Memorandum

To: Tim Dallmann, ICCT
Leticia Pineda, ICCT

From: John Koupal, ERG
Cindy Palacios, ERG

Date: March 1, 2021

Re: Analysis of 2019 Mexico City RSD HC Levels

Background

ERG analyzed roadside remote sensing data (RSD) gathered across several locations in Mexico City during SEDEMA's 2019 campaign. As requested by ICCT, our analysis focused on HC emission trends for light vehicles, including taxis, and indications of excess evaporative emissions in these readings. Our approach was patterned off an analysis of 2016 Mexico City RSD published in ERG 2019.[1] This study found that model year average HC emissions from Mexico City RSD increased rapidly past age three; were an order of magnitude higher than Mexico City's exhaust-only PVVO program and RSD from the Denver area; and using aggregate HC:CO correlation, identified potential high evaporative emissions via comparison to U.S. evaporative field measurements. As detailed in the following sections, for this project we evaluated whether similar trends were present in the 2019 data, and compared a small subset of vehicles present in both the 2016 and 2019 data.

Data Analyzed

ICCT provided the 2019 dataset to ERG with a total of 34,839 records representing a mix of vehicle types and domiciles in Mexico. Based on license plate, 52 percent were domiciled in Mexico City (CDMX), 33 percent in Estado Mexico (EdoMex), and 15 percent other states. Figure 1 shows the breakdown of RSD readings by measurement location in Mexico City.

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[1] John Koupal and Cynthia Palacios, *Impact of new fuel specifications on vehicle emissions in Mexico*, Atmospheric Environment Volume 201 (2019) 41-49 https://doi.org/10.1016/j.atmosenv.2018.12.028.

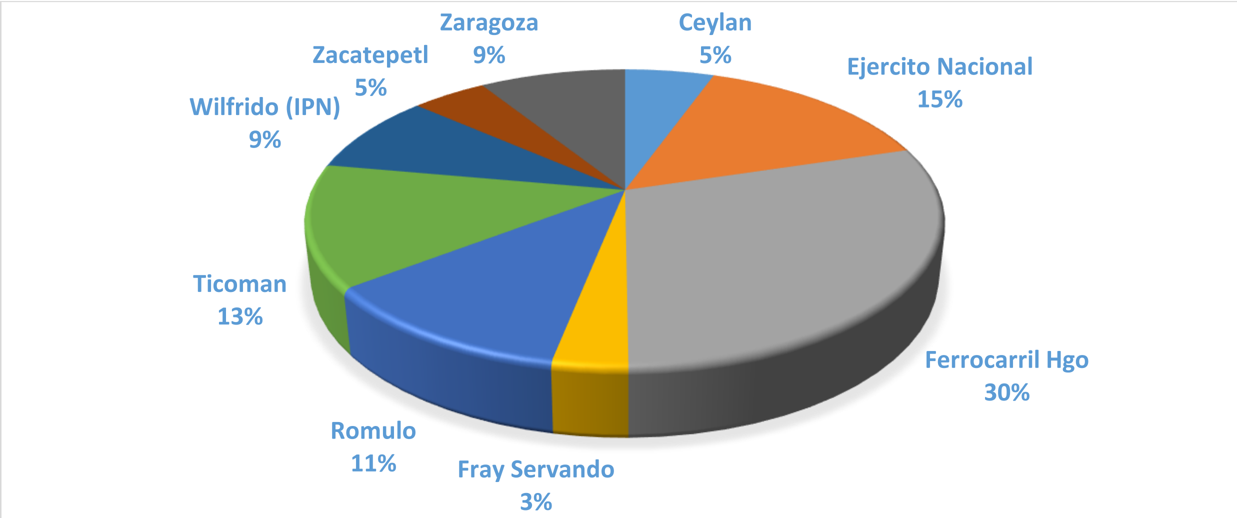

Figure 1. Distribution of 2019 RSD Measurement by Location

A comparison of RSD collected in different years, on different vehicles and different locations, introduces a lot of unexplained variability. Normal variation in vehicle speed, meteorology, and fleet makeup can average out with large enough samples of RSD, but systematic differences such as changes in fuel quality may bias the comparison. 2016 fuel survey results published in ERG 2019 showed that Mexico City was already in compliance with NOM-16 standards; 2019 fuel properties are assumed nominally similar to 2016.

Data Preparation & Plate Matching

Analyzing RSD by specific vehicle type and model year requires vehicle registration data be added to the RSD, matched on license plate. The original dataset ICCT provide included this matching for about 40 percent of the records (14,216). A request by SEDEMA to Mexico City and Estado de Mexico vehicle registration agencies to extract vehicle information on unmatched plates in the RSD database yielded 1,016 additional records in CDMX, and 6,610 records in EdoMex. This brought the total count of RSD readings matched with vehicle information to 21,842, defining the dataset used for further analysis. For matched RSD records in CDMX 10,279 were *Vehicle De Uso Particular* (private use light-duty vehicles, or LDVs); 4,450 were taxis, and the remaining 307 vehicles spread amongst cargo vehicles, buses and special purpose. EdoMex records were reported as nearly all *Transporte de pasaje particular* and identified by SEDEMA as transit network companies (TNC), a.k.a. ride share vehicles, with fewer than ten other and zero taxis reported. Whether these vehicles were indeed ride share, or were mixed with private vehicles and taxis, could not be determined. To evaluate whether some taxis in the EdoMex dataset may have been misclassified as TNC, we identified the vehicle makes and models that have the highest taxi numbers in CDMX, and are also majority taxi vs. private use. The Nissan Tsuru, Chevrolet Aveo, and Nissan Tilda accounted for nearly 70 percent of taxis in the CDMX data. Of these makes, 80 percent are taxis, so their occurrence in the

EdoMex fleet might suggest misclassification as private vehicles. We found that these three vehicle makes total about 7 percent of the EdoMex fleet, and that their average HC emissions are less than one-half of the same makes in CDMX (137 ppm vs. 311 ppm). Given the uncertainty as to whether the EdoMex vehicles were ride share, private vehicles, or taxis, they were analyzed as a single group. Samples sizes by model year for each dataset included in the analysis is shown in Table 1.

Table 1. RSD Sample Size by Model Year

Model Year	2016 Dataset		2019 Dataset		
	CDMX Private LDV	CDMX Taxi	CDMX Private LDV	CDMX Taxi	EdoMex
<1996	650	5	102		159
1996	66	0	15		16
1997	177	2	27		35
1998	348	3	46		39
1999	365	1	37		32
2000	492	4	63		41
2001	733	9	106		80
2002	828	13	116		64
2003	789	12	99		77
2004	977	16	130		68
2005	1276	61	171		105
2006	1245	360	216		153
2007	1646	553	312	16	181
2008	1977	911	349	122	188
2009	1923	1224	373	391	151
2010	2208	689	434	284	137
2011	2434	792	492	355	148
2012	3322	715	784	422	197
2013	3619	742	806	415	271
2014	2980	952	846	571	308
2015	1028	1273	999	690	482
2016	1944	705	1173	449	865
2017	-	-	1024	399	1153
2018	-	-	1110	388	1193
2019	-	-	448	64	520

CDMX Model Year & Age Trends

To assess whether trends observed in 2016 RSD appear in the 2019 data, model year averages were compared between the datasets, focused on private light-duty vehicles and taxis. Figure 2 shows this first for CDMX only. For private vehicles, the 2019 data shows higher emissions for model years 2011 through 2016, indicating deterioration in emissions over three years for the vehicles that were the newest in the 2016 fleet. Average HC emissions for the 2011-16 model years were 2.6 times (160 percent) higher in 2019 vs. 2016; by comparison, a U.S. EPA analysis of Denver I/M data estimated an emissions increase of 1.7-2.0 for U.S. Tier 1 and Tier 2 vehicles over a *20 year* period.[2] On a relative basis the three-year increase was much higher for HC than for CO, which increased about 30 percent for private vehicles, comparable to U.S. deterioration trends per Denver I/M data. As discussed later, a divergence in HC and CO values is a marker for excess evaporative HC emissions, suggesting evaporative emissions play a role in the high HC deterioration observed in Mexico City. 2010 and earlier model years do not show a difference between 2016 and 2019 fleets. For taxis, the average emissions for each model year were also significantly higher with three additional years of age.

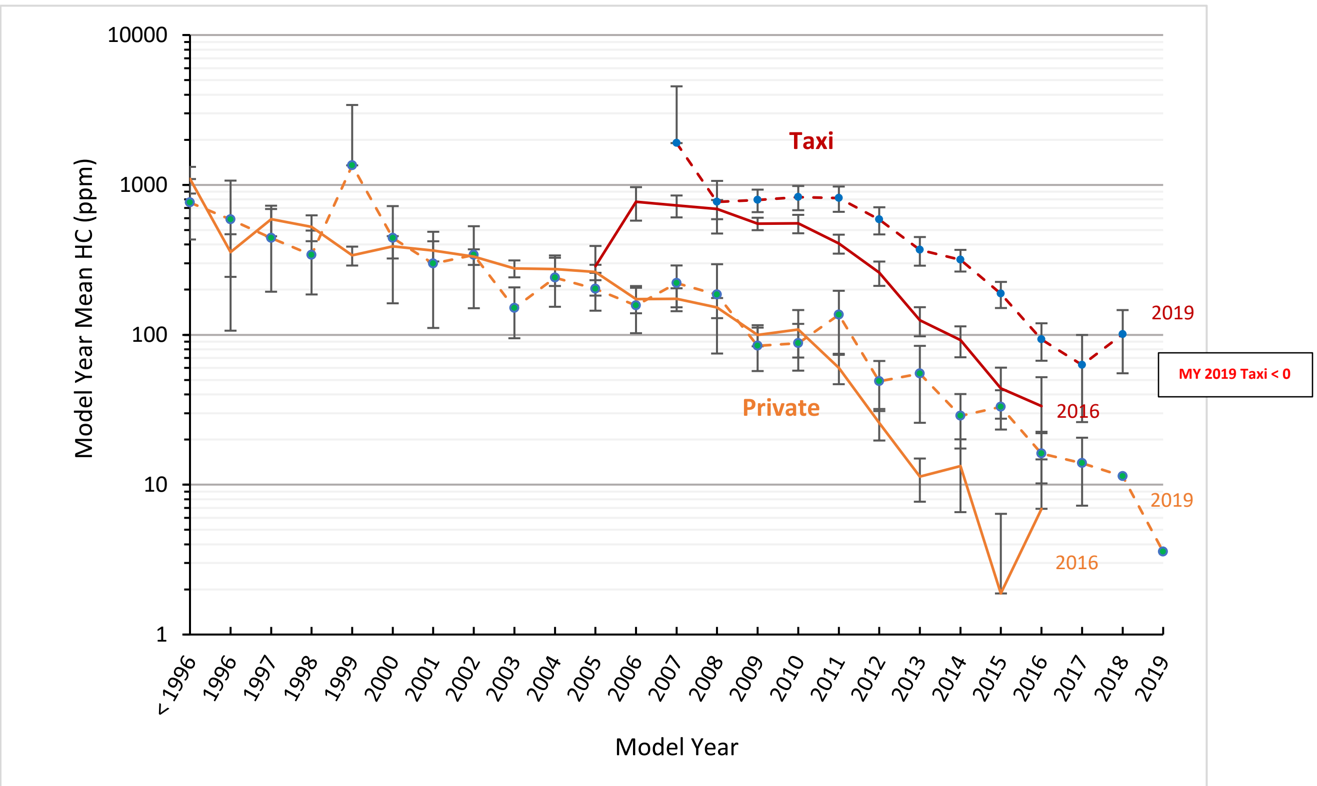

Figure 2. Mean HC by Model Year for CDMX Private Vehicles & Taxis, with 95% CI

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[2] U.S. EPA, *Exhaust Emission Rates for Light-Duty Onroad Vehicles in MOVES3,* EPA Report EPA-420-R-20-019, November 2020

A comparison of the same data by vehicle age, rather than model year, is shown in Figure 3. This look at the data compares the rate of emissions deterioration over time, assuming no systematic biases from vehicle operation, fuels etc. There is a shift in model years between the two datasets, with age 0 = model year 2016 in the 2016 dataset, and age 0 = model year 2019 in the 2019 dataset. Figure 3 shows lower emissions for private LD vehicles in the 2019 dataset starting with age 5 (model year 2014) vs. 2016 (model year 2011), with significant differences for nearly each age thereafter.   Emissions by age for taxis are lower for some ages in 2019, though the rate of deterioration is similar between the two years.

Determining the reason for lower emissions by age in 2019 is a challenge, as the comparison pits two different vehicle samples measured at different locations, different times of year (2019 sample collected mostly in April-May, while 2016 sample most July-November), and different operation. Potential reasons for an emissions offset could include implementation of NOM-42 vehicle emission standards, overcompliance with standards via U.S. vehicles, or improvements in the PVVO program.

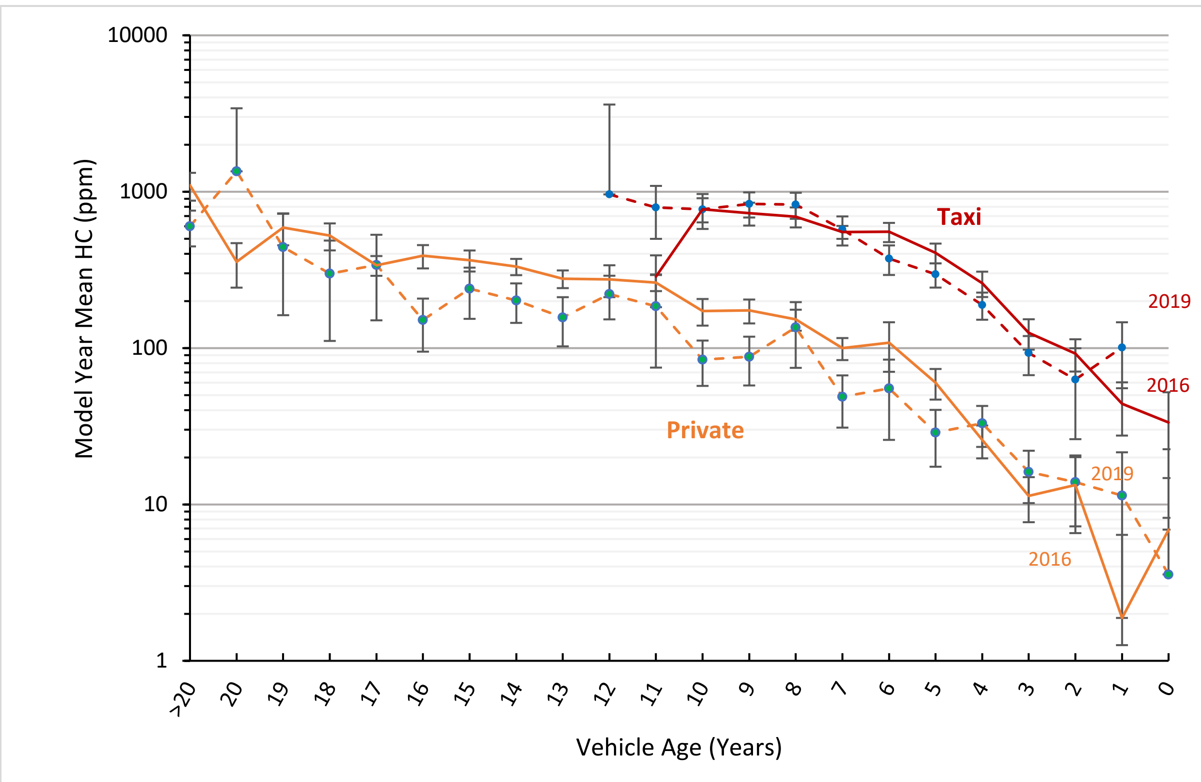

Figure 3. Mean HC by Age for CDMX Light-Duty Vehicles, with 95% CI

CDMX vs EdoMex

The delivery of decoded license plate data from EdoMex allowed a comparison between vehicles registered in CDMX vs. EdoMex, which wasn't possible in the 2016 database. As noted earlier nearly all EdoMex vehicles were classified as ride share vehicles, though the actual fleet makeup is uncertain. The comparison of mean HC emissions by model year for CDMX and EdoMex in 2019 in shown in Figure 4, with the private and taxi CDMX results included for comparison. The EdoMex fleet falls in between these, with higher HC emissions vs. CDMX private vehicles for nearly all model years, significant to 95 percent for several model years. The EdoMex results merit further investigation; they may be indicative of a the influence of ride share or taxis relative to private vehicles, or differences in fuel properties or PVVO effectiveness between the two domiciles.

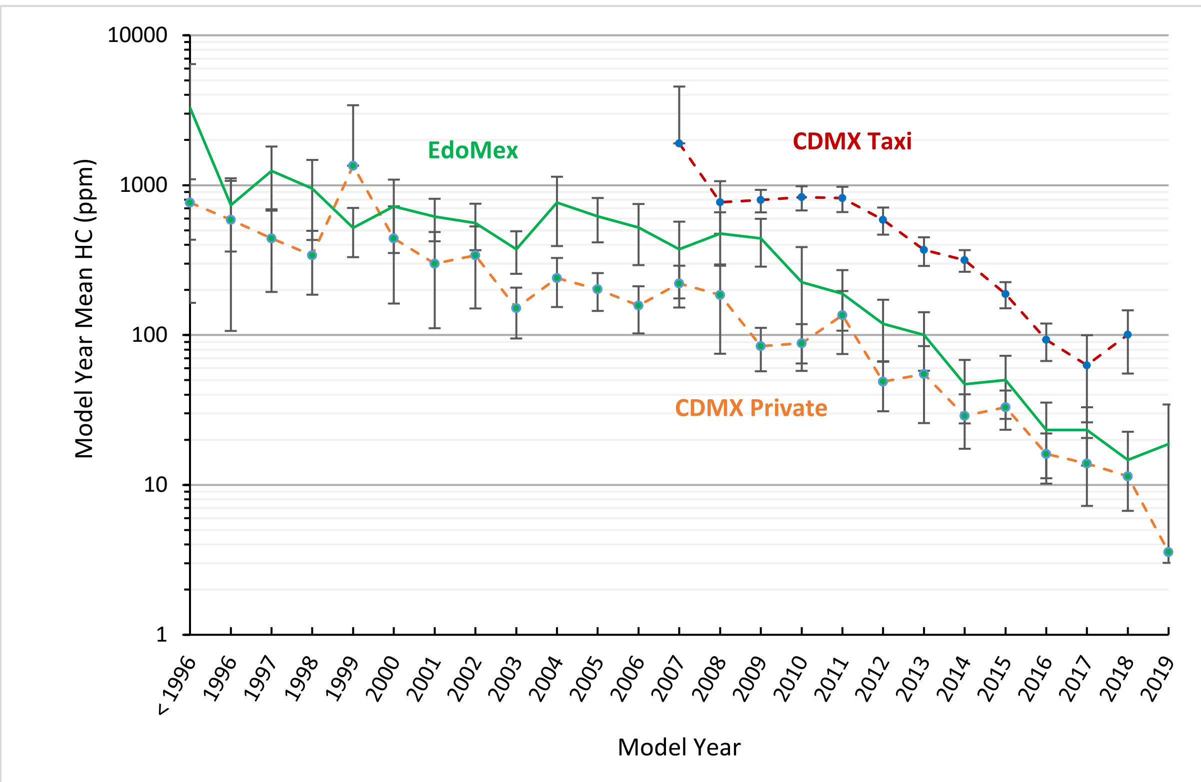

Figure 4. Mean HC by Model Year for CDMX & EdoMex Vehicles, with 95% CI

HC:CO Correlation

The correlation between HC and CO concentrations was employed as a marker for excess evaporative emissions. As detailed in ERG 2019, this approach was adapted from studies inferring evaporative emissions in RSD measurements based on correlation of HC and exhaust-only pollutants (mainly CO_2) within the sample of 10ms observations typically averaged within a single RSD "hit". With Mexico City's RSD samples lacking underlying 10ms readings, this concept was adapted in ERG 2019 to comparing the slope of model year mean HC (ppm) vs. model year mean CO (percent). This slope is higher for vehicles with excess evaporative emissions, confirmed by comparing RSD HC:CO for a sample of vehicles with low ("pass") vs. high ("fail") evaporative emissions as measured in a PSHED[3] at Denver's Lipan St. I/M station.[4] In ERG 2019, the HC:CO slope for 2016 Mexico City RSD was found to correspond to RSD readings for high PSHED vehicles, while the HC:CO correlation for exhaust-only PVVO and Denver RSD corresponded closely with to RSD readings from low PSHED vehicles. Figure 5 shows this comparison repeated with the 2019 RSD data. For reference, the Mexico City PVVO and Denver RSD samples from ERG 2019 are included, showing linear correlation comparable to the slope of vehicles of low PSHED vehicles. In contrast the 2019 RSD values (shown for CDMX private car, EdoMex private car, and taxi) are highly scattered with levels more consistent with high PSHED vehicles. The 2019 data thus continues to suggest evaporative emissions contribute to high HC levels.

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[3] PSHED stands for Portable Sealed Housing for Evaporative Determination, an enclosed 3 x 6 x 2.5 meter vinyl tent coupled with a portable emissions measurement system first used by U.S. EPA to improve estimates of high evaporative emitter prevalence.

[4] U.S. EPA, Estimated Summer Hot-Soak Distributions for Denver's Ken Caryl I/M Station Fleet EPA-420-R-14-027 Prepared for U.S. EPA by Eastern Research Group, Inc. March 2014

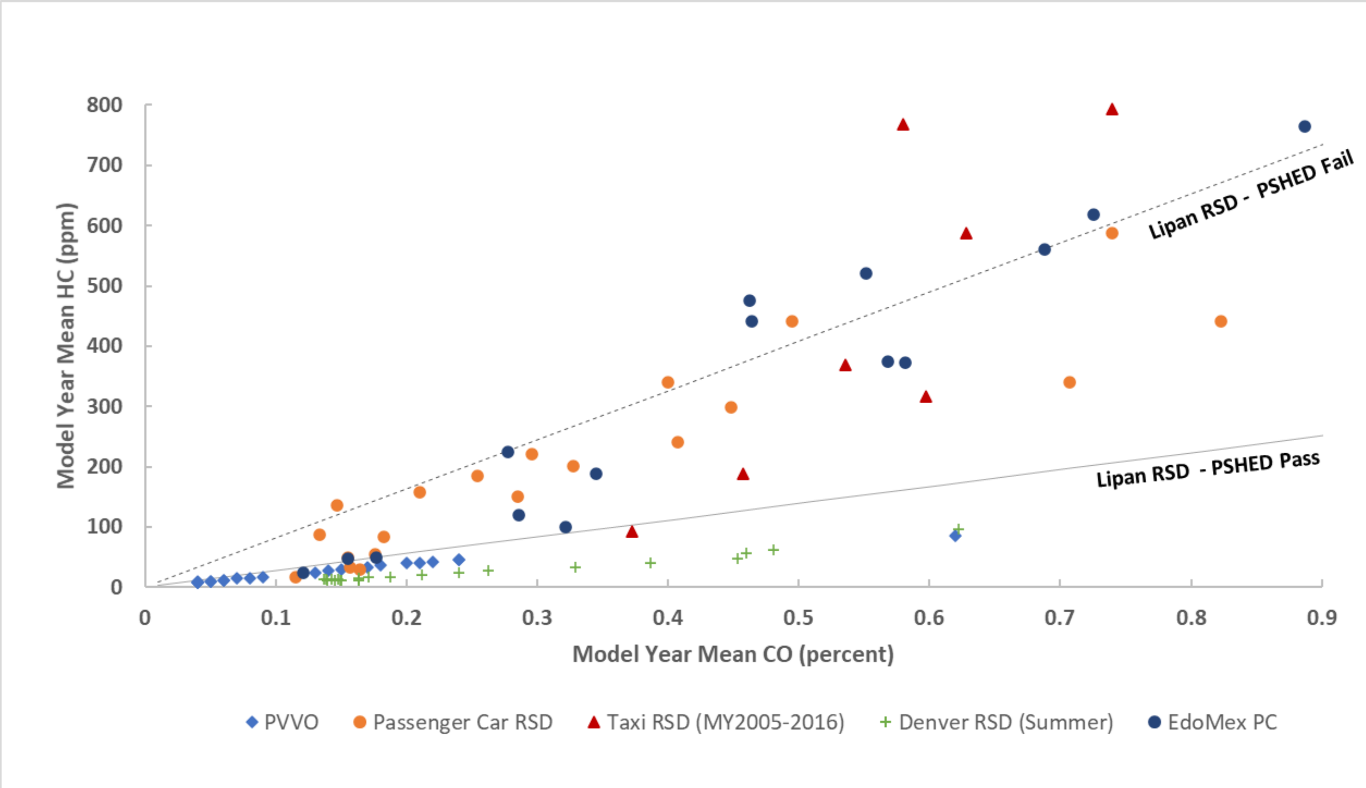

Figure 5. Mean Model Year HC vs. CO compared to High & Low PSHED Vehicles

Paired Analysis

By matching license plates between the 2016 and 2019 data, ERG was able to identify 642 vehicles that appeared in both samples: 487 private light-duty vehicles, 45 taxis, 11 other, and 99 unidentified. These vehicles provide some ability to observe changes in emissions over three years, although the small sample size and uncontrolled differences in vehicle operation, fuel, weather and other factors lend considerable variability to the observations. These factors render a vehicle-level paired sample statistical analysis meaningless, but with aggregation trends do emerge. Figure 6 shows model year average HC concentrations for the paired sample of private vehicles in 2016 and 2019. The 2019 sample averages are higher for all model years, though with small sample sizes the differences are not significant at 95 percent.

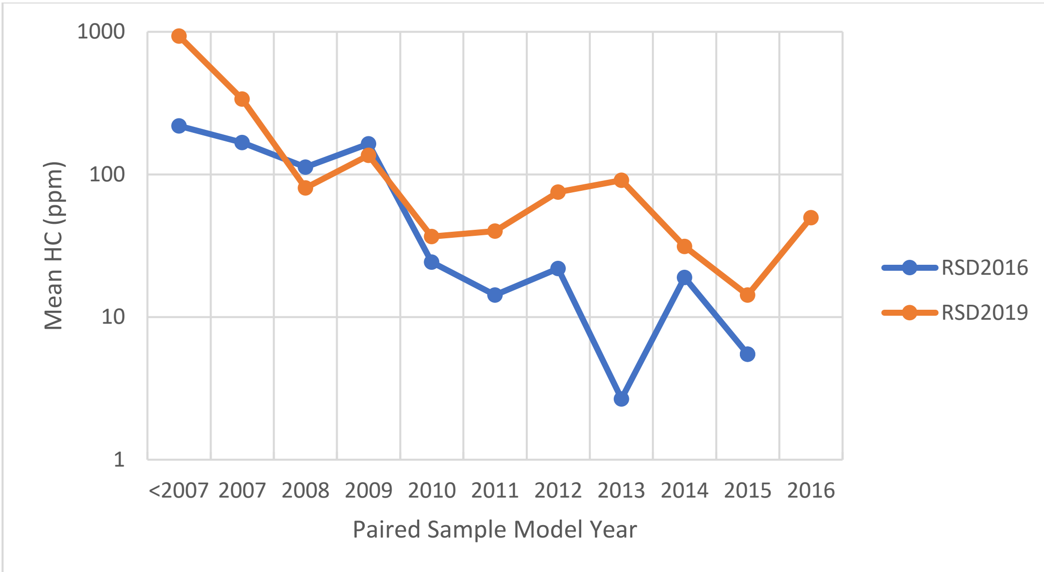

Figure 6. Private Vehicle Paired Sample Mean HC by Model Year

HC:CO correlation for the model year averages of the private vehicle paired sample in 2016 and 2019 is shown in Figure 7, with linear trendlines. The higher slope for the 2019 sample suggests higher evaporative emissions contribute to the higher HC levels observed by model year.

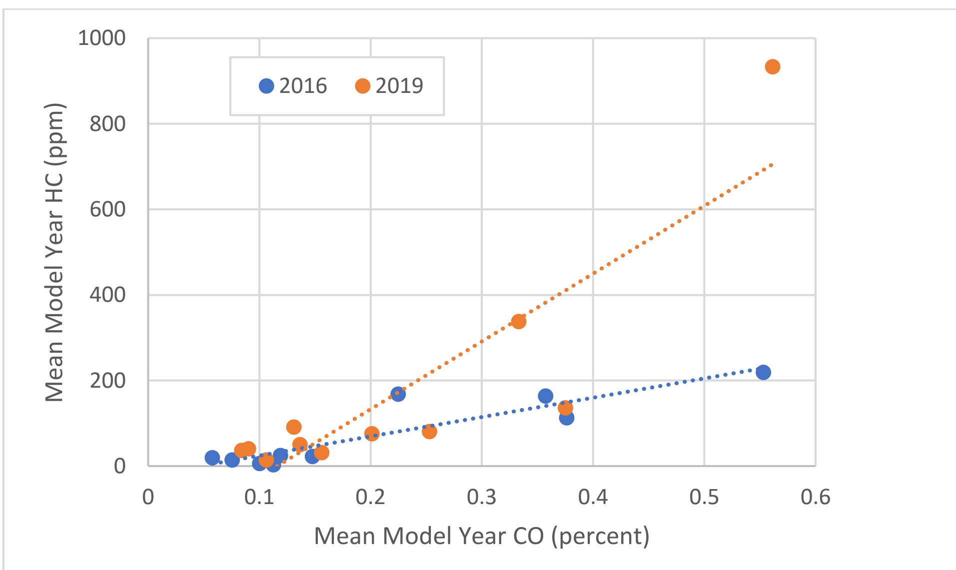

Figure 7. HC:CO Correlation for Private Vehicle Paired Sample

Summary of Findings

Overall, the 2019 Mexico City RSD confirms trends observed three years prior: high HC emissions for private LDVs, exceedingly high HC emissions for taxis, and continued indication of excessive evaporative emissions. The 2019 data shows a high rate of HC deterioration for model years 2011-2016 relative to CO emissions for the same model years, and relative to U.S. deterioration rates. However, a comparison by vehicle age shows lower emissions for the 2019 fleet vs. 2016. The cause of this is difficult to pinpoint from these data alone, and merits further investigation to assess whether NOM-42 light duty vehicle standards, PVVO improvements, RSD siting, ambient conditions, or other factors contribute to the difference. Though taxis showed some age-based reductions in 2019, their rate of deterioration over three years was very high, with emissions doubling during that span even for the newest model years. An additional finding from the 2019 data is that HC emissions in EdoMex appear higher than private LDVs in CDMX, though the influence of ride share vehicles and taxis in the EdoMex fleet is unknown. Finally, correlation of HC:CO continues to suggest high evaporative emissions in Mexico City's fleet, underscoring the need to study and mitigate this major emissions source. Recommendations for this are discussed in the following section.

Recommendations for Further Research on Evaporative Emissions with RSD

Though RSD has traditionally focused just on tailpipe exhaust emissions, over the past decade studies conducted with newer generation RSD technology and calculation methods have confirmed the presence of evaporative emissions in roadside HC measurements. The presence of evaporative emissions in RSD measurements was first investigated in studies that found a divergence in RSD and exhaust-only inspection/maintenance (I/M) results, including high RSD HC readings for vehicles that had passed exhaust-only I/M tests.[5] Follow-on studies confirmed the ability of RSD to detect known high evaporative emissions, based on measurements on a passing vehicle with induced evaporative control malfunctions.[6] As noted earlier, additional studies focused on establishing a correlation between RSD direct evaporative emission measurements made in a PSHED. The refinement of methods for applying RSD to assess evaporative emissions is ongoing; a recently published study applied these methods to RSD collected in Los Angeles in 2013 and 2015, estimating that 0.1 - 0.2 percent of the vehicles measured had extreme running loss evaporative emission levels, at least 50 times higher than current Federal (Tier 3) standards.[7] These studies confirmed that RSD can be useful to quantify excess evaporative emissions, and to identify high evaporative emitters. However, all relied on more than the aggregate RSD vehicle "hit" typically reported, supplementing this with either underlying 10ms readings and/or independent emissions measurements such as PSHED or I/M. To replicate these studies in Mexico City (or elsewhere) will thus require additional data collection during RSD campaigns, plus supplemental data to provide independent comparison

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[5] Burnette, A. et al, Evaluation of Remote Sensing for Improving California's Smog Check Program Final Report, ARB-080303, prepared for California Air Resources Board and California Bureau of Automotive Repair by Eastern Research Group, Inc., 2008.
[6] DeFries, T. et. al, Estimated Summer Hot-Soak Evaporative Emissions Distributions for the Denver Fleet, Report prepared for Colorado Department of Public Health and Environment by ERG, Inc., 2012
[7] Bishop, G. at al, *Vehicle Exhaust Remote Sensing Device Method to Screen Vehicles for Evaporative Running Loss Emissions*, Environmental Science & Technology 2020 54 (22), 14627-14634
DOI: 10.1021/acs.est.0c05433

and cross-check of RSD results. To improve diagnosis of evaporative emissions from RSD in Mexico City and elsewhere ERG makes the following recommendations:

- Keep raw 10 millisecond readings from RSD devices, to enable a more certain detection of evaporative vs. exhaust HC emissions. Typical RSD measurements are an aggregation of 50 absorbance readings spaced every 10 milliseconds; ERG has analyzed such data in the U.S. and developed algorithms to flag high evaporative emissions.

- Improve the matching of license plates between RSD and Mexico City's I/M (PVVO) program, which prior studies found to be only about 55 percent. Having paired data on more vehicles will provide a more robust comparison of exhaust-only measurement and RSD, to help diagnoses the presence of excess non-exhaust HC in the RSD sample.

- Conduct field studies to better quantify evaporative emissions from gasoline vehicles, and the frequency of vehicles with vapor or liquid fuel leaks, for use in MOVES. Recent studies in the U.S. have developed methods for field work that are more cost-effective than full-fledged evaporative chamber testing (SHED). These methods include use of a portable SHED at inspection stations, parking lots etc.; use of hydrocarbon "sniffers" or infrared cameras to detect excess vapor on parked vehicles; and analysis of 10 millisecond RSD readings. These approaches can be complimentary – a study can begin with non-intrusive screening of a large population of vehicles (RSD, infrared cameras) to flag a smaller sample of high-emitters for more in-depth testing (sniffer, portable SHED). Methods to test for excess vapor or liquid leaks could also be introduce to PVVO to gather on-going data on high evaporative emitters.