European Commission

RETROFITS

A STOPGAP SOLUTION TO AIR QUALITY PROBLEMS?

The results of the Horizon Prize for the cleanest engine retrofit

By Maurizio Maggiore (EC) &
Barouch Giechaskiel (JRC)

For ETH Particles Conference
Zurich 20/6/2019

Horizon Prizes|Background

Cars emit > NOx limits in real driving and cause air quality exceedances

RDE hopefully a fix. However, it leaves 29M polluting cars on EU streets

SCR could cause other problems (e.g. new pollutants)

EU Commission has high ambitions for air quality (WHO limits?..)

→ two prizes to cover all issues:

✓ Cleanest Retrofit
✓ Cleanest Engine of the Future

Horizon Prizes|Cleanest Engine

Started in 2012
Announced in WP2015

- ✓ Strong JRC contribution, growing support from cities
- ✓ Officially launched at Transport Research Arena (TRA) in 2016
- ✓ Retrofit prize → to Amminex Bluefit solution at TRA 2018
- ✓ Engine of the Future prize → might be awarded at TRA 2020

Retrofit Prize: Clean Up Existing Fleet

- Most high emitters will be around for >10 years, some possibly still for sale as zero-kilometre cars even today
- Many will move East and South, displacing pollution
- Not everybody can afford to change these almost new cars
- Electric is the really clean alternative (covering GHGs too), still not affordable for many
- RETROFITS: DEMOCRATIC AND COST-EFFECTIVE WAY TO CLEAN THE FLEET FAST

Cleanest Engine Prize: Design for the Future

- An alternative to electrification if growth is slow (safety net)
- Useful to make hybrids and cars using decarbonised fuels really CLEAN, so beneficial even for the longer term
- Also looks for low "real driving" fuel consumption, i.e. decarbonisation
- Given the progress in batteries, might be overtaken by events

3.5 M€ Prize value

Deadlines[3]	
LAUNCH OF THE CONTEST Call for applications is open on the Participant Portal All detailed information is available on the Horizon Prize website	20 April 2016
DEADLINE FOR REGISTRATION Contestants register trough the Participant Portal and by sending email to RTD_FUTURE_ENGINE_PRIZE@EC.EUROPA.EU	20 May 2019 at 17:00:00 CET[4]
CLOSING DATE FOR SUBMISSION Applicants submit the application form Part A and Part B thorough the Participant Portal and deliver the prototype vehicle to JRC	20 August 2019 at 17:00:00 CET[5]
EVALUATION Applicant submissions are evaluated against the award criteria described in this document, and on the basis of verification testing performed by JRC	September 2019 - March 2020
AWARD Announcement of the Winner of the Horizon Prize for the Cleanest Engine of the Future	April-June 2020

Retrofit | Main Award Criteria

- ✓ NO_x <180 mg/km (i.e. Euro 5 RDE, no CF), reduction>100mg and NO_2 <60mg, <35% of NO_x → More stringent than German retrofit rules!
- ✓ Solid particles, both number <6 × 10^{11} particles/km and mass <4.5 mg/km

Other pollutants:

- Total hydrocarbons (THC+NOx<230 mg/km)
- Carbon monoxide (CO, <500 mg/km),
- Nitrous oxide (N2O, <40 mg/km)
- Ammonia (NH3, <60 mg/km)
- Catch-all provision: "any other pollutant whose existence might be inferred by the way of functioning of the proposed solution due, for instance, to additives or catalysts"

- ✓ Fuel consumption (<10% increase)
- ✓ Performance and driveability (accelerations less than 20% worse)
- ✓ Acquisition and running costs (<2000 Euros TCO)
- ✓ Acceptable noise, safety, durability, maintenance and usability

TEST RESULTS OF THE PRIZE-WINNING EURO 5 VEHICLE

ELSEVIER

Environmental Research

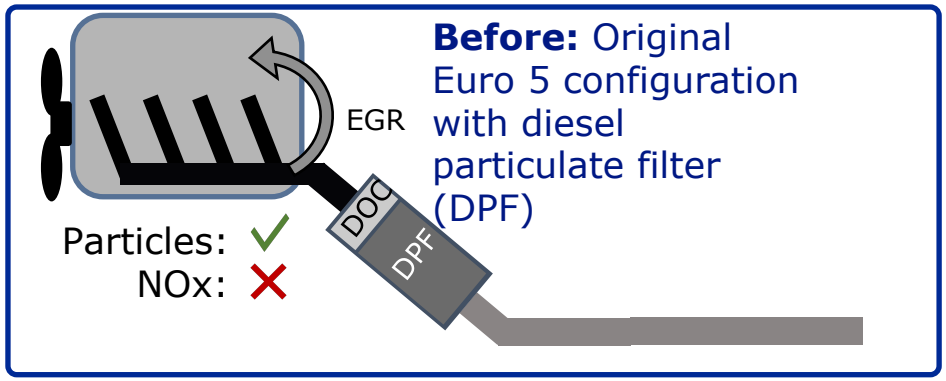
Volume 166, October 2018, Pages 298-309

Evaluation of NO_x emissions of a retrofitted Euro 5 passenger car for the Horizon prize "Engine retrofit"

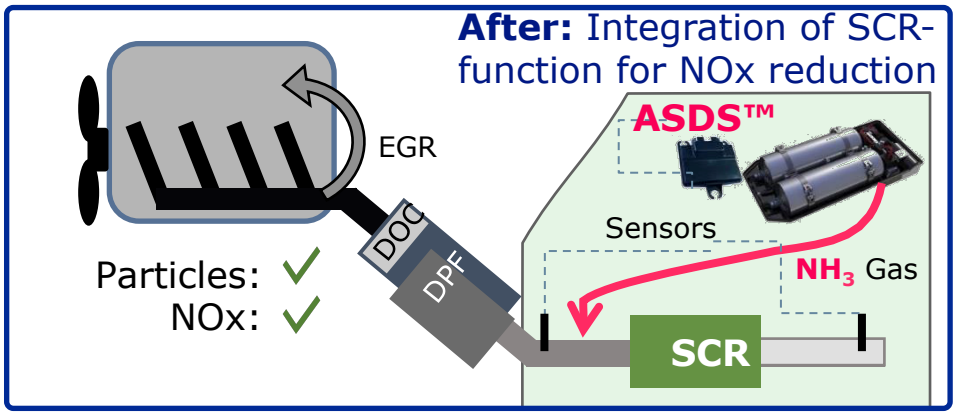
Barouch Giechaskiel [a], Ricardo Suarez-Bertoa [a], Tero Lähde [a], Michael Clairotte [a], Massimo Carriero [a], Pierre Bonnel [a], Maurizio Maggiore [b]

TECHNICAL APPROACH: ADDING SCR TO EURO 5 CARS

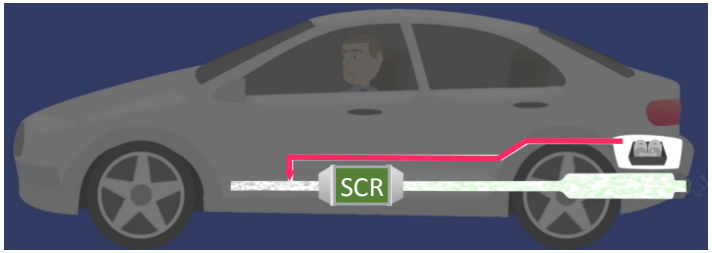
- A Euro 5 diesel car from 2014: Retrofitted with the NOx-reducing ASDS prototype from Amminex together with an SCR catalyst from Johnson Matthey
- Strategy and main features of the demonstrated solution:
  - Upgrade with low impact on CO_2
  - Adding under-floor SCR to the existing Euro 5 DOC/DPF
- The optimal NO_X reductant to activate "cold" uf-SCR:
  LD-ASDS prototype with controller installed in spare-wheel well
- Stand-alone integration:
  - No engine recalibration or modification on the certified DOC/DPF in engine compartment
  - Use existing vehicle power/battery system



Before: Original Euro 5 configuration with diesel particulate filter (DPF)



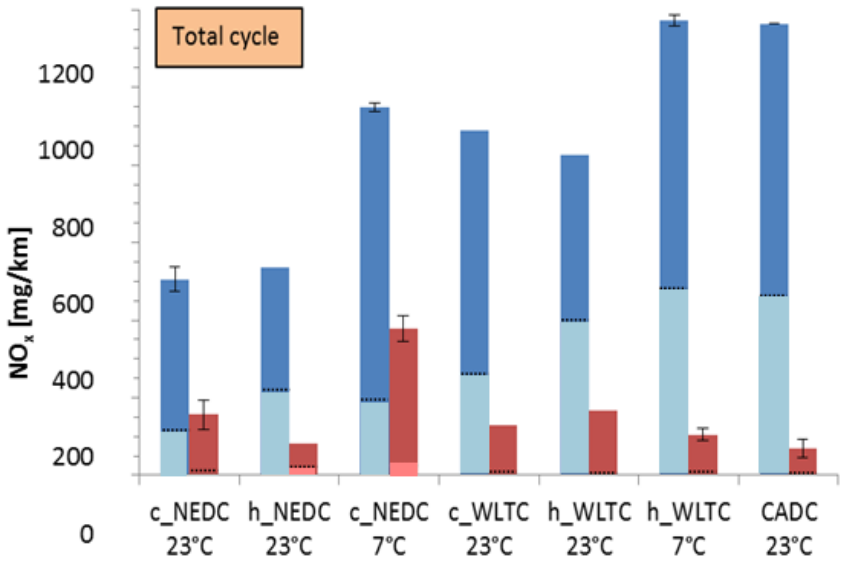
After: Integration of SCR-function for NOx reduction



Amminex
solid technology - clean air

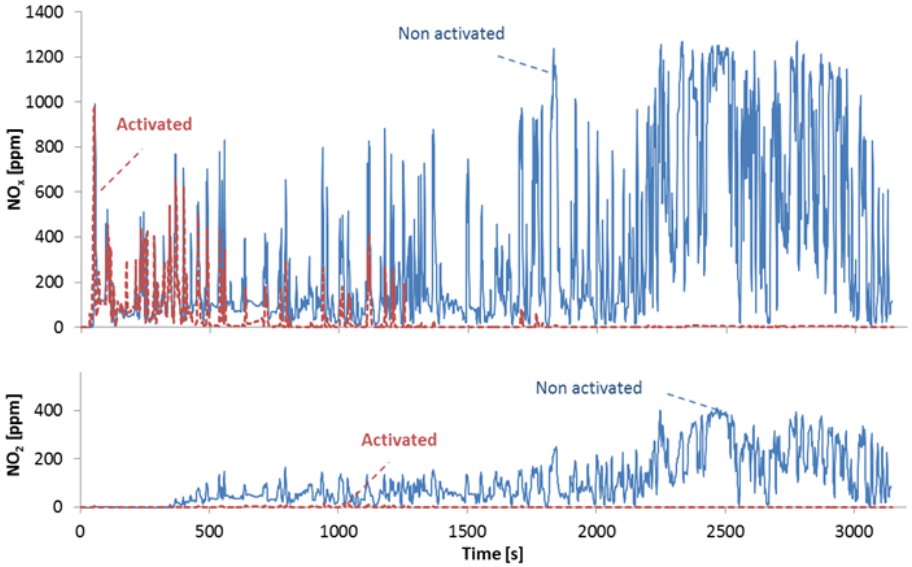
Nitrogen oxides (NOx, NO2), lab

- ✓ Base car → narrow thermal window and possibly power/torque window, poor cold start strategy at 7°(active on 23°NEDC), but also in cold WLTC at 23°
- ✓ Technology works earlier than standard SCR, yet struggles in the first minutes due to lack of support of a cold start strategy
- ✓ Cooperation with OEM needed to apply the heat-up strategy used for certification
- ✓ 65-90% reductions except for NEDC 7°
- ✓ At 130km/h in Artemis rural/highway 1200-1700mg/km, reduced to low tens by the system
- ✓ Overall, even more outstanding results on NO2 (light bars), in most cases to zero



Nitrogen oxides (NOx, NO2), lab

- A zoom in ARTEMIS test result
- Ammonia injection starts after 400", at around 100°C, by 1250" NOx emissions are non existent
- NO_2 is presented in the lower graph, with the system on it's almost zero in all the cycle

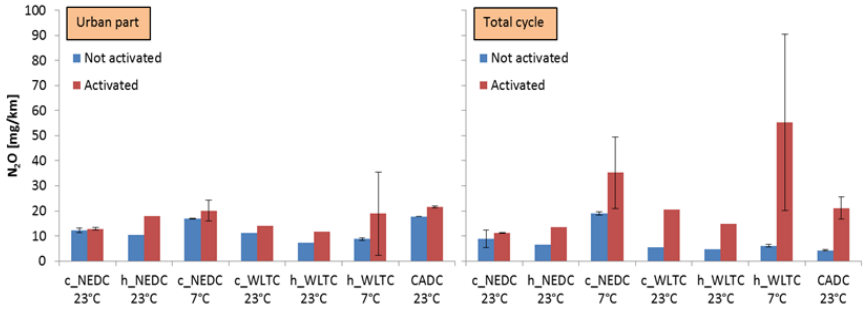


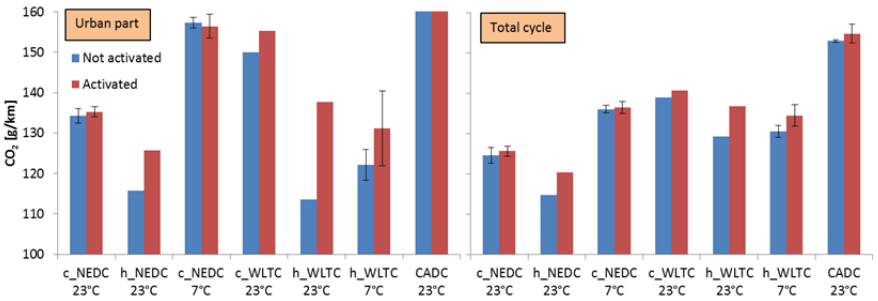
Solid particles (mass/number), THC, CO, lab

- No modification to the DPF introduced
- In general low PN emissions ($<10^{10}$ p/km)
- Only during cold start tests emissions high ($>10^{11}$ p/km) in excess of PN limit (6×10^{11} p/km) in the cold NEDC at 7C
- No negative effect of retrofit on PN: the emissions even slightly lower (due to DPF filling state and deep bed filtration?)
- Most importantly, retrofit did not increase sub-23 nm particle concentration (not part of this prize, but tested to prepare for the Engine of the Future prize)
- Hydrocarbons and CO also remained low and unaffected (or slightly improved) by the presence of the retrofit

GHGs, lab

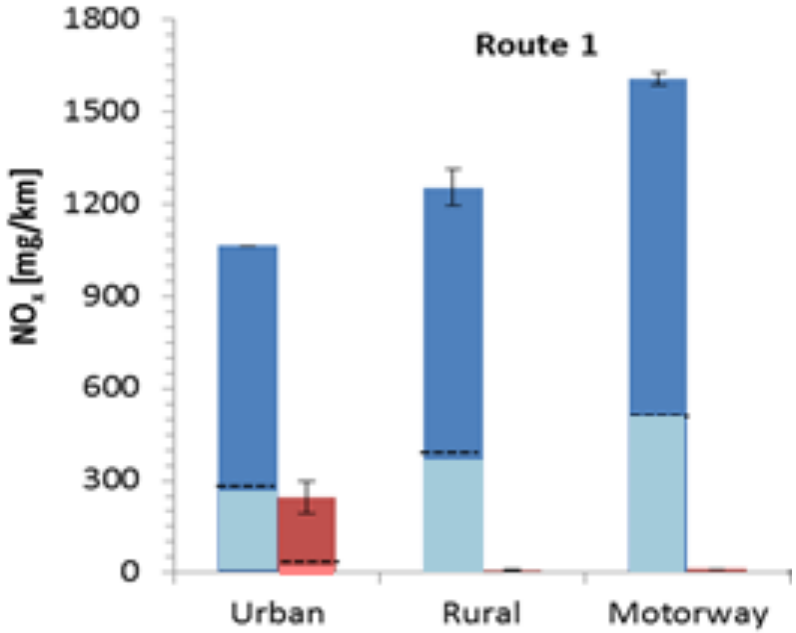
- N_20, a powerful GHG (GWP=265)
  - For the urban part, significant N_20 emissions (6g CO_{2eq}) already without retrofit, small increase with
  - Strong increases for the hot parts of cycles, some up to 30g CO_{2eq}
  - Correlates with high flue T, and NH_3 dosing, a warning for series vehicles, although not regulated
- CO2
  - Cold start, battery fully charged, low influence of the retrofit. Hot start, 4-7 g/km increases
  - One exception (hot start WTC urban part) where start/stop was different for unknown reasons (difference in test sequence?)
  - On average 1-2% fuel penalty (CO2 increase)





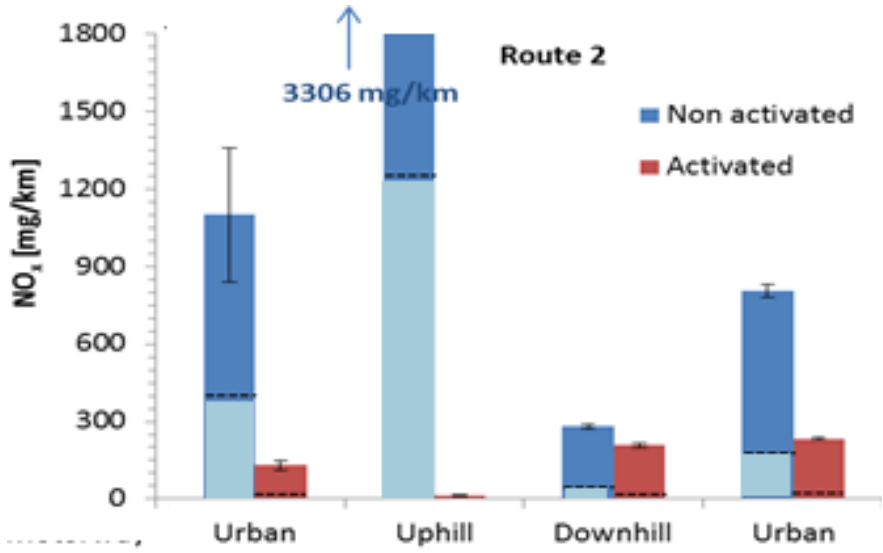
Nitrogen oxides (NOx, NO2), RDE tests

- Route 1 is RDE compliant, but quite hilly
- NOx emissions on base car test from around 1000mg/km to >1500 mg/km, tests in winter to stress even more
- With the retrofit on, NOx emissions decrease to <240 mg/km in urban, zero at higher speeds
- Total NOx reduction is 830-1500 mg/km
- Further improvements possible with heat up strategy, possibly to 180 mg/km and less
- Again, high effectiveness on NO2, almost zero in all conditions
- OVERALL 150mg/km, BETTER THAN MOST EURO 6 b/c STILL AVAILABLE ON THE MARKET



Nitrogen oxides (NOx, NO2), RDE tests

- ✓ Route 2 is additional extra-hard test performed on steep mountain roads (non-RDE compliant, 1800 m/100km)
- ✓ Base NOx emissions from 280 to 3306mg/km, NO2/NOx ratio 18-36%
- ✓ With the retrofit NOx emissions decrease to <240 mg/km, NO2/NOx ratio <15%
- ✓ Total reduction of NOx is 240-3300 mg/km (or >70%)
- ✓ Exception in "Downhill" driving, where reduction is only 75 mg (or 26%) due to cooler exhaust flow for a long period, leading to higher emission in the following urban segment



RECENT RESULTS ON A EURO 6b VEHICLE

atmosphere

Emissions of a Euro 6b Diesel Passenger Car Retrofitted with a Solid Ammonia Reduction System

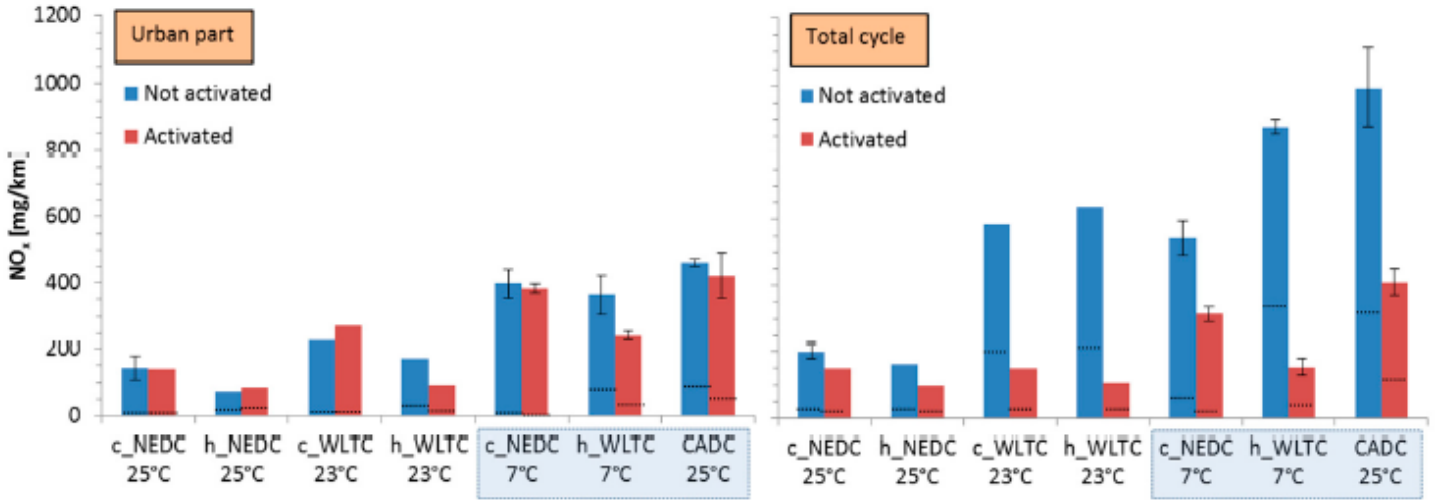
Barouch Giechaskiel [1,*], Ricardo Suarez-Bertoa [1], Tero Lahde [1], Michael Clairotte [1], Massimo Carriero [1], Pierre Bonnel [1] and Maurizio Maggiore [2]

[1] European Commission—Joint Research Centre, I-21027 Ispra (VA), Italy
[2] European Commission—DG Research & Innovation, B-1049 Brussels, Belgium
* Author to whom correspondence should be addressed.

Atmosphere **2019**, *10*(4), 180; https://doi.org/10.3390/atmos10040180

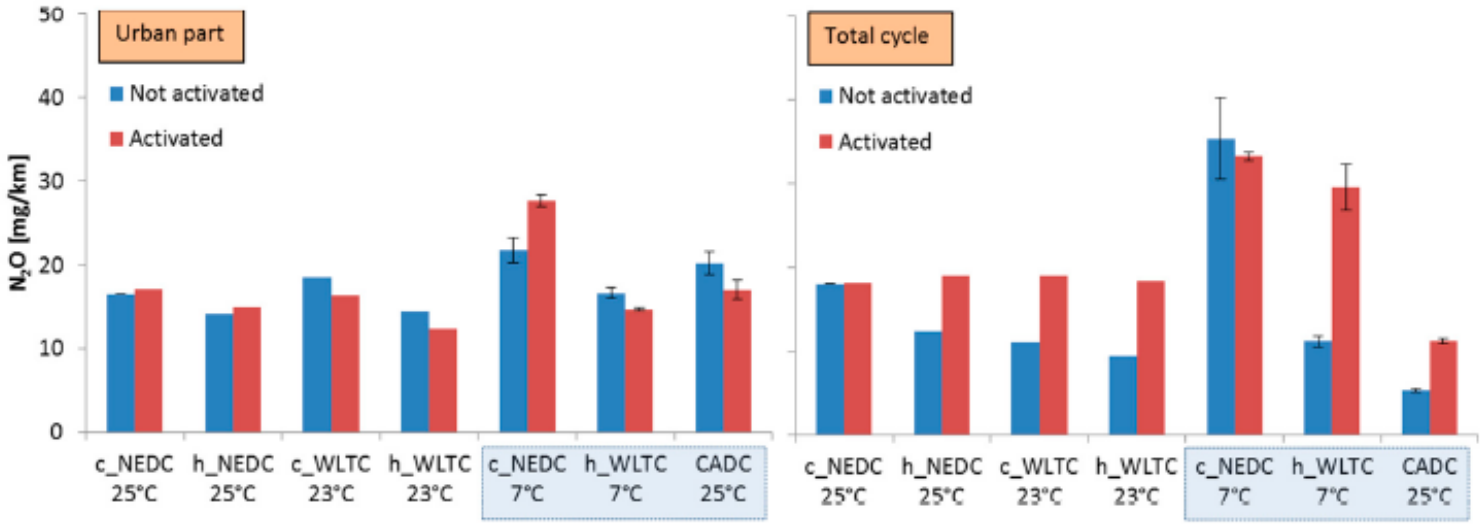
- The prize submission included a same model Euro 6b vehicle
- Results were also good, but missed the strict target (2.1 Conformity Factor on Euro 6 limit) specified to earn additional points
- This is particularly surprising in view of the presence of an LNT
- JRC tests showed differences with Amminex results, which might suggest a malfunction, a revised test vehicle was provided for testing some time after the closing of the prize

Nitrogen oxides (NOx, NO2), lab



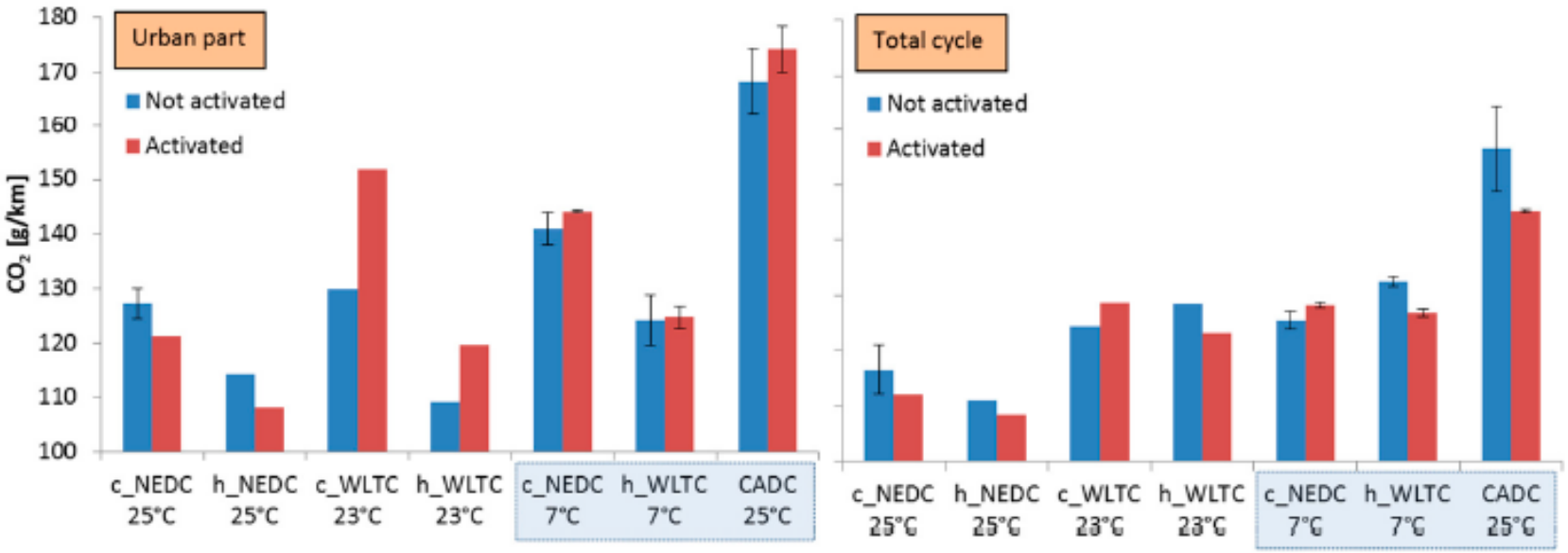
- LNT promising for cold start but colder exhaust and still with windows
- Very high emissions outside NEDC, particularly at motorway speeds
- As tested (standard road loads, not specific ones), widely above certification limit, 180 vs 80 mg/km
- SW retrofit being applied? Cold start might be fixed after HW retrofit
- Pre-conditioning dependent, lower emissions if three EUDC done
- Overall, despite (or because) LNT, lower retrofit effectiveness
- Urban negligibe to 120 mg/km depending on cycle
- Total cycles 25-82%, average from 571 to 198 mg
- It was not thermally insulated, calibration was less aggressive

Nitrous oxide (N2O) and ammonia, lab



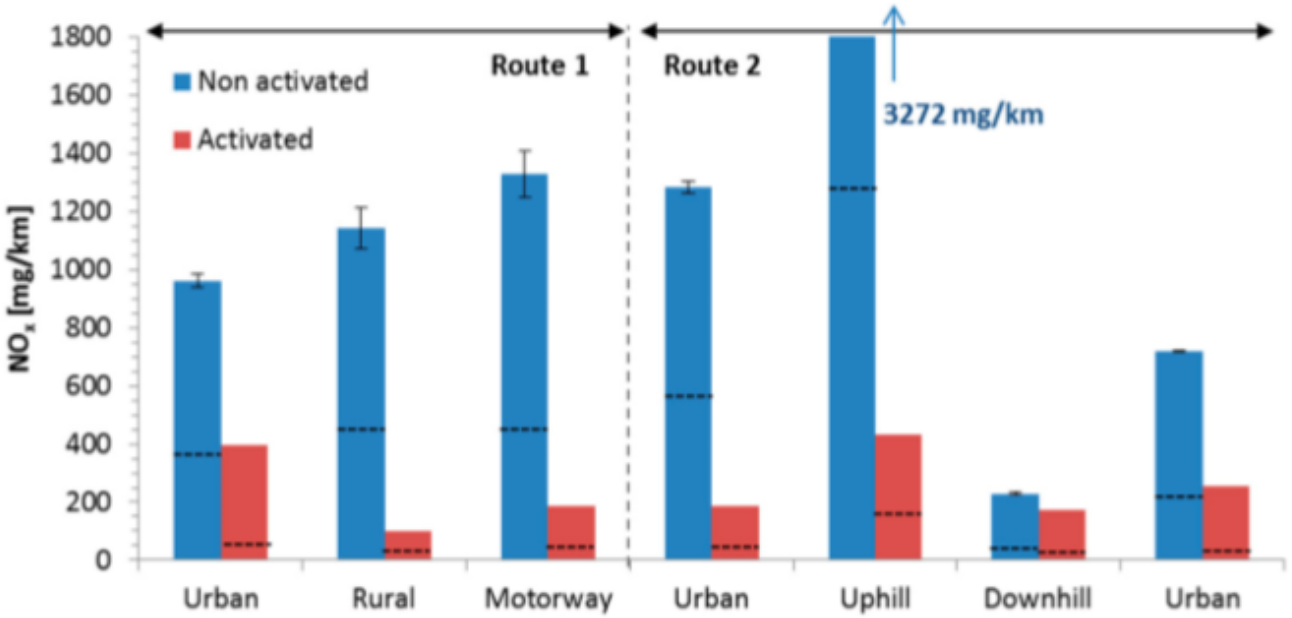
- High emission without retrofit also in this case (3-10g CO_{2eq}), undermining GHG legislation, particularly for urban, cold and high-speed parts
- Turning the retrofit on did not result in a significant increase
- Strong increases and spikes (due to LNT?) for the hot parts of cycles, some almost reaching 30g CO_{2eq}
- Ammonia was at background level in all conditions
- Compared with Euro 5; the less aggressive approach on NO_x (required to reach Prize targets) reduced ammonia injection and therefore N_20 spikes at high speeds and the slight ammonia slip

Fuel consumption, lab



- Cold start, battery fully charged, low influence of the retrofit on CO2
- Hot start, the retrofit increases the CO2 emissions by 4-7 g/km
- One exception (hot start WTC urban part) where the start/stop behaviour was different than in other tests for unknown reasons (difference in test sequence?)
- On average 0,6% fuel penalty (CO2 increase) in urban, negligible or even negative on complete cycles

Nitrogen oxides (NOx, NO2), RDE tests

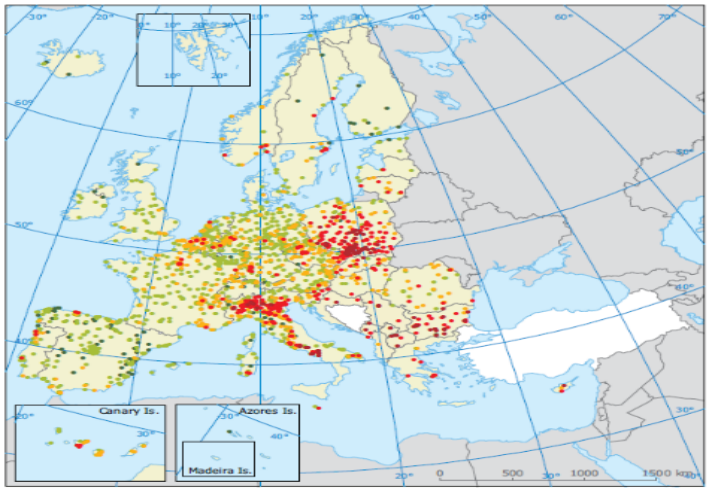


- Very high emissions form base car on both routes, from around 950mg/km to >1300 mg/km in RDE route, 230 up to 3272 on mountain route
- With the retrofit on, NOx emissions decrease to 100-430 mg/km, never reaching close to zero as in Euro 5
- Total NOx reduction is 465-2840 mg/km (-60%)
- Combustion, LNT regeneration and EGR strategies overall made retrofit life harder than for Euro 5 car yet interesting benefits, even more if SW updated

MORE RETROFITS ?

Particles pollution levels remain high…

Concentrations of PM_{10} in 2013



Source: EEA Air Quality in Europe 2015

… current EU AQ standards not as strict as WHO's…

Health impact underestimated?

Air pollution deaths are double previous estimates, finds research

Researchers say dirty air is killing 800,000 people a year in Europe, and urge the phasing out of fossil fuel burning

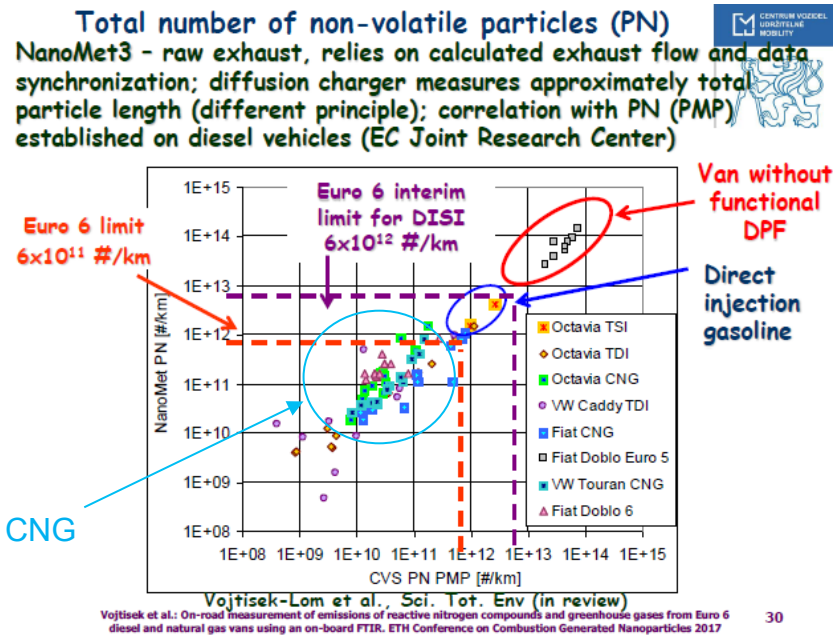
Swiss TPH

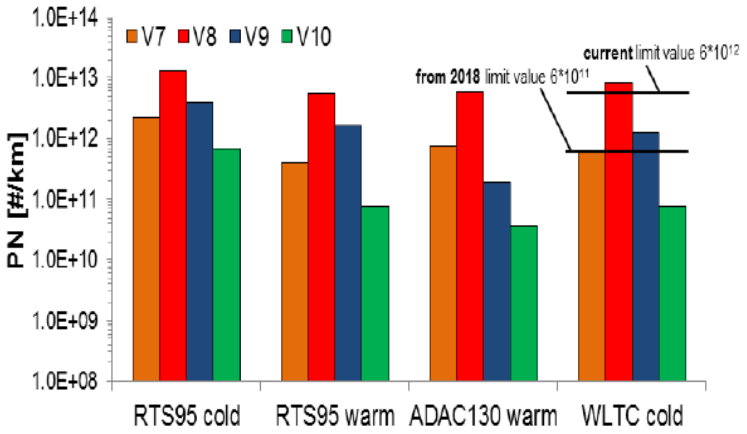
Set and enforce science based targets as proposed by WHO to protect health!

EU limits are NOT SCIENCE BASE and do NOT protect people's health

Pollutant	EU limit	% citizens Exceeding EU limit	Science based Guidelines of WHO	% citizens Exceeding WHO limit
PM10	50 µg/m³ in 24 h	16	20 µg/m³ a year	50
PM2.5	25 µg/m³ a year	8	10 µg/m³ a year	85
BaP	1 µg/m³ a year	20	0.12 ng/m³ a year	88
NO_2	40 µg/m³ a year	8	40 µg/m³ a year	8
SO_2	125 µg/m³ in 24 h	<1	20 µg/m³ in 24 h	38
O_3	120 µg/m³ in 8 h	8	100 µg/m³ in 8 h	96

Mass standards are insufficient, close to traffic an exposure limit to NP is needed, and aggregated nanoparticles are broken down in our body

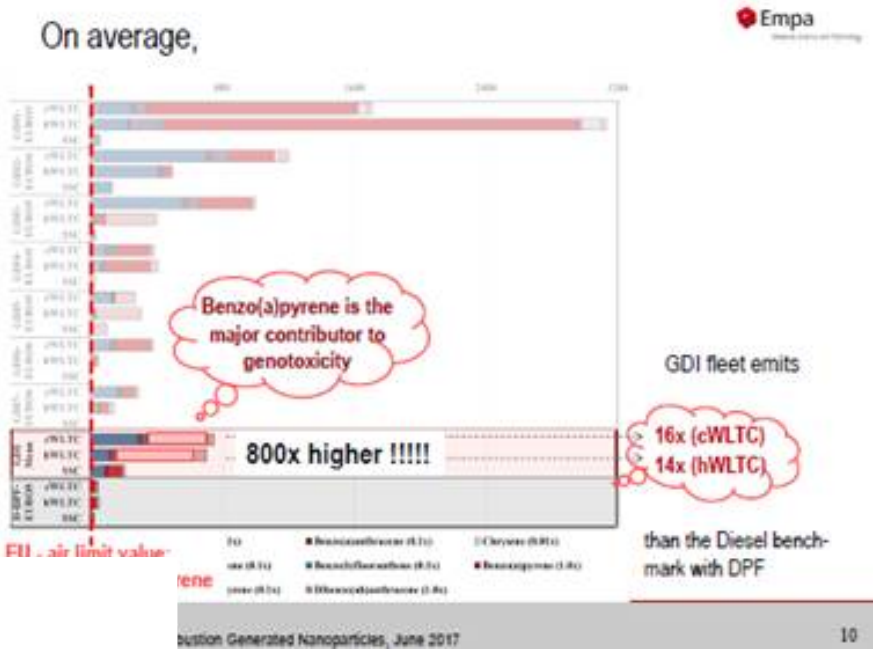




PN results in all driving cycles.

… all ICEs contribute… BTW, tampering is a huge threat when vehicles get old due to extortionary filter prices

… gasoline particles (finer and with more PAH) are more dangerous than diesel's…



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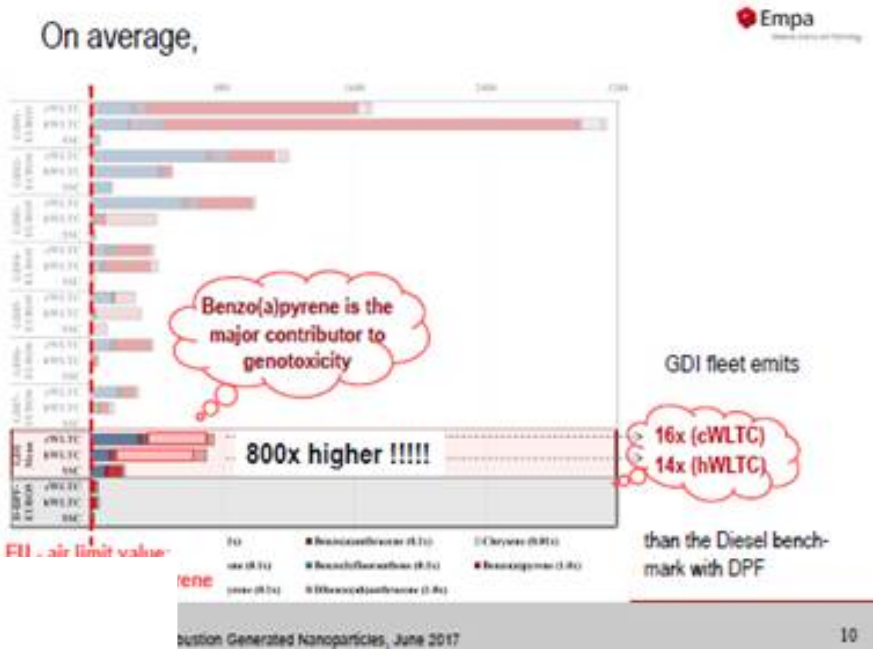
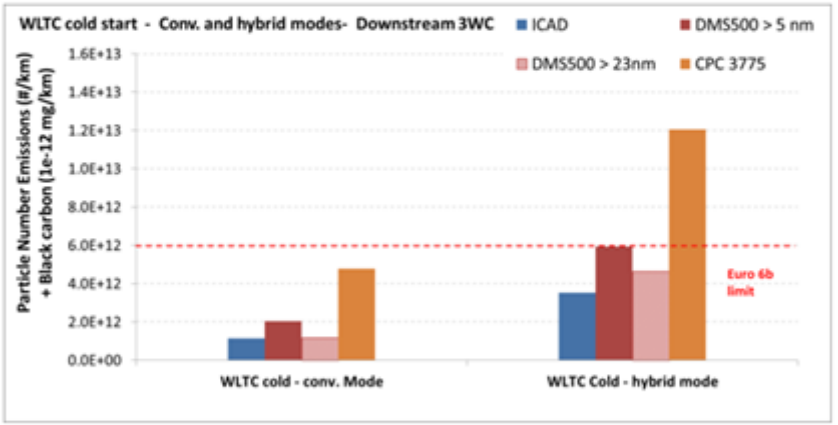


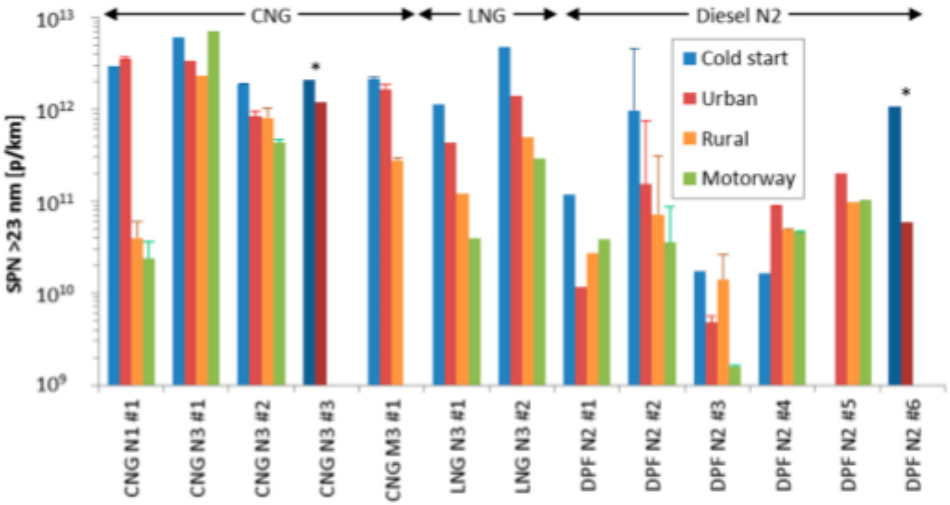
SUREAL-23

Effect of hybrid mode



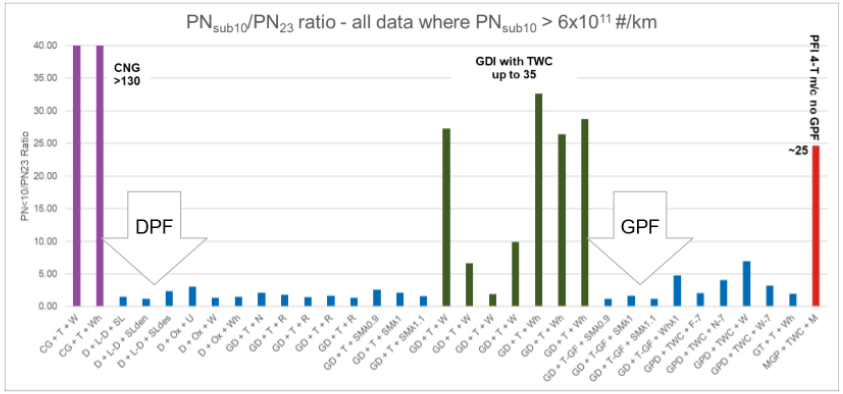
Hybrid operation can increase particle emissions by more than 2x

… including when used in „clean" hybrids

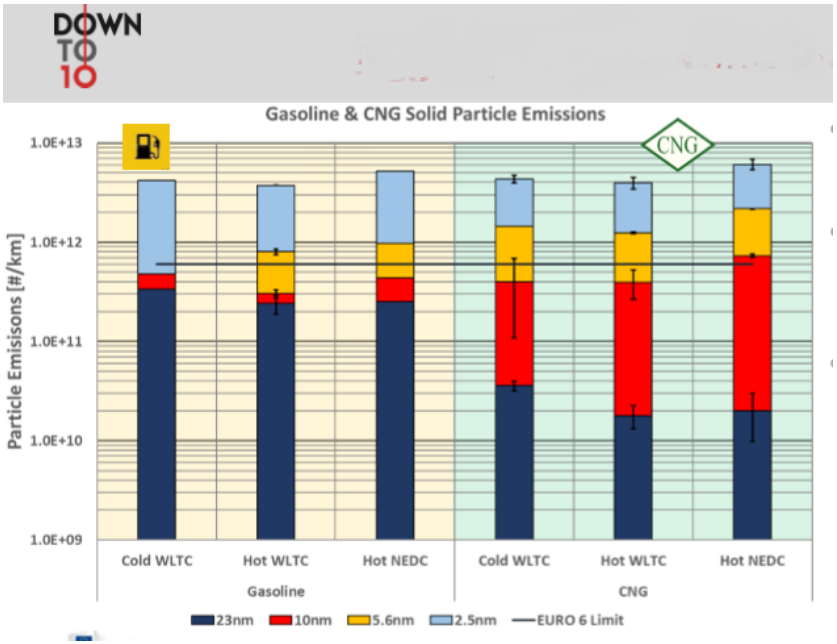


… even natural gas is emerging as a potential threat, with large shares escaping counting due to small size (3-10nm) yet total count similar to unfiltered diesel

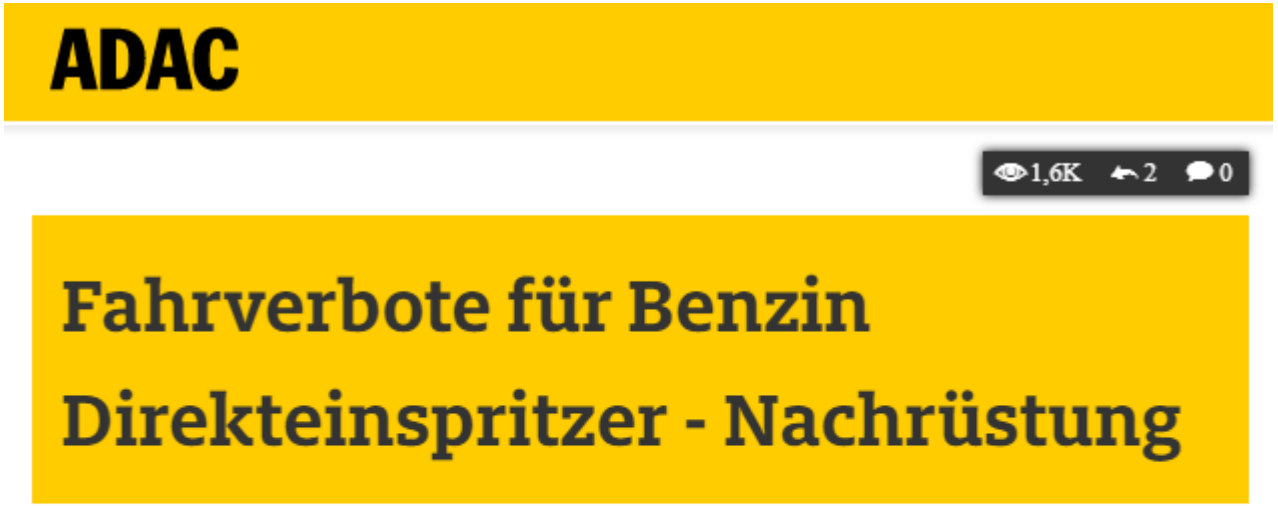
PN_{sub10} v PN_{23}: outside regulatory regime (no PCRF)



- Whole emissions cycle data, where PN_{sub10} > $6x10^{11}$#/km
  - No excessive PN increases in <10nm region when DPF and GPF are present
  - High PN emissions observed with some PFI and CNG applications, without particle filters!
    - (over 100x >23nm levels for CNG)



OTTO ENGINE XPF RETROFITS, ANYONE?



ADAC

1,6K 2 0

Fahrverbote für Benzin Direkteinspritzer - Nachrüstung

Hallo, ich fahre zZ einem BMW M140i , BJ 04/2017, Euro 6b. Dank der DUH wird ja inzwischen auch über Fahrverbote für Direkteinspritzer diskutiert, und wird wohl auch kommen. Nun die Frage, es gibt ja von BMW seit Mitte 2018 das gleiche Model mit Partikelfilter... also alle Teile für eine Nachrüstung vom Hersteller verfügbar... also sollte ja einer Nachrüstung nichts im Wege stehen ? Ist halt die Frage was es kostet und was alles getauscht werden muss, Auspuffstrang , Steuergerät .... ? Und ist dann eine Umschlüsselung auf Euro 6d möglich ?

THANK YOU FOR YOUR ATTENTION

- DG RTD
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- JRC
  - **Barouch Giechaskiel: barouch.giechaskiel@jrc.ec.europa.eu**

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