Introducing the parSYNC ® FLEX (iPEMS) for Carbon Emission Measurement & Testing

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Introducing the need for testing

Air quality in Nigeria

- In transportation sector, the total number of registered cars on Nigerian road increased to about 11.8 million in the year 2018 with almost 630,868 additional drivers' licenses issued that same year. These vehicles account for over 90% of total consumption of petroleum products in Nigeria [1].
- The annual average $PM_{2.5}$ level in Nigeria in 2019 was 14 times greater than the World Health Organization (WHO) 2021 recommended levels[2]. More recent ambient air monitoring of particulate matter in Abuja[1] showed that the daily average concentration quantified for the period under study were 50 μg/m^3 for $PM_{2.5}$ and 56 μg/m^3 for PM_{10}. This is still far above the updated WHO guideline (5 μg/m^3 and 15 μg/m3 respectively).
- The levels of other pollutants such as CO, NO_2 and SO_2 have also been of concern in Nigeria, though generally below the WHO recommended levels[3].
- WHO Director-General, Dr Tedros Adhanom Ghebreyesus: "Air pollution is a threat to health in all countries, but it hits people in low- and middle-income countries the hardest" [2].

[1] M.A. Lala, C.S. Onwunzo, O.A. Adesina, J.A. Sonibare. Particulate matters pollution in selected areas of Nigeria: Spatial analysis and risk assessment. Case Studies in Chemical and Environmental Engineering. 2023; **7**: https://doi.org/10.1016/j.cscee.2022.100288.

[2] https://www.who.int/news/item/22-09-2021-new-who-global-air-quality-guidelines-aim-to-save-millions-of-lives-from-air-pollution

[3] Obanya HE, Amaeze NH, Togunde O, Otitoloju AA. Air Pollution Monitoring Around Residential and Transportation Sector Locations in Lagos Mainland. J Health Pollut. 2018; **8** (19): doi: 10.5696/2156-9614-8.19.180903.

Carbon emissions and carbon credits

- COP27 reached a breakthrough agreement on a new "Loss and Damage" fund for vulnerable countries[1].
  - Governments took the ground-breaking decision to establish new funding arrangements, as well as a dedicated fund, to assist developing countries in responding to loss and damage.
- COP27 saw the launch of the African Carbon Markets Initiative[2]:
  - Aims to produce 300 million carbon credits annually across the continent by 2031, and 1.5 billion annually by 2050.
  - Voluntary carbon markets (VCMs) represent a major opportunity to accelerate economic development and simultaneously curb greenhouse gas emissions

[1] https://unfccc.int/news/cop27-reaches-breakthrough-agreement-on-new-loss-and-damage-fund-for-vulnerable-countries
[2] https://www.seforall.org/publications/africa-carbon-markets-initiative-roadmap-report

The need for testing in Nigeria

- Air pollution is one of the biggest environmental threats to human health, alongside climate change.
- Reducing emissions will improve air quality, and improving air quality can also enhance climate change mitigation efforts.
- By striving to achieve these guideline levels, countries will be both protecting health as well as mitigating global climate change.
- Leveraging a National Vehicle Emissions Programme with the United Nations COP27 Loss and Damage fund is a way to achieve this aim.

Introducing the 3DATX parSYNC ® FLEX

3DATX Corporation

- 3DATX (pronounced "three-DADT-eks") Corporation develops and manufactures next generation emissions measurement technologies for the transportation and power generation markets.
- 3DATX manufactures a range of accurate, low-cost, and ultra-lightweight portable emissions measurement systems (PEMS) that make industry and academic research testing, and compliance screening practical on a mass scale.

3DATX parSYNC ®

- The 3DATX parSYNC ® iPEMS (integrated Portable Emissions Measurement System) equipment series provides an extensive utility and range of applications in the developing requirements of Periodic Technical Inspections and other emissions testing.
- The latest iteration of parSYNC ® iPEMS is called the parSYNC ® FLEX. It has the following properties:
  - Approx. 402 mm x 300 mm x 294 mm,
  - 9.8 kg weight without batteries,
  - 12.7 kg weight fully equipped with batteries,
  - Approx. 4 hours runtime fully equipped with batteries (runs indefinitely with mains power).

parSYNC ® FLEX

parSYNC ® FLEX main sensor unit

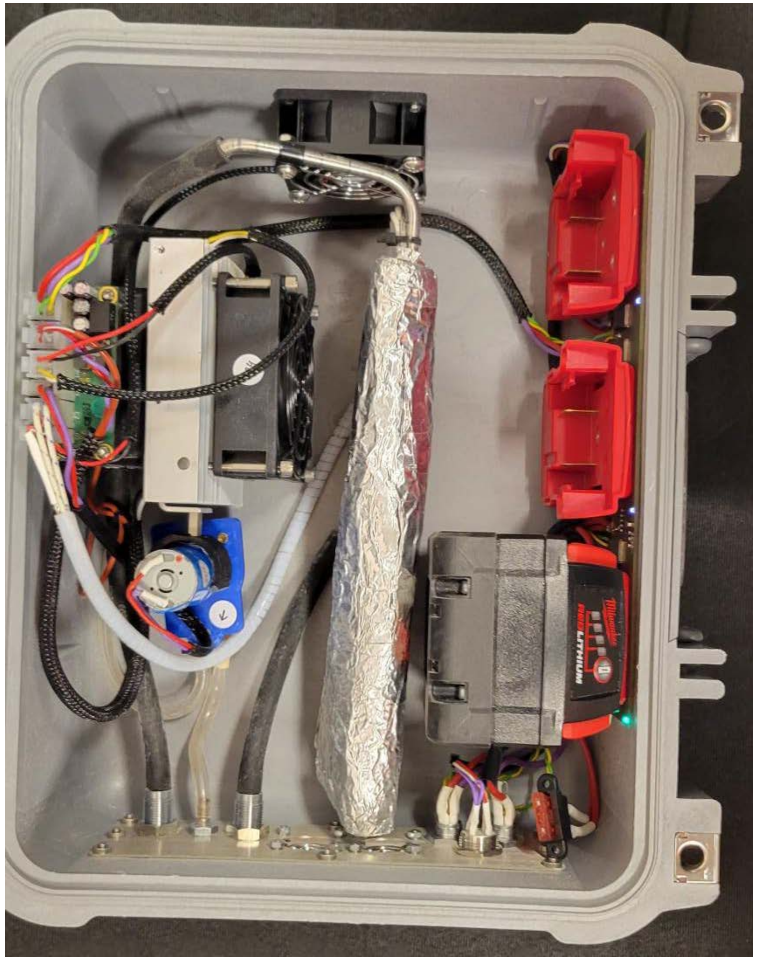
- The lightweight parSYNC ® FLEX utilizes multiple miniaturized sensors, packaged in patented, replaceable cartridges, designed to obtain real-time emissions measurement. These are:
  - C-GasMOD Cartridge to measure CO, CO_2, HC and O_2,
  - N-GasMOD Cartridge to measure NO and NO_2,
  - Particulates Cartridge to measure PN and PM.

Sensor specifications

Cartridge	Gas	Method	Measuring range	Response Time (s)	Absolute Tolerance (PPM)	Relative Tolerance (% of sample)
N-GasMOD	NO	Electrochemical	0-5000 ppm	< 5	±30 ppm	2.00%
	NO_2	Electrochemical	0-300 ppm	< 35	±6 ppm	2.00%
C-GasMOD	CO	NDIR	0-150,000 ppm (0-15%)	< 3.5	±400 ppm (0.04%)	5.00%
	CO_2	NDIR	0-20 % (0-200,000 ppm)	< 3.5	±4000 ppm (0.4%)	5.00%
	HC	NDIR	0-4000 ppm	< 3.5	±14 ppm	5.00%
	O_2	Electro-galvanic	0-100 % (0-1,000,000 ppm)	< 6	±2000 ppm (0.2%)	4.00%
P	PM	Ionization + Scattering + Opacity	*0.03-300 mg/m^3*	< 5	NA	NA

CUBE

- The parSYNC ® CUBE™ (Conditioning Unit for Batch Emissions) conditions the sample gas:
  - Removes water vapour from the sample via the condensation unit,
  - Removes volatiles from the sample via a volatile particle remover (VPR).

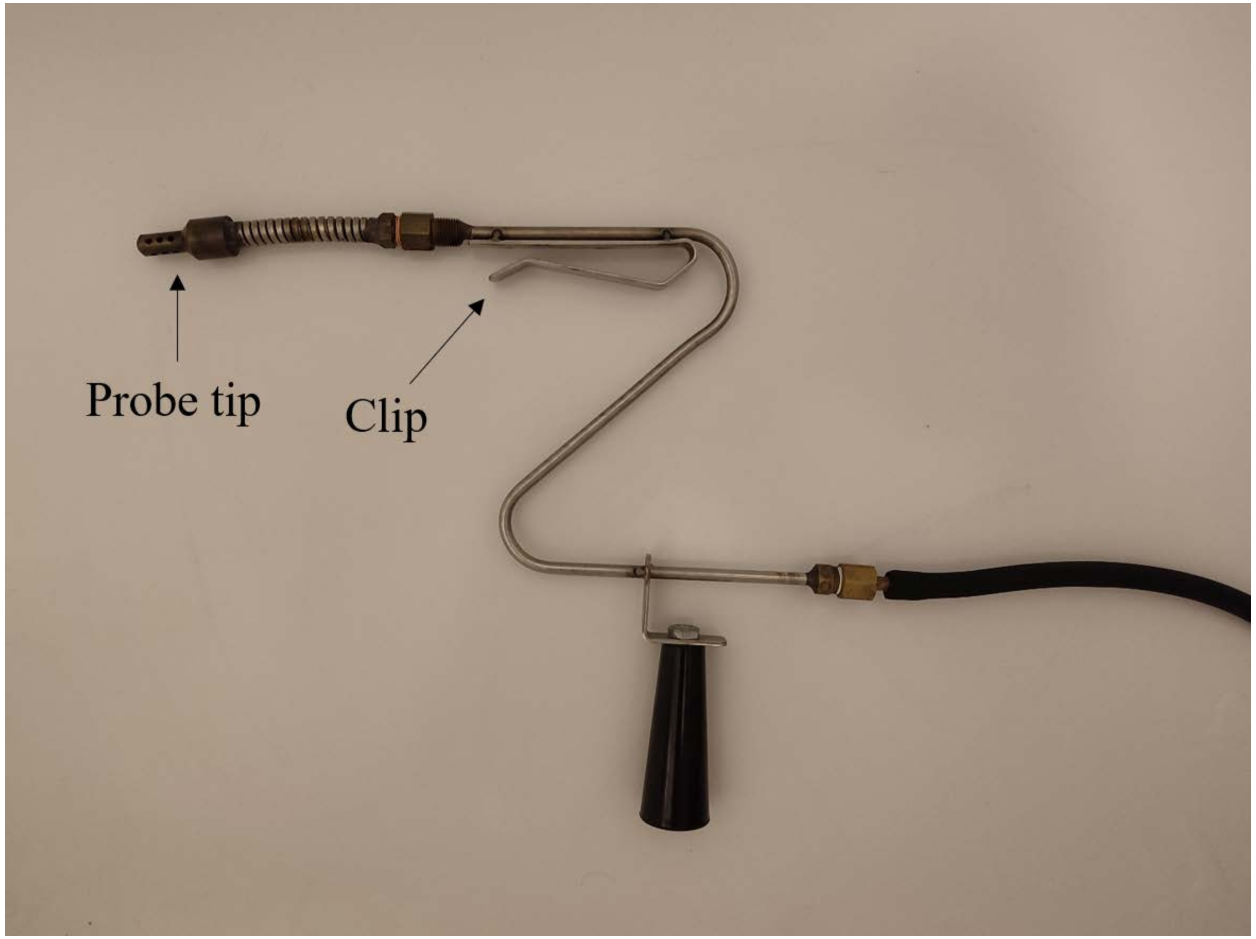


Laptop & software

- The parSYNC ® FLEX also comes with a laptop computer, pre-installed with a user-friendly software suite called FLEXstudio,
  - FLEXstudio has been designed to be intuitive – significantly reducing field training time.
- Post-processing data software helps to eliminate many of the bottlenecks associated with teasing out meaningful data from the numbers:
  - Enables easy time alignment of data inputs,
  - Automated calculation of mass emission rates and factors (where possible).

Sample probe

- The parSYNC ® FLEX also comes with a sample probe with built-in attachment clip for tailpipe placement



Accessories – OBD adapter

- Bluetooth OBD Adapter to read ECU parameters from vehicle at 1 Hz frequency.
- Available Parameters:
  - Intake Manifold Absolute Pressure (kPa),
  - Engine RPM (rpm),
  - Vehicle Speed (km/h),
  - Intake Air Temperature (degC),
  - Mass Air Flow (g/s),
  - Absolute Throttle Position (%),
  - Engine Fuel Rate (L/h),
  - Lambda,
  - Exhaust Flow Rate (kg/h).

Accessories – Scotty GPS and weatherstation

- CAN input at 1Hz frequency
- Parameters include:
  - Ambient temperature (degC),
  - Ambient pressure (hPa and kPa),
  - Ambient relative humidity (%),
  - Ambient absolute humidity (% and g/m3),
  - Epoch,
  - Latitude (deg),
  - Longitude (deg),
  - Altitude (m),
  - Speed (km/h),
  - Heading (deg).

Accessories - Thermocouples

- parSYNC ® FLEX has CAN-based thermocouple interface to get real-time temperature data easily and quickly from over ten (10) sensors simultaneously. This allows collection of temperature data from aftertreatment catalyst, tailpipe tip, engine bay, engine oil or coolant, cabin, ambient air, etc.
- Some of the key features that thermocouple incorporation offers:
  - Real-time data at high acquisition frequency,
  - Potential for access to a wide range of different system temperatures,
  - Ability to design your own bespoke emissions test setup,
  - Low power consumption.

Accessories – Third party flow meters

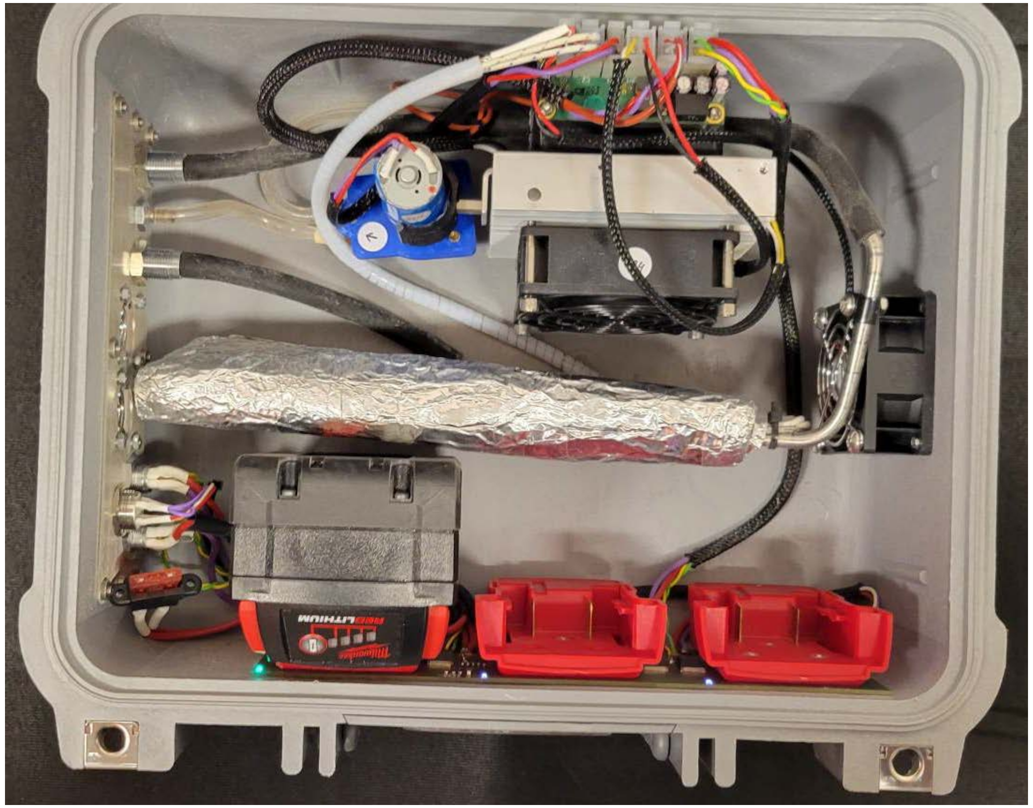
- parSYNC ® FLEX has and adapter to allow for integration of the Keyence fuel flow meter,
  - Useful for carbon studies.

- parSYNC ® FLEX CAN-based interface also allows for integration of third-party exhaust flow meters,
  - Useful for mass emission studies.

Operating the parSYNC ® FLEX

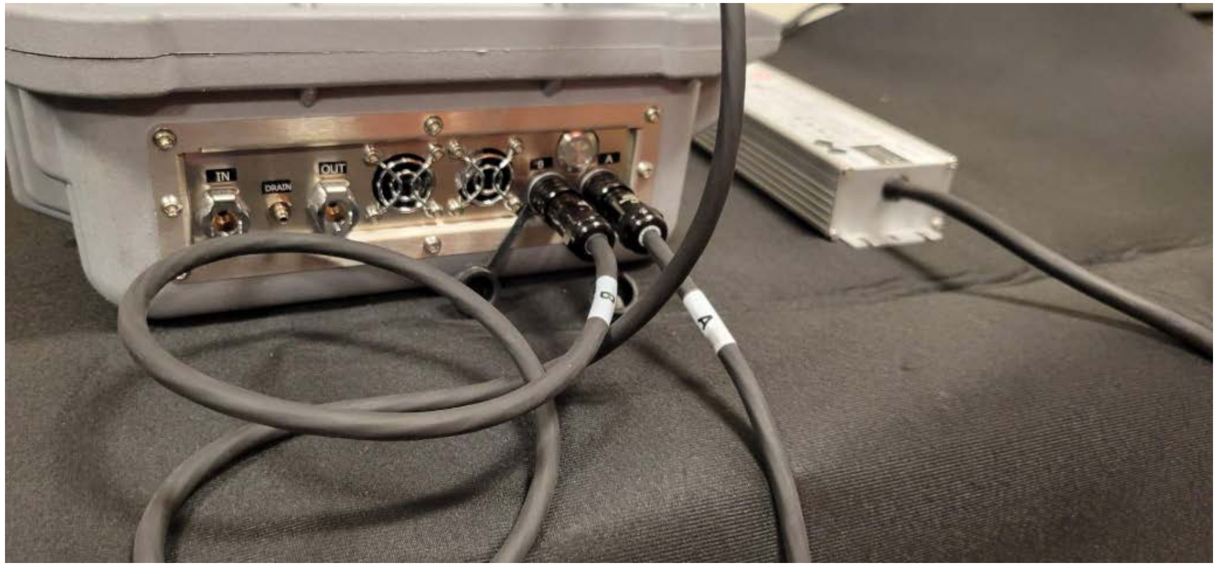
Setup – Batteries

➢Install all charged batteries (1 into FLEX, up to 3 into CUBE).



Setup – cables

- ➢Attach power/data cable and power supply.

Setup – sample lines

- Attach all tubing connections: Push the plugs into the ports until they snap in. There should be tubing at the following locations:
  - Inlet (sample gas in),
  - CUBE Drain (water out),
  - CUBE-to-FLEX - The CUBE-to-FLEX sample tubing comes pre-attached to the external water trap. The shorter length of tubing must plug into the FLEX inlet ("IN") port. The longer length of tubing must plug into the CUBE outlet ("OUT") port,
  - Outlet (sample gas out),
  - Zeroing Line (zero gas in).

Setup – other connections

- Attach any other accessories, e.g.
  - Scotty to CAN input,
  - Thermocouples to CAN input,
  - Keyence fuel flow meter to CAN input,
  - Exhaust flow meter to CAN input,
  - OBD adapter to vehicle ECU and connect via Bluetooth.
- Before zeroing the equipment, attach HEPA filters to Zero and Sample lines.
- But, before testing, remove HEPA filter from Sample line, attach sample probe and affix sample probe to vehicle tailpipe. Attach Scotty (if used) to vehicle roof.

Powering the equipment on (and off)

- Before powering on the equipment, verify the following:
  - Ensure all power and tubing connections are correct.
  - Ensure there are no kinks in the tubing and the inlet/outlet are not blocked.
  - Verify there is at least 13 cm (5 in) around each unit to allow for adequate airflow.
- To power on the FLEX, press and hold the power button for three seconds.
  - When the FLEX is turned on, the power switch will illuminate and onboard display will display “no data” while the internal computer boots up, which typically takes 5-15 seconds.
  - To turn the FLEX off, hold the power button and watch the onboard display. The display will show “SHUTDOWN” with a timer. Once the timer reaches zero, release the button to turn off the unit.
- To power on the CUBE, press and hold the power button for three seconds.
  - Note: If using the power supply, power on the CUBE with battery power before connecting or turning on the power supply.
  - A blue light on the CUBE power switch will illuminate when the CUBE is powered on.
  - To turn the CUBE off, press and hold the power button for three seconds. The blue light will turn off simultaneously.

Software use

- Launch the software by clicking the FLEXstudio icon in the Windows taskbar or by double clicking the desktop shortcut. When you start the software, it will default to the Dashboard/Test tab. If connection is successful, then data will be visible.
- The software enables review of system status and full control of the FLEX unit and its attachments.
- The software operation will not be covered in detail today – this will be covered in future training courses where appropriate

Testing with the parSYNC ® FLEX

The operation procedure for the FLEX will be outlined in this section using an example trial; the demonstration project recently undertaken in Abuja, Nigeria (more about that later).

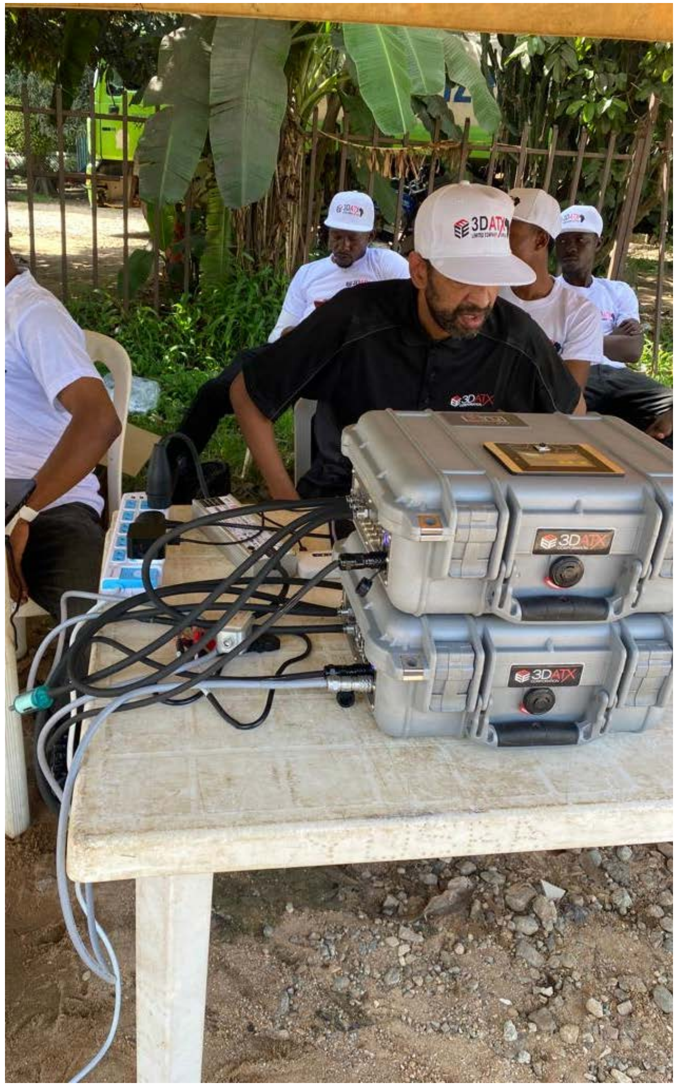
Example Test Procedure Overview

Phase	Segment Bag	Test Time (seconds)	Distance (km)
Prepare equipment & Zeroing (with HEPA)	0	90	0.000
Measuring with HEPA	1	30	0.000
Measuring ambient air	2	30	0.000
Move parSYNC	3	20	0.000
Measuring Idle	4	60	0.000
Drive Test - 3 x 34 km/h - 1 x 72 km/h	5	160	1.918
Measuring Idle	6	60	0.000
Move parSYNC	7	20	0.000
Measuring ambient air	8	60	0.000
Purge / Measuring with HEPA	9	60	0.000

Segment bag 0

- In segment bag 0, the parSYNC® is zeroed. The steps are as follows:

1. The parSYNC® should be turned on and connected to wall power (and warmed up),
2. START RECORDING (ensure vehicle identification in software),
3. Inlet (to IN-GAS line) MUST be positioned away from any running vehicle exhausts (preferably upwind),
4. To minimise time, all zeroing can be performed through the IN-GAS line with HEPA filter in the place of the probe. START ZEROING,
5. During Zeroing, the vehicle to be tested should be idling (to avoid any cold start effects),
6. While zeroing, install all on-vehicle equipment:
   a. Tailpipe Probe,
   b. OBD connector (if vehicle is compatible, then ensure OBD is activated in software),
   c. Scotty.



Segment bag 1

➢ In segment bag 1, ambient air is sampled through the HEPA filter. The steps are as follows:

1. The parSYNC® remains connected to wall power,
2. Measurement is performed through the IN-GAS line with HEPA filter in the place of the probe,
3. Inlet (to IN-GAS line) MUST be positioned away from any running vehicle exhausts (preferably upwind),
4. Continue any installation of on-vehicle equipment.

Segment bag 2

- In segment bag 2, ambient air is sampled without the HEPA filter. The steps are as follows:

1. HEPA filter is removed from the IN-GAS line for continued measurement,
2. Inlet (to IN-GAS line) MUST be positioned away from any running vehicle exhausts (preferably upwind),
3. ATTENTION: NOT TO ALLOW DIRT TO BE SUCKED IN OR TO DROP THE IN-GAS LINE,
4. The parSYNC® remains connected to wall power,
5. Continued installation of on-vehicle equipment.

Segment bag 3

- In segment bag 3, the parSYNC® is moved to the vehicle and installed. The steps are as follows:

1. parSYNC® (now operating on battery power) is moved to vehicle trunk or tailgate and all connections are made:
   a. IN-GAS line to Tailpipe Probe (already installed in the vehicle),
   b. Verification of OBD data activation (observe engine RPM),
   c. Connection of Scotty.

Segment bag 4

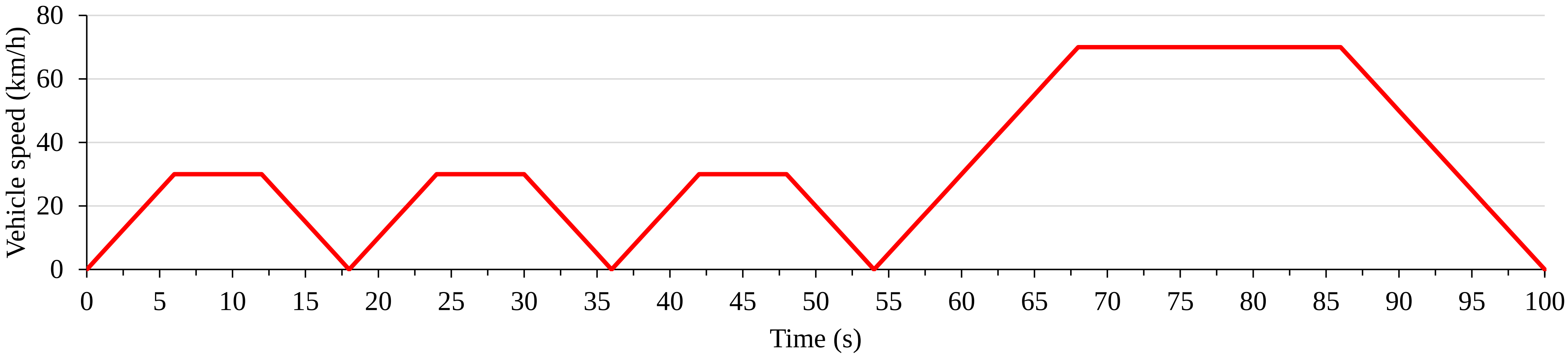
- In segment bag 4, an engine idle measurement is taken. The step is as follows:

1. Measurement of engine idle (through IN-GAS line connected to installed Tailpipe Probe, parSYNC® is still on battery power).

Segment bag 5

- In segment bag 5, the drive test is performed. The steps are as follows:

1. Perform +/-1.9 km drive test (through IN-GAS line connected to installed Sample Probe):
    a. 3 x 150 m signposted sections:
        i. Repeated acceleration (+/-5 km/h per second) to approx. 34 km/h (maintained for 10 seconds) then deceleration (+/-5 km/h per second) to stop.
    b. 1 x 1.45 km section:
        i. Acceleration (+/-5 km/h per second) to approx. 72 km/h (maintained for a minute), then deceleration (+/-5 km/h per second) to stop (return to start point).



Segment bag 6

➢ In segment bag 6, the step is as follows:

1. Measurement of engine idle (through sample line connected to installed Sample Probe, parSYNC® is on battery power).

Segment bag 7

➢ In segment bag 7, the parSYNC® is moved out from tested vehicle. The steps are as follows:

1. parSYNC® is disconnected from vehicle:
   a. IN-GAS line removed from Tailpipe Probe, Scotty (if available) disconnected,
   b. Moved to position away from any running vehicle exhausts (preferably upwind),
2. parSYNC® is connected to wall power.

Segment bag 8

➢ In segment bag 8, an ambient air measurement is taken. The steps are as follows:

1. Continued measurement from the IN-GAS line without HEPA filter,
2. Inlet (to IN-GAS line) MUST be positioned away from any running vehicle exhausts (preferably upwind),
3. ATTENTION: NOT TO ALLOW DIRT TO BE SUCKED IN OR TO DROP THE IN-GAS LINE,
4. The parSYNC® remains connected to wall power,
5. At the same time, all on-vehicle equipment is removed from the tested vehicle:
   a. Tailpipe Probe,
   b. OBD connector (if vehicle was compatible),
   c. Scotty.

Segment bag 9

➢ In segment bag 9, the parSYNC® is purged by measurement with HEPA filter, then the test is stopped. The steps are as follows:

1. The parSYNC® remains connected to wall power,
2. Measurement is performed through the IN-GAS line with HEPA filter in the place of the probe,
3. Inlet (to IN-GAS line) MUST be positioned away from any running vehicle exhausts (preferably upwind),
4. Continued removal of on-vehicle equipment from tested vehicle,
5. STOP RECORDING,
6. Vehicle is released.

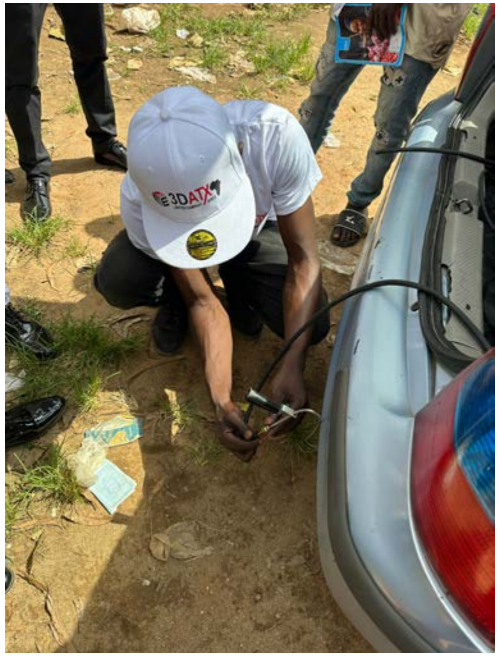
Demonstration project using the FLEX

The section outlines a vehicle emissions testing trial conducted in Abuja, Nigeria.

Overview

Trial objective: Test approximately 100 on-road passenger cars on a first-come first-served basis according to a standard programme to ensure accurate vehicle emissions testing and data integrity.

- Outcome: 103 vehicles tested in 5 days

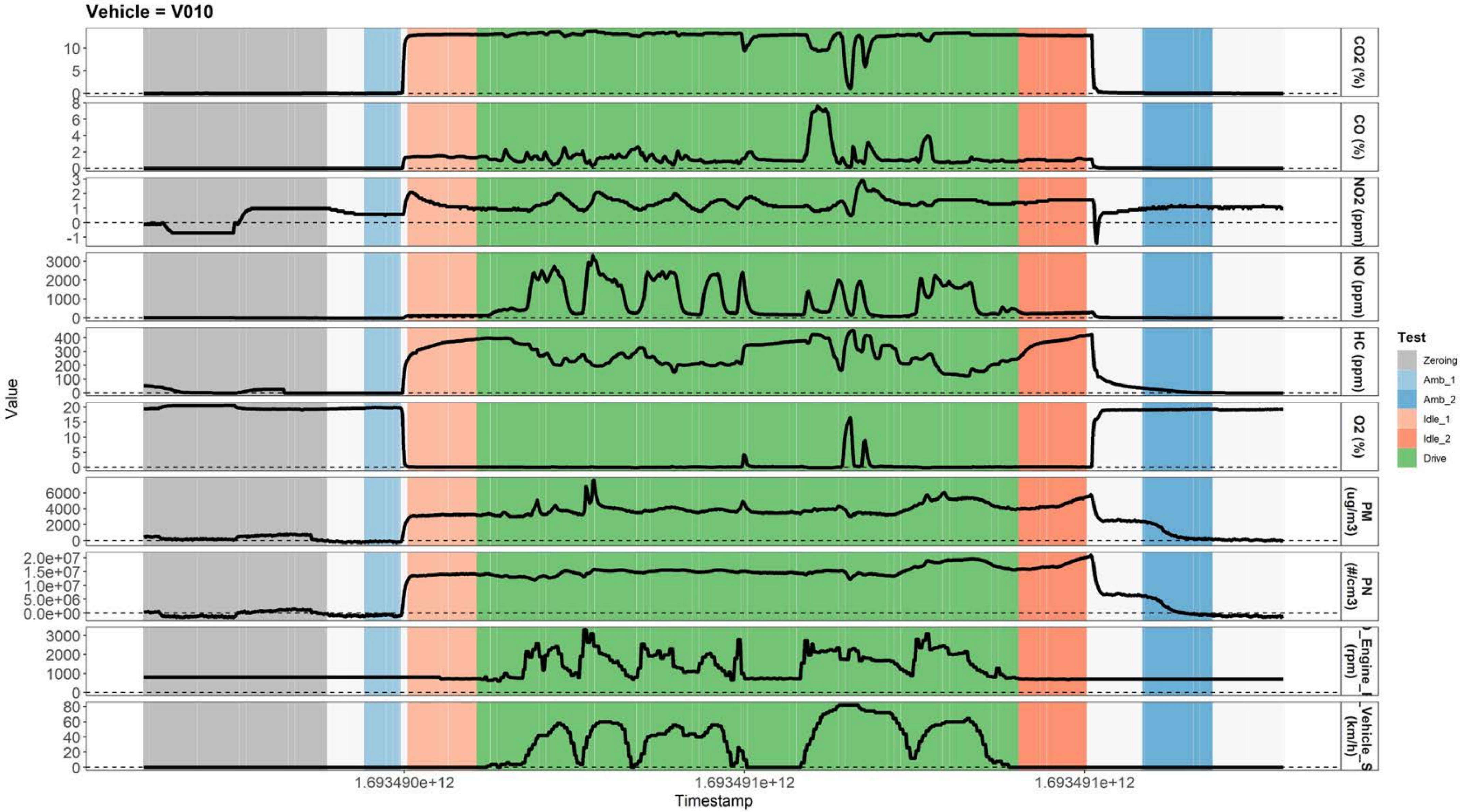


Test protocol followed by each vehicle

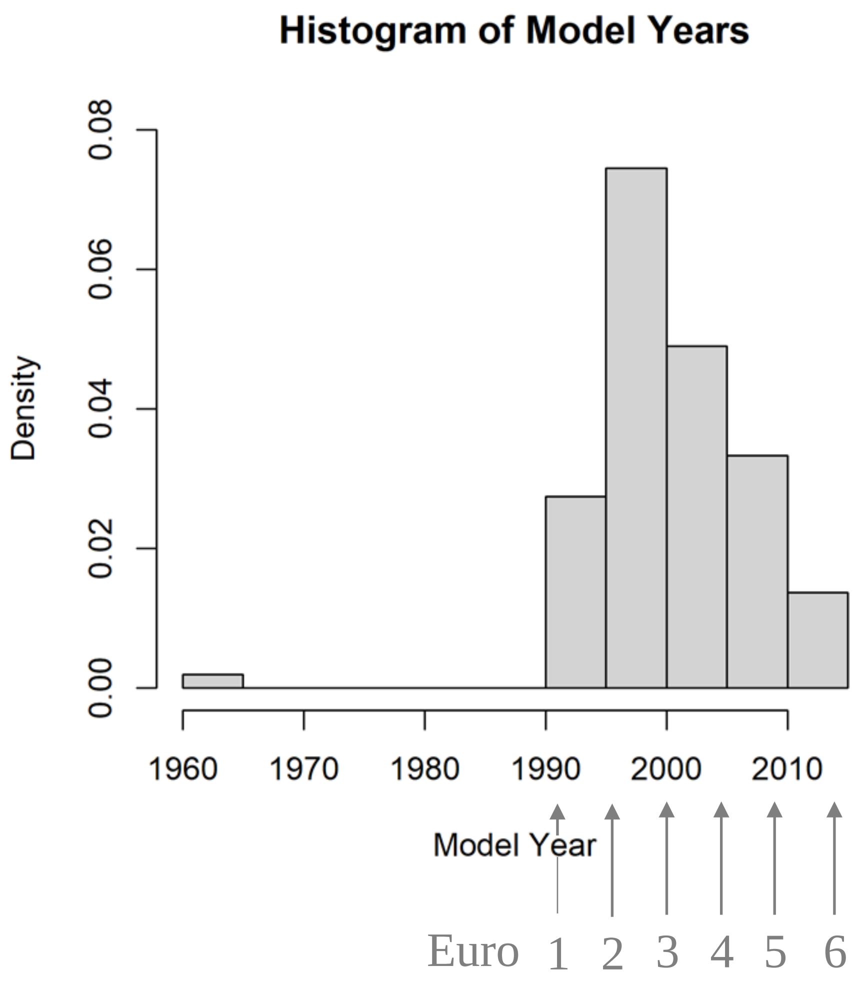
Phase	Objectives
1. Zeroing	Zero the parSYNC® FLEX instrument
2. Measure filtered air	Pre-verification of zero
3. Measure ambient air	Pre-check ambient conditions
4. Measure vehicle exhaust at idle	Verify test vehicle emissions without load
5. Measure vehicle exhaust while driving	Verify test vehicle emissions under load: The vehicle is driven around a standard and repeatable route under safe conditions
6. Measure vehicle exhaust at idle	Reverify test vehicle emissions without load
7. Measure ambient air	Post-check ambient conditions
8. Measure filtered air	Post-verification of zero

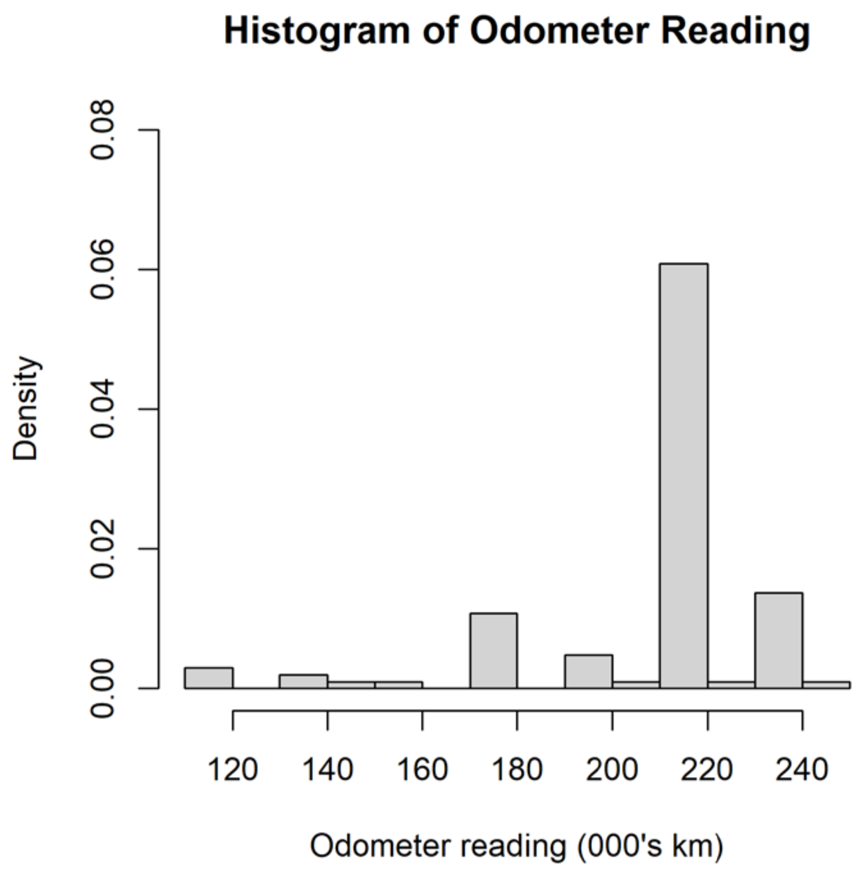
- Test procedure performed in approx. 10 minutes at road-side.
- Drive section took on average 366 ± 23 s to complete, had a mean speed of 34 ± 2 km/h and maximum speed of 73 ± 2 km/h *(calculated from 25 tests)*.

Test Example



Fleet characteristics





Comparison of vehicle results to Type Approval standards

Mass emissions were calculated for a sample of vehicles. Many had emissions far exceeding their type approval values

Vehicle	Sec.	Distance (km)	NO2 (mg/km)	NO (mg/km)	NOx (mg/km)	CO2 (g/km)		CO (mg/km)	HC (THC) (mg/km)	PM (mg/km)	PN (#/km)
						EPA	Tested				
V04	502	4.98	0.92	2,080	2,081	162 - 177	128	4,954	639	3.45	9.24E+12
V20	451	5.1	5.52	2,665	2,670	177	149	8,620	1,426	2.76	1.08E+13
V21	415	5.03	1.67	2,444	2,445	157 - 171	149	5,085	473	2.70	9.41E+12
V22	492	4.91	3.29	2,598	2,601	177	139	11,821	1,266	2	8.77E+12
V23	488	5.01	5.57	2,484	2,489	210	132	7,357	568	2.29	9.41E+12
V28	472	4.89	4.79	2,023	2,028	177	152	8,422	1,102	2.55	1.14E+13
EURO3 (from Jan 2001)			NA	NA	150	NA		2,300	200	NA	NA
V10	478	4.79	2.74	3,076	3,079	177 - 183	230.05	18,715	435	4.39	1.59E+13
V12	418	4.68	-0.13	2,783	2,783	183 - 195	174.9	5,552	1,036	3.44	1.16E+13
EURO4 (from Jan 2006)			NA	NA	80	NA		1,000	100	NA	NA

Repairing two vehicles

- Two vehicles had their three-way catalysts (TWC) replaced and were retested.





Repairing two vehicles

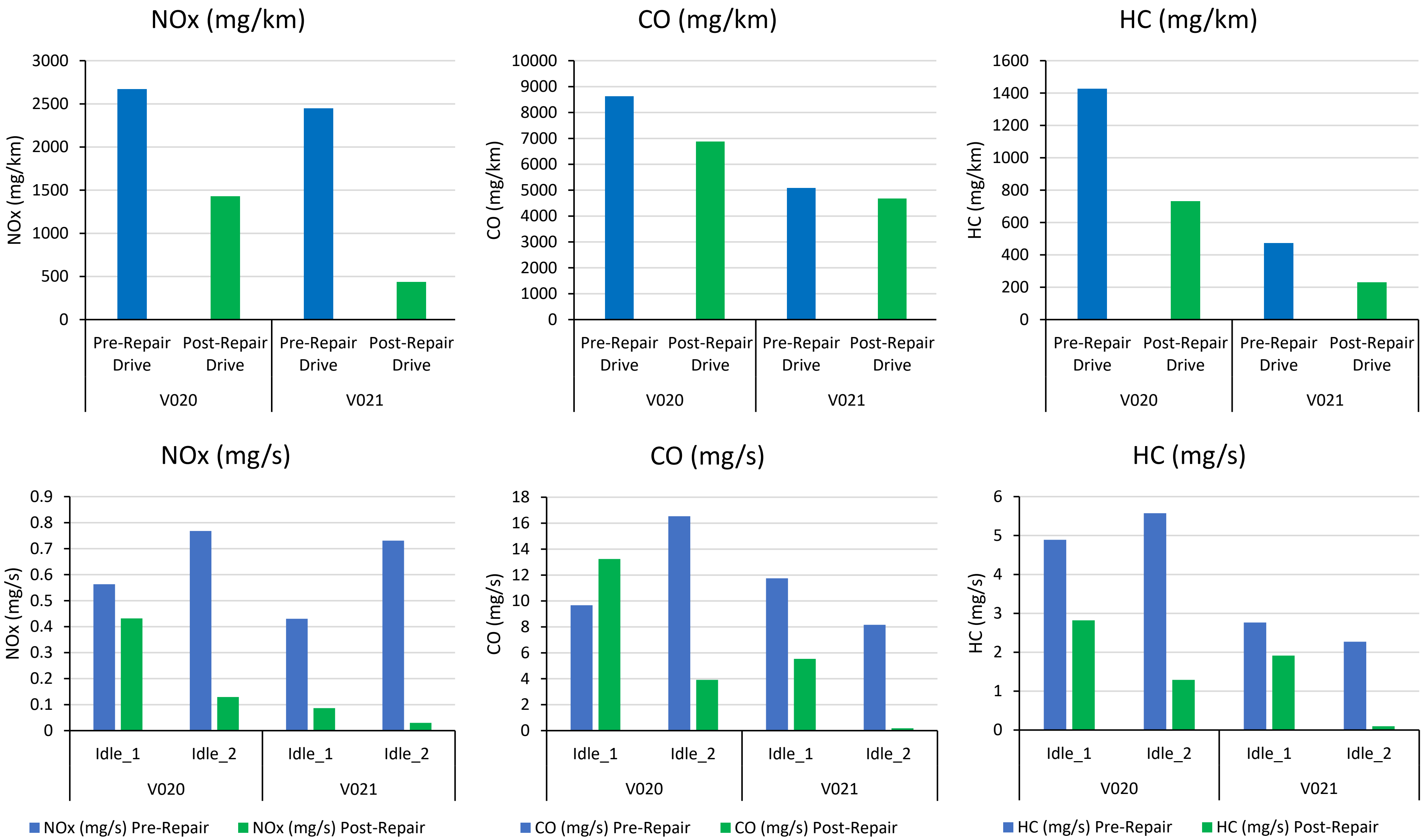
- Pollutant emissions of NOx, CO and HC reduced, though they were still above the type approval thresholds.
  - TWC efficiency improved, wasn't the only issue with the vehicles
- Emissions of PM increased, as did CO_2
  - Further investigation required

Vehicle	Sec.	Distance (km)	NO2 (mg/km)	NO (mg/km)	NOx (mg/km)	CO2 (g/km)		CO (mg/km)	HC (THC) (mg/km)	PM (mg/km)	PN (#/km)
						EPA	Tested				
V20 – pre-repair	451	5.1	5.52	2,665	2,670	177	149	8,620	1,426	2.76	1.08E+13
V20 – repaired	352	2.92	1.19	1,427	1,429	177	187	6,867	732	5.26	1.18E+13
V21 – pre-repair	415	5.03	1.67	2,444	2,445	157 -171	149	5,085	473	2.70	9.41E+12
V21 – repaired	311	2.92	0.73	433	433	157 - 171	200	4,675	229	5.75	1.23E+13
EURO3 (from Jan 2001)			NA	NA	150	NA		2,300	200	NA	NA

Repairing two vehicles

Drive cycle – mass emission factors

Idle cycles – Average mass emission rates



The same trends were seen for average concentration

Thank you for listening.

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Any Questions?