# New Approaches to Vehicle Emissions Inspections

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# Outline

- PTI Overview
- 3DATX parSYNC iPEMS
- PTI Pilot at Opus, Sweden
  - Locations and Vehicles
  - Test Protocol
  - Initial Findings
  - Feedback
- PTI Pilot Next Steps

# PTI Today

- PTI for exhaust emissions are mostly regulated by Directive 2014/45/EU:
  - Correct performance of complex exhaust after-treatment systems are verified only by visual inspection (absence, modification, leaks, etc.)
  - Different exhaust emission requirements for vehicle engine type:
    1. Positive ignition engines:
       a. CO emissions below specified thresholds
       b. Lambda coefficient within specified range
       c. OBD does not indicate significant malfunction
    2. Compression ignition engines:
       a. Opacity does not exceed specified thresholds

- Directive 2014/45/EU is out of date:
  - Not referenced to regulatory thresholds and measurements defined for type-approval testing, notably for $NO_x$ and PN measurement/thresholds and CO or $CO_2$ thresholds
  - Existing PTI equipment cannot meet these requirements

# PTI Tomorrow

- Post Dieselgate, European emission measurement is progressing:
  - VERT advocates PN measurement at EU and member state levels
  - EU has implemented PMP and RDE protocol for vehicle type-approval testing, with measurement of CO, $NO_x$, HC+$NO_x$, PM and, from EURO-5, measurement of PN
  - Some member states are introducing new PTI regulations independently of EU regulation:
    - Netherlands, Germany, and Belgium for PN for diesel vehicles post EURO5
    - France for $NO_x$ for diesel vehicles
  - EU regulates OBM $CO_2$ monitoring for new vehicles from 2021, with PTI procedures to be defined
  - EU PTI emissions procedure is not homogeneous across the EU

- Further work to implement emissions measurement at PTI:
  - Particulate protocol, measurement & threshold as per modified NPTI/Dutch procedure to be tested
  - NOx protocol, measurement & threshold as per CITA experience, to be developed and tested
  - CO and $CO_2$ protocol, measurement & threshold to be developed and tested
  - Advocating EU homogeneity and building future-proof systems

# parSYNC® iPEMS Solution

- Next Generation: integrated PEMS
  - Easy to use and versatile
  - Rugged, light weight and mobile: <4 kg and >4 hours on battery
- Modular Sensor Cartridge Advantage: Particulates and Gases
  - GasMod cartridge measures NO (0-5000 ppm), $NO_2$ (0-300 ppm), CO (0-15%), and $CO_2$ (0-20%)
  - PM/PN cartridge measures Opacity Scattering and Ionisation and uses a matrix transform to calculate PM ($ug/m^3$) and PN ($\#/cm^3$)
  - Simplifies measurement and maintenance.


parSYNC® iPEMS will meet current (Opacity and Gas Analyser) & future (PN, NOx, …) PTI equipment standards

# PTI Pilot – OPUS Sweden

# Test Location

This presentation covers Phase-1 data collected at the Borås site.
We expect the Skellefteå site to join the pilot this week.



# Vehicles Tested







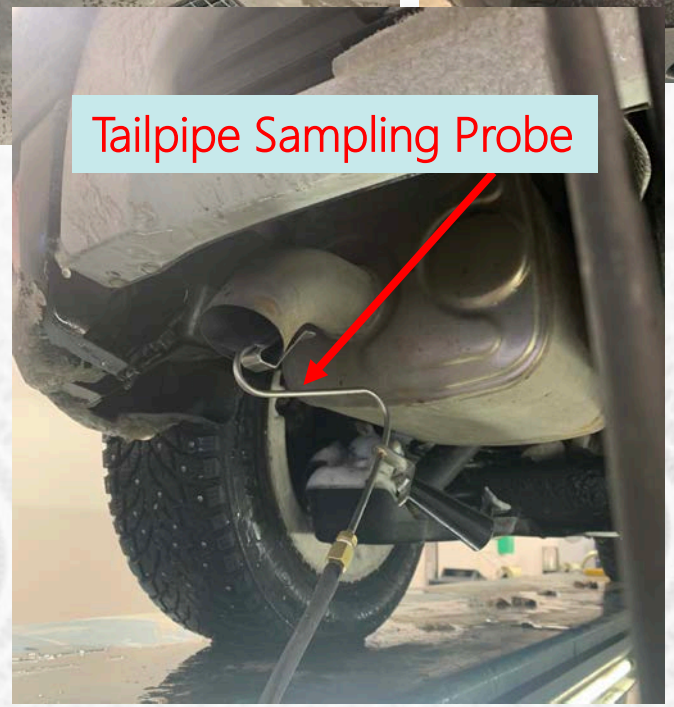

# Vehicle Summary

| MAKE | Diesel | Petrol | 2005 | 2006 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AUDI | 4 | 1 | 1 | 1 | | | | 1 | 1 | 1 | | | | | | 5 |
| BMW | 5 | | | | | 1 | | 1 | | 1 | 2 | | | | | 5 |
| CITROEN | 1 | | | | | | 1 | | | | | | | | | 1 |
| DACIA | | 2 | | | | | | 1 | | | 1 | | | | | 2 |
| FORD | 4 | 1 | | | 1 | | 1 | 2 | 1 | | | | | | | 5 |
| HONDA | 1 | 1 | | | | | | | | | 1 | | 1 | | | 2 |
| HYUNDAI | 1 | 1 | | | | | | 1 | | | 1 | | | | | 2 |
| JEEP | | 1 | | | | | | | 1 | | | | | | | 1 |
| KIA | 4 | | | | | | | | 2 | 1 | | | 1 | | | 4 |
| MAZDA | 2 | 2 | | | | | | | | 1 | 1 | 1 | | | 1 | 4 |
| MERCEDES-BENZ | 1 | | | | | | | | | 1 | | | | | | 1 |
| MITSUBISHI | 2 | | | | 1 | | | 1 | | | | | | | | 2 |
| NISSAN | | 1 | | | | | | | | | 1 | | | | | 1 |
| OPEL | | 1 | | | | | | | | | | 1 | | | | 1 |
| RENAULT | 1 | 2 | | 1 | | | | | | 1 | | | 1 | | | 3 |
| SAAB | 1 | 1 | | 1 | | 1 | | | | | | | | | | 2 |
| SKODA | | 2 | 1 | | | | | 1 | | | | | | | | 2 |
| SUBARU | 1 | | | | | | | 1 | | | | | | | | 1 |
| TOYOTA | 1 | | | | | | 1 | | | | | | | | | 1 |
| VOLKSWAGEN | 2 | 1 | 1 | | | | | 1 | | | | | | 1 | | 3 |
| VOLVO | 10 | 1 | | | | 1 | | 1 | 1 | 1 | 3 | 2 | 2 | | | 11 |
| VW | 1 | | | | | | | | 1 | | | | | | | 1 |
| **Total** | **42** | **18** | **3** | **3** | **2** | **3** | **3** | **11** | **7** | **7** | **10** | **4** | **5** | **1** | **1** | **60** |

Jan 21
to
Feb 18,
2021

# Test Setup and Conditions

parSYNC warmup and zeroing while vehicle is being prepared

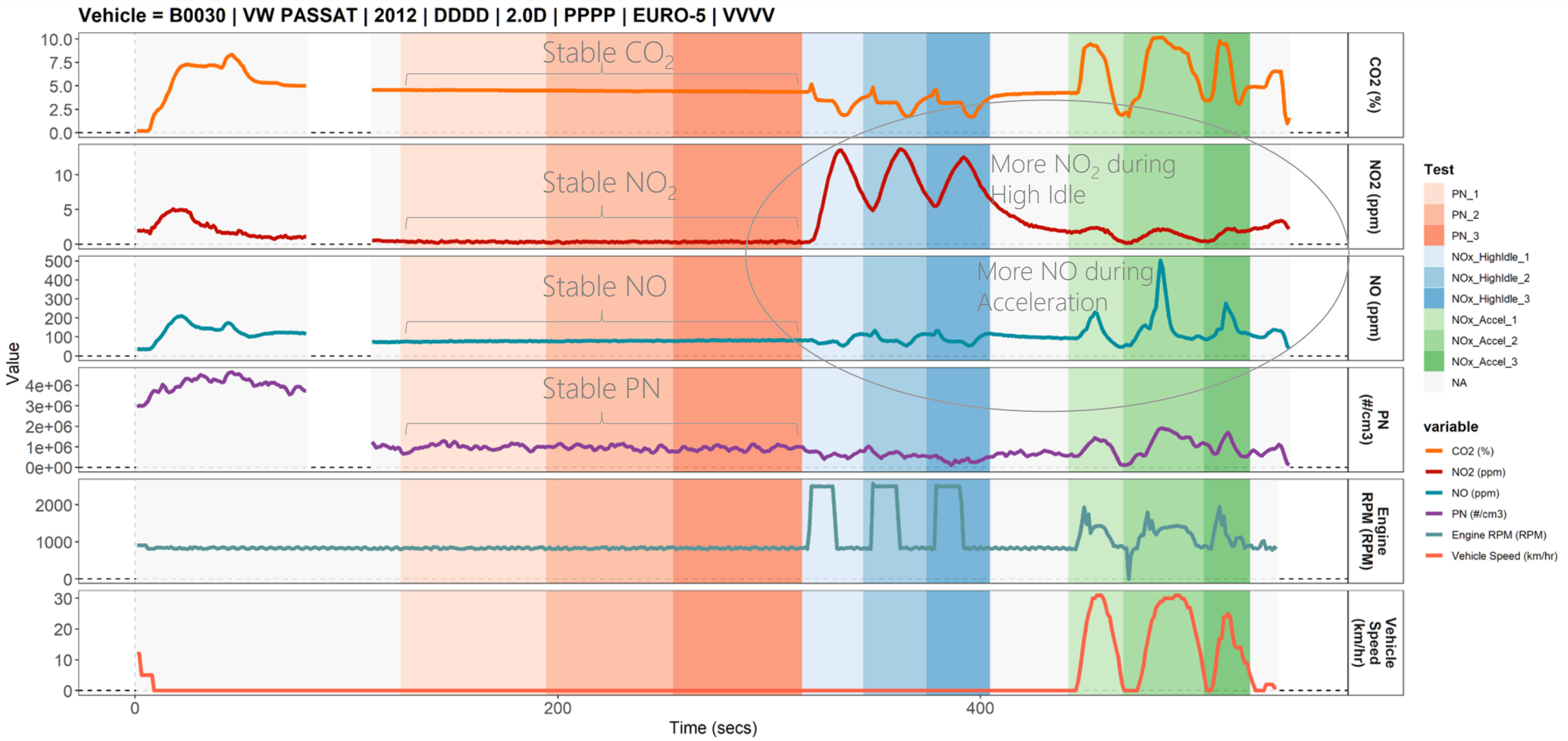


# Test Protocol

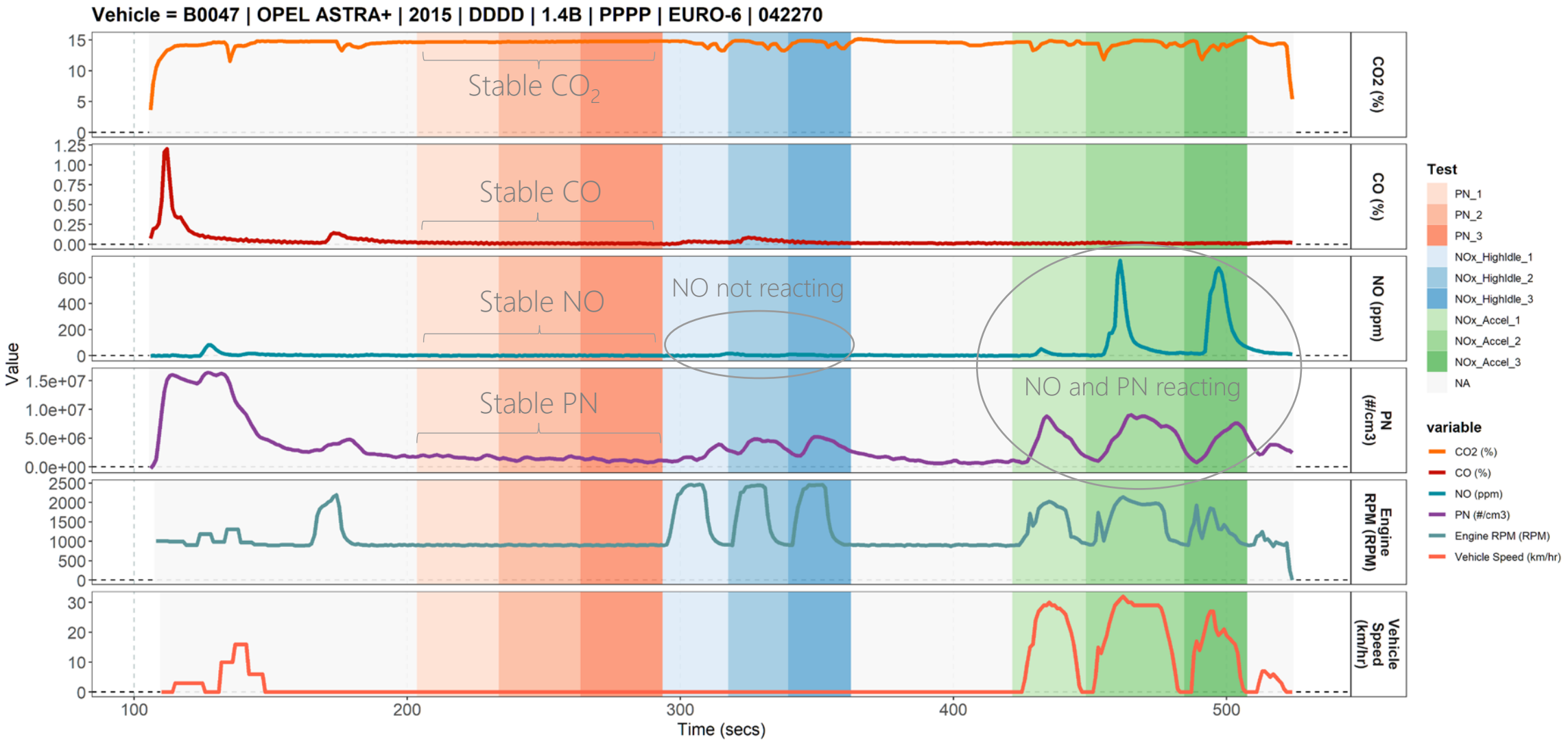
| | |
|---|---|
| Prep | • Warmup (or dry-out) the parSYNC using wall power while sampling clean ambient air (use HEPA filter if available) |
| 0 | • Start test data file \| Sample clean ambient air for ~60 seconds |
| Zero | • Run the zeroing procedure while parSYNC is on the bench |
| 0 | • With parSYNC running on battery power move it to the vehicle \| Connect to tailpipe probe \| Connect OBD reader to ECU port \| Start the vehicle \| Drive to parking lot position \| Idle vehicle for 60 seconds |
| 1-3 | • PN – 30 seconds of idle \| Repeat 3 times |
| 4-6 | • $NO_x$ High Idle – Idle → ~2500 RPM, hold for 5 seconds → return to Idle and hold for 10 seconds \| Repeat 3 times |
| 7 | • Idle for 60 seconds to allow $NO_x$ emissions to stabilise |
| 8-10 | • $NO_x$ Acceleration – Stationary → 30 kph → Stationary \| Repeat 3 times |
| 11 | • Return vehicle to workshop/garage to uninstall \| Disconnect parSYNC and place on bench and connect to wall power \| Sample clean ambient air for 60 seconds |
| Zero | • Run zeroing procedure with parSYNC on the bench |

# PTI Pilot Data – Initial Findings

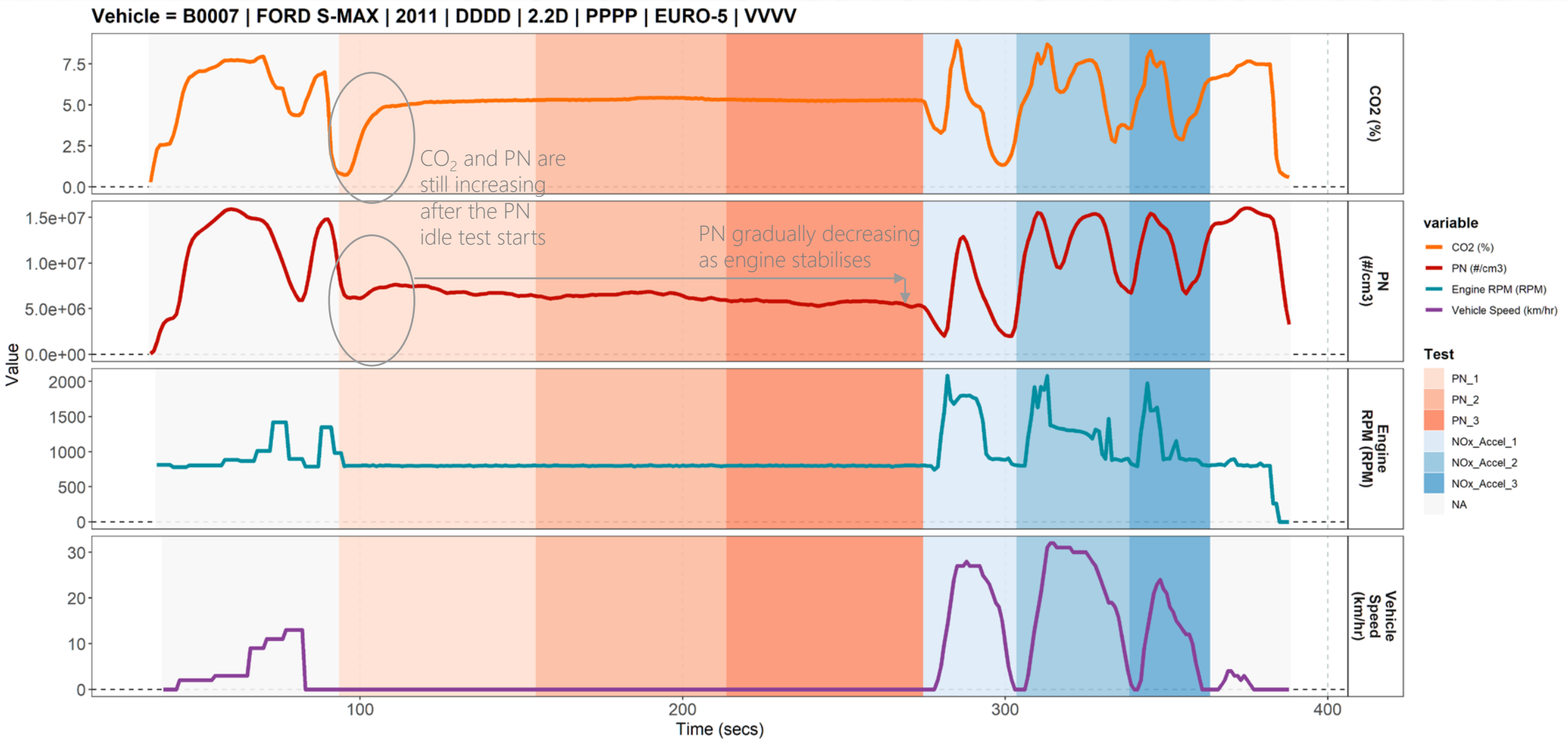
# Example of a PTI Protocol Test – Diesel



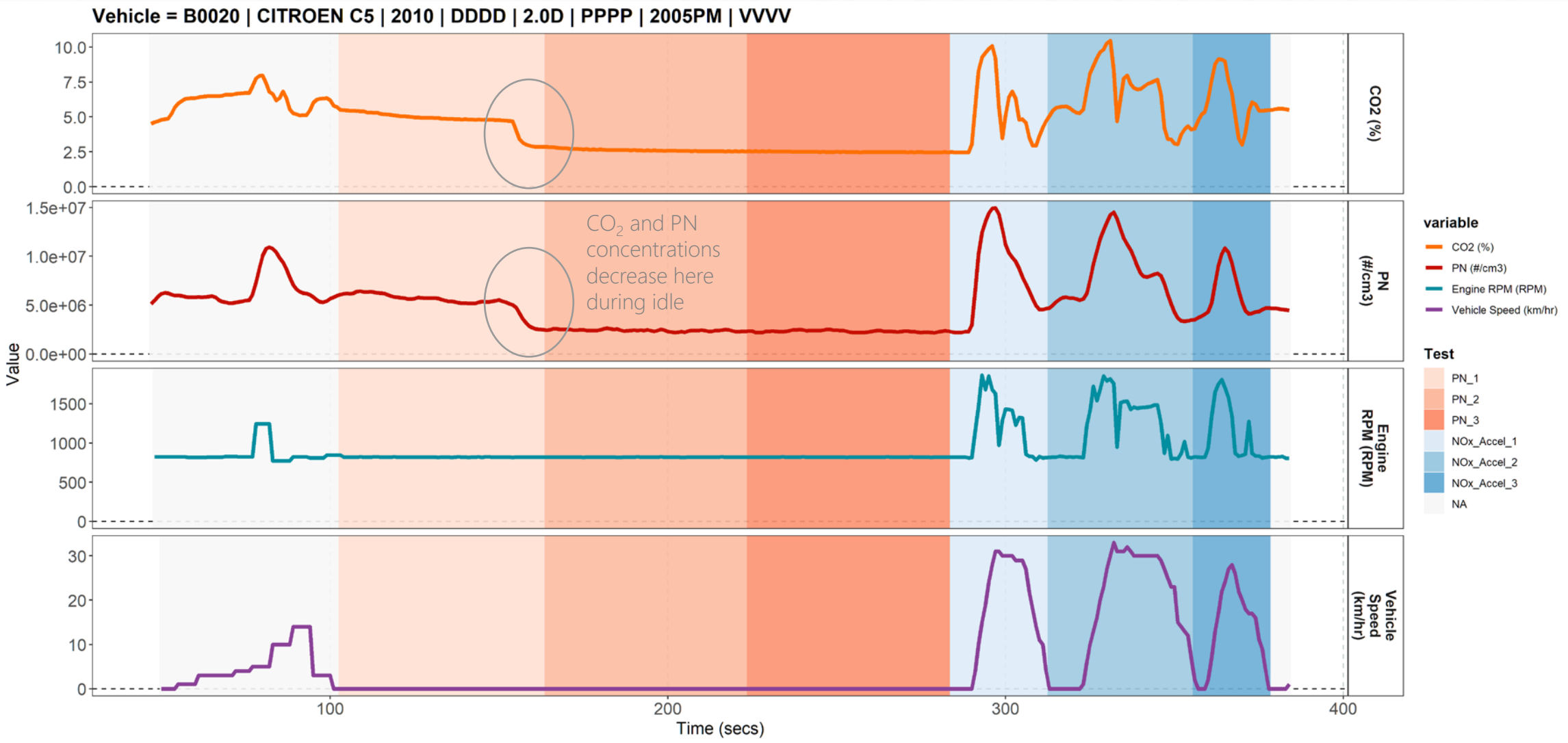
# Example of a PTI Protocol Test – Petrol



# Example of Starting the PTI PN Idle too soon after Engine Ignition

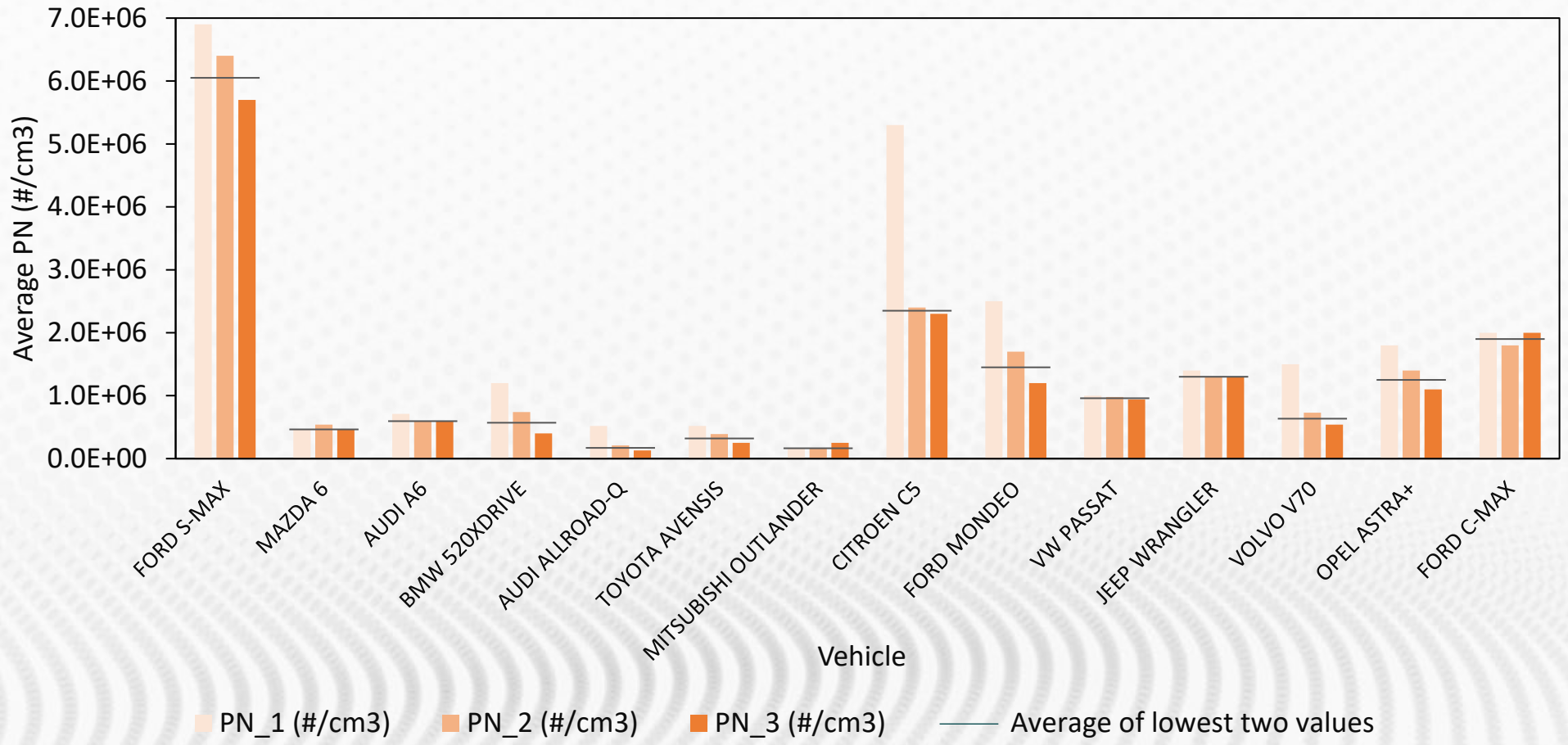


# Example of Instability on the PTI PN Idle



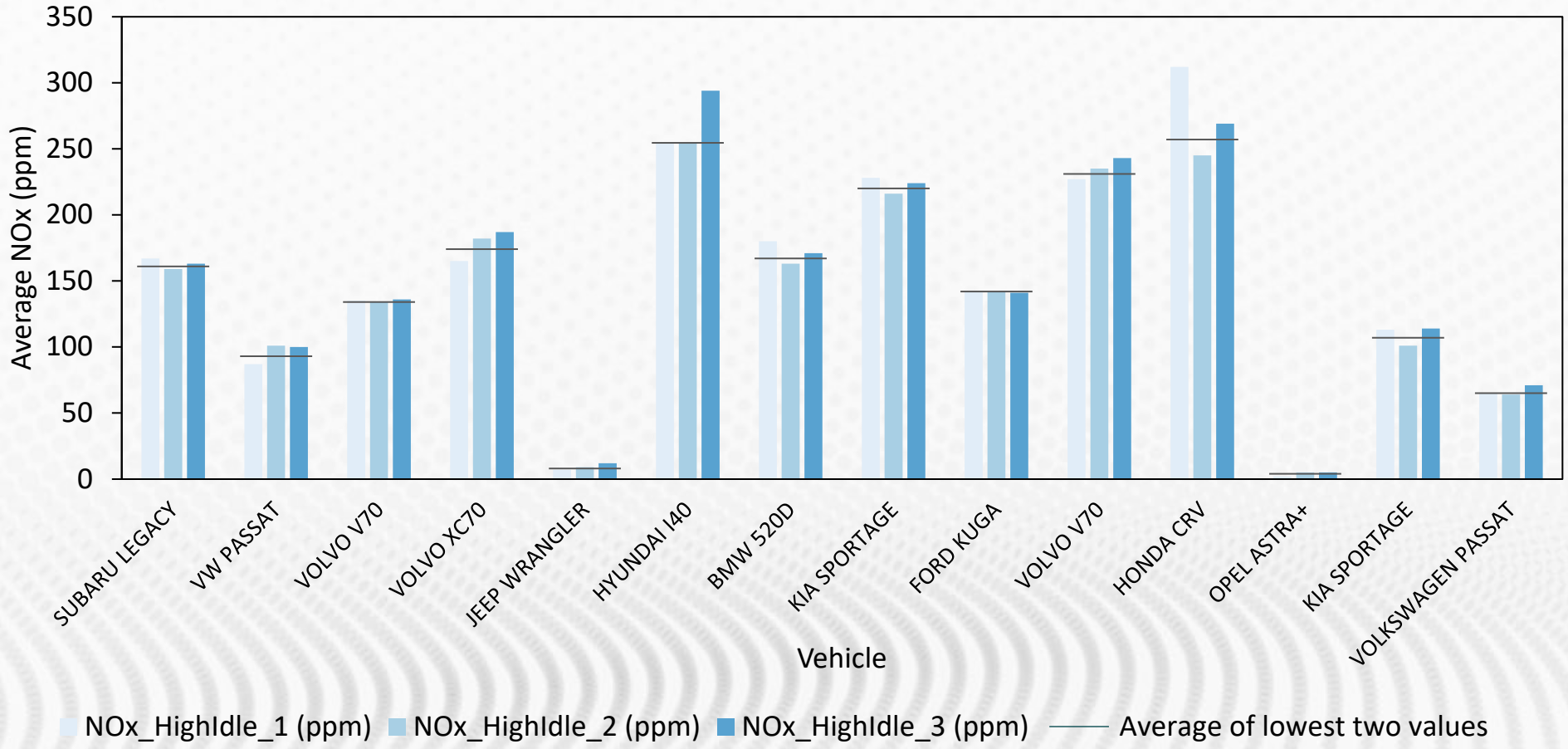
# Preliminary PN Results – Idle Test

Initial findings from 14 trial PTI tests. Average PN concentrations are calculated from the PN engine idle test periods.



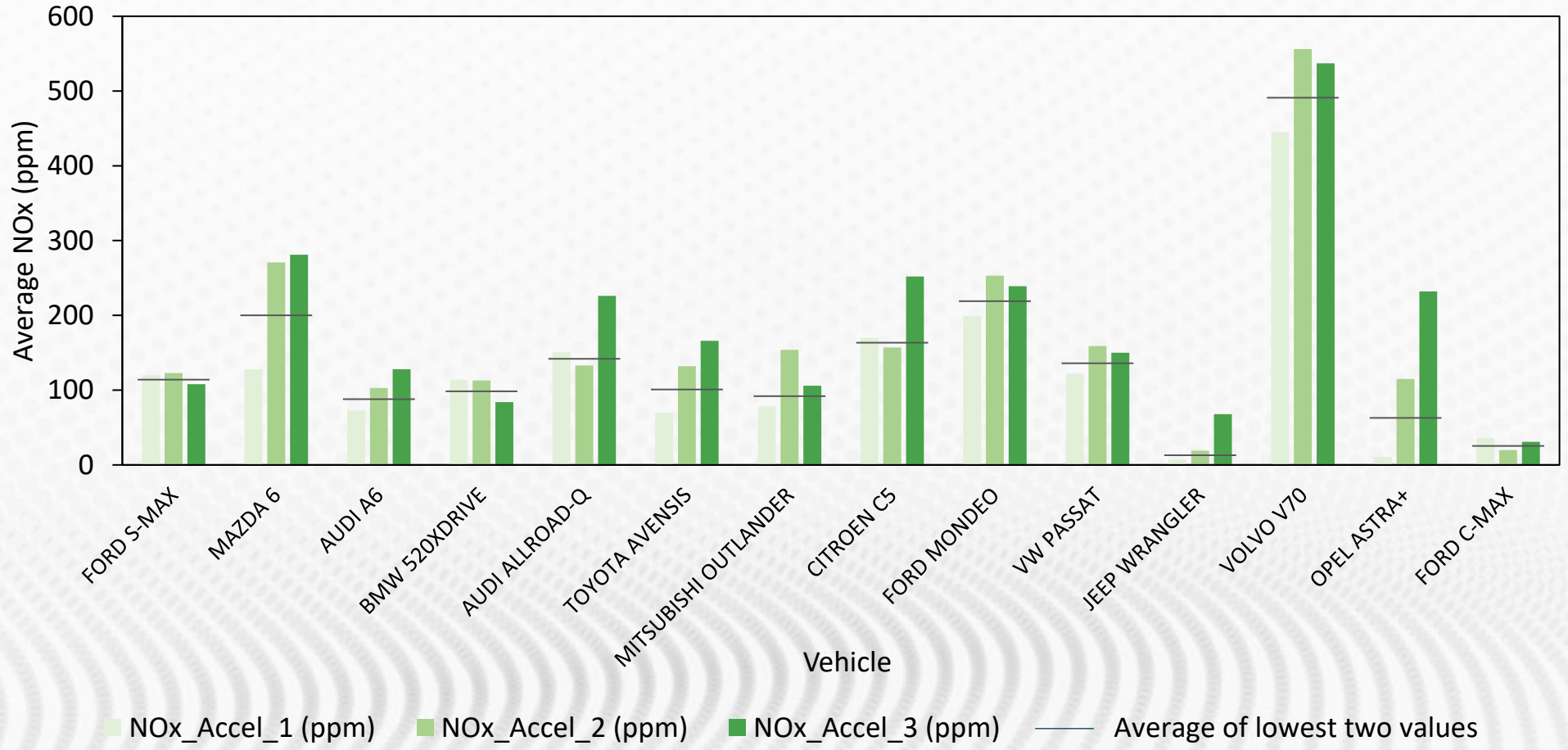
# Preliminary NOx Results – High Idle Test

Initial findings from 14 trial PTI tests. Average NOx concentrations are calculated from the NOx High Idle test periods.



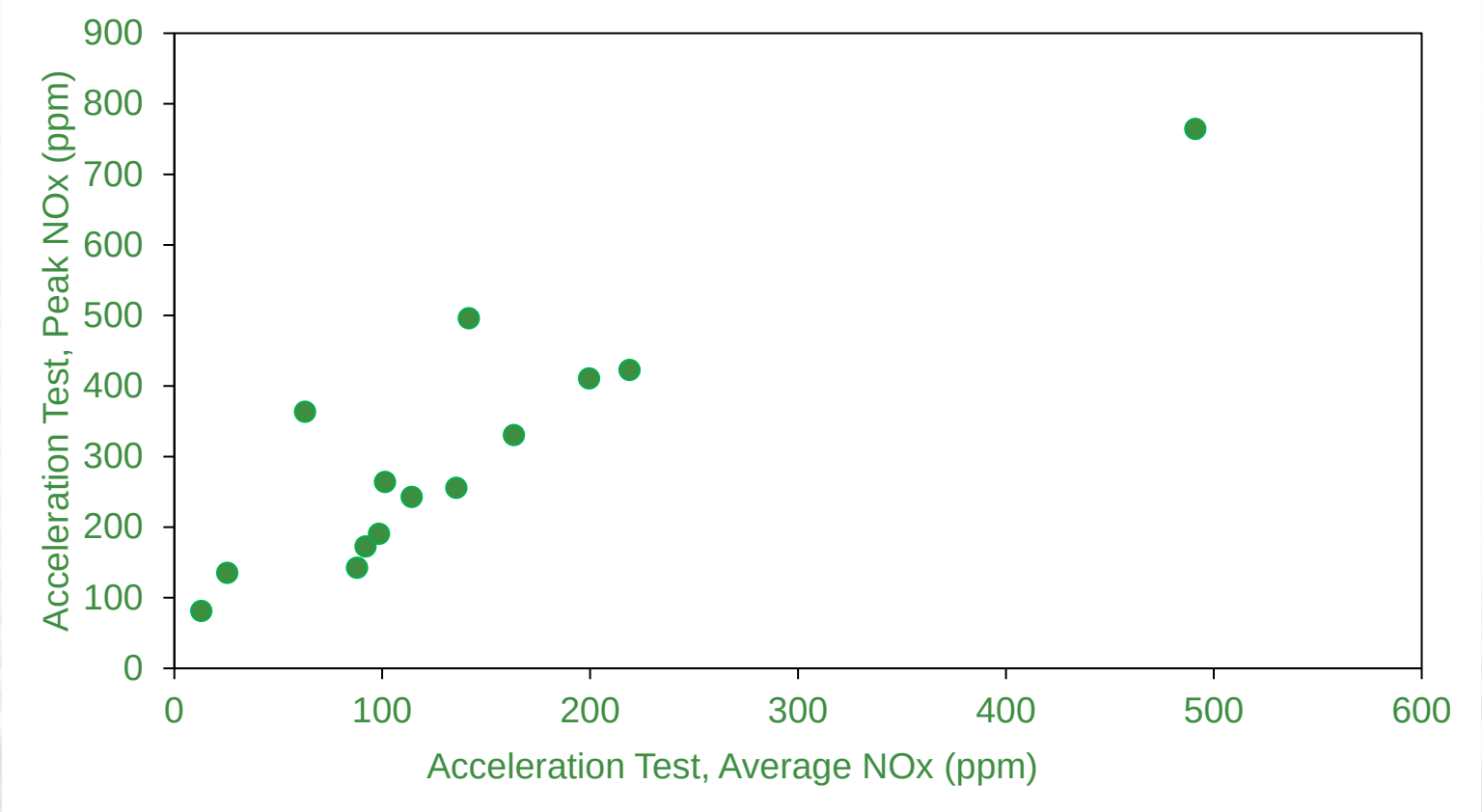
# Preliminary NOx Results – Acceleration Test

Initial findings from 14 trial PTI tests. Average NOx concentrations are calculated from the NOx acceleration test periods.



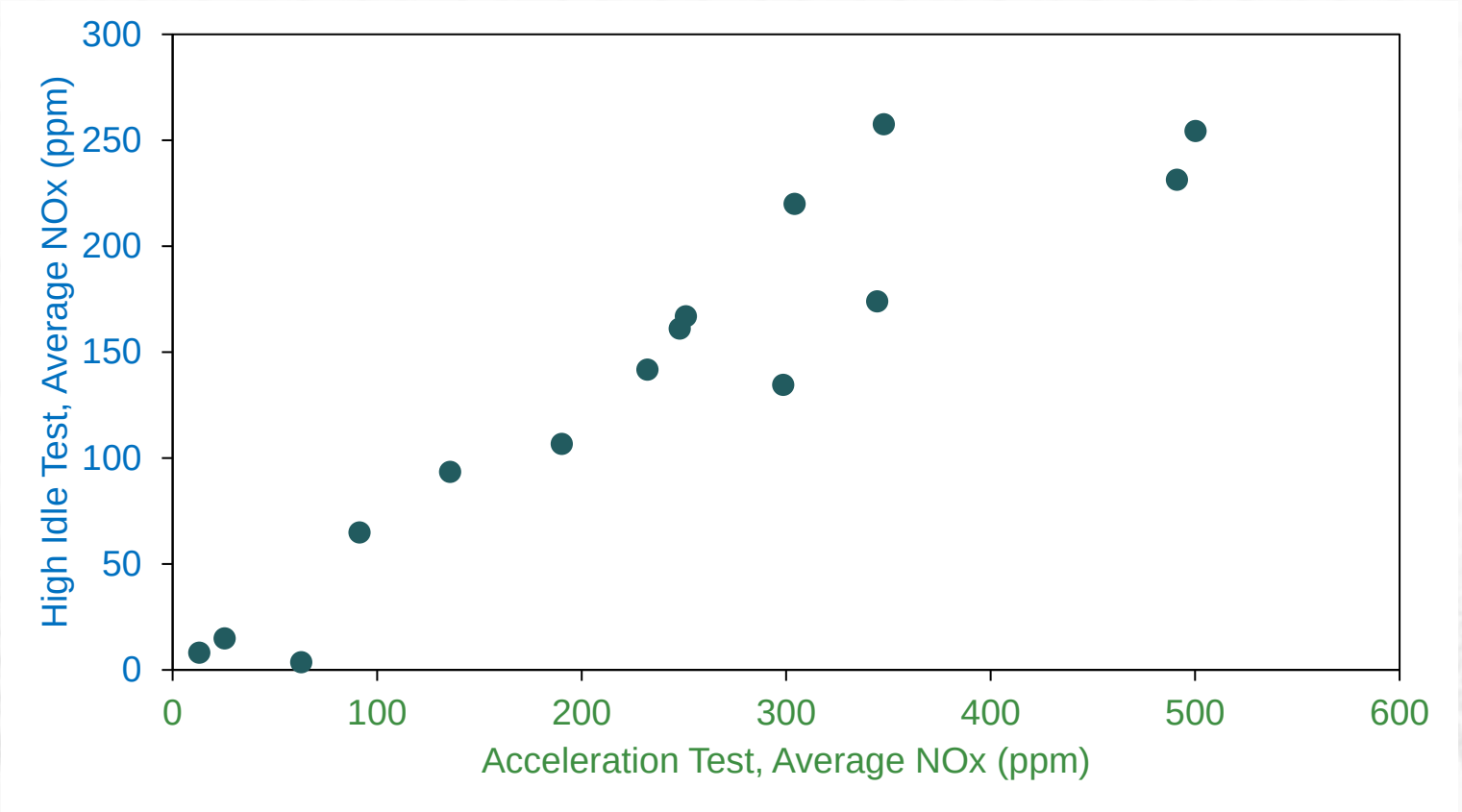
# Relationship between Average and Peak Values

Positive correlation seen between the $NO_x$ acceleration test's average $NO_x$ value and peak $NO_x$ value for individual vehicles.



# Relationship between Acceleration and High Idle Test Results

Positive correlation seen between the average $NO_x$ high idle test results and acceleration test results for individual vehicles.



# Opus Trial Overview

## ➢OPUS Trial Preliminary Conclusions:

- The PN Idle test works well, but an improved engine warming/conditioning procedure is required
- Both NOx tests appear promising, with good correlation between the two tests for individual vehicles

## ➢Feedback from Opus Inspectors:

- parSYNC® iPEMS is “like a lab instrument” and is “pretty easy to use”
- Time to complete extended test protocol, including install and uninstall –> 15-20 minutes
- Can be installed and operated by one person
- Bluetooth connection is robust – no disconnections yet
- Improvements requested – tailpipe probe design to reduce install time, test protocol wizard GUI single rugged container for all components
- Customer voluntary participation – 100% ☺

# PTI Pilot Next Steps

- Adding more test locations in EU:
  - Germany: Simulated PTI Trial in progress with TRT Engineering in Munich,
    TüV-Nord in Essen – training completed, measurements starting soon
    Dekra in Stuttgart – training scheduled for 1st week in April
  - Spain: Participating in AECA-ITV (association of PTI inspection groups) trial
  - France and Belgium: Trials expected to begin in summer

- Phase 2 of PTI Pilot:
  - Continue to refine the test protocol and pollutant metrics
  - Expanded testing locations and strategic partners in EU and other target markets >> significantly larger vehicle sample size

- Database Development:
  - Coordinate with suitable partners such as JRC
  - Share vehicle emissions database with pilot partners
  - Provide a web-based interface to extract emissions trends and reports from the database

# Acknowledgements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  - Thomas Nilsson, Quality and Environmental Manager
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  - Jonas Lindén, Inspection Technician
  - Natalie Wester, Inspection Technician
- 3DATX
  - Ami Alderman, Ph.D., Director of Operations
  - Larry Mattison, Director of Engineering
  - Mike Dio, Lead – Customer Sales and Support
  - Sean Dineen, Head Engineer of Production
- Other
  - Claudia Toro, Ph.D., Data Analysis Scientist

# Thank You for Listening!

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# Tables

# Preliminary PN Results

Initial findings from 14 trial PTI tests. Average PN concentrations are calculated from the PN engine idle test periods (points 1-3 on slide 11).

| Vehicle Make | Vehicle Model | Year | Engine | Euro Standard | PN_1 (#/cm³) | PN_2 (#/cm³) | PN_3 (#/cm³) | Average of lowest 2 PN (#/cm³) |
|---|---|---|---|---|---|---|---|---|
| FORD | S-MAX | 2011 | 2.2D | EURO-5 | 6.9E+06 | 6.4E+06 | 5.7E+06 | 6.1E+06 |
| MAZDA | 6 | 2013 | 2.2D | EURO-6 | 4.6E+05 | 5.4E+05 | 4.7E+05 | 4.6E+05 |
| AUDI | A6 | 2012 | 2.0D | EURO-5 | 7.1E+05 | 5.9E+05 | 6.0E+05 | 5.9E+05 |
| BMW | 520XDRIVE | 2014 | 2.0D | EURO-6 | 1.2E+06 | 7.4E+05 | 4.0E+05 | 5.7E+05 |
| AUDI | ALLROAD-Q | 2006 | 3.0TDI | EURO-4 | 5.2E+05 | 2.1E+05 | 1.3E+05 | 1.7E+05 |
| TOYOTA | AVENSIS | 2010 | 2.0D | EURO-5 | 5.2E+05 | 3.9E+05 | 2.5E+05 | 3.2E+05 |
| MITSUBISHI | OUTLANDER | 2008 | 2.2D | EURO-4 | 1.6E+05 | 1.7E+05 | 2.5E+05 | 1.6E+05 |
| CITROEN | C5 | 2010 | 2.0D | EURO-4 | 5.3E+06 | 2.4E+06 | 2.3E+06 | 2.4E+06 |
| FORD | MONDEO | 2011 | 2.0D | EURO-5 | 2.5E+06 | 1.7E+06 | 1.2E+06 | 1.4E+06 |
| VW | PASSAT | 2012 | 2.0D | EURO-5 | 1.0E+06 | 9.8E+05 | 9.4E+05 | 9.6E+05 |
| JEEP | WRANGLER | 2012 | 3.6B | EURO-5 | 1.4E+06 | 1.3E+06 | 1.3E+06 | 1.3E+06 |
| VOLVO | V70 | 2009 | 2.4D | EURO-4 | 1.5E+06 | 7.3E+05 | 5.4E+05 | 6.4E+05 |
| OPEL | ASTRA+ | 2015 | 1.4B | EURO-6 | 1.8E+06 | 1.4E+06 | 1.1E+06 | 1.3E+06 |
| FORD | C-MAX | 2008 | 1.8B | EURO-4 | 2.0E+06 | 1.8E+06 | 2.0E+06 | 1.9E+06 |

Proposed limits[1]
≤ 2014: $1x10^6$ #/cm³
≥ 2015: $2.5x10^5$ #/cm³

[1] Zuidgeest, Louis. 'Phased Introduction of a Particle Test for DPFs in the Netherlands'. Netherlands: Ministry of Infrastructure and Water Management, Netherlands, 14 March 2019. https://www.vert-dpf.eu/j3/images/pdf/VERT_Forum_2019/NL-Zuidgeest.pdf.

# Preliminary $NO_x$ Acceleration Test Results – Average Values

Initial findings from 14 trial PTI tests. Average $NO_x$ concentrations are calculated from the $NO_x$ acceleration test periods (points 8-10 on slide 11).

| Vehicle Make | Vehicle Model | Year | Engine | Euro Standard | NOx_1 (ppm) | NOx_2 (ppm) | NOx_3 (ppm) | Average of lowest 2 NOx (ppm) |
|---|---|---|---|---|---|---|---|---|
| FORD | S-MAX | 2011 | 2.2D | EURO-5 | 120 | 123 | 108 | 114 |
| MAZDA | 6 | 2013 | 2.2D | EURO-6 | 128 | 271 | 281 | 200 |
| AUDI | A6 | 2012 | 2.0D | EURO-5 | 73 | 103 | 128 | 88 |
| BMW | 520XDRIVE | 2014 | 2.0D | EURO-6 | 114 | 113 | 84 | 99 |
| AUDI | ALLROAD-Q | 2006 | 3.0TDI | EURO-4 | 151 | 133 | 226 | 142 |
| TOYOTA | AVENSIS | 2010 | 2.0D | EURO-5 | 70 | 132 | 166 | 101 |
| MITSUBISHI | OUTLANDER | 2008 | 2.2D | EURO-4 | 78 | 154 | 106 | 92 |
| CITROEN | C5 | 2010 | 2.0D | EURO-4 | 170 | 157 | 252 | 163 |
| FORD | MONDEO | 2011 | 2.0D | EURO-5 | 199 | 253 | 239 | 219 |
| VW | PASSAT | 2012 | 2.0D | EURO-5 | 122 | 159 | 150 | 136 |
| JEEP | WRANGLER | 2012 | 3.6B | EURO-5 | 7 | 19 | 68 | 13 |
| VOLVO | V70 | 2009 | 2.4D | EURO-4 | 445 | 556 | 537 | 491 |
| OPEL | ASTRA+ | 2015 | 1.4B | EURO-6 | 11 | 115 | 232 | 63 |
| FORD | C-MAX | 2008 | 1.8B | EURO-4 | 36 | 20 | 31 | 25 |

# Preliminary $NO_x$ Acceleration Test Results – Peak Values

Initial findings from 14 trial PTI tests. Peak $NO_x$ concentrations are calculated from the $NO_x$ acceleration test periods (points 8-10 on slide 11).

| Vehicle Make | Vehicle Model | Year | Engine | Euro Standard | NOx_1 (ppm) | NOx_2 (ppm) | NOx_3 (ppm) | Average of lowest 2 NOx (ppm) |
|---|---|---|---|---|---|---|---|---|
| FORD | S-MAX | 2011 | 2.2D | EURO-5 | 302 | 303 | 183 | 243 |
| MAZDA | 6 | 2013 | 2.2D | EURO-6 | 406 | 475 | 415 | 411 |
| AUDI | A6 | 2012 | 2.0D | EURO-5 | 133 | 151 | 226 | 142 |
| BMW | 520XDRIVE | 2014 | 2.0D | EURO-6 | 195 | 204 | 186 | 190 |
| AUDI | ALLROAD-Q | 2006 | 3.0TDI | EURO-4 | 409 | 582 | 742 | 496 |
| TOYOTA | AVENSIS | 2010 | 2.0D | EURO-5 | 135 | 452 | 392 | 264 |
| MITSUBISHI | OUTLANDER | 2008 | 2.2D | EURO-4 | 158 | 497 | 187 | 173 |
| CITROEN | C5 | 2010 | 2.0D | EURO-4 | 304 | 356 | 427 | 330 |
| FORD | MONDEO | 2011 | 2.0D | EURO-5 | 410 | 435 | 470 | 423 |
| VW | PASSAT | 2012 | 2.0D | EURO-5 | 232 | 505 | 279 | 256 |
| JEEP | WRANGLER | 2012 | 3.6B | EURO-5 | 21 | 141 | 254 | 81 |
| VOLVO | V70 | 2009 | 2.4D | EURO-4 | 708 | 934 | 821 | 764 |
| OPEL | ASTRA+ | 2015 | 1.4B | EURO-6 | 53 | 731 | 674 | 363 |
| FORD | C-MAX | 2008 | 1.8B | EURO-4 | 182 | 88 | 212 | 135 |

# Preliminary $NO_x$ High Idle Test Results – Average Values

Initial findings from 15 trial PTI tests. Average $NO_x$ concentrations are calculated from the $NO_x$ high idle tests (points 4-6 on slide 11).

| Vehicle Make | Vehicle Model | Year | Engine | Euro Standard | NOx_1 (ppm) | NOx_2 (ppm) | NOx_3 (ppm) | Average of lowest 2 NOx (ppm) |
|---|---|---|---|---|---|---|---|---|
| SUBARU | LEGACY | 2011 | 2.0D | EURO-5 | 167 | 159 | 163 | 161 |
| VW | PASSAT | 2012 | 2.0D | EURO-5 | 87 | 101 | 100 | 93 |
| VOLVO | V70 | 2014 | 2.0D | EURO-6 | 135 | 134 | 136 | 134 |
| VOLVO | XC70 | 2016 | 2.4D | EURO-6 | 165 | 182 | 187 | 174 |
| JEEP | WRANGLER | 2012 | 3.6B | EURO-5 | 7 | 9 | 12 | 8 |
| HYUNDAI | I40 | 2011 | 1.7D | EURO-5 | 255 | 254 | 294 | 254 |
| BMW | 520D | 2013 | 2.0D | EURO-5 | 180 | 163 | 171 | 167 |
| KIA | SPORTAGE | 2016 | 1.7D | EURO-6 | 228 | 216 | 224 | 220 |
| FORD | KUGA | 2012 | 2.0D | EURO-5 | 142 | 142 | 141 | 142 |
| VOLVO | V70 | 2009 | 2.4D | EURO-4 | 227 | 235 | 243 | 231 |
| HONDA | CRV | 2014 | 1.6D | EURO-5 | 312 | 245 | 269 | 257 |
| OPEL | ASTRA+ | 2015 | 1.4B | EURO-6 | 2 | 5 | 5 | 4 |
| KIA | SPORTAGE | 2012 | 1.7D | EURO-5-2 | 113 | 101 | 114 | 107 |
| VOLKSWAGEN | PASSAT | 2011 | 2.0TDI | EURO-5 | 65 | 64 | 71 | 65 |
| FORD | C-MAX | 2008 | 1.8B | EURO-4 | 13 | 25 | 16 | 15 |