



**Johnson Matthey**  
Inspiring science, enhancing life

# Catalyst technologies for current and future vehicle emissions legislation

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10<sup>th</sup> January 2020



# JM has a holistic approach to support clean mobility

## ICE

Emission Control Catalysts  
TWC / GPF  
DOC / LNT / CSF / SCR / SCRF / ASC



Pt

Pd

Rh

## BEV

Li-Ion Battery Materials  
Lithium Iron Phosphate  
Nickelate Materials  
High Voltage Spinel  
Lithium Titanate

Li

Ni

## PHEV

Emission Control Catalysts  
Li-Ion Battery Materials



Li

## FCEV

Hydrogen Catalysts  
On-Board Reforming  
Proton Exchange Membranes  
Coated Catalyst Systems  
Membrane Electrode Assemblies  
Li-Ion Battery Materials

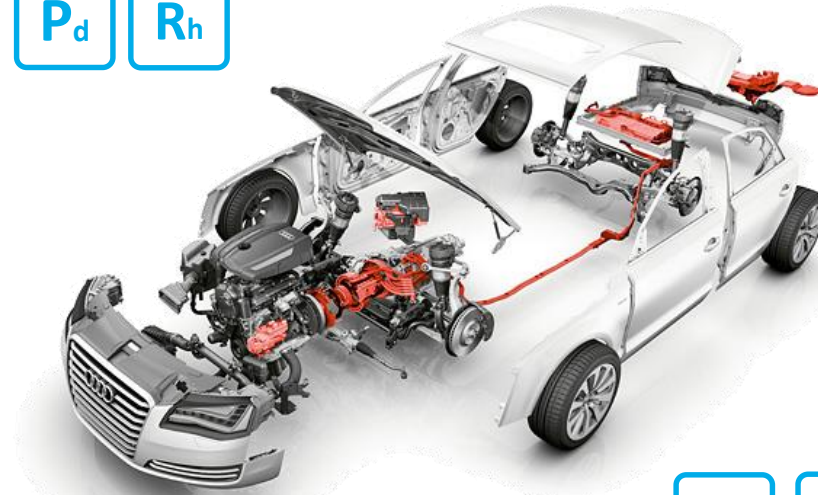
Ru

Ir

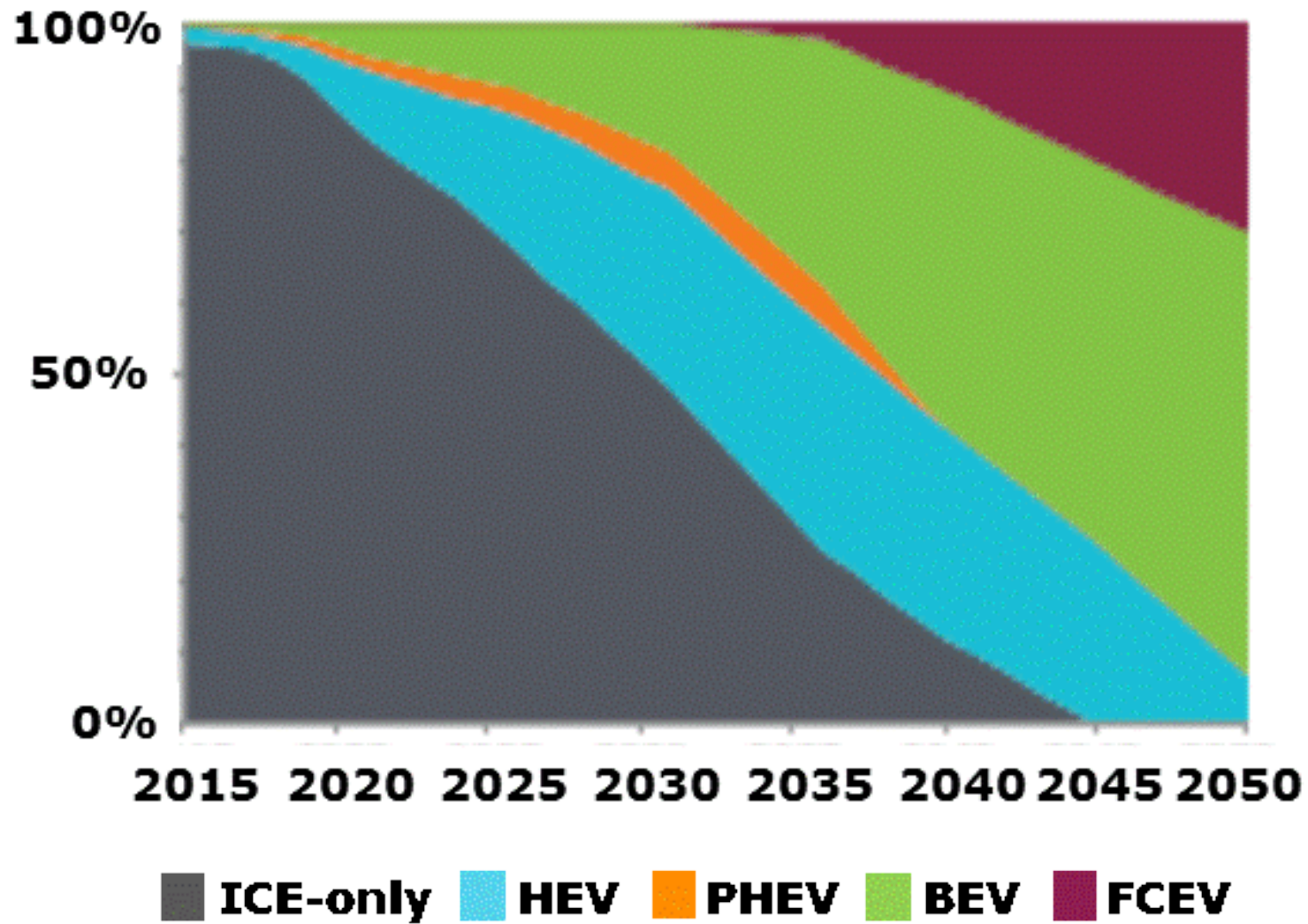
Pt

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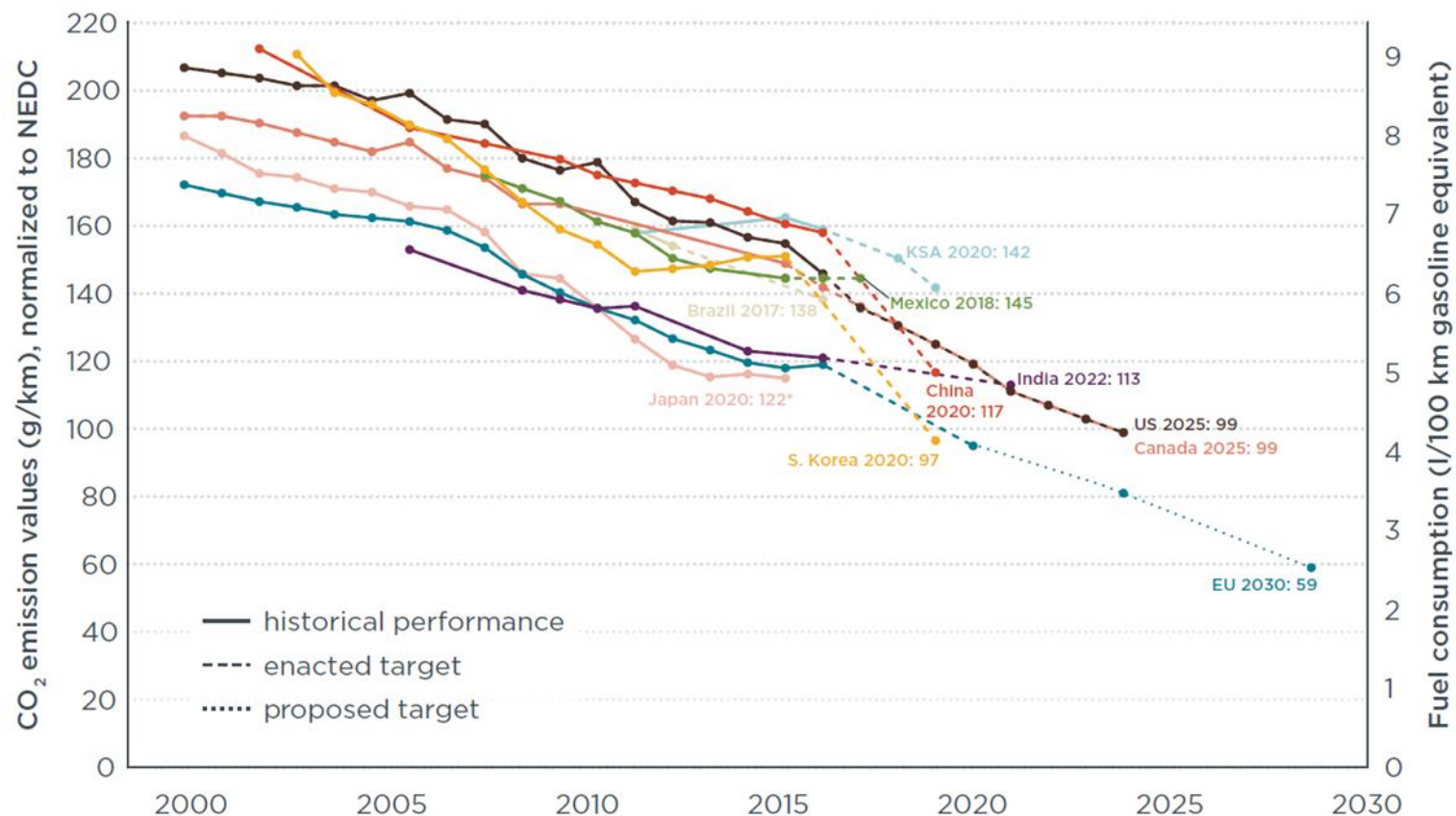


# The Internal Combustion Engine still has some life...



LMC Automotive

# Tightening CO<sub>2</sub> / Fuel Economy / GHG Requirements



**Additional GHG limits for the US:**

N<sub>2</sub>O: 0.010 g/mile  
CH<sub>4</sub>: 0.030 g/mile

\* Note that Japan has already met its 2020 statutory target as of 2013

Supporting data can be found at: <http://www.theicct.org/info-tools/global-passenger-vehicle-standards>

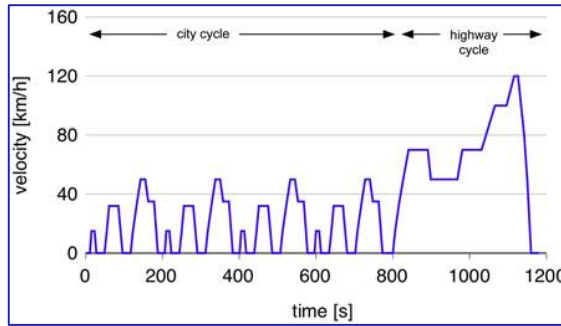
Leads to lower catalyst temperatures and increased electrification

# Light duty emissions control – European legislation

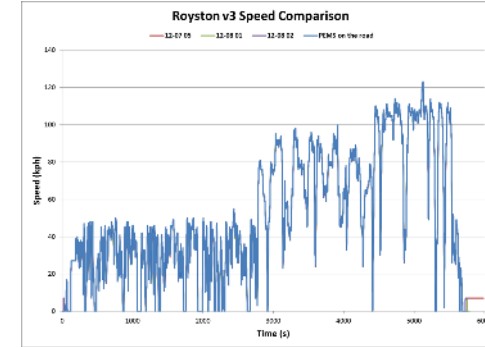
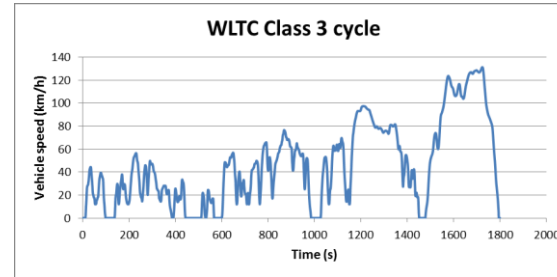
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Europe	EU 6b		EU 6c / Euro 6d temp			Euro 6d final / 95 g/km CO <sub>2</sub>		EU 7?			
North America EPA	Tier 2		Tier 3 Phase In: NMOG + NOx, PM Tightening								
North America CARB	LEV III		<ul style="list-style-type: none"> <li><b>Euro 6b – In full effect from September 2015</b> <ul style="list-style-type: none"> <li>Common use of Diesel NOx control</li> </ul> </li> <li><b>Euro 6c – From September 2017</b> <ul style="list-style-type: none"> <li>Gasoline particle number (PN) limit to 6x10<sup>11</sup>/km</li> </ul> </li> </ul>			<b>Real World Driving Emissions (RDE)</b> <ul style="list-style-type: none"> <li>Euro 6d Temp 2017/2019                             <ul style="list-style-type: none"> <li>NOx conformity factor (CF) of 2.1x, PN CF of 1.5x</li> </ul> </li> <li>Euro 6d Final 2020/2021                             <ul style="list-style-type: none"> <li>NOx CF of (1+0.43)x – down from 1.5</li> <li>PN CF of (1+0.5)x</li> </ul> </li> </ul>					
Japan	JP										
South Korea (Gasoline)	K-ULEV										
South Korea (Diesel)									EU 7?		
China (Beijing & big cities)									/ RDE		
China (Nationwide)	China 4 (EU)										
India	BS3 (EU)		<ul style="list-style-type: none"> <li>Implementation of WLTP drive cycle to replace the unrealistic NEDC, plus tightening of rules on test vehicle mass etc</li> </ul>			<ul style="list-style-type: none"> <li>European Commission now formally timetabled discussions on post Euro 6 emissions legislation, expected to take effect <i>ca.</i> 2025</li> </ul>			RDE		
Indonesia (Gasoline)											
Indonesia (Diesel)											
Thailand	EU 4					EU 5		EU 6			

# Test cycle evolution

## NEDC



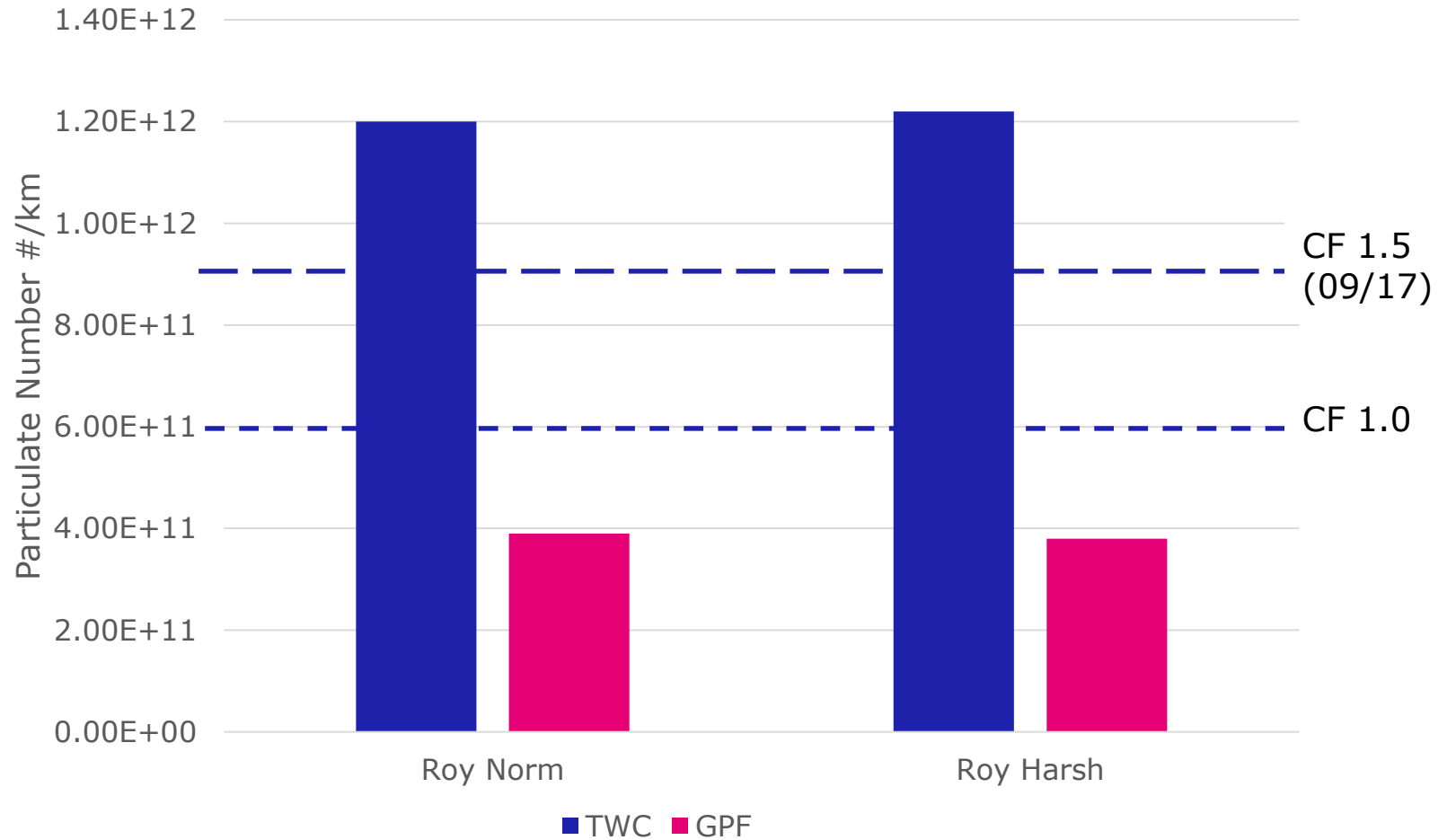
## WLTP plus RDE



							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 <sub>pos</sub> 95 RPA

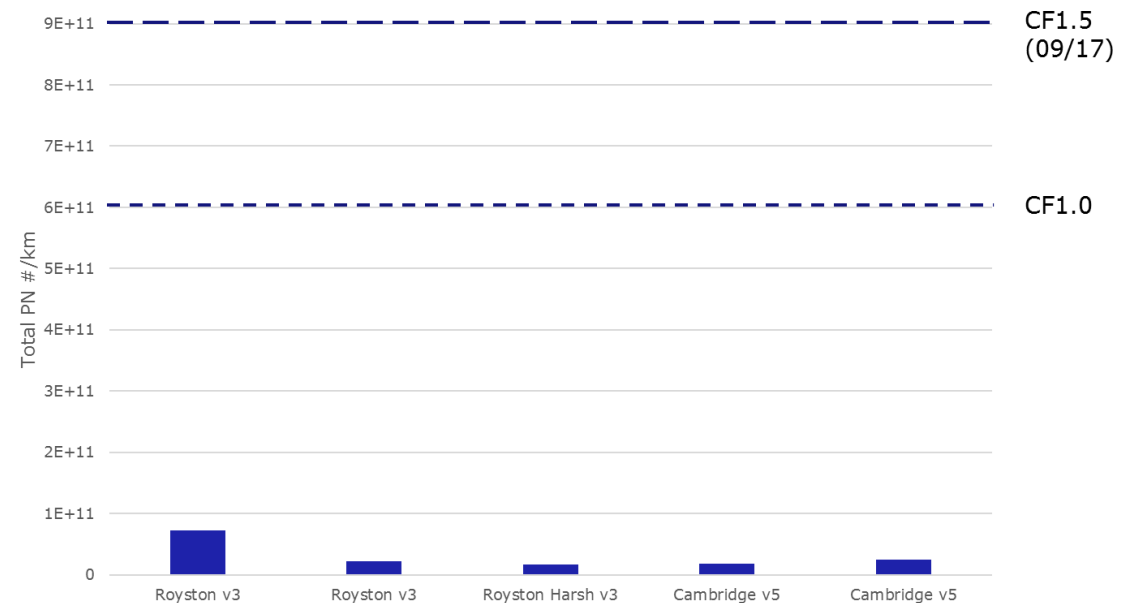
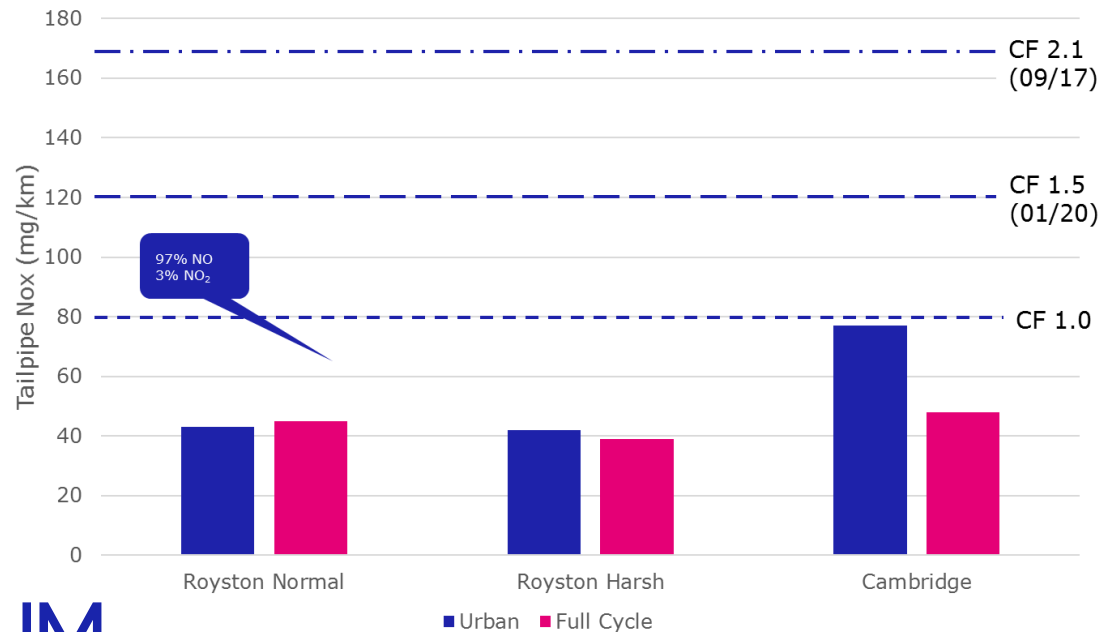
# JM RDE demonstration of coated GPF

Standard Gasoline Euro 6b vehicle retrofitted with aged GPF (no change to vehicle calibration)



# JM RDE Evaluation of modern Diesel car

- Mercedes E220d 2.0L Eu6
- State of the art JM diesel catalyst and filter system
  - DOC + SCRF + SCR + SCR/ASC
  - Artificially aged to replicate full useful life (160,000 km)

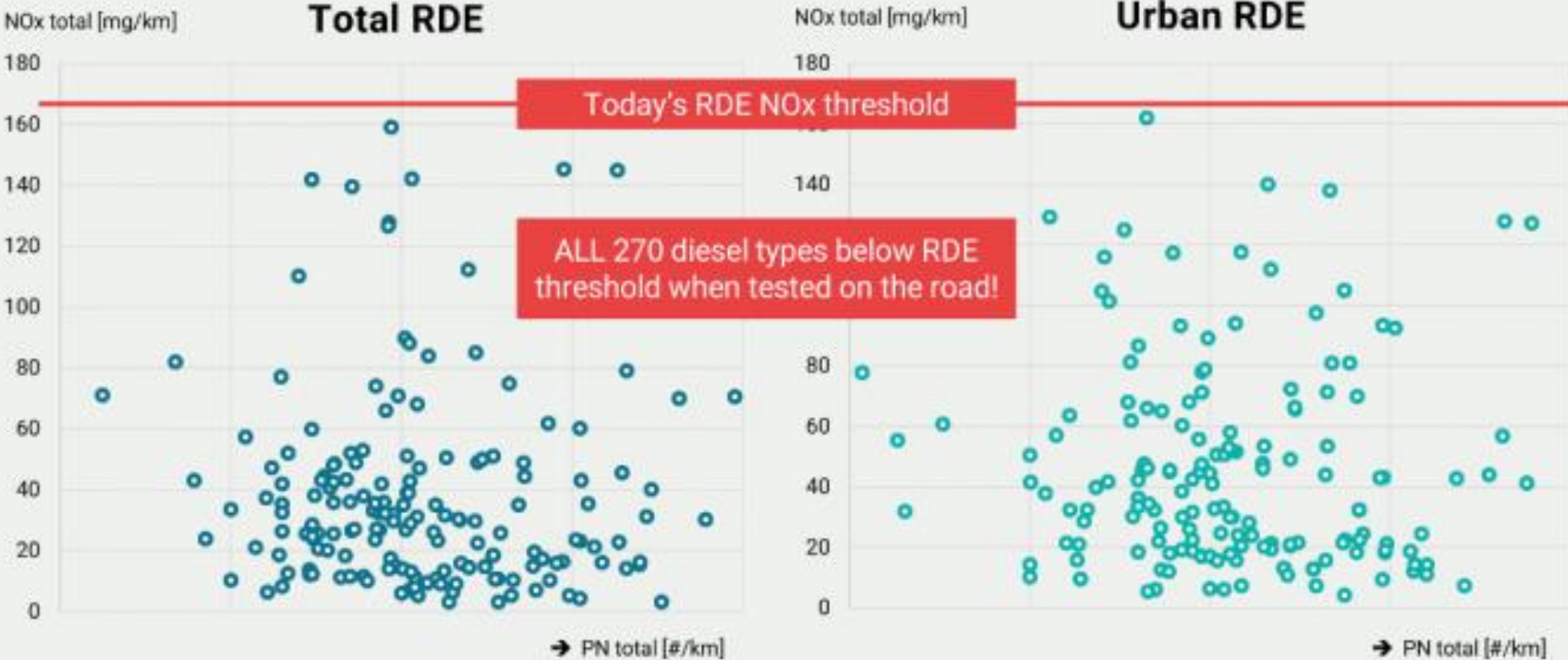


The data included herein were collected in a Johnson Matthey laboratory which has not been certified by the relevant authorities/agencies to perform emissions testing. These are indicative data and do not represent a guarantee that the tested catalyst or emissions system will pass the relevant emissions legislation.



# Many Light Duty Diesel Vehicles Meeting Euro 6d Today

## MODERN DIESEL CARS EMIT LOW POLLUTANT EMISSIONS ON THE ROAD, NEW DATA PROVES



# AECC Ultra-low NOx diesel demonstrations on You Tube

The screenshot shows a YouTube search results page for the query 'aecc ultra-low NOx diesel'. The search bar at the top contains the text 'aecc ultra-low NOx diesel'. The left sidebar shows navigation options like Home, Trending, History, and Get YouTube Premium, along with a 'BEST OF YOUTUBE' section listing categories like Music, Sports, Gaming, Films, TV Shows, News, Live, Fashion, and Spotlight. The main content area displays five video results, each with a thumbnail, title, channel name, view count, and a brief description. The videos are:

- City driving with ultra-low NOx mild-hybrid diesel** (AECC eu, 5 months ago, 322 views): Explore how the NOx emissions are reduced from engine-out (left) towards near-zero levels at the tailpipe (right) during city ...
- Rural driving with ultra-low NOx mild-hybrid diesel** (AECC eu, 5 months ago, 273 views): Explore how the NOx emissions are reduced from engine-out (left) towards near-zero levels at the tailpipe (right) during rural ...
- Motorway driving with ultra-low NOx mild-hybrid diesel** (AECC eu, 5 months ago, 213 views): Explore how the NOx emissions are reduced from engine-out (left) towards near-zero levels at the tailpipe (right) while ...
- AECC unveils what a future-proof diesel car looks like** (AECC eu, 3 months ago, 657 views): AECC's ultra-low NOx diesel demonstrator vehicle was the centre of attention on 3 July when regulators, industry professionals, ...
- City driving with ultra-low NOx mild-hybrid diesel demonstrator car** (AECC eu, 6 months ago, 888 views): Explore how the NOx emissions are reduced from engine-out (left) towards near-zero levels at the tailpipe (right) during city ...

Each video thumbnail includes a 'Filters' dropdown and a 'SUBTITLES' button. The thumbnails also show a small inset of the NOx emissions data being discussed in the video descriptions.

# Expectations for Post Euro 6/VI

- European Commission started discussions on Post-Euro 6/VI (not yet called Euro 7/VII!)
- Light Duty expectations
  - Fuel and technology neutral, *i.e.* same limits apply to gasoline and diesel vehicles, level playing field for conventional ICE and hybrid vehicles
  - NOx likely to be between 35 and 60 mg/km (range from China 6b to Euro 6 gasoline)
  - RDE conformity factors of 1x, some OEMs expecting shorter urban RDE distance
  - Additional controls for N<sub>2</sub>O, NH<sub>3</sub>, NO<sub>2</sub> possible to likely
- Heavy Duty Diesel expectations
  - Developing to CARB 202x expected limits as likely to worst case (latest signals from CARB are 0.05g/bhp-hr for MY24, 0.02g for MY27, 850k miles FUL but still subject to change)
  - Tight control of NOx emissions: warm-up strategy and high NOx conversion efficiency

# Gasoline Catalyst Systems

- Two families of architectures for Euro 7
  - TWC + coated GPF – most compact
  - TWC + uncoated GPF + TWC – simpler for OEMs to calibrate and control
- Variations include
  - Additional TWC volume for high speed NOx control
  - Use of electrical heating for light-off/urban driving
  - High filtration efficiency requirements
- No special requirements for hybrids
  - Electrification generally assumed in OEM base case

Three Way Catalyst (TWC) plus coated Gasoline Particulate Filter (cGPF)



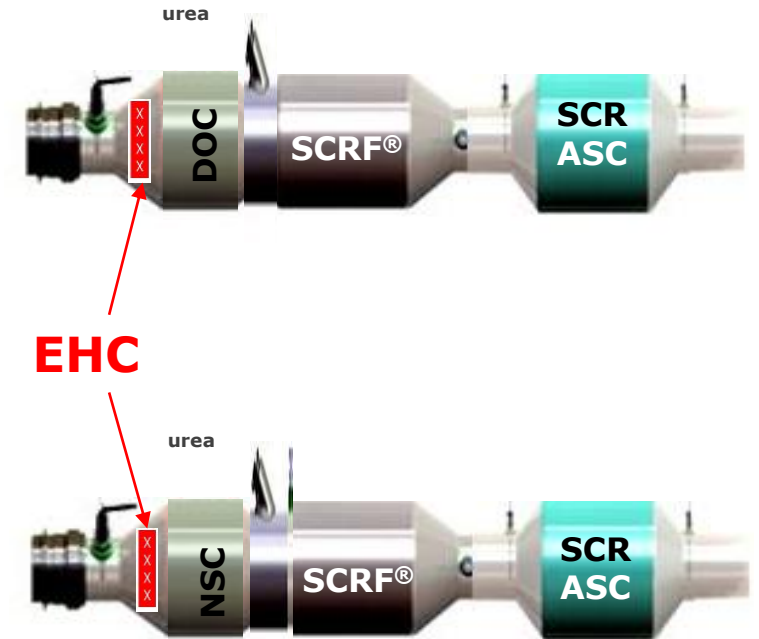
Three Way Catalyst (TWC) and uncoated Gasoline Particulate Filter (uGPF) plus downstream TWC



# Light Duty Diesel (LDD) Catalyst Systems

- Two families of architectures for Euro 7
  - Heated DOC + SCRF + SCR/ASC – simpler to calibrate
  - NOx Storage Catalyst + SCRF + SCR/ASC – better urban NOx
- Variations include
  - Increased SCR volume for high speed NOx control
  - Additional close coupled SCR slice for urban driving
  - Use of electrical heating for light-off/urban driving/low T urea injection
  - High filtration efficiency requirements, especially at high load/after soot regeneration

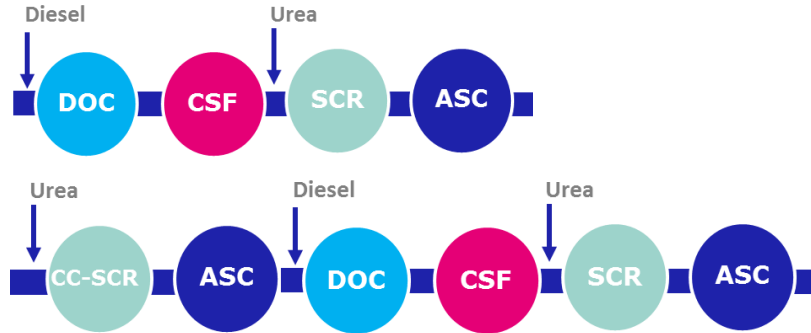
Typical Euro 7 LDD architectures



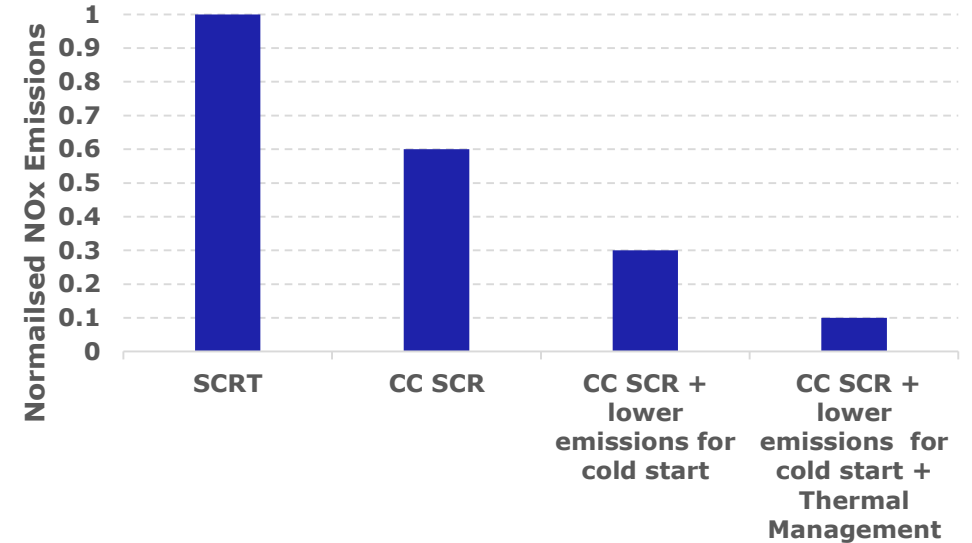
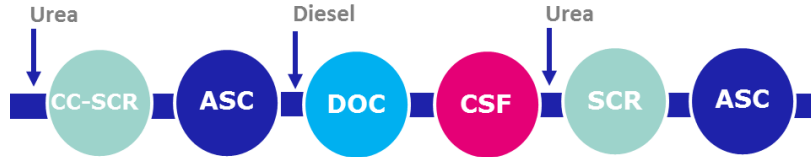
# HDD systems for future legislation e.g. CARB and Euro VII

## Effect on NOx emissions when adding $CC$ SCR + ASC components

SCRT®



$CC$  SCR + SCRT®



- CC SCR configuration is expected to yield a significant gain in NOx conversion
- To reach future very low emissions targets, will need to be complemented by improved thermal management and lower Engine Out NOx levels

# Key Catalyst System Development Targets

## Systems for enhanced NO<sub>x</sub> reduction

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Better fuel efficiency / lower CO<sub>2</sub> typically leads to increased engine-out NO<sub>x</sub> emissions, while limits are reducing

## Lower temperature operation

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The drive for improved fuel efficiency / reduced CO<sub>2</sub> leads to lower catalyst operating temperatures

## Robust particle number reduction

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Lower PN emissions, especially in real-world driving conditions

## Smaller, lighter systems at lower cost

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Cost reductions, through e.g. size reduction and pgm reduction

## Reduced system backpressure

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To maximise power delivery from engine and minimise fuel consumption

## Precious metal balance

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Pd prices increasing, desire to substitute some Pt

## Lower N<sub>2</sub>O emissions (potent GHG)

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Catalyst systems which generate lower N<sub>2</sub>O levels

# Glossary

- ACEA - Association des Constructeurs Européens d'Automobiles
- AECC – Association for Emissions Control by Catalyst
- ASC – ammonia slip catalyst
- BEV – battery electric vehicle
- CARB – California Air Resources Board
- CC – close coupled
- CSF – coated soot filter
- DOC – diesel oxidation catalyst
- EHC – electrically heated catalyst
- FCEV – fuel cell electric vehicle
- FUL – full useful life
- GHG – greenhouse gas
- GPF – gasoline particulate filter
- HEV – (mild) hybrid electric vehicle
- ICE – internal combustion engine
- MY – model year
- NEDC – “New” European Drive Cycle
- NOx – oxides of nitrogen
- NSC – NOx storage catalyst
- OEM – original equipment manufacturer
- PGM – platinum group metals (Pt, Pd, Rh...)
- PHEV – plug-in hybrid electric vehicle
- PN – particulate number
- RDE – real-world driving emissions
- SCR – selective catalytic reduction
- SCRf – SCR on a filter
- TWC – three way catalyst
- WLTP – World-harmonised Light-duty Test Protocol



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