STATE OF CALIFORNIA
AIR RESOURCES BOARD

Proposed Revisions to the On-Board Diagnostic	**)**	
System Requirements and Associated	**)**	**Hearing Date: July 22, 2021**
Enforcement Provisions for Passenger Cars,	**)**	**Agenda Item: 21-6-1**
Light-Duty Trucks, Medium-Duty Vehicles and	**)**	
Engines, and Heavy-Duty Engines	**)**	

COMMENTS OF THE TRUCK AND ENGINE MANUFACTURERS ASSOCIATION

July 19, 2021

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STATE OF CALIFORNIA
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Proposed Revisions to the On-Board Diagnostic System Requirements and Associated Enforcement Provisions for Passenger Cars, Light-Duty Trucks, Medium-Duty Vehicles and Engines, and Heavy-Duty Engines	**)))))**	**Hearing Date: July 22, 2021** **Agenda Item: 21-6-1**

Introduction

The Truck and Engine Manufacturers Association ("EMA") hereby submits its comments in response to the Initial Statement of Reasons ("ISOR") that the State of California Air Resources Board ("CARB") published on June 1, 2021, in conjunction with CARB's "Proposed Revisions to the On-Board Diagnostic System Requirements and Associated Enforcement Provisions for Passenger Cars, Light-Duty Trucks, Medium-Duty Vehicles and Engines, and Heavy-Duty Engines." EMA is the trade association that represents the world's leading manufacturers of internal combustion engines, including heavy-duty on-highway ("HDOH") diesel engines, as well as the heavy- and medium-duty vehicles in which those diesel engines are installed. EMA and its members are strongly committed to improving air quality both in California and nationwide. We have worked collaboratively to help develop and implement effective standards to meet those goals, and we stand ready to continue that work.

The engines, vehicles, and equipment manufactured by EMA's members are heavily regulated under numerous CARB regulations, including multiple recent regulatory actions that are being issued by CARB essentially simultaneously. Those actions include the Advance Clean Trucks rule (which will be further amended in the near future), the Heavy-Duty Omnibus Low NO_x program, and the upcoming Heavy-Duty Inspection and Maintenance program. In assessing EMA's comments, we respectfully request that the Board take note of the multiple pending programs, especially in cases where regulatory changes to one program would either conflict or create duplicative requirements with another program, as will be the case with this rulemaking. Further, the Board should consider the cost and burden to regulated entities of such compounding impacts.

Specific Comments on the Proposed Regulation Order and Initial Statement of Reasons

EMA's specific comments on the proposed amendments to the HD OBD regulations are set forth below:

- **§1971.1(e)(11.2.4), (g)(3.2.2)(B)(i)c.2., and (h)(5.9.7):** CARB's proposal specifies a phase-in schedule of 20% of MY2026 and 50% of MY2027 vehicles/engines for implementing these new monitor requirements, but would allow manufacturers to use an alternate phase-in schedule until MY2028, when 100% of vehicles/engines must comply with the requirements. EMA does not believe that such amendments are needed, as it could cause unnecessary burdens in the final year of production when manufacturers would need to make major changes for a small volume of product for that year. However, if proposed amendment (g)(3.2.2)(B)(i)c.2. is finalized, a conforming language change in subsection (B)(i) is needed (i.e., "when any of the following conditions occur").

- **§1971.1(e)(5.2.4) and (6.2.3):** Proposed new subsection (C) would allow for a waiver of the requirements of subsections (A) and (B) "if the plan and data have been submitted for a previous model year and the calibrations and hardware of [the monitor], the engine, and the emission control system for the current model year have not changed from the previous model year." Manufacturers request that the language of subsection (C) be modified to instead state "if the plan and data have been submitted for a previous model year and are substantially similar with respect to catalyst aging mechanisms." It is unlikely that all calibrations and hardware will remain completely unchanged from one model year to the next. Further, calibration changes are unlikely to affect catalyst aging mechanisms in the field and, unless there is a major technology change, most hardware changes are unlikely to result in different catalyst aging in the field. The proposed language disincentivizes continuous improvement by manufacturers due to the extensive cost of conducting a supplemental correlation effort.

- **§1971.1(e)(5.2.4)(B)(ii) and (e)(6.2.3)(B)(ii):** The introductory text of proposed subsection (ii) lacks clarity. EMA recommends that the proposed regulatory text be amended as follows (new language in dashed underlining): "(ii) Information and data collected on an engine dynamometer or a reactor bench to support methods established by the manufacturer to represent real world catalyst deterioration under normal and malfunctioning engine operating conditions in sections (e)(5.2.4)(A) must be submitted to the Executive Officer and shall at a minimum include an analysis of the potential failure modes and effects, highlighting the most likely cause of failure, comparison of laboratory aged versus real world aged catalysts, and include the following for a laboratory aged catalyst and a minimum of three field-returned catalysts (data for all field-returned catalysts that are collected for this aging correlation analysis must be submitted to the Executive Officer):"

- **§1971.1(e)(9.2.2):** In previous workshops and discussions, CARB Staff indicated that relief for dual SCR NO_x sensors 2 & 3 would be proposed in the ISOR. However, such a provision does not appear to be in either §1968.2 or §1971.1 of the proposed regulations.

- **§1971.1(e)(9.2.2)(D)(i)c.:** Subsection (i)c. appears to be missing text. EMA recommends that the proposed regulatory text be amended as follows (new language in dashed underlining): "The dependent monitor (e.g., catalyst monitor) makes a fail decision during testing for each data point (except the data point at the sensor monitor malfunction threshold) in the passing region of the sensor monitor,"

- **§1971.1(e)(5.2.3)(B):** Amendments related to DOC and DPF feedgas generation were proposed for the OBD II regulations in §1968.2(f)(1.2.3)(B) and (f)(9.2.4)(B), respectively, yet parallel amendments were not proposed in subsection (B) of the corresponding HD OBD regulations at §1971.1(e)(5.2.3) or (e)(8.2.4).

- **§1971.1(h)(1.4):** SAE J1979 and J1979-2 are "peers," and are mutually exclusive for a given engine or vehicle. EMA recommends the following amendments to the regulations, in lieu of the amendments proposed in the ISOR (new language in dashed underlining; note that the edits below are in relation to the existing §1971.1 regulatory text, not the ISOR):

  (1.4) ~~SAE J1979 "E/E Diagnostic Test Modes", February 2017 (SAE J1979).~~SAE J1979 as defined in:
  (1.4.1) ~~SAE J1979-DA "Digital Annex of E/E Diagnostic Test Modes", May 2019.~~ SAE J1979 "E/E Diagnostic Test Modes", February 2017 (SAE J1979).
  (1.4.2) SAE J1979-DA "Digital Annex of E/E Diagnostic Test Modes", April 2021.
  (1.4.3) SAE J1979-2, "E/E Diagnostic Test Modes: OBDonUDS", April 2021.

- **§1971.1(h)(4.3.2), (h)(5.9), and (d)(5.7):** NVRAM demand in sections (h)(4.3.2) (freeze frame), (h)(5.9) (CSERS trackers), and (d)(5.7) ("IUMPR-lite"), are estimated to require 29,760 bytes of NVRAM.[1] This additional demand comes on top of the increases required of MY2022 engines for NO_x binning and GHG tracking. Further, NVRAM additions are at risk given the uncertainty with the current worldwide semiconductor/chip supply chain shortage. (*See Attachment A, EMA Letter on US Innovation and Competition Act.*)

- **§1971.1(h)(5.3.4):** The proposed amendments state "Any negative concentrations reported by a NO_x sensor must be set to zero when used in a NO_x mass calculation. Any tracking and reporting of negative NO_x mass data must be done separately from the parameters covered by this regulation." As discussed in detail in the draft SAE J3349 Sensor Accuracy Taskforce report and in Attachment B to these comments, investigations of negative NO_x sensor readings have shown that such readings are meaningful and constitute an important contribution to measurement accuracy. They are not artifacts, and are no more biased than any corollary positive readings. Exclusion of negative NO_x sensor concentrations can have a significant impact on the accuracy of cumulative NO_x emissions for ultra-low NO_x emissions systems, as explained in Attachment B. EMA requests that CARB reconsider this amendment to allow for the inclusion of negative NO_x sensor concentrations.

- **§1971.1(l)(3.4.2)(A):** EMA opposes the addition of proposed section (l)(3.4.2)(A), which would require 300 general denominator events for IUMPR data collection, as this requirement will make an already challenging assignment virtually impossible. Supplemental Monitor Activity Ratio (SMAR) will provide a vast amount of additional data and monitor execution details that have not been previously available to CARB. These new data can be readily used for CARB's stated purpose of identifying potentially disabled diagnostic trouble codes (DTCs)[2] or low monitoring frequency to begin discussions/investigations with manufacturers on any DTCs that appear to have underperforming frequency. EMA recommends that the additional data restrictions should not be adopted. Furthermore, manufacturers do not agree with the

[1] 5 freeze frame DTCs x 2 instances x 256 bytes of data = 2,560 bytes x 2 spare locations per DTC = 5,120 bytes. 10 CSERS Tracker accumulators x 2 arrays x 4 bytes = 80 bytes. 80 bytes x 8 spare locations = 640 bytes NVRam. 3 bytes for MAR, Mini-N, and Mini-D x 1000 DTCs x 8 spare locations = 24,000 bytes. Spare locations compensate for flash memory wear-out phenomena.

[2] Supplemental Monitor Activity Data (SMAD) has design limitations in that it may not accurately represent in-use monitor performance ratio for some monitors. For example, Diesel Exhaust Fluid (DEF) heaters may not execute year-round in California by design/lack of actuator usage.

assertion that step changes in monitor performance occur with increased vehicle mileage/age. Step changes in monitoring frequency are more likely to occur early in the life of the engine or vehicle due to software/calibration updates. Manufacturers generally make fewer changes to software/calibration as the vehicle age matures.

Additionally, the proposed requirement is not practicable given running changes for calibrations and vocational vehicle considerations. This can be explained as 50 work weeks * 6 working days per week * 1 general denominator per day; two trips per day may result in 600 general denominator events. It effectively defines that vehicles are in use, without change for a year, to qualify the data for collection. The number of service calibration updates in a year can dramatically reduce the available general denominator events that may be captured during (l)(3) data collection. These updates are reported as running changes under §1971.1(m). As shown in Table 1, below, even two calibration updates in a production year reduces the likely number of general denominator events that may be captured below the desired threshold. The timing of the calibration updates are not considered. Data collection efforts shortly after the distribution of a calibration update are clearly challenged to provide 300 general denominator events. Manufacturers are not permitted to wait until there is a year of experience with the most recent calibration update. Heavy-duty vehicles are unlikely to be capable of providing IUMPR data containing only 300 general denominator events, and the additional data collection restriction should not be adopted.

Several vehicle vocations do not meet the 300-denominator model and will be unlikely to achieve 300 general denominator events, especially when the effects of calibration updates are considered. Certain vehicle categories – and thus the associated data – will be completely excluded because they will never achieve 300 events.

- For a 5-day work week:
  50 weeks * 5 days * 1 trip * 1 general denominator per trip is 250 possible events,
  50 weeks * 5 days * 2 trips * 1 general denominator per trip is 500 possible events.
- School busses are used 40 weeks or less per year, 5 working days per week, two or four trips per day, for approximately 30 minutes to one hour per trip:
  40 weeks * 5 days * 2 trips * 1 general denominator per trip is 400 possible events,
  40weeks * 5 days * 4 trips * 1 general denominator per trip is 800 possible events.
- Package delivery challenges general denominator requirement for 600 seconds of qualified operation per trip. Package delivery services minimize vehicle idling by turning the vehicle off at every stop. In an 8-hour shift, the available opportunities must consider the number of stops. When the scheduled number of stops exceeds 50 stops, the number of trips that exceed 600 seconds may be minimal:
  8 hours * (3600 s / 1 hour) / 25 stops = 1152 s / stop
  8 hours * (3600 s / 1 hour) / 50 stops = 576 s / stop
  8 hours * (3600 s / 1 hour) / 75 stops = 384 s / stop
  8 hours * (3600 s / 1 hour) / 100 stops = 288 s / stop
  8 hours * (3600 s / 1 hour) / 125 stops = 230 s / stop

Table 1		
Events Per Year	Number of Calibration Updates	Events per Calibration
300	0	300
300	1	150
300	2	100
300	3	75
300	4	60
600	0	600
600	1	300
600	2	200
600	3	150
600	4	120

- **§1971.1(l)(3.4.2)(C):** The proposed amendments to the Production Vehicle/Engine Evaluation would require a new data submission along with the typical IUMPR spreadsheet, plus "a summary of any problems identified in the data." EMA questions the requirement in subsection (C) of the summary for vehicles using SAE J1979-2. The IUMPR spreadsheet is simply a data spreadsheet and is not designed to identify or summarize problems. Such a requirement is onerous, and it would seem that this is an evaluation that CARB Staff currently performs as part of its review of manufacturer OBD submissions.

Additional Comments

- EMA strongly supports the comments of the Alliance for Automotive Innovation, including regulatory changes requested by the United States Council for Automotive Research (USCAR) with respect to the proposed amendments for Cold Start Emission Reduction Strategy (CSERS) provisions.

- The HD OBD exemptions being proposed for legacy engines at §1956.8(a)(2)(C)3.a.iv. in the "Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments; Second Notice of Public Availability of Modified Text and Availability of Additional Documents" (Appendix A-1: Title 13 - Proposed Second 15-Day Modifications to the Proposed Regulation Order) should also be documented in 13 CCR §§1971.1 and 1971.5. Any exceptions to the OBD provisions should be clearly stated, or, at minimum, referenced, in the OBD regulation. This will ensure that all of the applicable HD OBD certification and enforcement requirements are considered and applied appropriately to legacy engine families.

- **§1971.1(e)(11.2.2):** The newly proposed CSERS CWS monitor provisions do not appear to take into account the alternate malfunction criteria that changed as part of the HD Omnibus rulemaking. We recommend that CARB Staff review those changes to ensure that there are not regulatory conflicts.

- **§1968.2(j)(3.2.3)(C):** The amendment at §1968.2(j)(3.2.3)(C) does not appear to have a corresponding amendment in §1971.1. EMA questions if this is intentional or in error. If in error and a corresponding change to §1971.1 will be proposed at a later date, EMA notes that the intent of the proposed regulatory change is to allow manufacturers to draw data from a potentially larger group of vehicles when collecting in-use rate data electronically. Since the VIN is considered personally identifiable information, the current regulation allows for data collection only from customers who have opted into the highest level of information sharing. The proposed requirement that manufacturers retain information that matches the VIN to an alternate identifier would still only allow for data collection from customers who opt into the highest level of information sharing.

Allowing manufacturers to use an alternate identifier that is vehicle-specific but cannot be matched to the original VIN (such as a "VIN hash" derived from applying an irreversible mathematical operation to the VIN), would allow for data collection from a wider number of California vehicles while still ensuring that no vehicles are included more than once in the data set. CARB should provide for this type of alterative identifier.

The proposal also should be revised to still allow for manufacturers to use an alternate vehicle identifier, but also to collect additional VIN-inclusive data upon request of the Executive Officer if needed for specific investigations or to better understand issues identified in the submitted data set (e.g., bimodal distribution, significant numbers of vehicles with zero or non-compliant in-use rates, etc.).

This allowance should also be extended to §1971.1(l)(3) PVE data requirements, although it should be noted that manufacturers' collection of this standardized data may become moot if it is also collected from vehicle operators as part of upcoming Heavy-Duty Inspection & Maintenance requirements.

- **<u>§1971.1(e)(11) and (f)(4):</u>** Sections (e)(11.1.2) and (f)(4.1.2) were not proposed to be amended in this action. However, EMA requests that CARB consider amending the existing language to provide regulatory clarity – to allow "similar conditions" or unique diagnostic trouble codes to cover "different diagnostics." The regulation currently states, "For an element/component associated with the cold start emission reduction control strategy under section (e)(11) that is also required to be monitored elsewhere in section (e) or (g) (e.g., fuel injection timing), the manufacturer shall use different diagnostics to distinguish faults detected under section (e)(11) (i.e., faults associated with the cold start strategy) from faults detected under sections other than section (e)(11) (i.e., faults not associated with the cold start strategy)."

- The data and validation requirements of the upcoming Heavy-Duty Inspection and Maintenance (HD I/M) program would create duplicative requirements with the existing OBD reporting requirements, and thus would result in duplicative data submissions. EMA recommends streamlining or consolidation of the overlapping data submissions to better align the two programs, and we would like to discuss with CARB Staff potential options for such consolidation.

- The ISOR and Appendix F, "Economic Analysis Support," grossly underestimates the regulatory cost impacts to manufacturers of the proposed regulatory changes, especially with regard to catalyst system and adsorber monitoring (§1971.1(e)(5.2.4)), (e)(6.2.3), and (e)(7.2.6)). The cost of diesel catalyst/adsorber malfunction criteria determination requirements are also underestimated. One manufacturer estimated the total cost to obtain and test five high-mileage and five field returned catalysts as $350,000 per engine. This estimate includes approximately 50 hours of labor and emissions testing per catalyst. Considering that five high-mileage and five field returned catalysts are to be tested in addition to the BPU per catalyst type, approximately 1000 hours are required for test preparation and testing. Additional costs are incurred for field part replacement, shipping, and reactor testing to generate required data for the correlation. If multiple catalysts are used and diagnosed independently, this cost will increase. In light of this reality, it is clear that CARB's estimate of manufacturers' total testing cost ($8,555/$4,155) is grossly underestimated. (*See Appendix F, Tables F-3 and F-4.*) In that regard, just one emission test on engine dynamometers can be more than $500 per hour.

Further, with regard to cost impacts, the proposed program should have included a comprehensive technical review, including a thorough cumulative and aggregate cost assessment of the HD OBD regulatory program. In the Final Statement of Reasons for the 2018 HD OBD revisions, CARB noted that: "As stated in Resolution 18-53, the Board specifically directed CARB staff to report back in approximately 3 years (i.e., the 2021 calendar year) with a technical review of the HD OBD and OBD II regulations in light of any heavy-duty on-highway regulations adopted in the interim [e.g., the Omnibus Low-NO_x Regulations], and to include **an updated economic analysis of the OBD program costs and benefits** conducted consistent with the methodologies used by the agency for other programs." (*FSOR*, *p.12.*) (Emphasis added.) "CARB staff has agreed to conduct an updated cost analysis of the HD OBD program in the 2021 timeframe." (*Id.*) Accordingly, in the context of this rulemaking, CARB Staff need to specify their plans to implement, document and solicit comments on the Board-directed technical review and cumulative cost assessment of the HD OBD program, and how the results of those analyses will be utilized to reevaluate the overall cost-benefit ratios and efficacy of the existing HD OBD program, especially since the mandated review was not performed in advance of (or in conjunction with) the issuance of the pending proposed amendments to the program.

CARB's commitments to conduct such thorough aggregate analyses are critically important to the ongoing feasibility of the HD OBD program, since, as CARB Staff well know, the HD OBD regulations are the most expensive HDOH regulations by more than an order of magnitude, and involve many millions of dollars per year for each OEM. Significant streamlining of those regulations is necessary to preserve the viability of the HDOD market in California, as would be revealed by the cumulative cost assessment that needs to be done, as the Board has directed. Staff are not justified in ignoring that important directive.

Respectfully submitted,

TRUCK & ENGINE MANUFACTURERS ASSOCIATION

Encl.

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May 28, 2021

The Honorable Chuck Schumer
Majority Leader
United States Senate
Room S-221, The Capitol
Washington, D.C. 20510

The Honorable Nancy Pelosi
Speaker
U.S. House of Representatives
H-232, The Capitol Building
Washington, D.C. 20515

The Honorable Mitch McConnell
Minority Leader
United States Senate
Room S-230, The Capitol
Washington, D.C. 20510

The Honorable Kevin McCarthy
Minority Leader
U.S. House of Representatives
H-204, The Capitol Building
Washington, D.C. 20515

RE: Support for the U.S. Innovation and Competition Act

Dear Senate Majority Leader Schumer, Senate Minority Leader McConnell, House Speaker Pelosi, and House Minority Leader McCarthy:

The Truck and Engine Manufacturers Association (EMA) strongly supports the *U.S. Innovation and Competition Act.* EMA represents the major manufacturers of internal combustion engines, zero-emission powertrains, and medium- and heavy-duty commercial vehicles. The Act would make bold investments in semiconductor supply chains that are crucial to the success of the U.S. truck, engine, and powertrain manufacturing industry.

From the onset of the COVID-19 pandemic, medium- and heavy-duty trucks have never slowed in transporting food, water, fuel, medical supplies, vaccines, and other critical goods and services throughout the country. To keep the trucking industry operational during the pandemic, the Department of Homeland Security's Cybersecurity and Infrastructure Security Agency identified much of the trucking workforce as essential, including its manufacturing, repair, maintenance, and supply chains. Keeping commercial trucks running without interruption has been imperative during the pandemic, and now the industry is serving as the lifeblood of the post-pandemic economic recovery.

However, truck manufacturers and their suppliers are experiencing severe shortages of semiconductors for electronic devices used in heavy truck engines, transmissions, safety systems, and emissions control devices. At a time when the economy is expanding and the demand to move freight is increasing, trucking fleets have an urgent need for new highly reliable trucks to enable them to meet freight shipping demands without delay. Yet semiconductor supply constraints are forcing heavy truck, powertrain and component production slowdowns, resulting in furloughs of highly-paid skilled workers, and causing significant delays in delivering the needed trucks and service parts to fleets.

We fully support the substantial investments in the *U.S. Innovation and Competition Act* aimed at strengthening domestic semiconductor supply chains. We also endorse the prioritization of motor vehicle grade semiconductors that are needed for heavy trucks. Establishing the long-term resiliency of the supply of those chips will provide multiplicative benefits by supporting the thousands of domestic jobs in the labor-intensive trucking industry, including heavy truck, engine, powertrain, and component manufacturing.

We greatly appreciate your careful consideration of this important matter. If you have any questions, or if there is any additional information we could provide, please do not hesitate to contact me.

Very truly yours,

Jed R. Mandel
President

124242_2

Update on On-Board-Monitoring: Negative NO_x Value Truncation

Tyler Rash

07-13-2021

Prepared by Cummins for CARB/EMA

Background: SAE Input to OBD-REAL

- SAE's "Tracking Parameter Accuracy Task Force" was tasked with generating a standardized way of complying with OBD-REAL regulations by drafting an informational report (J3349).
- Extensive discussions between CARB and the entire industry were held.
- J3349 is a *prospective* de facto OBD-REAL regulation because such documents are routinely adopted "by reference" by CARB.

Background: Expected future CFR 1065 Language & Theory

(a) General. Calculate brake-specific emissions over each applicable duty cycle or test interval.

…Unless specified otherwise, for the purposes of calculating and reporting mass (or mass rate) of emissions you must leave unaltered negative values of all measured and calculated quantities…

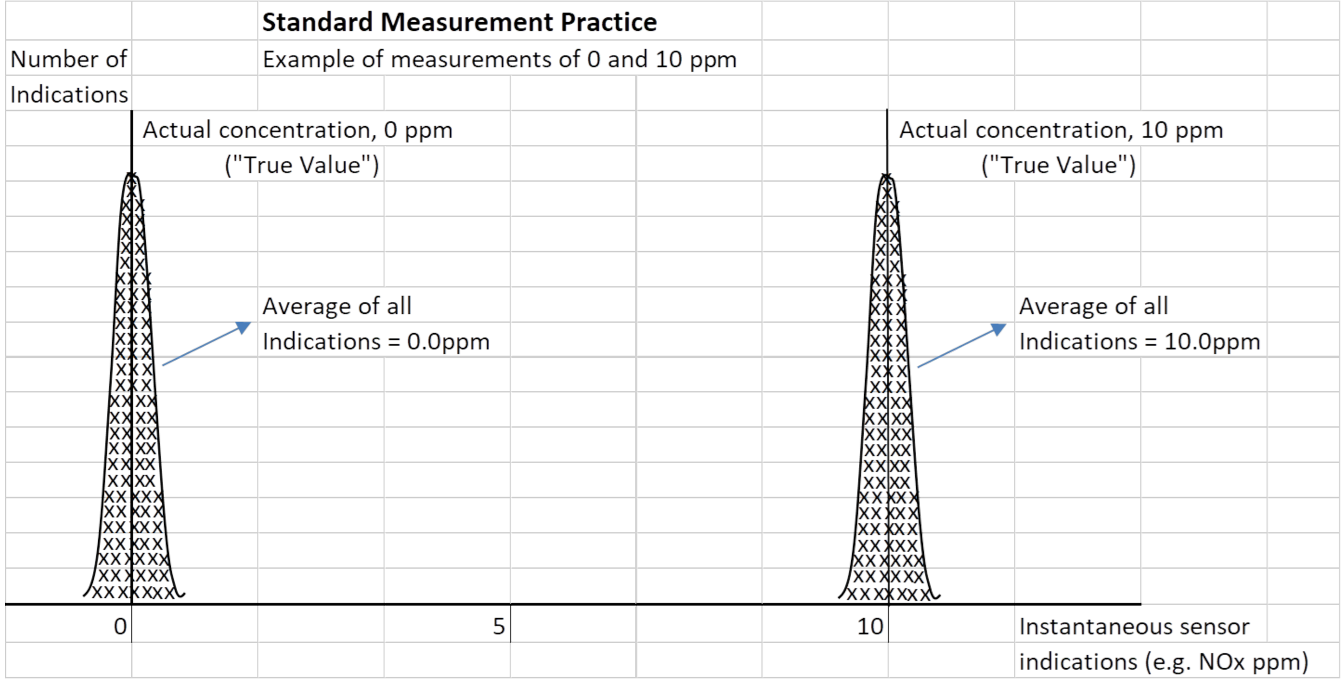


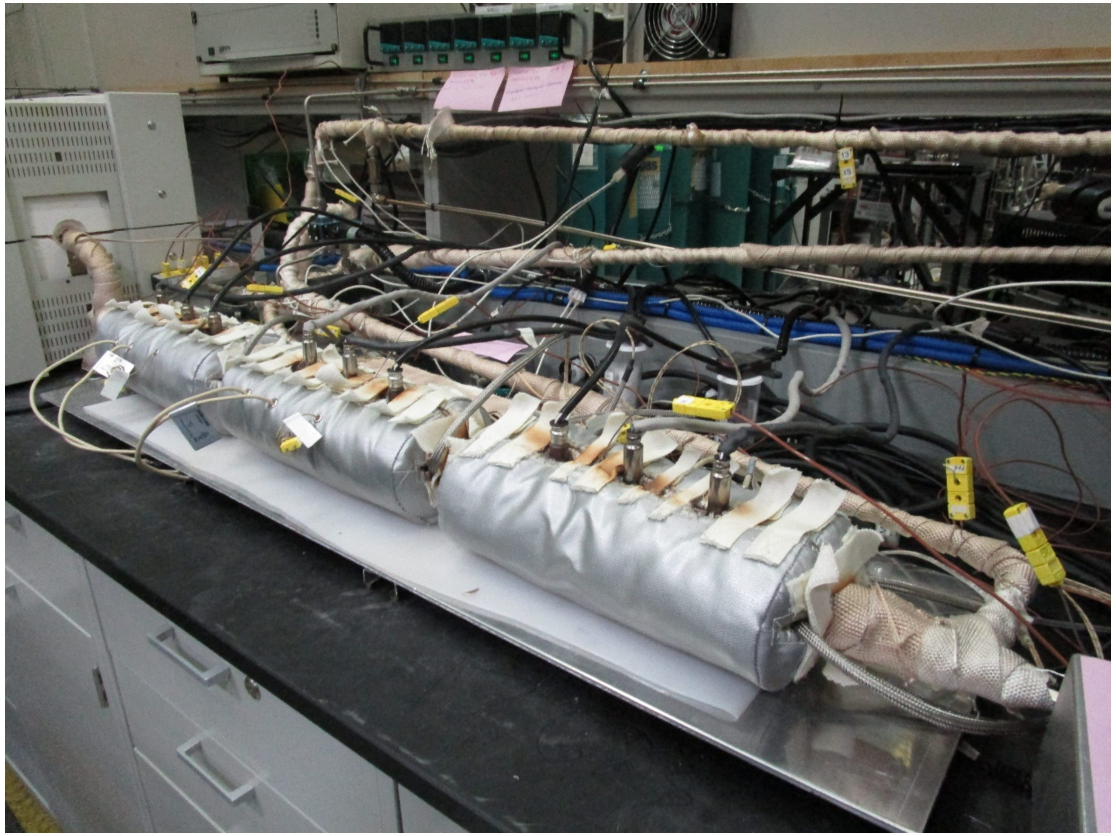
Figure Courtesy Steve Berry, EMA

Background: University of West Virginia Input

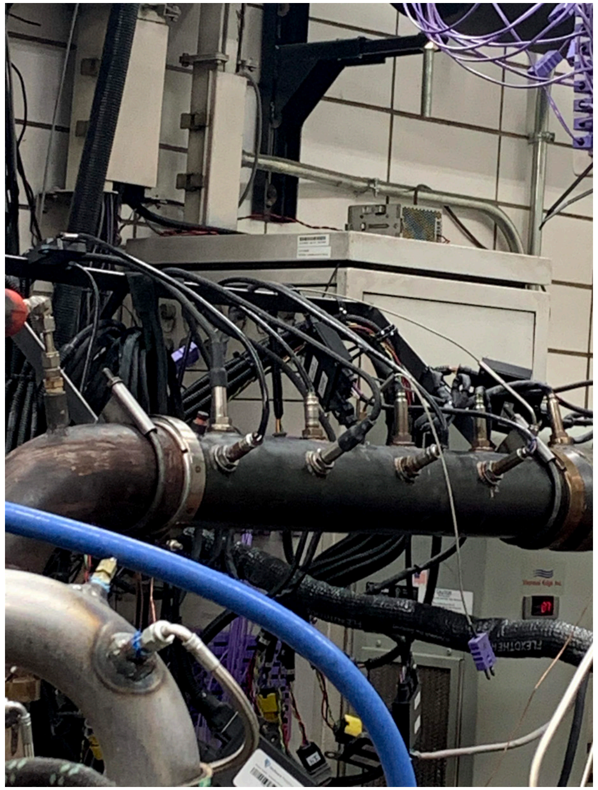
- CAFEE provided data from their EMA study to the SAE task force
- CAFEE opted to characterize OBD-REAL performance three ways
  1. Including all positive and negative values.
  2. Including all negative values above -5 ppm because “that seemed to include the sensor’s inherent noise.”
  3. Considering only positive readings.
- CAFEE determined that discarding negative readings on some applications (esp. line haul) resulted in 10% higher *perceived* emissions with common modes of operation being the most effected.
  - For more on this, see the supplemental section of this slide deck.

Cummins Inputs & Methods:

- Phase 1: Flow bench sensor characterization and “modeling”
- 22 “Run of the Field” sensors characterized

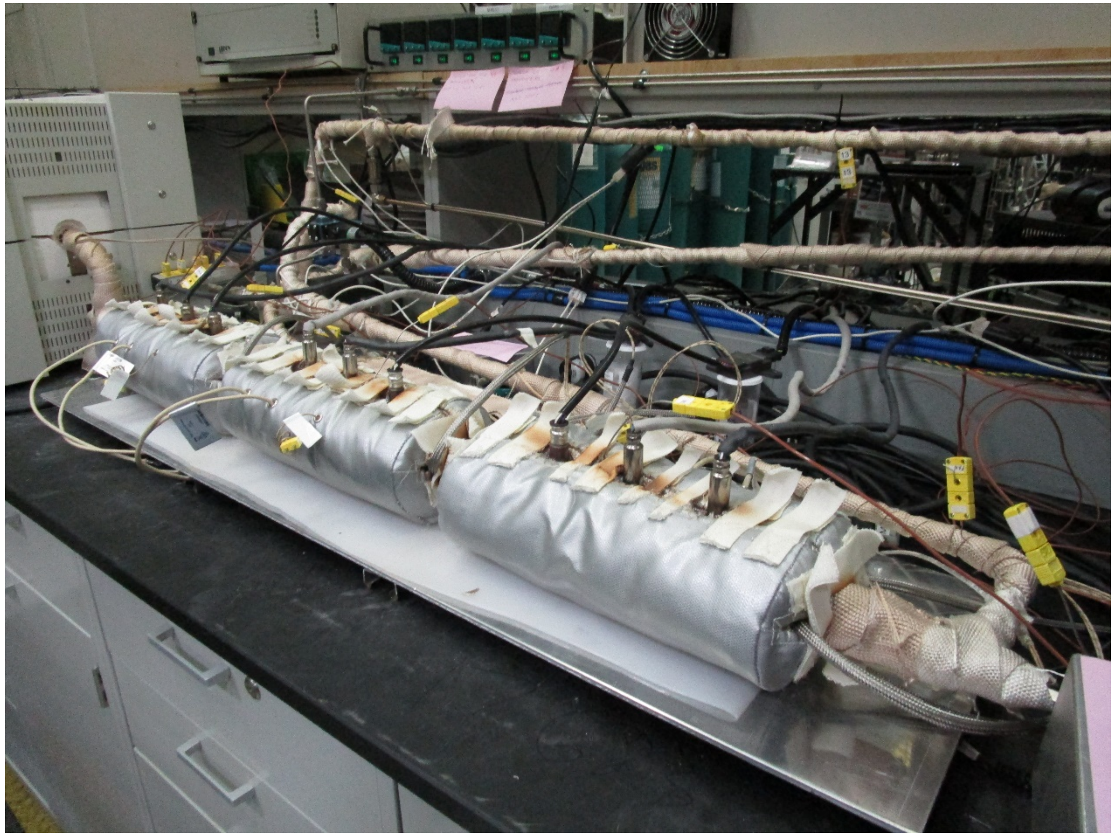


- Phase 2: Test Cell Sensor Characterization
- 13 sensors characterized, 3 different NO_x sensor technologies



Phase 1 Methods: Laboratory investigation of sensor performance

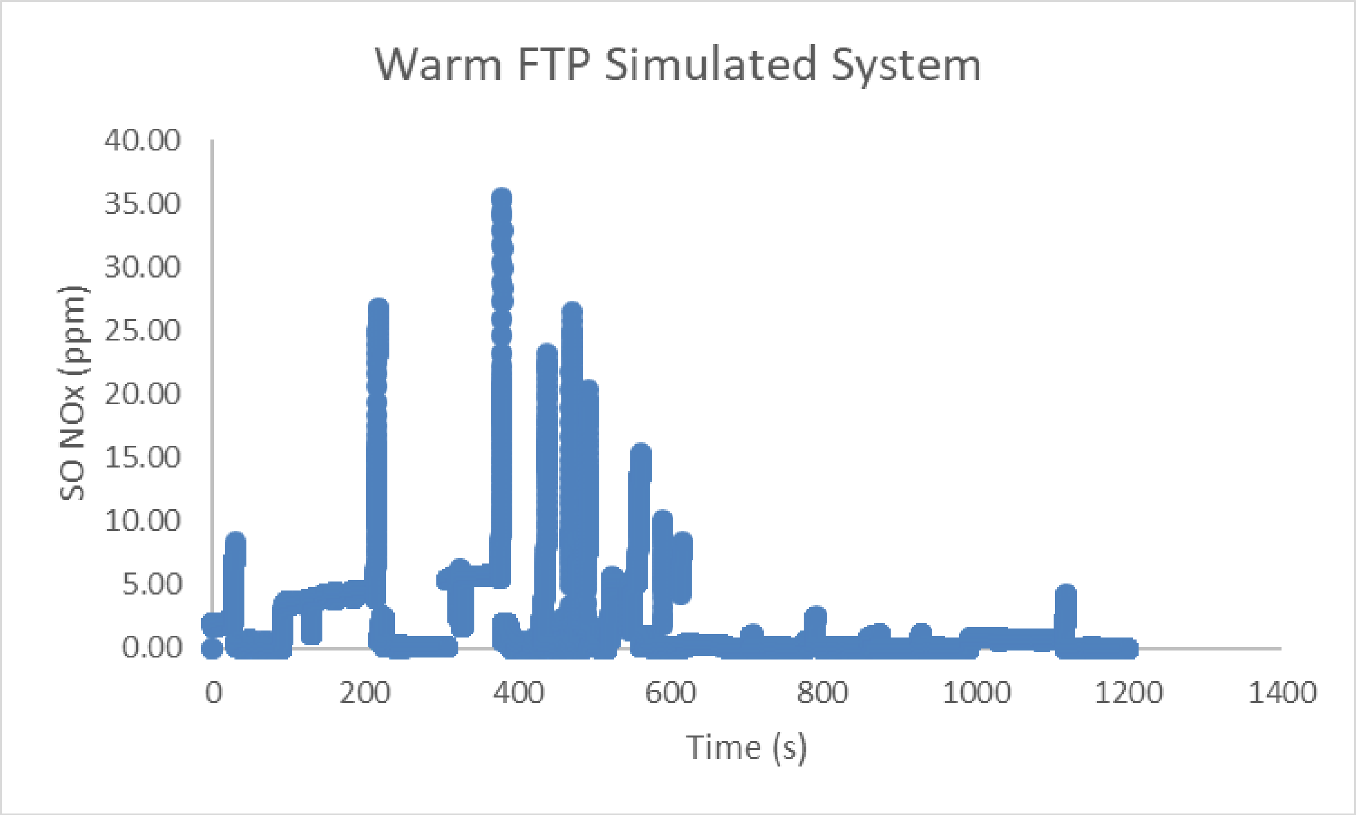
Conditions of Test									
O2 (%)	H2O (%)	CO2 (%)	NO (ppm)	NO2 (ppm)	NH3 (ppm)	Temperature (°C)	Flow (lpm)	Flow (m/s)	Pressure (psia)
9.6	7.5	6.5	0.7	-0.3	-0.6	200	40	4	18.1



All sensors were compensated for offset and pressure according to the manufacturer's suggested methods

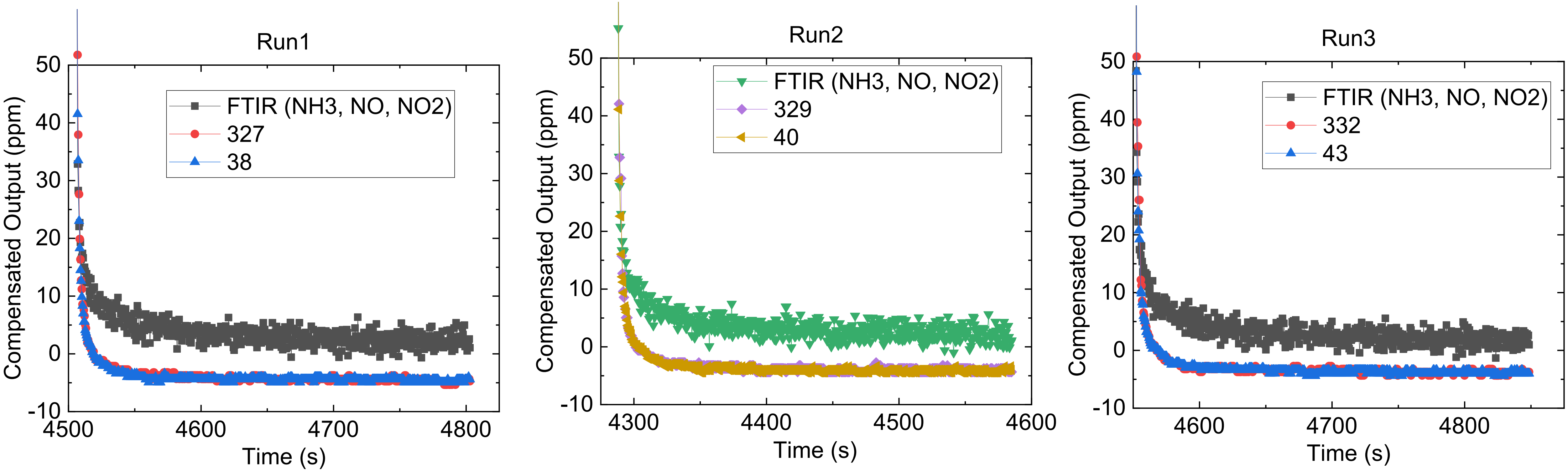
Phase 1 Methods: Simulated System

- The simulated performance of a hypothetical ULN diesel engine and AT system is shown below.
- The system as simulated emits less than e 0.02 g NO_x/(bhp*hr) across some standard emissions cycles.
- Here we use it as a test case for different binning/filtering methodologies.



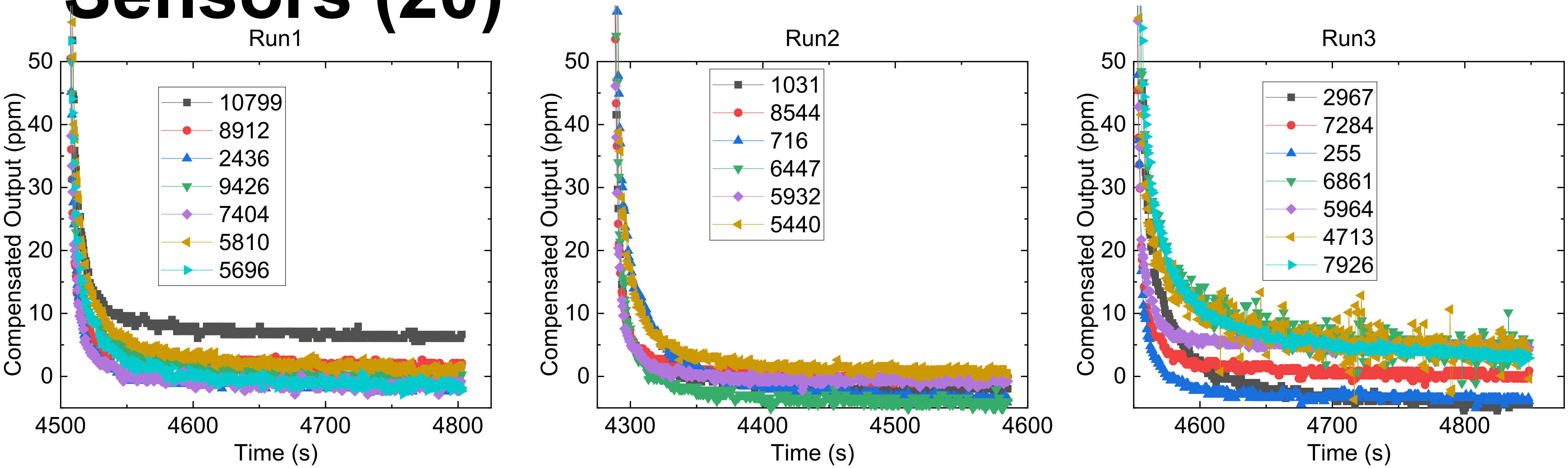
Simulation Data Courtesy Jinyong L

Laboratory Sensor Performance Results: Run to Run Repeatability of ~New Sensors



Results indicate that the test was repeatable

Results: Three Runs of Aged in the field Sensors (20)



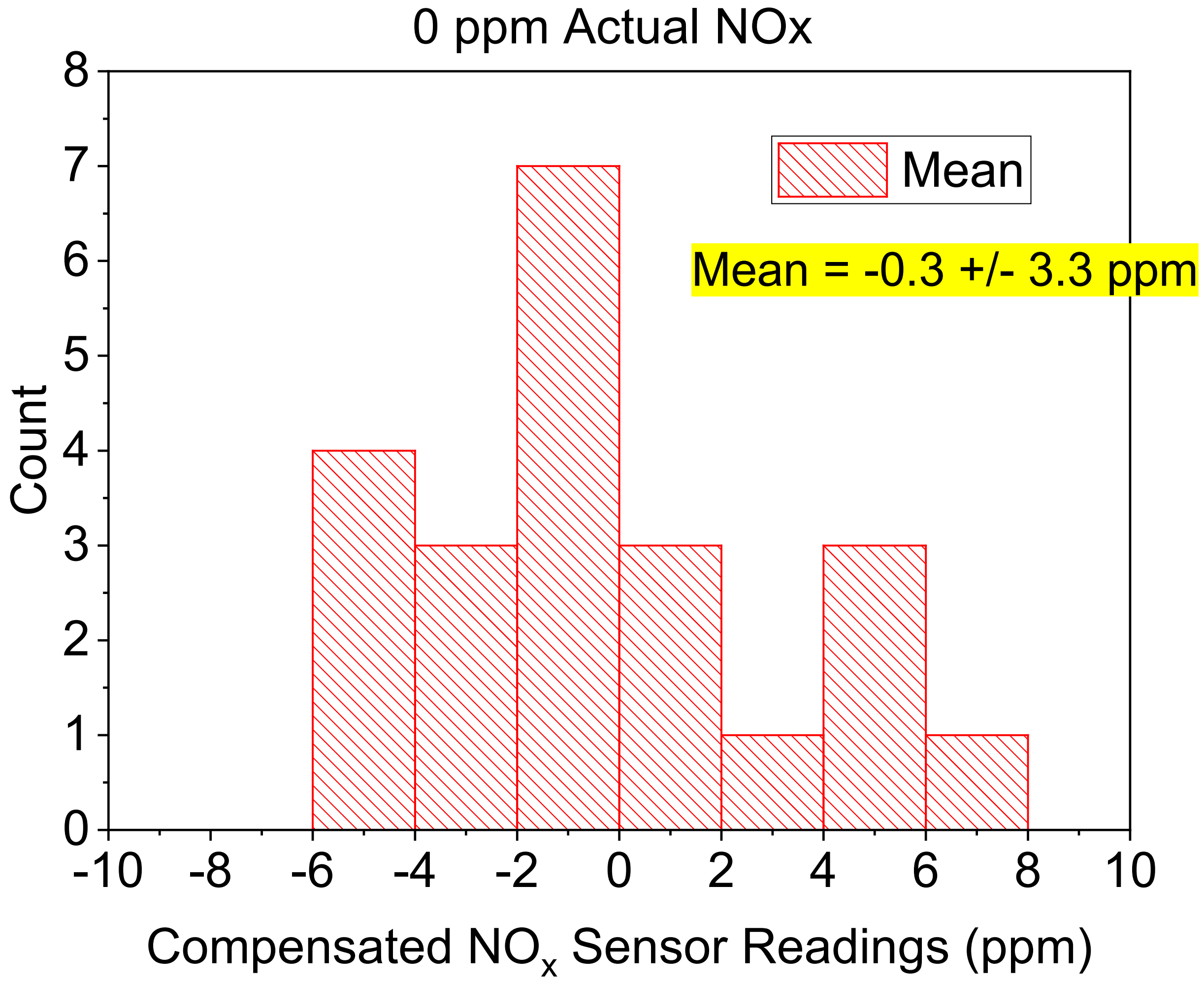
Average mean zero shift is -0.3 +/- 3.3 ppm

The average mean was computed by computing the mean for the last 15 s for each sensor for each of the runs and averaging them

Legend shows the number of operating hours on each sensor.

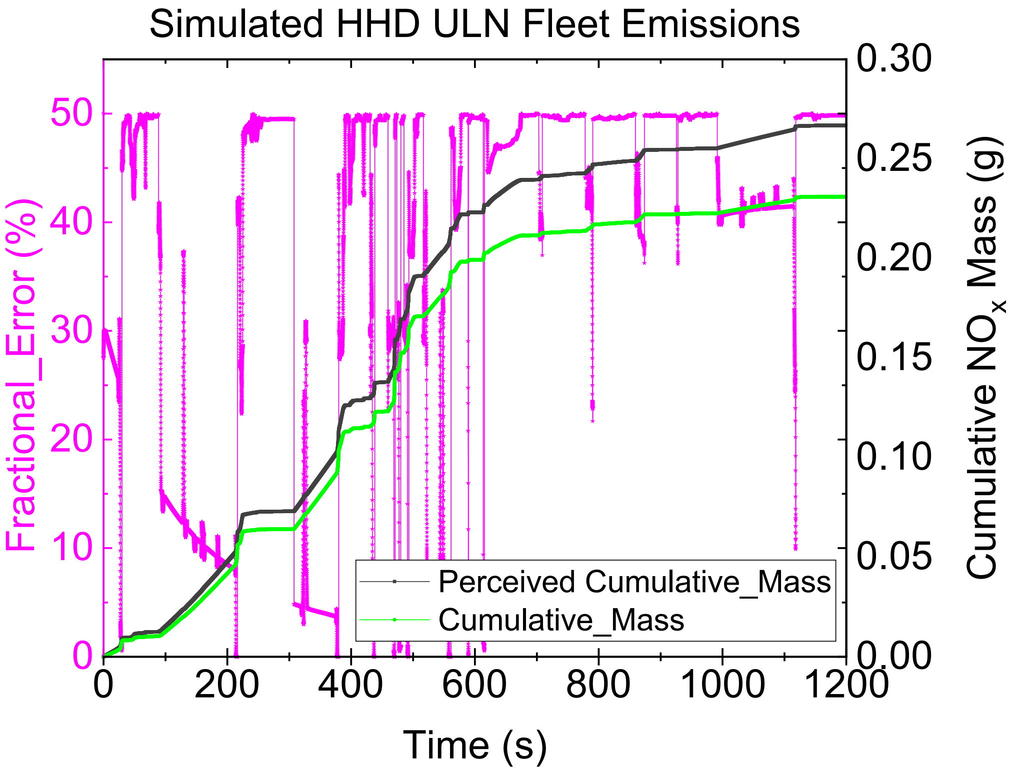
Sensors were aged on customer vehicles in the field and harvested for analysis after a ~random interval.

Results: Sensor readings when exposed to 0 actual NO_x



The plot above was computed by computing the mean for the last 15 s of the runs featured on the previous slides

Phase 2 Analysis: Perceived vs Actual Emissions on a Simulated ULN HHD-Hot FTP



- The NO_x mass was computed using the positive half of a normal distribution . That is, if you did the integral from negative to positive infinity the value computed would equal the emitted NO_x mass (i.e. “Cumulative_Mass”). Instead the mass is overestimated by not including the negative values within the distribution (i.e. “Perceived Cumulative_Mass”).
- At the end of the cycle cumulative mass is overestimated by ~15% of the actual value for the fleet when using the negatively truncated binned values (i.e. Perceived Cumulative Mass).
- Results demonstrate individual engine emissions will deviate substantially from the mean on ULN vehicles.

System Simulation Courtesy Jinyong L

Phase 2 Methods: Test Cell Testing

Phase 2a: Testing many sensors concurrently

- Prototype ~0.2 g/bhp-hr NO_x System
- Custom sensor communication/data logger
- Motoring dyno
- Three sensor types tested (6 “A”, 3 “B”, 4 “C”)
  - Something that is at least similar to all of these *will* be used on both CMI and competitor future AT systems for years to come.
  - Sensor “type B” samples were carried over and re-tested in Phase 2b
- FTIR utilized as NO_x reference
- Pseudo-hot FTP cycles used as test case

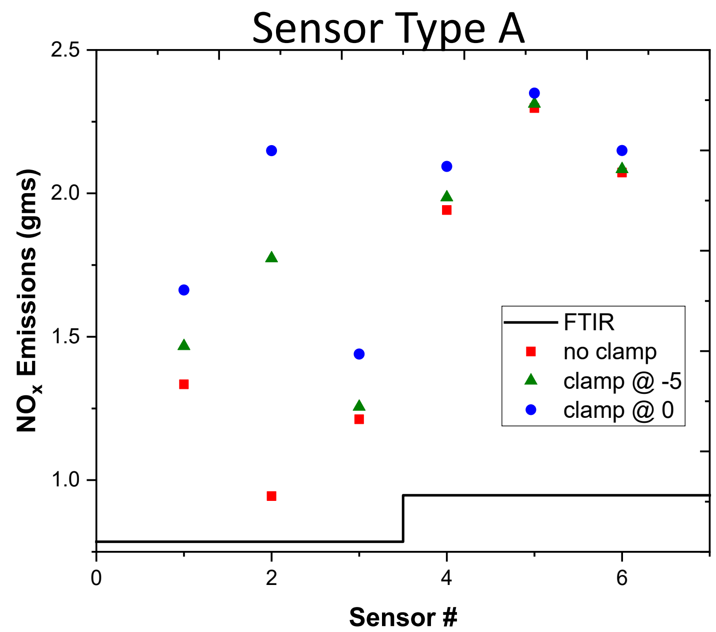
Phase 2b: Testing sensors consecutively

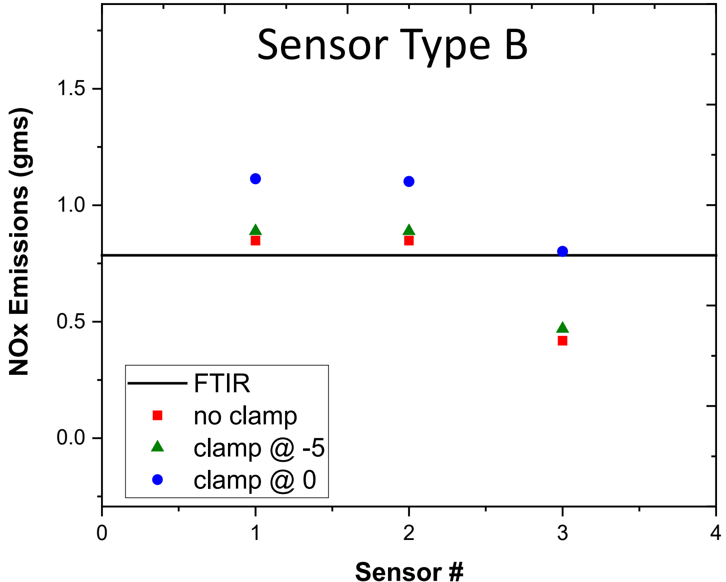
- Different prototype ~0.2 g/bhp-hr NO_x system
- Stock sensor communication/logger
- Motoring dyno
- Three sensors from sensor “type B” tested
- CLD utilized as NO_x reference
- FTIR utilized as NH_3 reference
- Pseudo-hot FTP cycles used as test case

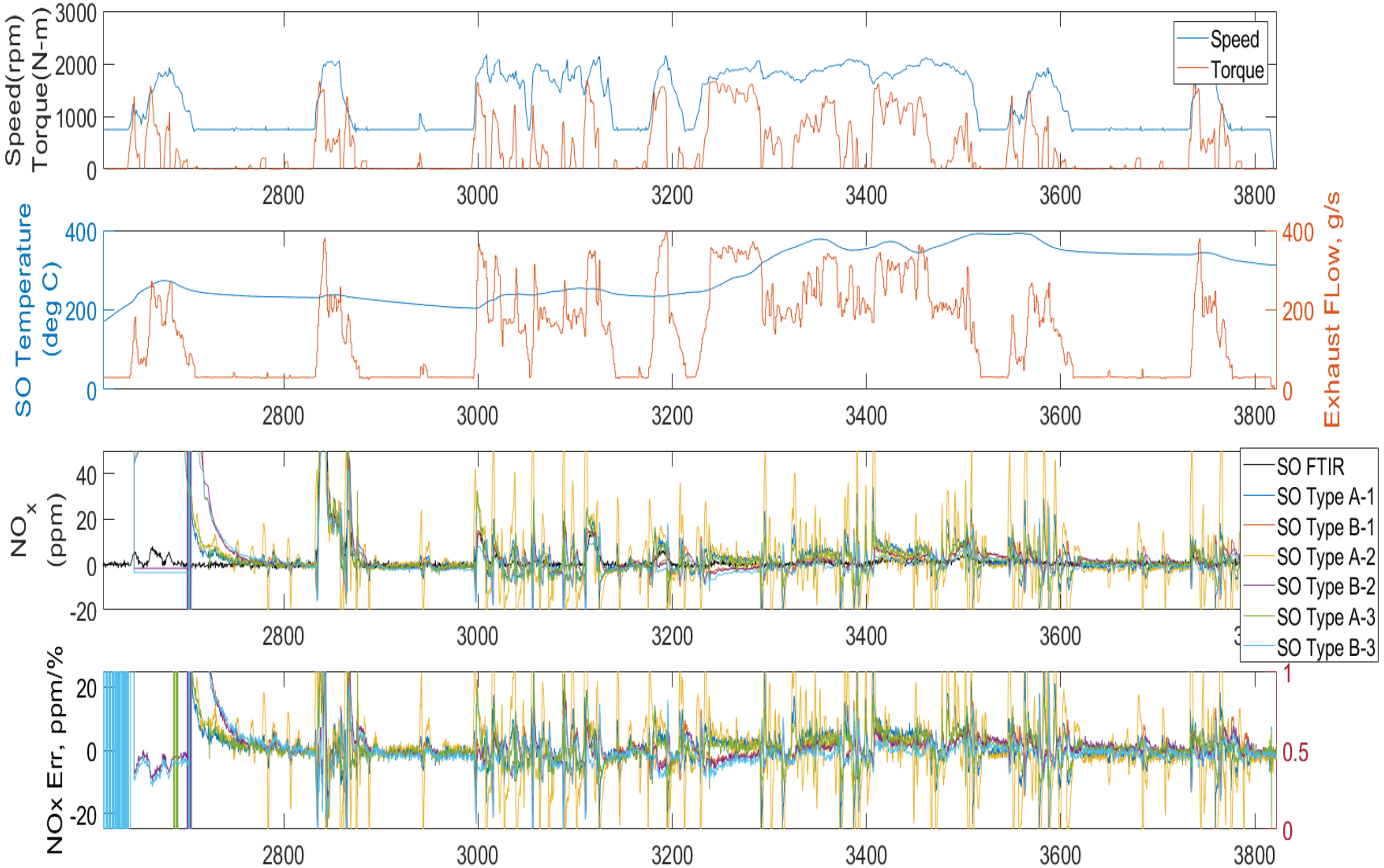
Phase 2a: Sensor Types A & B

Sensor Type A = 6: Two runs with three sensors each

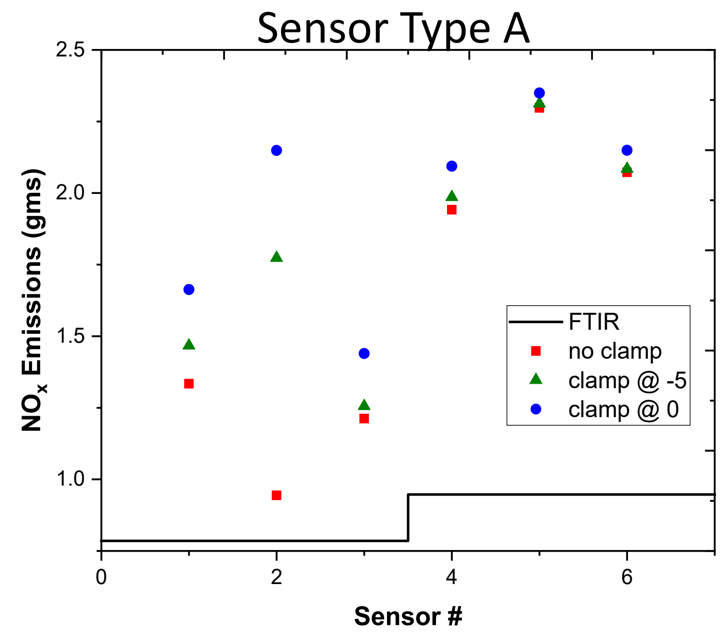
Sensor Type B = 3: One run with three sensors

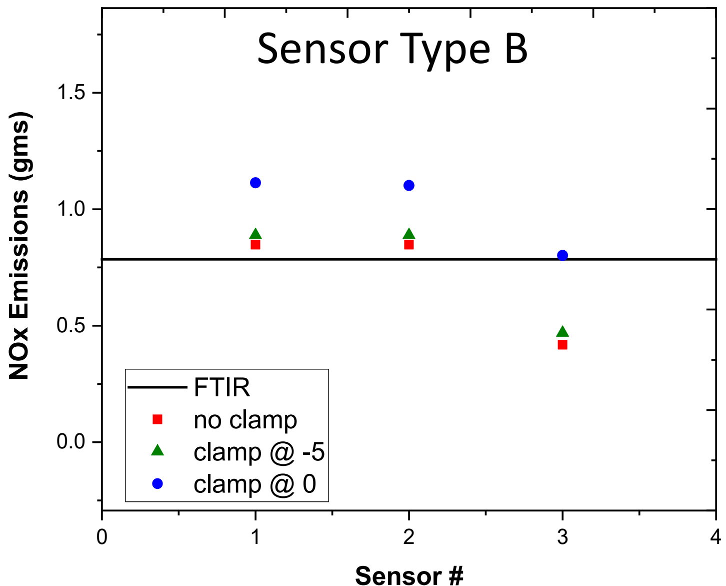






Phase 2a: Sensor Types A & B





Sensor Type A = 6: Two runs with three sensors each

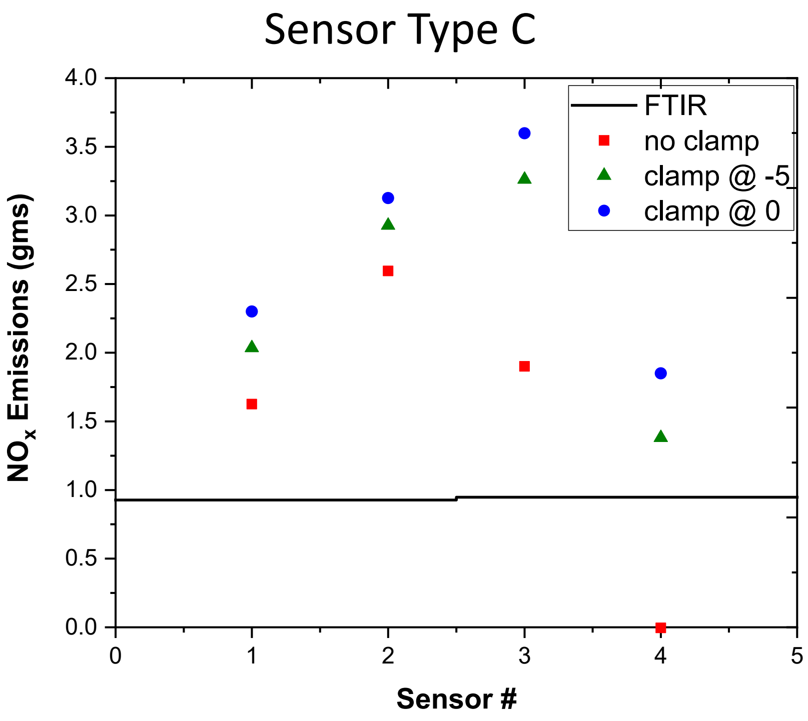
Sensor Type B = 3: One run with three sensors

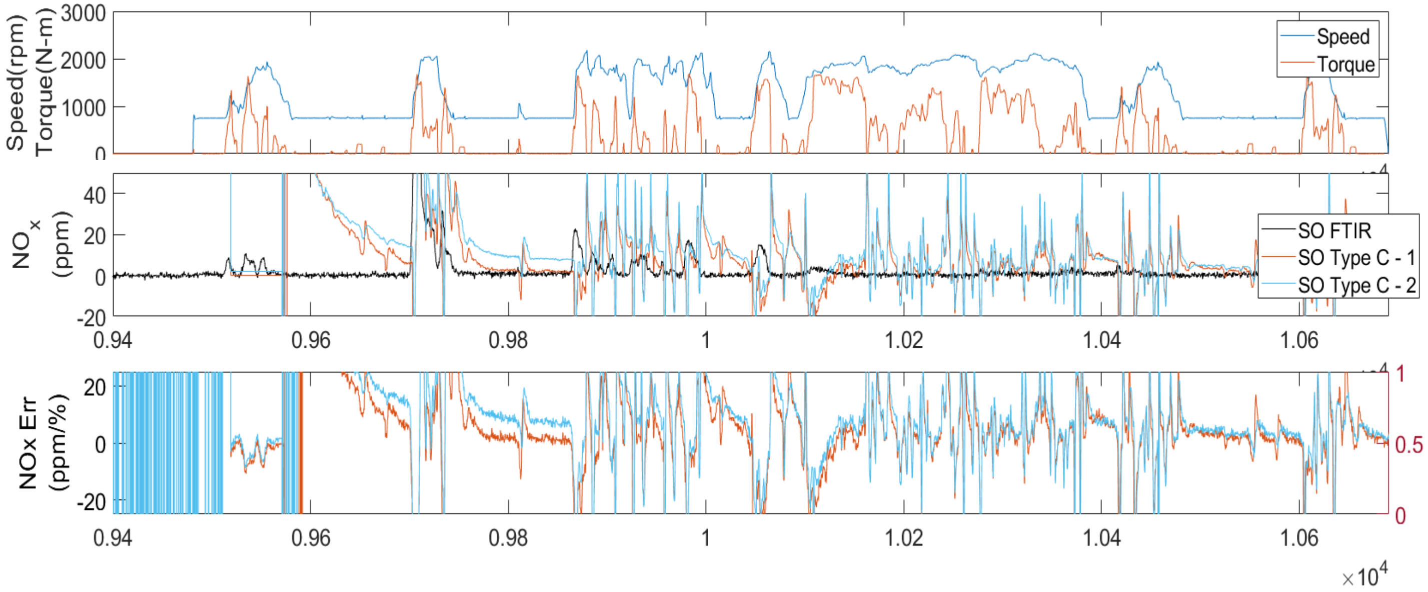
- Sensor Type A consistently over-reported emissions as compared to the FTIR.
- Including all negative values was better than truncating for some of the drive cycles.

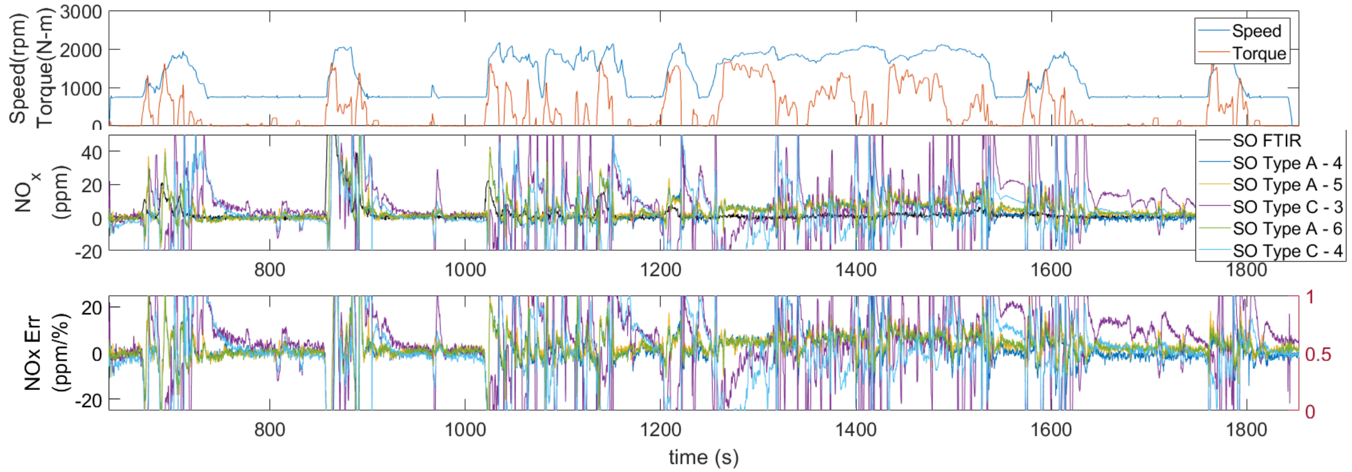
- Sensor Type B was ~close to the FTIR.

Phase 2a: Sensor Type C

Two Runs with two sensors each

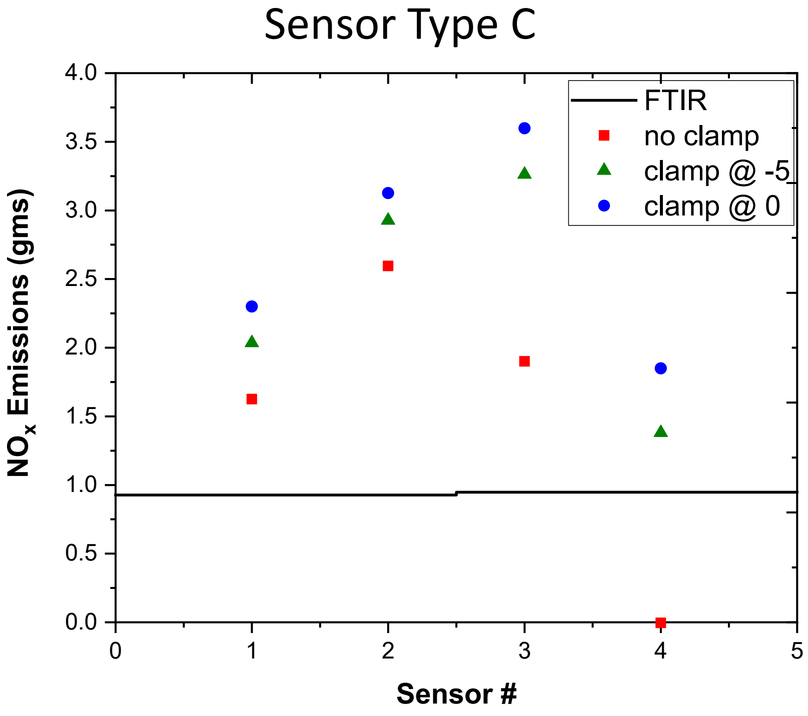


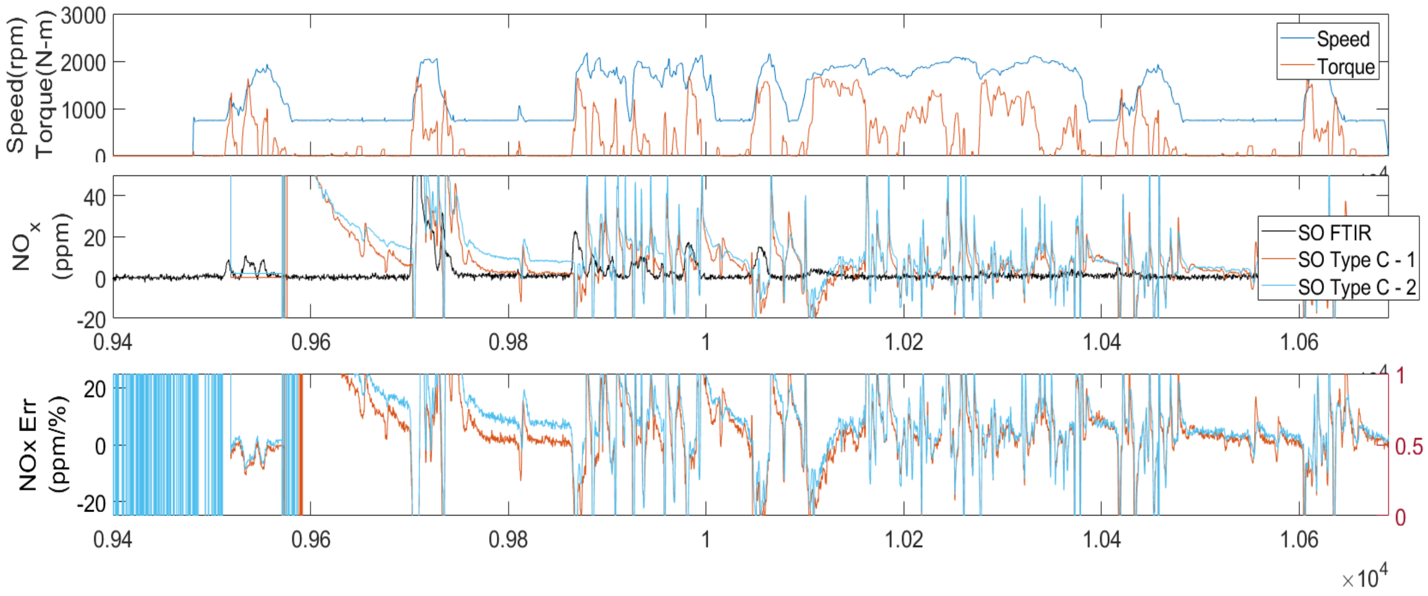




Phase 2a: Sensor Type C

Two Runs with two sensors each





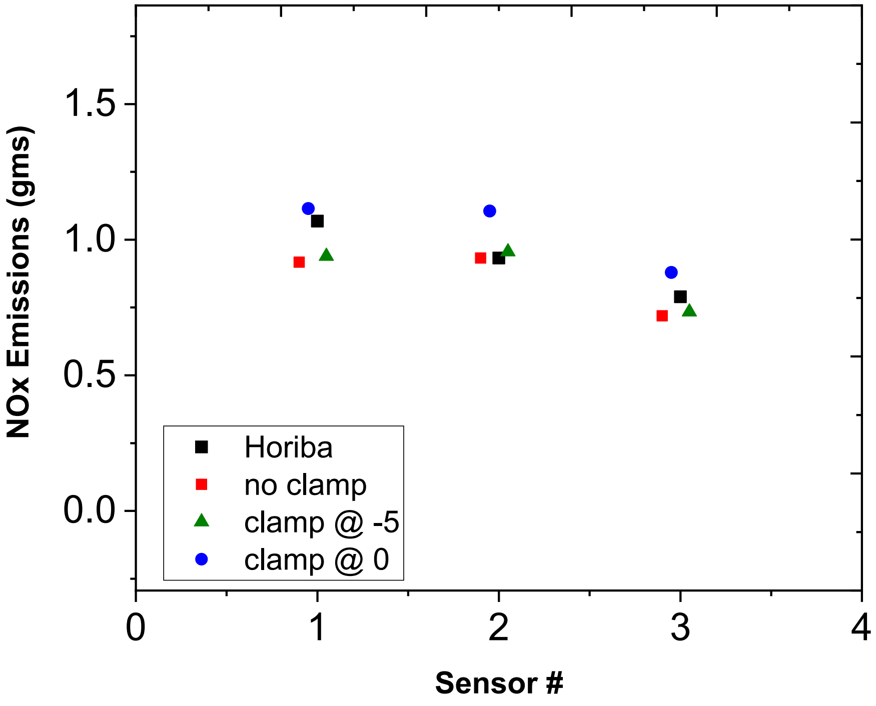
Sensor Type C tended to over measure with respect to FTIR with sensors generally being closer when all values are kept.

Phase 2a takeaway: Compared to FTIR, all sensor types tended to measure NO_x mass closer to the FTIR when all negative values were included with the only exception being sensor type B where it didn't make a consistent difference either way.

Phase 2b: Sensor Type B Compared to CLD

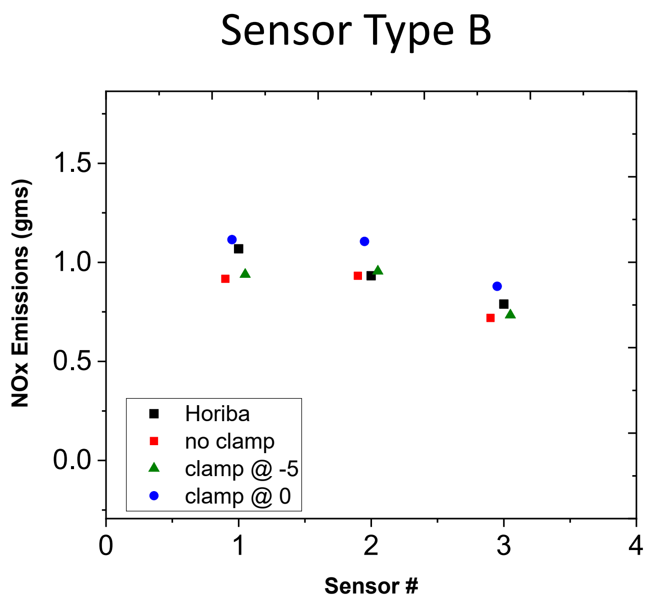
Sensor Type B

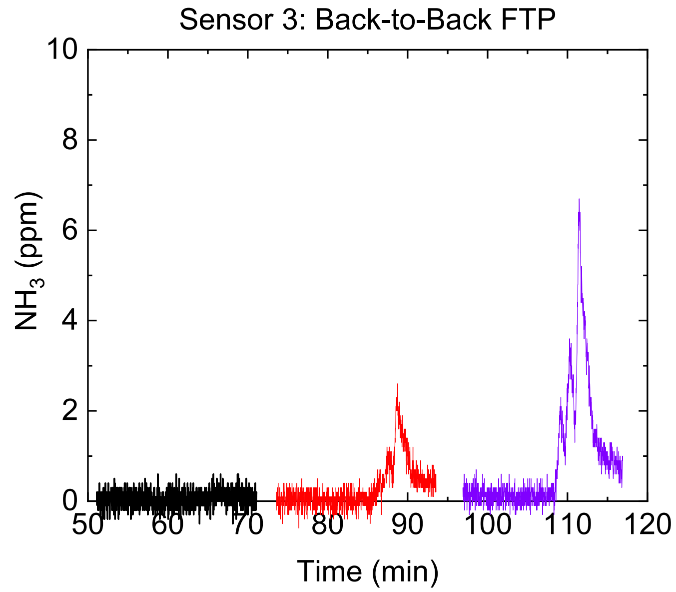
(Avg of 3 runs)



- Sensor Type B samples again measured close to the reference instrument; in this case a freshly calibrated CLD that also passed the relevant CFR 1065 performance checks.
- Across all three sensor types, results continue to suggest that all negative values can be kept without damage

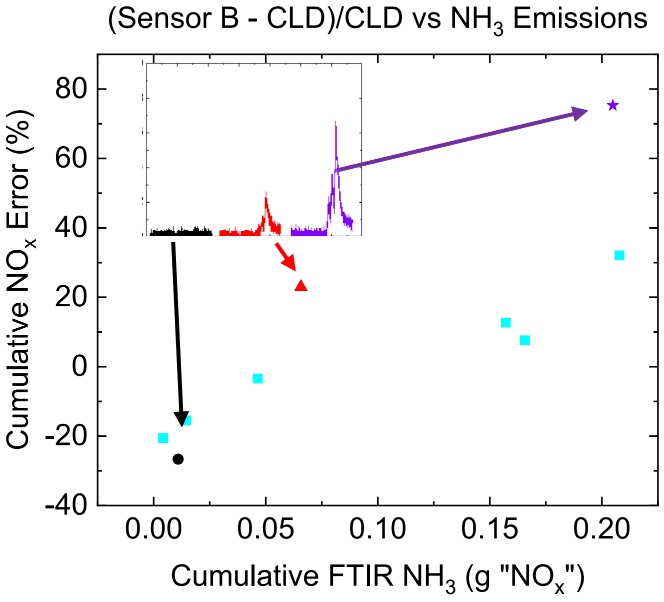
Phase 2b: …About that average of 3 runs

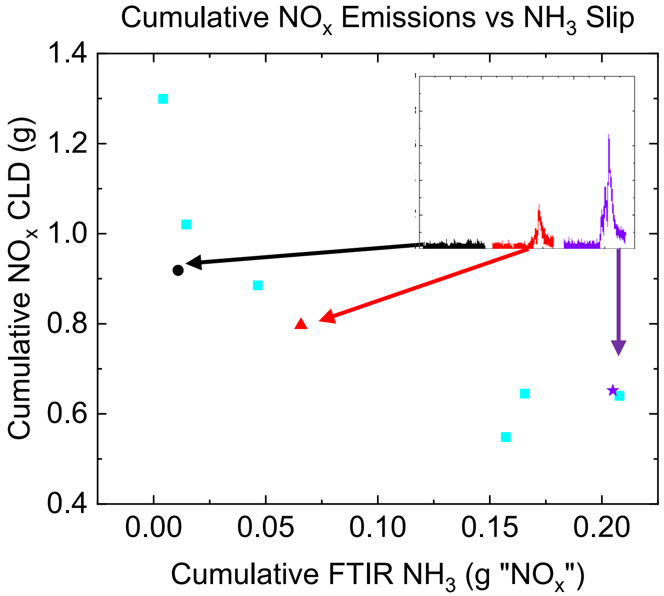




- For all three sensors, we saw variable but always small/negligible amounts of NH_3 slip that were impactful nonetheless.
- Here we consider sensor 3 which experienced, on one of its runs, the largest (still small) amount of NH_3 slip of Phase 2b testing.

Phase 2b: …About that average of 3 runs





- Here we plot sensor 3's performance on each run and compare it to the broader population's runs.
- For the entire population of sensor type B we see the accuracy of our NO_x mass estimate get progressively worse as cumulative NH_3 emissions increase.
- However, actual emissions became progressively lower as NH_3 slip increased.
- Like was the case with sensor 3 here, one can imagine engines with especially low NO_x emissions being perceived as having the opposite.

Key Takeaways & Next Steps

- Phase 1 & 2 experiments showed that one sensor type demonstrated close to nominal performance while the others tended to overreport when negative values were not truncated with the negative truncation making things worse in 2/3 cases while being of minimal impact in the third case.
- Sensor to sensor variabilities explored in phase 1 laboratory investigations demonstrated how different data binning strategies can induce bias by excluding negatives.
- The magnitude of discrepancy between data processed by truncating negative values vs data in which the negatives were left intact in CAFEE's real world study was well within the discrepancies observed in the analogous laboratory investigations conducted by Cummins ("Phase 1").

Supplemental Slides

CARB REAL ANALYSIS
IMPACT OF NEGATIVE NOX SENSOR CONCENTRATIONS

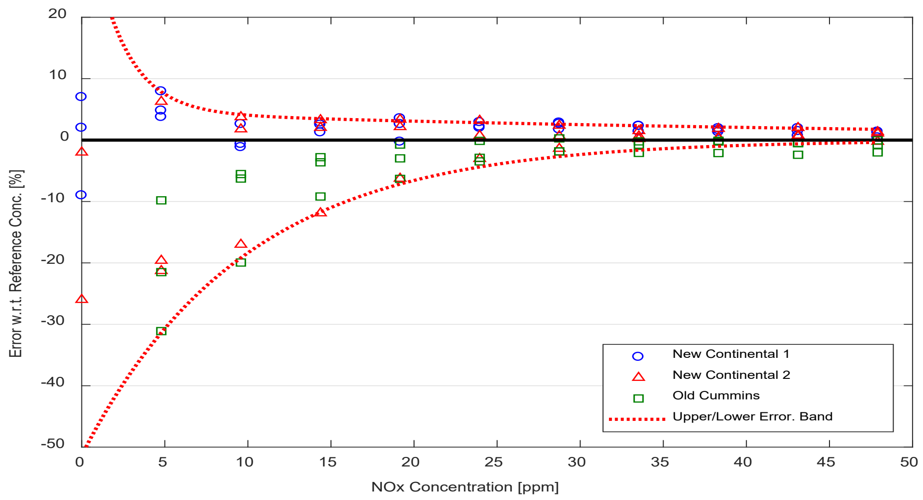
October 27th, 2020

CAFEE
CENTER FOR ALTERNATIVE FUELS, ENGINES AND EMISSIONS

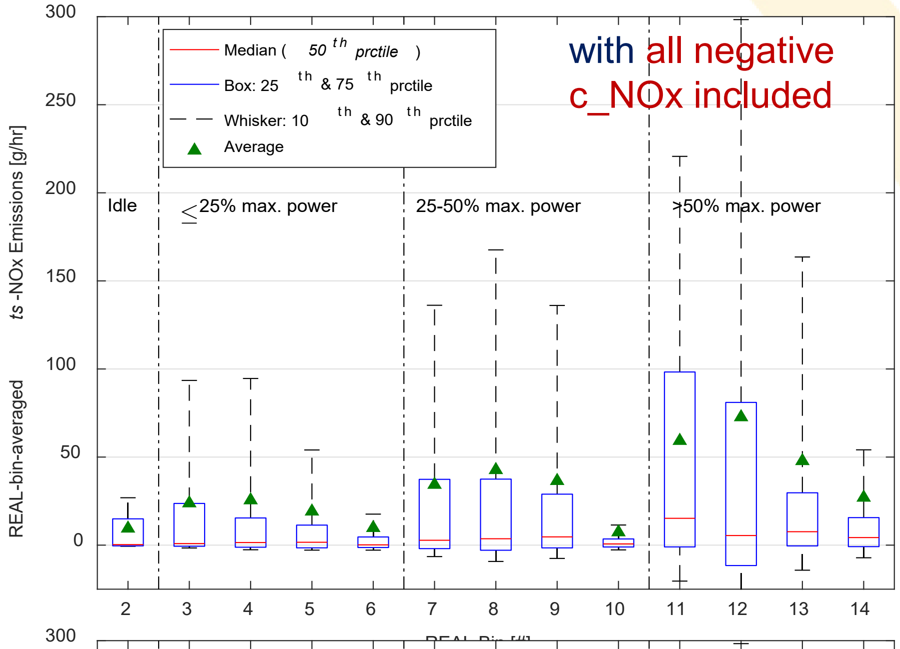
West Virginia University
Benjamin M. Statler College of Engineering and Mineral Resources
Department of Mechanical and Aerospace Engineering (MAE)

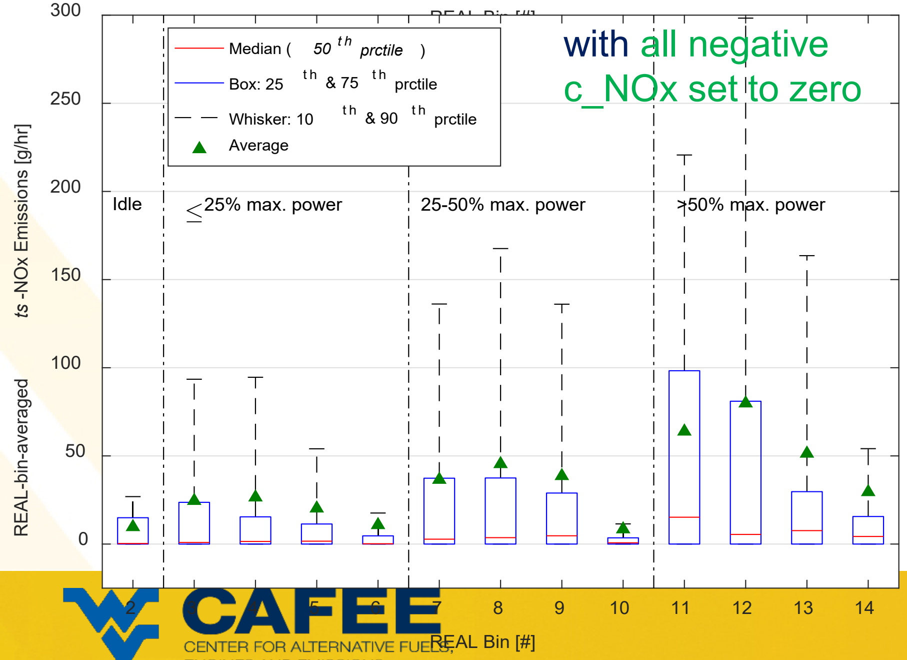
DATA ANALYSIS - REAL BINNING

- Calculate total duration-specific NOx emission rates for each REAL bin for entire operation of vehicles using three methods:
  - with all negative c_NOx included
  - with all negative c_NOx set to zero (CARB proposal)
  - with negative c_NOx below pre-defined threshold value set to zero and negative c_NOx between above threshold value and below 0ppm retained as negative c_NOx value for bin statistics.
    - Use sensor accuracy criteria to establish threshold value for example
    - WVU selected 5ppm as threshold value for setting negative NOx concentrations to zero



DATA ANALYSIS - REAL BINNING





Cat 1a – Long-haul truck

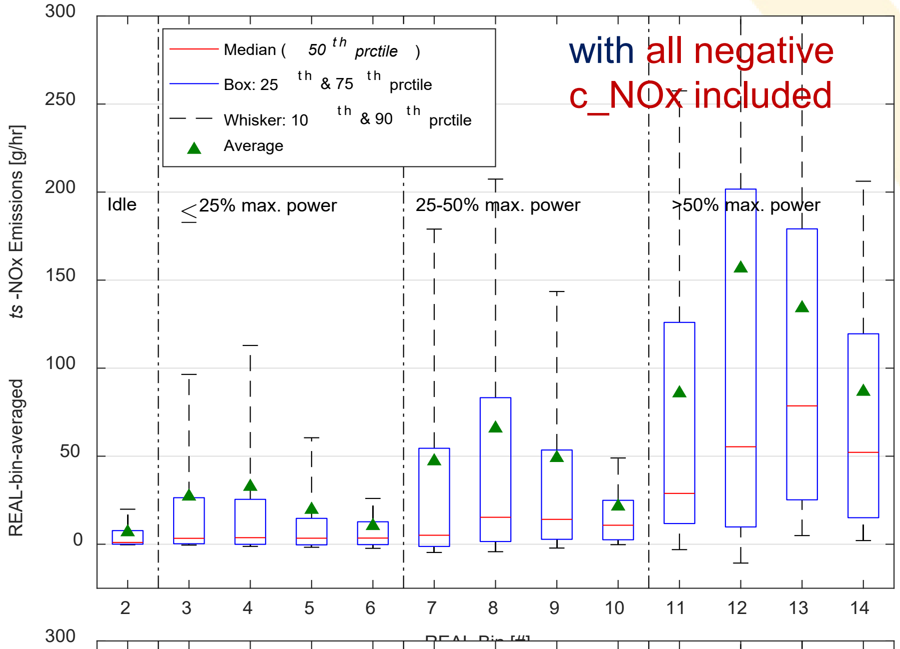
Vehicle	160
Category	1a
Vehicle MY	2018
Total Duration [hrs]	334
Total Distance [miles]	11816

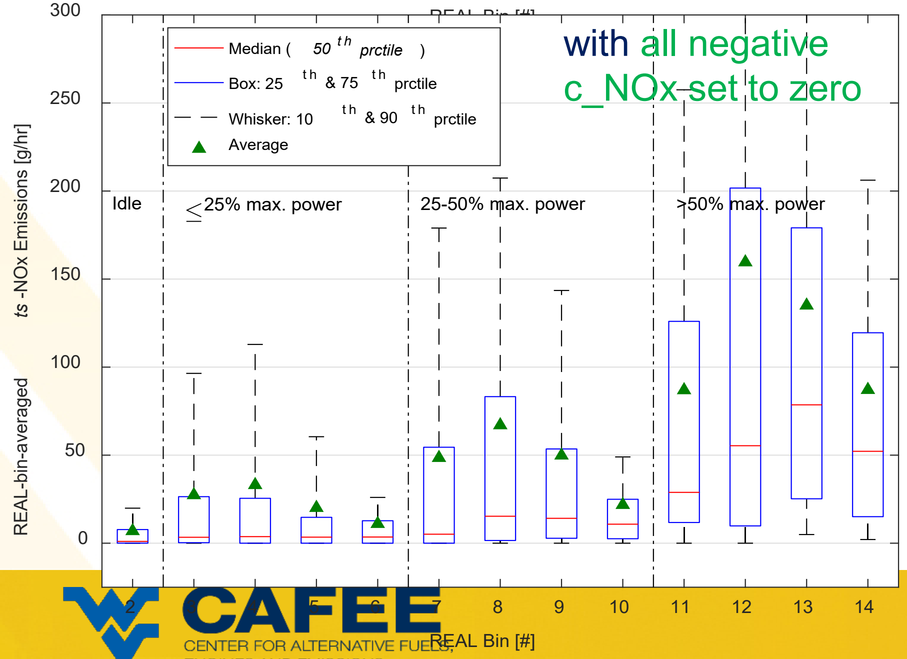
Sum-over-Sum bsNOx [g/bhp-hr]	Δ [%]
0.1751	
0.1835	-4.80
0.1883	-7.54

Bin Membership [Bin]	[hrs]
2	39.8
3	28.6
4	23.2
5	15.1
6	81.5
7	2.0
8	4.4
9	4.5
10	62.6
11	0.4
12	4.0
13	9.2
14	45.2

	NOx Emission Rate per Bin for Entire Operation [g/hr]				
Bin	*w/ all neg. c_NOx*	*w/ c_NOx < -5ppm set to 0*	*Δ to all neg. NOx included*	*w/ c_NOx < 0 ppm set to 0*	*Δ to all neg. NOx included*
2	9.5	9.5	-0.1	9.7	-2.2
3	23.8	24.2	-1.7	24.5	-3.1
4	25.5	26.0	-1.9	26.5	-3.8
5	19.1	19.6	-2.5	20.2	-5.7
6	9.8	10.1	-3.1	10.8	-10.3
7	34.3	36.0	-5.0	36.5	-6.4
8	42.7	45.0	-5.5	45.4	-6.4
9	36.5	38.3	-4.9	38.6	-5.9
10	7.3	7.9	-8.0	8.4	-14.6
11	59.2	63.7	-7.5	63.9	-7.8
12	72.7	79.4	-9.3	79.8	-9.9
13	47.8	51.0	-6.8	51.3	-7.4
14	27.0	29.1	-7.8	29.5	-9.3

DATA ANALYSIS - REAL BINNING





Cat 1b – Short-haul food distribution truck

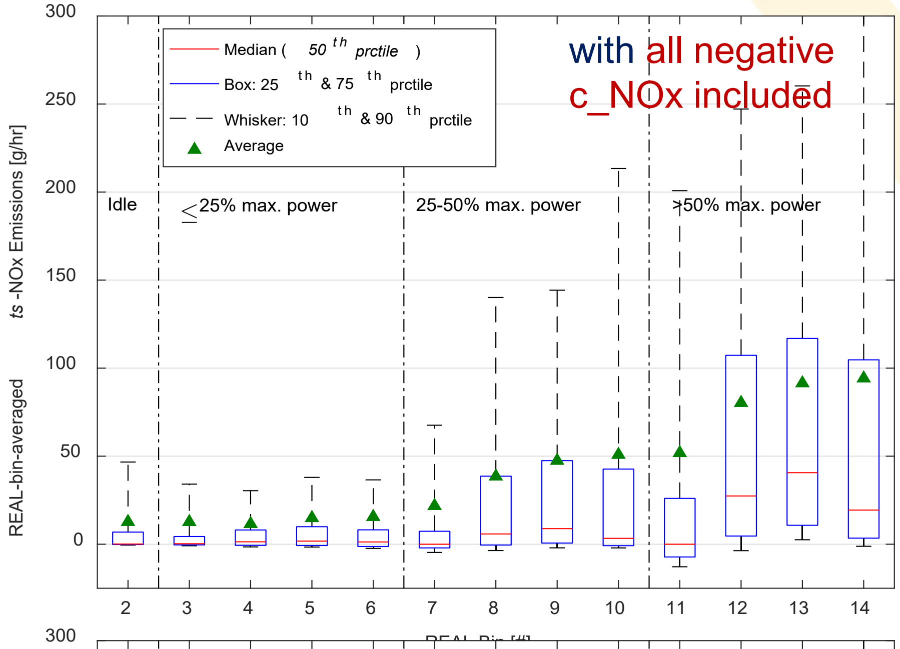
Vehicle	3
Category	1b
Vehicle MY	2013
Total Duration [hrs]	196
Total Distance [miles]	6341

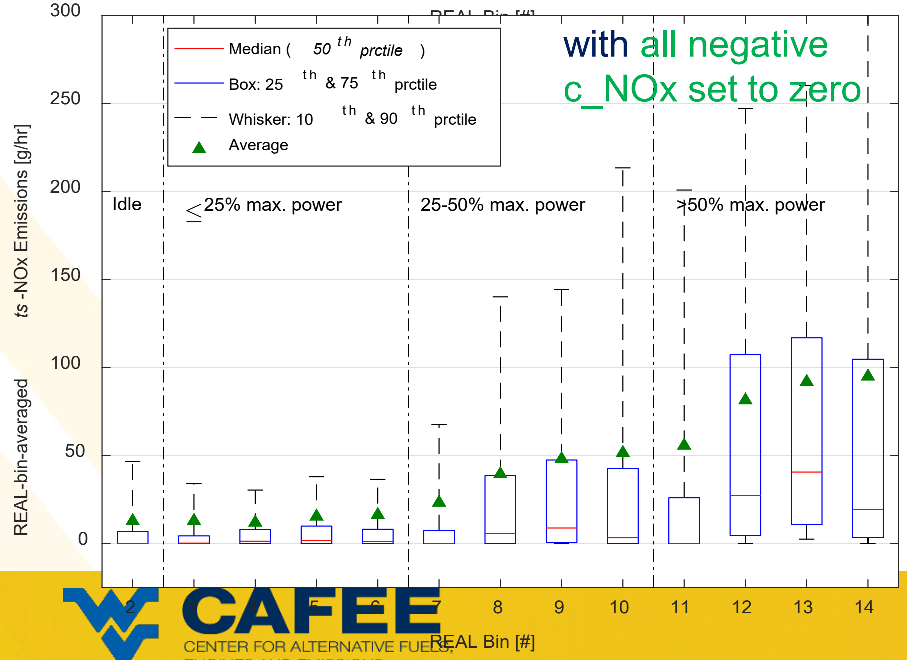
Sum-over-Sum [g/bhp-hr]	Δ [%]
0.3697	
0.3723	-0.68
0.3752	-1.48

Bin Membership [Bin]	[hrs]
2	29.2
3	21.0
4	19.2
5	13.2
6	49.9
7	1.2
8	3.9
9	3.7
10	26.4
11	0.1
12	2.7
13	4.4
14	20.9

	NOx Emission Rate per Bin for Entire Operation [g/hr]				
Bin	***w/ all neg. c_NOx***	***w/ c_NOx < -5ppm set to 0***	***Δ to all neg. NOx included***	***w/ c_NOx < 0 ppm set to 0***	***Δ to all neg. NOx included***
2	6.9	6.9	0.0	6.9	-0.9
3	27.1	27.2	-0.3	27.3	-0.7
4	32.7	32.8	-0.5	33.1	-1.3
5	19.6	19.7	-0.7	20.1	-2.5
6	10.4	10.5	-0.7	11.0	-5.8
7	47.1	48.1	-2.0	48.5	-2.8
8	65.8	66.8	-1.6	67.0	-1.9
9	49.0	49.7	-1.3	49.8	-1.7
10	21.5	21.6	-0.8	21.8	-1.5
11	85.8	86.8	-1.3	86.9	-1.4
12	156.7	159.4	-1.7	159.6	-1.9
13	134.1	135.0	-0.6	135.0	-0.7
14	86.6	87.0	-0.4	87.1	-0.5

DATA ANALYSIS - REAL BINNING





Cat 6b – Food/Beverage Distribution / Towing (T6 instate heavy)

Vehicle	150
Category	6b
Vehicle MY	2015
Total Duration [hrs]	150
Total Distance [miles]	3529

Sum-over-Sum [g/bhp-hr]	Δ [%]
0.5061	
0.5108	-0.92
0.5150	-1.74

Bin Membership [Bin]	[hrs]
2	26.7
3	18.0
4	24.6
5	17.6
6	11.8
7	3.9
8	6.3
9	5.5
10	11.8
11	0.6
12	6.4
13	7.2
14	9.8

	NOx Emission Rate per Bin for Entire Operation [g/hr]				
Bin	***w/ all neg. c_NOx***	***w/ c_NOx < -5ppm set to 0***	***Δ to all neg. NOx included***	***w/ c_NOx < 0 ppm set to 0***	***Δ to all neg. NOx included***
2	12.7	12.7	-0.2	12.8	-1.0
3	12.7	12.8	-0.7	13.0	-2.3
4	11.5	11.7	-1.2	12.0	-3.9
5	14.9	15.1	-0.9	15.4	-3.2
6	15.5	15.8	-1.8	16.3	-4.9
7	21.8	22.8	-4.8	23.3	-6.9
8	38.5	39.2	-1.9	39.5	-2.5
9	47.4	47.9	-0.9	48.0	-1.3
10	50.8	51.1	-0.6	51.5	-1.4
11	51.8	55.3	-6.7	55.7	-7.4
12	80.3	81.3	-1.3	81.4	-1.4
13	91.5	91.8	-0.4	91.8	-0.4
14	94.2	94.8	-0.6	94.9	-0.8

Analysis: Consider a hypothetical zero emission future system running an FTP

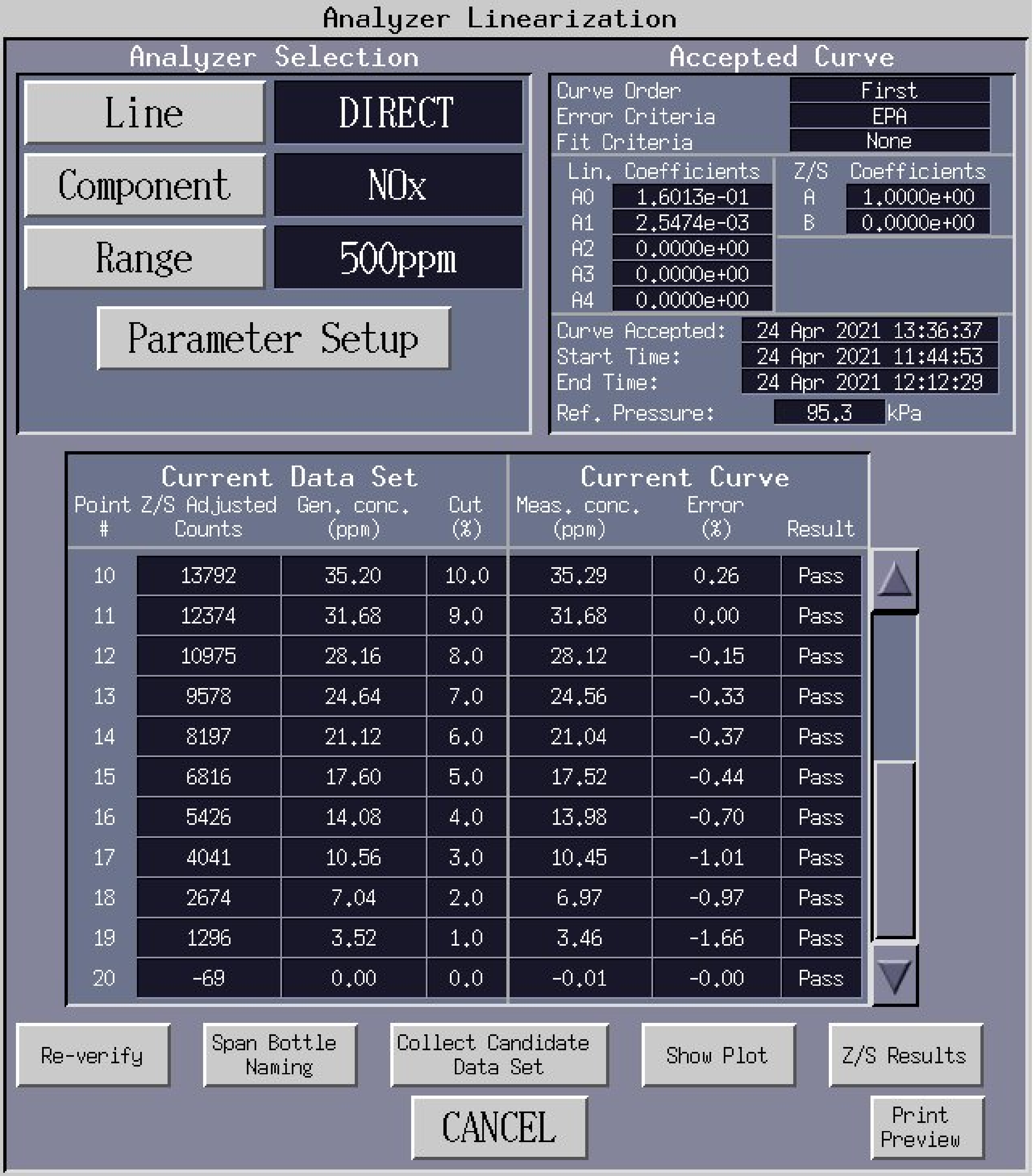
For a Cummins HHD system the average flow rate during an FTP is ~0.17 kg/s and it does 36 bhp*hr of work over that cycle.

With σ=3.3 ppm and the integral in equation 5 we will perceive half of the population producing emissions of 0.407 g per vehicle and the other half emitting -0.407 g per vehicle on average.

Consider a population of two vehicles, one with a "nominal" negative reading sensor and one a nominal "positive" reading sensor, in which we treat the vehicle with negative perceived emissions as emitting zero. In this case the fleet will do 72 bhp*hr of work and perceive a total of 0.407 g of emissions from the two vehicles which equates to a fleet emission of 0.0056 g/bhp*hr (even though the actual emissions are 0).

Note that some jurisdictions plan to impose FEL's of 0.02 g/(bhp*hr). Under this scenario, which may be coupled with continuous monitoring, the zero-truncating binning strategy would induce a fleet wide error of 28% of the relevant threshold all by itself for vehicles with zero emissions.

These results are consistent with results collected by others on current product 0.2 g/(bhp*hr) systems. Minimal impact is expected by introducing this "error" on such systems.


Analyzer Linearization
Analyzer Selection
Line
DIRECT
Component
NOx
Range
500ppm
Parameter Setup
Accepted Curve
Curve Order First
Error Criteria EPA
Fit Criteria None
Lin. Coefficients
A0 1.6013e-01
A1 2.5474e-03
A2 0.0000e+00
A3 0.0000e+00
A4 0.0000e+00
Z/S Coefficients
A 1.0000e+00
B 0.0000e+00
Curve Accepted: 24 Apr 2021 13:36:37
Start Time: 24 Apr 2021 11:44:53
End Time: 24 Apr 2021 12:12:29
Ref. Pressure: 95.3 kPa
Current Data Set
Current Curve
Point # | Z/S Adjusted Counts | Gen. conc. (ppm) | Cut (%) | Meas. conc. (ppm) | Error (%) | Result
10 | 13792 | 35.20 | 10.0 | 35.29 | 0.26 | Pass
11 | 12374 | 31.68 | 9.0 | 31.68 | 0.00 | Pass
12 | 10975 | 28.16 | 8.0 | 28.12 | -0.15 | Pass
13 | 9578 | 24.64 | 7.0 | 24.56 | -0.33 | Pass
14 | 8197 | 21.12 | 6.0 | 21.04 | -0.37 | Pass
15 | 6816 | 17.60 | 5.0 | 17.52 | -0.44 | Pass
16 | 5426 | 14.08 | 4.0 | 13.98 | -0.70 | Pass
17 | 4041 | 10.56 | 3.0 | 10.45 | -1.01 | Pass
18 | 2674 | 7.04 | 2.0 | 6.97 | -0.97 | Pass
19 | 1296 | 3.52 | 1.0 | 3.46 | -1.66 | Pass
20 | -69 | 0.00 | 0.0 | -0.01 | -0.00 | Pass
Re-verify
Span Bottle Naming
Collect Candidate Data Set
Show Plot
Z/S Results
CANCEL
Print Preview


Plot
Y Var
DIRECT NOx 500ppm -- (Current)
525.00
437.50
350.00
262.50
175.00
87.50
0.00
ppm
-69
34432
68933
103433
137934
Z/S Adjusted Counts
CANCEL