Catalyzed Exhaust Filters: Future directions

Johnson Matthey Catalysts

CLEERS
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EMISSION CONTROL TECHNOLOGIES

Outline

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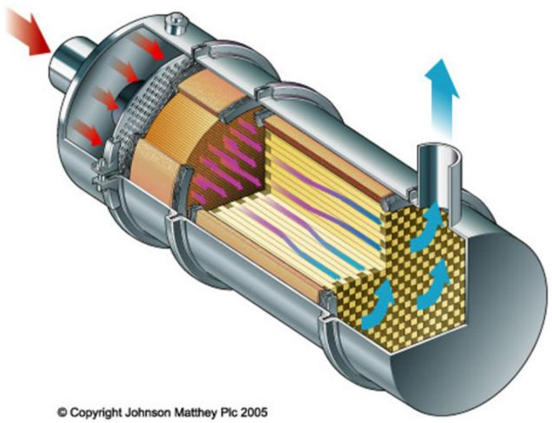
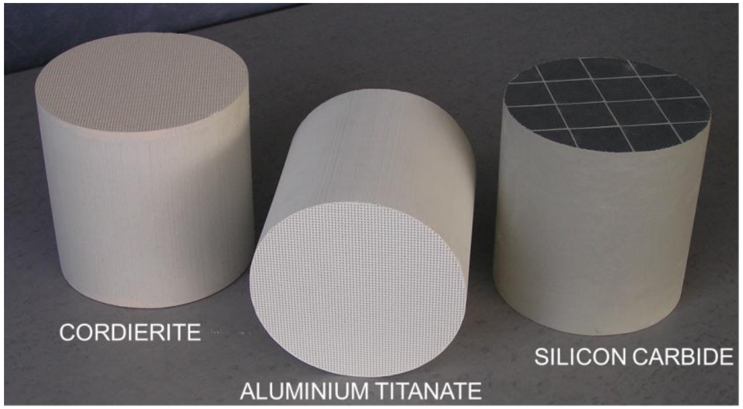
- Introduction to catalysed filters
  - Drivers for catalyzed filter technology
- Next generation catalyzed filters
  - SCR filter (SCRF®) system
  - 3-way filter (TWF®) system
- Summary





Johnson Matthey's history with filters

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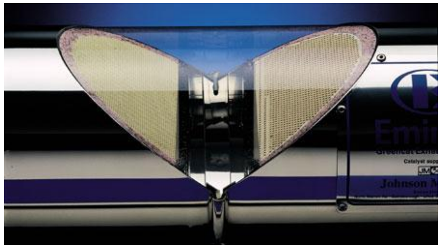
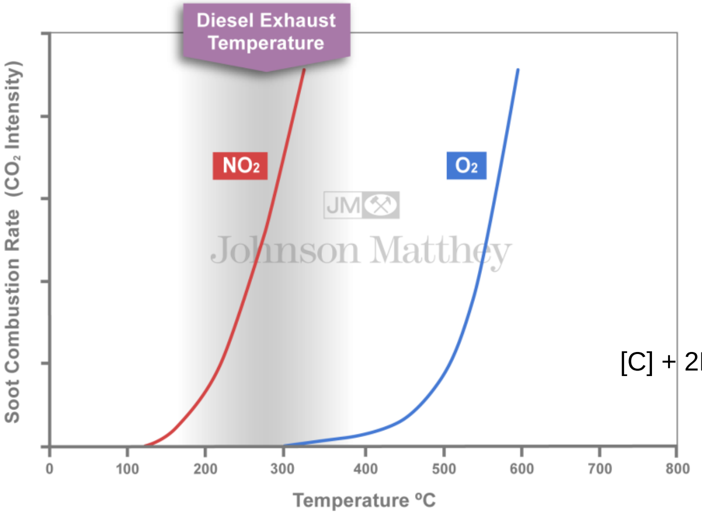
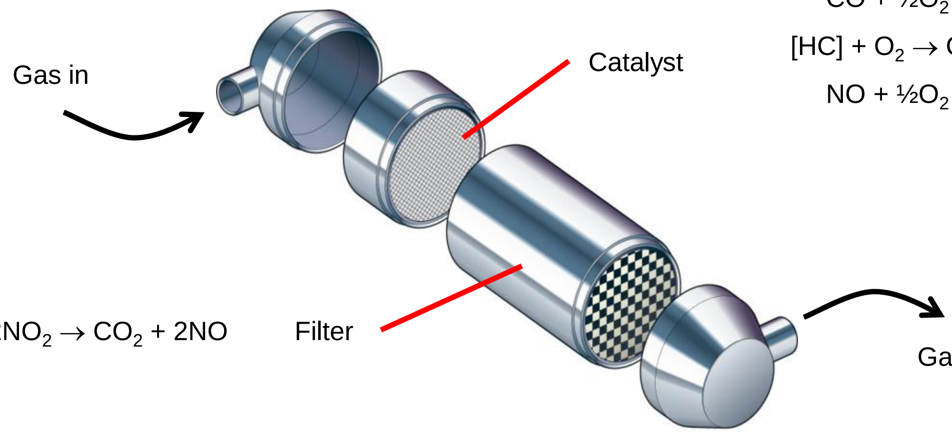
- Patented the Continuously Regenerating Trap (CRT®) system
  - Commercialized in 1995 for HD retrofit market
  - Use of a DOC to generate increased NO_2 at filter inlet, and use of that NO_2 to combust filtered particulate at normal exhaust temperatures.
  - The principle of the CRT® technology underpins the function of the majority of filter systems in the market.





$$CO + \tfrac{1}{2}O_2 \rightarrow CO_2$$
$$[HC] + O_2 \rightarrow CO_2 + H_2O$$
$$NO + \tfrac{1}{2}O_2 \rightarrow NO_2$$



$$[C] + 2NO_2 \rightarrow CO_2 + 2NO$$

Evolution of diesel exhaust filter systems

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Year	Filter system	Catalyzed filter?	Comment
Before 2000	DOC upstream	N	Retrofit systems
2000	DOC upstream + fuel-borne catalyst (fbc)	N	First OEM commercialization (PSA)
2003 – 07	DOC upstream (+ fbc) Filter only	Y (DOC) Y (NAC) Y (DOC)	Substantial use of catalyzed filter substrates First catalyzed filter with NOx removal function (Toyota) Systems without additional catalysts employed (e.g. VW)
2007 - 10	DOC (+NAC) upstream (+SCR downstream)	Y (DOC)	Mass production by HD OEMs Limited integration of specialized NOx control catalysts
2010 - 13	DOC upstream + SCR downstream DOC + SCR (or NAC) upstream	Y (DOC)	Majority of on-road filter systems combined with NOx control catalysts

Benefits of an oxidation catalyst on a filter

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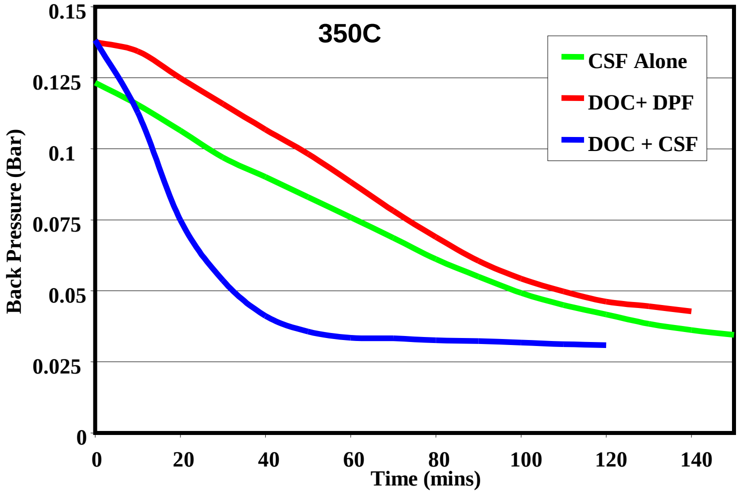
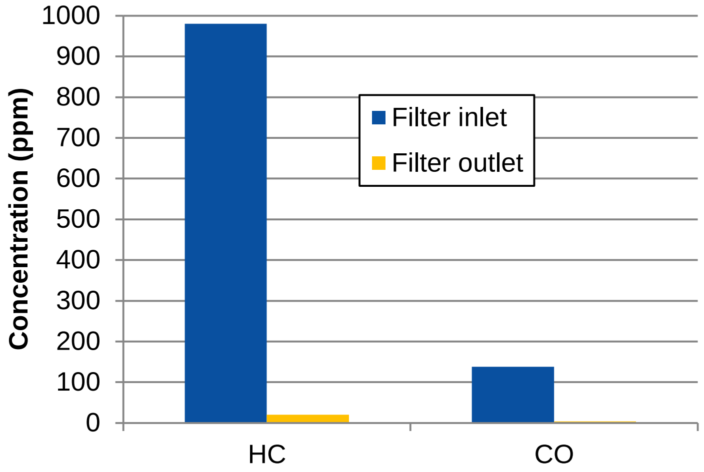


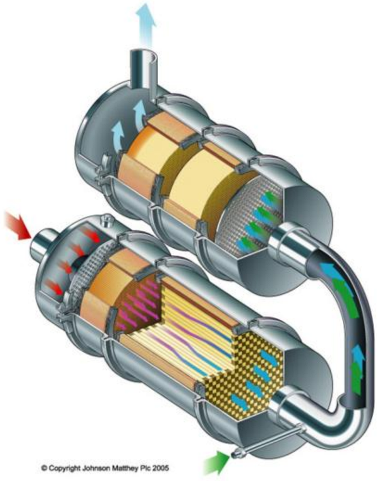


- Faster passive regeneration
- Less frequent active regeneration
  - CO_2 savings as less thermal management required

- Clean-up of active regeneration emissions
  - Enhanced emissions performance

Drivers for next generation catalyzed filters

- CO_2 emissions and light-off
  - An increasing focus on cold-start emissions and a filter upstream of SCR is a large heat sink
  - A filter downstream of SCR means more active regens
  - Multiple components increases backpressure
- Emission performance
  - Enhanced passive soot regeneration
  - Multifunction filter may minimize compromises made in arranging separate components
- Smaller packaging
  - A large total catalyst volume impacts vehicle design and weight
- PN legislation means engines designed without filters today may need them in the future



Possible future diesel exhaust system evolution

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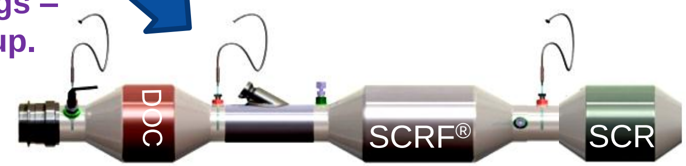
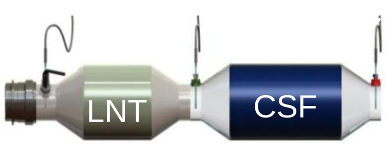
Lower total volume, same performance

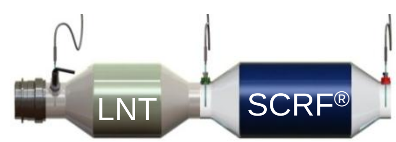
Low volume helps packaging and commonality across platforms

High performance allows fuel savings – higher EO NOx and/or less warm-up.

Similar total volume, increased performance







SCRF may find use in high-performance LNT systems

Performance of SCRF® systems require extensive optimization of catalyst/substrate characteristics with OEM

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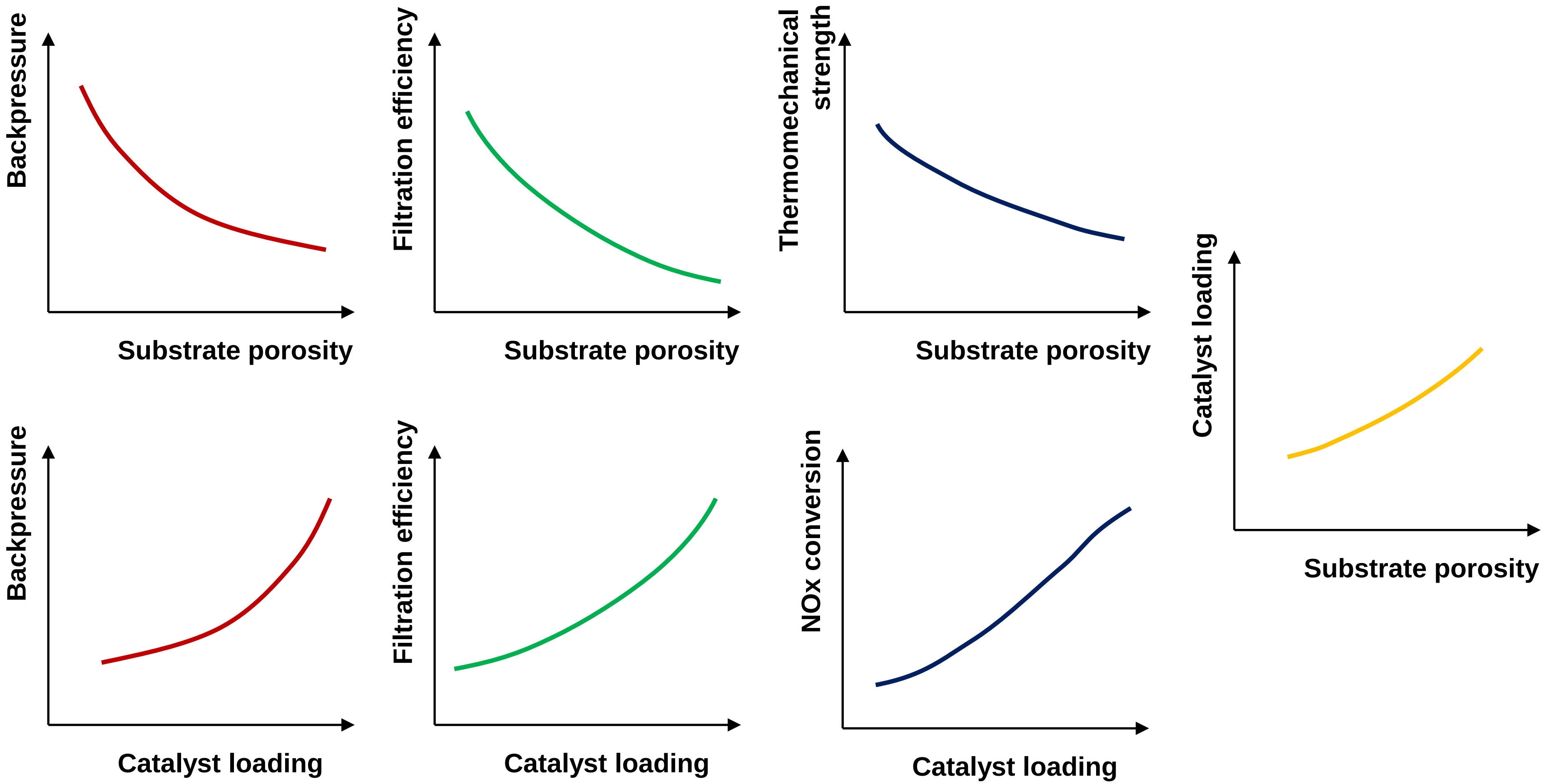
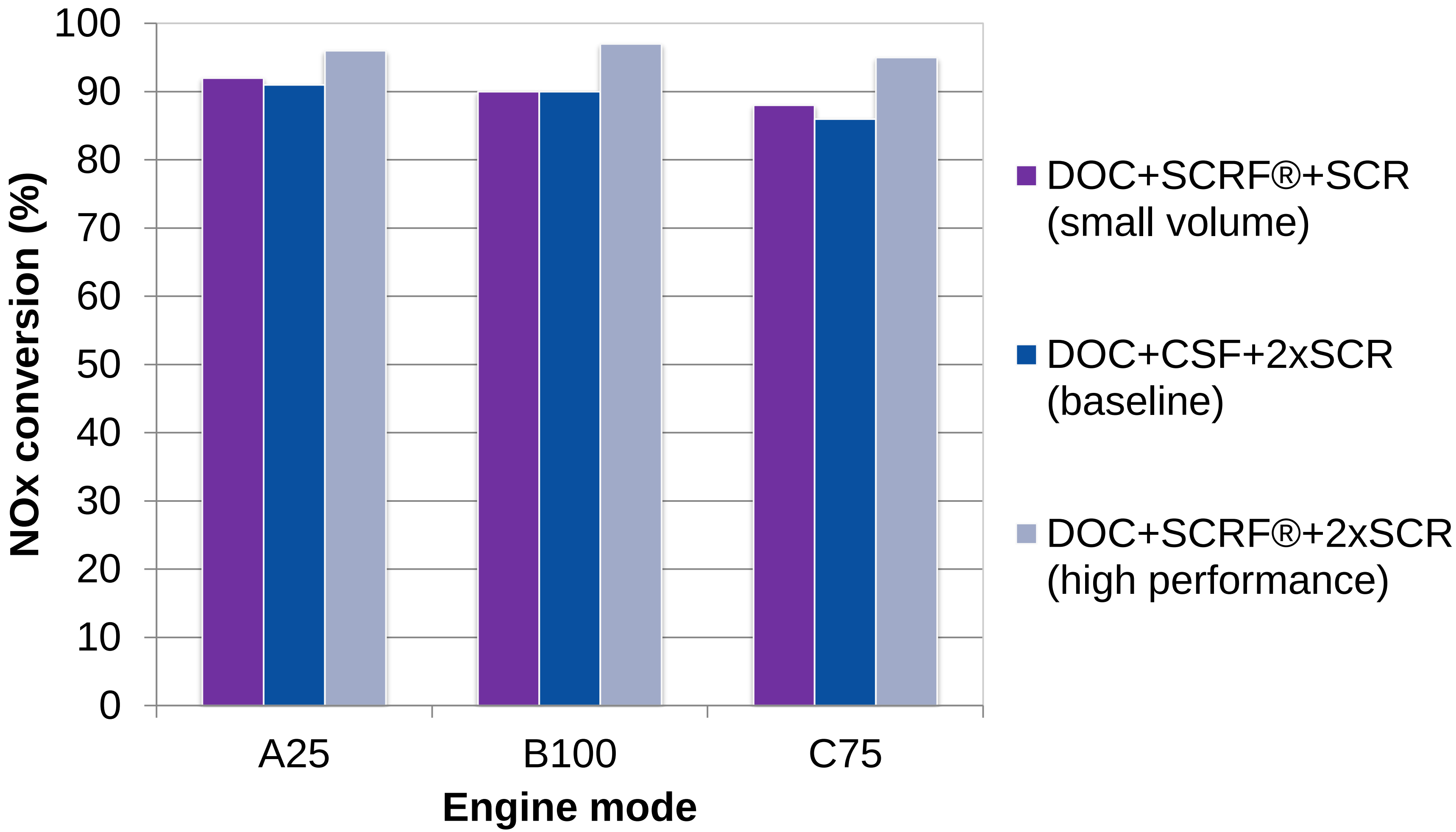


SCRF® system advantages on a HD engine

Equivalent performance at lower volume, or improved performance at equivalent volume



Performance window of different SCR/SCRF® system configurations

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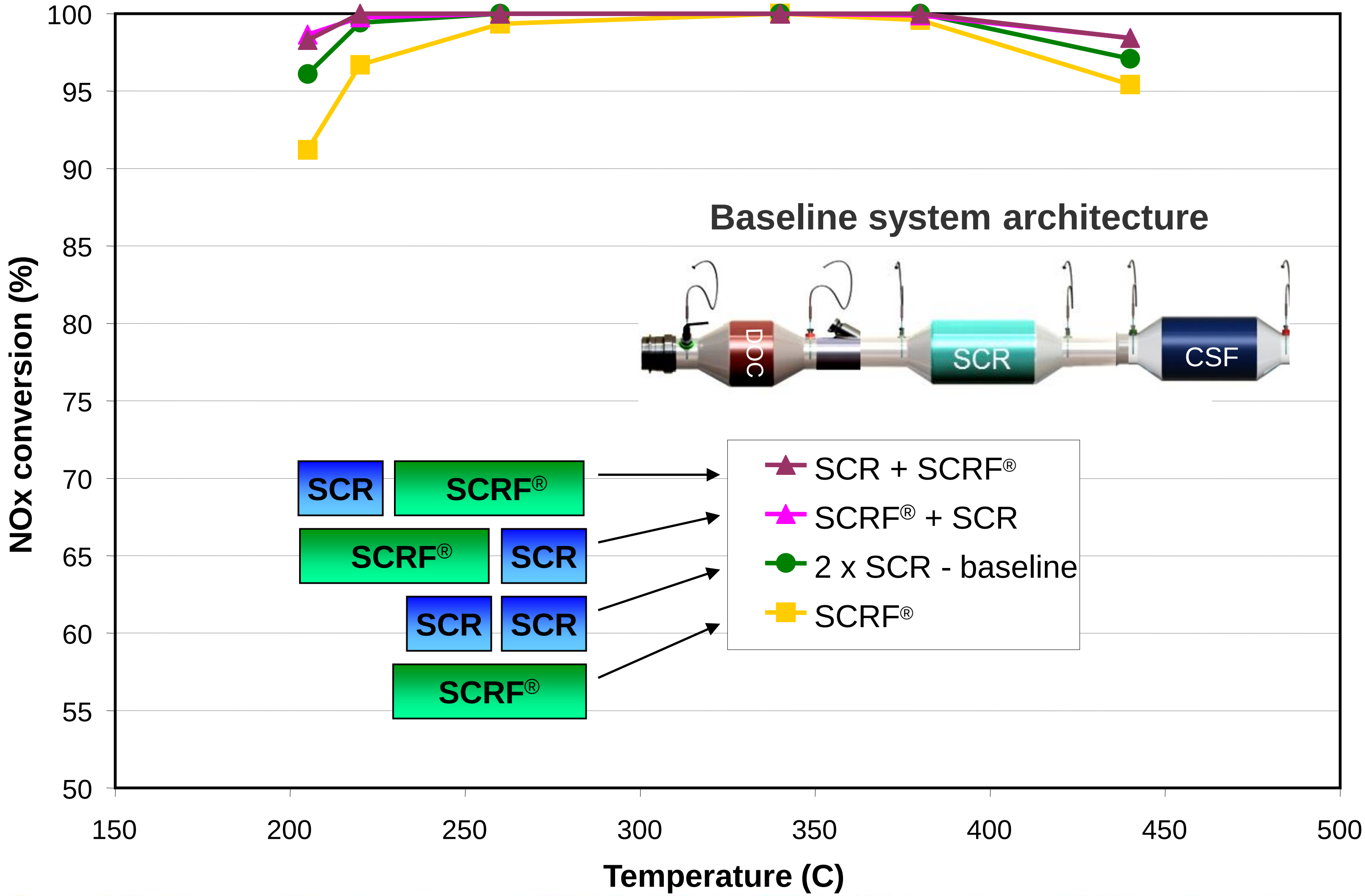

SCRF® system has equivalent performance to SCR system on a transient cycle

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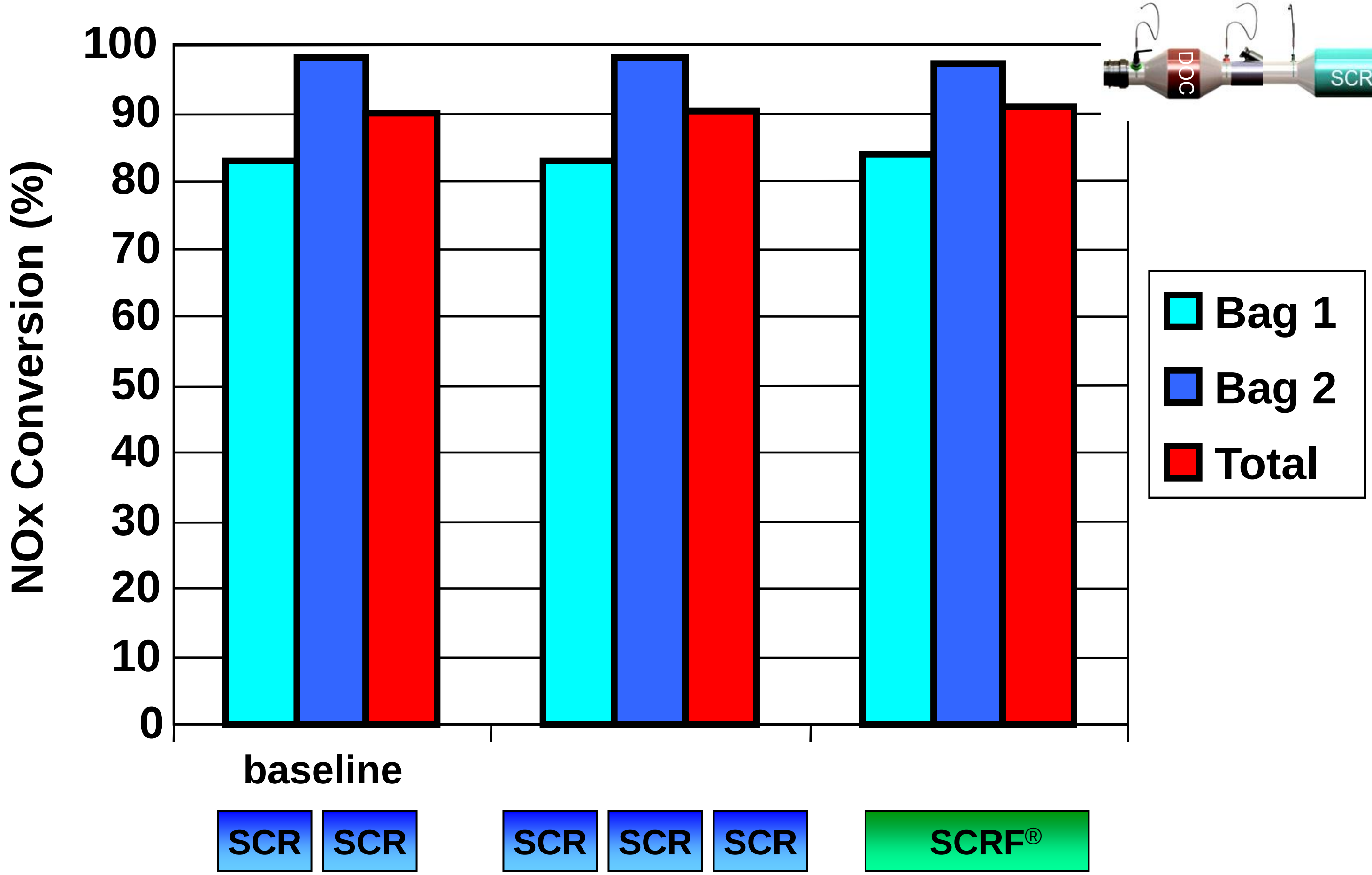
Hot LA4 cycle

Baseline system architecture



SCRF® system can warm up faster than an uf SCR system

Enables earlier urea dosing and increased NOx performance

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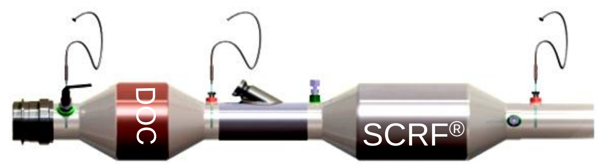

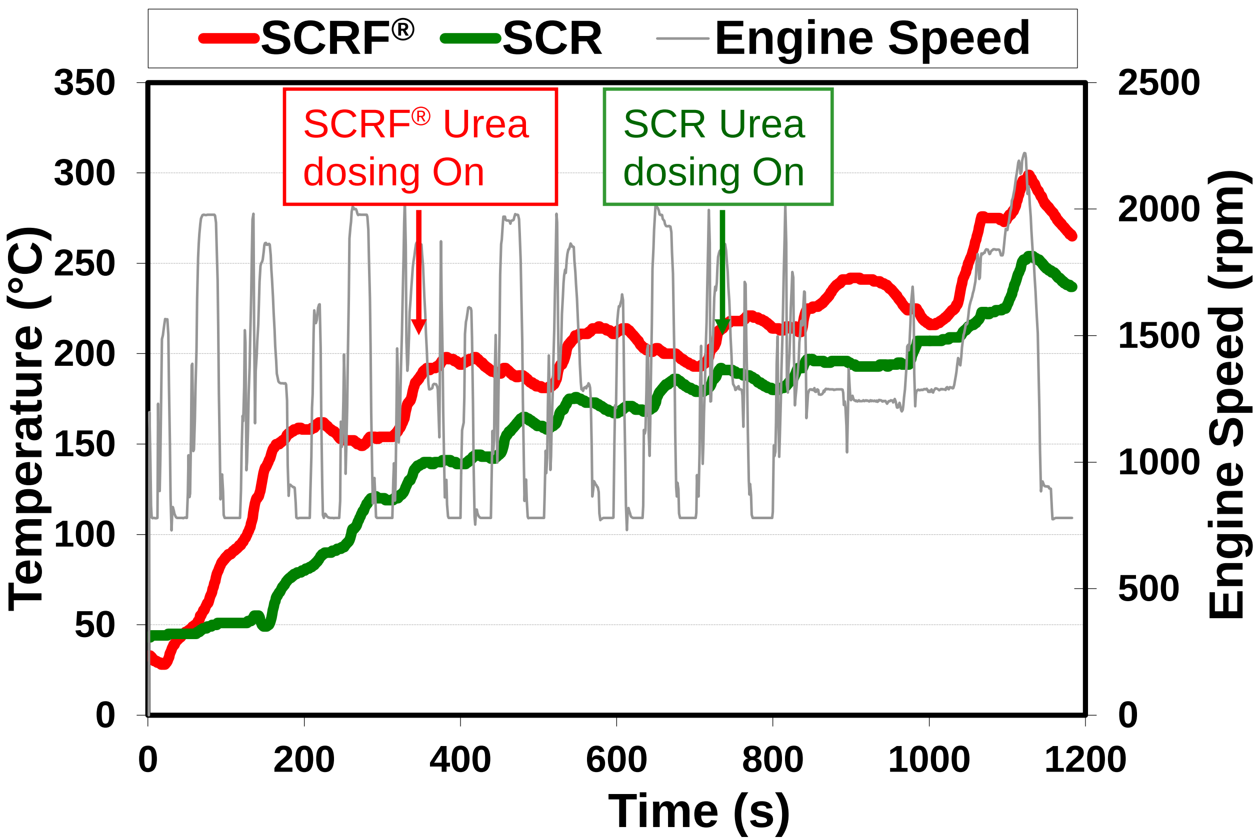

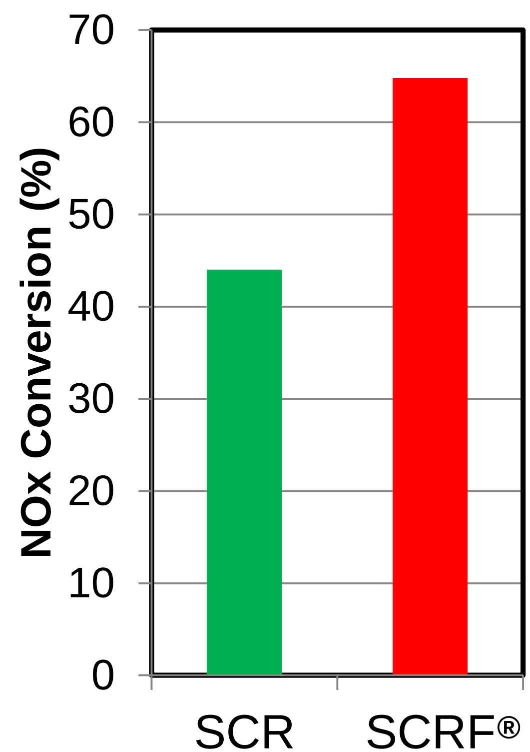

Effect of filtered soot on SCRF® system NOx conversion is minimal

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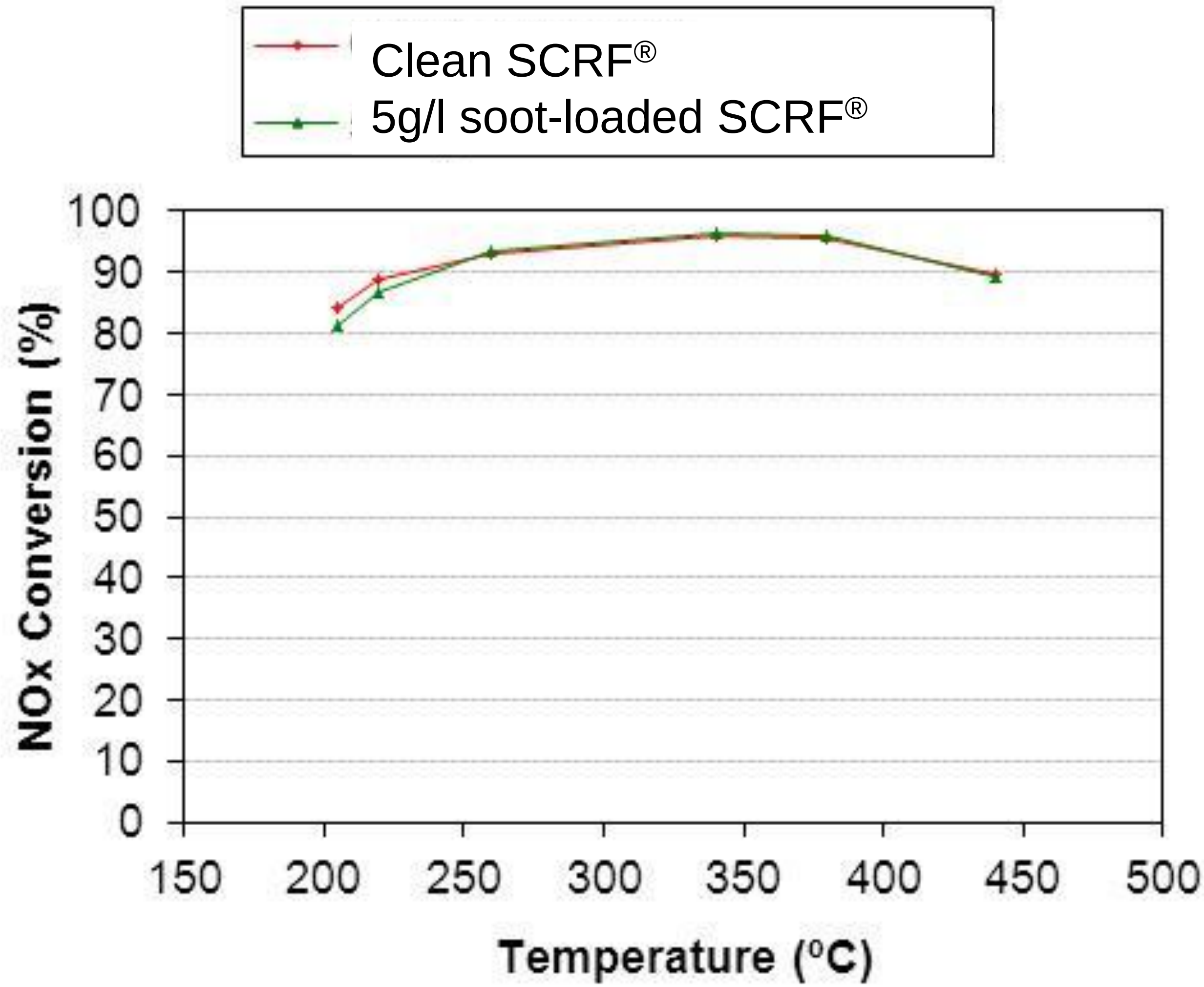

Urea can reduce passive soot removal over SCRF® system

NO_2/NOx ~ 40%, 400ºC, 8g/l soot

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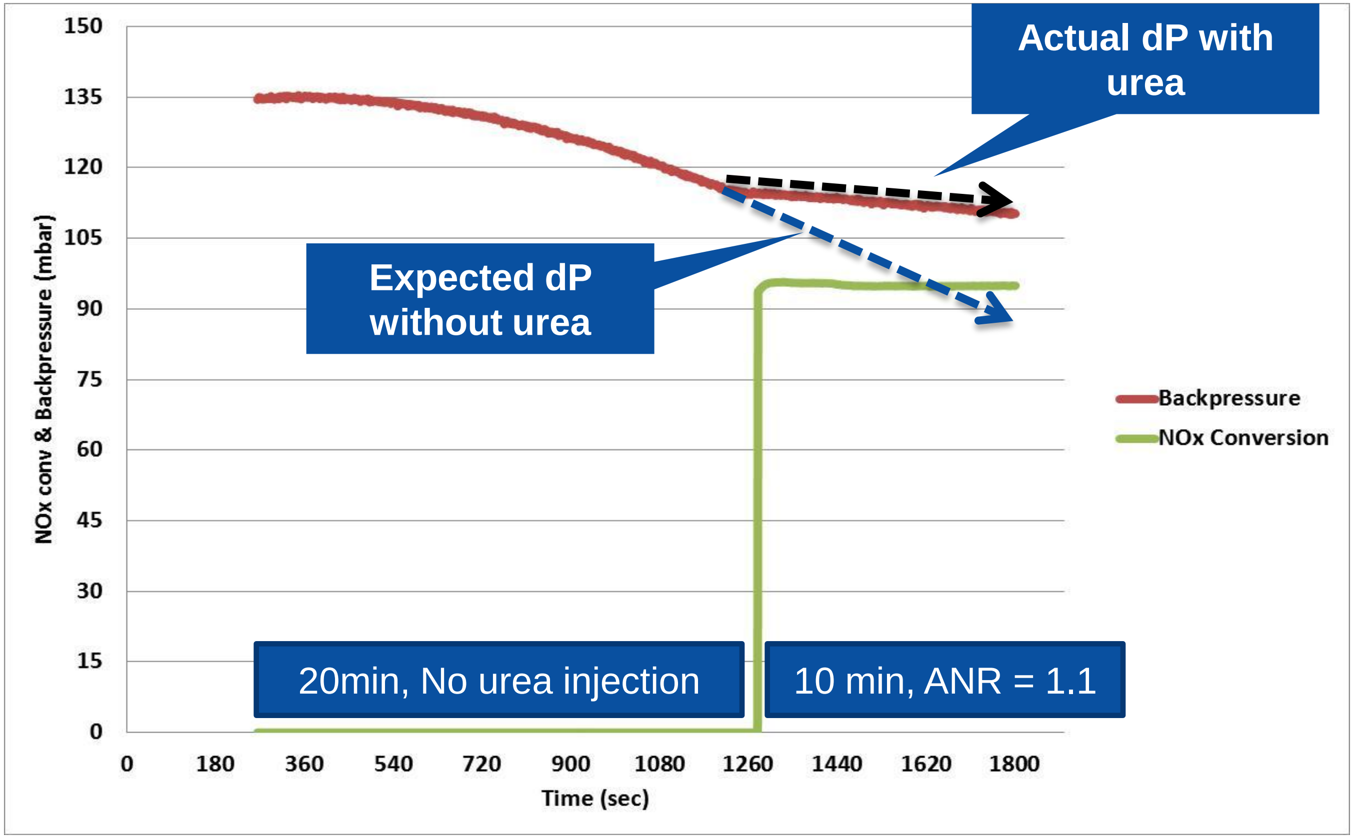

NO_2 reacts preferentially via fast SCR reaction

Good passive regen is achievable with optimised SCRF® system

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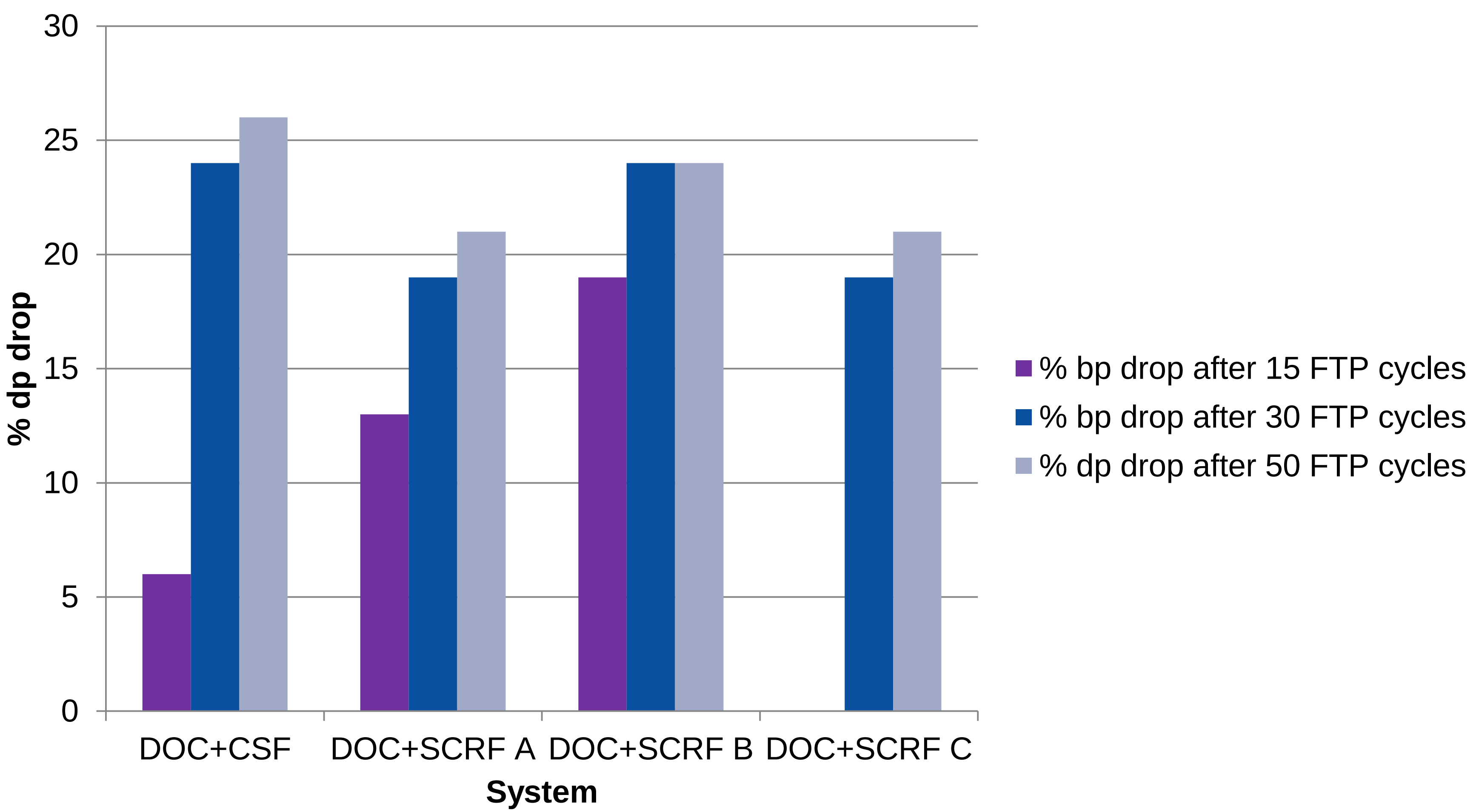
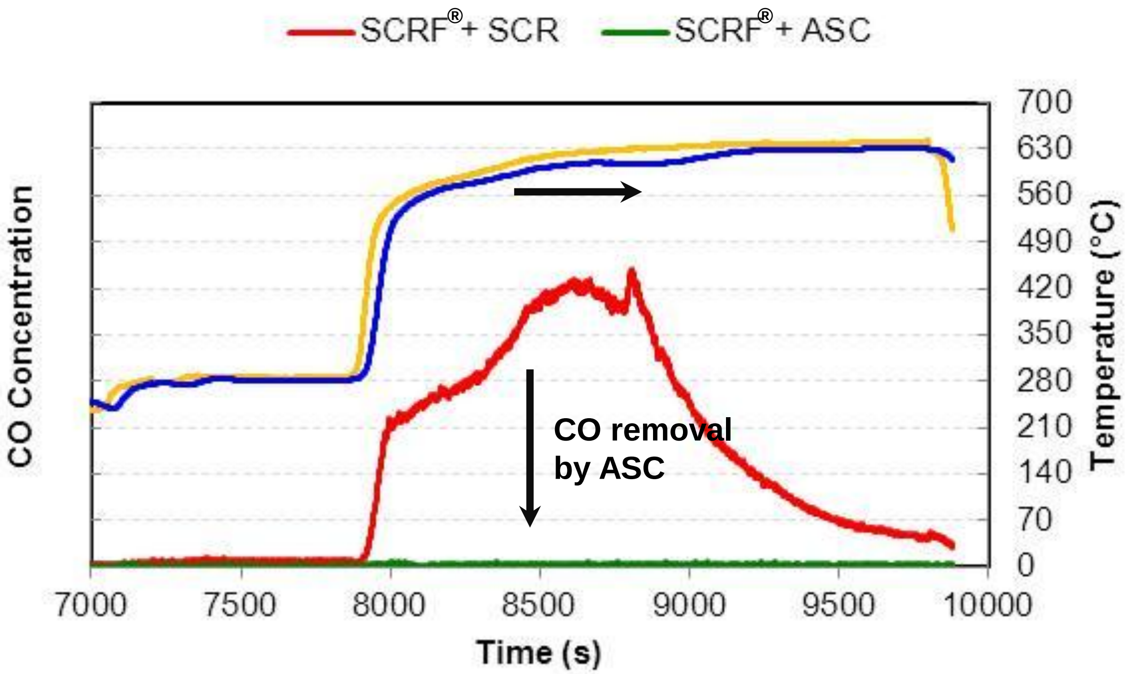
Filters loaded to 3g/l soot, bp monitored over repeated FTP cycles



A downstream ASC can be used to provide additional performance benefits

Removal of the oxidation coating from filter can result in increased emissions during active regeneration

Use of an ASC downstream can oxidise active regeneration emissions



A downstream ASC can be used to provide additional performance benefits

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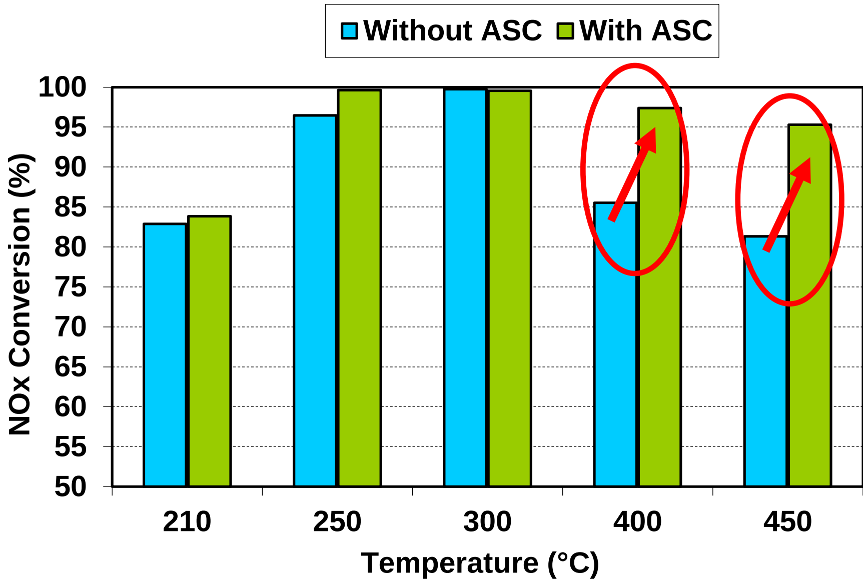
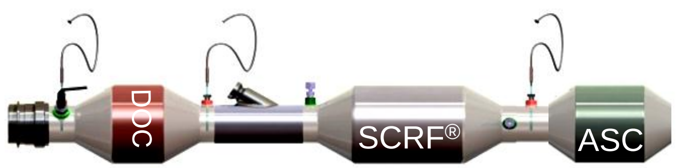
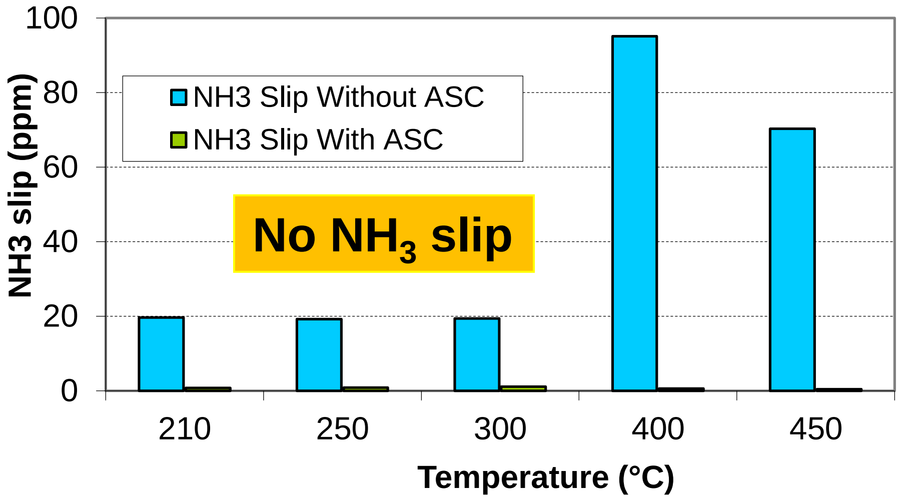




Improved High Speed NO_x Conversion



Possible to incorporate SCRF® system into LNT systems

Passive SCR

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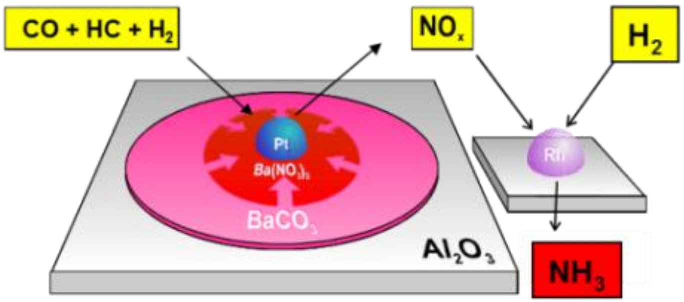
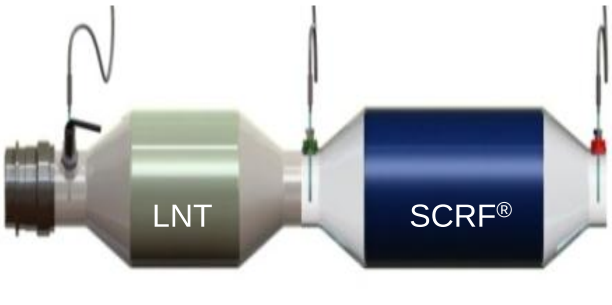
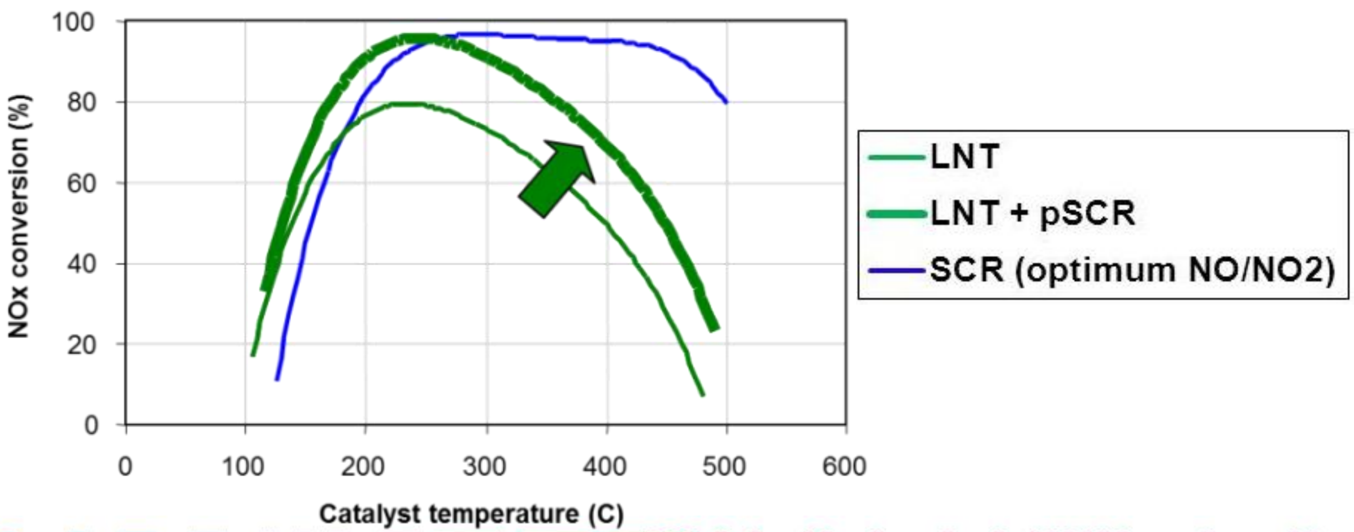
Optimise LNT to make NH3 when rich



Store NH3 on downstream SCRF for SCR use when lean





An LNT+SCRF® system with urea injection can give additional benefits

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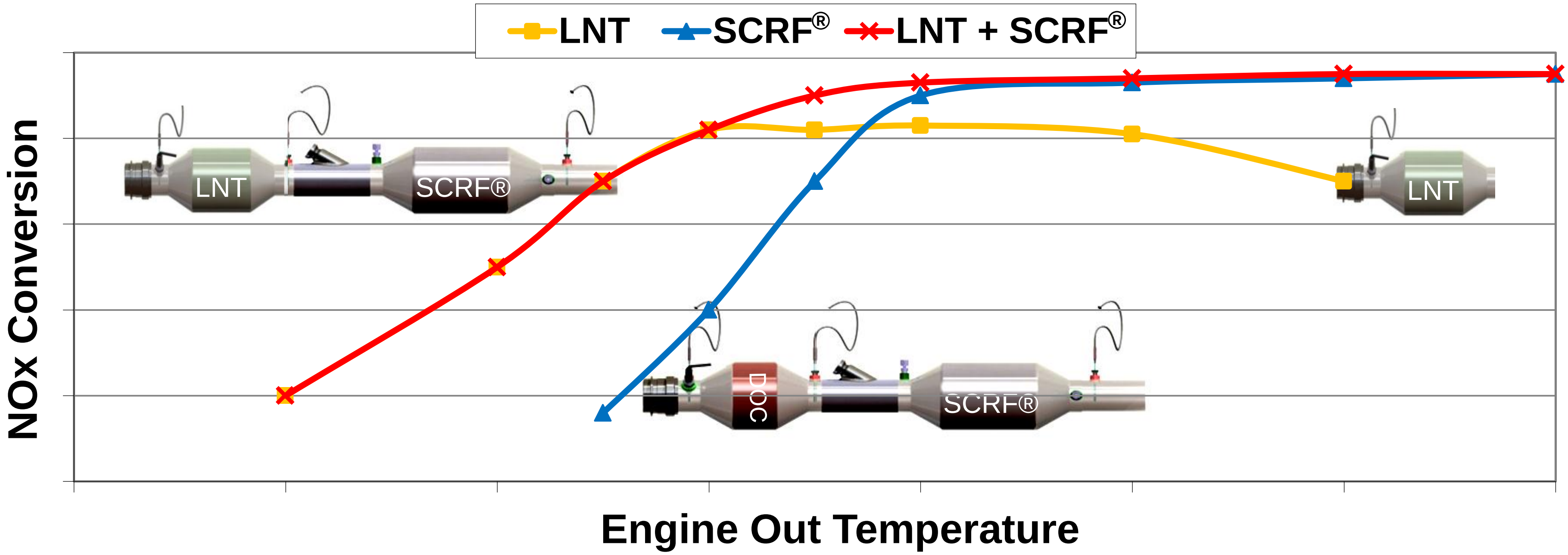
- Combination with active SCR or SCRF® systems
  - Urea injection downstream of LNT for high temperature / high flow conversion



SCRF® system summary

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- Replacement of flow-thru SCR system with SCRF® system is demonstrated for both HD and LD applications
  - SCRF® systems can be compatible with LNT systems and bring additional performance benefits

- Competition for NO_2 between soot and SCR reactions can be managed with appropriate SCRF® system design

- Utilise SCRF® systems for packaging reduction or high performance systems
  - High performance can bring CO_2 benefits via increased engine-out NOx and less aggressive warm-up requirements
  - Optimisation of system design needs close collaboration beween substrate suppliers, catalyst companies and OEM.

TWF™ product requirements

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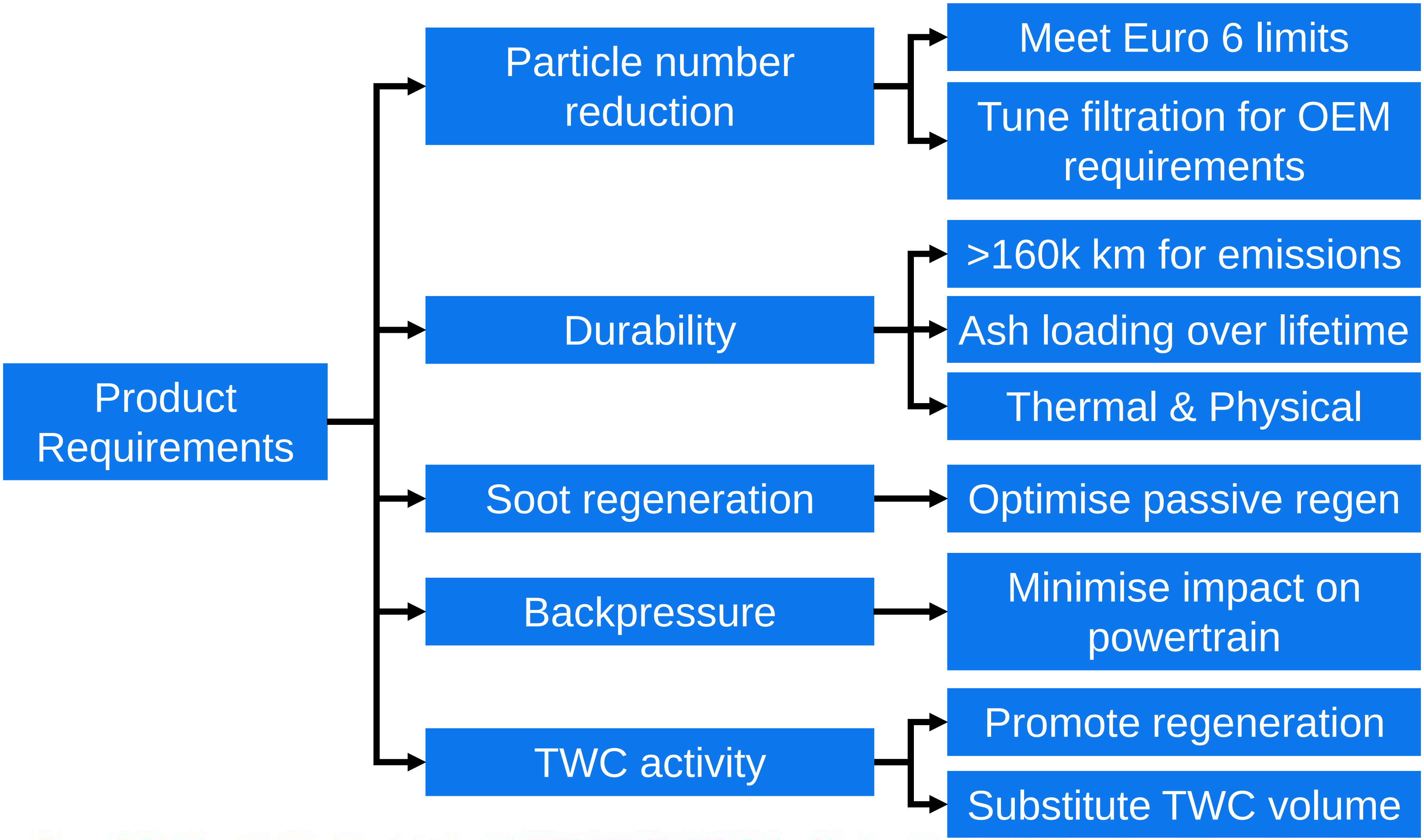

TWF™ product benefits compared to an uncoated gasoline exhaust filter

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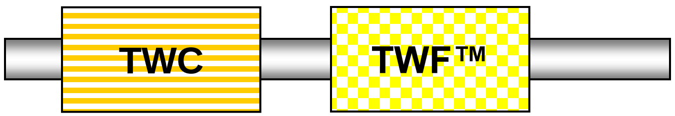
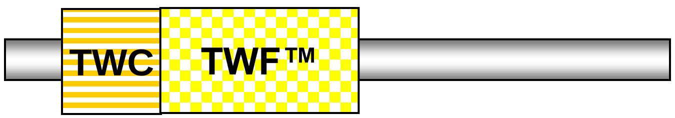
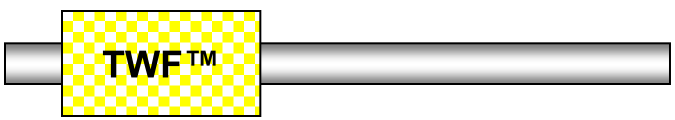
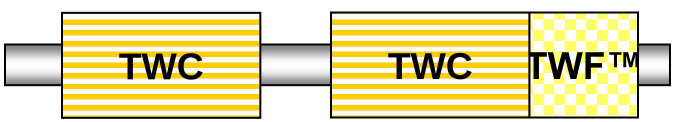
- Allows substitution for TWC volume
  - TWF™ coating is based on current TWC coating chemistry
  - Reduced packaging space and cost
  - Many Euro 6 systems will be twin brick for OBD requirements
- Enhanced soot regeneration
- Good particle filtration from fresh
  - Don’t need to build up soot layer for effective filtration
- Potential for OBD diagnosis of thermal events using λ sensors

Possible system architectures

Architectures	Comments
	Substitute TWF™ part for rear TWC, allows good TWC emissions control and PN filtration
	Close-coupled cascade TWC + TWF™ system, especially for smaller vehicles
	TWF™-only system for minimised components
	TWF™ part additional to existing TWC system, increases packaging, remote location hinders regeneration and activity

PGM impacts soot regeneration

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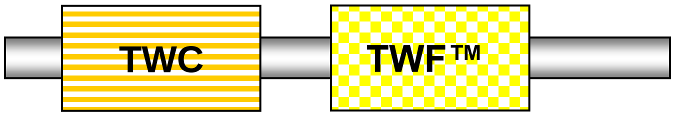
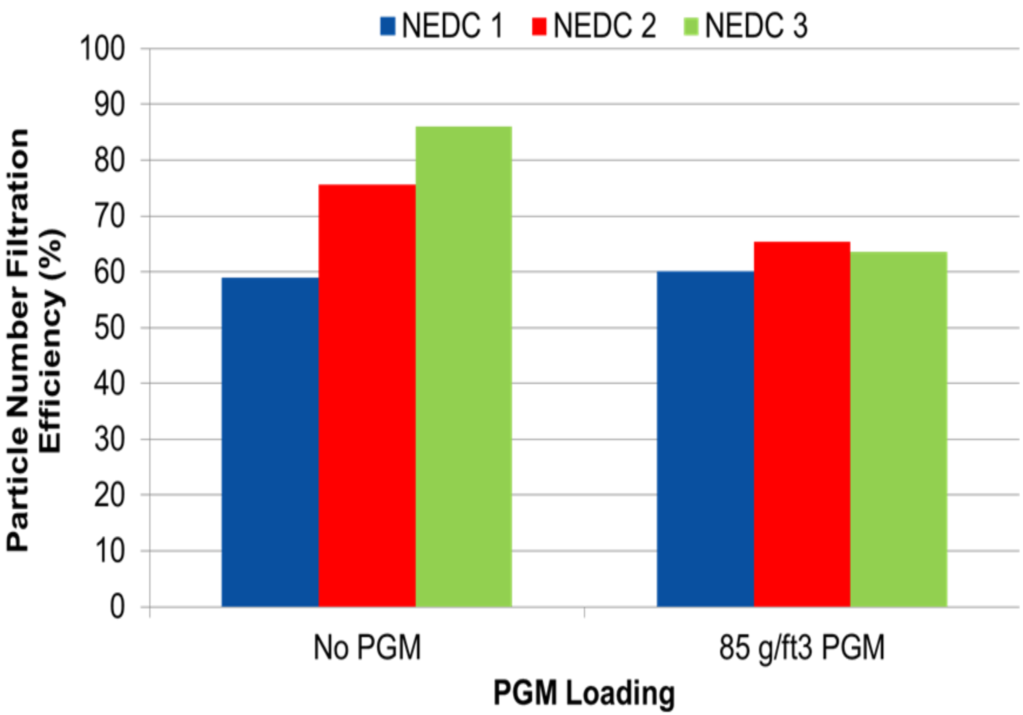


- TWF™ part with and without PGM
- PGM promotes oxygen-based passive regeneration
- Stable filtration and backpressure
- Additional emission benefits over single TWC



Regeneration of a TWF™ system using fuel cuts

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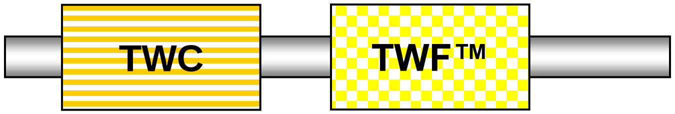

- DI vehicle
- 45 repeat NEDCs to accumulate soot layer
  - >99% PN filtration efficiency
- Only 320 mg of soot (0.26 g/l) accumulated in filter in ~500 km

- Regeneration conditions
  - Steady state cruise (140 kph) with filter inlet T of 650 ºC
  - Introduction of fuel cuts by decelerating to 95 kph in 25 seconds

- Fuel cuts over hot filter gave clear regeneration
  - Soot reacts with oxygen

Regeneration of a TWF™ system using fuel cuts

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TWF™ system condition	Backpressure on 140 kph cruise (mbar)	PN emissions on 140 kph cruise (#/cc)
Fresh	119	3.44E+04
After 45 NEDC cycles	157	1.56E+04
After 1 fuel cut	137	2.67E+04
After 2 fuel cuts	124	3.39E+04
After 3 fuel cuts	120	3.41E+04

Effect of poisoning and ash accumulation

- Is a filter-only system robust to poisoning and thermal ageing?
- What is the effect of an upstream TWC?
  - Studies of twin-brick TWC systems show that the first catalyst is an effective trap for fuel and oil poisons

- Engine aging study using fuel doped with oil additives
  - 80 hours Lean Spike ageing, 950 °C inlet
  - Total poison deposition on catalyst system typical of that observed from full useful life vehicle durability trials

- Comparison between CC TWC + TWF™ cascade system and a CC TWF™ -only system
  - TWC, 20/0:18:2, NGK 118.4x101.6 mm, 600/4 substrate
  - TWF, 85/0:16:1, NGK C650 118.4x101.6 mm, 300/12 filter

Ash accumulation

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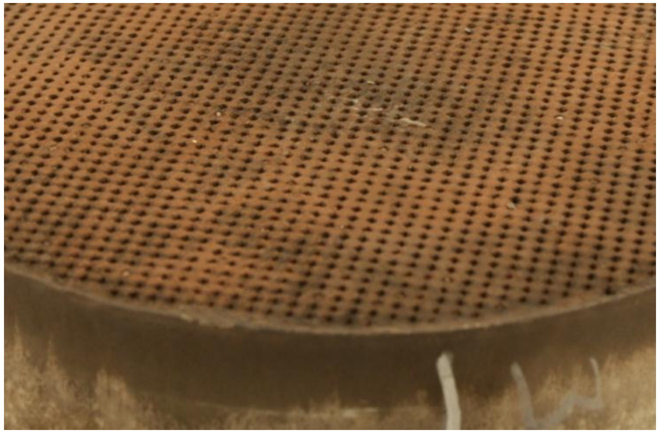
- Mass of TWF™ -only system increased by 13g from ash deposition
  - Ash-rich deposit visible on inlet face and washcoat surface
  - No plugging of inlet face or build up of loose ash within channels
  - Filter retained good filtration efficiency and TWC activity, meeting Euro 6 limits

- Upstream TWC reduced ash deposition in filter by 80%
  - No visible ash deposits on inlet
  - Backpressure lower by 20%



Aged as filter-only system

Aged behind TWC

Emissions comparison of ash-aged filters

2.0l turbo DI EU5 vehicle, Testing as TWF™ -only in CC position

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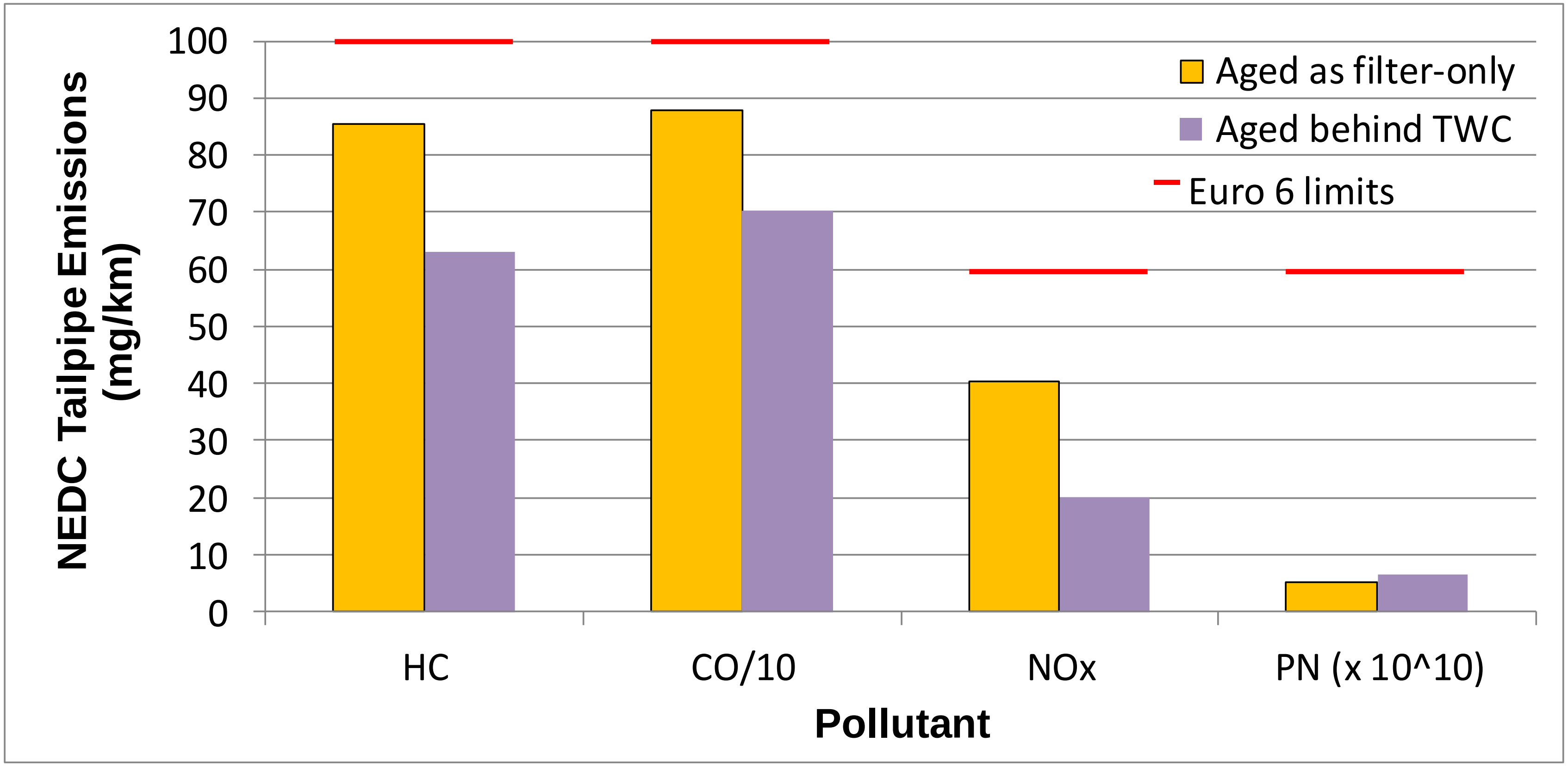

An upstream TWC acts as a poison and ash trap during ageing

Filtration of poisoned TWF™ remains high

Emission performance of different CC systems

Equivalent volume and PGM, oven aged

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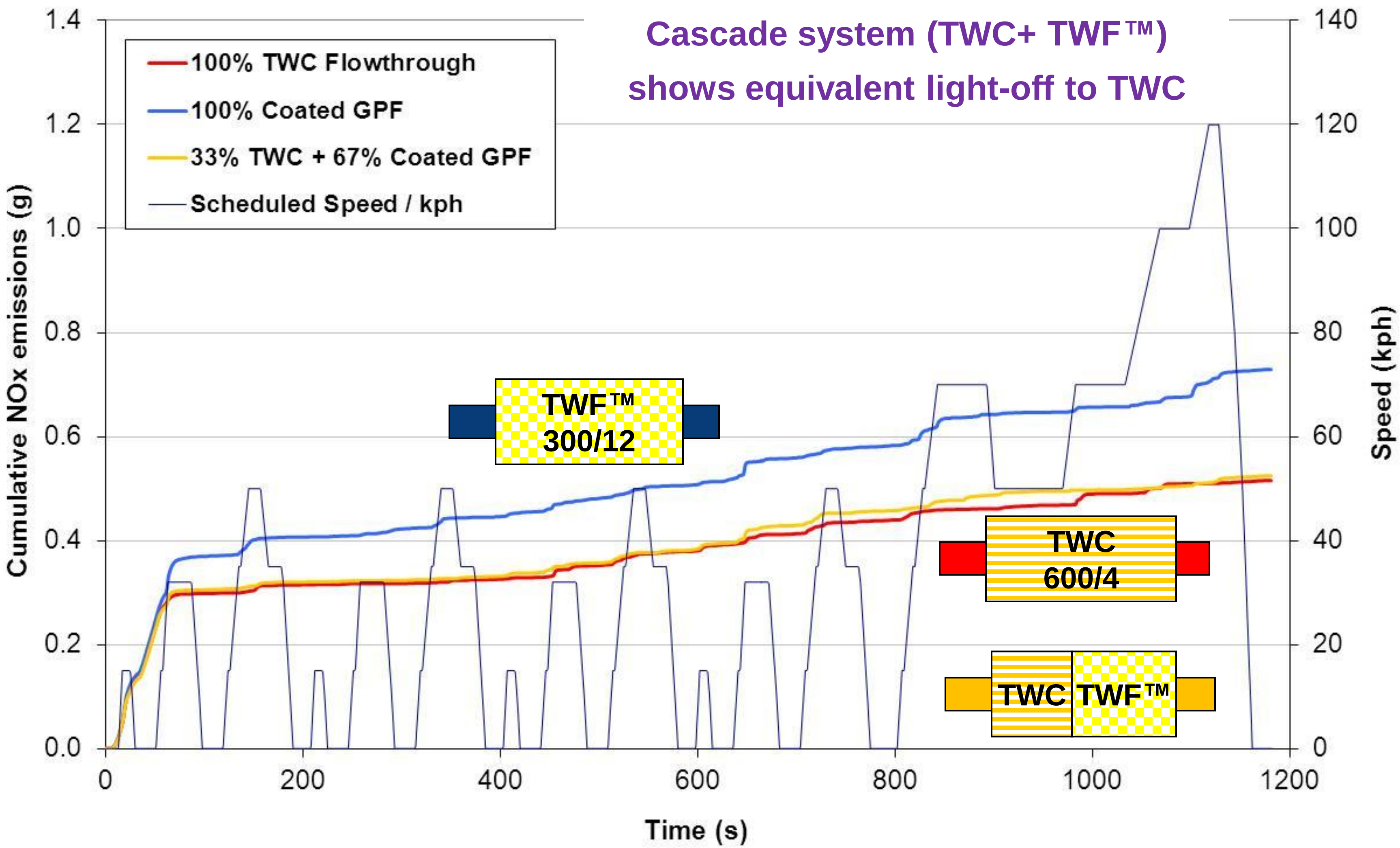

Demonstration that a TWF™-only system can meet EU6

- Coated NGK 4.66 x 5.5” (1.54L) C650 cordierite filter samples
  - PGM 40/0:12:1
  - Emissions optimised washcoat *vs*. backpressure optimised washcoat

- Oven ageing at 1100 ° C, equivalent thermal load to JM Lean Spike engine ageing cycle

- Evaluation on a 2.0 litre DI EU5 vehicle

Backpressure at high speed

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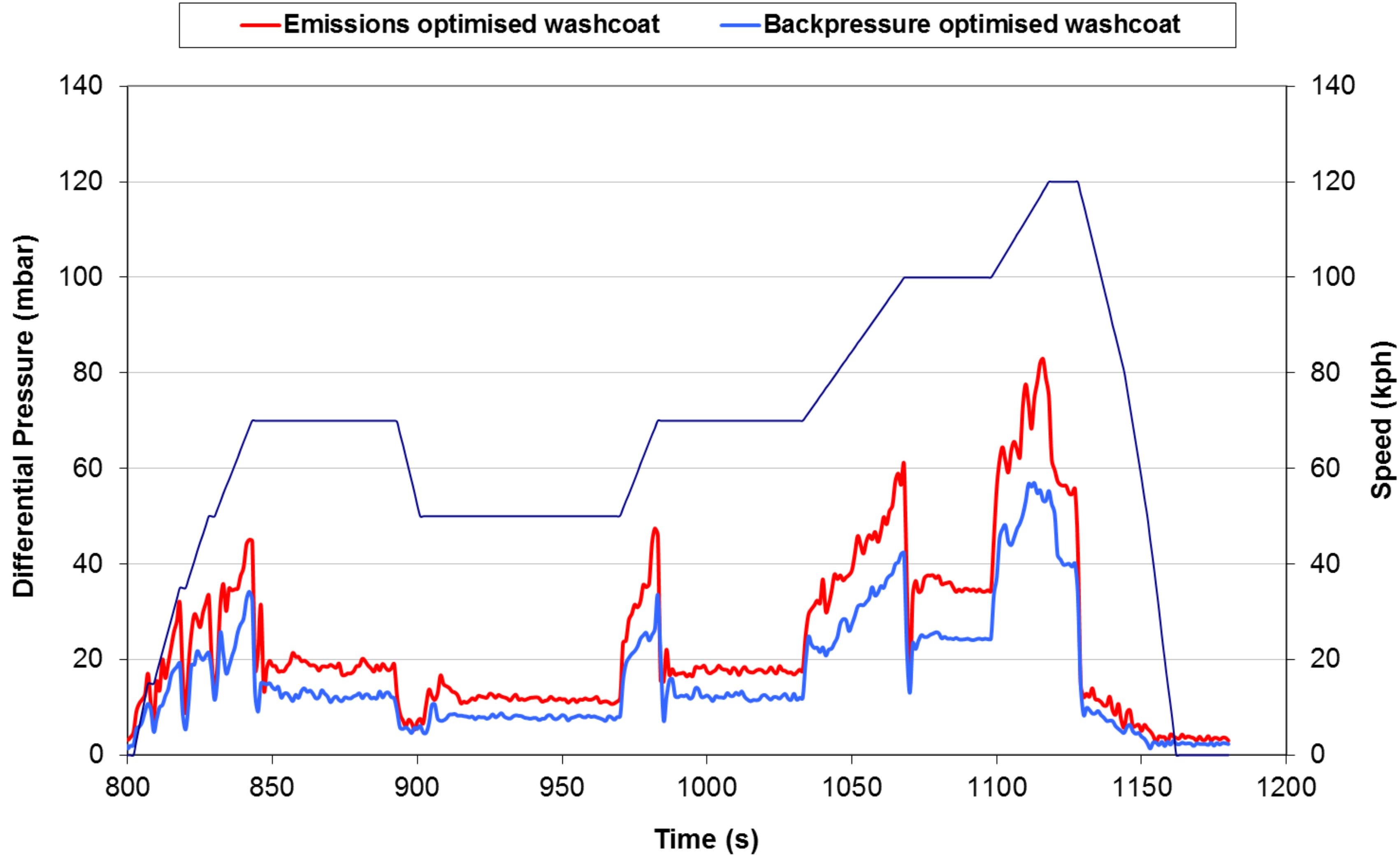

Particle number

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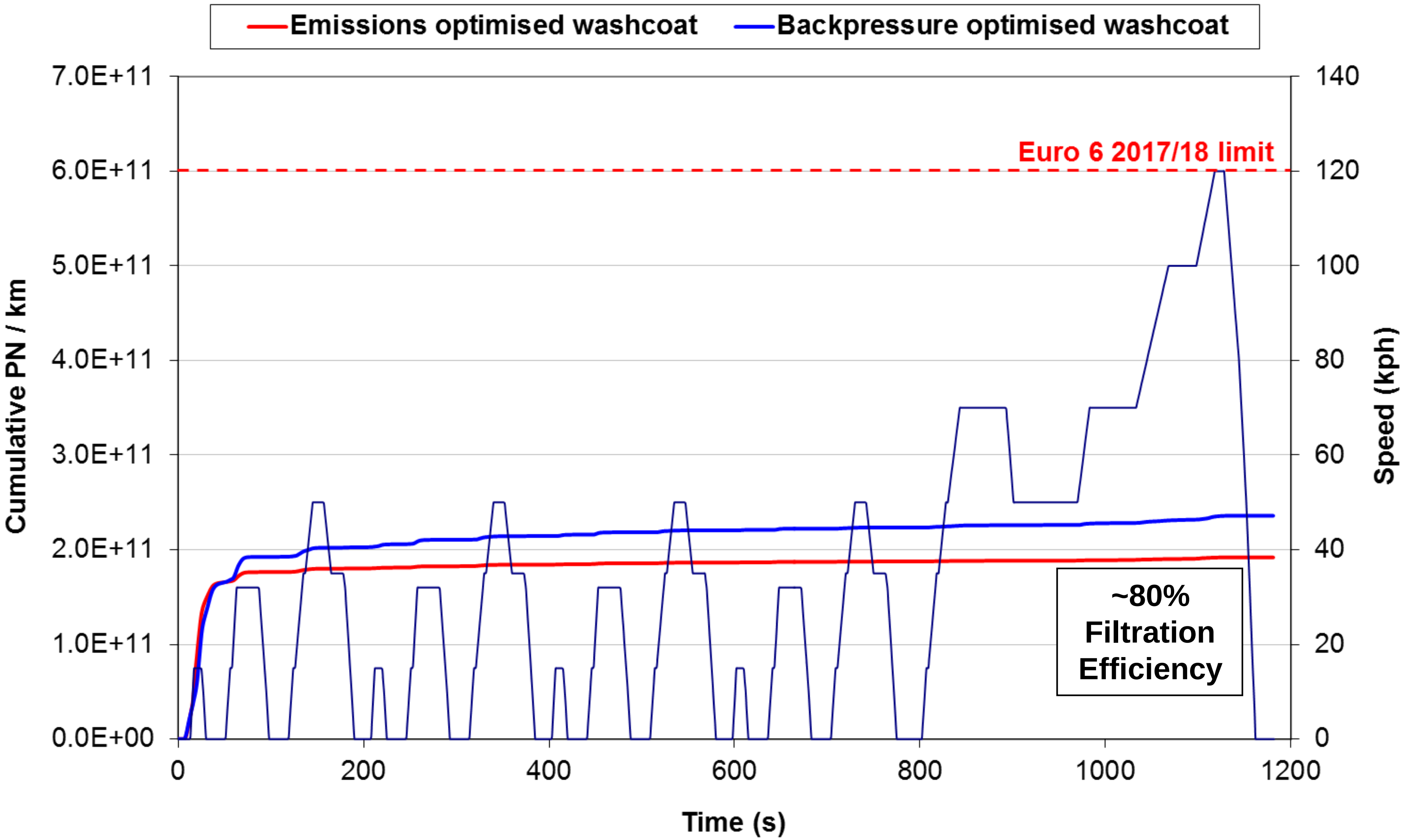

Emissions of both TWF™ versions meet EU6

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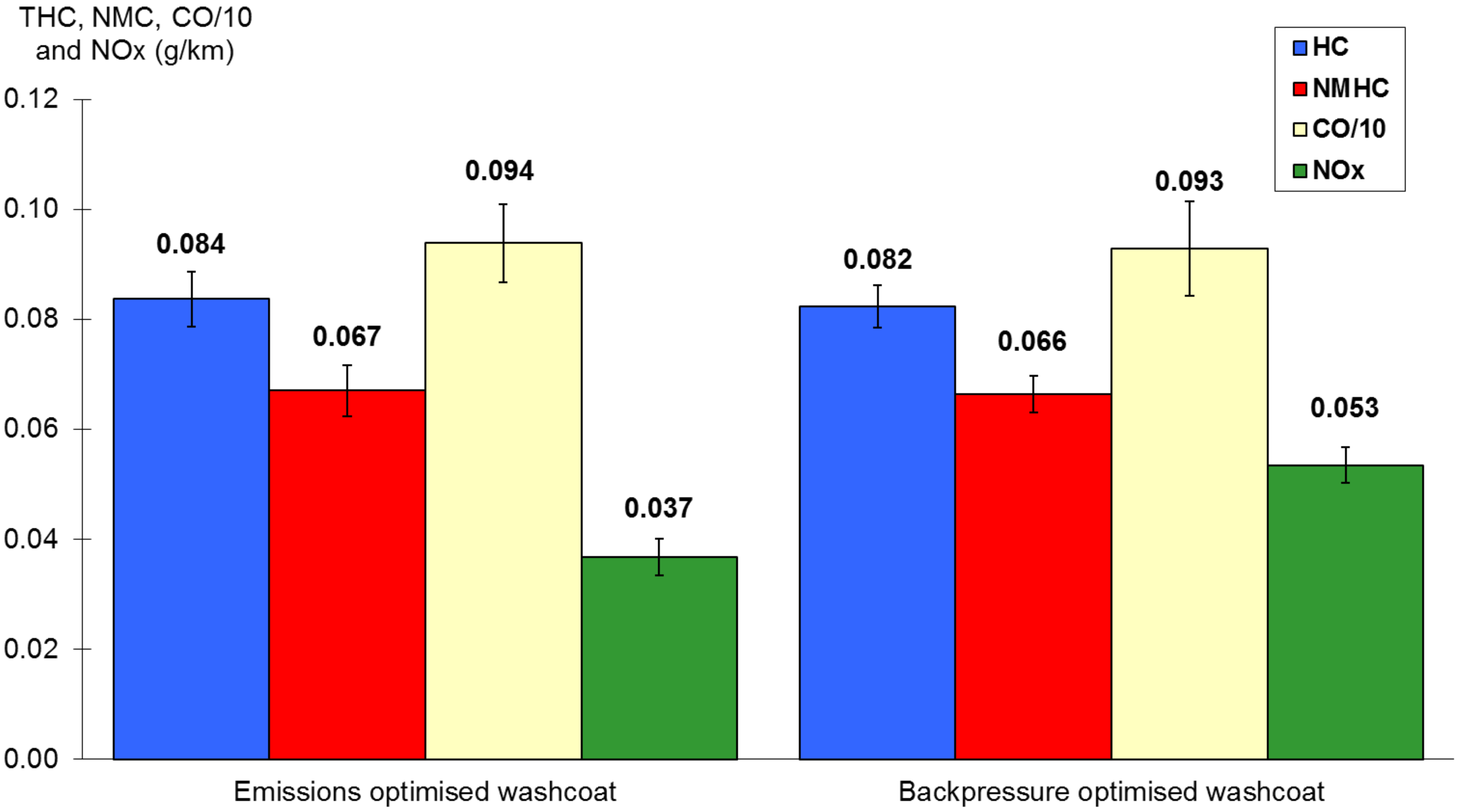

Conclusions

- Coated gasoline filters demonstrated on a range of commercially available direct injection gasoline vehicles
  - TWF™-only and TWC + TWF™ systems
  - Good particulate filtration and three way activity
  - Durability trials after various full useful life ageing conditions
    - Oven ageing, engine ageing, poisoning
- Met Euro 6 limits with aged TWF™ -only system on series DI cars
  - Emissions capable without changing engine hardware & calibration
- Washcoat optimisation concepts to enhance emissions performance and reduce backpressure exist

Future work

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- Significant filter optimisation and system integration work required
  - Close collaboration between OEM, substrate manufacturer and catalyst company is essential for success
- Key challenges include:
  - Real world durability trials
  - OBD of particulate filters
  - Evaluation of advanced development substrates
    - Thinner wall, high porosity materials
  - Low backpressure solutions for high performance engines
  - Soot regeneration protocols

Overall summary

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- Effective design of a catalysed filter and the surrounding system directly impacts key strategic drivers
  - Criteria emissions performance and PN
  - CO_2 emissions
  - Packaging space

- Next generation catalyzed filters need intensive optimization of performance factors and system design

- SCR and TWC catalysts coated on filters bring novel but surmountable challenges
  - Performance / durability are demonstrated
  - Full systems are being proven out today