Catalyst Technologies Meeting BS5 and BS6 Norms

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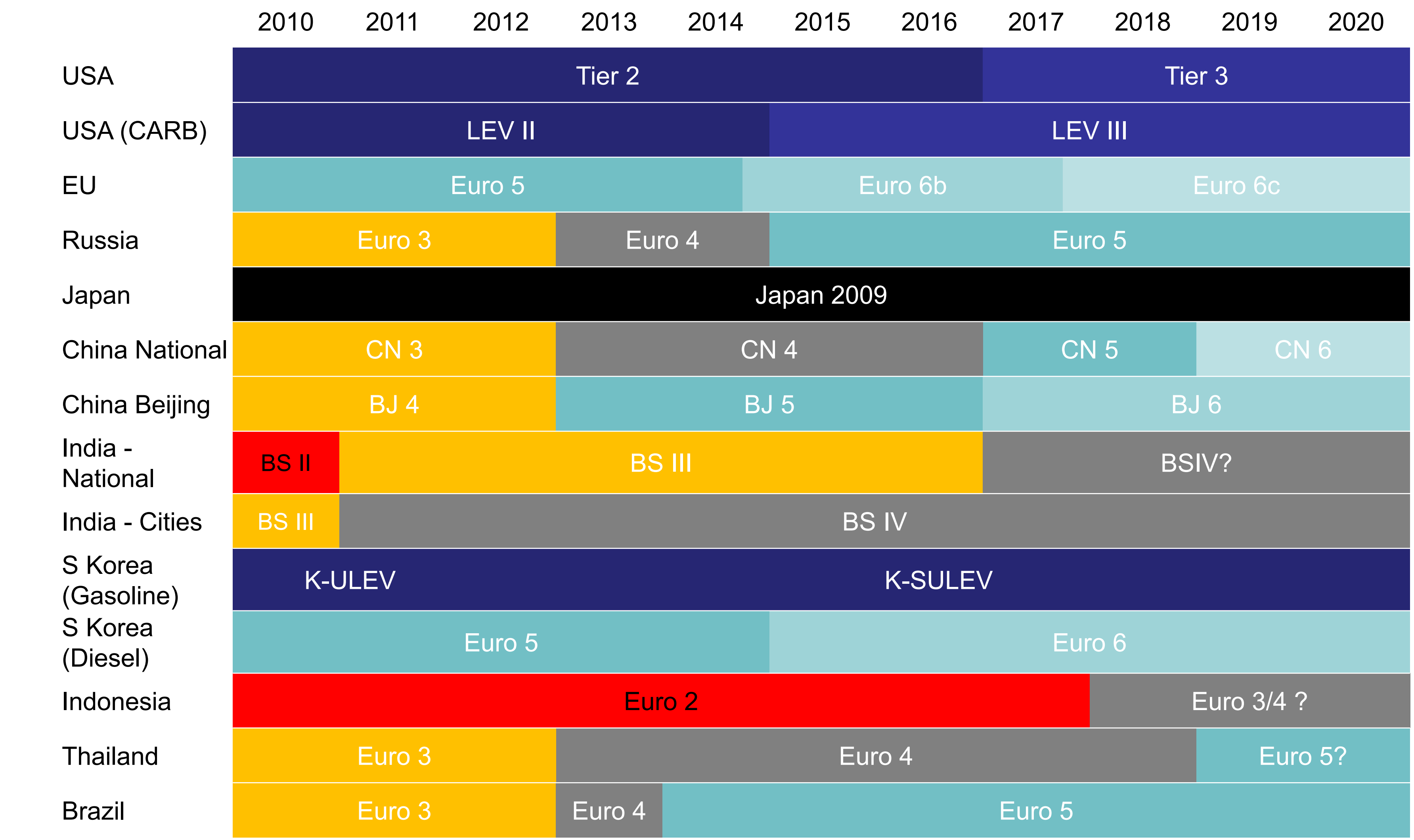
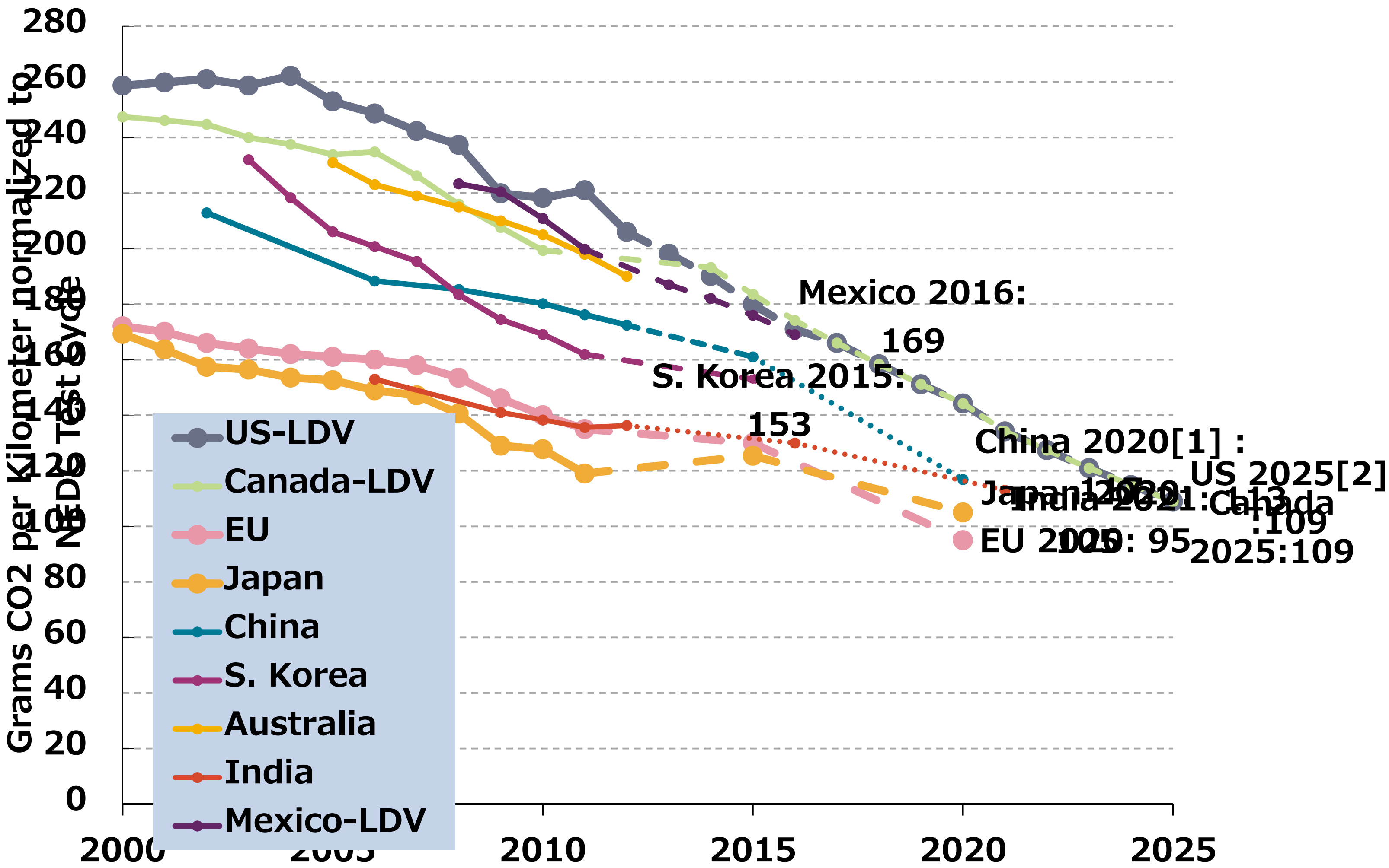
LD Regulations



FUEL ECONOMY & CO_2 LEGISLATION COMPARISON



Experience of EU5

- Gasoline
  - PGM selection
  - PGM loading

- Light Duty Diesel
  - Pt-Pd DOC
  - Sulfur poisoning

Emission Legislation

Gasoline

Stage	Date	CO (g/km)	HC (g/km)	NMHC (g/km)	NOx (g/km)	PM (mg/km)	PN (#/km)
4	2005	1.0	0.100		0.080		
5	2009	1.0	0.100	0.068	0.060	5.0/4.5	

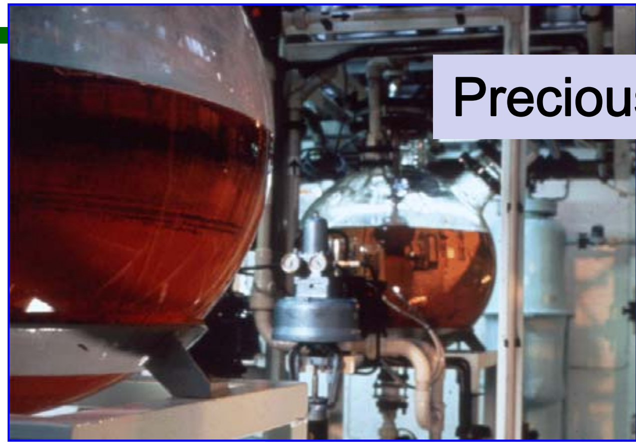
Diesel

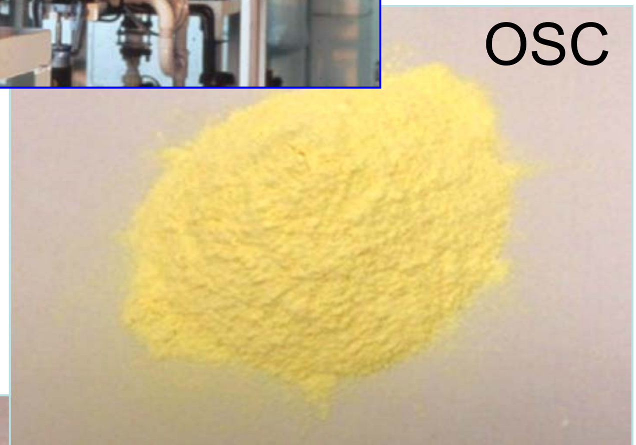
Stage	Date	CO (g/km)	HC+NOx (g/km)	NOx (g/km)	PM (mg/km)	PN (#/km)
4	2005	0.50	0.30	0.25	25	
5	2009	0.50	0.23	0.18	5.0/4.5	6.0* E11

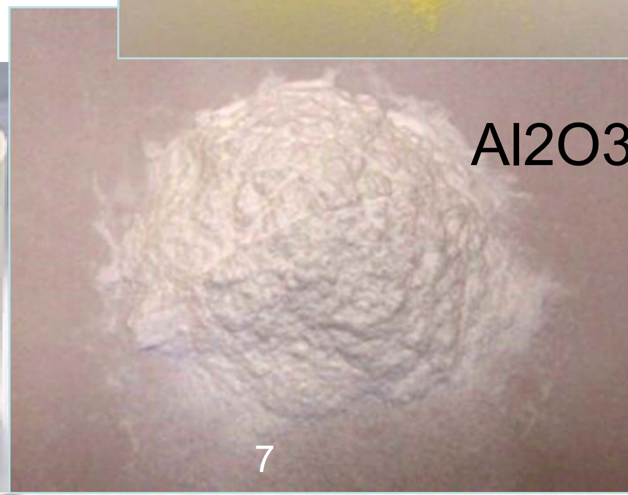
Catalyst Technologies

Three-Way-Catalyst(TWC) contains

- Precious metal (PGM) as active components as catalyst
- Al2O3 as the support of Precious Metal (Pt, Pd, Rh)
- OSC material
- Additives

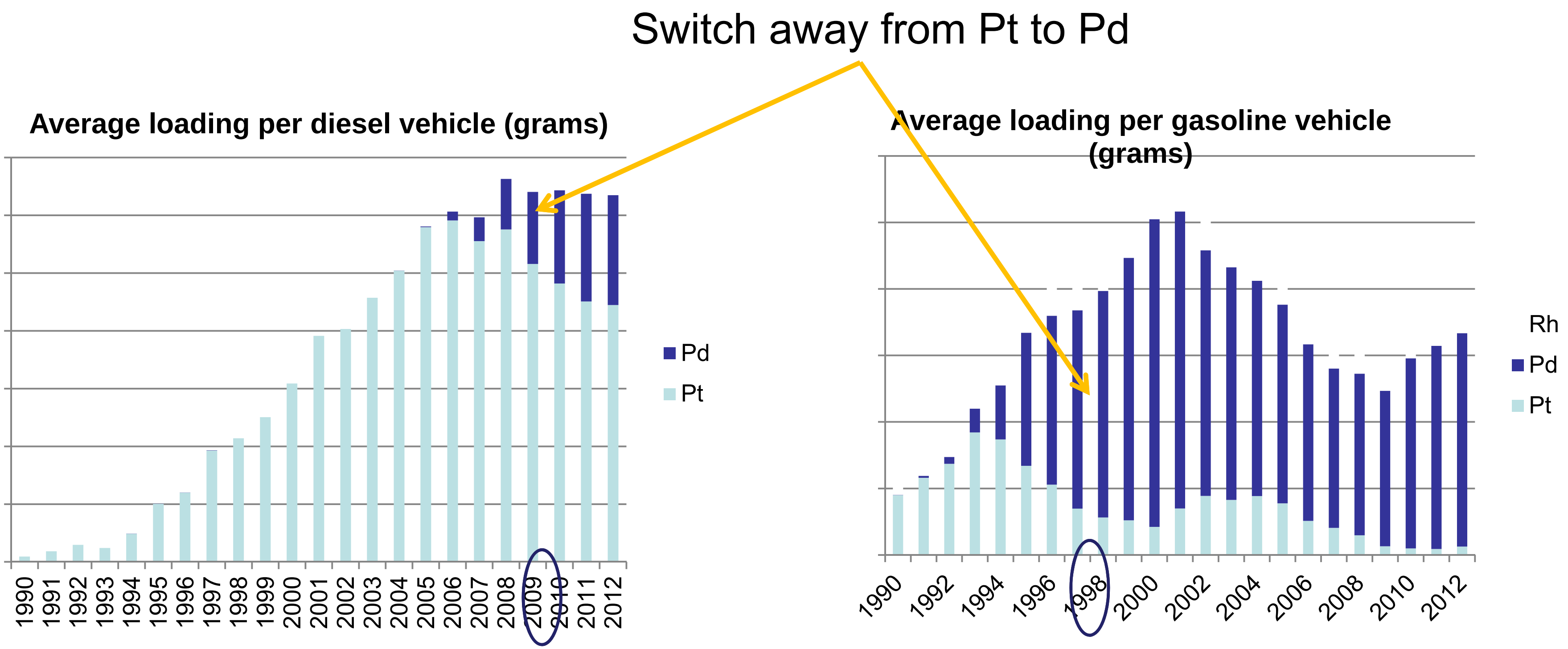






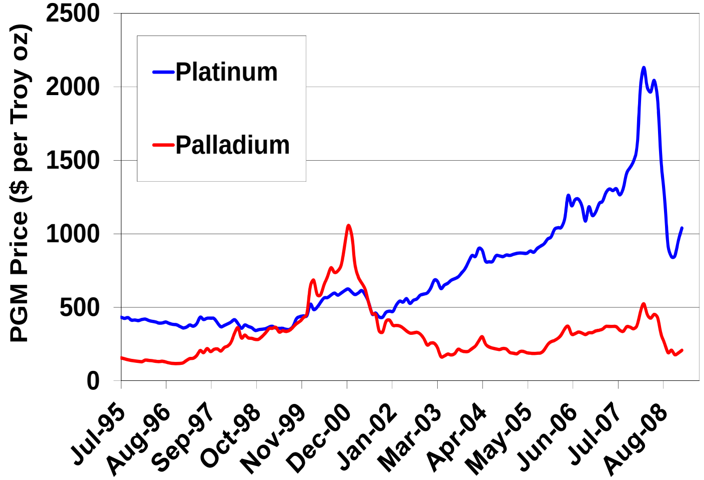
Which PGMs have been used and why?

Focus on Europe (Passenger Cars)



Includes vehicles with no catalyst (pre-1992/3)

Pt vs Pd

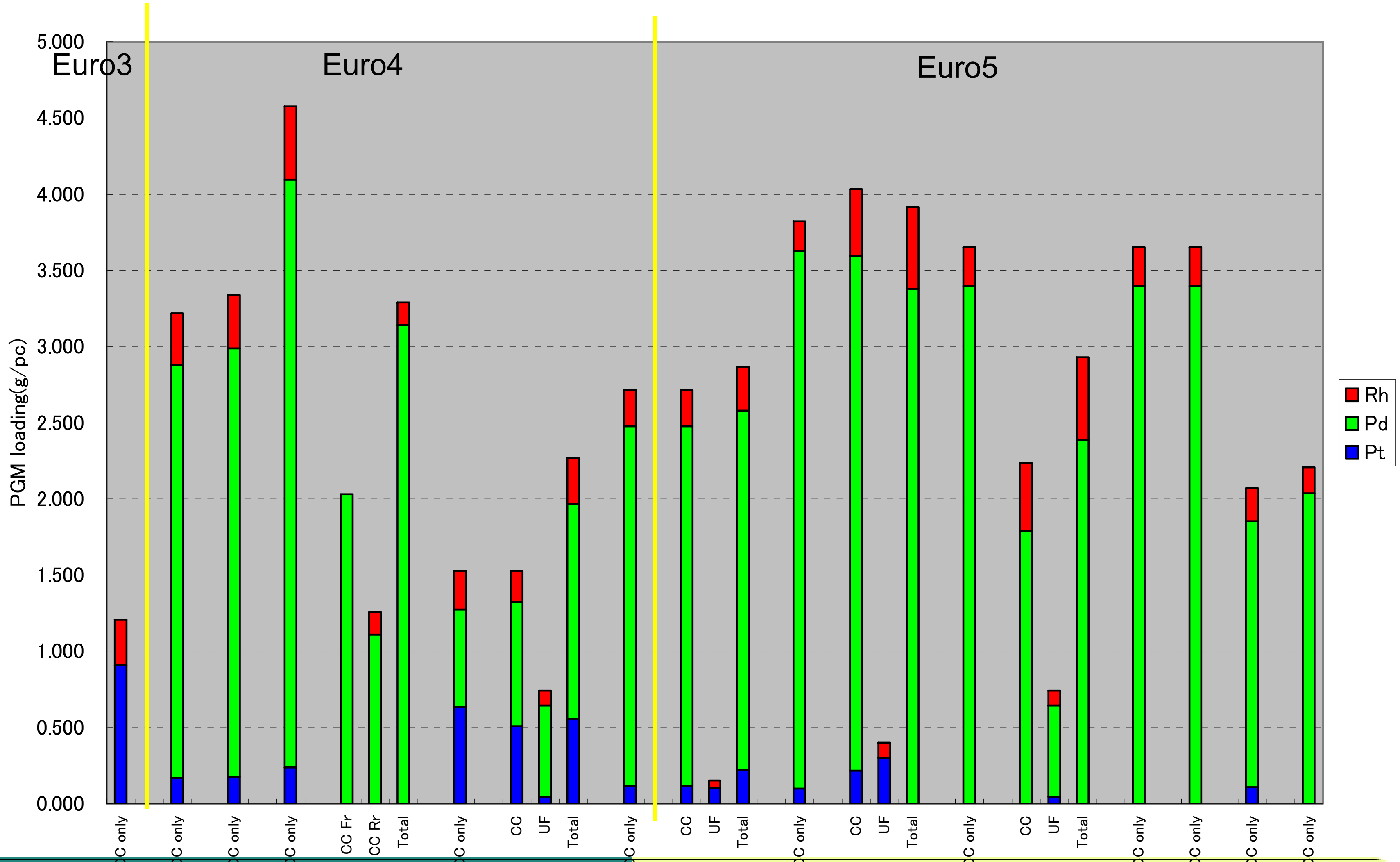


- Fuel sulphur levels were high in Europe in the early 1990s - 1000ppm or more

- Platinum autocatalysts are more sulphur tolerant
  - Especially in lean conditions as for diesel catalysts
  - Sulphur can be cleaned off at high temperatures, as can be found in gasoline cars

PGM loading Comparison

(Engine displacement: 1.0 – 1.5L)



Emission Legislation

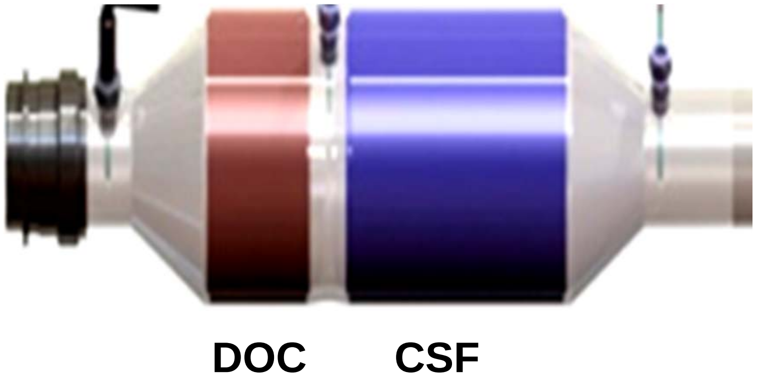
Gasoline

Stage	Date	CO (g/km)	HC (g/km)	NMHC (g/km)	NOx (g/km)	PM (g/km)	PN (#/km)
4	2005	1.0	0.10		0.080		
5	2009	1.0	0.100	0.068	0.060	0.005	

Diesel

Stage	Date	CO (g/km)	HC+NOx (g/km)	NOx (g/km)	PM (g/km)	PN (#/km)
4	2005	0.50	0.30	0.25	0.025	
5	2009	0.50	0.23	0.18	0.005	6.0* E11

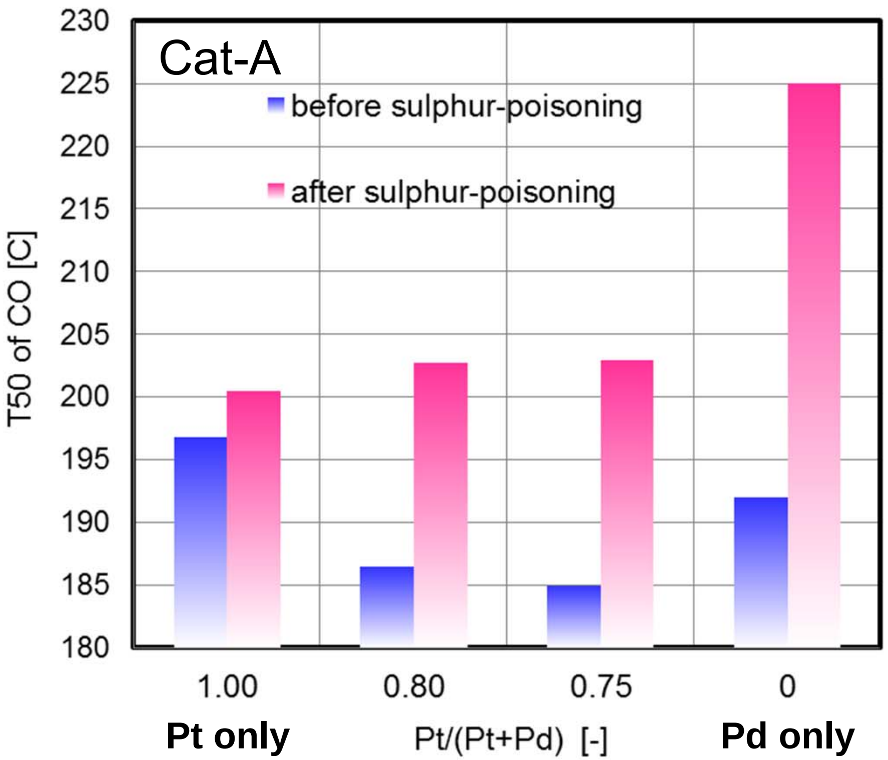
LDD EU5 System Technology



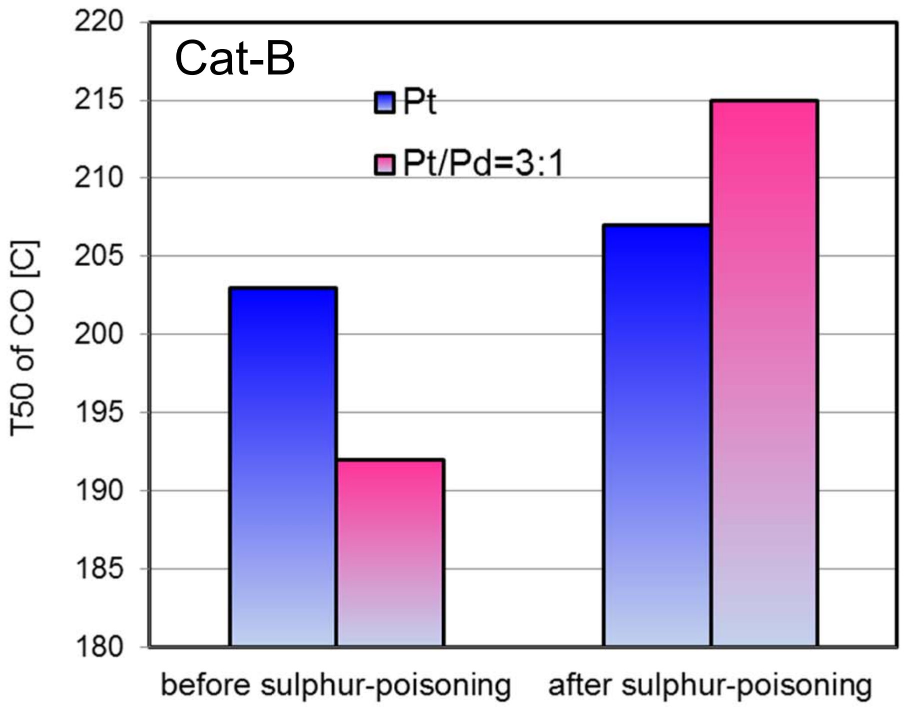
DOC: Pt, or Pt-Pd technology

- Oxidize HC and CO for reduction of emission
- Convert NO into NO2 for passive soot regeneration.
- Generate temperature at inlet of CSF for active soot regeneration.

Design Concepts



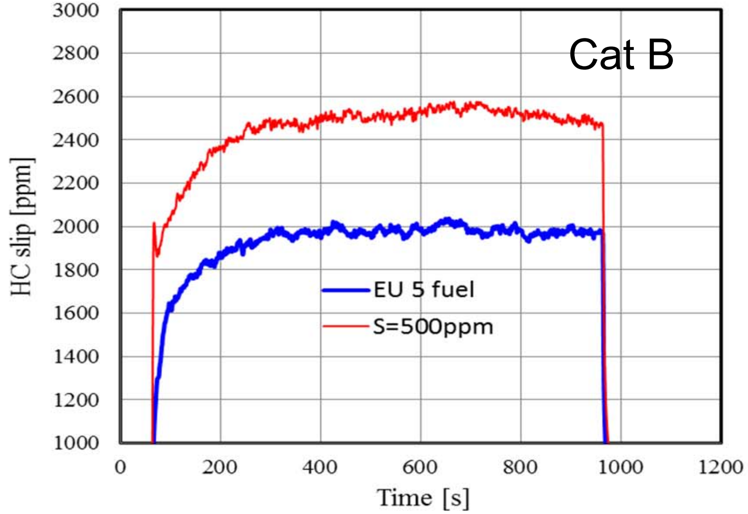
Sulfation : at 300C, to be 8 g-S/L with 500 ppm S fuel

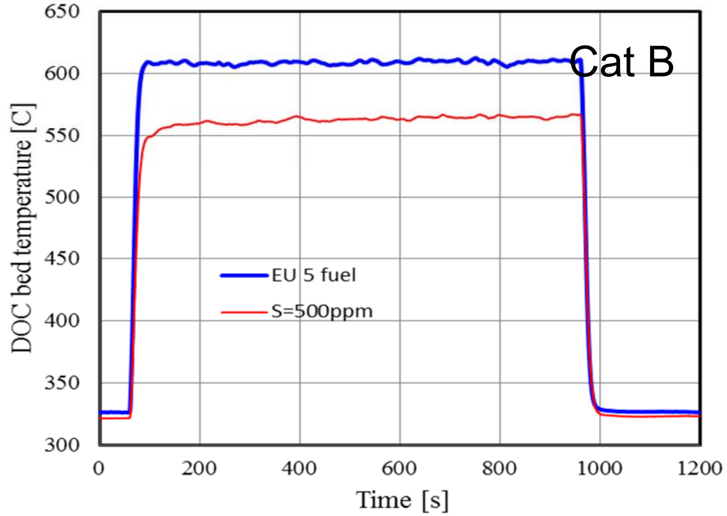


Sulfation : at 250C, to be 8 g-S/L with 500 ppm S fuel

- All samples were evaluated with EU 5 E/G. Pt/Pd show poorer CO/THC oxidation activity than Pt DOC after S-poisoning.

Verification in Bench and vehicle test





- DOC will need to combust fuel to generate heat for filter regeneration.
  - PGM: 2:1/113.1
  - 750C aged.
- Hi sulfur content fuel is deactivating the activity of Pt/Pd DOC.

Summary-1

EU5 experience

- Gasoline
  - PGM type has been shifted from Pt-Rh to Pd-Rh
    - To potentially reduce cost
    - Technology development effort
      - Inter-changeable of PGM type used in TWC to mitigate price fluctuation in PGM market
    - Lower Sulfur content in the fuel is helpful for adoption of Pd-Rh catalyst.

- Diesel
  - DOC + CSF is the typical after-treatment solution to meet EU5
  - Pt-Pd based DOC
    - Pt-rich DOC for NO2 formation and S-tolerance
    - Pd contributes largely on LO and fuel combustion
  - Low sulfur content in fuel is important to maximize the contribution of catalyst.

Experience of EU6

- Gasoline
  - GPF
- Light Duty Diesel
  - NAC + SCRF

Emission Legislation

Gasoline

Stage	Date	CO (g/km)	HC (g/km)	NMHC (g/km)	NOx (g/km)	PM (mg/km)	PN (#/km)
4	2005	1.0	0.10		0.080		
5	2009	1.0	0.100	0.068	0.060	5.0/4.5	
6b	2014					4.5	$6x10^{12}$(**)
6c(*)	2017					4.5	$6x10^{11}$(**)

*) RDE will be introduced.
**) PN limits for DI engine only.

EU6 Regulation

Particle Number limits for GDI engines take effect from 2017

- Euro 6c
  - PN limit reduces from $6x10^{12}$/km to $6x10^{11}$/km

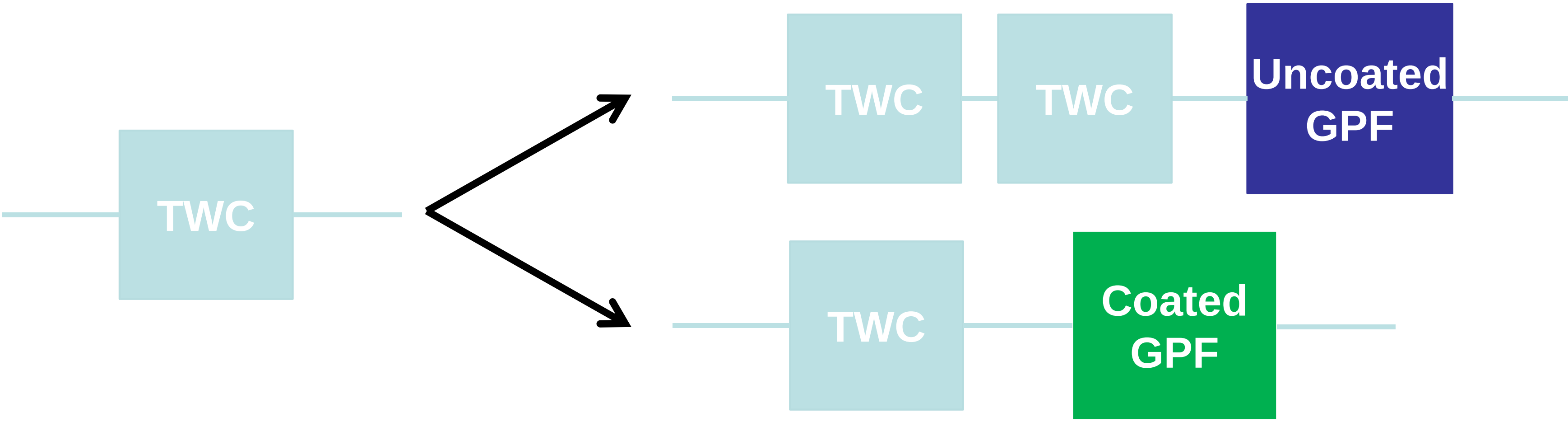
- European Real-World Driving Emissions (RDE)
  - Methodology expected to be confirmed.
  - Conformity Factors and Not To Exceed limits to be decided in 2015
  - PN by PEMS or random drive cycle

Use of coated filters to help meet emissions limits over alternative drive cycles

JM

- Euro 6c/RDE limits will require
  - Control of PN emissions, and
  - Control of gaseous pollutants over a wider range of driving conditions

- Many Euro 5 systems have been optimised for NEDC testing
  - Beneficial to integrate coating onto filter for Euro 6c/RDE, rather than add both TWC volume and an uncoated filter



Impact of Catalyst Design on Emissions breakthroughs

Increasing Rh content of the coated GPF is also an effective method to minimise breakthroughs under transient conditions

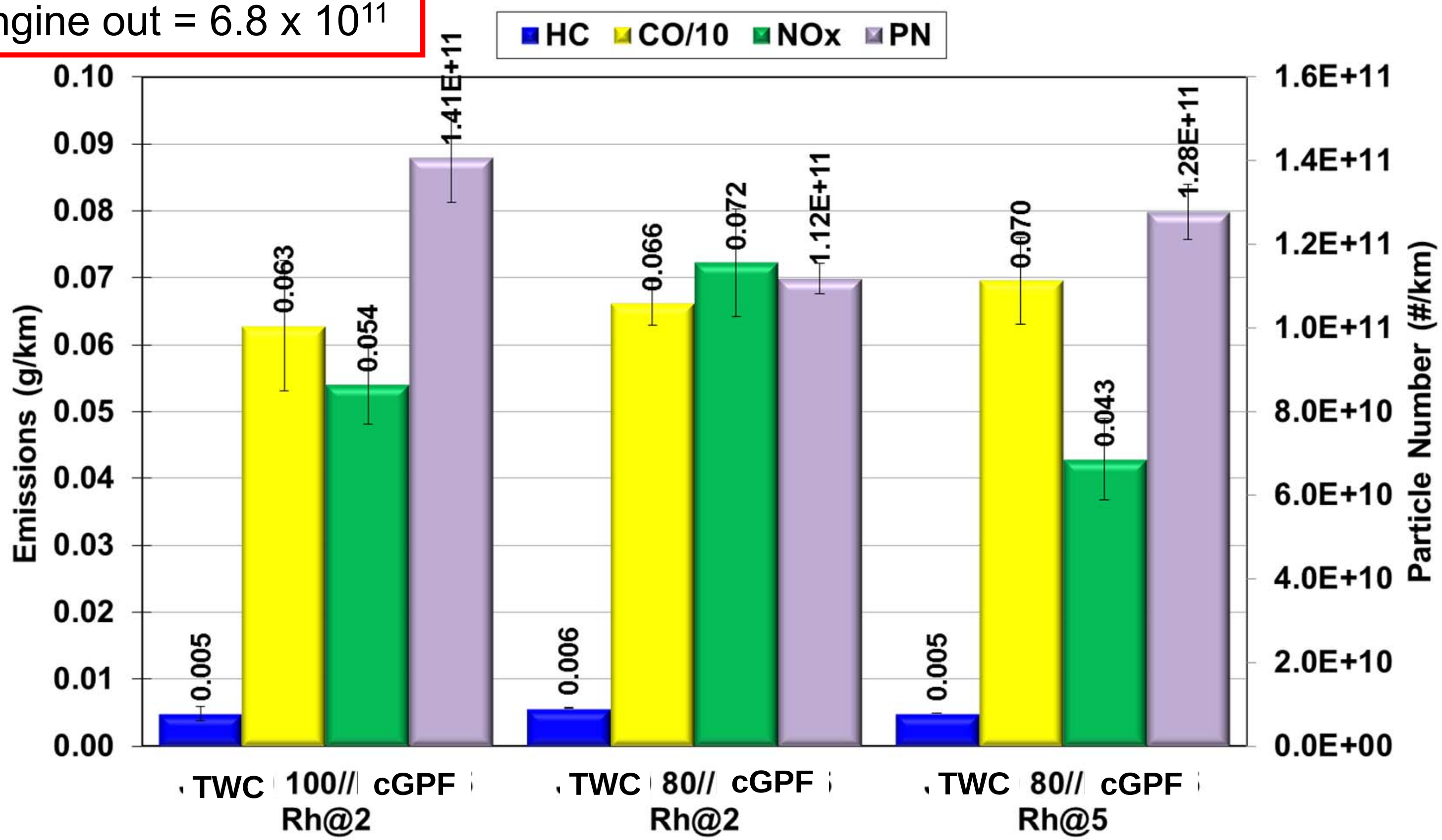
- Small (0.5L) TWC with PGM loading of 100 g/ft^3 (Rh = 7.5) or 80 g/ft^3 (Rh=2)
- Downstream 1.3L, 65% porosity, 300/12 cordierite filter
  - Washcoat loading 100 g/l, PGM loading of 22 g/ft^3 (Rh = 2 or 5)
- Testing on 2.0L Euro 5 GTDI vehicle over Artemis cycle
- Lower Rh loading on TWC resulted in significant NOx breakthrough
- Increasing Rh loading on the Coated GPF mitigated the effect

PGM Loading Impact on TWC and Coated GPF

2.0L Euro 5 GTDI vehicle, Artemis cycle

Lower TWC Rh loading gave significant NOx breakthrough, increased Rh loading on coated GPF gave lower NOx emissions

PN engine out = 6.8 x 10^{11}



Emission Legislation

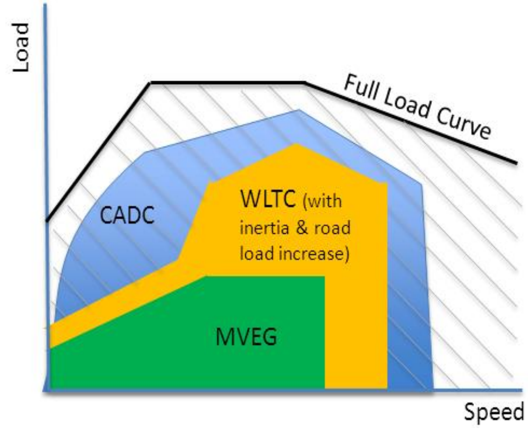
Diesel

EU6

Stage	Date	CO (g/km)	HC+NOx (g/km)	NOx (g/km)	PM (mg/km)	PN (#/km)
4	2005	0.50	0.30	0.25	25	
5	2009	0.50	0.23	0.18	5.0	
6b/c	2014	0.50	0.17	0.080	4.5	$6x10^{11}$

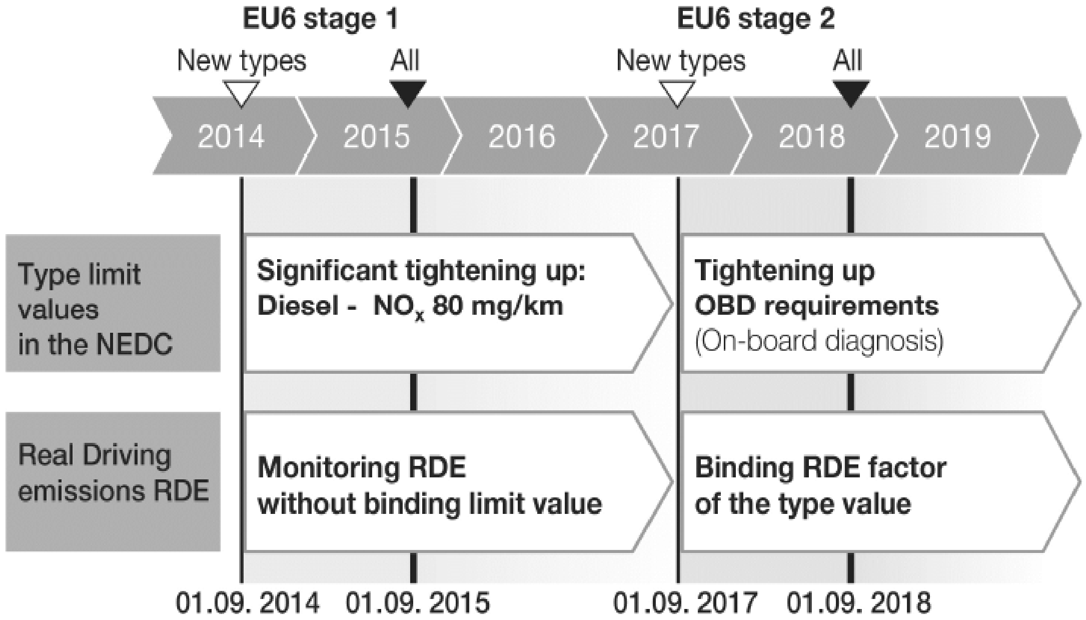
Legislation Requirements & Trends

- Euro 6c adds Real Driving Emissions
  - **NOx main challenge**
  - Conformity Factors TBD



- By 2021 assume CF 1.0 to 1.5

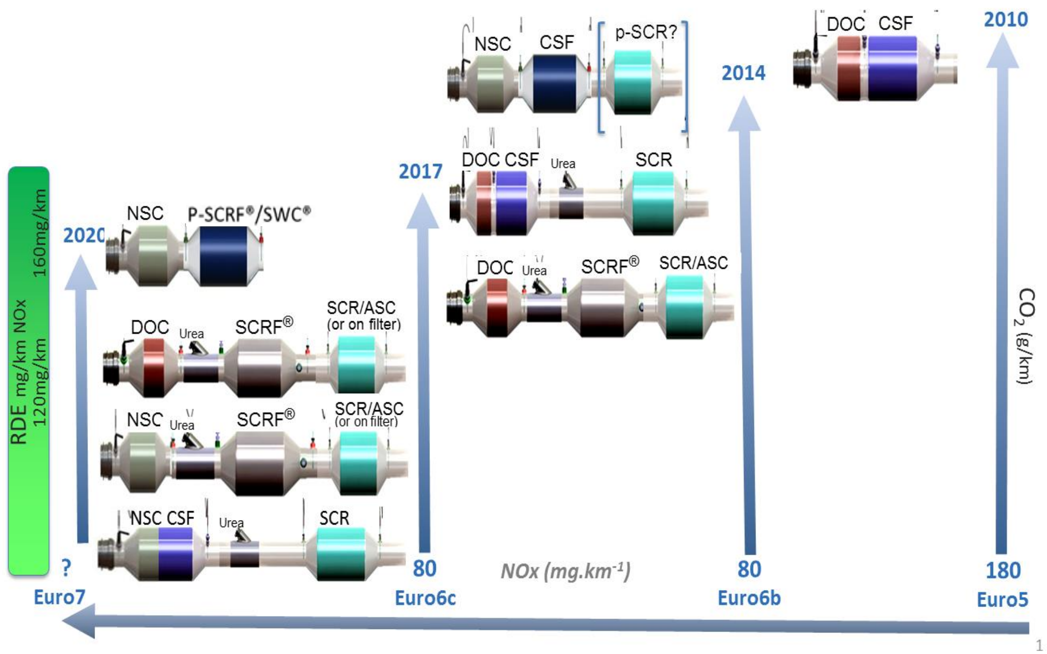
- CF critical to system selection…therefore intervenir roadmap deals with all reasonable scenarios



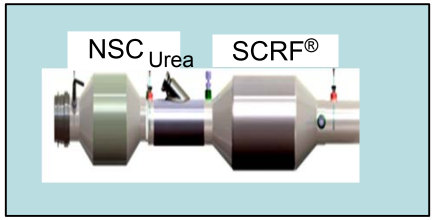
Eligible Roadmap to Europe 2020

Severity of RDE

- Close-couple (except slip cat)
- NSC-only possible for less demanding scenario (CF>1.5)
- NSC + SCRF® for most demanding scenario

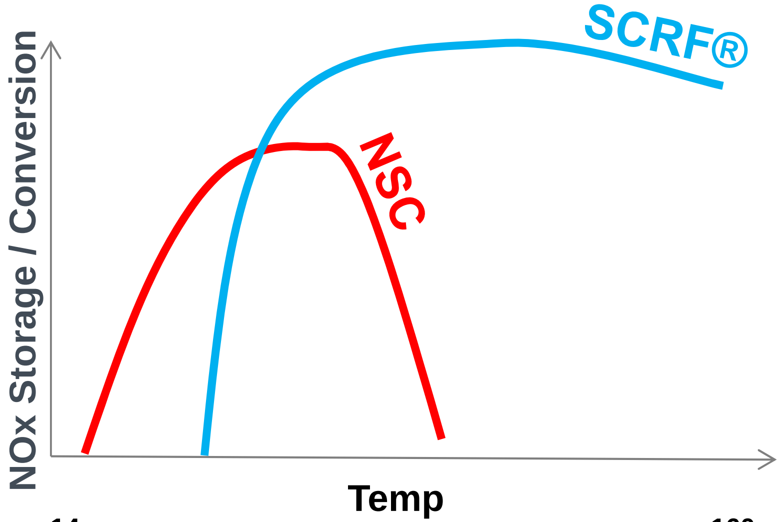


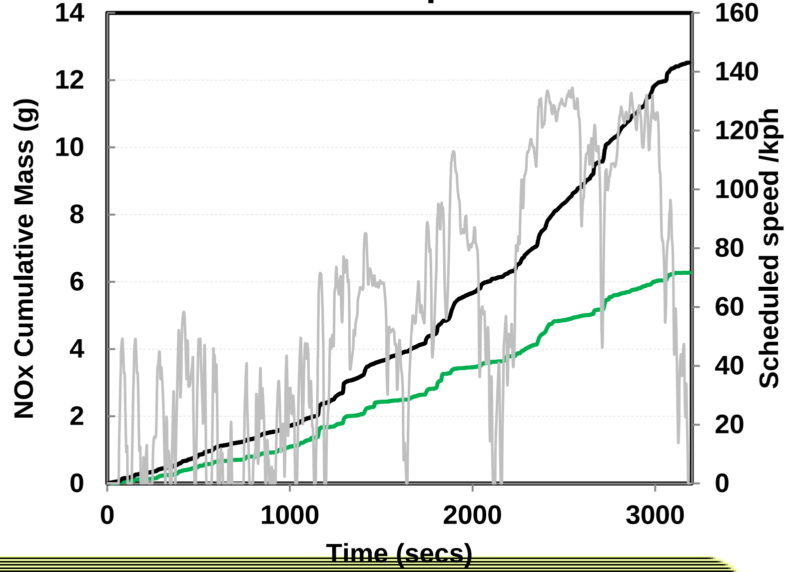
NSC for a-SCR(F) Requirements



•Key Requirements

- Low temp (city) NOx storage –
  - **Increase low temp capacity**
  - Increase release temperature
  - Minimise high temp storage
  - Convert stored NOx at low (city) temperatures
- Stable (& low temperature) HC / CO light-off



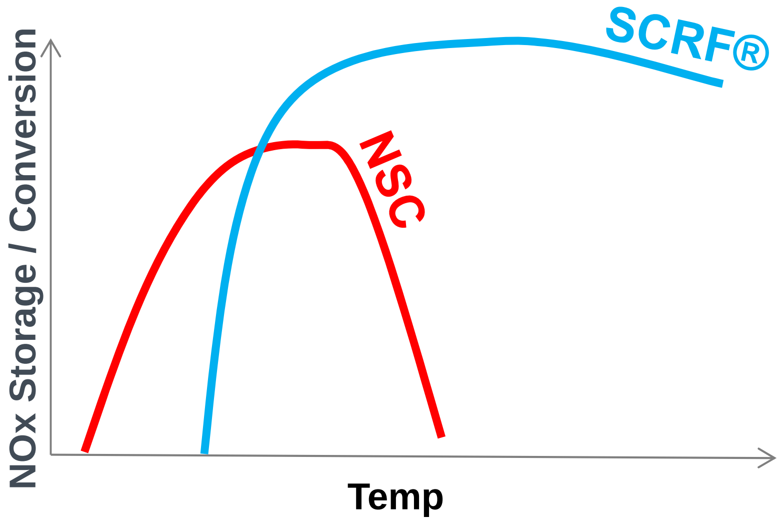


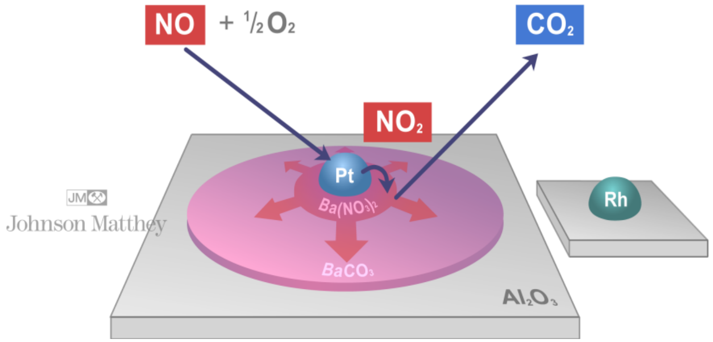
NSC + SCRF®

Store NOx until SCRF® operational

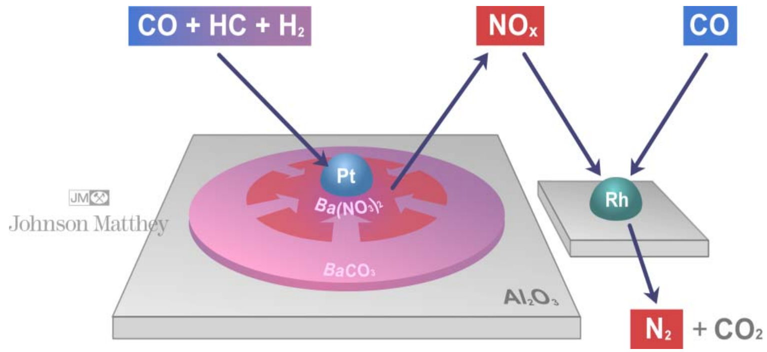
•Basic System Method

- Store low temperature NOx to above SCRF® light-off
- Release NOx with temperature or rich purge
- Optimise NSC storage & SCRF® conversion windows
    - Low light-off SCRF® for best system performance



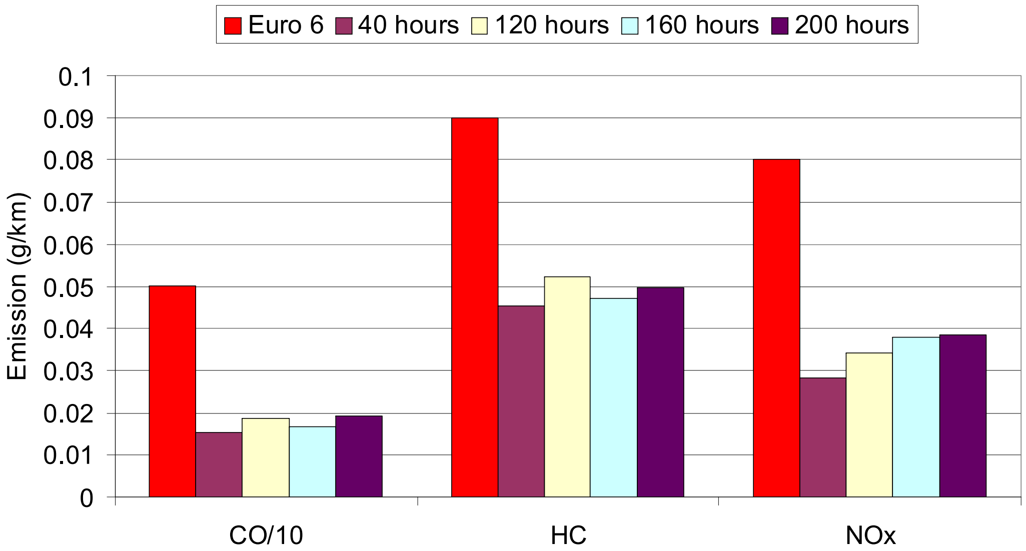


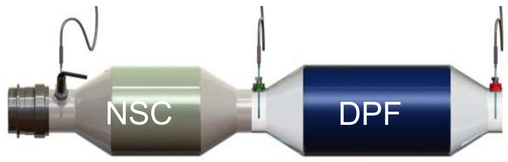
Lean



Rich

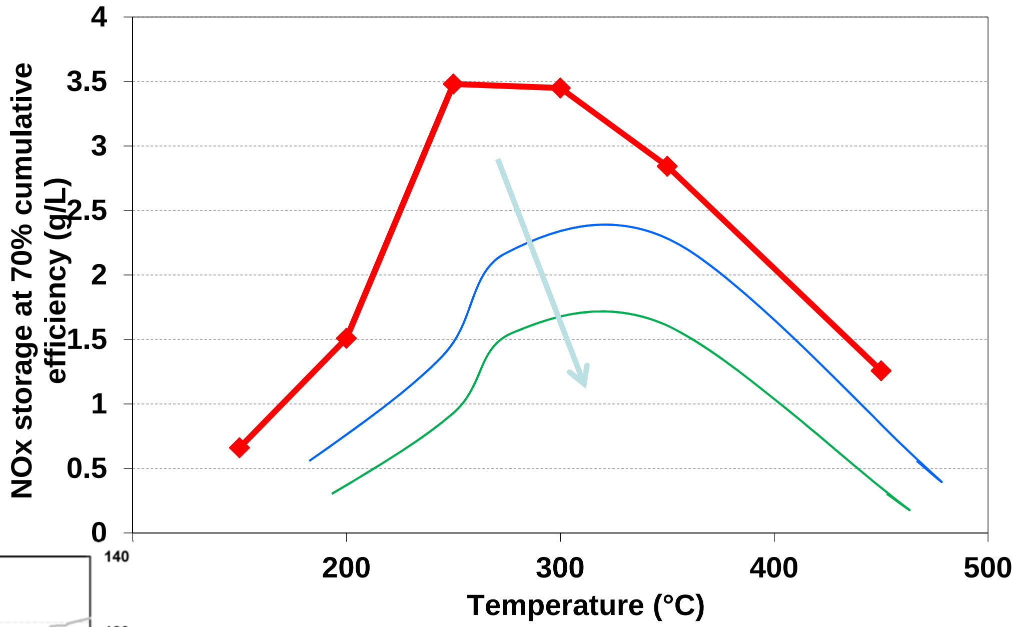
Highly Durable Advanced NOx Traps Show Good Stability after Extended Engine Ageing



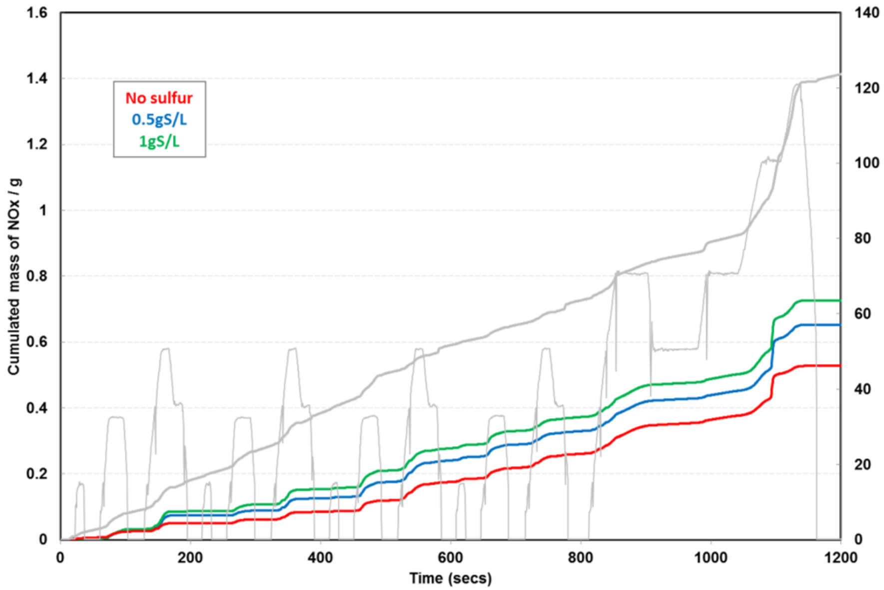


- 75% ESV NSC + CSF on 4 cylinder Euro 6 engine
- Harsh engine ageing with temperatures >800ºC
  - 300 CSF regenerations
  - 70 De-sulfation regenerations

Sulfation effects – NOx performance



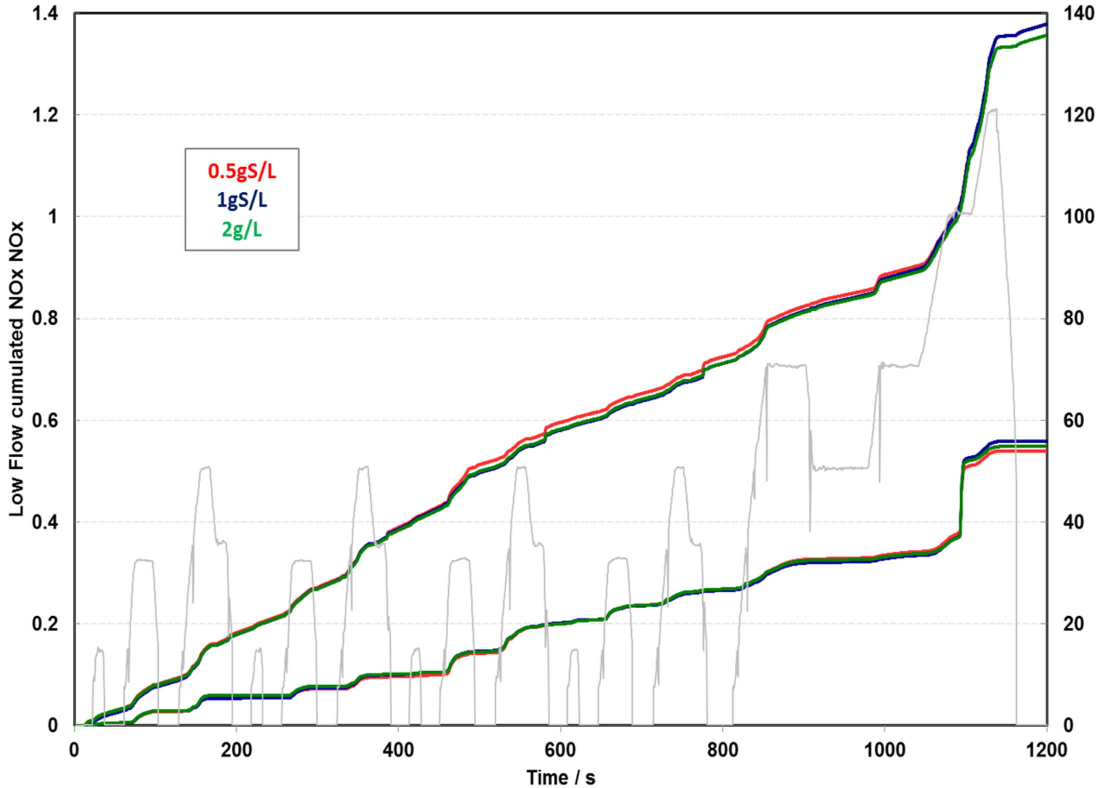
- Increasing sulfur levels will decrease storage capacity
- This impact NOx performance



- Preferred strategy is more frequent desulfation
- Extended sulfation can result in bulk sulfate formation which can be more difficult to remove
  - Requires extended duration of high temp rich operation

Performance after deSOx

Impact of sulfur loading

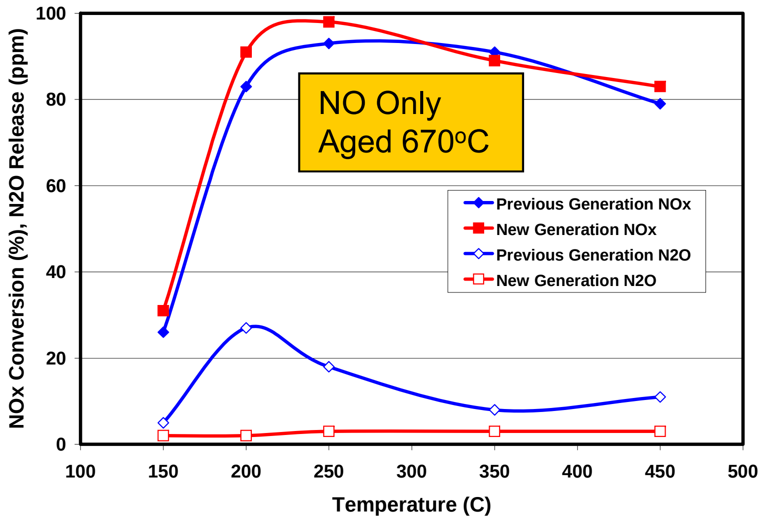


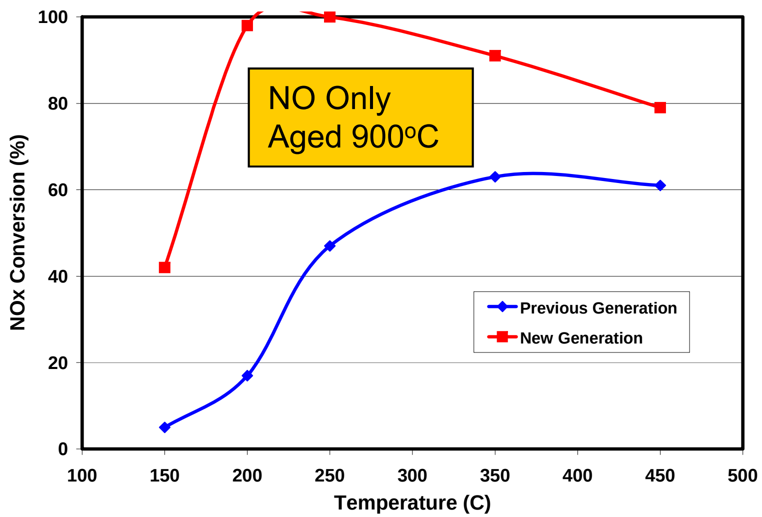
- Good recovery of the performance after deSOx
- Extended sulfation can result in bulk sulfate formation which can be more difficult to remove
  - Requires extended duration of high temp rich operation

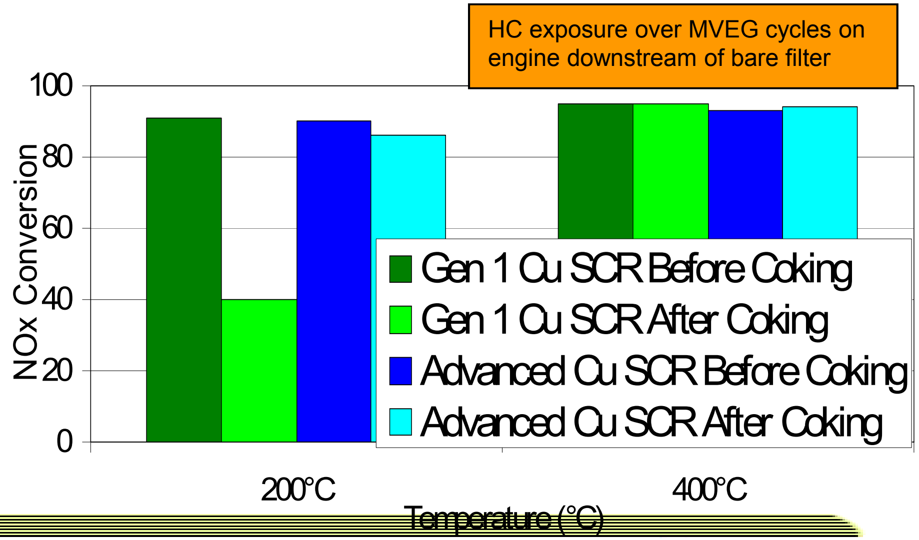
Advanced Cu SCR

Advanced Cu SCR has

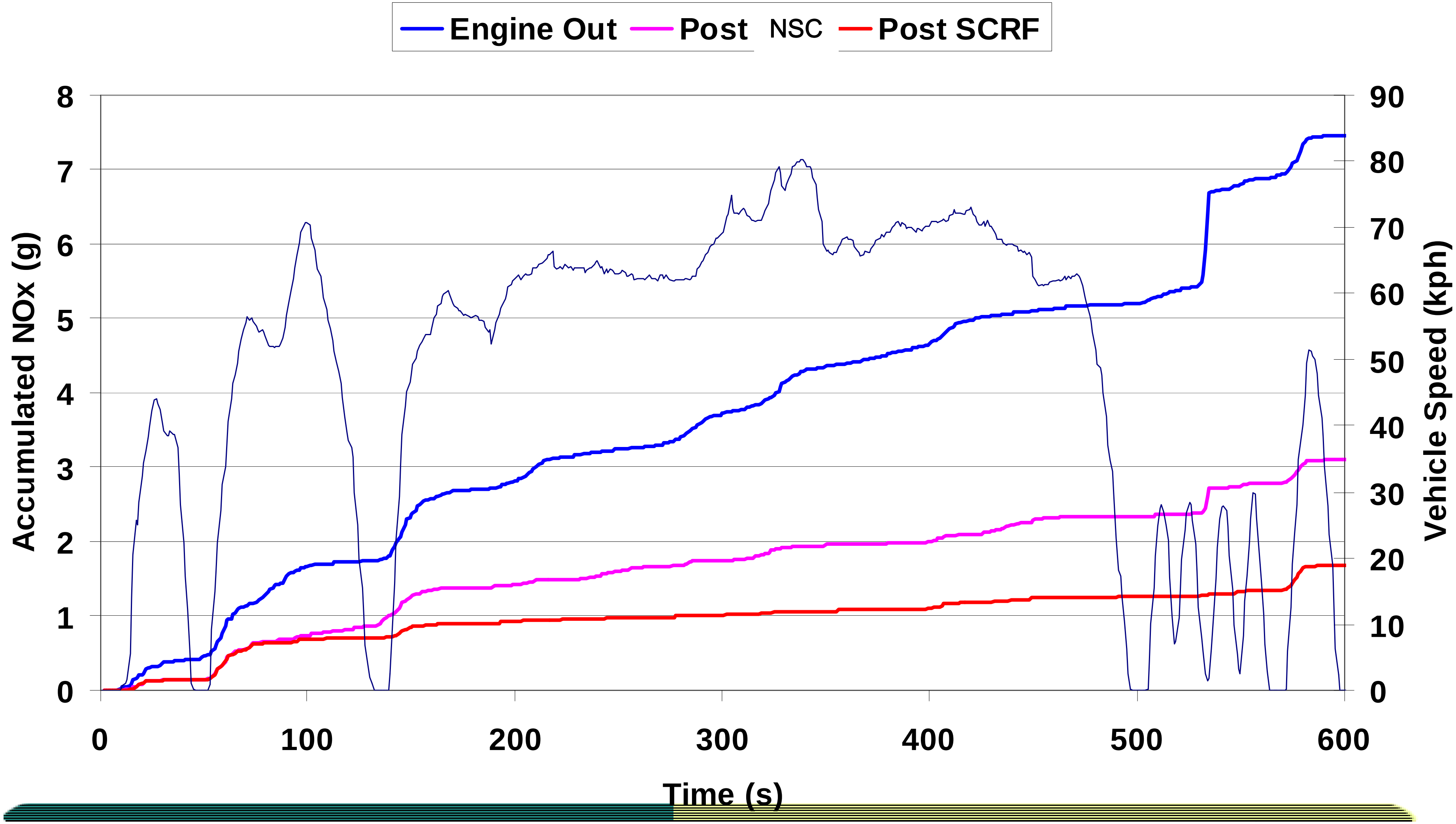
- Good conversion, especially at low temperature
- Low N_2O
- Good HC tolerance
- Good high temperature thermal durability







NOx conversion after high temperature 800°C ageing



Summary

- EU5 experience
  - Gasoline
    - Pd-Rh TWC is the most popular technology.
    - Other technologies are in place to use best combination of PGM type and loading.
  - Light Duty Diesel
    - DOC+CSF is the typical system for EU5. Pt-Pd is well-used PGM in DOC.
  - Low Sulfur content in fuel is important to maximize catalytic function.
- EU6 experience
  - Gasoline
    - GPF is effective after-treatment technology for reduction of PN and other pollutants from DI engine.
  - Light Duty Diesel
    - Advanced NSC plus SCRF® is able to meet most sever scenario of upcoming EU6c regulation.