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ECMA 11th International Conference & Exhibition Experience for Data Generation from RDE for Catalyst Development

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Johnson Matthey Clean Air, UK

Agenda Slide

Johnson Matthey’s Sectors:

Clean Air

- Light Duty Catalysts
- Heavy Duty Catalysts
- Stationary Emission Control

Health

- Active Pharmaceutical Ingredients – API’s
- Research Chemicals
- Catalysis and Chiral Technologies

Efficient Natural Resources

- Syngas
- Advanced Glass Technologies
- Noble Metals
- Tracerco

New Markets

- New Business Development
- Water Technologies
- Fuel Cells
- Atmosphere Control Technologies

Clean Air’s Global Network

13 Manufacturing Sites **9 Technology Centres**

Introduction

The introduction of RDE legislation has required a new approach to exhaust emissions after-treatment development.

This presentation discusses the challenges of designing unique test cycles to meet the new regulations and difficulties and tips to developing new routes to deliver repeatable and reliable test data.

Additionally, for specific catalyst development programmes, it is desirable to replicate specific emissions events found during the on-road tests, in the vehicle laboratory in order to develop solutions. The advantages and disadvantages of two separate methods that have been developed by Johnson Matthey at the UK Technology Centre are discussed here.

RDE Legislation

EU 2016/427 (Package 1) – Original – 10/03/2016

EU 2016/646 (Package 2) – Added driver dynamics – 20/04/2016

EU 2017/1151 (WLTP) – Package 2 written into WLTP – 01/06/2017

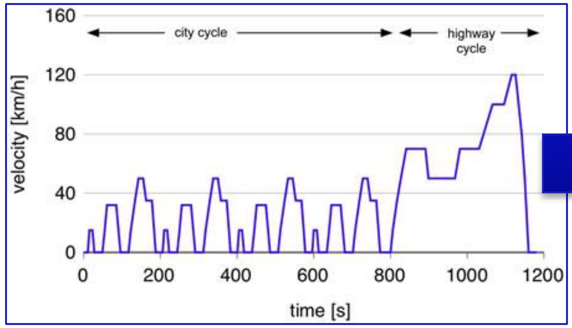
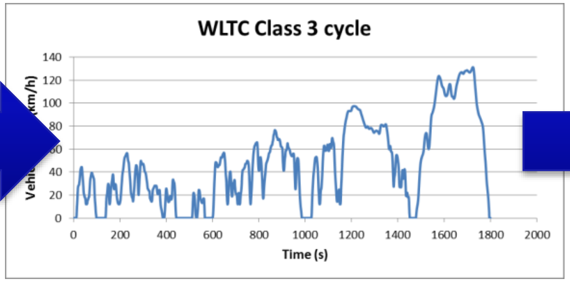
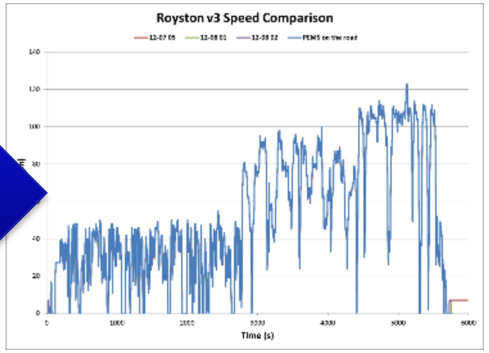
EU 2017/1154 (Package 3) – Includes cold start and defines PN limit – 07/06/2017

Package 4 - In-service conformity and simplify post processing tools

PEMS testing emissions limits for NOx and PN

Limit = 2.1 x EU6 NOx, 1.5 x EU6 PN

Test Cycle Evolution

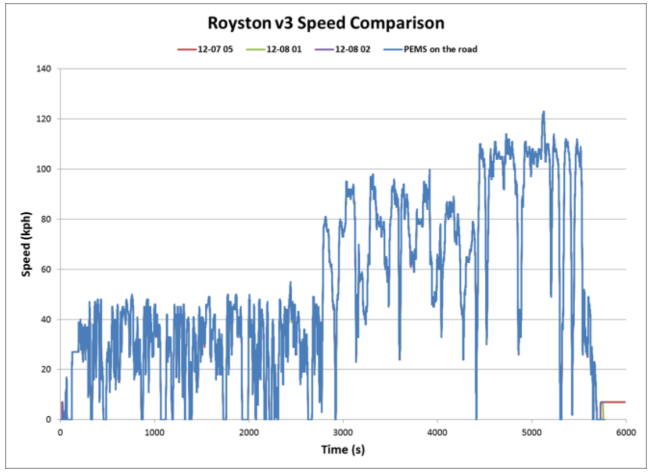
NEDC	WLTP	RDE
		

							Driving Dynamics
NEDC	20-30°C	11km	20 mins	Max: 120km.h	0m	Min.	n/a
WLTP	20-30°C	23km	30 mins	Max: 131km.h	0m	TMH TML	n/a
RDE	-7°C to 35°C	Approx 90km	90-120 mins	Max: 160km.h	0-1300m	upto 90% mass	$v*a_{pos}95$ RPA

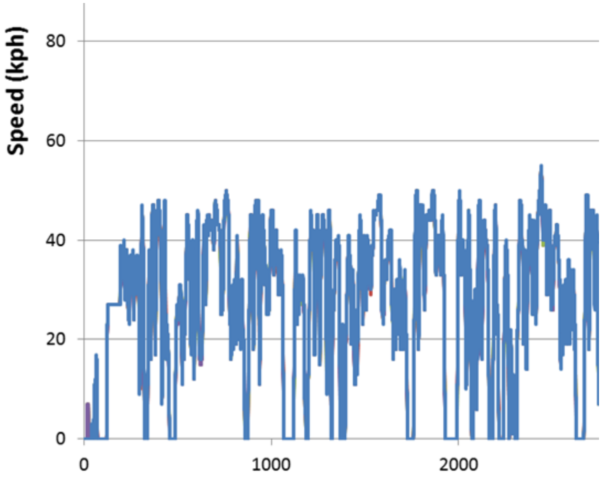
RDE Legislation

…but the **urban** test section result must not exceed EU6 x CF for NOx and PN

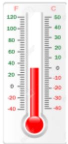
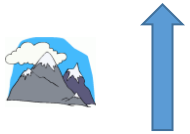
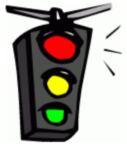
RDE total



RDE urban



The urban test section also has additional criteria

							
Urban	Cold start, preconditioned*	16km min	~45 - 60 mins norm	< 60 kph, av speed 15-45 kph	1200m / 100km pos elevation rate	Total stop time 6 - 30%	Max stop 300s (90s in first 300s)

*Preconditioning is at least 30mins of driving 6 - 56 hours before start of RDE test

Objectives of PEMS Testing at JM UK

1. Research real driving conditions on the road and understand the challenging conditions for the development of exhaust after-treatment systems
2. Benchmark different vehicle types (Gasoline, Diesel, xEV) to understand the different vehicle characteristics in relation to catalyst performance
3. Real on-road measurement for new projects

PEMS Equipment

One AVL MOVE gas PEMS + PN (CO, CO_2, NO, NO_2, O_2)

Advanced diffusion charger PN measurement

Two EFMs – 2” and 2.5”

Can be tow-bar mounted or in-vehicle

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PEMS Equipment

Delivered in September 2018

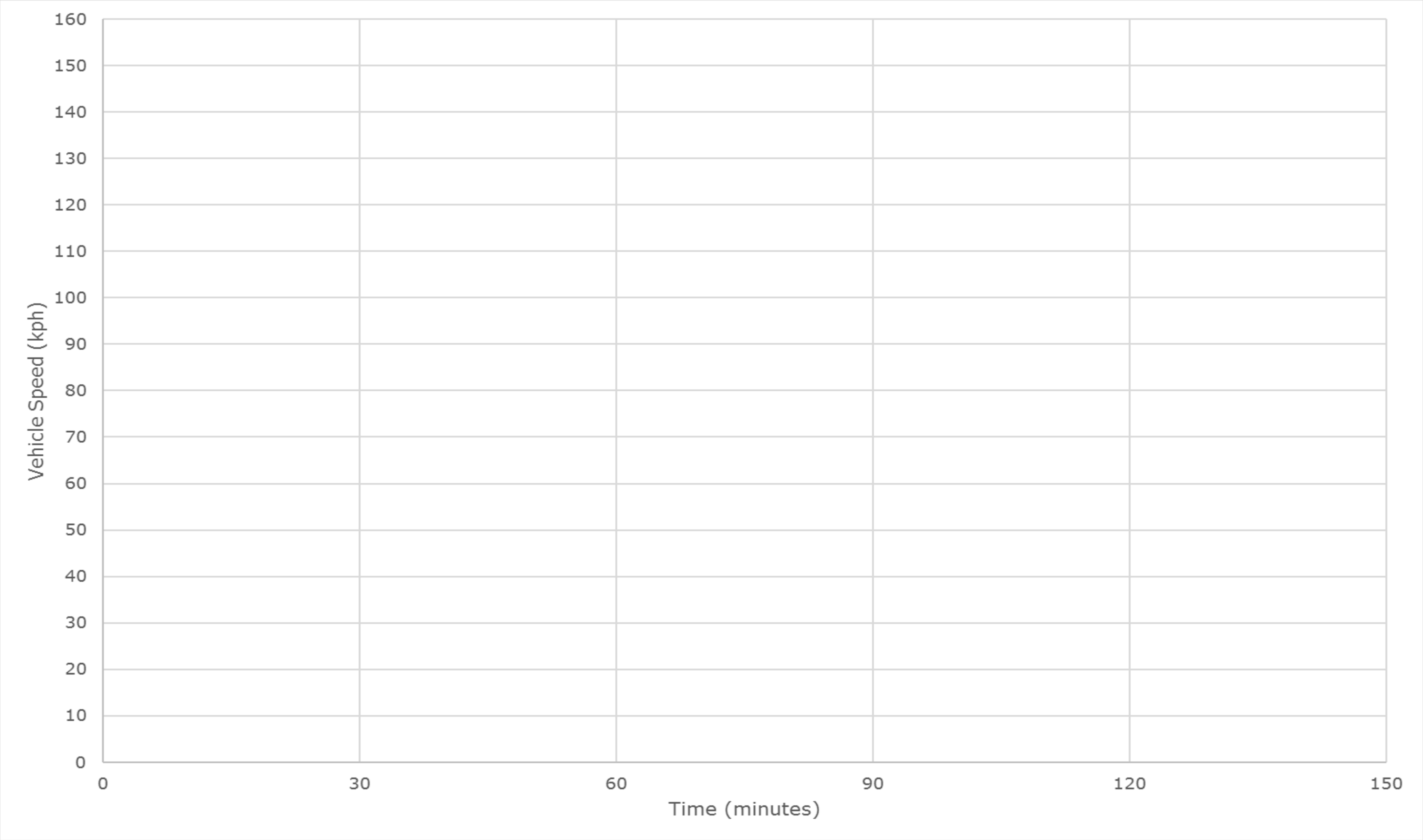
Sensors PEMS
(CO, CO_2, NO, NO_2, O_2) + PN

CPC Particle Number Counter

Wireless connections to reduce cabling

Optional future FID / Dual FID

RDE Route Rules



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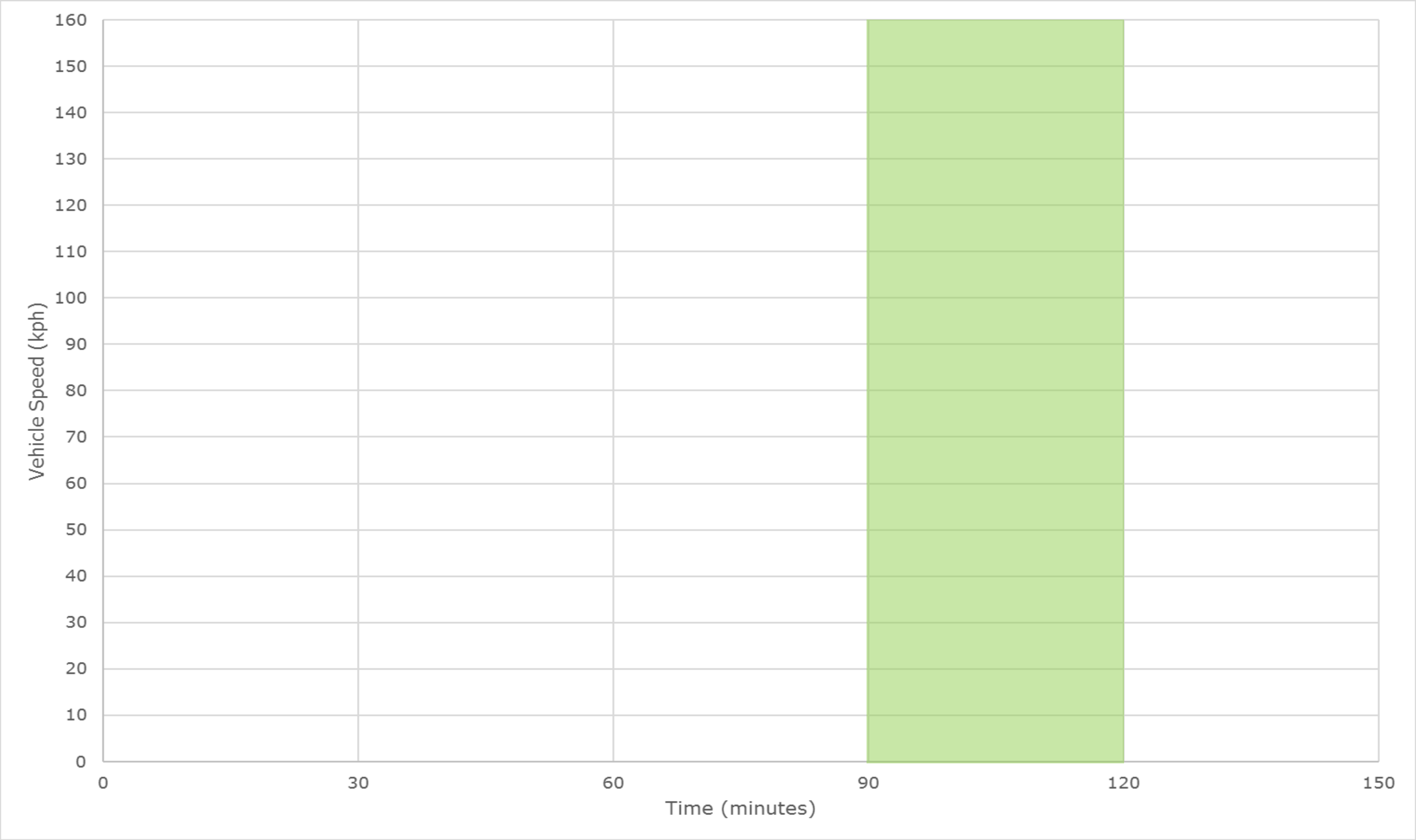
RDE Route Rules



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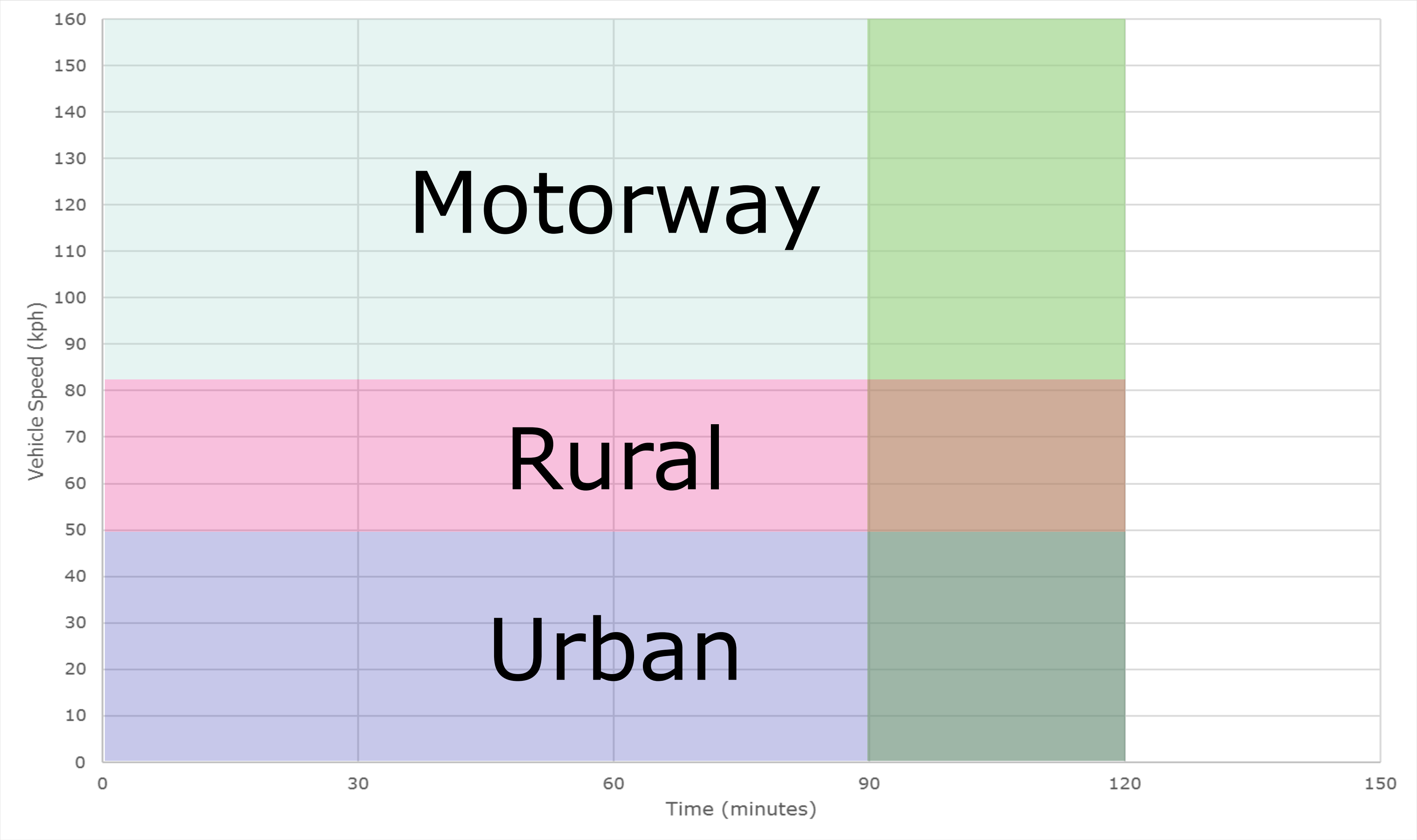

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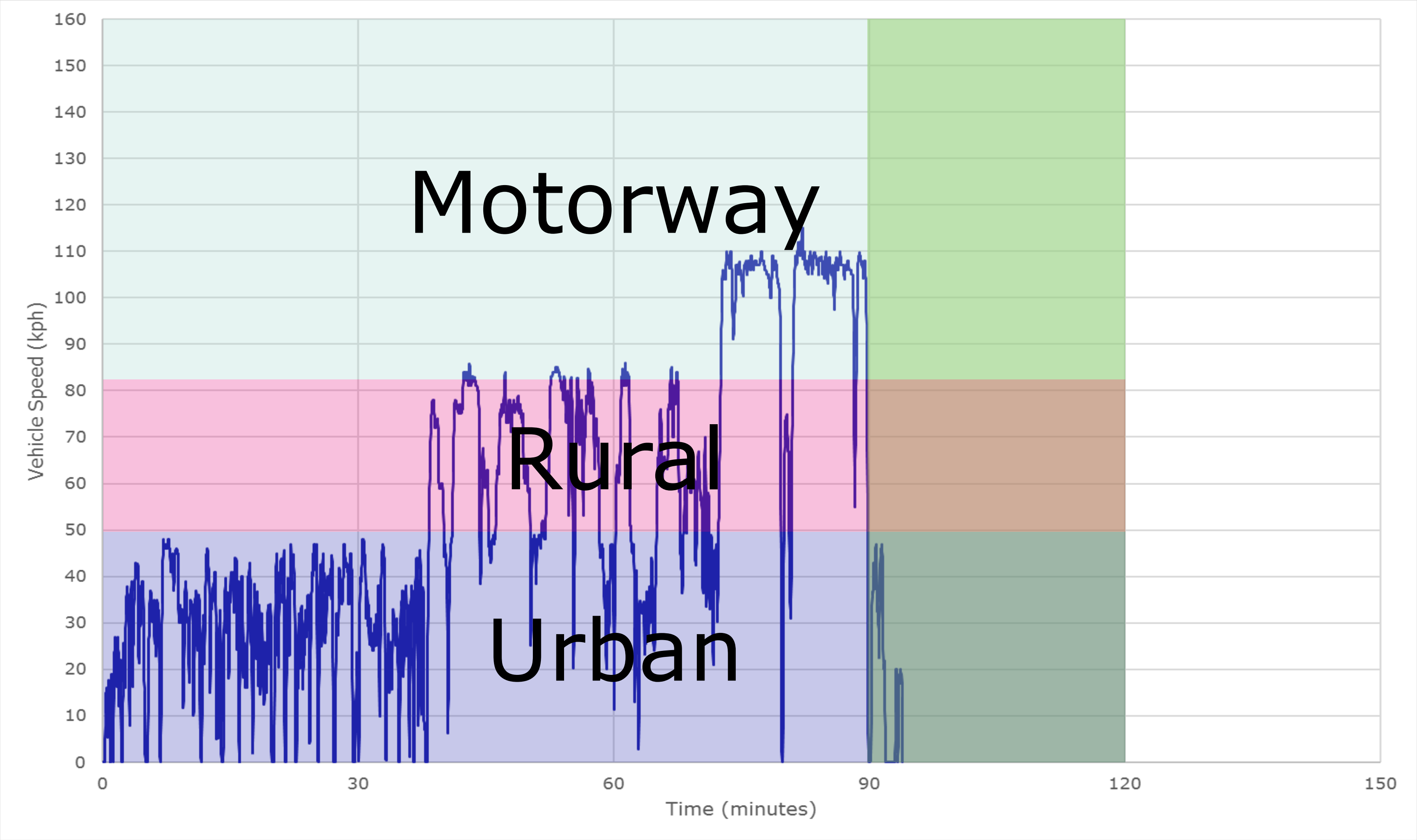
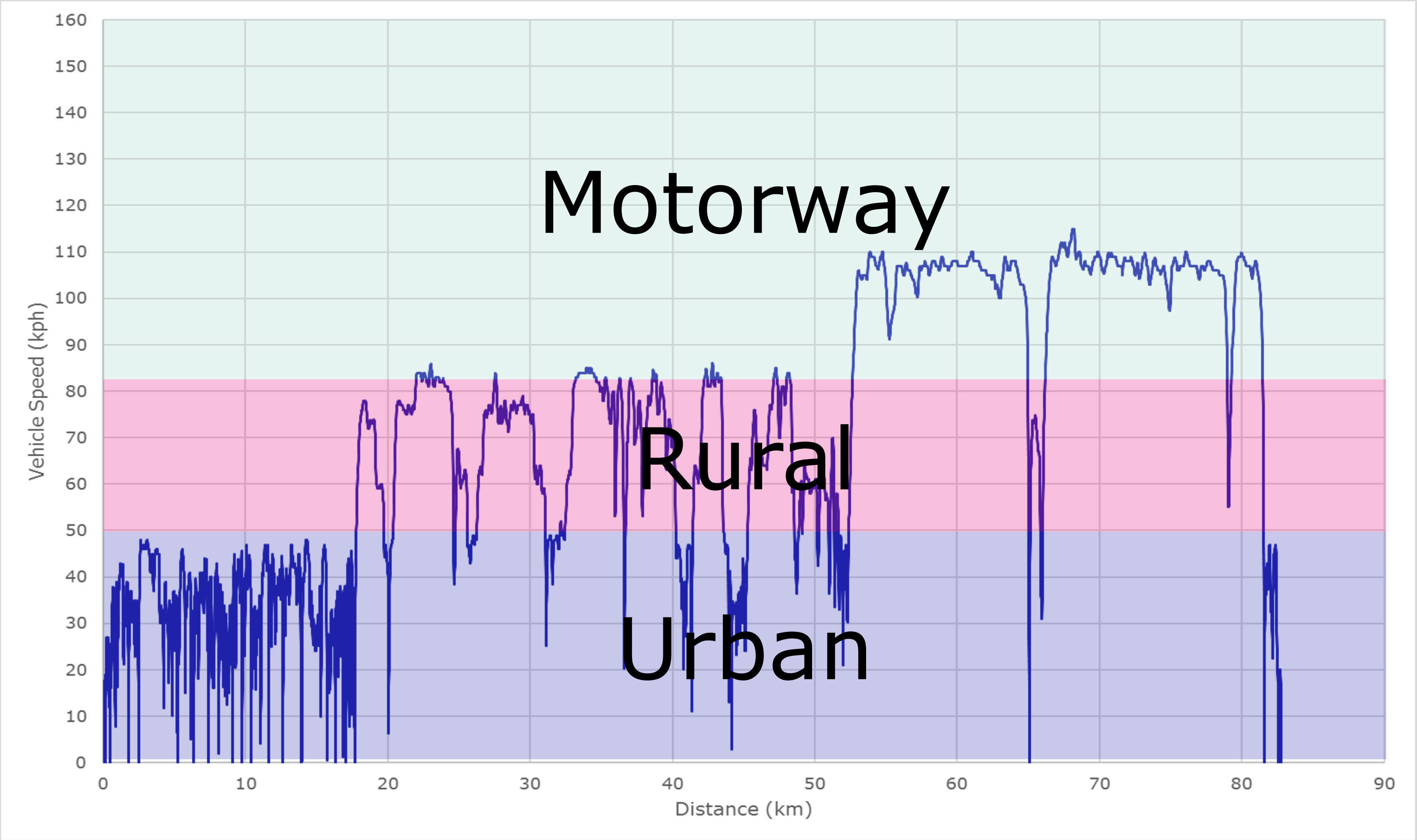


RDE Route Rules



23-43%

23-43%

29-43%
> 16km

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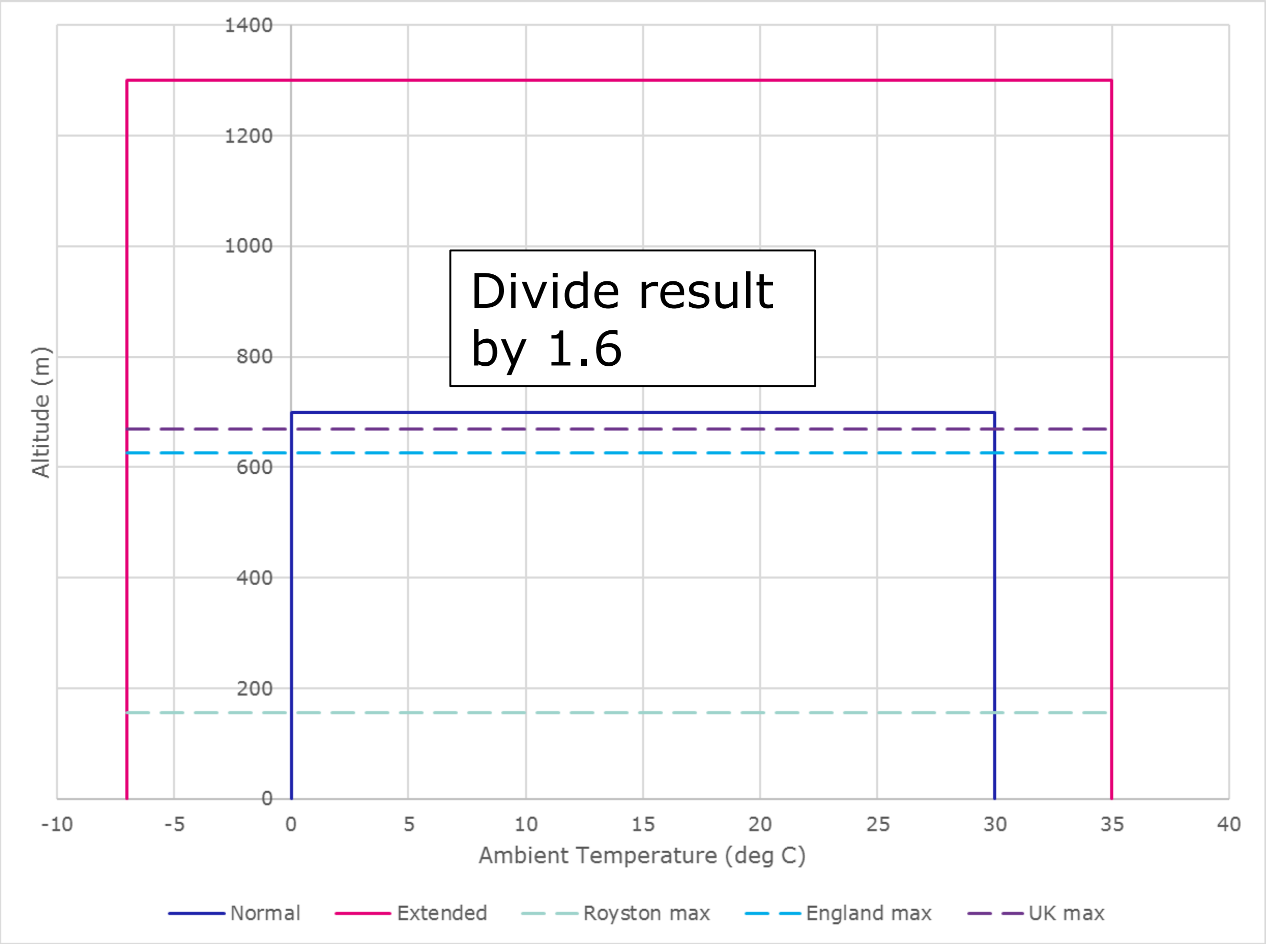
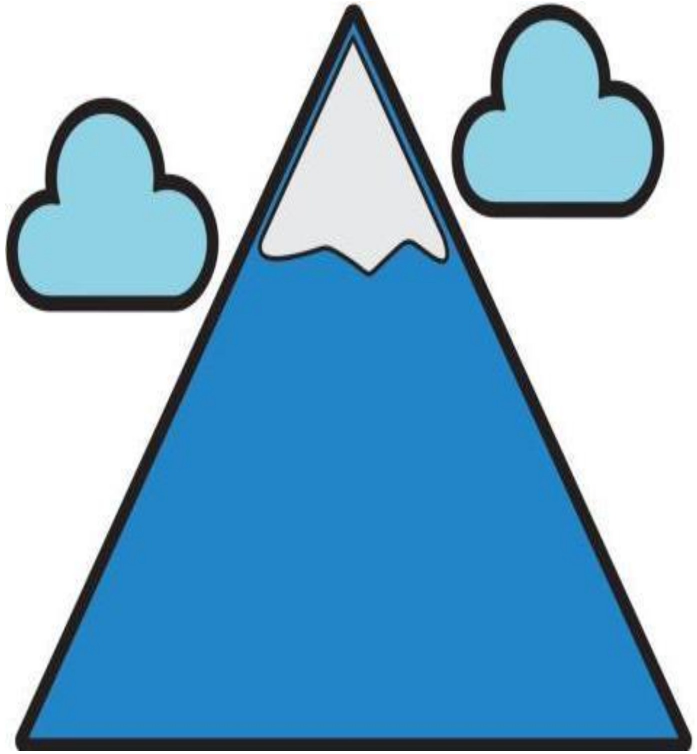
RDE Boundary Conditions





Highest point in UK = 1,345m (Ben Nevis)

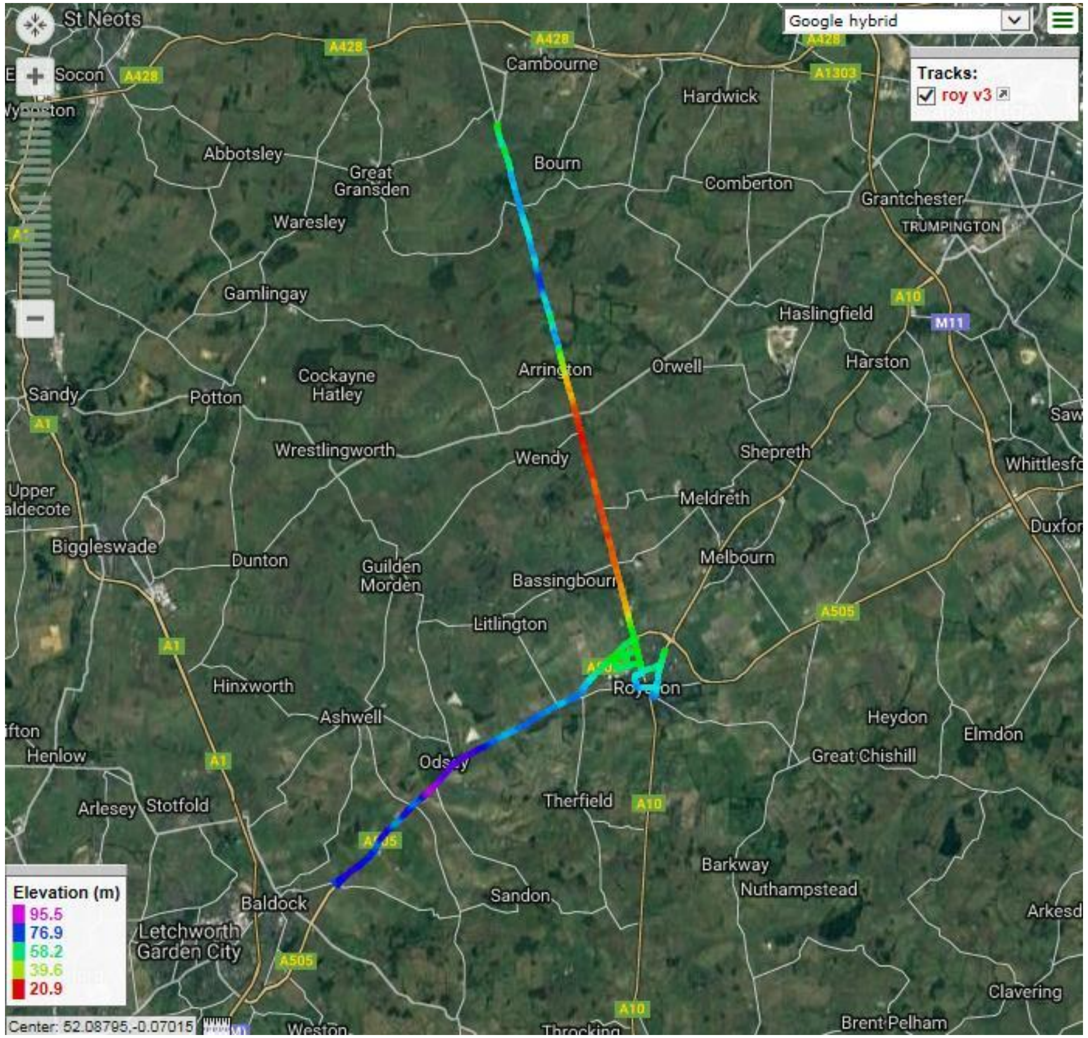
RDE gradient extremes must be investigated in CVS labs

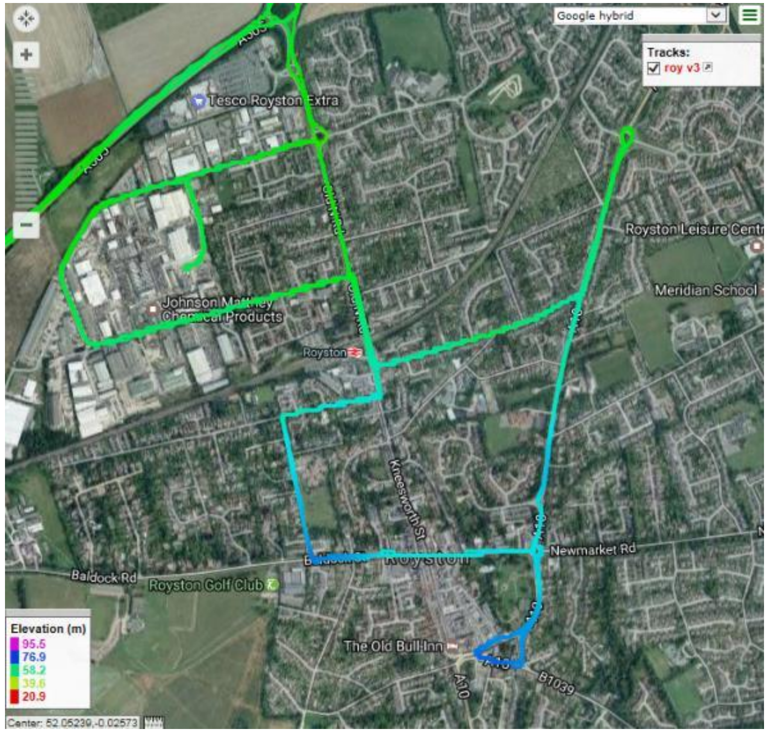
The Start of the RDE Test

- The first 5 mins of engine running or coolant reaching 70ºC (whichever faster) is classified as the 'cold start' section
- In the cold start, only 90s total vehicle stop time is allowed after the first engine start
- Important to have a clear route from preparation area to route start

RDE Routes

Royston normal – first iteration to meet cycle rules





Elevation rate = 455m/100km
Length = 84 km
Needs 'false' stops adding in urban section

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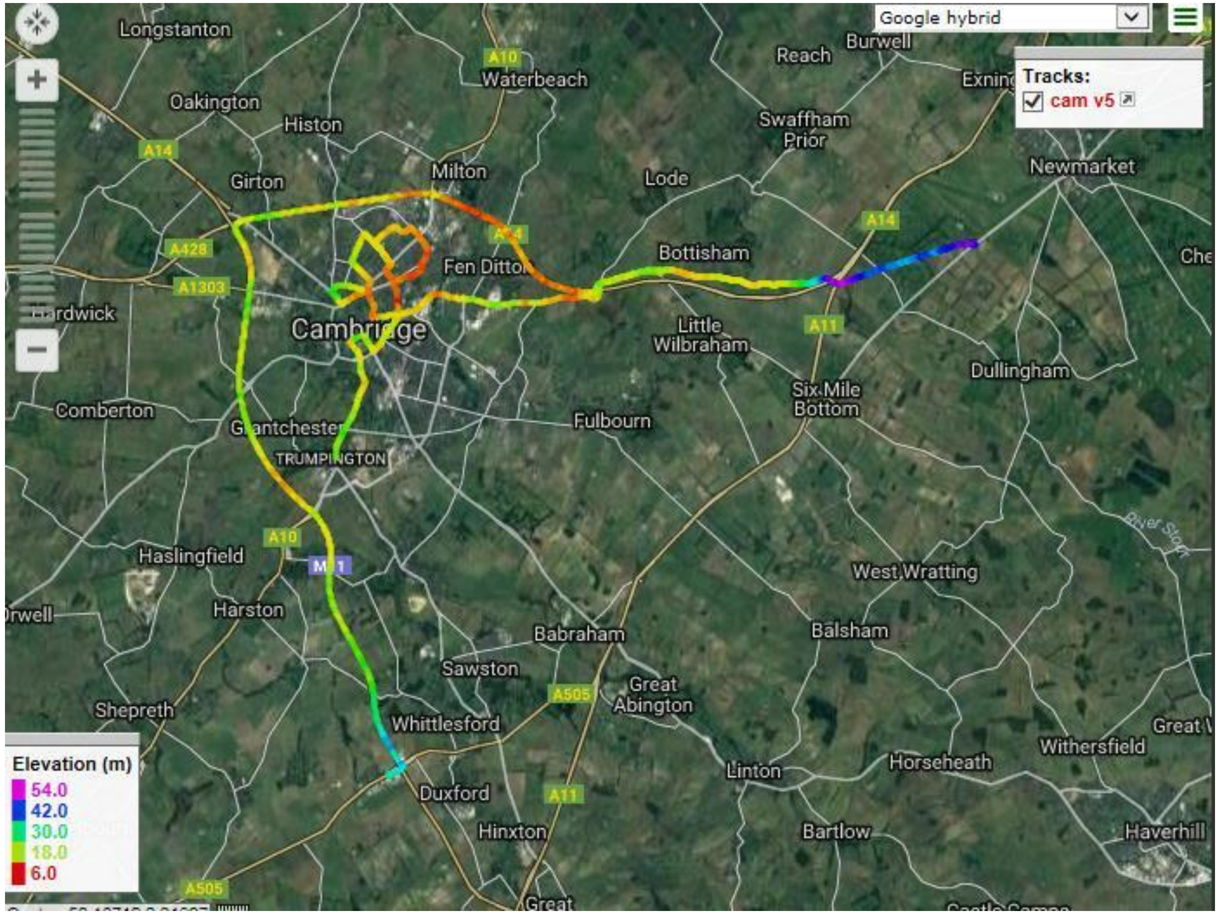
RDE Routes

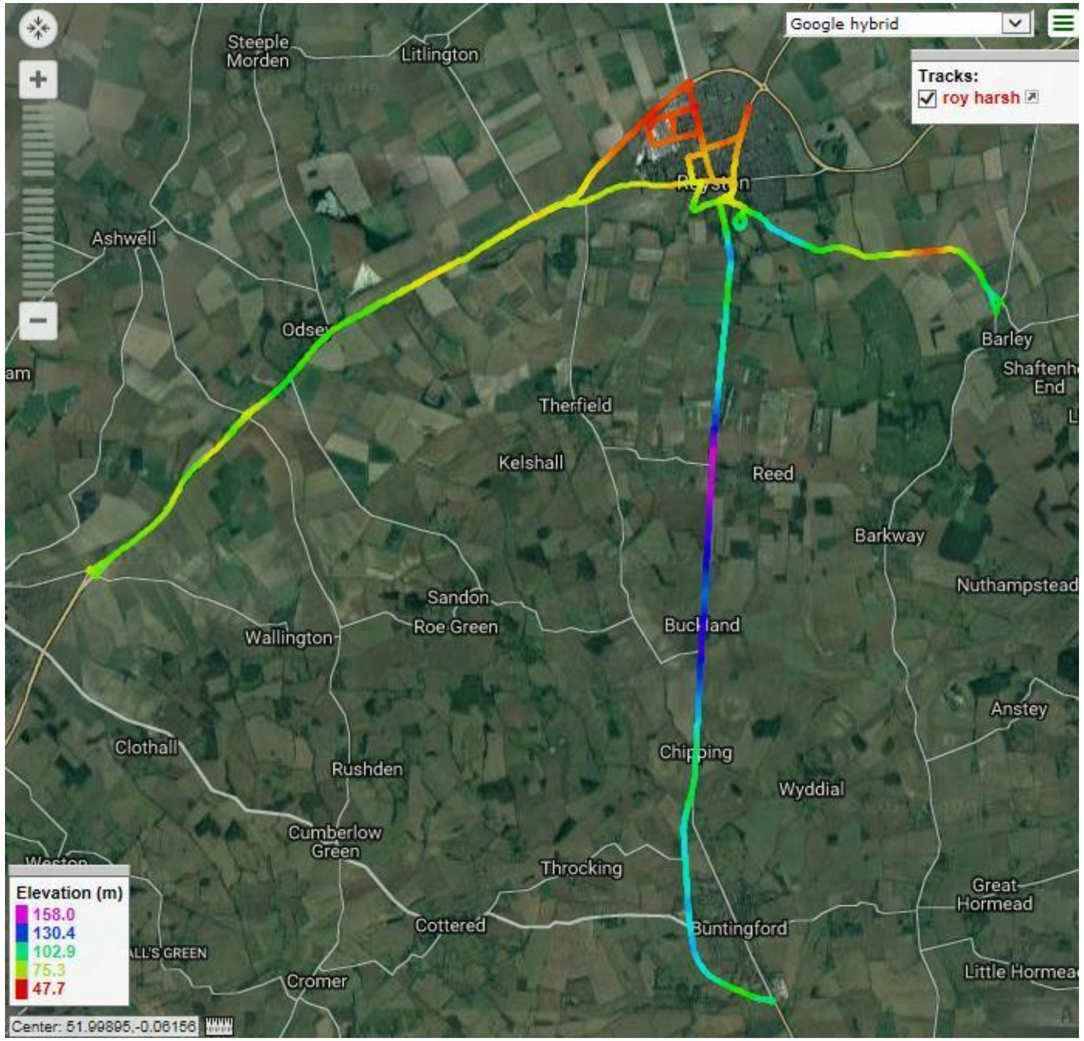
Cambridge – much more representative urban section

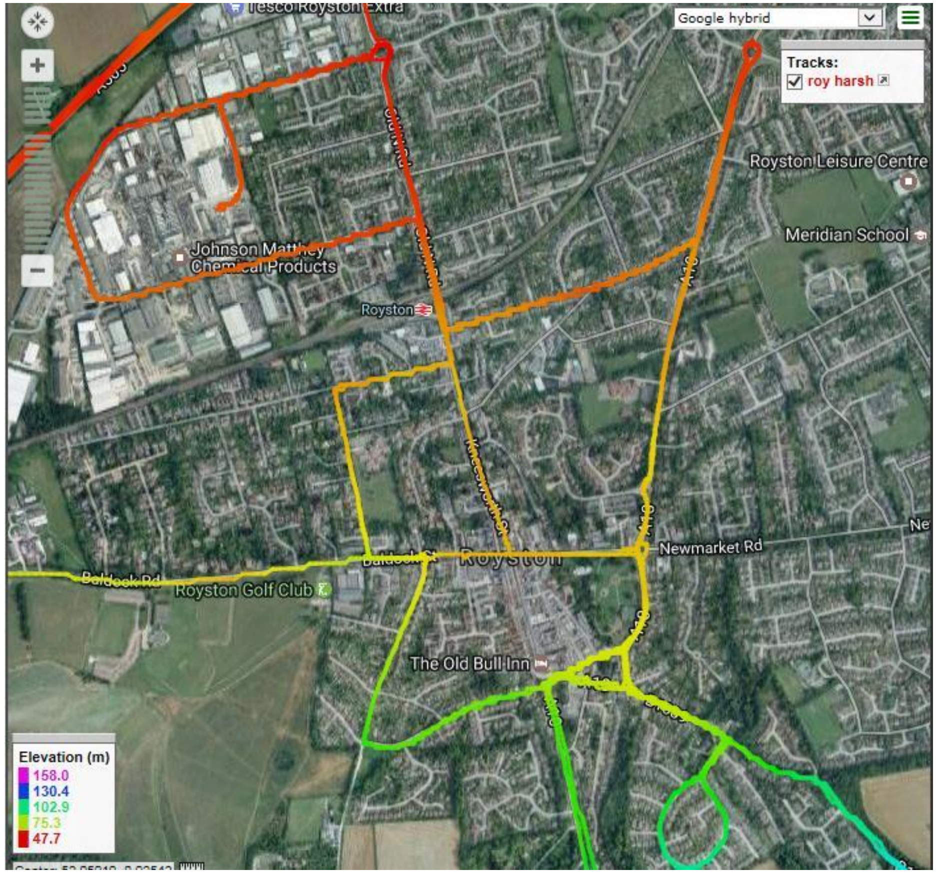


Elevation rate = 291m/100km
Length = 74 km
Hot start only

RDE Routes

Royston harsh – more elevation





Elevation rate = 754m/100km
Length = 93 km
Still requires ‘false’ urban stop

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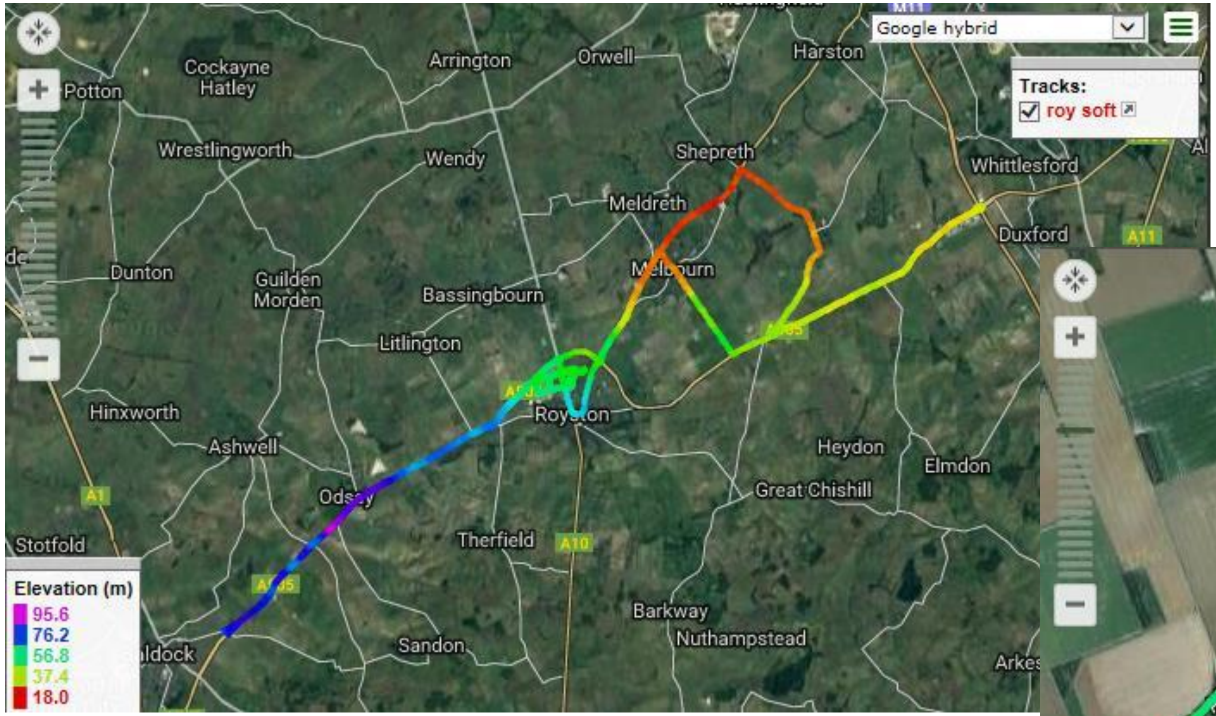
RDE Routes

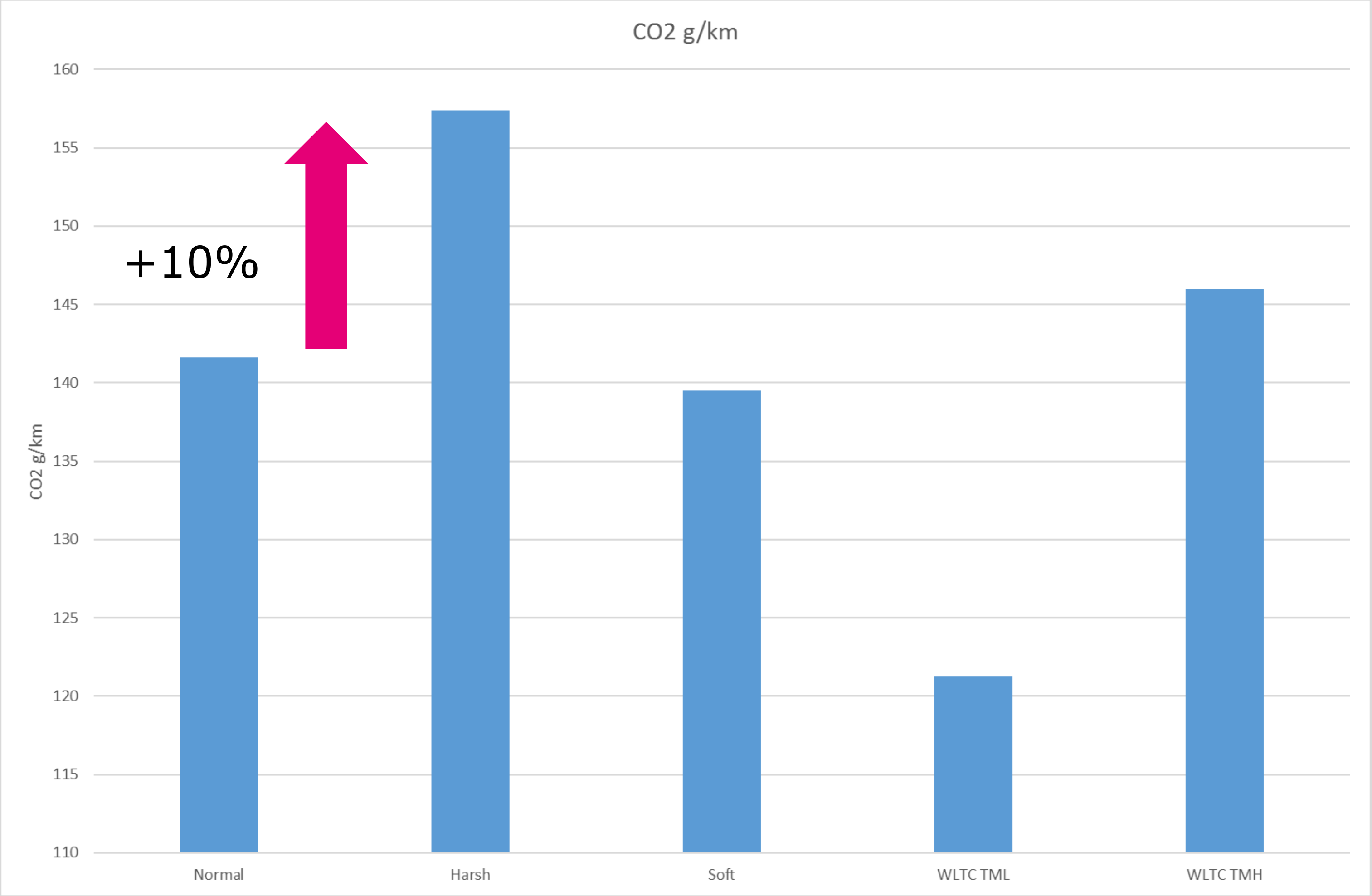
Royston soft – flattest possible cycle starting and finishing at JM



Elevation rate = 355m/100km
Length = 87 km

Route Comparison

Route comparison CO_2, 1.4 Gasoline Turbocharged DI,



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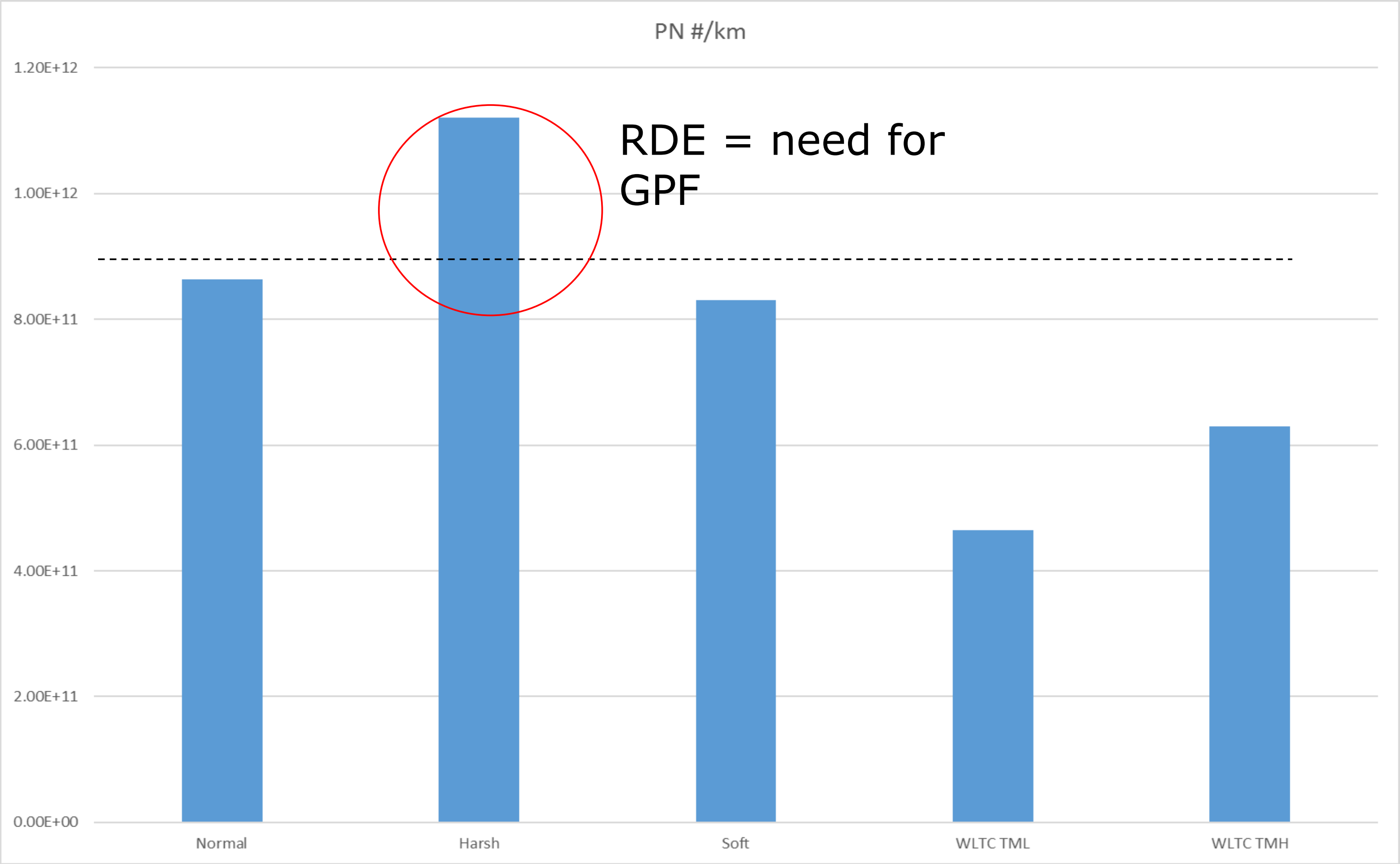
Route Comparison

Route comparison PN, EU6b 1.4 Gasoline Turbocharged DI (without filter)



EU6 RDE limit 9E11#/km

Further Route Development

2017/1154:

(19) point 6.2 is replaced by the following:

"6.2 The trip shall always start with urban driving followed by rural and motorway driving in accordance with the shares specified in point 6.6. The urban, rural and motorway operation shall be run continuously, but may also include a trip which starts and ends at the same point. Rural operation may be interrupted by short periods of urban operation when driving through urban areas. Motorway operation may be interrupted by short periods of urban or rural operation, e.g., when passing toll stations or sections of road work.";

JRC guidance:

also advisable to design alternative routes and/or local detours. It is also recommended to avoid using the same street more than twice in a specific route.

- Start at JM (for cold-start) and end at JM or within short (< 30 min) drive
- No repeated loops in cycle
- Minimise 'there and back' driving – not realistic
- Include anticipated high stress events i.e. light-out, uphill accelerations
- Standard urban route to make routes more comparable and easier to operate

Further Route Development – Royston Urban

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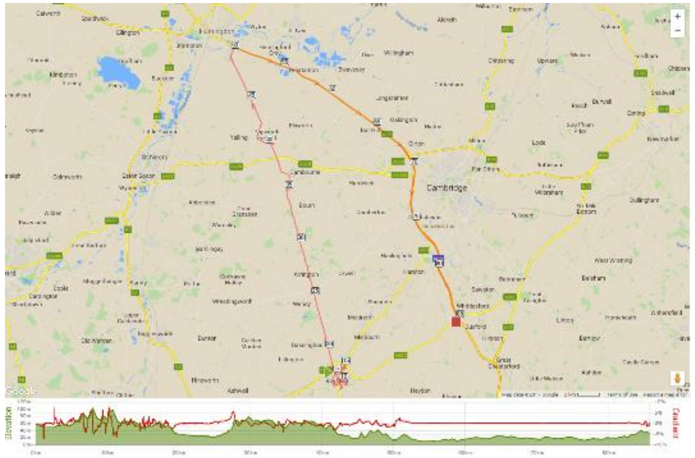
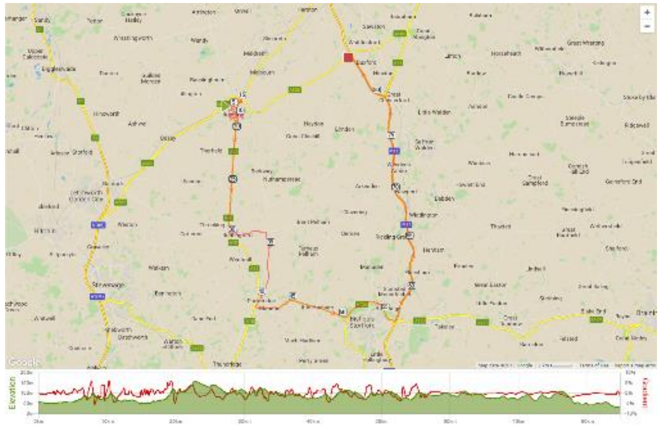
Urban – Motorway sections

Developed 4 different rural and motorway routes to allow contingency and to give different options for testing catalyst performance

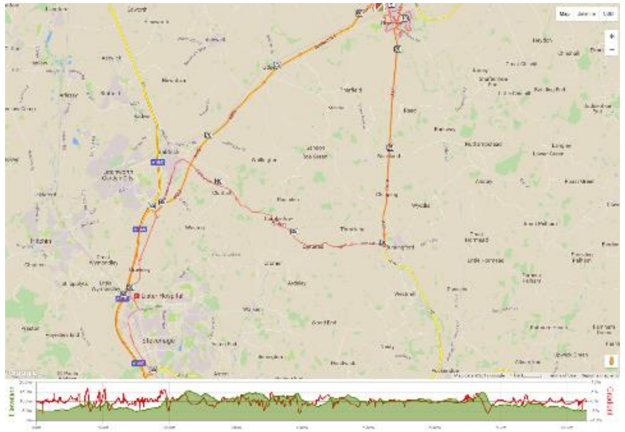
NE route



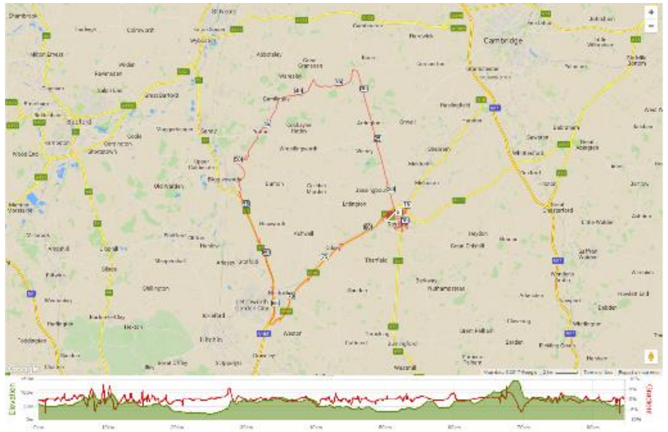
SE route



SW route

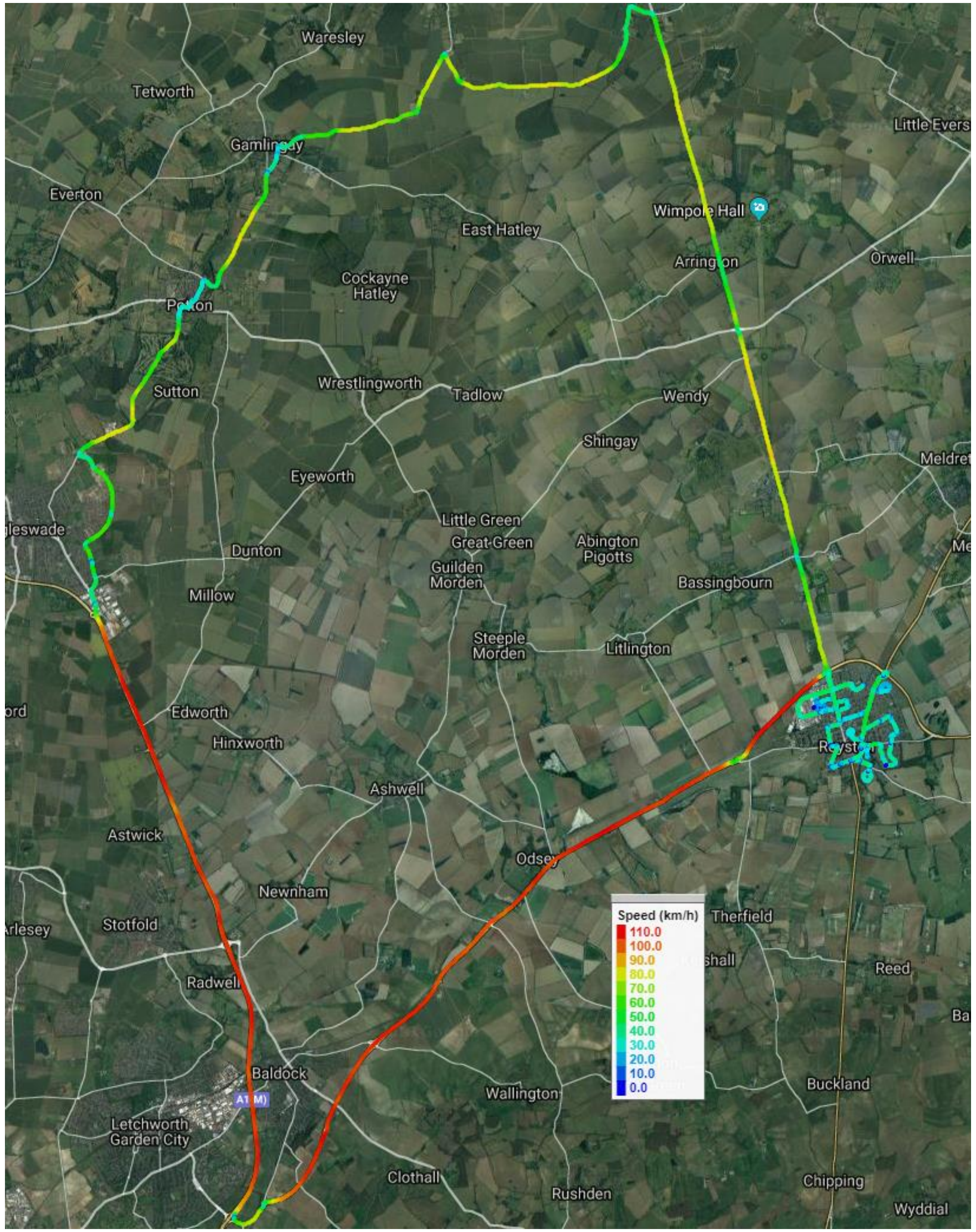


NW route



NW Route

NW Route includes Royston Urban with no repeated loops, then rural and motorway loop back to JM



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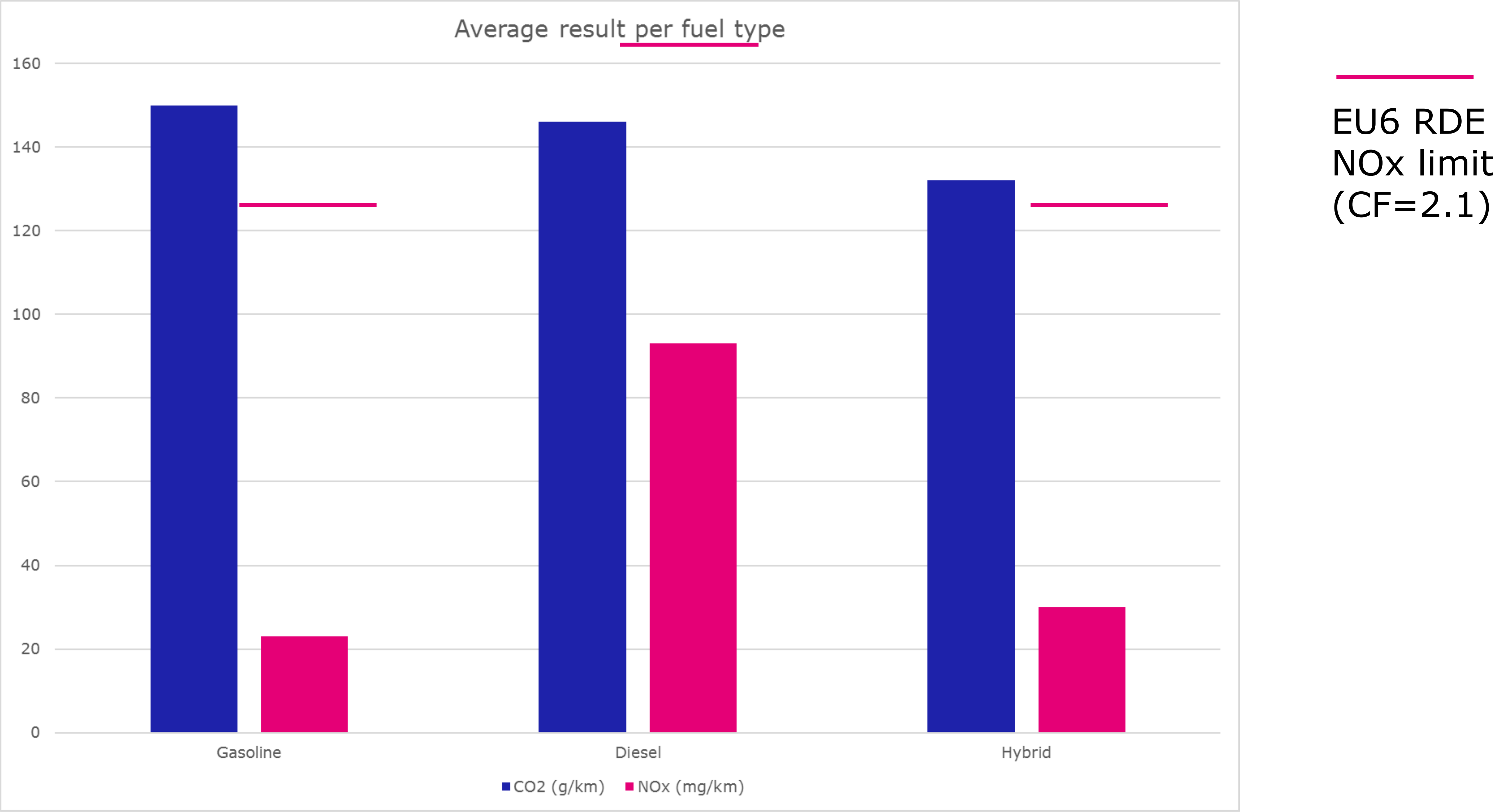
RDE Results

Royston Data Summary



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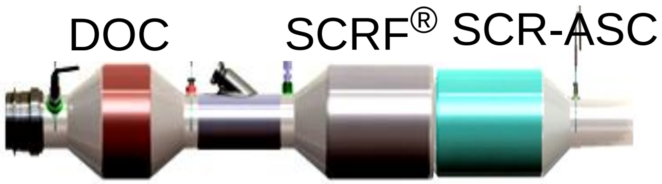
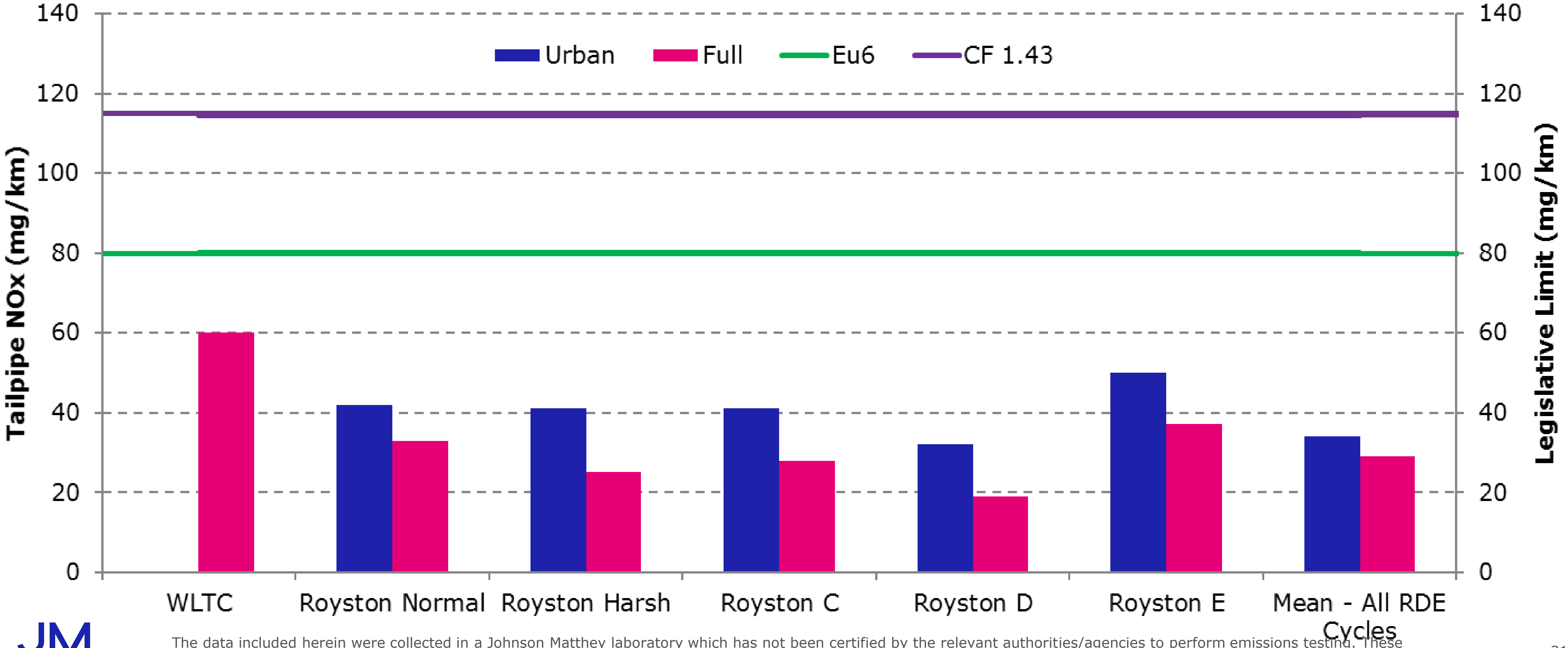
Royston Eu6 Diesel Vehicle Real World NOx

	"Normal"	"Harsh"	C	D	E
Elevation Rate (m/km)	455	754	548	670	706
Length (km)	84	93	82	92	95
Average Speed (kph)	51	56	53	50	53



De-greened Catalysts



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Road to Rig Correlation

Road to Rig Testing

- To support rapid catalyst development and improve repeatability it is necessary to have a repeatable laboratory test cycle

PEMS on-road testing to gather vehicle emissions & ECU data

On-road tests re-played in the CVS laboratory multiple times

Final validation carried out on-road

Road to Rig Correlation

2 Methods

Driver	Control 1	Control 2	Advantage	Disadvantage
Robot	Vehicle Speed	Throttle Position	- Engine load is matched exactly - Good for automatic vehicles	- set up time is slow - Need to collect throttle position from the road - Need ECU access for throttle
Human	Vehicle Speed	Gradient	- Quick set up - No special data needed for the vehicle	- some road forces are missing (ambient wind, cornering…)

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1) Robot Driven

Control Throttle Position & Speed

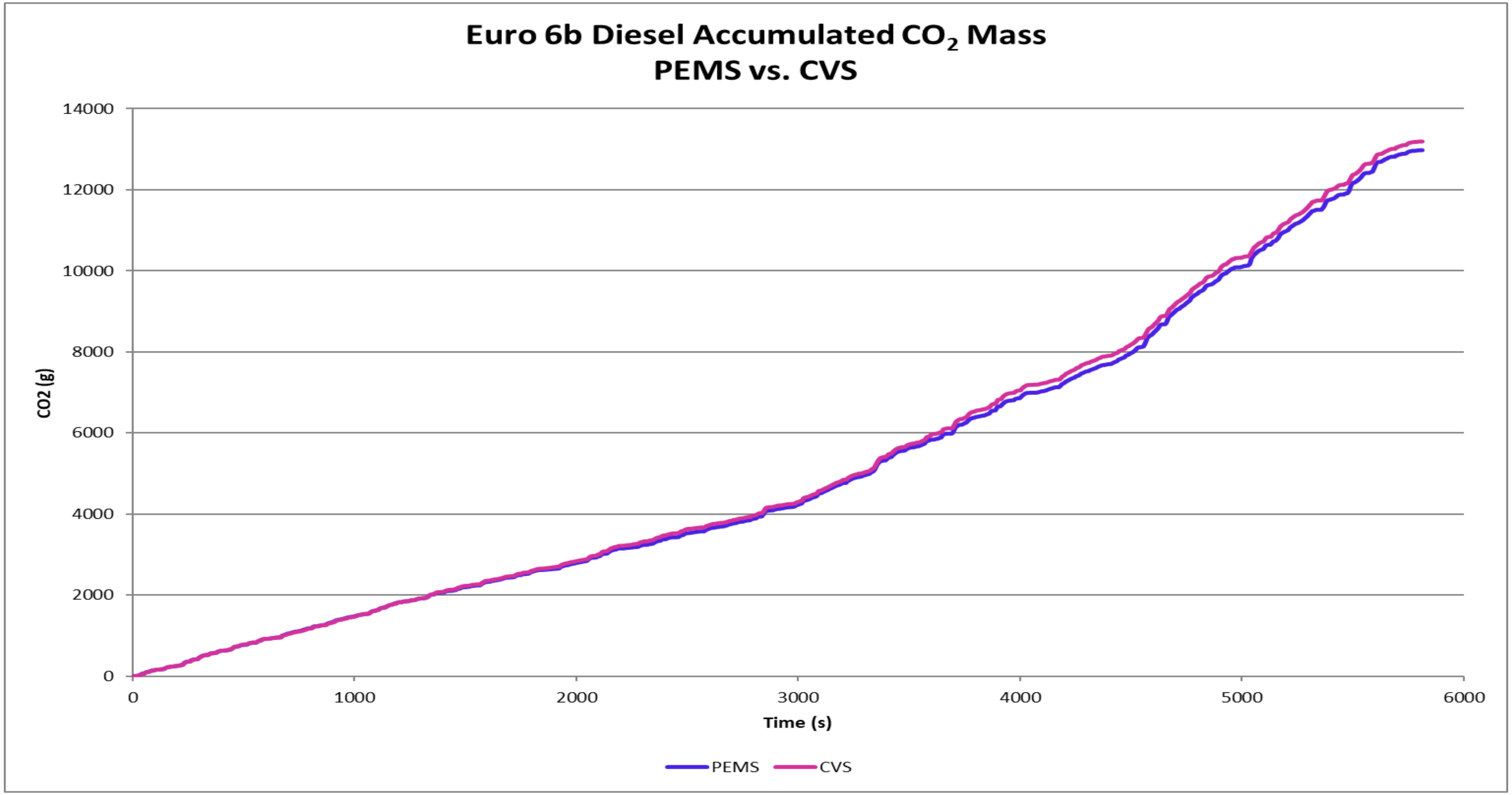
- Accelerator pedal position recorded when the vehicle was driven by a human on the road

- Robot replicates throttle position

- Dynamometer controls vehicle speed as recorded on the road

Results

Accumulated CO_2 (g)



1.6% difference

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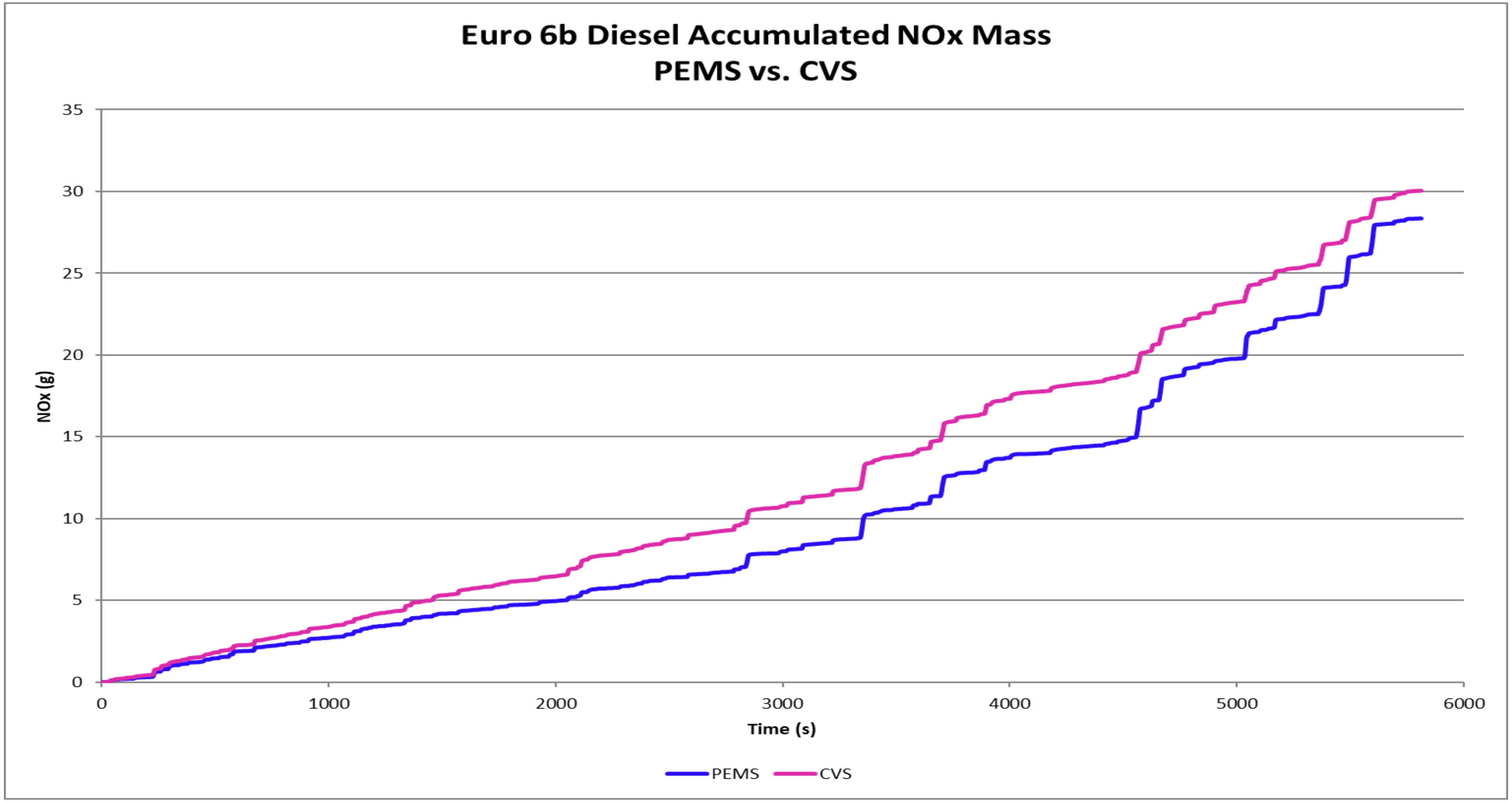
Results

Accumulated NOx (g)



6% difference

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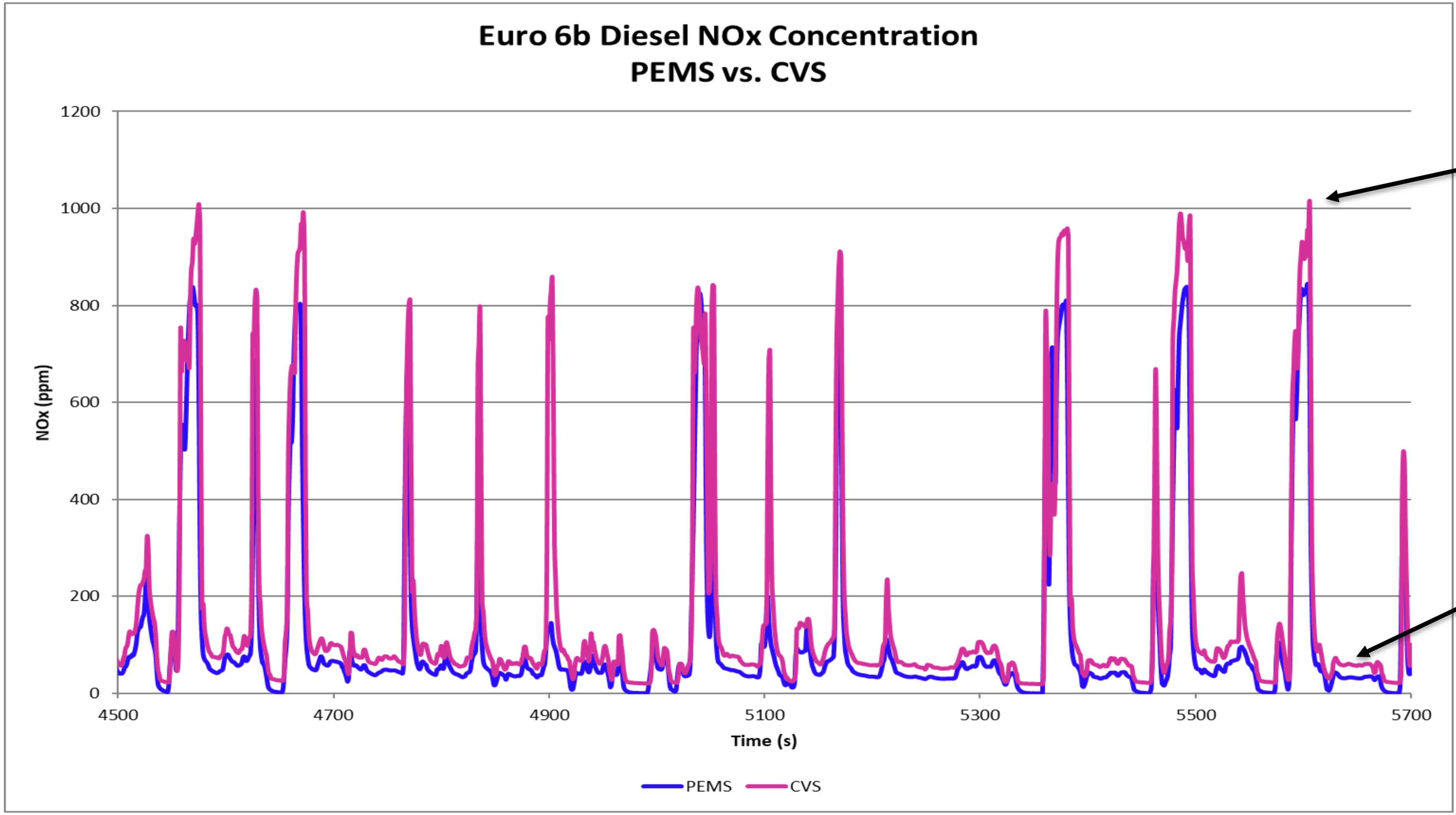
Results

NOx Concentration



Higher peak on CVS accelerations

Errors in PEMS flow rate – compromise on which diameter flow tube to use

2) Dynamic Gradient Simulation

Control Road Load Gradient & Speed

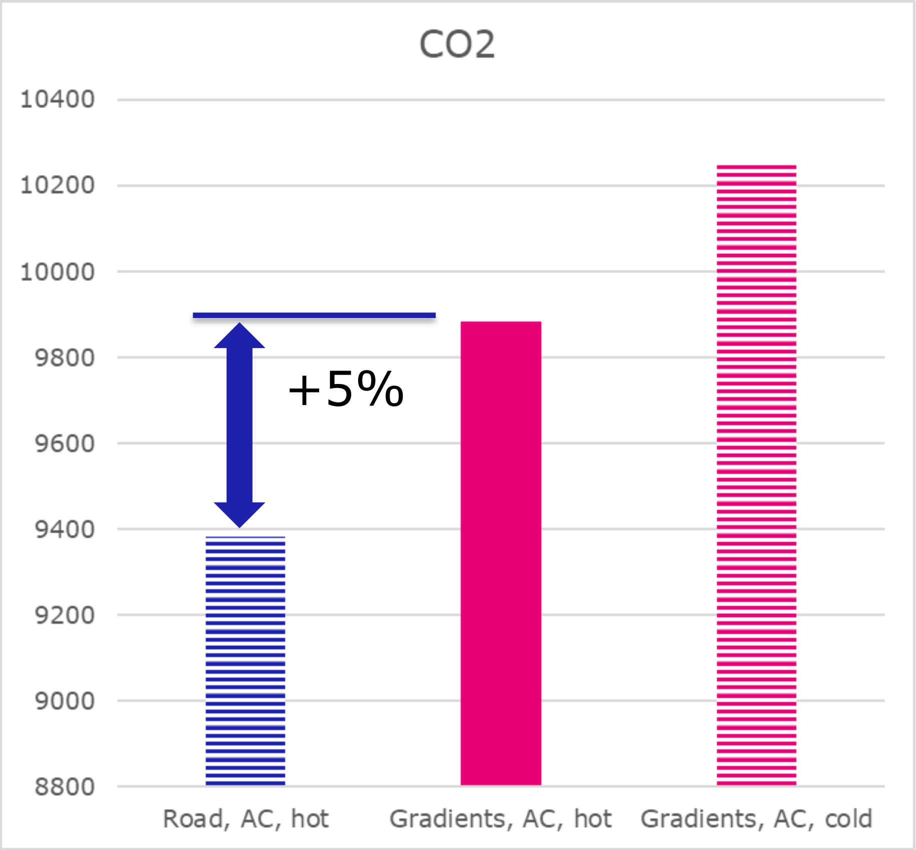
- The road load on the dynamometer is continually adjusted to match the simulated gradient

Test	Matching		
	Gradient	Air Con	Start
11-13-07	Y	N	Cold
11-14-04	Y	Y	Cold
11-15-05	Y	Y	Cold
11-17-04	N	Y	Cold
11-19-01	N	Y	Cold
11-19-02	Y	Y	Hot

To be investigated:

- Effect of A/C on CO_2
- Effectiveness of gradient replication
- Effect of hot vs. cold start

CO_2 Comparison

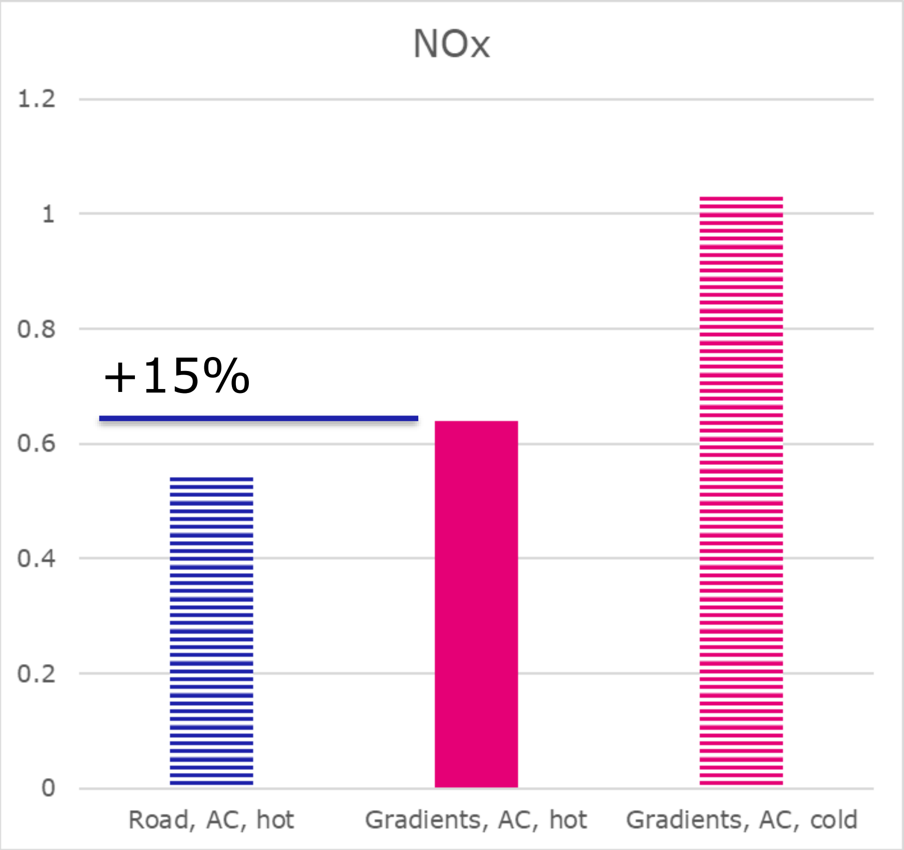


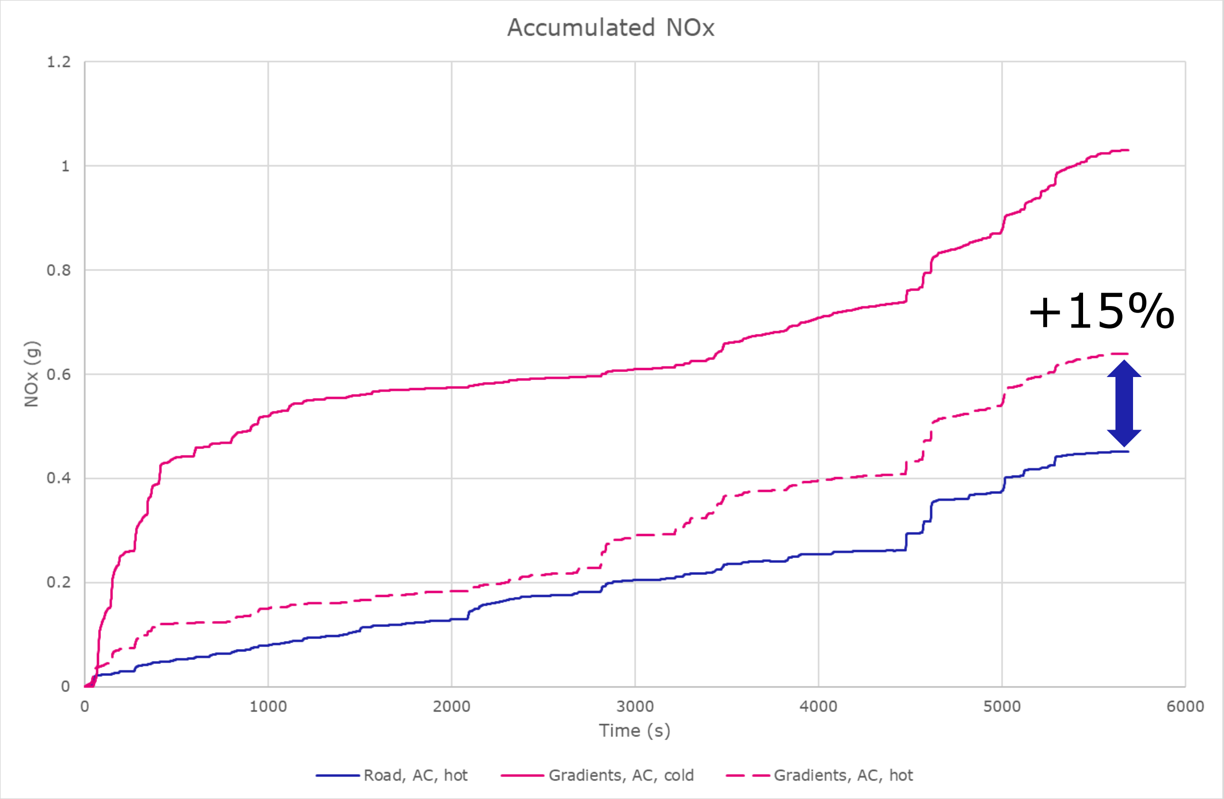
When replicating gradient, AC, hot start, CO_2 within 5%

Wind speed affects motorway section CO_2 correlation – on-road test had 10 km/h tail wind which cannot be replicated in the laboratory

~4% increase in CO_2 when cold start is simulated

NOx Comparison





When replicating gradient, AC, hot start, NOx within 15%

~80% increase in NOx with cold start

Summary

Johnson Matthey, Royston has been developing RDE routes and using PEMS equipment for over 2 years

Working in collaboration with the Gasoline & Diesel catalyst development groups to understand the different requirements for Gasoline, Diesel and xEV vehicles

Real on-road drive cycles have been brought into the test laboratory to provide more repeatability and to assist catalyst development for stress events, but final on-road confirmation is necessary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