Evolution of Advanced Emissions Control System to meet NOx and Particulates Regulations

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Exhaust emissions control technologies for original equipment, retrofit and aftermarket for all new cars, commercial vehicles, motorcycles, and non-road mobile machinery
Content

❯ Context
❯ Overview of emission control technologies
❯ Plug-In Hybrid vehicle emissions towards the boundaries of RDE
EU Air Quality has improved over the years
But further efforts are needed

Source: European Environment Agency (EEA)
50-70% of powertrains still expected to include an ICE in 2030

Predictions of pure electric vehicles market share by 2030

Sources:
ING – Breakthrough of electric vehicle threatens European car industry, July 2017
Roland Berger – Fuels and vehicles roadmap 2030+, April 2016
McKinsey&Company – Boost! Powertrain KIP, January 2011
EMISSIONS CONTROL TECHNOLOGIES SIGNIFICANTLY REDUCE POLLUTANT EMISSIONS AS PART OF AN INTEGRATED APPROACH

Fuel, lubricant and reductant quality

Sensors and Control

Engine and combustion

Emissions Control Technology
Content

- Context
- Overview of emission control technologies
- Plug-In Hybrid vehicle emissions towards the boundaries of RDE
Core emissions control technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Light-duty</th>
<th>Heavy-duty</th>
<th>NRMM</th>
<th>Motorcycle &amp; Moped</th>
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<tbody>
<tr>
<td></td>
<td>Acronym</td>
<td>Petrol</td>
<td>Diesel</td>
<td>Gas, Petrol</td>
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<td>Oxidation catalyst</td>
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<td>3-Way Catalyst</td>
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<td>DPF</td>
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<td>NOx Adsorber</td>
<td>LNT</td>
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<td>Selective Catalytic Reduction</td>
<td>SCR</td>
<td>●</td>
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<tr>
<td>Gasoline Particulate Filter</td>
<td>GPF</td>
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</table>

**Equations:**

\[
4 \text{NO} + 4 \text{NH}_3 + \text{O}_2 \rightarrow 4 \text{N}_2 + 6 \text{H}_2\text{O}
\]

\[
6 \text{NO}_2 + 8 \text{NH}_3 \rightarrow 7 \text{N}_2 + 12 \text{H}_2\text{O}
\]
EU RDE legislation

Aims to close the emissions gap between lab and real-world

Source: average on-road diesel NOx emissions, the ICCT

Source: Gasoline Particulate Filters Market and Technology Trends and their Impact on Calibration, FEV, SIA powertrain 2017
PEMS equipment used to measure emissions on the road
Low NOx emission diesel cars: a reality
Bosch demonstrated urban NOx Real-Driving Emission (RDE) consistently below 80 mg/km

Figure 9: On-road measurements "Stuttgart – urban"

Source: Kufferath (Bosch), the path to a negligible NO₂ immission contribution from the diesel powertrain, Vienna Motor Symposium, April 2018
Light-duty diesel emissions control technology evolution
Towards combination of technologies in a compact design for RDE compliance

Source: Daimler – Aachen Colloquium 2015
Source: Peugeot – 308 press release 2017
Source: BMW – Aachen Colloquium 2015

Source: Daimler – Aachen Colloquium 2015
Light-duty diesel emissions control technology evolution

Potential for future improvements to cover a wide range of driving conditions

- SCR in different locations to cover urban and motorway driving
- Dual urea injection to provide more flexible dosing
- Optimising thermal management for urban driving

Source: AVL – Highly Efficient Exhaust Gas Aftertreatment for Future Diesel Applications – 10th International Exhaust Gas and Particulate Emissions Forum February 2018
Light-duty gasoline emissions control technology evolution

Introduction of particulate filters on cars with direct injection for RDE compliance

Source: Daimler – Vienna Motorensymposium 2017

Source: Peugeot – 308 press release 2017
RDE-compliant cars (Euro 6d-TEMP) are available on the market

List at [www.adac.de/infotestrat/umwelt-und-innovation/abgas/modelle_mit_euro_6d_temp/default.aspx](http://www.adac.de/infotestrat/umwelt-und-innovation/abgas/modelle_mit_euro_6d_temp/default.aspx)

569 models (on 12.06.18)

- Incl. 224 diesel models

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<tr>
<th>Marke</th>
<th>Modell</th>
<th>Motorart</th>
<th>Abgasnorm</th>
<th>Benzin- oder Dieselmotor</th>
<th>Leistung</th>
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**and many more...**

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Emissions performance of latest diesel and gasoline vehicles

Declared values of Euro 6d-Temp vehicles well within standards

Source: PEMS results and maximum declared values from ACEA RDE database consulted on 26 April 2018
Content

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- Plug-In Hybrid vehicle emissions towards the boundaries of RDE
2017 PHEV test programme set-up

Objective: measure the real-world behaviour of a market-representative Plug-in Hybrid Electric Vehicle (PHEV)

Vehicle: C-segment, 1.5l class GDI engine, Euro 6b, E5 market fuel

Test Matrix

- All 4 driving modes: Electric, Hybrid, Charge and Sport
- Variation in initial battery State of Charge (SOC)
- RDE on-road and on the chassis dyno
- 2 tests repeated with a coated Gasoline Particulate Filter (GPF) replacing the second (underfloor) Three-Way Catalyst (TWC)

Emissions are compared to similar GDI vehicle tested in 2016 AECC test programme*

* Real-World Emissions Measurements of a GDI Vehicle without and with a GPF, Demuynck, et al., SAE 2017-01-0985
8 combinations of mode and initial battery SOC tested

Change in battery SOC (State of Charge) during on-road RDE tests

<table>
<thead>
<tr>
<th>SOC</th>
<th>Electric</th>
<th>Hybrid</th>
<th>Charge</th>
<th>Sport</th>
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<tr>
<td>100%</td>
<td>1x</td>
<td>1x</td>
<td>-</td>
<td>1x</td>
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<tr>
<td>85%</td>
<td>1x</td>
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<tr>
<td>55%</td>
<td>1x</td>
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<td>25%</td>
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Comparison to WLTP definitions

- **Charge depleting:** Electric – 100%
- **Charge sustaining:** Hybrid – 85% and Electric – 25%
Most urban PN emissions higher than GDI with GPF

Results presented at Integer Emissions Summit 2017 (Dresden)

Electric mode – full battery: urban part entirely run electric → zero urban tailpipe PN emissions

Charge mode – empty battery: high power demand on ICE → highest PN emissions

ICE: Internal Combustion Engine
All total RDE PN emissions higher than GDI with GPF

Results presented at Integer Emissions Summit 2017 (Dresden)

Electric mode – full battery: ICE operates for 2/3 of trip, but PN emissions as high as other modes

Charge mode – empty battery: high power demand on ICE → highest PN emissions

ICE: Internal Combustion Engine
Investigate going to the boundaries of RDE
Severitized RDE (SRDE) methodology developed on chassis dyno

1. Change accelerations

2. Change dyno load

3. Change ambient temperature

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Severitized RDE (SRDE) shows need for GPF to meet NTE PN limit

Note: 1.6 factor for extended ambient temperature included where applicable

Euro 6d NTE limit (CF=1+0.5)

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Conclusions

- A new era for vehicle emissions control started 1/9/2017 with RDE and WLTP introduction.
- Emissions control technologies evolved for RDE compliance up to boundary conditions.
- On-road emissions performance of latest diesel and gasoline vehicles are well within standards.
THANK YOU!

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