

Low-Cost Sensor Validation for Vehicle Emissions Measurement

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Motivation for the project

Growing environmental concern

Road transport remains a major source

Regulations and targets

Reference-grade sensors and limitations

Opportunity of low-cost sensors

- Air quality (AQ) has been a growing focus point since the late 20th century with the emergence of acid rain.
- Vehicle emissions have been linked to acid rain, poor air quality, and serious health impacts.
- WHO and EU have set ambitious AQ and zero-pollution targets through legislations such as Euro standards.
- Accurate emissions data from reference-grade sensors is critical for these goals – but also expensive and complex.
- Advances in micro-sensor technology enable dense monitoring for a low cost.

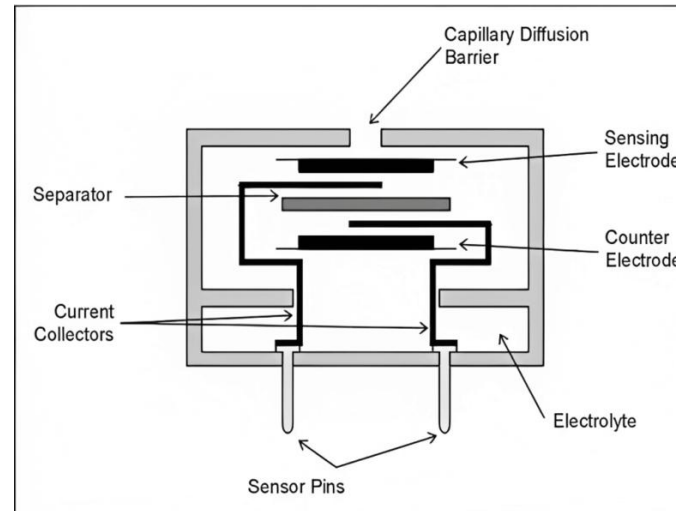


What is an LCS?

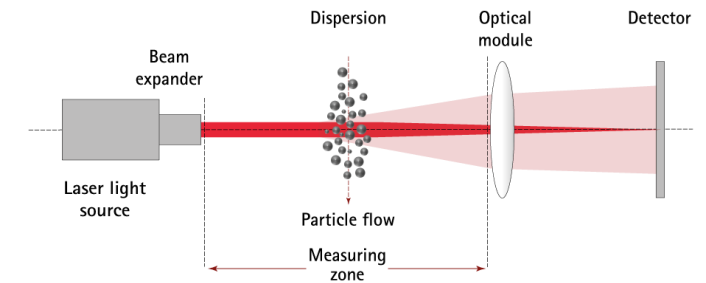
- Low-Cost Sensor
- Affordable alternative
- Monitor emissions and pollution
- Multiple different sensing technologies

Trade-offs:

- Lower accuracy
- Lower life expectancy
- Cross-sensitivity



Electrochemical

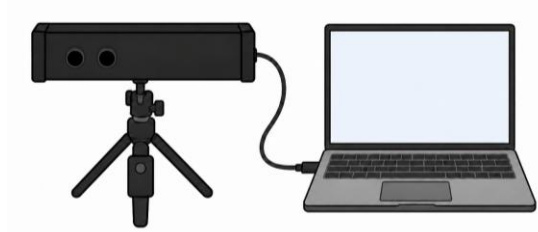


Optical

Aims and Objectives

AIM 1

Develop and validate an LCS



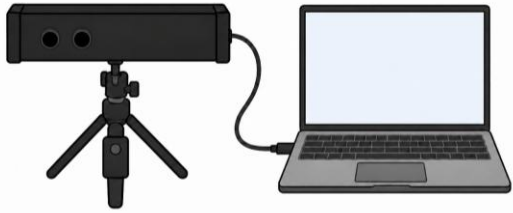
Design and develop an LCS for vehicle emissions measurement.

Assess via testing if the in-house low-cost sensor can capture trends similarly to existing data and reference-grade sensors.

Aims and Objectives

AIM 1

Develop and validate an LCS

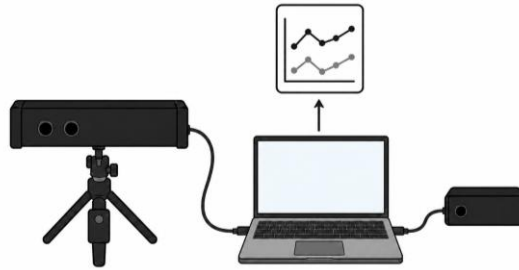


Design and develop an LCS for vehicle emissions measurement.

Assess via testing if the in-house low-cost sensor can capture trends similarly to existing data and reference-grade sensors.

AIM 2

Benchmark the LCS



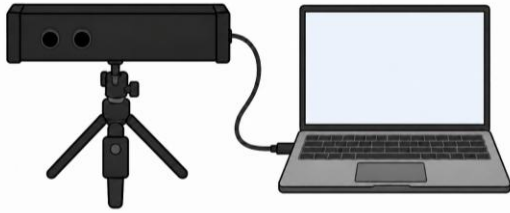
Benchmark the LCS measurements against an alternative LCS to understand agreements and deviations.

Evaluate the differences and understand why they occurred.

Aims and Objectives

AIM 1

Develop and validate an LCS

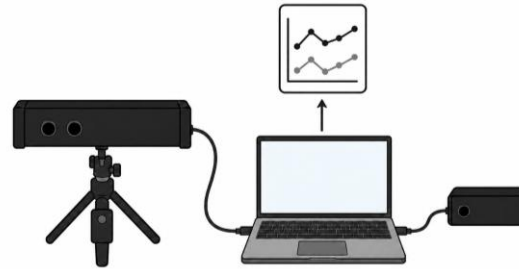


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Benchmark the LCS

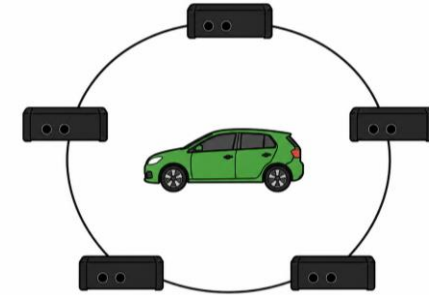


Benchmark the LCS measurements against an alternative LCS to understand agreements and deviations.

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AIM 3

Evaluate LCS suitability



Determine whether the compact and simplified LCS design can justify its implementation in a dense monitoring network.

Testing Methodology

Two test approaches were used to evaluate LCS performance under controlled and real-world conditions:

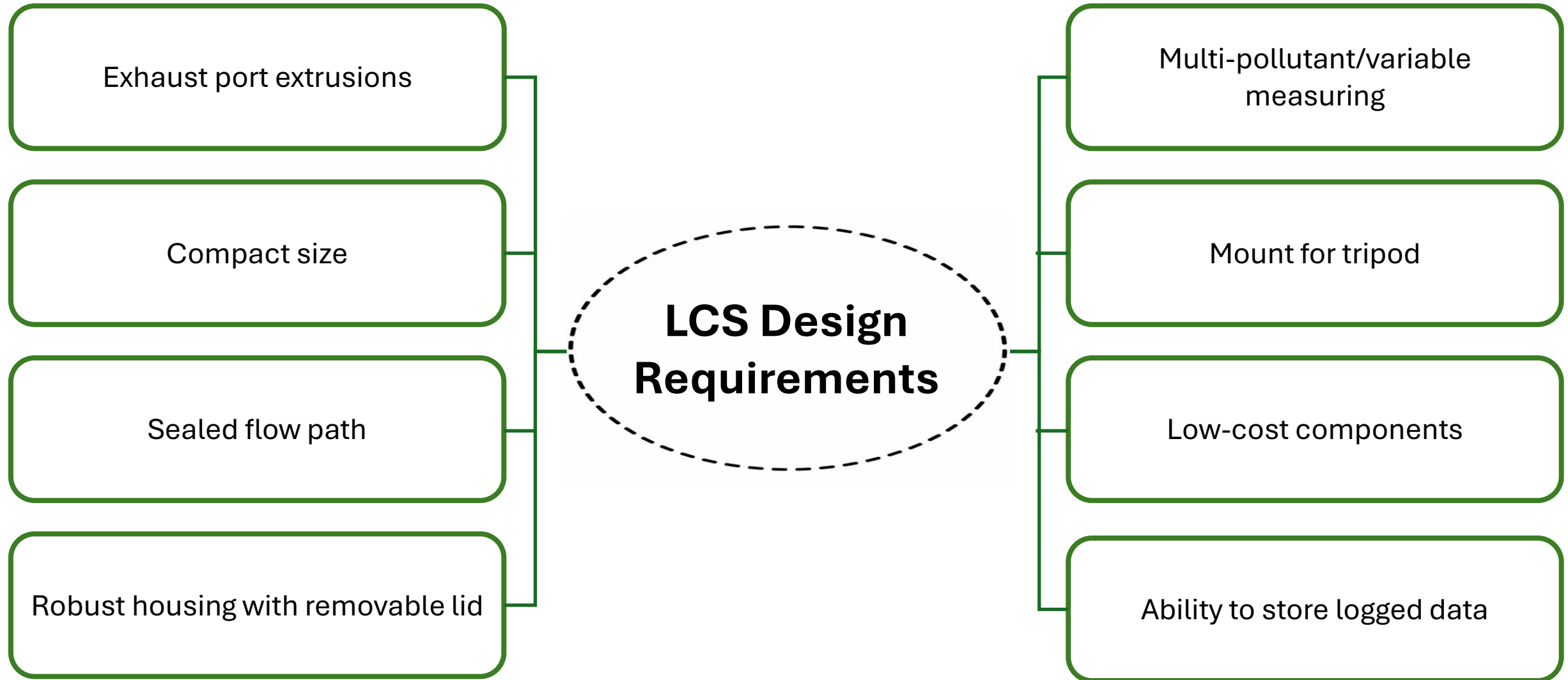
Testing Methodology

Two test approaches were used to evaluate LCS performance under controlled and real-world conditions:

Dynamometer Testing

Static Vehicle Testing

LCS Design Requirements



LCS Design and Component Selection

Sensirion SEN66



- Multi-pollutant sensing module.
- PM_{1.0} – PM₁₀, CO₂, relative humidity (RH), temperature.
- Internal fan for fixed flow rate.

Sensirion SensorBridge



- Communication interface module for SEN66.
- Enables data transfer to host unit.
- Designed for 'plug and play'.

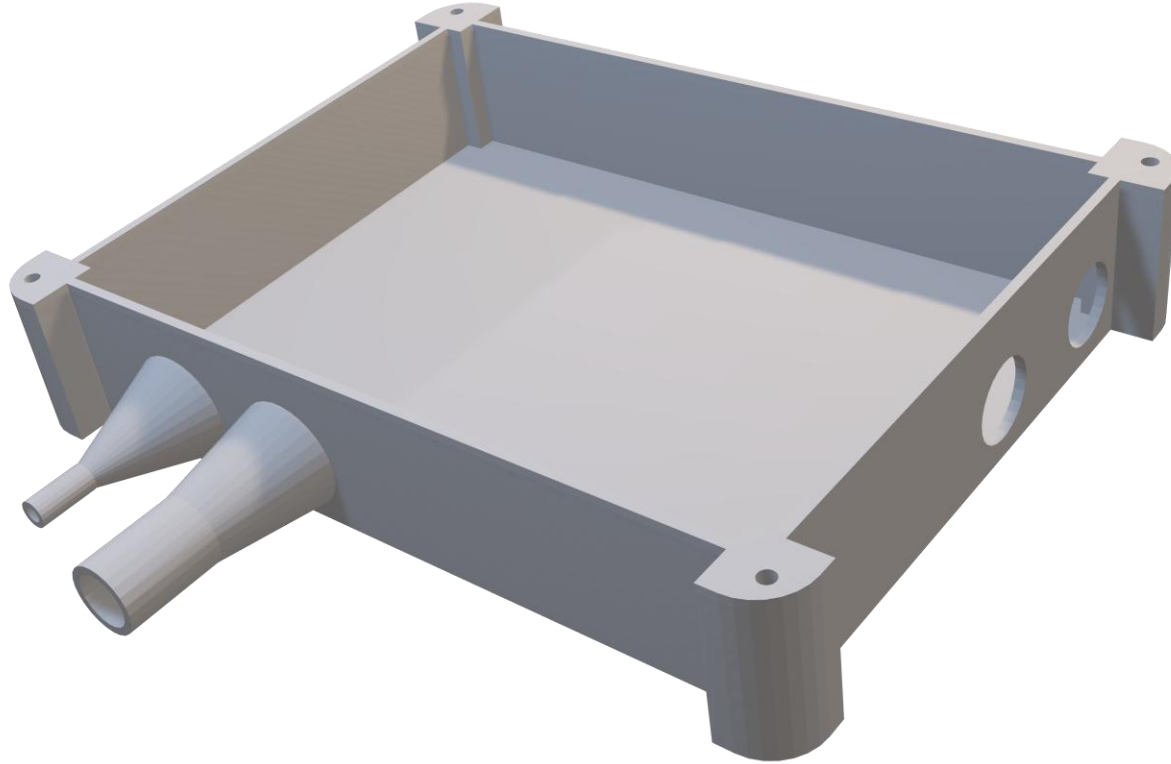
TOTAL COST: £120 inc. VAT

LCS Design and Component Selection

Sensirion SEN66



Sensirion SensorBridge

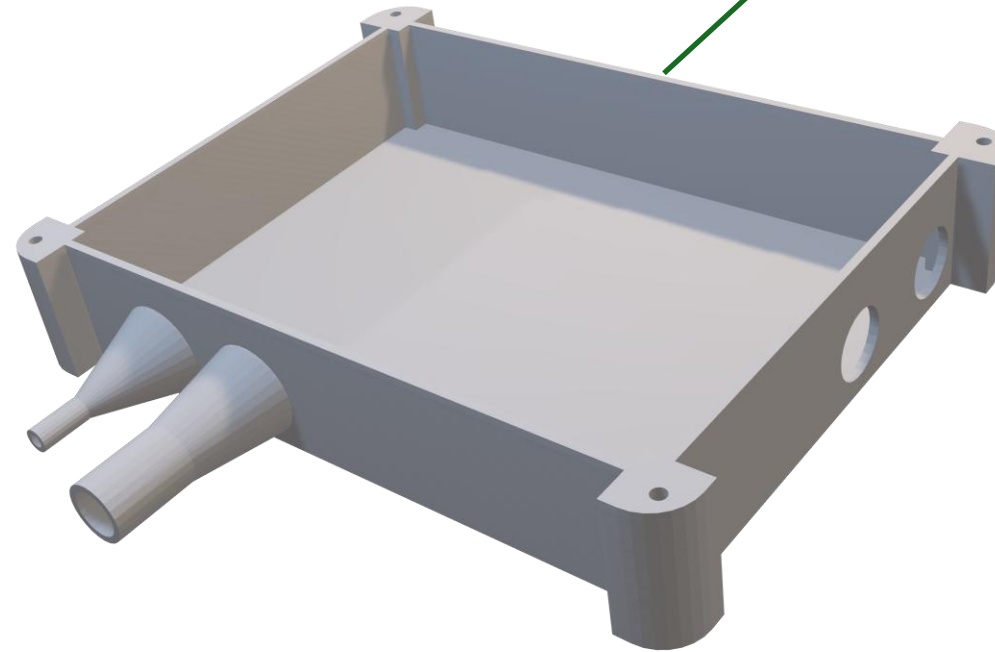


LCS Design and Component Selection

Sensirion SEN66



Sensirion SensorBridge



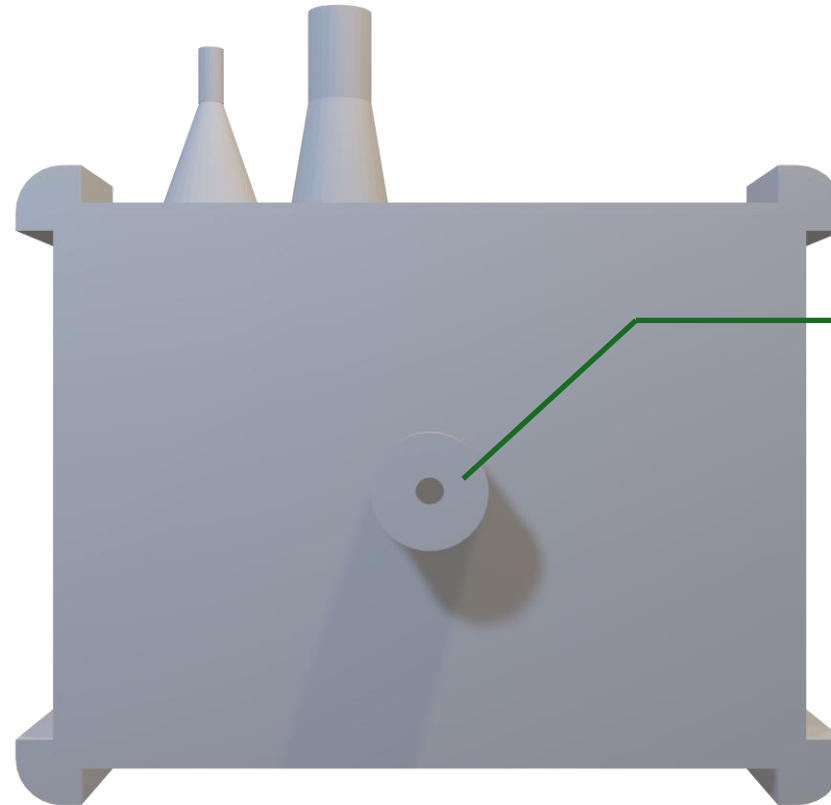
2.5mm thick PLA plastic 3D-printed casing.

LCS Design and Component Selection

Sensirion SEN66



Sensirion SensorBridge



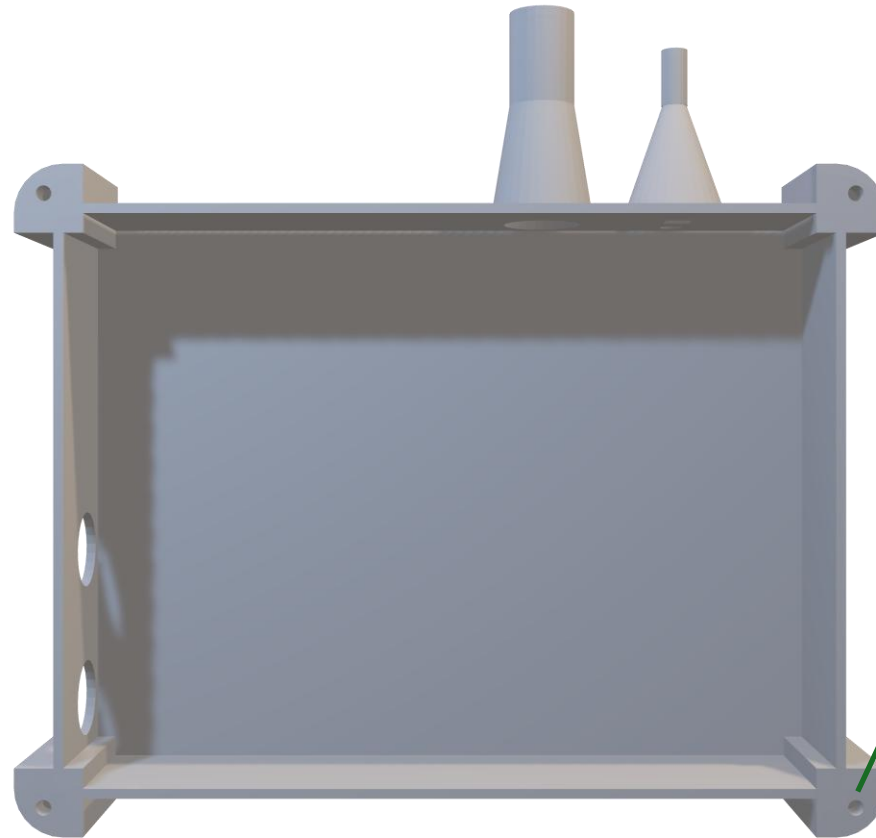
Sturdy mounting location for tripod with cutout for fitting.

LCS Design and Component Selection

Sensirion SEN66



Sensirion SensorBridge



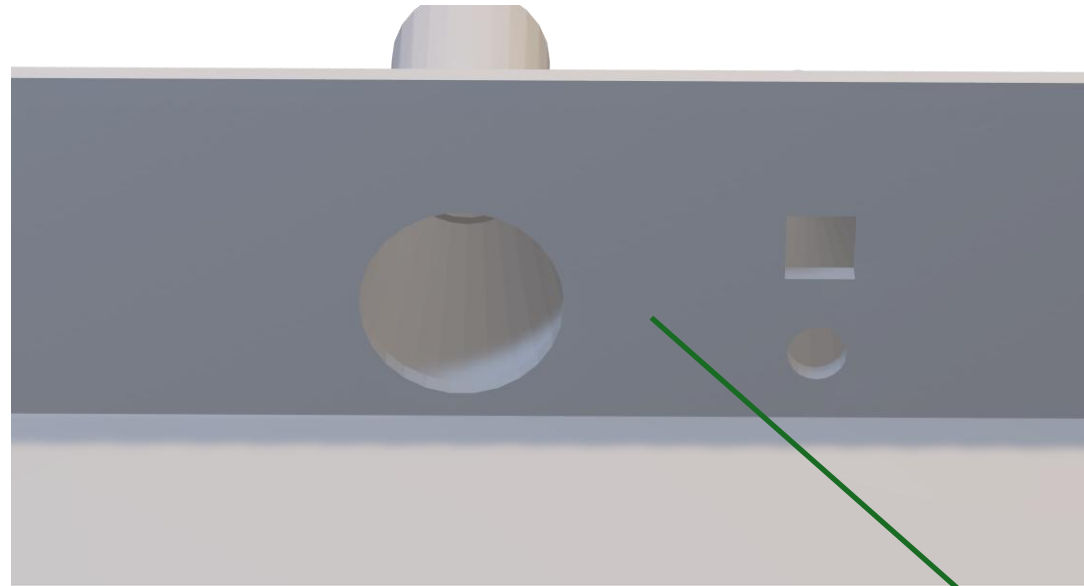
Fittings for lid attachment
and removal.

LCS Design and Component Selection

Sensirion SEN66



Sensirion SensorBridge



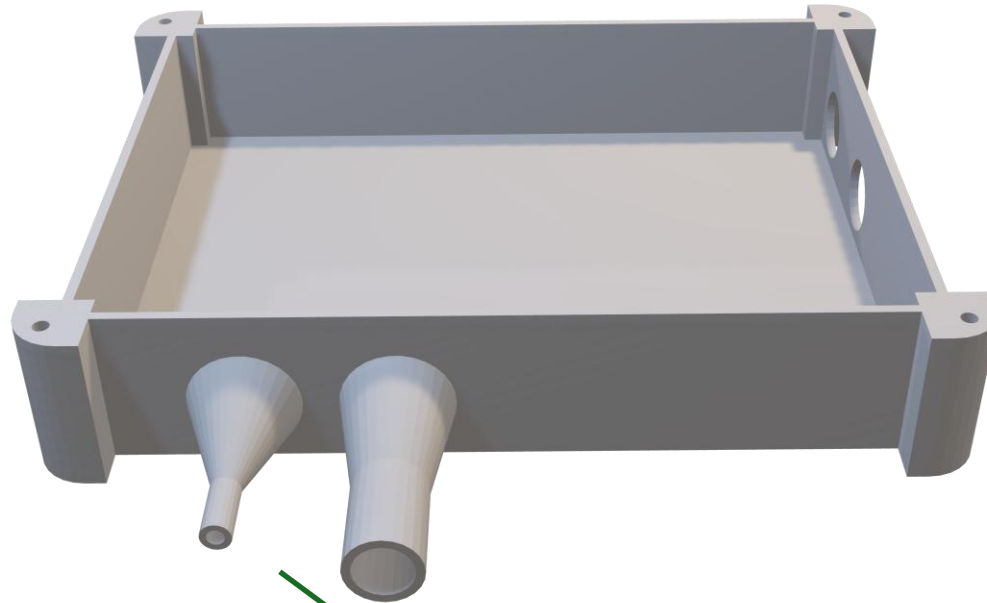
Holes to align sensor inlet
and outlet.

LCS Design and Component Selection

Sensirion SEN66



Sensirion SensorBridge



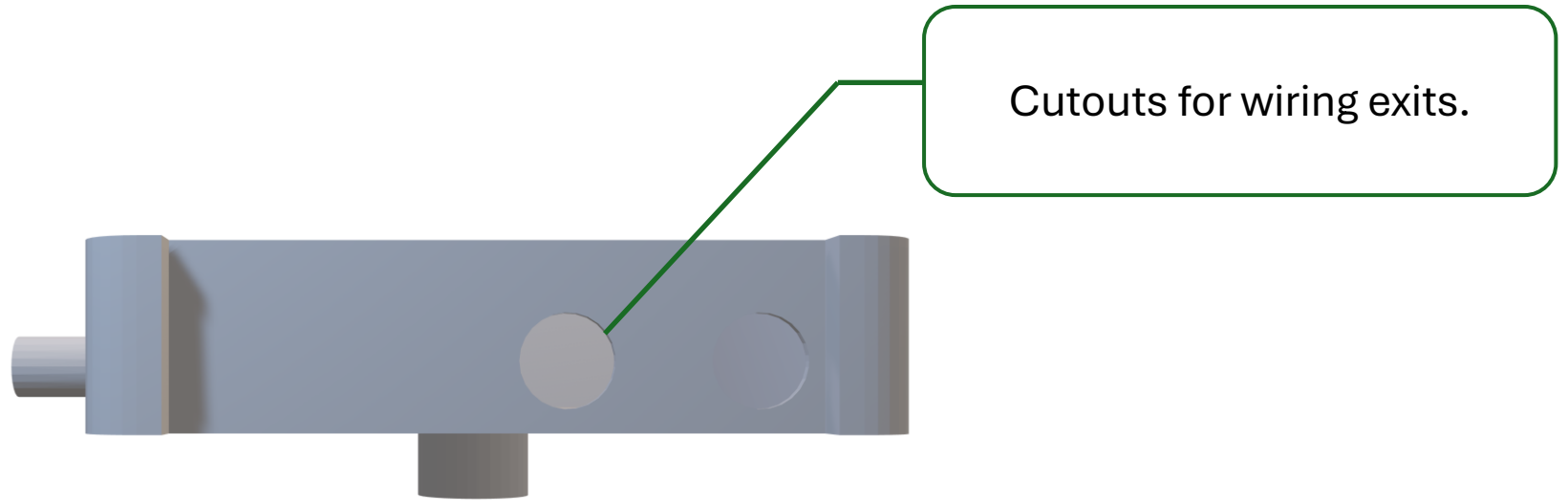
Extrusions compliant with
dynamometer sampling
setup.

LCS Design and Component Selection

Sensirion SEN66



Sensirion SensorBridge

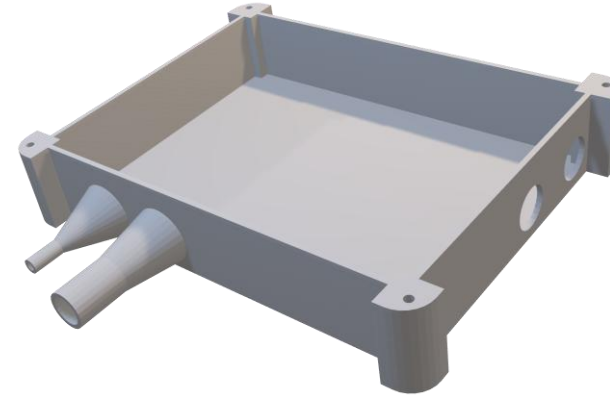


LCS Design and Component Selection

Sensirion SEN66



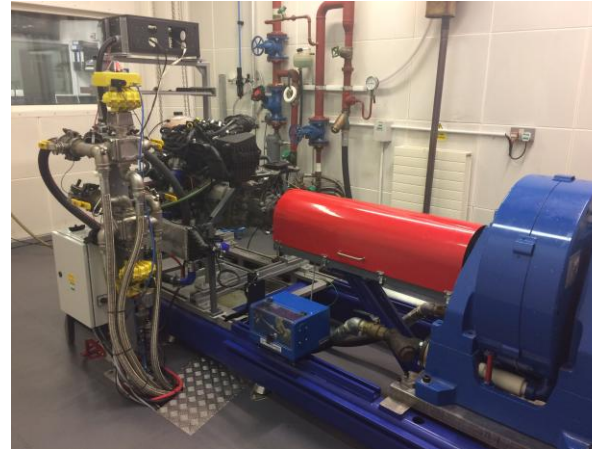
Sensirion SensorBridge



Dynamometer Test Setup

Dynamometer Testing:

- Controlled laboratory testing.
- Ford Zetec 1.6L I4 with 14.4 AFR.
- Pre- and post-treatment data.
- Horiba analyser used as reference system.



Horiba MEXA-584L

- RPM sweep points: 1000, 2000, 3000, 4000, and 5000 RPM.
- Load sweep points below.

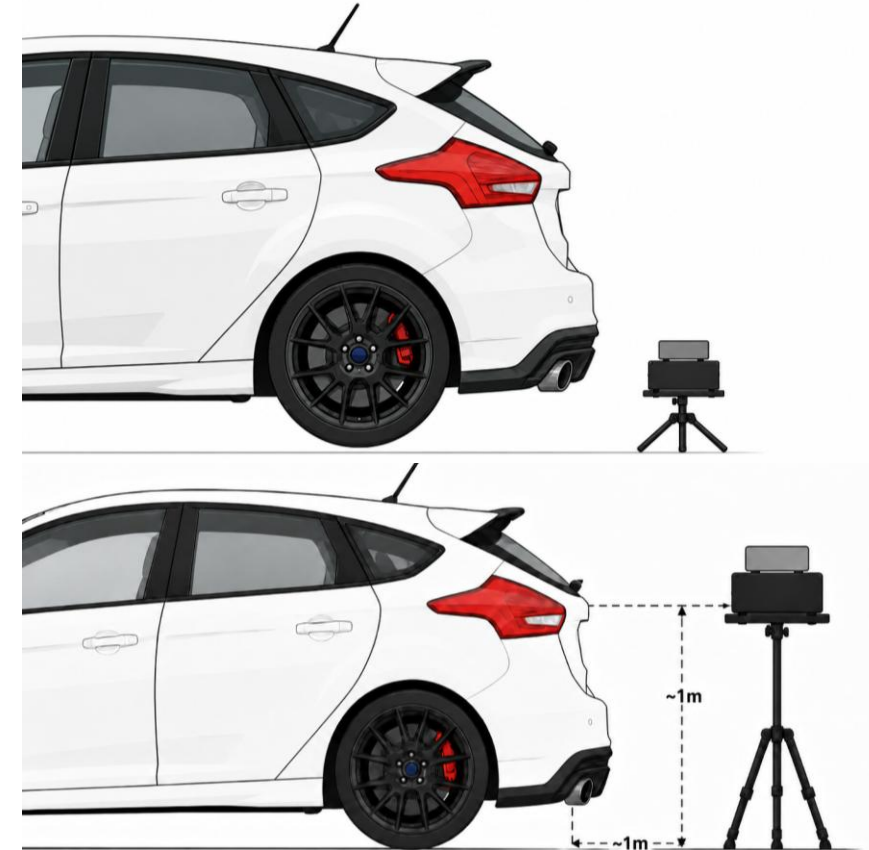
Point	Configuration	Point	Configuration	Point	Configuration
1	2000 RPM – 25%	4	3000 RPM – 25%	7	4000 RPM – 25%
2	2000 RPM – 50%	5	3000 RPM – 50%	8	4000 RPM – 50%
3	2000 RPM – 100%	6	3000 RPM – 100%	9	4000 RPM – 100%



Static Vehicle Test Setup

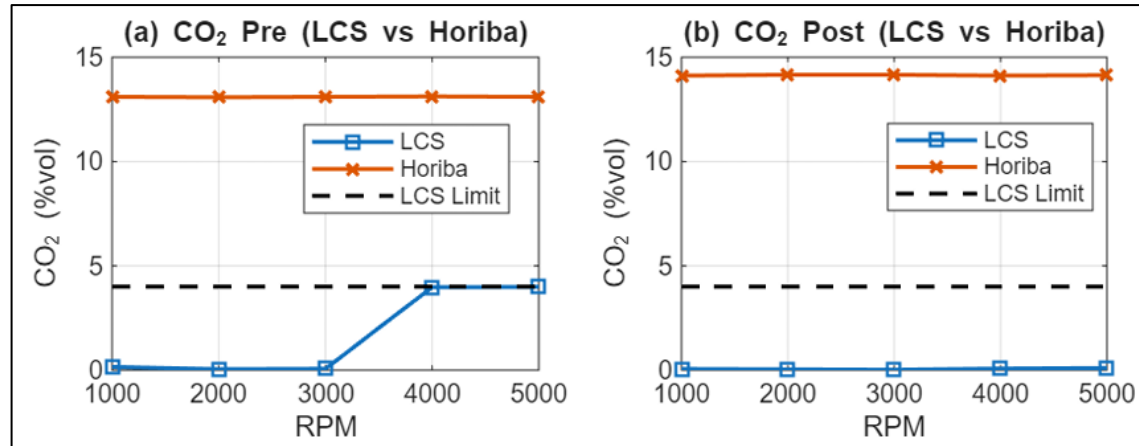
Static Vehicle Testing:

- Real-world plume testing.
- Ford Focus ST 2.0L I4 factory-tuned.
- MIRA indoor workshop facility.
- **Three tests:**
 - Directly at exhaust exit.
 - 1m distance horizontally.
 - 1m horizontally and 1m vertically (1m raised).
- Alternative LCS positioned above developed LCS.
- RPM sweep points: 800, 1500, 2000, 2500, 3000, and 3500 RPM.

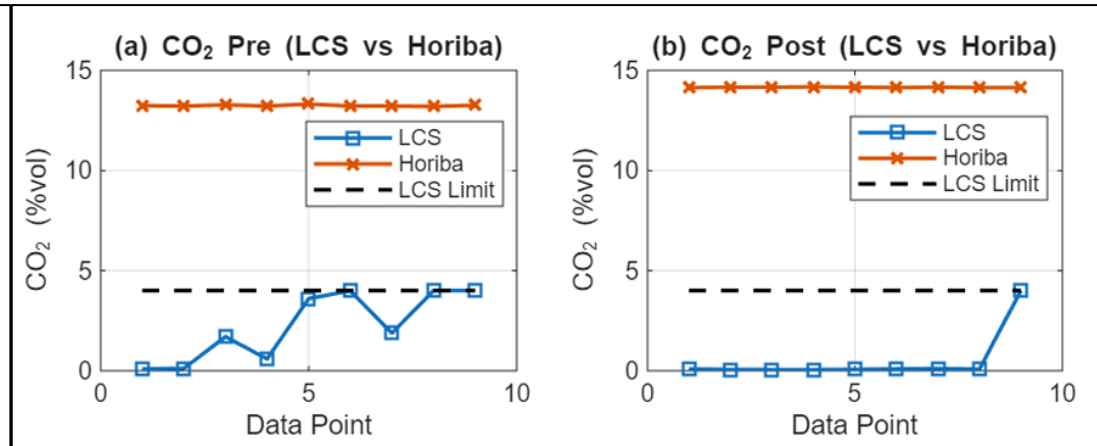


Key Results – CO₂

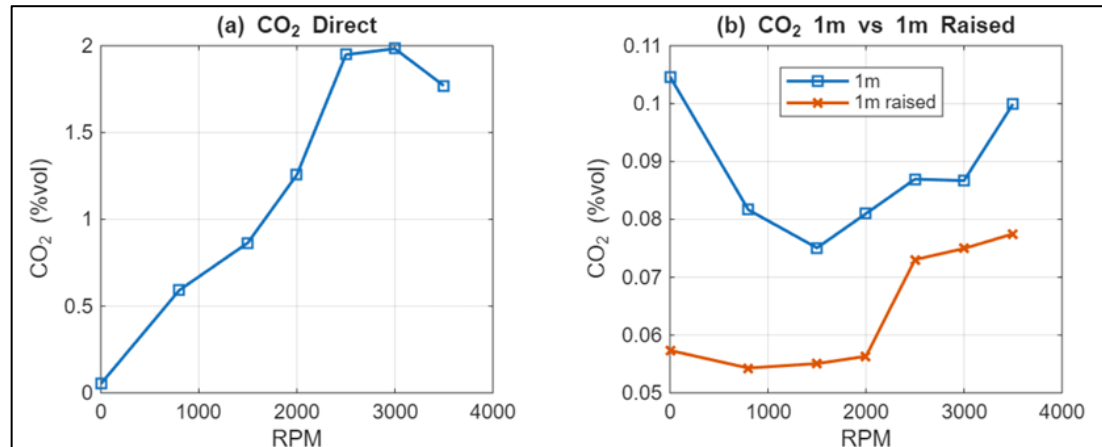
DYNO – RPM



DYNO – LOAD



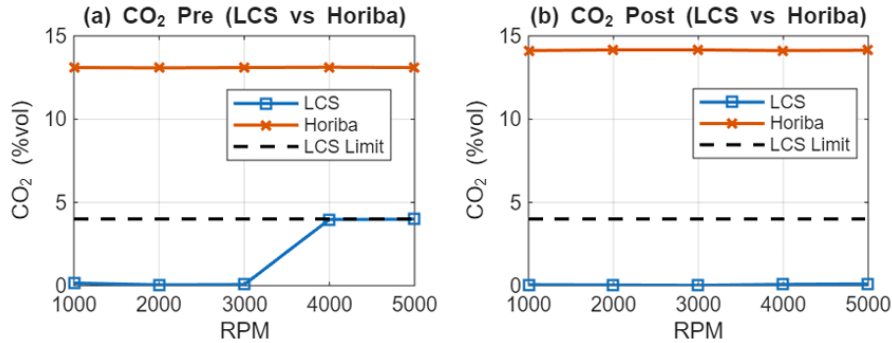
STATIC



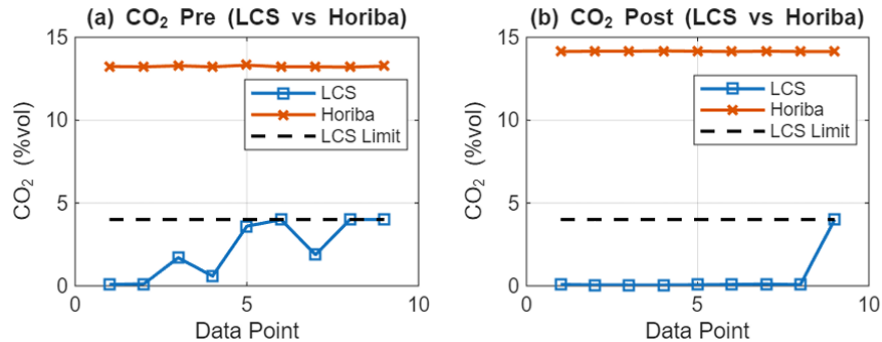
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Key Results – CO₂

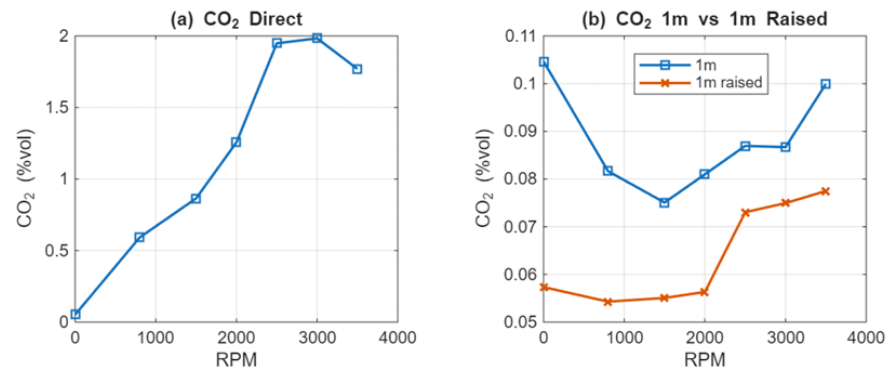
DYNO – RPM



DYNO – LOAD

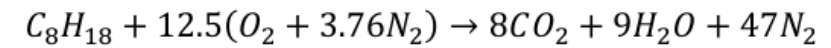


STATIC



EXPECTATIONS AND ANALYSIS

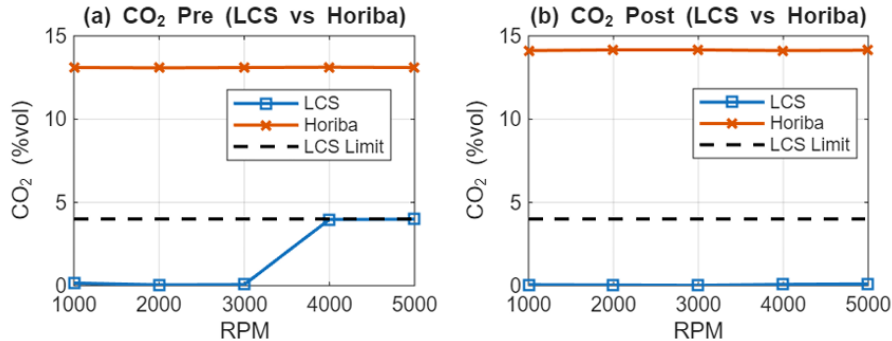
- Tests conducted at stoichiometric AFR or near-stoichiometric.
- Below are equations for **combustion of octane**:



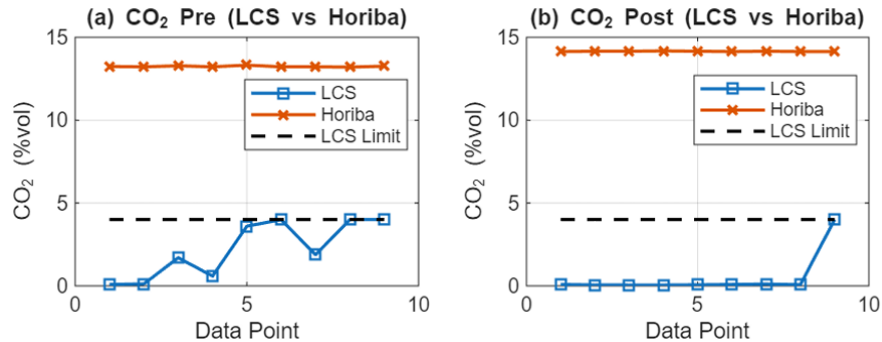
$$\text{Volume fraction of } CO_2 = \frac{\text{Moles of } CO_2}{\text{Moles of Reactants}} = \frac{8}{8 + 9 + 47} = 12.5\%$$

Key Results – CO₂

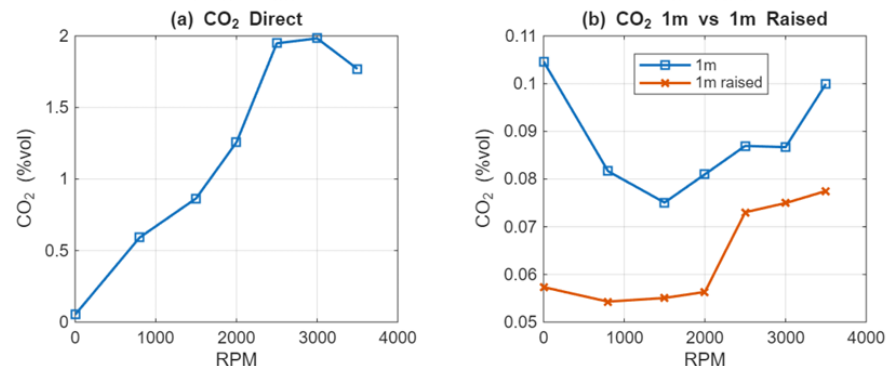
DYNO – RPM



DYNO – LOAD

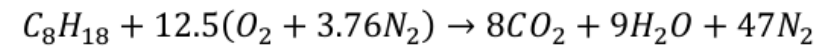


STATIC



EXPECTATIONS AND ANALYSIS

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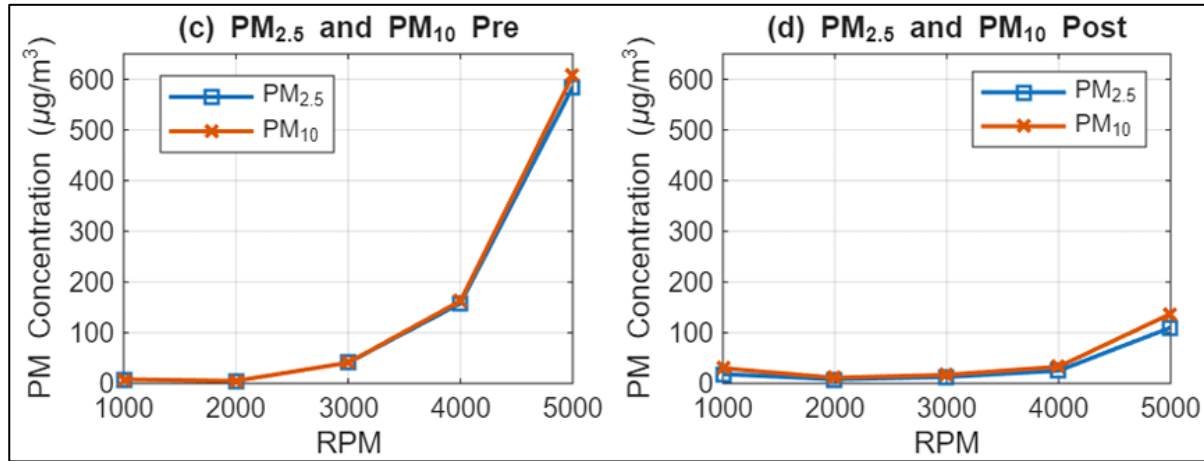
- LCS increase for dynamometer is due to **gas transport behaviour**.
- Static increase explained by **higher mass flow rate**.
- 4% LCS limit caused **saturation** in dyno values. **Value likely higher**.

Key Takeaways:

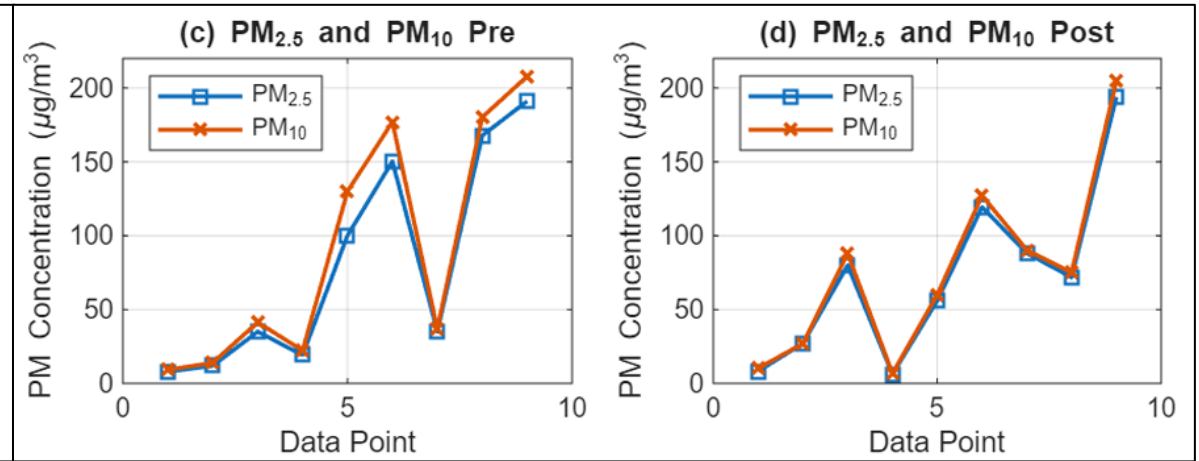
The LCS is more promising for vehicle plume trend monitoring in comparison to the dynamometer tests, due to the restricted airflow that comes with sample lines.

Key Results – PM

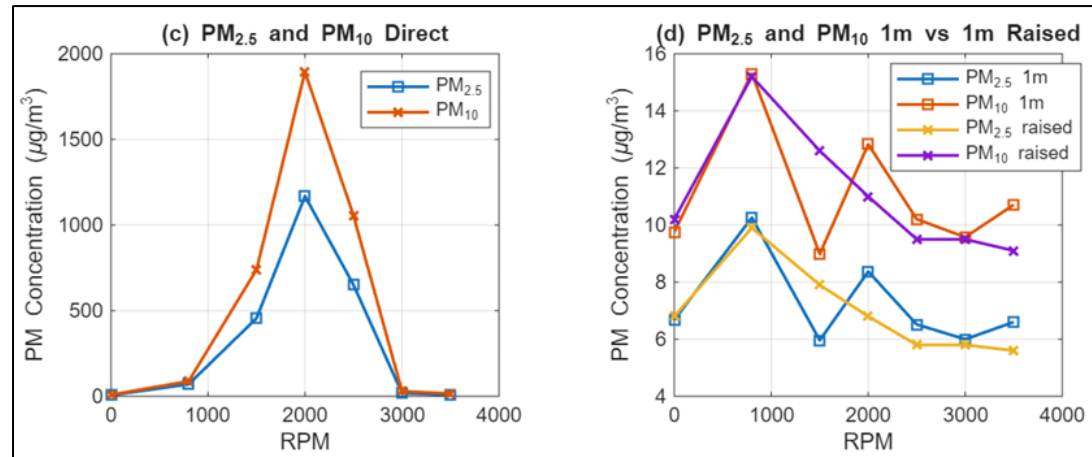
DYNO – RPM



DYNO – LOAD

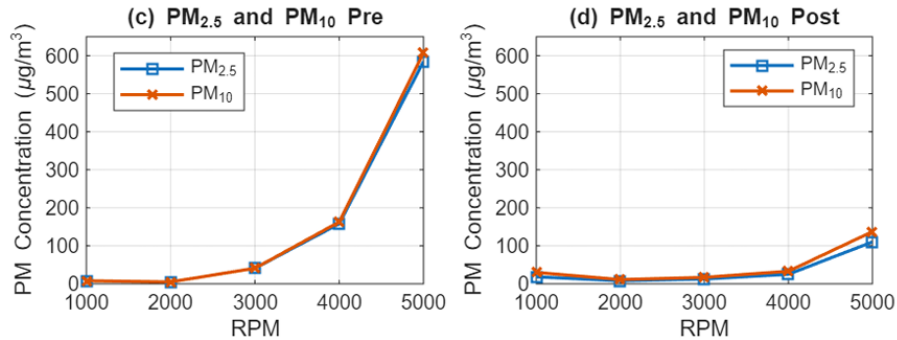


STATIC

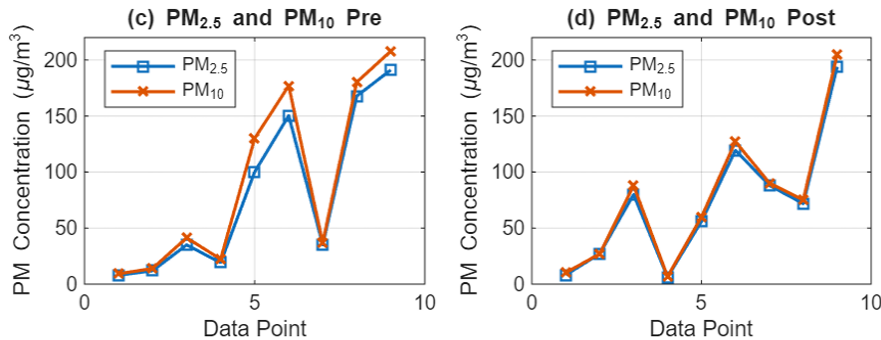


Key Results – PM

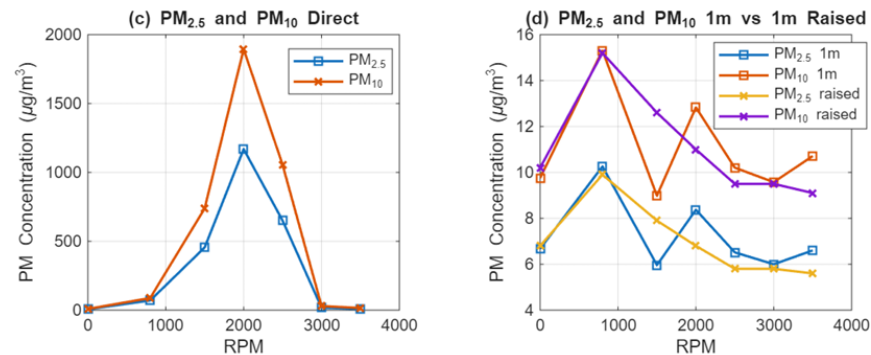
DYNO – RPM



DYNO – LOAD



STATIC



EXPECTATIONS AND ANALYSIS

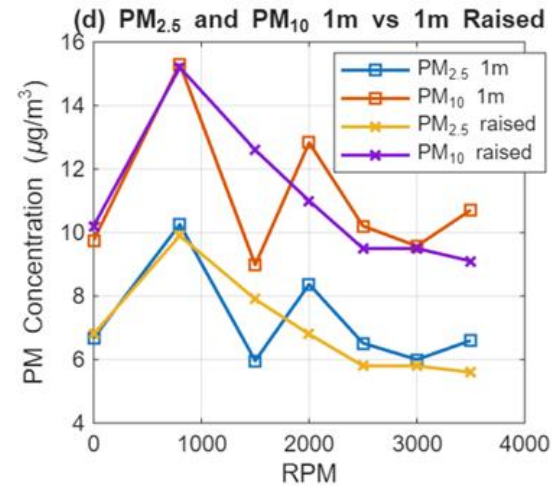
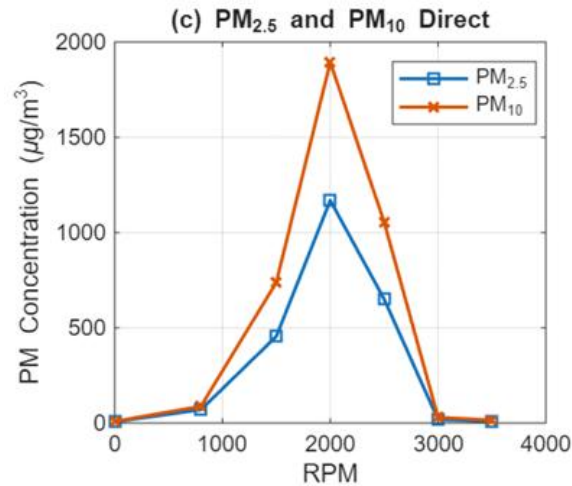
- PM expected to **increase** with RPM/load.
- Post-treatment sampling path expected to **lower measured values**.
- Dyno results follow **expected upward** trend.
- Static vehicle test exhibit **unexpected behaviour** comparing to data.
- Alternative LCS trend **agreement**, but higher **magnitude**.

Key Takeaways:

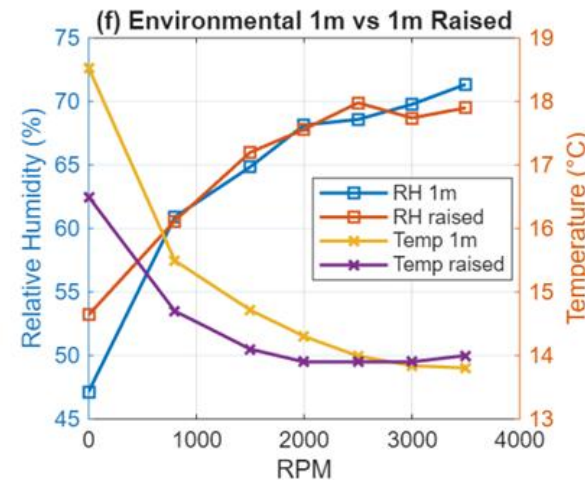
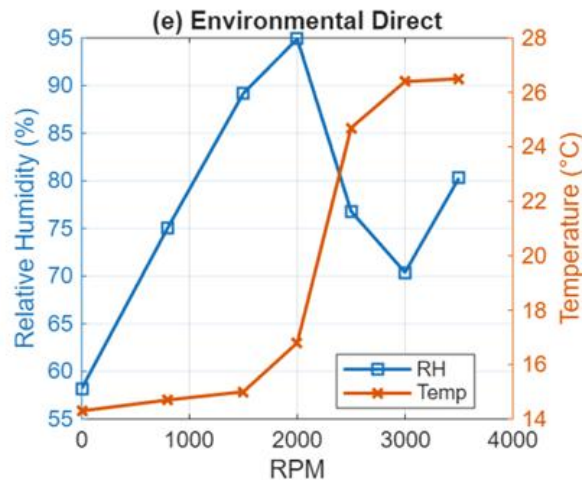
The LCS captured expected PM trends during dynamometer testing, while static plume tests showed irregularities and stronger sensitivity to setup changes.

Key Results – Environmental Factors

STATIC PM



STATIC
RH/Temp

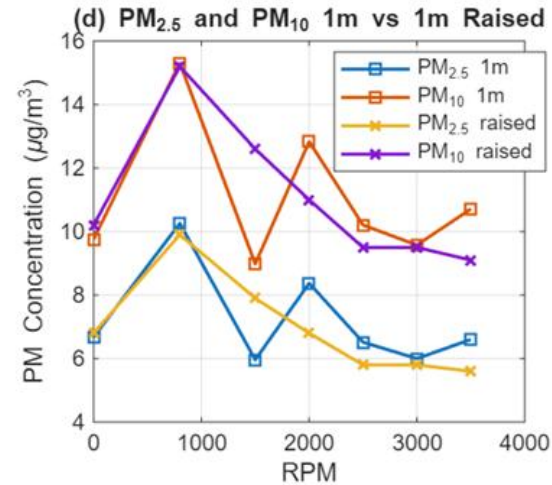
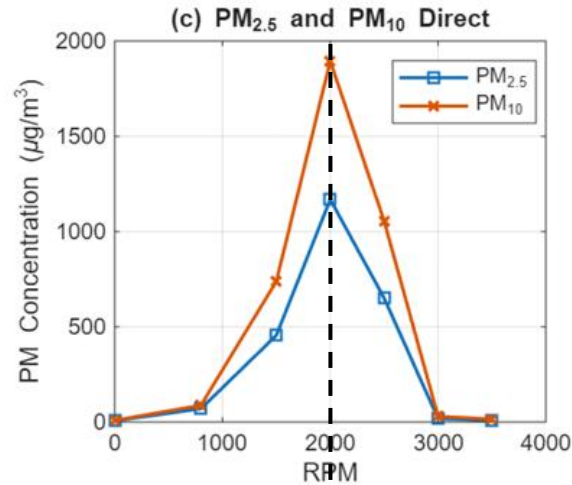


Principle of Hygroscopic Growth

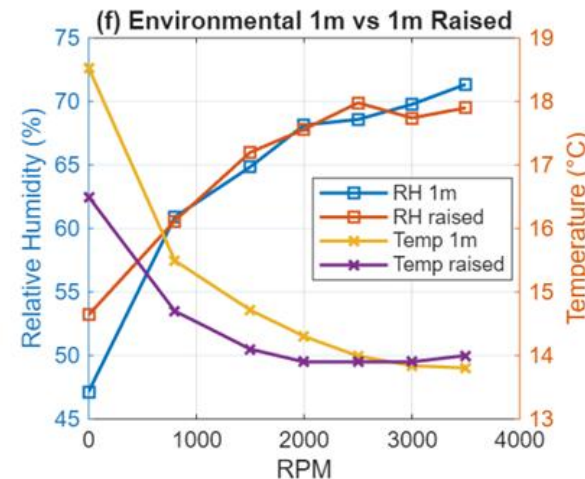
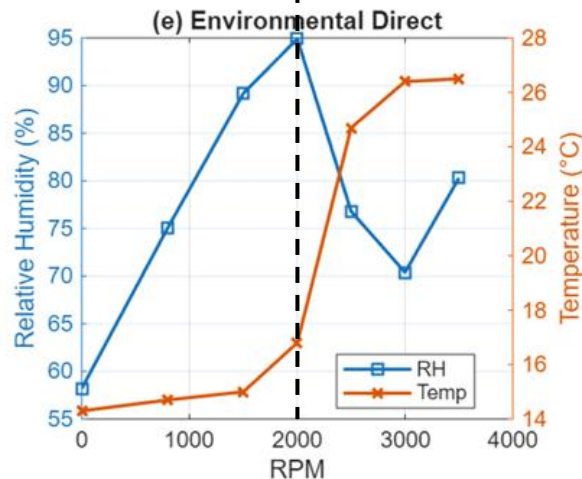
- **Hygroscopic Growth** – Particles absorb water, causing them to swell.
- Above ~75% RH, **expands exponentially**.
- Increase in **engine speed** = Increase in **RH%**.

Key Results – Environmental Factors

STATIC PM



STATIC
RH/Temp



Principle of Hygroscopic Growth

- **Hygroscopic Growth** – Particles absorb water, causing them to swell.
- Above ~75% RH, **expands exponentially**.
- Increase in **engine speed** = Increase in **RH%**.
- Peak for RH% and PM **occur at 2000 RPM**.
- Steep drop-off in RH afterwards to **~75% and below**, paired with steep drop in PM.

Key Takeaways:

The PM readings are influenced by both plume behaviour and hygroscopic growth at high RH, particularly for the direct plume.

Conclusions and Further Work

Conclusion

- A functional multi-pollutant LCS was produced for £125.
- Trends captured for CO₂ static and PM dynamometer.
- Sampling airflow was the dominant design limitation.
- **For the cost, if acknowledging emissions hotspots is the priority, the LCS shows strong potential for cost-effective monitoring.**

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- Trends captured for CO₂ static and PM dynamometer.
- Sampling airflow was the dominant design limitation.
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Further Work

- Wider validation set with g/km measuring for comparison.
- Integrate active sampling.
- Introduce removable extrusions

Thank You for Listening

Please feel free to ask any questions.