rd	4th
Capão Redondo	36	136	134	124	123	0	22	18	68	67	62	62
Carapicuíba	36	136	133	128	128	0	28	18	68	67	64	64
Cid.Univ.- USP-Ipen	35	153	135	134	130	1	46	18	77	68	67	65
Diadema	35	177	160	147	137	3	26	18	89	80	74	69
Grajaú-Parelheiros	44	144	127	126	124	1	28	22	72	64	63	62
Guarulhos-Paço Mun	37	144	137	134	132	1	33	19	72	69	67	66
Guarulhos-Pimentas	42	138	134	133	122	0	27	21	69	67	67	61
Ibirapuera	41	174	156	153	142	4	59	21	87	78	77	71
Interlagos	40	152	146	141	138	3	43	20	76	73	71	69
Itaim Paulista	38	133	130	126	124	0	25	19	67	65	63	62
Itaquera	39	162	157	153	146	6	37	20	81	79	77	73
Mauá	32	130	122	119	114	0	9	16	65	61	60	57
Mooca	34	130	121	117	116	0	19	17	65	61	59	58
N.Senhora do O.	30	122	122	118	118	0	23	15	61	61	59	59
Parque D. Pedro	34	164	122	122	121	1	30	17	82	61	61	61
Mogi das Cruzes	50	158	143	141	138	3	25	25	79	72	71	69
Pico do Jaragua	51	148	147	136	135	2	70	26	74	74	68	68
Pinheiros	28	150	124	123	116	1	11	14	75	62	62	58
S.André-Capuava	37	172	151	142	139	3	28	19	86	76	71	70
S.Bernardo-Centro	41	162	159	156	156	9	40	21	81	80	78	78
Santana	33	155	145	139	138	2	40	17	78	73	70	69
Santo Amaro	29	125	120	115	115	0	13	15	63	60	58	58
São Caetano do Sul	39	181	171	157	150	4	42	20	91	86	79	75
Total Violations						44	724		0	0	0	0
Numerical Average	37	150	139	134	131			19	75	69	67	65
Difference								18	75	70	67	66

As can be seen in Table 4, the average concentrations drop by 18 ug/m³ and the highest projected ozone values range from 61-91 ug/m³ for all stations, eliminating all violations considering the present sources. The analysis projects no violations of even the 100 ug/m³ WHO ozone standard after light vehicles with improved evaporative and ORVR technology are fully phased in to the fleet.

While this analysis suggests great progress toward compliance several points of caution are needed. First, this assumes no offsetting decreases in NOx emissions. Second, as reported by CETESB, the 2018 ozone values used here are relatively low compared to the preceding four years.[40] Third, there are likely to be other increases in the VOC inventory related to an increase in the vehicle population, annual driving and fuel use as well as greater VOC emissions from other industrial activity. Fourth, as was stated above, ozone formation is very dependent of meteorology and this of course may be different in each ozone season. Finally, fleet turnover takes 30 years, so other measures may be needed to reduce VOCs in the interim years.

Even with the cautions presented above, there is no doubt that the VOC reductions from improved evaporative and ORVR technology on ozone concentrations in the SPMA are significant and critically important. As can be seen in Table 5, all of the new predicted maximum values far fall below the 100 ug/m³ ozone standard. Finally, it is worthy of note that while this assessment is based in the SPMA data because this is the most populated, well known and studied area, similar conclusions are valid for the other areas highly urbanized. In addition, air quality monitoring in the state of São Paulo shows that even small cities are exposed to high ozone concentrations, under meteorological events favorable for ozone formation, as studied by CETESB in 2018[41]. Considering the 50% reduction estimated in ozone levels in case of P7 implementation, all violations of the WHO target would be eliminated in the same event. Both findings reinforce that vehicle emission control must be done in the entire fleet, nationwide.

6. Quantification of the monetary value of these positive benefits

In July 2016, Abe et al published a paper which contains an algorithm which permits an estimate of the health impact effects of ozone reductions and a monetary quantification of the health benefits.[42] This study, which used 2009-2011 data, projected positive changes in respiratory system related hospitalizations for adults and the elderly and the total number of premature deaths avoided. The study shows health benefits if all ozone values greater than 100 ug/m^3 were reduced to 100 ug/m^3 (the WHO standard) or less or if the mean ozone concentration was reduced by 5 ug/m^3. The ozone reductions from the combination of improved evaporative and ORVR technology would meet the 100 ug/m^3 scenario.

The SPMA has a population of about 21.7 million in 2018. Of these citizens, 72% are adults 15-64 years of age and 9 % are over 64 years old. The health effects information for meeting the 100 ug/m^3 ozone goal is shown below based on the current SPMA population, with costs adjusted for inflation since 2009. Basically, as discussed above, there are two ways to value the avoidance of premature death. The first, value of life year (VOLY), used in some types of cost benefit analysis and preferred by some analysts, is based on surveys of what an individual would be willing to pay in exchange for one year of additional life or conversely the loss of one year of life expectancy. The second approach, value of a statistical life (VSL) is based on surveys of what a respondent would pay to avoid a premature death, not just to add a year to life expectancy. In this case, it is believed the respondent inherently factors in his/her age and life expectancy and other key factors in formulating their answer. The authors of the July 2016 paper (Abe et al) drew the VOLY value from a 2005 paper from the European Commission.[43] The shortcoming of this approach for this paper is not the VOLY monetary value or the premature death incidents avoided estimate, but to calculate a total VOLY the use of VOLY needs to also include an estimate of the average years of life lost for the at risk population in the SPMA. The information is not available and without this information the VOLY method cannot be credibly applied. This same 2005 paper also discusses the VSL approach specifically for air pollution and provides a value of one million Euros as the VSL monetary value. Using the VSL, a premature death avoided would be valued at $1.45 million USD in 2018.[s] Other studies show values similar to the VSL used here. For example, a recent study for São Paulo estimated health costs of $1.65 million dollars for each violation of the 140 ug/m^3 ozone standard.[44] For 2018, a remarkably good ozone year, this would have been almost $30 million dollars. For the recently enacted China 6 motor vehicle regulation the Chinese MEP used a value of $1.89 million USD.[45] The US EPA currently used a VSL value of $6.3 million USD in its 2014 Tier 3 automotive emission standards rulemaking. This is four times the value used here based on the European study.[46]

[s] This is adjusted upwards from one million euros using the euro to dollar conversion and inflation since 2005.

Table 5: Potential Health Benefits to Reducing Maximum Ozone Concentrations to $\leq$ 100 ug/m^3 in the SPMA

	Respiratory Hospitalizations age 15-64 Annual Number of Cases Avoided per 100,000	Respiratory Hospitalizations age >64 Annual Number of Cases Avoided per 100,000	Premature Deaths Annual Number of Avoided Deaths per 100,000 (VSL)
population	15,648,971	1,956,121	21,734,682
cases per 100,000	0.15	4.56	1.36
cases/events	23	89	296
cost per case/event	$4,720	$4,720	$1.45 million
Monetary Value	$110,795	$421,020	$428.6 million

As discussed above, the VSL is the better metric for valuing premature deaths avoided. It does not suffer from the "one year" limitation of the VOLY and the value derived for VSL from the European study referenced by the authors ($1.45 million USD) is low but at least comparable to those from the U.S. and Chinese cost/benefit studies for motor vehicle air pollution. The morbidity and mortality benefits taken together sum to about $429 million per year.

In addition, these ozone reductions bring positive monetary benefits related to economic welfare impacts such as effects on forest and agricultural ecosystems (damage to plant foliage, reduced plant growth, decreased crop yield), and effects on manmade materials (elastomers, textiles fibers, and dyes, and certain paints). More recently, there is a great concern over climate change, and reduced fuel use from improved evaporative and ORVR technology will reduce carbon dioxide (CO_2) emissions by 69,000 Mg per year in the SPMA. Overall, the monetary value of these benefits is difficult to quantify. In its regulatory evaluation of ORVR, the U.S. EPA used a value of $500 per Mg which was derived from input from General Motors.[47,48] For the SPMA this would calculate to a value of $15.6 million dollars per year. Finally, as a comparison, it is interesting to note that a 2005 study from Europe looked at the marginal VOC damages from crop yield reductions. For the 24 countries studied, the values ranged from 140 – 2700 euros/Mg with a mean value of about $970 euros or about $1000 USD/Mg.

E. <u>Occupational Health – gas stations</u>

We now turn away from a view of just the SPMA, to all of Brazil. Currently, gasoline vapor is emitted at service stations during refueling of vehicles with gasoline C. This vapor contains a known human carcinogen, benzene. The current benzene limit for gasoline C is 1%. At the temperatures seen during vehicle refueling there is about 0.0137 g/liter of benzene emitted per liter dispensed.[49] For Brazil this calculates to an inventory of 332 Mg of benzene emitted at service stations per year. This is small in comparison to the total VOC inventory, but significant because benzene is a known carcinogen (leukemia) and an occupational health risk.

There are about 41,600 service stations in Brazil,[50] and it is estimated each station employees about eight attendants for the fueling of vehicles.[51] This is an exposed population of 332,000 nationwide.

There have been many studies of service station worker exposure to benzene both in Brazil and in many countries around the world. This exposure is clearly an occupational health risk. A recent study in Brazil measured breathing zone exposures of 47-435 ug/m^3 benzene (212 ug/m^3 average) at 10 service stations.[52]

Using methodology developed by the U.S. EPA for its ORVR assessment,[53] this average value represents an individual risk of about 2.8 chances in 10,000 of contracting cancer from occupational benzene exposure over a lifetime. For Brazil as a nation, this converts to a risk of 1.33 incidences per year or 93 cases over a 70 year life expectancy.

Public health professionals consider a risk of one in a million as acceptable. The risk value for service station workers is 4 in a million, four times the acceptable rate. At a 98% control efficiency, ORVR will reduce this risk to 0.03 incident per year, or a risk of 0.08 in a million.

F. <u>$PM_{2.5}$ and Secondary Organic Aerosol Reduction Co-Benefits</u>

In many regions of the world, a significant fraction of $PM_{2.5}$ is attributed to secondary organic aerosol (SOA). CETESB estimates 51% of $PM_{2.5}$ in the SPMA is attributed to secondary aerosol.[54] SOA is formed from the atmospheric oxidation of gas-phase VOC emissions in the presence of sunlight and chemical oxidants. Sources of SOA can come from biogenic VOCs emitted naturally from vegetation and anthropogenic VOCs emitted by human activities, such as fuel vapors. Published studies have shown that evaporated fuel vapors contribute to the formation of SOA and that the SOA formation potential or SOA yield[t] of a fuel generally increases with an increasing aromatic content of the fuel.[55,56] Past modeling studies have reported a substantially low SOA yield (0.0024) for non-tailpipe gasoline emissions;[57] however, recent experimental laboratory studies conducted by the University of California at Riverside report a significantly higher SOA yield of 0.055 from the photo-oxidation of gasoline vapor in the presence of NOx.[58] This 0.055 SOA yield is representative of Southern California winter-grade E10 gasoline, was consistent across fuel manufacturers and octane rating, and was driven by the aromatic content of the gasoline. As discussed in Section A, Brazil Gasoline C has a higher ethanol blend than the E10 used in California, so a SOA yield of 0.055 could be considered a conservative upper limit for a Gasoline C in Brazil. Brazil E100 would not be expected to have any significant SOA contributions.

[t] A SOA yield is defined as the ratio of the mass of organic aerosol formed to the mass of parent hydrocarbon (e.g., fuel vapor) reacted.

As shown in Section D, the technologies used for advanced evaporative emission and refueling control would reduce the SPMA VOC inventory by 31,196 metric tons annually. Using the experimentally-derived SOA yield for evaporated gasoline vapor of 0.055, this could translate into a potential annual reduction of SOA/$PM_{2.5}$ from the SPMA on the order of 702 metric tons. This value represents 37% of the total stationary and mobile PM estimated by CETESB for the SPMA.[u] Any reduction in SOA/$PM_{2.5}$ would be a significant co-benefit to the ozone reductions already discussed, as the health and economic welfare benefits associated with any reductions in $PM_{2.5}$ are significant. For example, the Abe and Miraglia study, referenced above for ozone, also suggested that if São Paulo could diminish $PM_{2.5}$ by 5 µg/m^3, nearly 1725 premature deaths would be postponed annually, and the population would gain more than 5 months in life expectancy, resulting in a gain of $4.96 billion USD. While a more significant and comprehensive air quality modeling analysis would need to be conducted to fully quantify the benefit of VOC reductions on SOA/$PM_{2.5}$ in the SPMA, it is quite clear that additional and potentially significant co-benefits could be realized.

Conclusion:

Whether from gasoline C or E100, vehicle evaporative and refueling emissions are the most significant source of ozone precursors in Brazil. The PRONCONVE L7 requirements will bring about the development and installation of integrated evaporative/refueling control systems on the vehicle. The fuel value of the recovered vapors related to controlling evaporative and refueling emissions will exceed the cost of putting this hardware on the vehicle by a factor of 2.6. The cost-effectiveness of the improved evaporative and ORVR requirements taken together is - $750/Mg of control, which represents net savings to the consumer.

The VOC emission reductions from improved evaporative and ORVR technology will reduce the VOC inventory by 49% in the SPMA and this will lead to ozone reductions of about 50% in both the mean and maximum values in the SPMA. Compliance with the 140 ug/m^3 ozone air quality standard will be attained in São Paulo and in other urban areas. The reductions from these technologies will also lead to significant progress toward meeting the future 100 ug/m^3 goal without adding any significant regulatory burden to the automakers and without requiring increased government resources for certification or oversight.

These reductions in ambient ozone concentrations will reduce emergency room visits and hospital admissions related to respiratory problems caused by ozone exposure as well as premature deaths. The health-related cost savings are about $429 million (USD) per year. In addition, there will be economic welfare benefits related to the ozone and CO_2 reductions valued at $15.6 million per year. The overall benefit/cost ratio is 37:1 using the VSL approach to value a premature death avoided. This value does not include the fuel savings of $46.6 million. In addition, beyond this, there are co-benefits on health and economic welfare associated with

[u] Calculated from data in Table 13 and Table 15 of reference 54. Stationary PM sources estimated at 3,570 tons per year and mobile PM sources estimated at 1240 tons per year for a total of 4810 tons PM per year. Note these estimates do not include SOA, only stationary and mobile PM sources.

SOA/$PM_{2.5}$ reductions and a decrease in cancer incidences that are caused by gasoline C benzene vapor exposures of service station attendants, which were not monetized in this study.

With a cost effectiveness that reflects a net monetary savings and health and economic welfare benefits which exceed costs by a factor of 37, improved evaporative and ORVR requirements are good economic and environmental policy.

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