Johnson Matthey
Inspiring science, enhancing life

# Johnson Matthey – ECMA

## On-road BSVII & $H_2$-ICE Challenges and Strategies

Oct 2024

# Contents

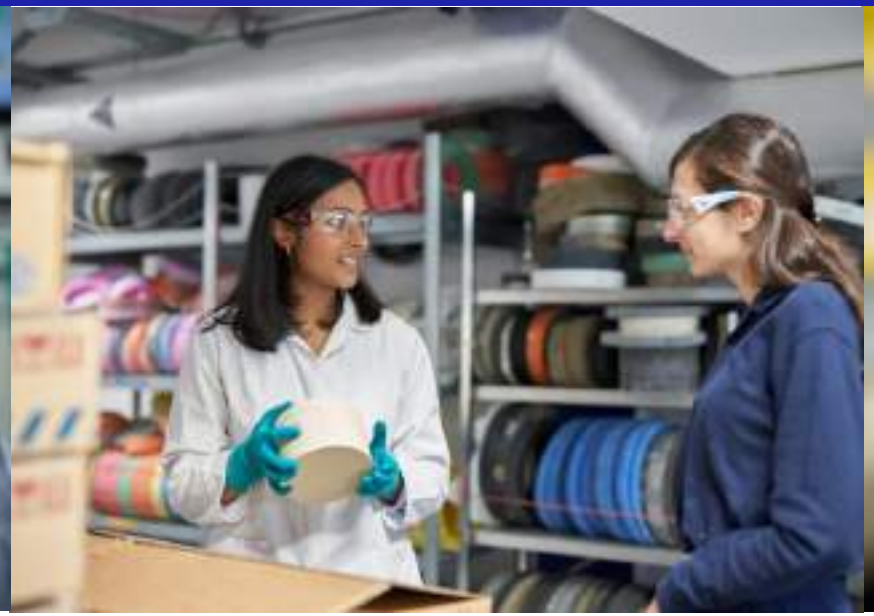
# Johnson Matthey: strong credentials supporting our strategy

Strong brand
**207 year history**

Technology leadership
**#1 or 2**
in chosen markets

2023/24 sales[1]
**£3.9 billion**

**11,600 employees**
worldwide[2]



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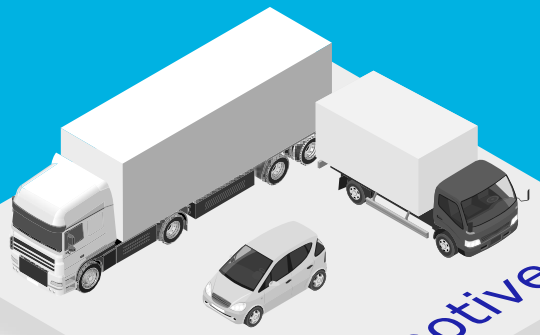
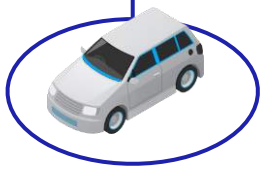
[1]Sales excluding precious metals [2] As at 31st March 2024



## Automotive

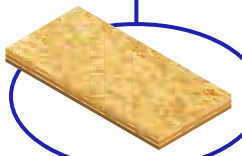
Emission control systems



Components for fuel cells

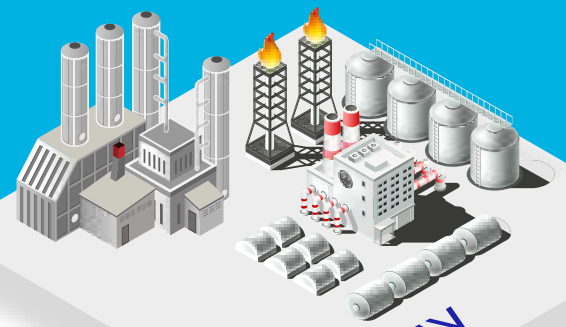
## Chemicals


Sustainable methanol and ammonia technology



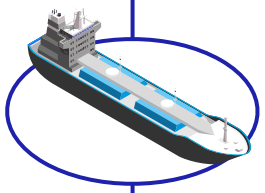
Sustainable formaldehyde technology

Low carbon solutions



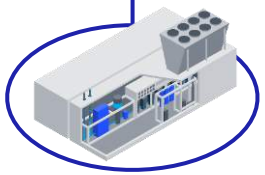
## Energy

Sustainable fuels technology



Sustainable methanol and ammonia technology

Blue hydrogen technology



Components for green hydrogen electrolysers

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**Catalysing** the net zero transition

**Aspiring t**o lead across our four businesses

**Clean Air**

Leading in autocatalyst markets

**Catalyst Technologies**

#1 in syngas-based chemicals and fuels technology

**Hydrogen Technologies**

Market leader in performance components for fuel cells and electrolysers

**PGM Services**
(Platinum Group Metals Services)

#1 recycler of PGMs[1]

1. Iridium, Palladium, Platinum, Rhodium and Ruthenium

# Driving down transport emissions

We’re driving down the emissions of internal combustion engine vehicles and enabling the transition to net zero transport

**Emission control systems** for diesel, gasoline & hydrogen internal combustion engine vehicles

**1 in 3**

new cars contain a catalytic converter made by JM

Components for **hydrogen fuel cells** for cars and commercial vehicles

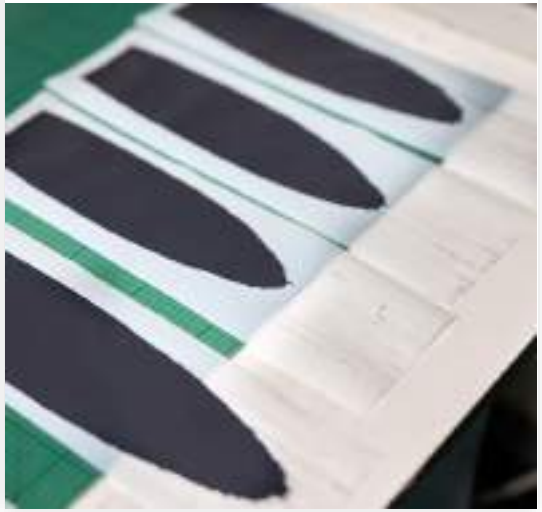
**30+ years’**

experience in fuel cells catalysts
(and even back to 1842!)

Note: William Grove invented the fuel cell in 1842, using platinum supplied by JM

# 2023/24: A year of progress

Recycling PGM's and precious ionomer from fuel cell and electrolyser material using **HyRefine™ technology** enables circularity for hydrogen customers.



Johnson Matthey **LCH™ technology** enables blue hydrogen production whilst capturing more than 97% of carbon used in the process.

Johnson Matthey can offer **100% recycled platinum group metal (PGM)** to achieve complete circularity for customers.

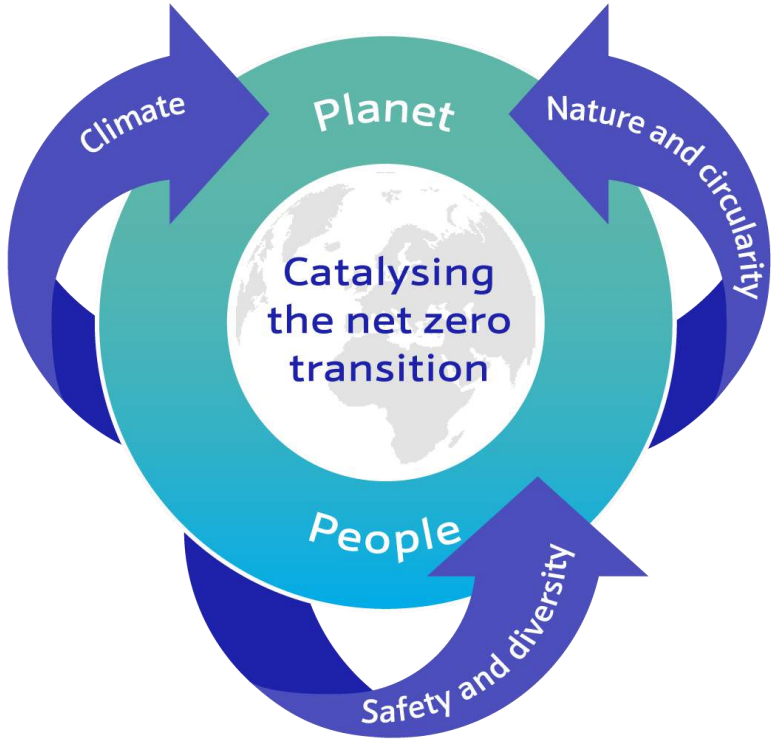
**50 years since pioneering the first commercial auto catalysts**, JM catalysts prevent 98 % of emissions from entering the atmosphere.

# Committed to sustainability: protecting planet and people

**Protecting the climate**

Drive lower global greenhouse gas (GHG) emissions

Achieve net zero by 2040




**Protecting nature and advancing the circular economy**

Conserve scarce resources

Minimise our environmental footprint

**Promoting a safe, diverse and equitable society**

Keep people safe | Create a diverse, inclusive and engaged company | Uphold human rights | Invest in our local communities

## ...that are recognised by leading ESG rankings

| | |
|---|---|
| PLATINUM 2022 ecovadis Sustainability Rating | **Top 1% Platinum** rated |
| Member of Dow Jones Sustainability Indices Powered by the S&P Global CSA | 92nd **top percentile** |
| CDP DISCLOSURE INSIGHT ACTION | **'B' Climate** rated |
| MSCI | **AAA** rated |

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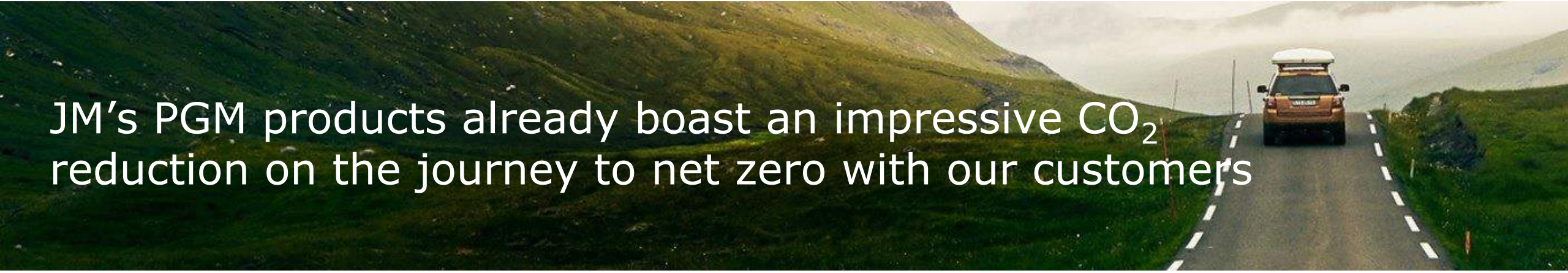


# JM's PGM products already boast an impressive $CO_2$ reduction on the journey to net zero with our customers

**World leader**

JM is the **largest secondary** recycler of PGMs by volume

**Pioneering**

We helped create one of the **world's first circular economies** in platinum group metals

**> Two thirds recycled PGM**

On average, **c.a. 70%** of the PGM used in our manufacturing plants globally was from **secondary sources** in FY22

**Scope 3 $CO_2$ Reduction**

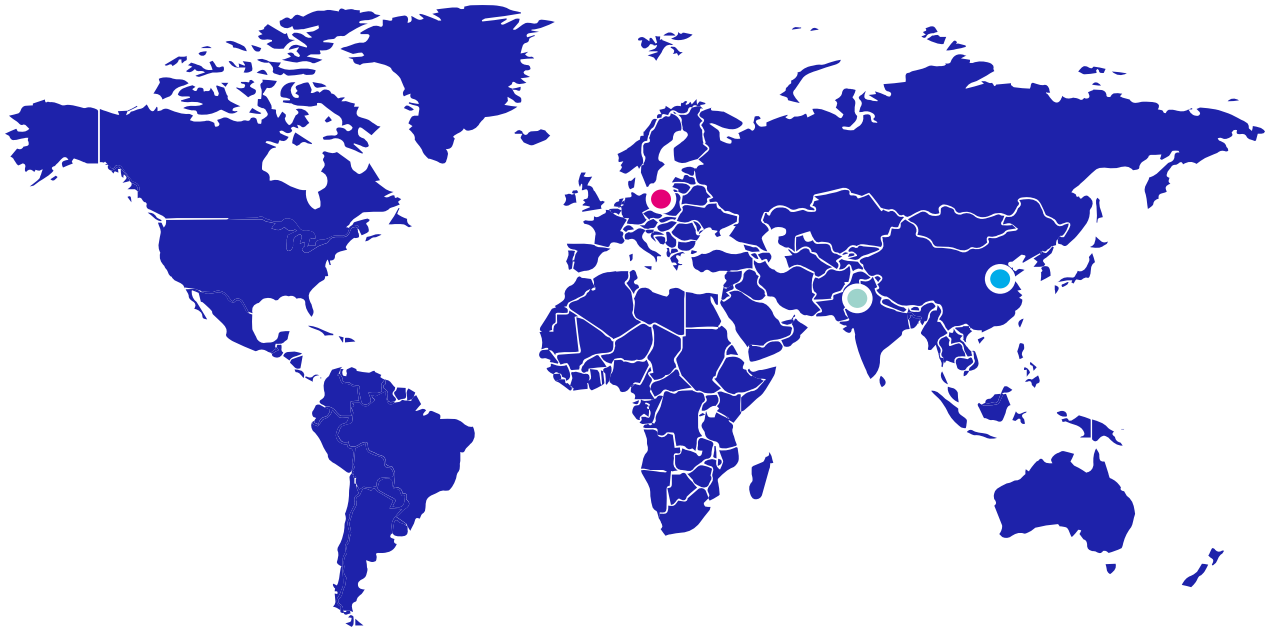
**Secondary** or **recycled** PGMs are anywhere from 10-60x lower in carbon intensity (tCO2e/kg) than **primary** (mined) metal*

JM

*GaBi Database 2021 (IPA 2022)

# Strong manufacturing and R&D presence to meet global customer demand

**16 manufacturing and 11 R&D centres globally**



**New manufacturing plants adding capacity**

**EU (Poland)** | **China** | **India**

**North and South America**

**4** manufacturing facilities
**3** R&D centres

**Europe, CIS & Africa**

**6*** manufacturing facilities
**4** R&D centres

**China**

**2*** manufacturing facilities
**1** R&D centre

**Japan**

**1** manufacturing facilities
**1** R&D centre

**India**

**2*** manufacturing facilities
**1** R&D centre

**Rest of Asia**

**1** manufacturing facility

* including the new manufacturing plants

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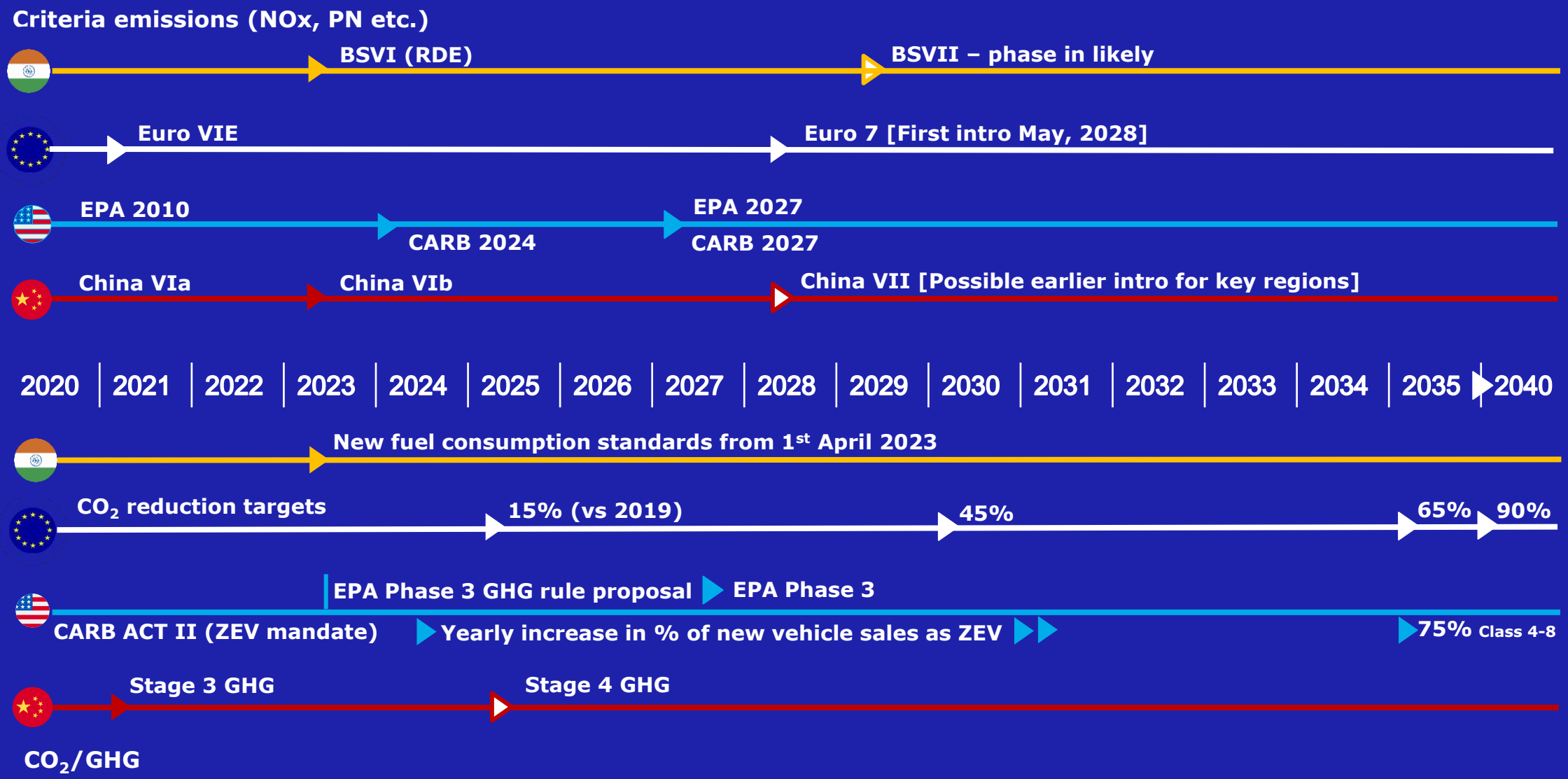
# Heavy Duty legislation landscape is clearer since Eu7 HD approval

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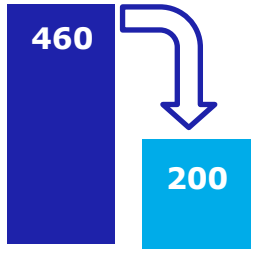
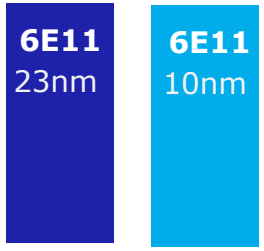
# Euro 7 HD will bring cleaner air – Will BS VII have the same limits? No focus on cold start for Eu7 HD

**NOx emissions mg/kWh**




**Euro VI** **Euro 7**

**PN emissions #/kWh**




**Other**

Ammonia @ 60mg/kWh

$N_2O$ @ 200mg/kWh

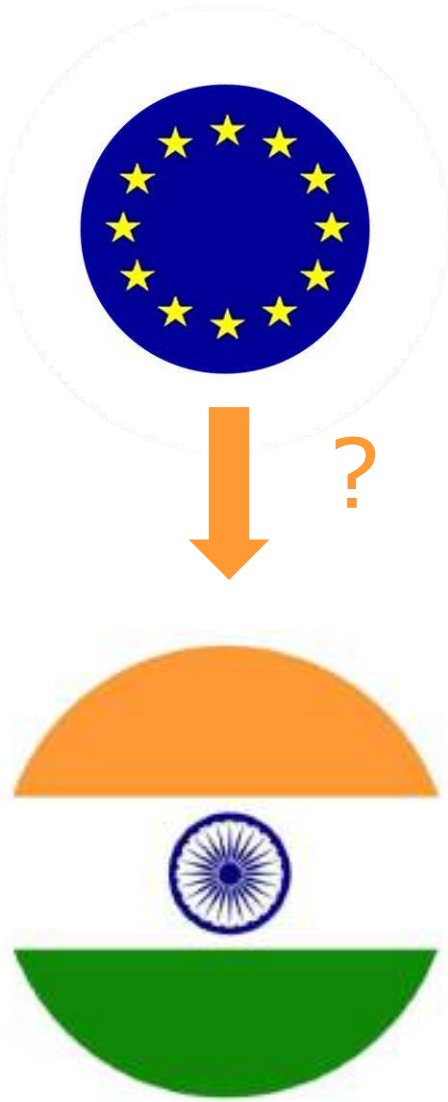
**Durability**
**$N_3$>16t, $M_3$>7.5t**

700k km **Euro VI**

700k km > 875k km **Euro VII**

**RDE summary**

RDE NOx at 260 mg/KWh
RDE PN at 9 x $10^{11}$ PN10
Test procedures mostly carried over from Euro VI-E

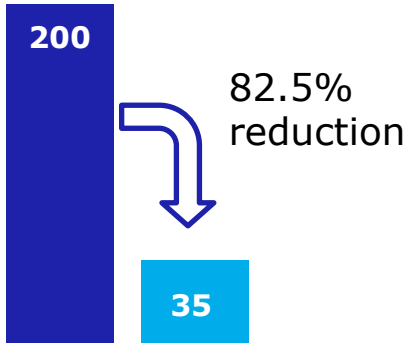



JM † passenger car NOx levels (Euro 6)

# EPA Heavy Duty Trucks Low NOx Rule

Focus on reducing NOx emissions and keeping trucks cleaner for longer

**NOx emissions mg/hp-hr**




**Current** **2027-on**

The new standards also include additional test cycles and off-cycle standards to demonstrate compliance while engines are in use under real-world conditions

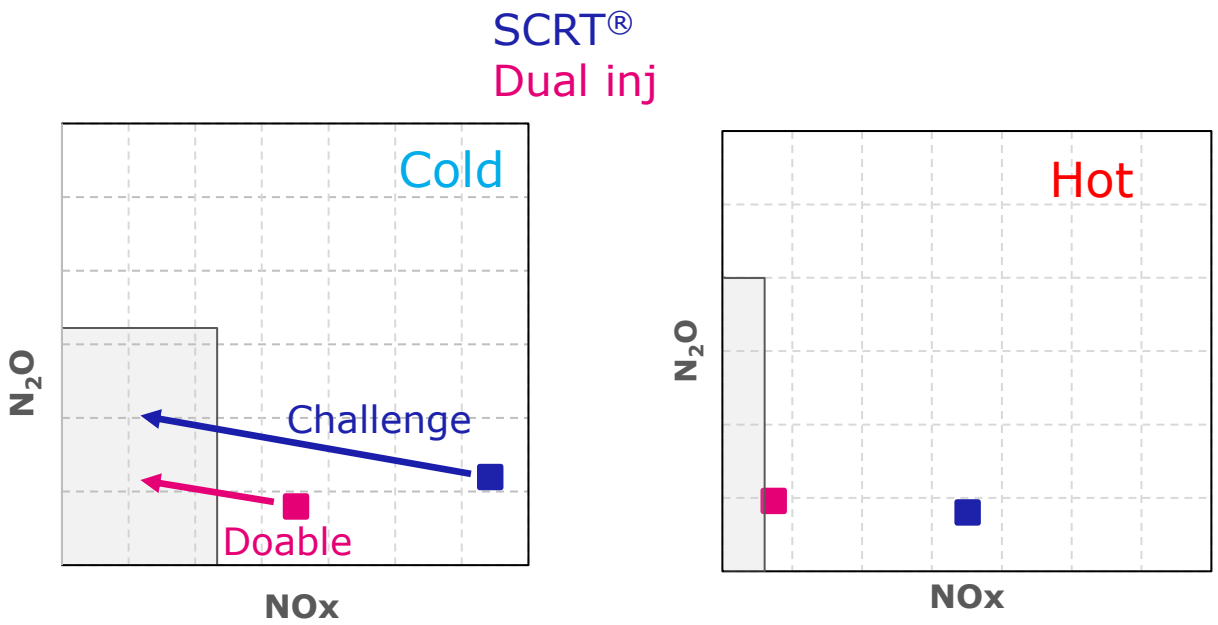
**Durability HDE**


Emissions control systems have an additional requirement to prove compliance to 750,000 miles – under lab cycle tests.

† passenger car NOx levels (Euro 6)

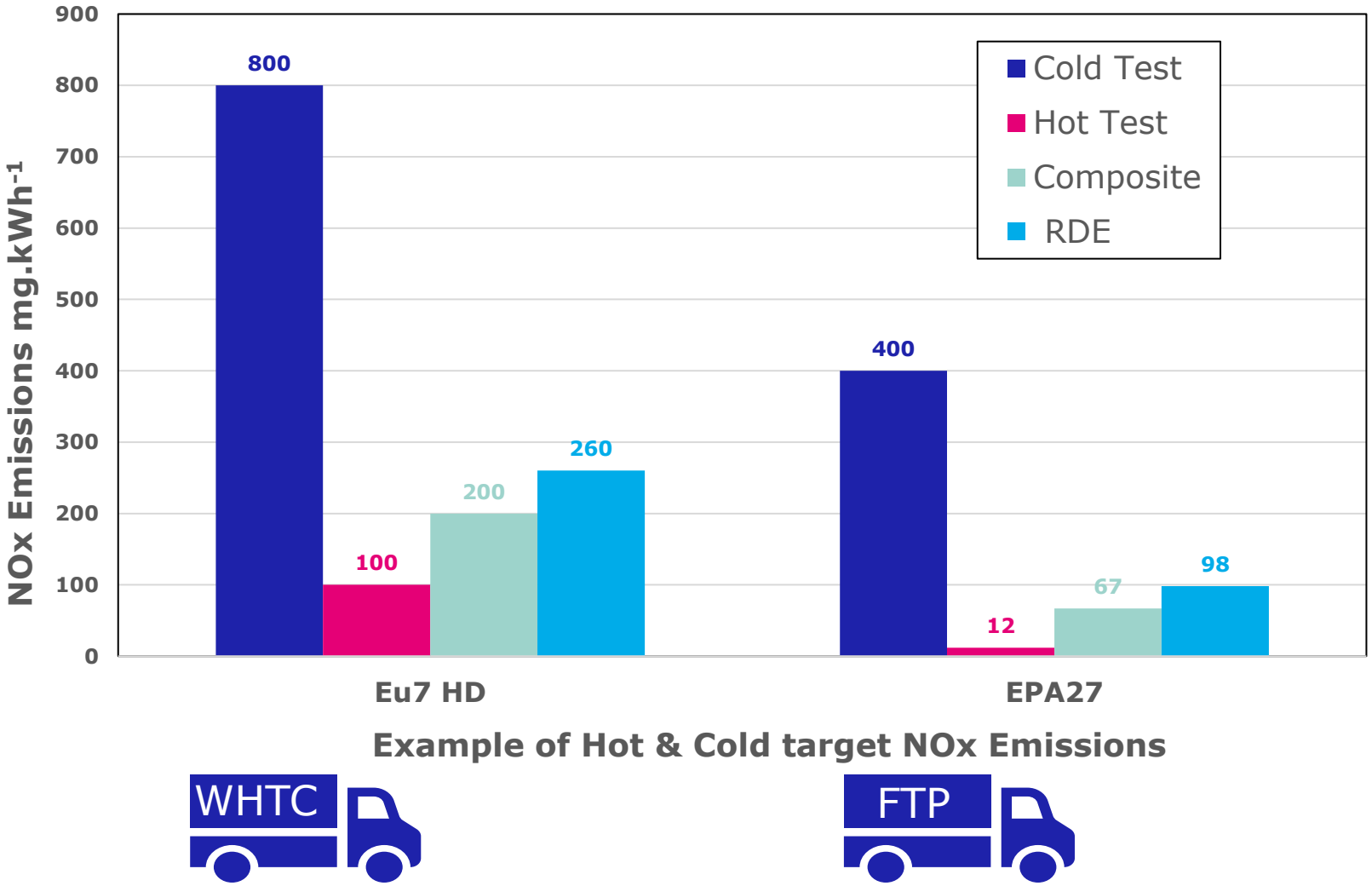
# NSVII - Dual injection may be optimum for cold test requirement (not final, Q1 2025?)

| Emissions | NSVII WHTC cold | NSVII WHTC hot | NSVI |
|---|---|---|---|
| NOx(mg/kWh) | 460 | 90 | 460 |
| PM(mg/kWh) | 10 | 10 | 10 |
| PN(#/kWh) | $6E+11_{PN10}$ | $6E+11_{PN10}$ | $6E+11_{PN23}$ |
| CO(mg/kWh) | 3500 | 200 | 4000 |
| NMOG(mg/kWh) | 200 | 50 | 160 |
| $NH_3$(mg/kWh) | 65 | 65 | 10ppm |
| $CH_4$(mg/kWh) | 500 | 350 | 500 |
| $N_2O$(mg/kWh) | 160 | 200 | - |
| HCHO(mg/kWh) | 30 | 30 | - |



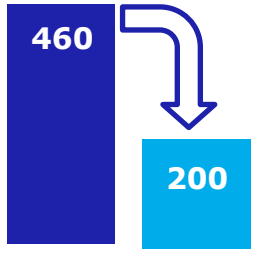

- Much easier to reach NOx limit with $_{cc}$SCR
- RDE limits are not available yet.

# Relative level of legislation limits -- > EPA27 is more challenging



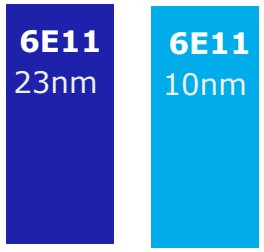
# BS VII – working hypothesis: Broadly the same as Eu7 HD

**NOx emissions mg/kWh**




**Euro VI** **Euro 7**

**PN emissions #/kWh**



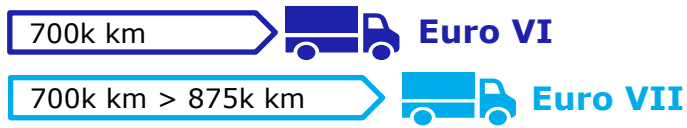

**Other**

Ammonia @ 60mg/kWh

$N_2O$ @ 200mg/kWh

Aftertreatment configuration options/system design?

**Durability**
**$N_3$>16t, $M_3$>7.5t**




**RDE summary**

RDE NOx at 260 mg/KWh
RDE PN at 9 x $10^{11}$ PN10
Test procedures mostly carried over from Euro VI-E

† passenger car NOx levels (Euro 6)

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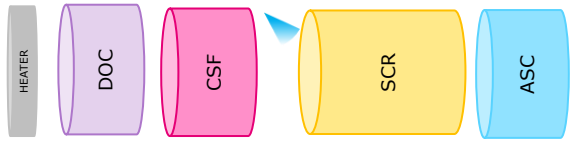
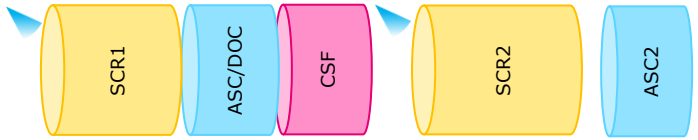
# System design options for BSVII

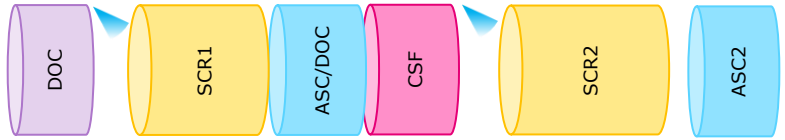
**SCRT®**




**Dual Inj without DOC**




**Dual Inj with DOC**

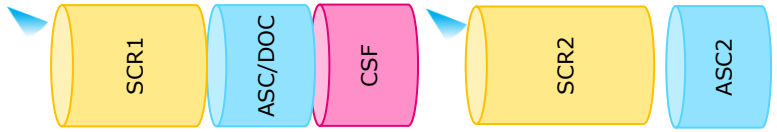
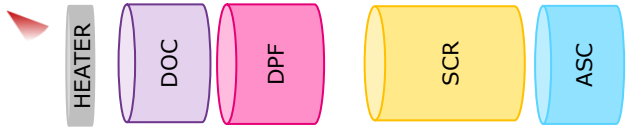



Opportunities to combine catalytic functions on the same substrate:

- ASC & DOC
- DOC & Filter
- SCR & ASC

- CSF - Enhanced Filtration Coating (EFC) for $PN_{10}$

# Dual urea injection vs SCRT® considerations

| | |
|---|---|
|  |  |
| Higher NOx engine (*better fuel efficiency)* | Low NOx engine |
| **Lower NOx** & calibration flexibility | Less flexibility & emissions performance *(FUL – extended durability)* |
| **Lower $PN_{10}$** less urea-derived emissions | Higher $PN_{10,}$all urea injected post-CSF |
| **Lower $N_2O$** when ccSCR used for low temperatures NOx reduction | *Higher $N_2O$ due to all NOx reduction in main SCR* |

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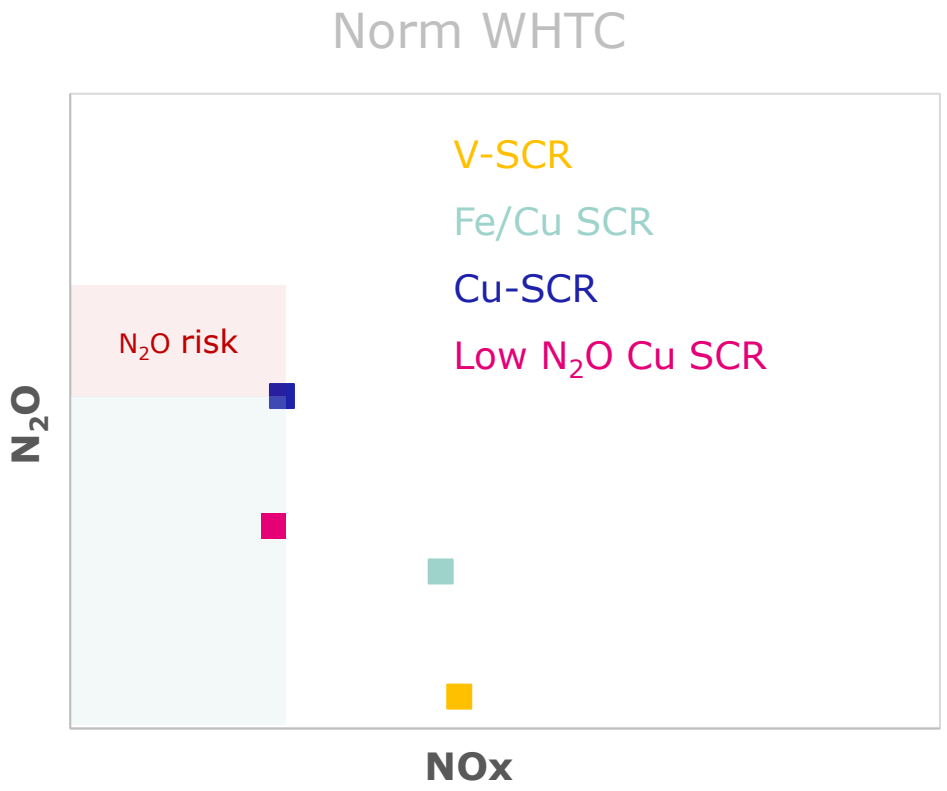
# Eu7 HD / BSVII - SCRT® configuration




For EUVI (global applications), Fe/Cu or V have been used as good compromises for NOx & $N_2O$ performance

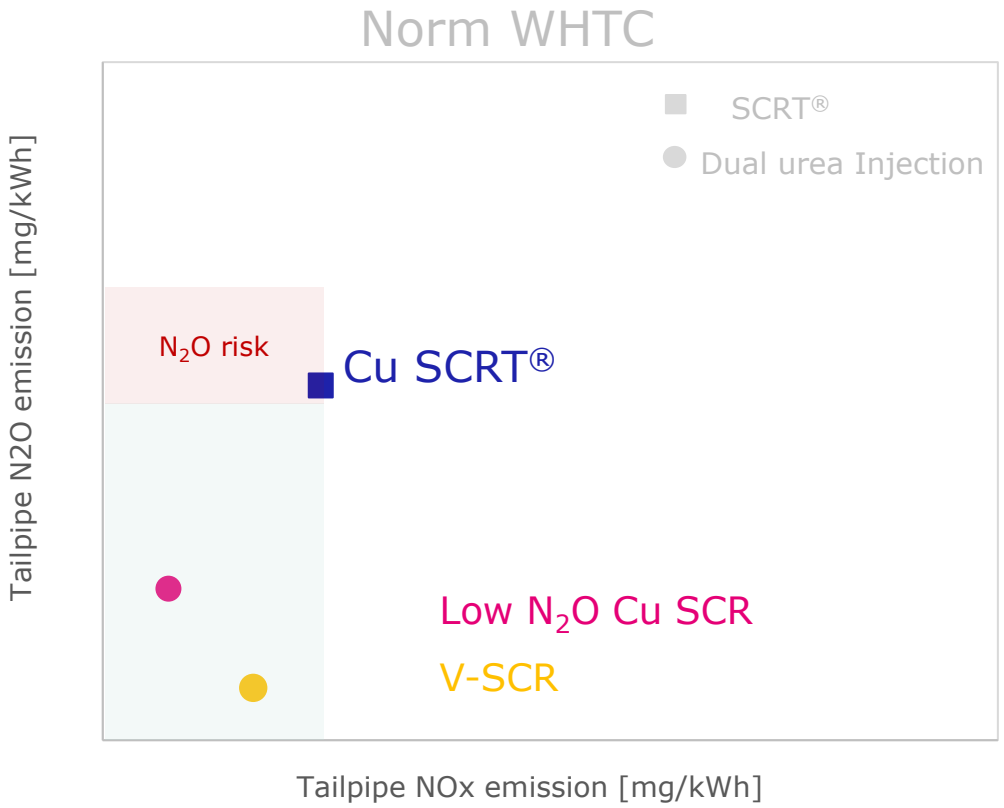
- ❑ Challenging for NOx Eu7 HD (possible?)
- ❑ Significant heating & engine measured required

Cu SCR-based formulations offer the best options with conventional Cu SCR catalysts likely to be borderline for for $N_2O$

- ❑ Best potential for SCRT® option with Low $N_2O$ Cu SCR

# Eu 7 HD / BSVII - Dual injection configuration

## Greater flexibility for system design & catalysts selection




Dual-injection gives flexibility to reach NOx & $N_2O$

- $_{cc}$SCR & $_{main}$SCR - mix of technologies possible

V has limitations for high temperature & RDE conditions

- Max temperature management & NOx conversion

Low $N_2O$ Cu SCR is the best option

# Modelling is a key tool for rapidly optimising complex catalyst and system options over wide variety of test cycles and fuels

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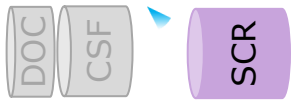
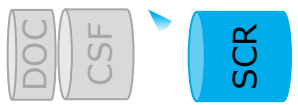



EU VI

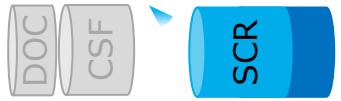
Formulation update

1.

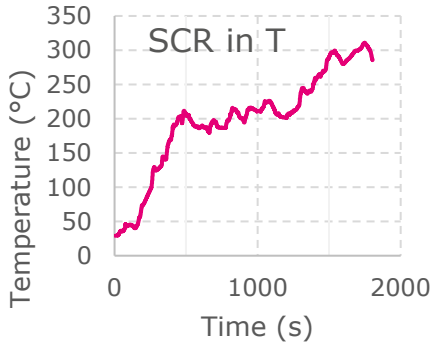



EU 7 HD

2. volume increase



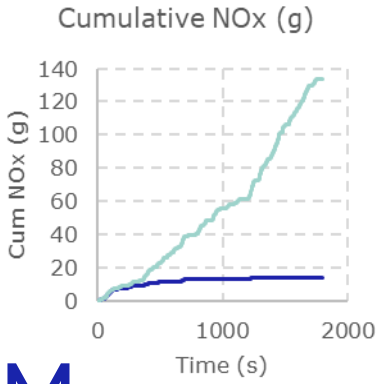

3.




Heating mode

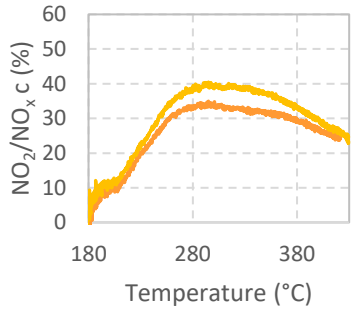
Engine out
Cold NOx reduction

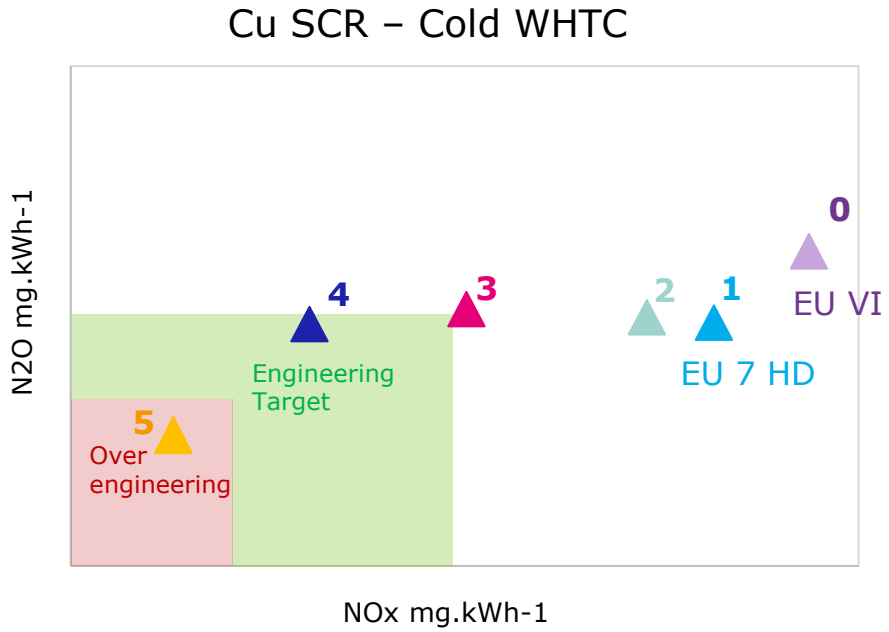
4.




5.

higher $NO_2$




To support the catalyst technologies selection and sizing for BS VII system design

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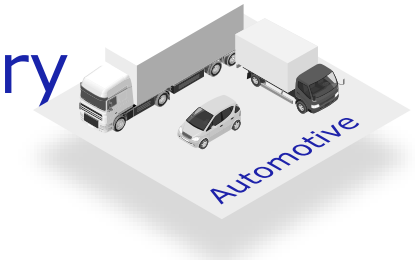
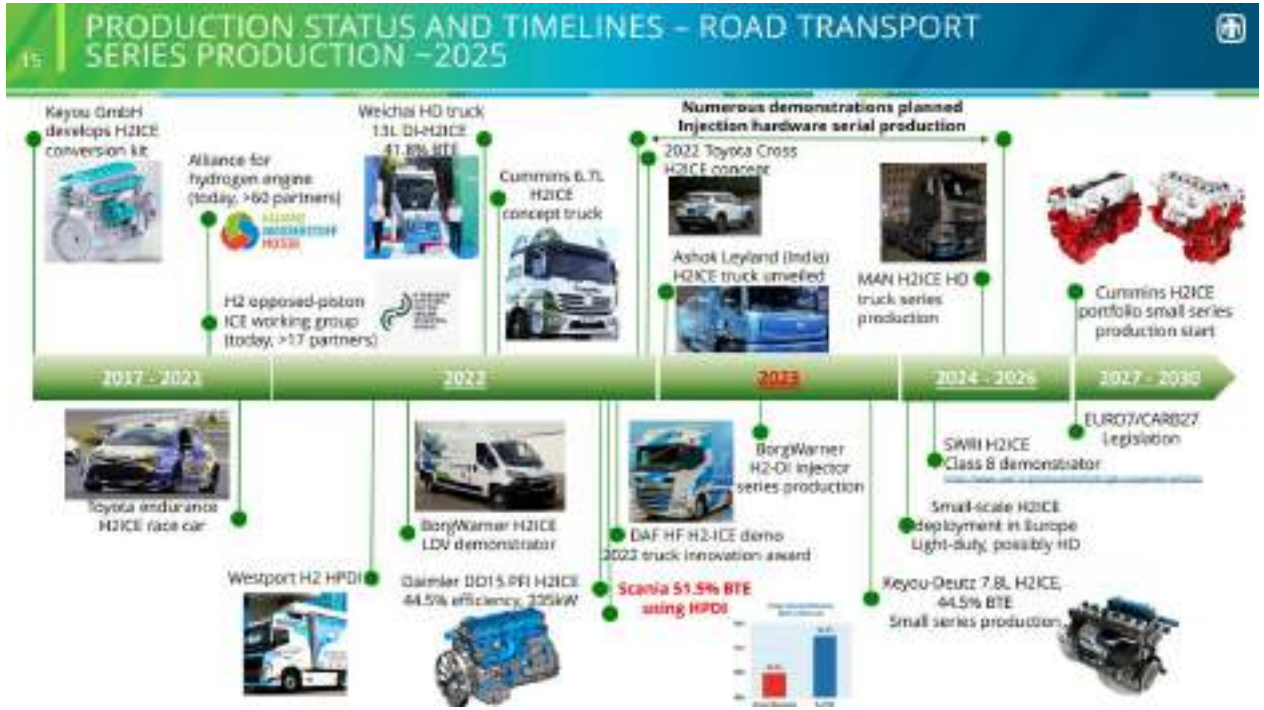
# Rapidly growing H2-ICE development across the HD industry





*Doe: Overview of hydrogen internal Combustion Engine (H2ICE) Technologies, Feb 23*

# Recent announcements

Cummins Newsroom:

TCPL GREEN ENERGY SOLUTIONS PRIVATE LIMITED (TCPL GES) INAUGURATES A STATE-OF-THE-ART MANUFACTURING FACILITY TO PRODUCE HYDROGEN-BASED INTERNAL COMBUSTION ENGINES; REAFFIRMS ITS COMMITMENT TO POWER A CLEANER INDIA

Mar 20, 2024 • Jamshedpur, Jharkhand

TCPL Green Energy Solutions Private Limited (TCPL GES) inaugurates a state-of-the-art manufacturing facility to produce Hydrogen-based Internal Combustion Engines; reaffirms its commitment to power a cleaner India | Cummins Inc.

MAN expands its zero-emission portfolio

Small truck series with hydrogen combustion planned for 2025

- Initially around 200 vehicles for selected markets
- hTGX particularly suitable for special applications
- Vehicle complements battery-electric portfolio

MAN expands its zero-emission portfolio (mantruckandbus.com)

*(Examples, non-exhaustive list)*

# IAA 2024 – more $H_2$-ICE …







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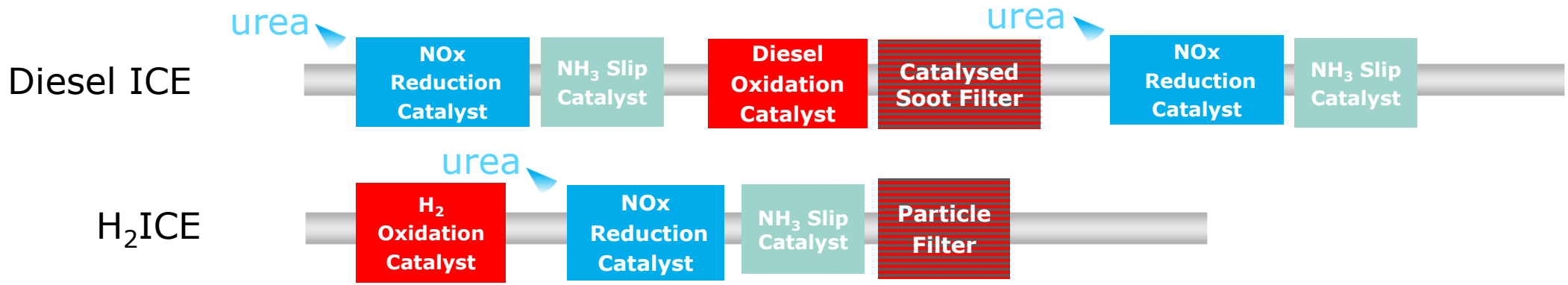
*(Examples of Exhibitors, non-exhaustive list)*

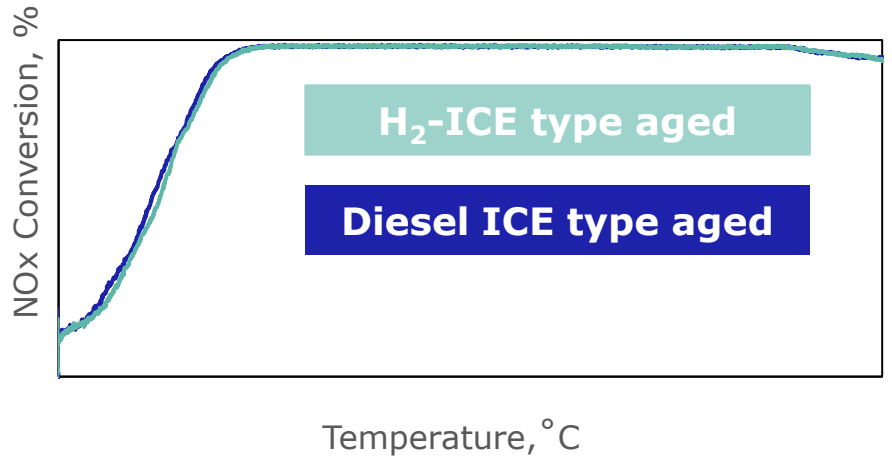
# $H_2$-ICE technologies are at advanced stage across the industry




| Key Feature | Benefit |
|---|---|

**Existing technology**
Optimisation of diesel technology

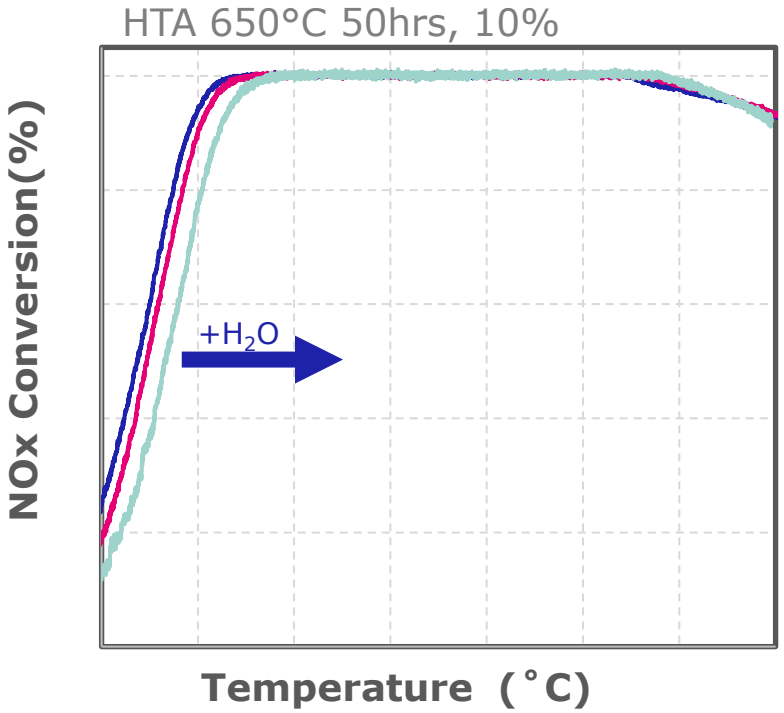
**Robust & timely introduction**



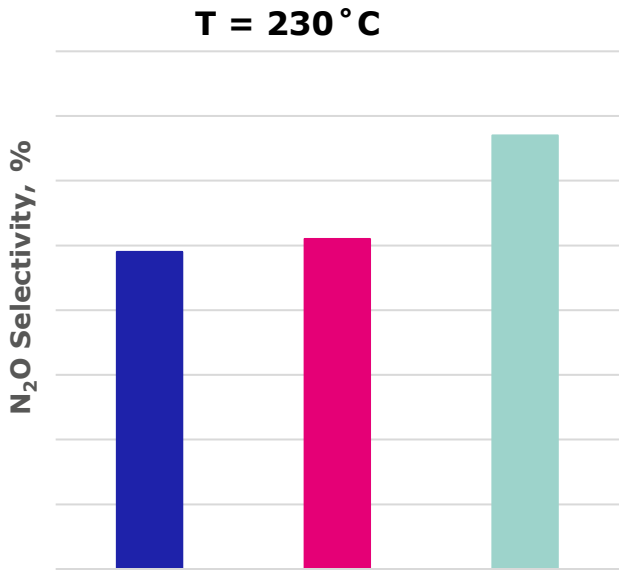
# SCR - Impact of high $H_2O$ content

**Water levels expected in $H_2$-ICE are considerably higher than in Diesel applications – up to 25%**

High $H_2O$ content → **Negative impact on low T activity & selectivity**

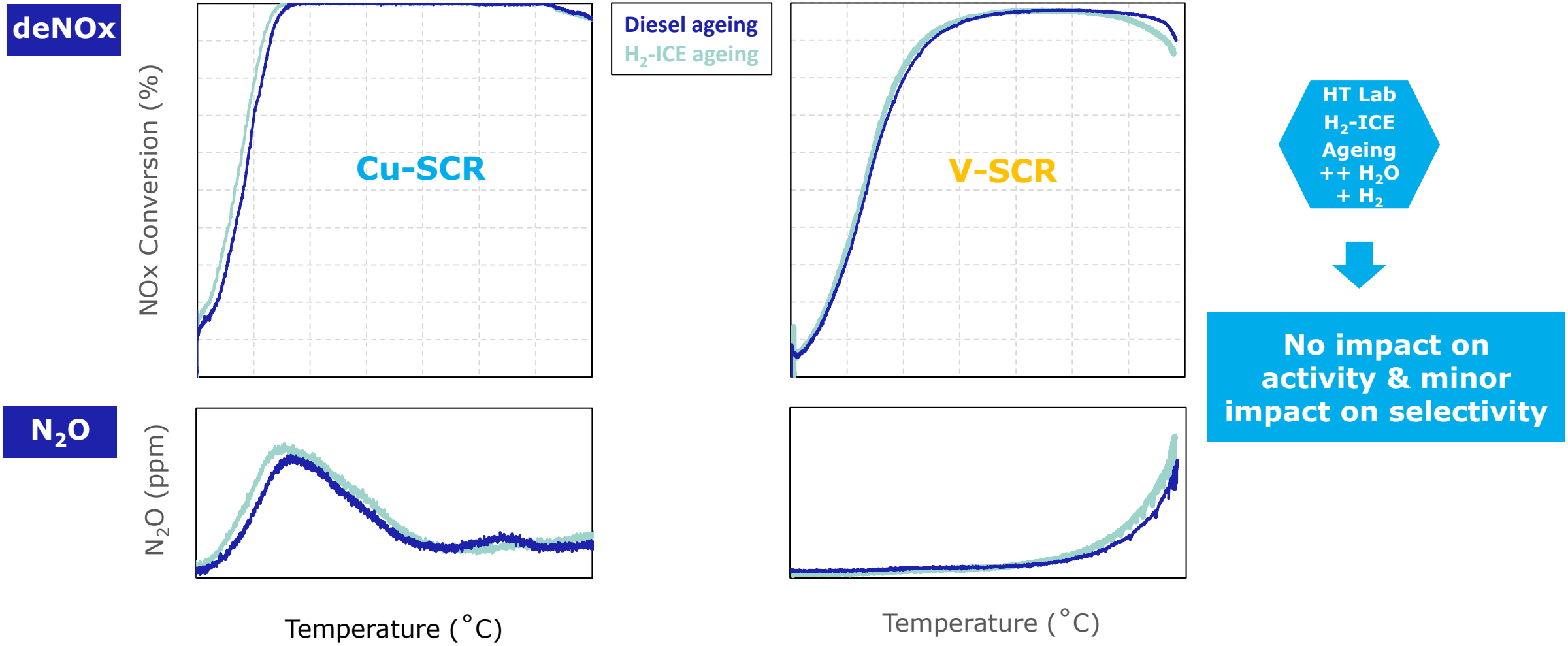



5% $H_2O$
15% $H_2O$
25% $H_2O$



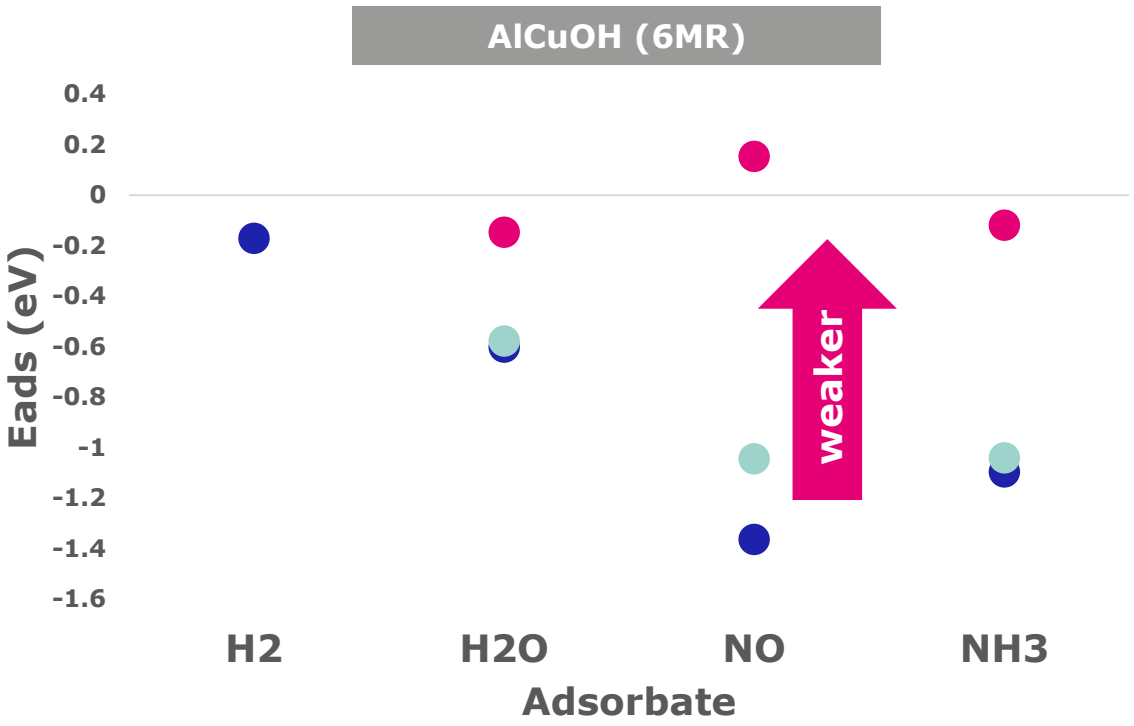
# Increasing water content for $H_2$-ICE ageing condition (lab experiment)

## Cu & V SCR have similar level of activity after Diesel or $H_2$-ICE lab ageing conditions

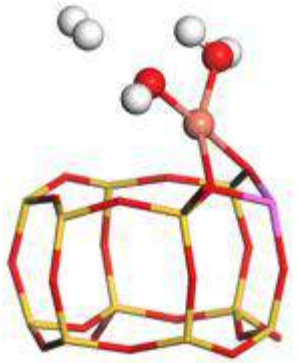


# Atomistic modelling for $H_2$-ICE – Reactive conditions

## $H_2$ interaction with $Cu^{2+}$ sites is weak – no measurable impact on SCR activity




**Co-adsorption of $H_2O$ and $H_2$**

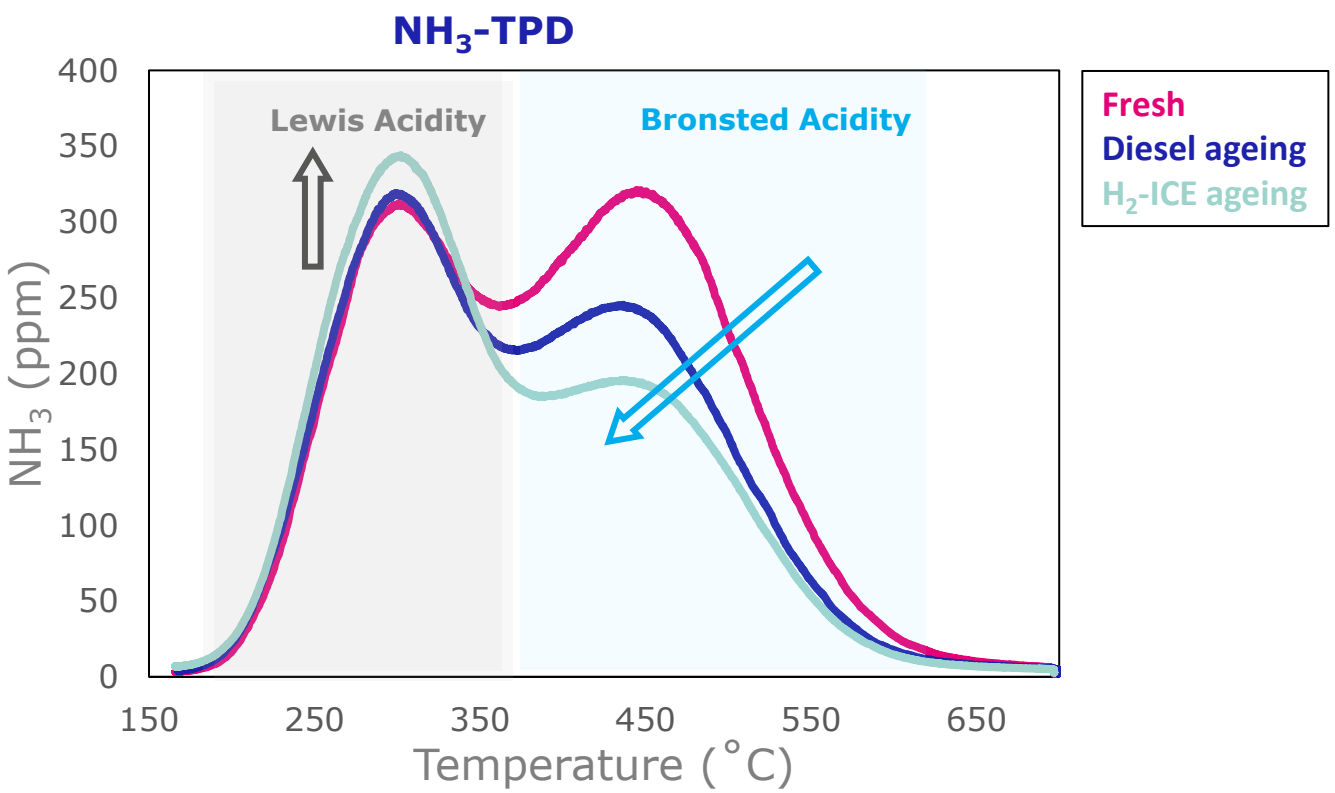


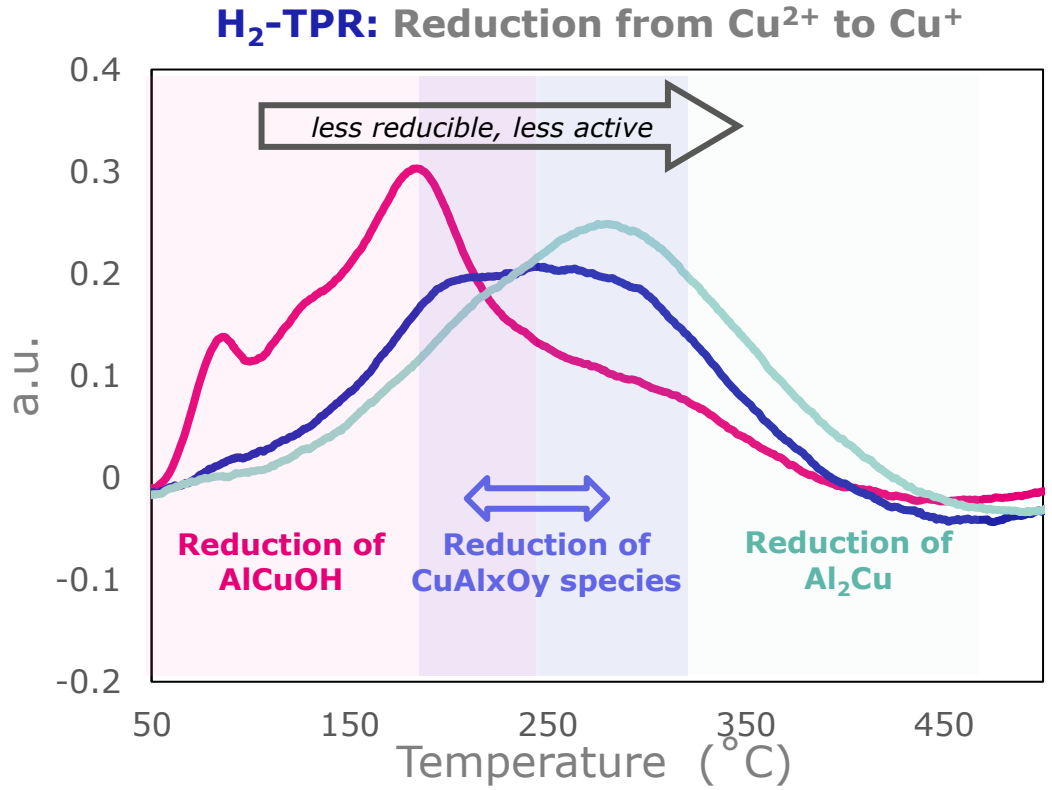
**single adsorbate**
**$H_2$ + co-adsorbate**
**co-adsorbate + $H_2$**

Interaction between Cu sites and $H_2$ with and without other reactants ($NH_3$, NOx, $H_2O$)

Minimal impact on co-adsorption of $H_2O$, NO, and $NH_3$

# Catalyst durability under lab $H_2$-ICE conditions
# Probing changes to catalyst structure



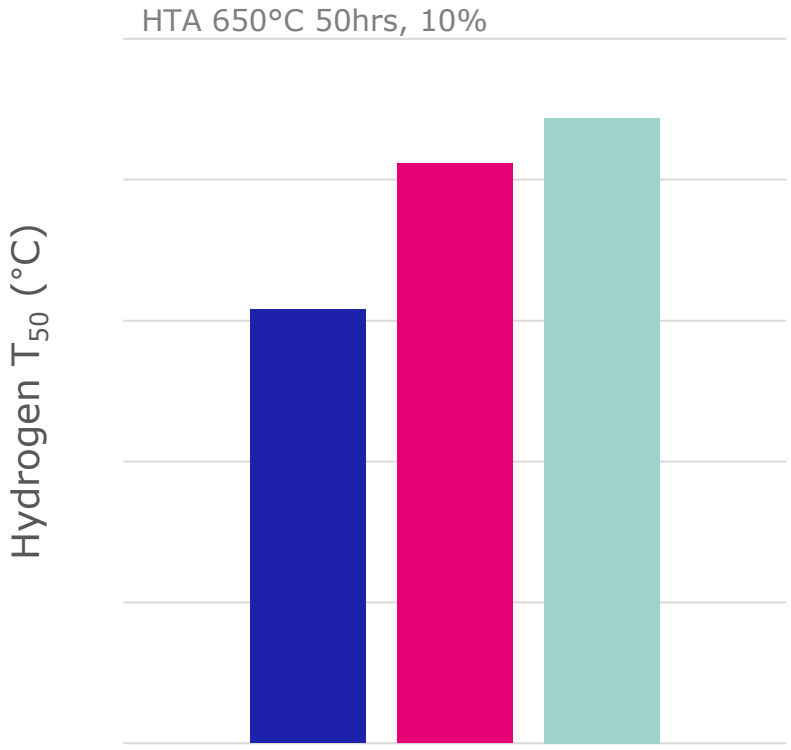

**HT Lab $H_2$-ICE Ageing ++ $H_2O$ + $H_2$**

- Minor changes in Cu speciation (confirmed by XAS), some zeolite dealumination
- Negligible impact of Hydrogen presence (test w & w/o $H_2$ – not shown here)
- No decernible impact on activity and selectivity when comparing ageing conditions

JM

# HOC – Effects of Water on $H_2$ Conversion

**High $H_2O$ content** → **Negative impact on H2 light off & NO Oxidation**




5% $H_2O$
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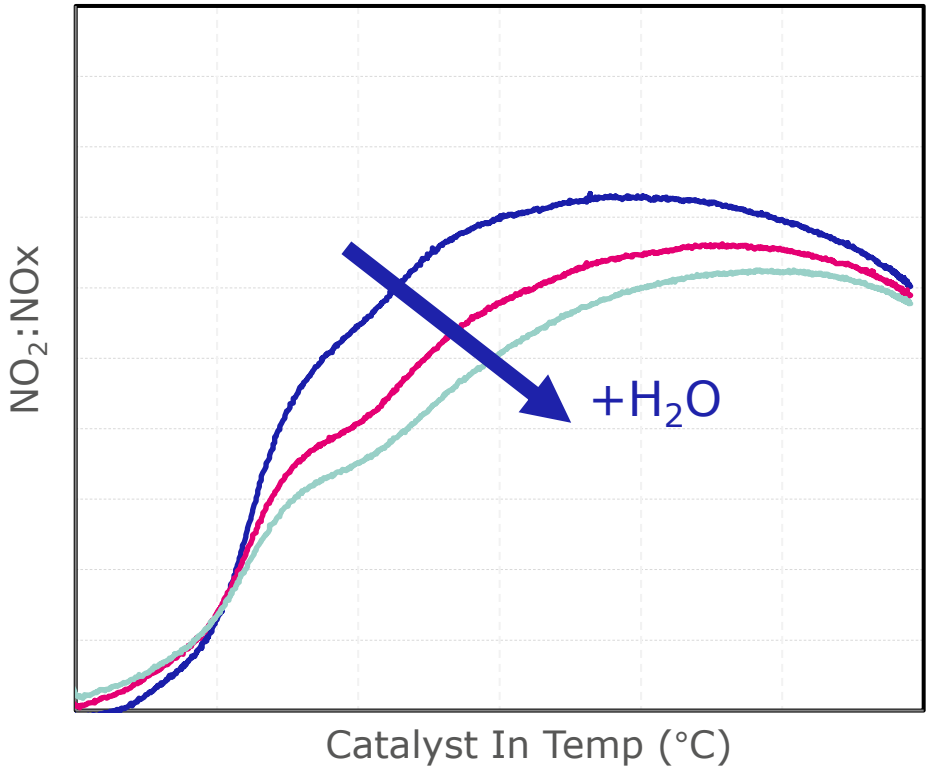
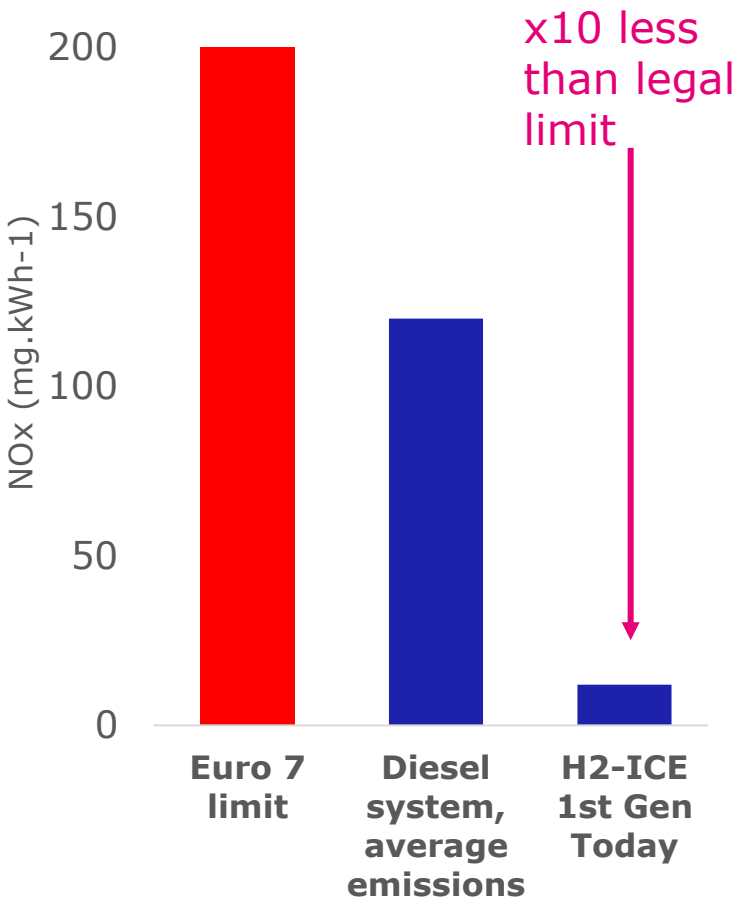
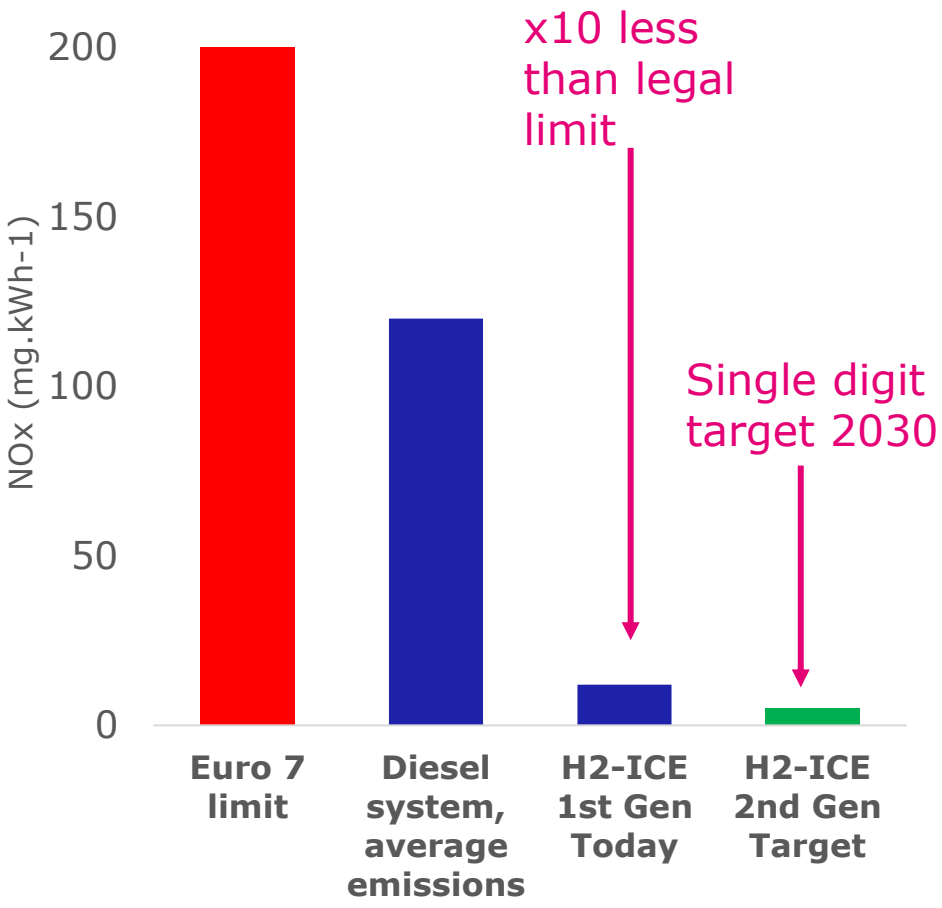


# Targetting near zero NOx emissions




# Targetting near zero NOx emissions





Challenge: NOx purge - thermal or rich


Challenge: $N_2O$ selectivity

JM Johnson Matthey

Inspiring science, enhancing life