MODALES D4.3: Retrofit solutions for road vehicles – *Executive Summary*

WORK PACKAGE	**WP4: Effectiveness of inspections and depollution systems**
TASK	T4.3: Retrofits for cars and HDVs
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Glossary of terms

Term	Description
AdBlue	Marketing name for Diesel Exhaust Fluid
GT-suite	GT-SUITE is the industry-leading simulation tool with capabilities and libraries aimed at a wide variety of applications and industries, in particular automotive engineering, vehicle design and simulation.
MODALES	This EU Horizon 2020 project: “Modify Drivers’ behaviour to Adapt for Lower Emissions” (2019-2022, http://modales-project.eu)

List of abbreviations and acronyms

Abbreviation/acronym	Meaning
ACCT	Ammonia Creation and Conversion Technology
ASDS	Ammonia Storage and Delivery Systems
DPF	Diesel Particulate Filter
DOC	Diesel Oxidation Catalyst
CO_2	Carbon Dioxide
DPF	Diesel Particulate Filter
EAT	Entity Attestation Token
EGT	Exhaust Gas Temperature
EGR	Exhaust Gas Recirculation
EHC	Electrically Heated Catalyst
HDV	Heavy Duty Vehicle
LDV	Light Duty Vehicle
LNT	Lean NO_X Trap
NAEI	National Atmospheric Emissions Inventory (https://naei.beis.gov.uk/)
NEDC	New European Driving Cycle
NRMM	Non-Road Mobile Machinery
NO_X	Nitrogen Oxides
OBD	On-Board Diagnostics
OEM	Original Equipment Manufacturer
PEMS	Portable Emissions Measuring System
PM	Particle Matter
PN	Particle Number
RDE	Real Driving Emissions
SCR	Selective Catalytic Reduction
WLTC	Worldwide harmonized Light vehicles Test Cycles
WP	Work Package

Publishable Executive Summary

The overall goal of the MODALES project is to substantially reduce air pollution from all types of on-road vehicles by encouraging adoption of low-emission driving behaviour and proper maintenance choice, improving the effectiveness of On-board Diagnostics (OBD) devices and retrofits. This report represents the work carried out in Task 4.3 of the project, aimed at studying the feasibility and potential of retrofit emission controls, and experimenting with prototype technologies for after-treatment that will retrofit passenger cars and HDVs targeting at dramatic reduction of NO_X from diesel engines.

The task started with a thorough State-of-the-Art review of potential retrofit innovations, and a comprehensive analysis of seven widely-recognised retrofit technologies, namely Selective Catalytic Reduction (SCR), Lean NO_X Trap (LNT), Ammonia Creation & Conversion Technology (ACCT), Ammonia Storage & Delivery system (ASDS), Thermal Insulation Technology, Electric Heated Catalyst (EHC), and External Burner. The analysis showed that each of these technologies has its own pros and cons, in terms of Response Time, Energy Penalty, Complexity, and Effectiveness. Overall, ACCT offered a good balance between these performance indicators, and was thus selected for simulation and modelling carried out later in the task, together with SCR as a benchmark which is the only retrofit device commercially available.

Both in-lab and real-world experiments of the retrofit SCR system for light commercial vehicles were carried out on Mercedes-Benz Sprinter Euro 5 models with 4-cylinder 2.2 litre diesel engine. All those vehicles have a Diesel Particulate Filter (DPF) as original after-treatment system and that was left in place without any modifications.

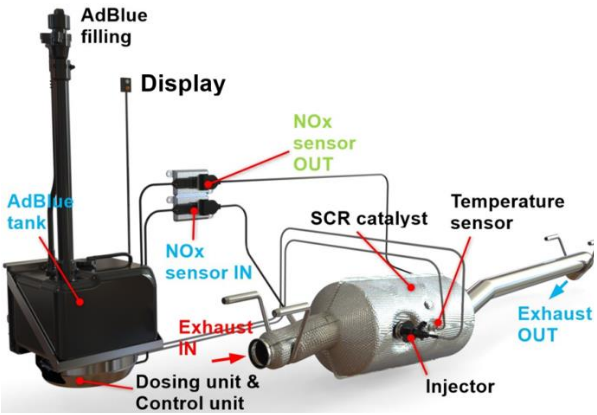

Figure 0.1: Operation principle of retrofit SCR system

Figure 0.2: NOxBUSTER City Light retrofit SCR system installed to vehicle

During early phase testing it was noted that this type of vehicle has very low exhaust gas temperatures at city driving speeds and on the other hand very high exhaust gas temperatures during DPF regeneration. Low temperature SCR may not handle temperatures above 500°C and therefore SCR material was changed to withstand up to 600°C during active DPF regeneration. Another challenge was possible hot shut down of engine during DPF regeneration, leading to overheating of urea nozzle. The tests proved that Euro 5 vehicles are optimised for the New European Driving Cycle (NEDC) and does not correlate well with the Worldwide harmonised Light vehicles Test Cycles (WLTC) results in general. A NO_X reduction of more than 50% over the whole cycle may be achieved depending on test cycle and operating conditions. The reduction (or NO_X conversion efficiency) was much greater when the retrofit system active (sufficient exhaust gas temperatures (EGT) reached), highlighting that retrofit SCR efficiency is highly dependent on the engine out exhaust temperature. Outdoor tests confirmed that the effect of ambient temperature for engine raw NO_X (and CO_2) is significant and ambient temperature affects tail pipe NO_X especially when EGT is lower than the SCR-activation threshold.

Figure 0.3: Emissions and fuel consumption test facility with a single-roller 2WD dynamometer

Finally, the task carried out sophisticated simulation and modelling of the ACCT and SCR retrofit innovations for passenger cars. The main findings are as follows:

(1) The performance difference of ACCT and SCR systems was slightly affected by thermal status of the start period in driving cycle. In the cold start process, NO_X reduction efficiency of ACCT system was much higher than SCR system due to low light-off temperature, accompanied by a shorter light-off duration.

(2) Regarding WLTC including cold start stages, the relationships between speed range, acceleration range and accumulated NO_X emissions showed similar patterns for ACCT scenarios and SCR scenarios; however, ACCT scenarios presented lower accumulated NO_X e missions than SCR scenarios.

(3) As for WLTC excluding cold start stages, the relationships between vehicle speed range and accumulated NO_X emissions for SCR scenarios differed significantly with those of ACCT scenarios whose accumulated emissions were almost zero within high-speed range. NO_X emissions only focused on high vehicle acceleration range for ACCT scenarios; however, it was low and high acceleration ranges for SCR scenarios.

(4) After-treatment temperature was sensitive to the vehicle speed when it was close to the engine; the longer distance of the after-treatment systems to the engine, the smoother and lower of the temperature profile was. For SCR and ACCT scenarios, NO_X emission distributions presented similar patterns over various layouts; however, ACCT scenarios showed a lower proportion over high emission rates regions.

(5) ACCT scenarios presented higher NO_X reduction efficiency than SCR scenarios under different layout conditions, especially the first 800 seconds of WLTC. NO_X reduction efficiency over original layout and layout 1 showed similar patterns, but there was a lag of approximately 130 seconds for the original layout. As for the DPF regeneration, original layout was much easier than layout 1 and 2, caused by higher DPF temperature.
(6) ACCT system showed lower NO_X emission factors and monetary penalty factors than SCR system over the three different layouts. Regarding the emission factors meeting the limits of emission regulations, layout 1 presented the best performance; however, layout 2 was the best from the viewpoints of dropping monetary penalty factors.

Whilst the results of Task 4.3 are described in this deliverable in detail, they are also presented in other formats of publication such as peer-reviewed scientific articles as listed in Table 0.1 below. These publications provide specific and thorough literature reviews, explanation of relevant studies and how the existing findings are used as well as where further work is needed.

Table 0.1: Peer-reviewed publications related to retrofit

Title of Publication	Journal	DOI link
Impacts of De-NO_X system layouts of a diesel passenger car on exhaust emission factors and monetary penalty	Energy Science & Engineering	10.1002/ese3.1001
The effect of after-treatment techniques on the correlations between driving behaviours and NO_X emissions of passenger cars	Journal of Cleaner Production	10.1016/j.jclepro.2020.125647

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Adapting driver behaviour
for lower emissions