PEMS Updates: Ultra-low NOx and NH_3 Measurements

2025 OSAR Conference

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Outline

SEMTECH NOx Updates

- Analyzer updates for ultra-low measurements
- On-road ultra-low NOx PEMS measurements compared to CCERT's Mobile Emissions Laboratory

SEMTECH NH_3 Introduction

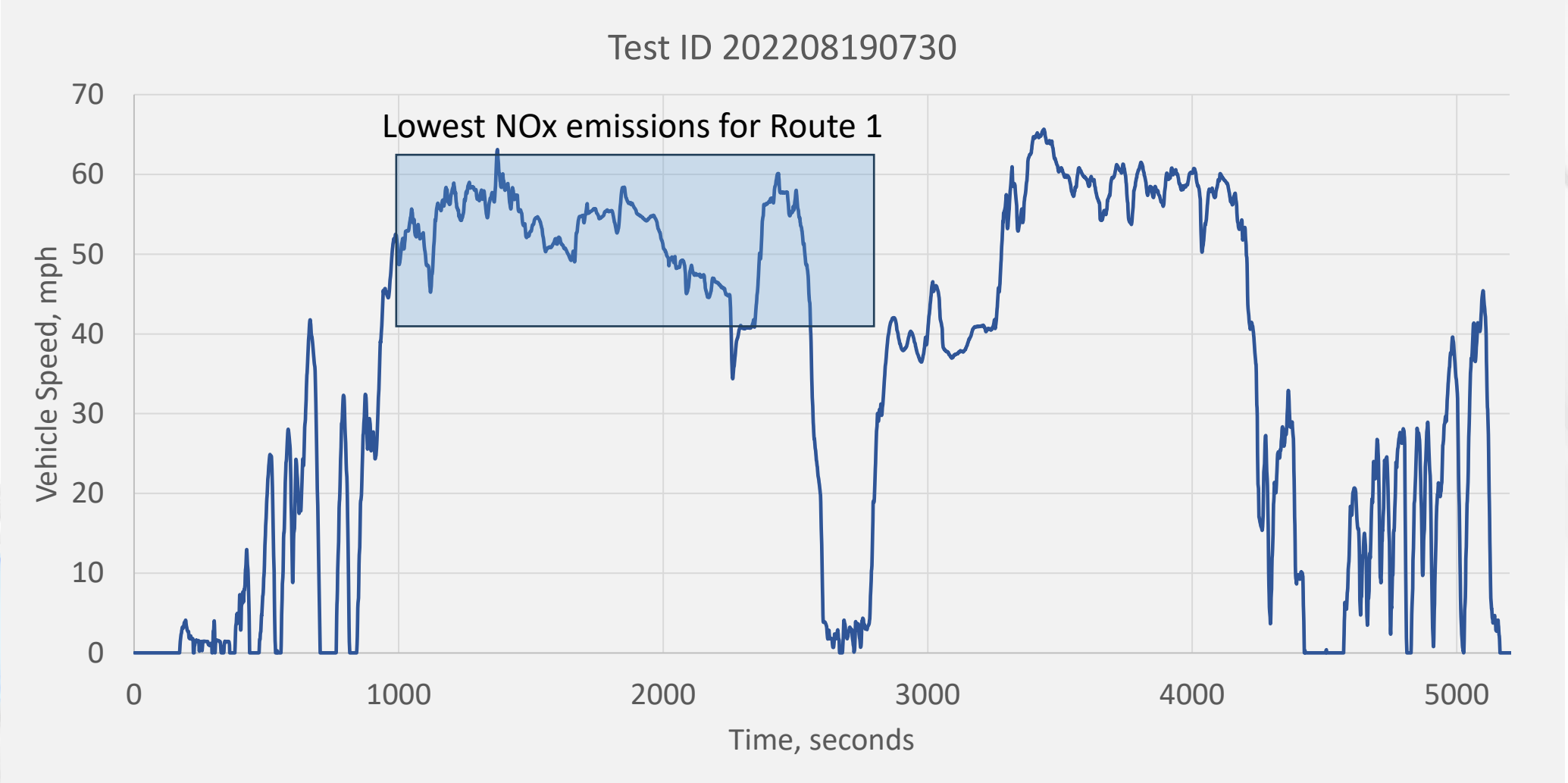
- Background on NH_3 formation and environmental effects
- SEMTECH NH_3 Analyzer introduction
- NH_3 measurements on passenger cars by CCERT
- Concluding remarks

Evaluation of Real-World of Ultra-Low NOx Measurements

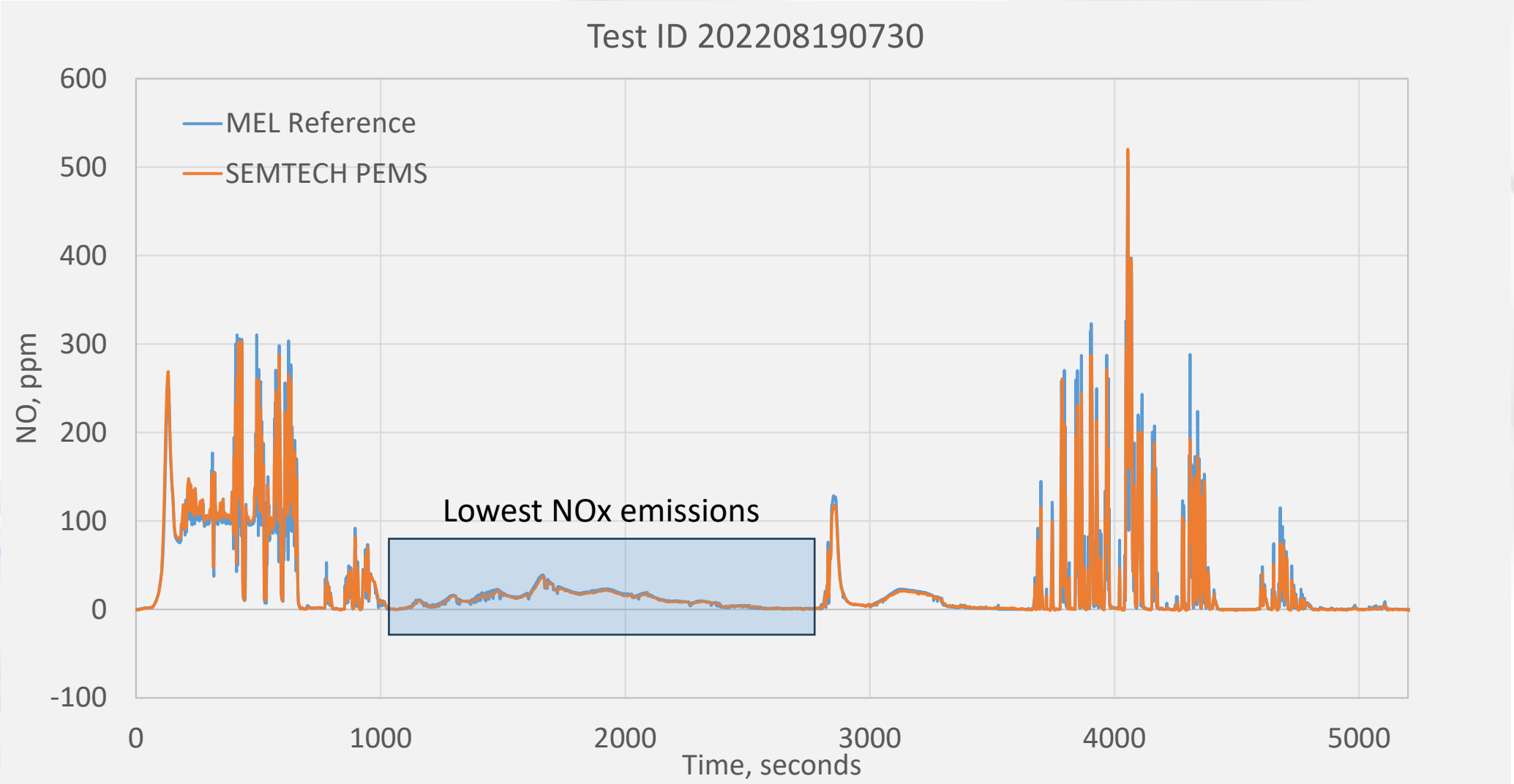
Comparison to CCERT's Mobile Emissions Laboratory

- The Measurement Allowance study included 2022 PEMS testing by CCERT using their Mobile Emissions Laboratory (MEL) as a Reference
  - MEL uses chemiluminescent analyzer for NO (raw and dilute)
  - MEL uses 2nd chemiluminescent analyzer for NOx, and NO_2 by subtraction – may not reliable enough to be a reference
- Test engine emitted at 0.15 g/bhp-hr, however there are segments of low NOx emission of 0.05 g/bhp-hr per CCERT report
- This study assesses the accuracy of measurements in these low emitting regions

On-Road Test Cycle - speed



SEMTECH PEMS compared to UCR's MEL



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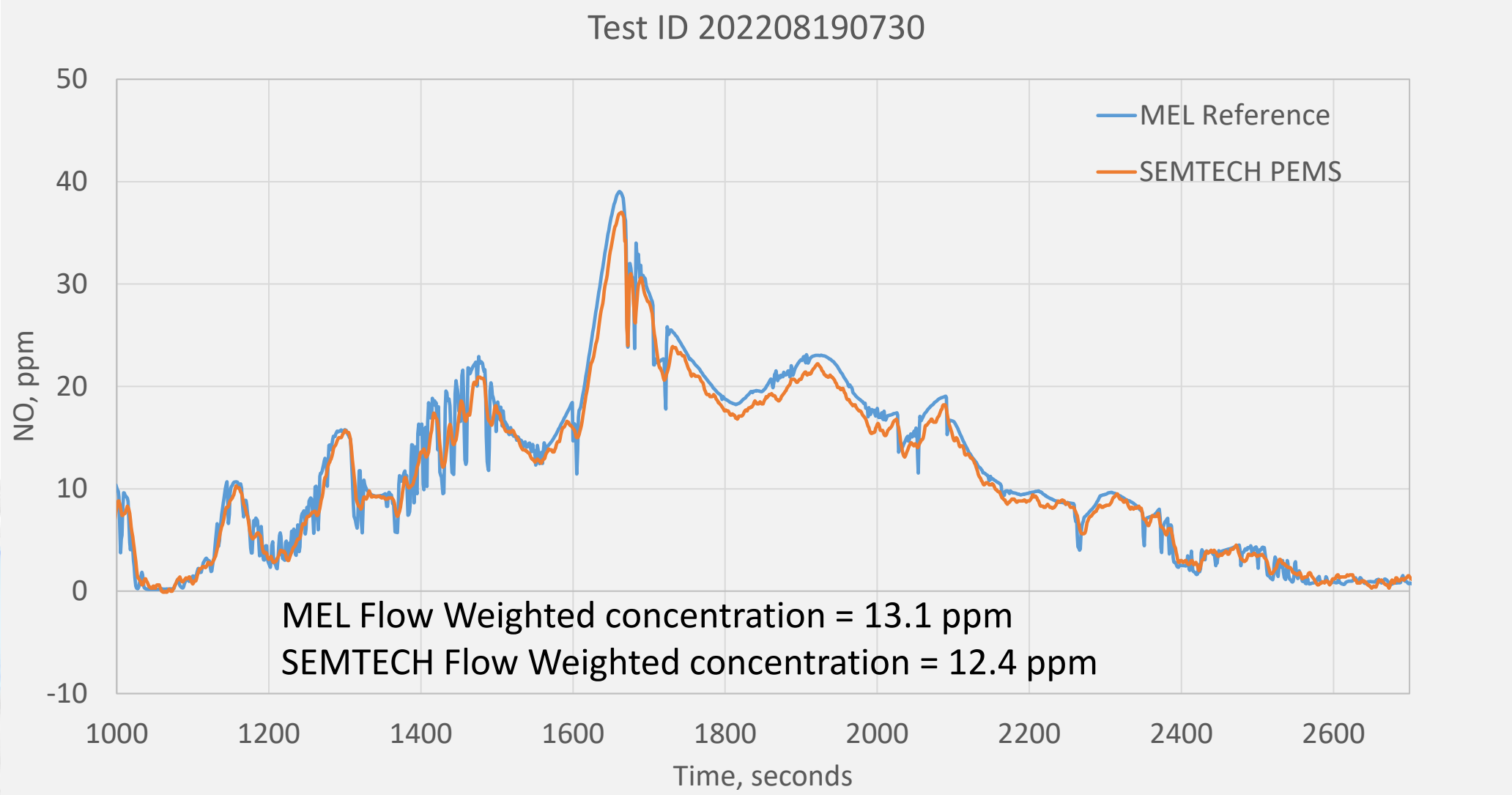

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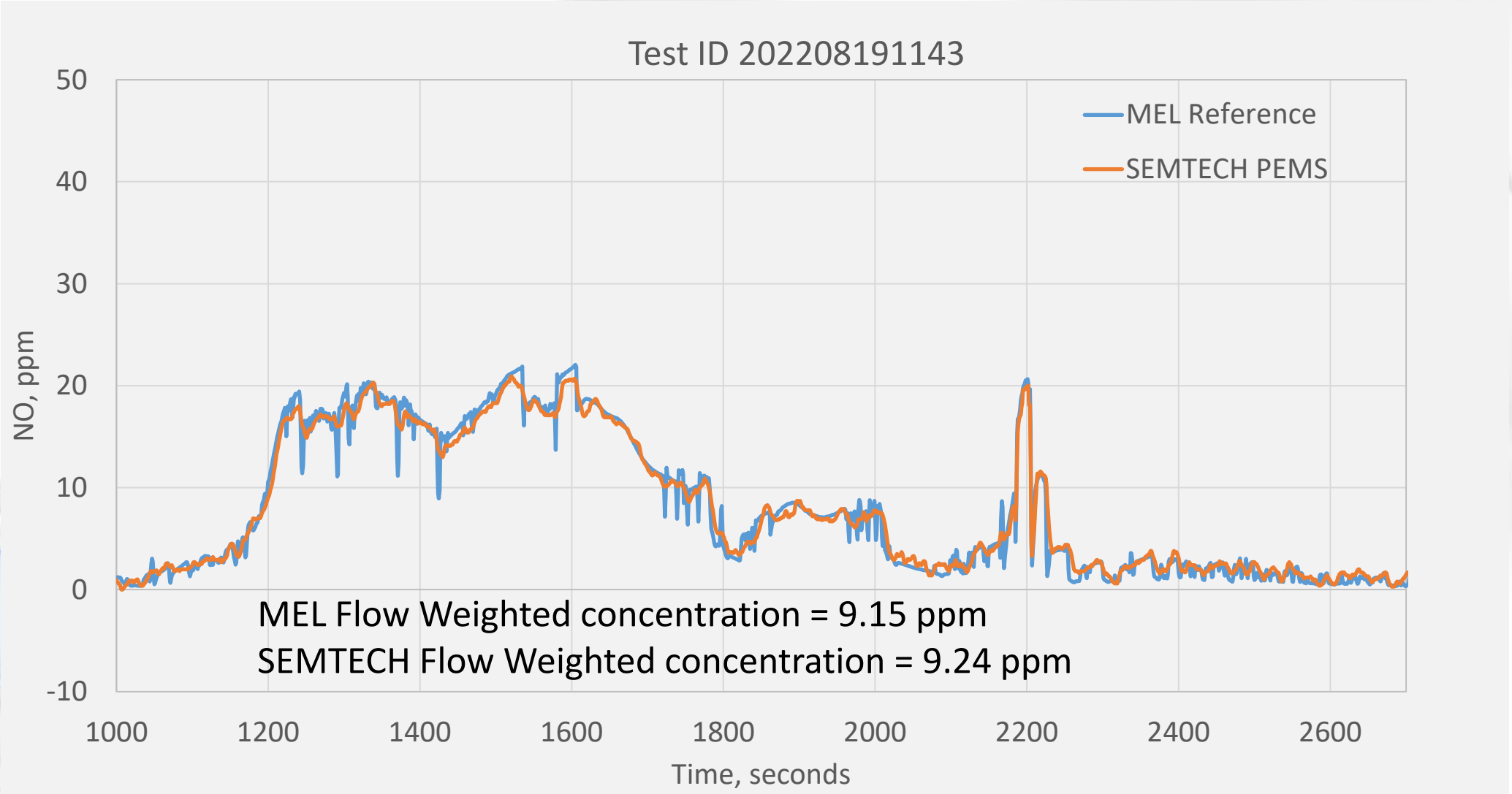

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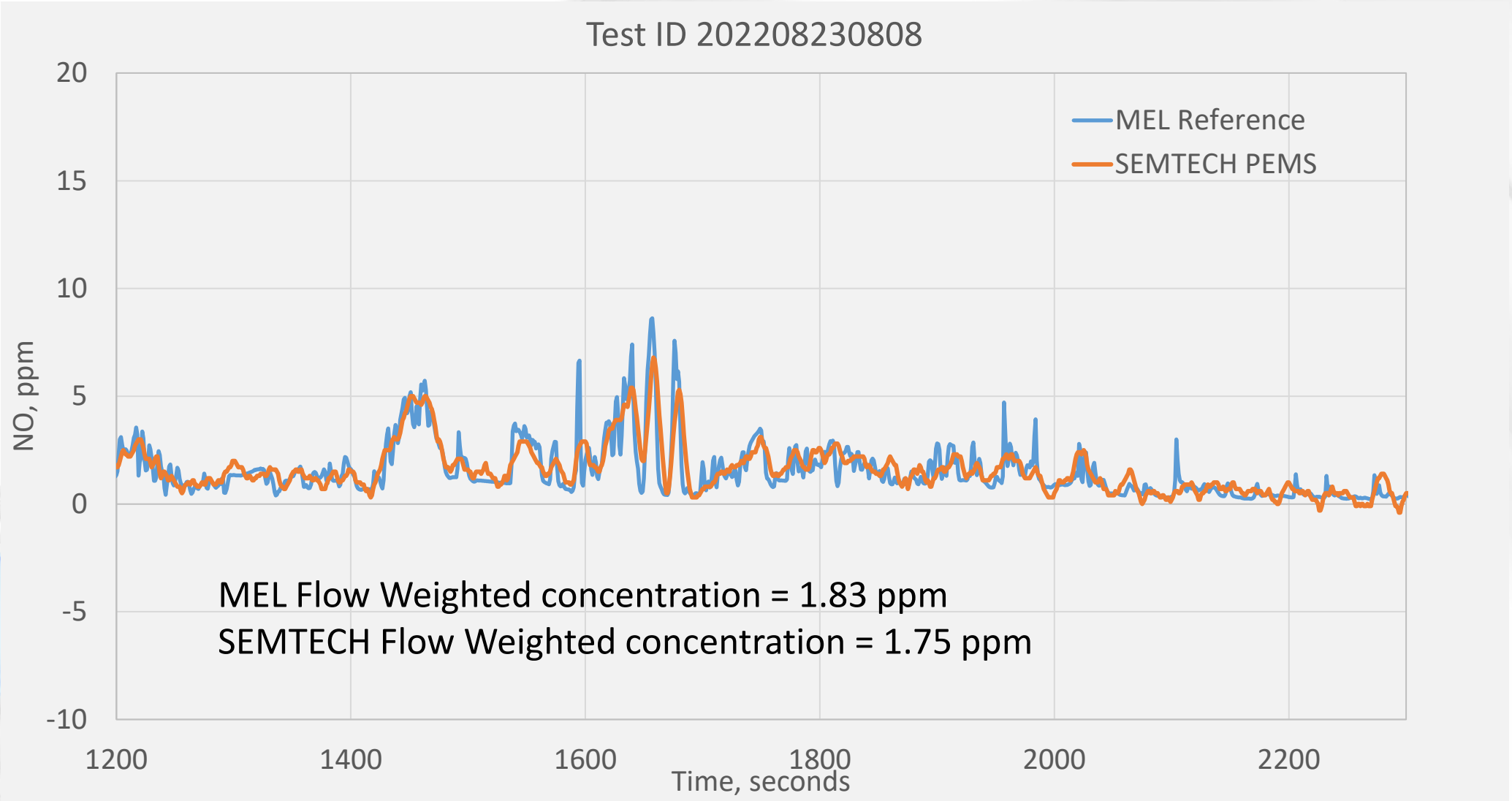


SEMTECH PEMS compared to UCR's MEL

Flow weighted Average NO Concentrations

Route	Test ID	segment	PEMS ppm	MEL ppm	Delta ppm
1	202208190730	1000 to 2700 sec	12.4	13.1	-0.7
1	202208190930	1000 to 2200 sec	10.2	10.8	-0.6
2	202208191143	1000 to 2700 sec	9.15	9.24	-0.1
2	202208191408	1400 to 3700 sec	6.38	6.33	0.1
3	202208220806	1500 to 2550 sec	2.98	3.18	-0.2
3	202208221020	4000 to 5400 sec	0.96	1.26	-0.3
4	202208221241	1000 to 2300 sec	5.31	5.21	0.1
4	202208230808	1200 to 2300 sec	1.83	1.75	0.1
				Ave	-0.20
				Std dev	0.30

Ultra-low NOx Conclusions and Recommendations

- Current technology SEMTECH NO measurements compare within 1 ppm flow-weighted average to the CCERT MEL laboratory reference during low concentration segments on all tests
- Sufficient to measure NOx at 2027 CARB standard
- CCERT report comes to same conclusion based on mass emissions analysis

SEMTECH® NH_3 Introduction

Background: NH_3 Environmental and Health Effects

- NH_3 reacts with nitric acid and sulfuric acid in the atmosphere to create secondary aerosols

  $NH_3 + HNO_3 \rightarrow NH_4NO_3$ (ammonium nitrate)

  $NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$ (ammonium sulfate)

- These are major contributors to $PM_{2.5}$ which are linked to cardiovascular and respiratory diseases
- Most atmospheric NH_3 comes from agricultural products, but NH_3 from vehicle emissions is believed to be under-reported

Background: Formation of NH_3 in Automotive Exhaust

- NH_3 is formed in aftertreatment systems, post-combustion:
  - Selective catalytic reduction (SCR) systems in diesel engines
  - Three-way catalysts (TWC) in gasoline vehicles

- In Gasoline vehicles, NH_3 is formed when H_2 is present in the exhaust by reacting with NO:

$$NO + 5H_2 \rightarrow 2NH_3 + 2H_2O$$

Why and when is there H_2 present in the exhaust of gasoline vehicles?

Formation of NH_3 in Automotive Exhaust

- H_2 is formed in the TWC when CO is present under two modes:

1. CO combines with hydroxyl radicals at the catalyst surface at low temperatures

$$2OH + 2CO \rightarrow 2CO_2 + H_2$$

2. CO combines with H_2O at high temperatures

$$CO + H_2O \rightarrow CO_2 + H_2$$

And how and when is CO formed?

Formation of NH_3 in Automotive Exhaust

- CO is readily formed as a byproduct of fuel-rich combustion
  - Insufficient O_2 to oxidize the fuel to CO_2
  - Occurs during hard accelerations (open-loop / uncontrolled AFR)
- Cold start events
- Aged catalysts

Therefore, we would expect all of these conditions to also increase NH_3 emissions by way of the described reactions.

SEMTECH® NH_3 Module

- Tunable diode laser (TDL) technology
- Accurate at high and low concentrations
- Minimal NH3 loss and fast response time
- Minimal cross-interference with other gases
- Low noise and low analyzer drift

- Stand-alone operation or add to your SEMTECH® PEMs system
- Euro 7 ready

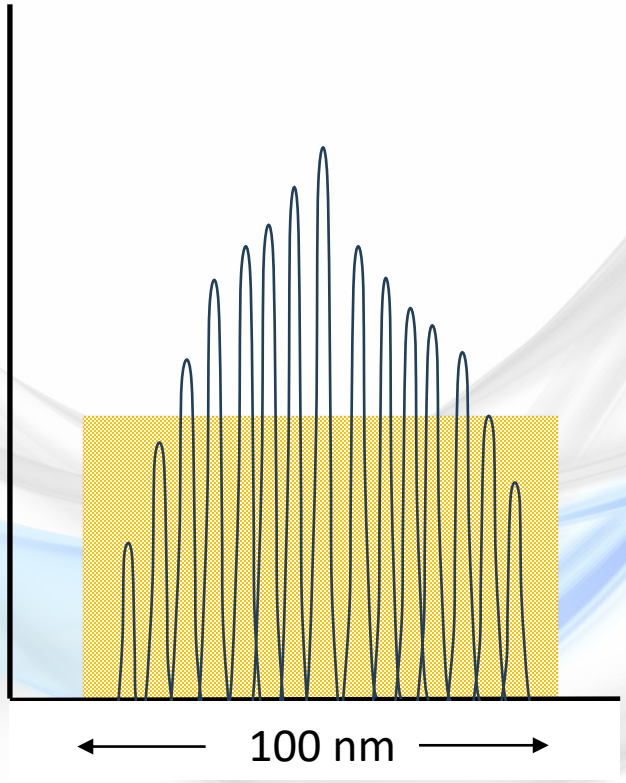
SEMTECH® NH_3 Module

Specifications

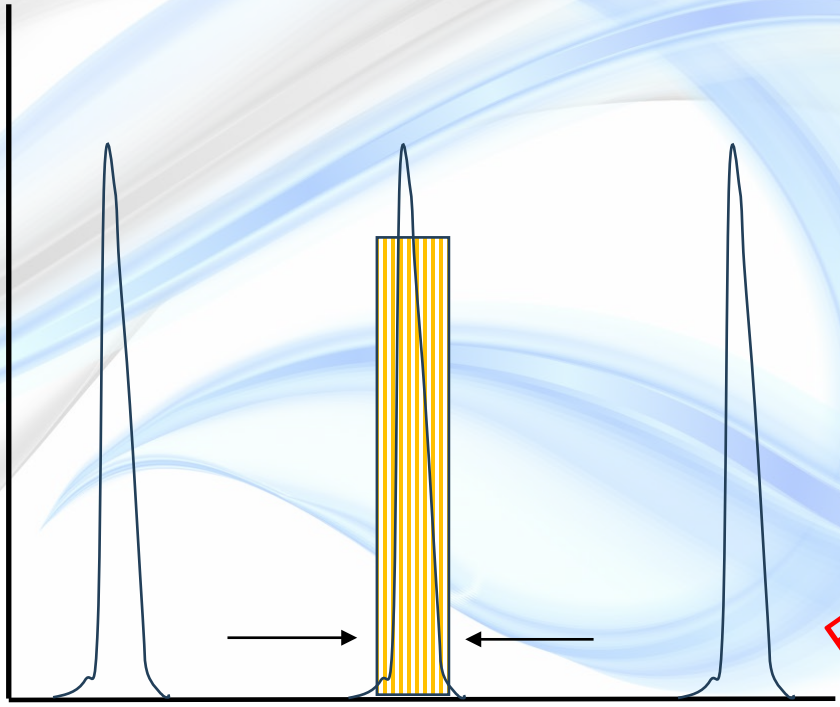
Operating environment	-10 to 45 °C ambient
Dimensions (WxDxH)	43.7 x 31.2 x 13.5 cm 17.2 x 12.3 x 5.3 in.
Weight	9.3 kg 20.5 lbs
Max Range (Full Scale / Max)	0 to 1000 ppm
Resolution	0.1 ppm
Linearity	$\lvert x_{min} \times (a1 - 1) + a0 \rvert \leq$ 0.5% of span
	Slope a1 0.99 - 1.01
	Standard Error of Estimates (SEE) ≤ 1% of span
	Coefficient of Determination r2 ≥ 0.998
Accuracy	≤ ± 2% of reading or ≤ ± 0.3% of full scale, whichever is larger
Noise	≤ 1 ppm
Zero Drift (over 4 hrs)	≤ 2 ppm using purified N2 as zero gas
Span Drift (over 4 hrs)	≤ 2% of reading or ≤ 2 ppm, whichever is greater
Data Rate	1 Hz
Sample Flow Rate (nominal)	5 l/min

Tunable Diode Laser Spectroscopy

- A TDL can emit across very narrow bands, thousands of times per second
- Can characterize individual absorption lines, avoiding interfering gases



Typical NDIR band Pass Filter width

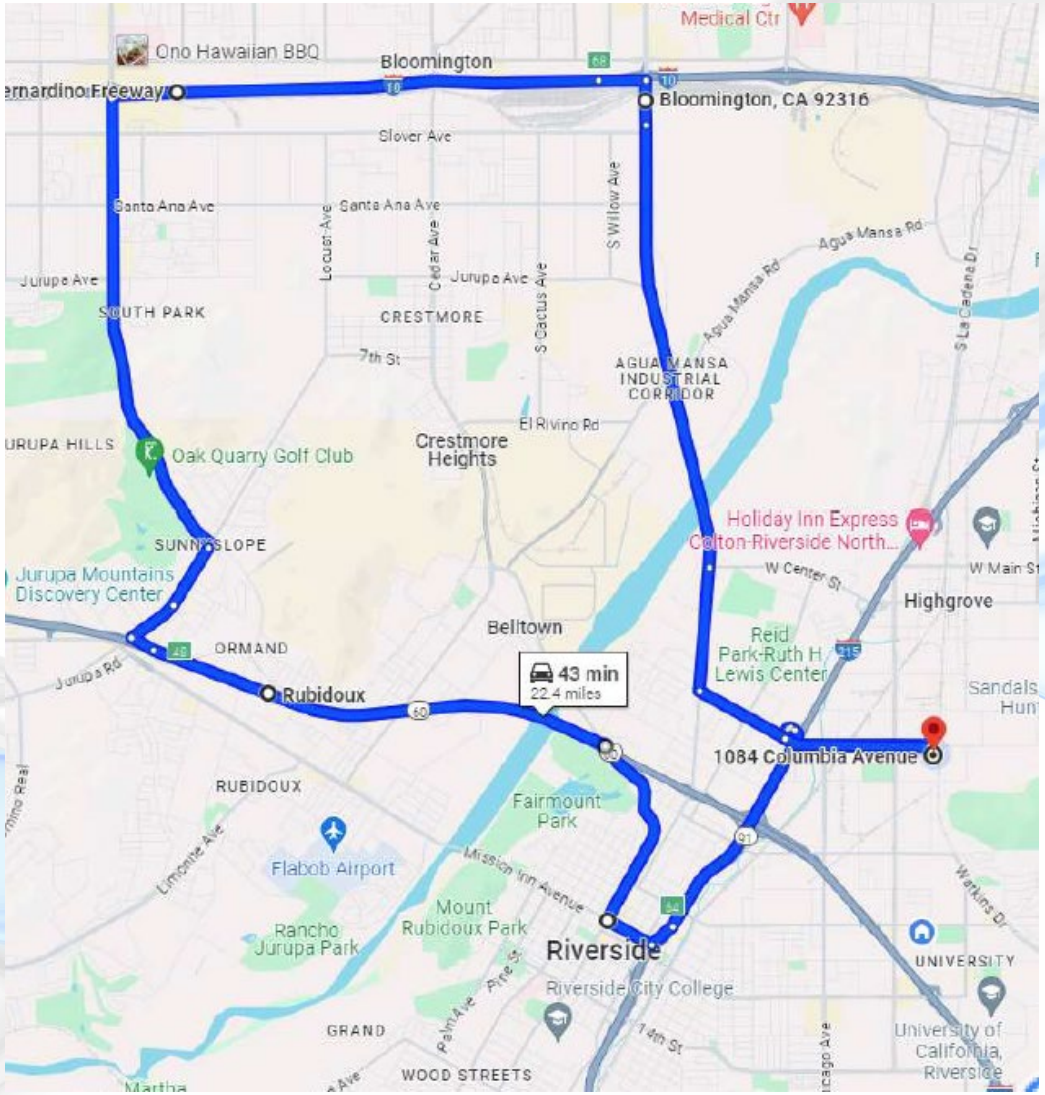


.002 nm wide laser scans a bandwidth of .05 nm
to characterize an individual absorption peak

CCERT Study: 5 Vehicles Tested with SEMTEH NH_3

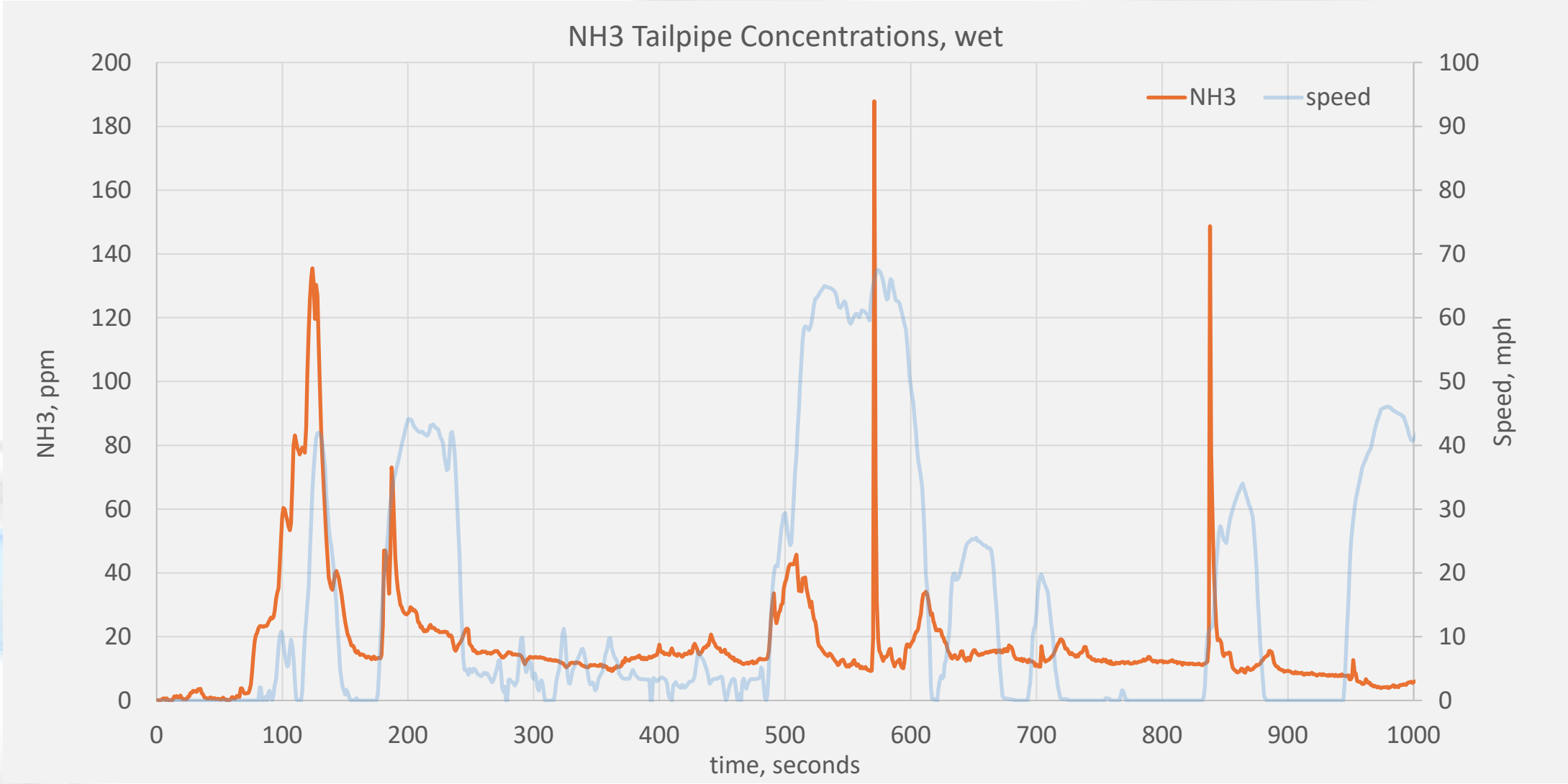
Test Date	Model Year	Make	Model	Milage
02/18/2025	2021	Hyundai	Sonata	45354
02/25/2025	2024	Mazda	CX-30	3830
03/11/2025	2024	BMW	X3	11354
03/12/2025	2012	Toyota	Corolla	79064
03/12/2025	2021	Audi	SQ5	83814

Test Route



- Start/End at UCR/CCERT
- Cold start measured for each vehicle
- Includes highway and urban driving

‘24 Mazda, 3800 miles



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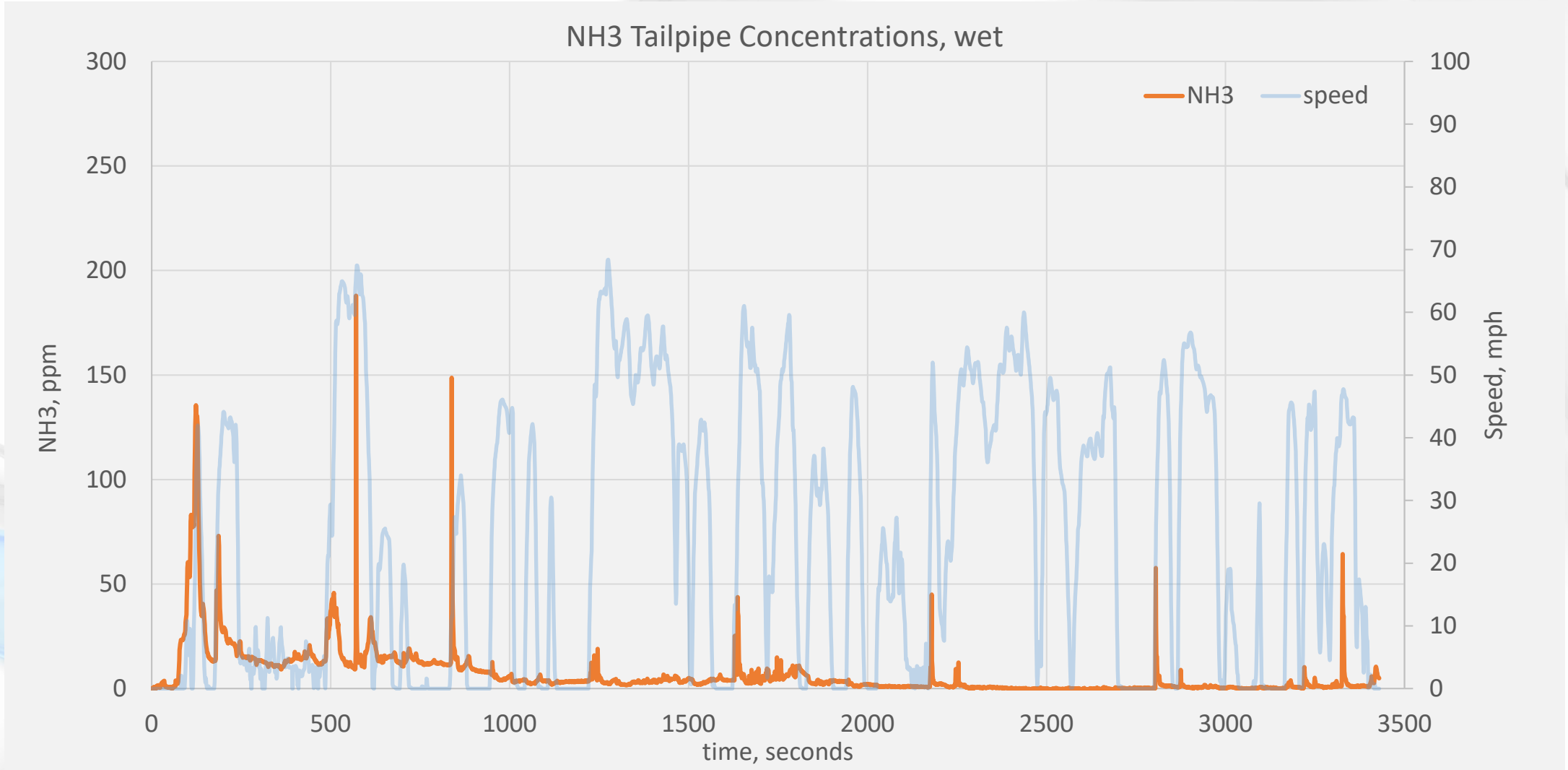
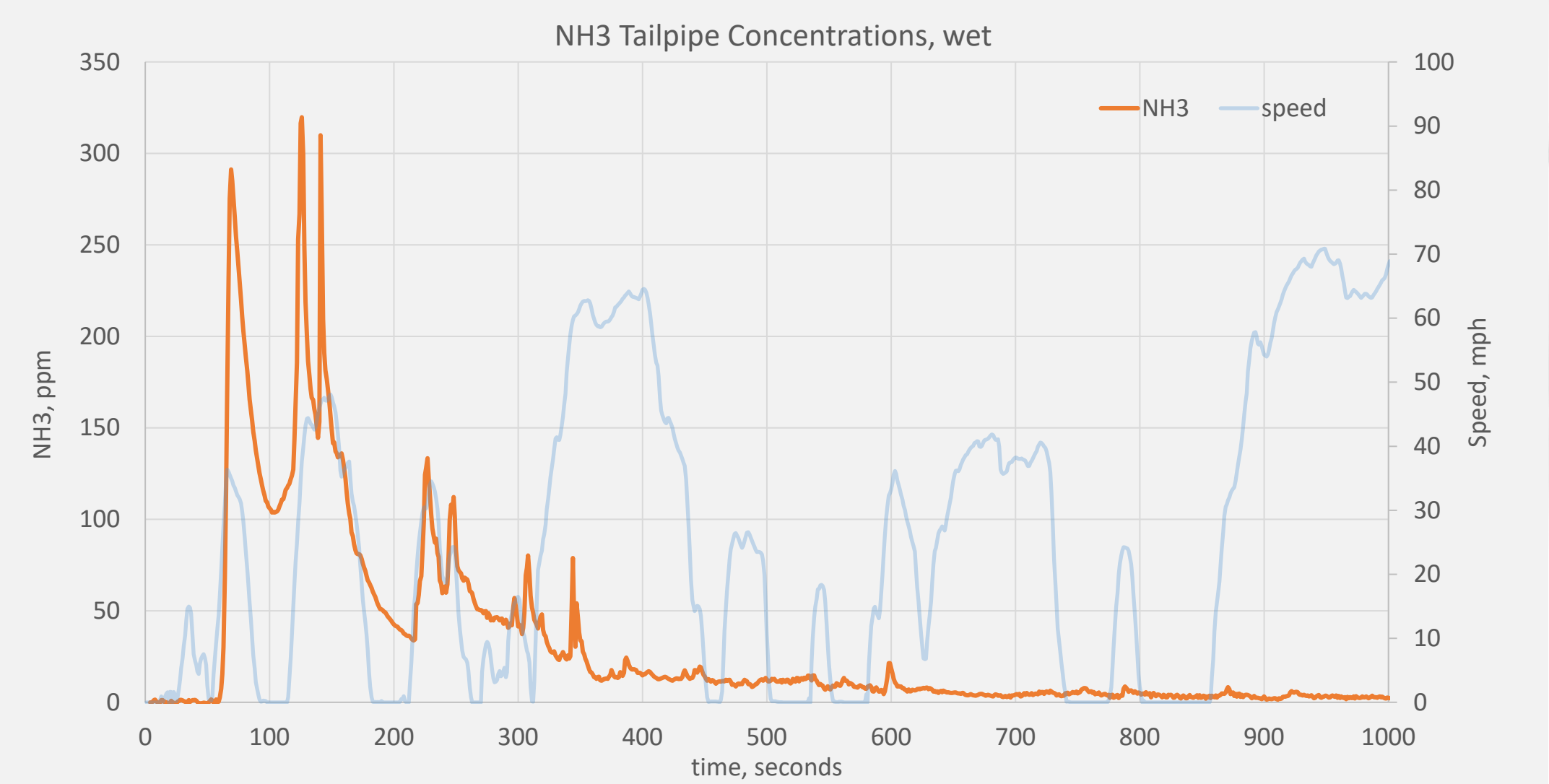


’12 Toyota Corolla, 79K miles



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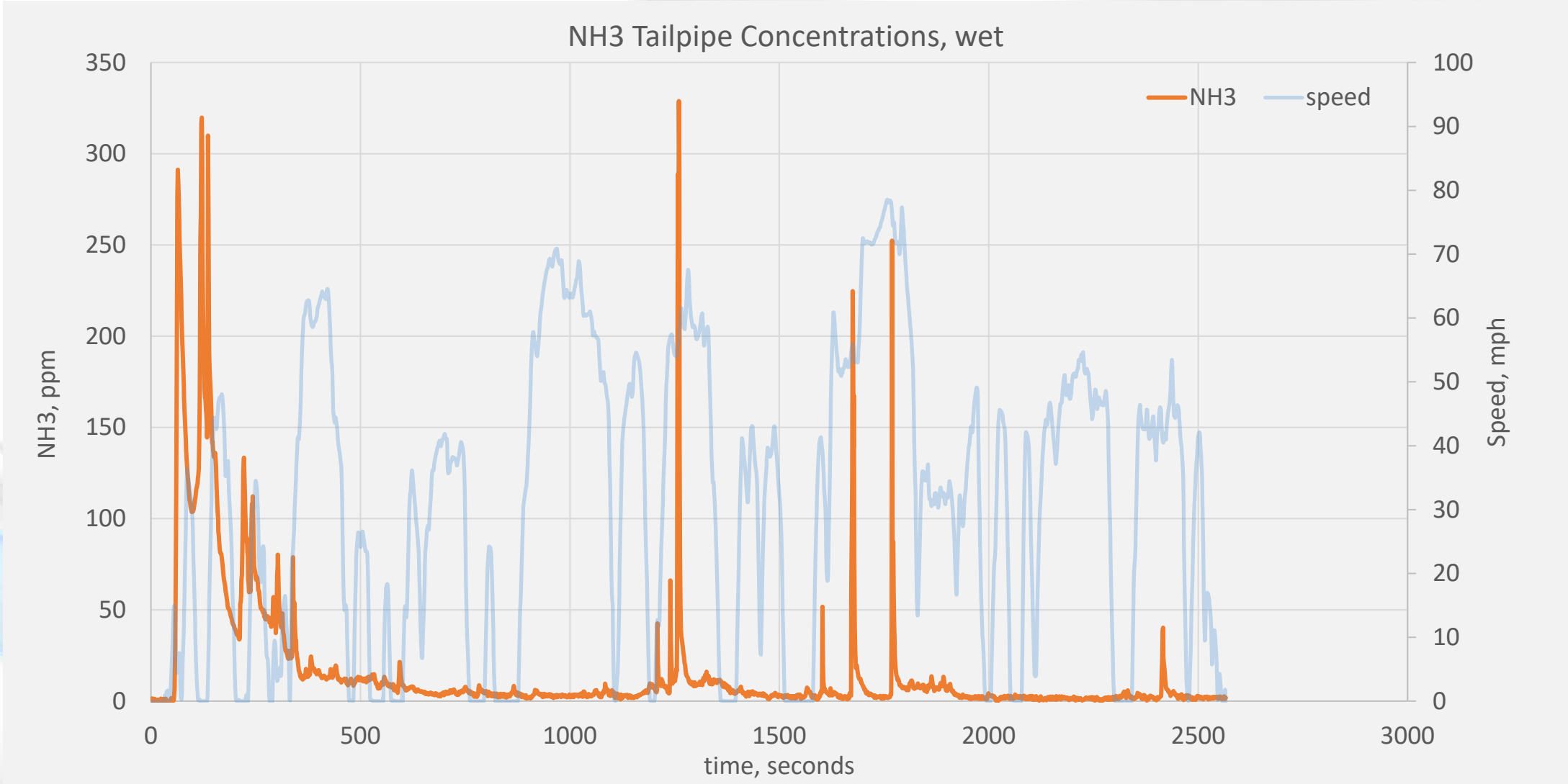

General Observations for the Vehicle Tests

- Cold start events produce the highest average concentrations of NH_3
  - ranges from 8 – 90 ppm for the first 5 minutes of driving for the 5 vehicles
- Trip average NH_3 ranged from 7 – 17 ppm for the 5 vehicles
- Peak values ranged from 79 – 470 ppm for the 5 vehicles
- Largest peaks are associated with acceleration events

Results Summary

Vehicle	Milage	Trip Peak NH3, ppm	Trip Ave NH3, ppm	Cold Start Ave NH3, ppm
'24 Mazda	3800	188	6.9	27
'24 BMW	11,300	92	3.3	10.6
'21 Hyundai	45,300	470	14.2	46.1
'12 Toyota	79,100	329	16.7	89.7
'21 Audi	83,800	79	6.6	8.0

Initial Conclusions and Recommendations

- Significant levels of NH_3 can occur intermittently on both high mileage and newer low milage vehicles
- Observations are consistent with the premise that NH_3 is formed during:
  - Inefficient catalyst operation (e.g. cold starts)
  - Fuel-rich conditions that can occur during acceleration events.

Recommendation for further testing:

- Combine NH_3 analyzer with other PEMS equipment to measure CO concentrations
- Expect strong correlation between CO spikes and NH_3 spikes

THANK YOU

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