The SCRF® Concept – A Competitive Johnson Matthey Approach to Off-road Emission Challenges

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SAENA Workshop 2016

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EMISSION CONTROL TECHNOLOGIES

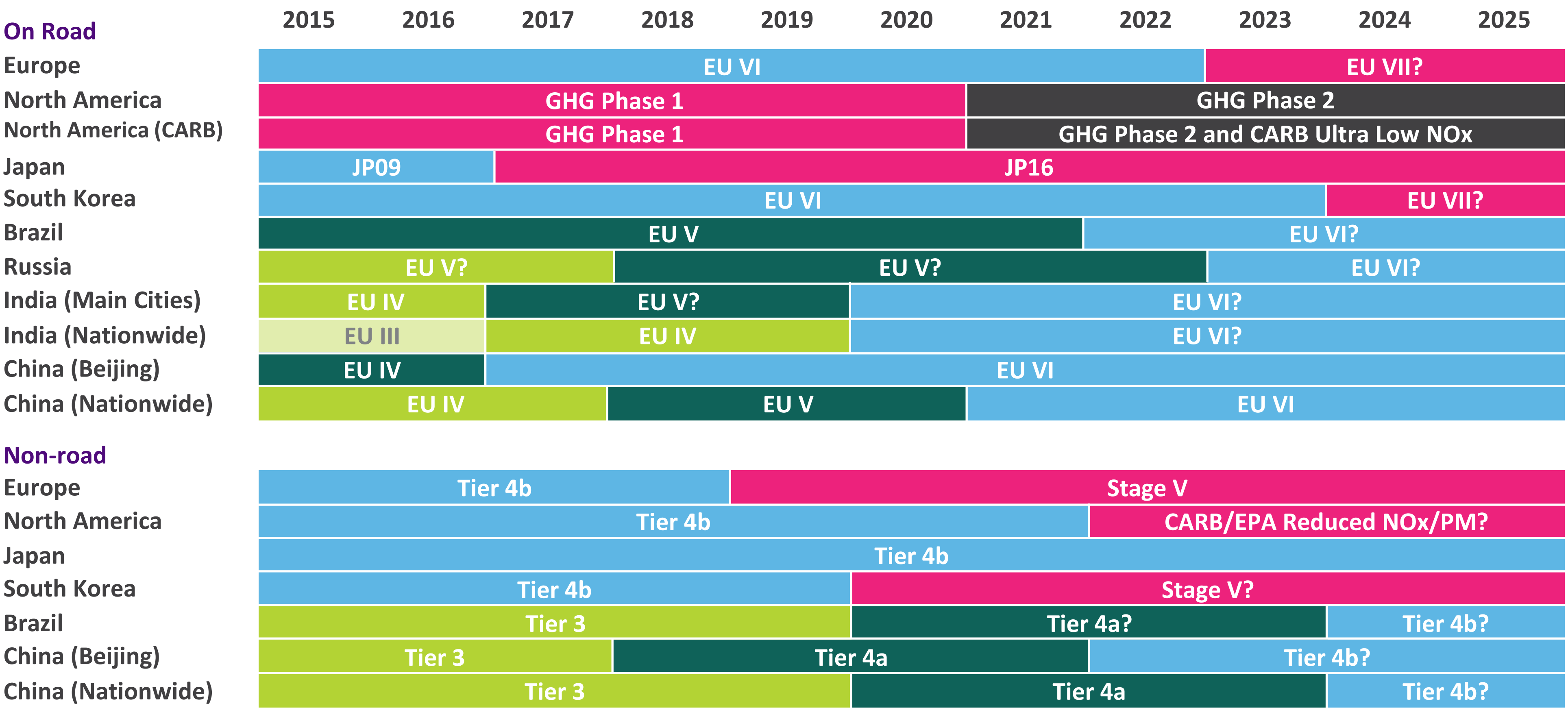
Outline of the Presentation

- Introduction of global legislation and market trends
- Development and technical drivers for SCRF®
- Technical features & challenges for SCRF® application
- System comparison SCRT® vs SCRF®
- Substrate definition affects SCRF® performance
- Impact of ash loading on SCRF® performance

Introduction of global legislation and market trends

Overview of HDD Legislative Roadmap

Further Tightening of Heavy Duty Regulation

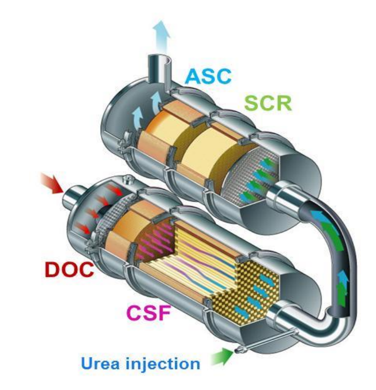


Incoming Europe and North America Regulations

HDD Emission Control Legislative Roadmap

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
On Road											
Europe	EU VI								EU VII?		
North America	GHG Phase 1						GHG Phase 2				
North America (CARB)	GHG Phase 1						GHG Phase 2 and CARB Ultra Low NOx				
Japan	JP09		JP16								
South Korea	EU VI									EU VII?	
Brazil	EU V							EU VI?			
Russia	EU V?			EU V?					EU VI?		
India (Main Cities)											
India (Nationwide)											
China (Beijing)											
China (Nationwide)											
Non-road											
Europe											
North America											
Japan											
South Korea											
Brazil											
China (Beijing)	Tier 3			Tier 4a				Tier 4b?			
China (Nationwide)	Tier 3					Tier 4a				Tier 4b?	

- **EU VII**
  - Possible NO_2, N_2O and fuel economy regulation to drive new systems design opportunities
- **EPA GHG Phase 2**
  - Further increases in fuel efficiency mandated from engines,
  - Lower catalyst operating temperatures and increased catalyst system NOx conversion needs



Optimised systems with improved NOx conversion and low temperature performance

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China / India EUVI Adds Filters

HDD Emission Control Legislative Roadmap

On Road	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Europe	EU VI								EU VII?		
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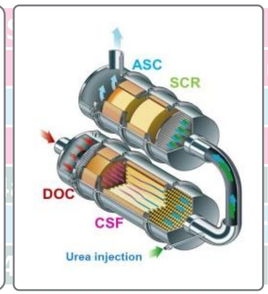
South Korea	EU VI									EU VII?	
Brazil	EU V							EU VI?			
Russia	EU V?			EU V?					EU VI?		
India (Main Cities)	EU IV		EU V?			EU VI?					
India (Nationwide)	EU III		EU IV			EU VI?					
China (Beijing)	EU IV		EU VI								
China (Nationwide)	EU IV			EU V			EU VI				

Non-road	
Europe	
North America	uced NOx/PM?
Japan	
South Korea	
Brazil	Tier 4b?
China (Beijing)	Tier 3 … 4b?
China (Nationwide)	Tier 4b?

- **India EUVI:** Filters and SCR on all HDD vehicles
- **China EUVI:** Filters and SCR on all HDD vehicles



Transition from SCR to SCRT systems increases system complexity

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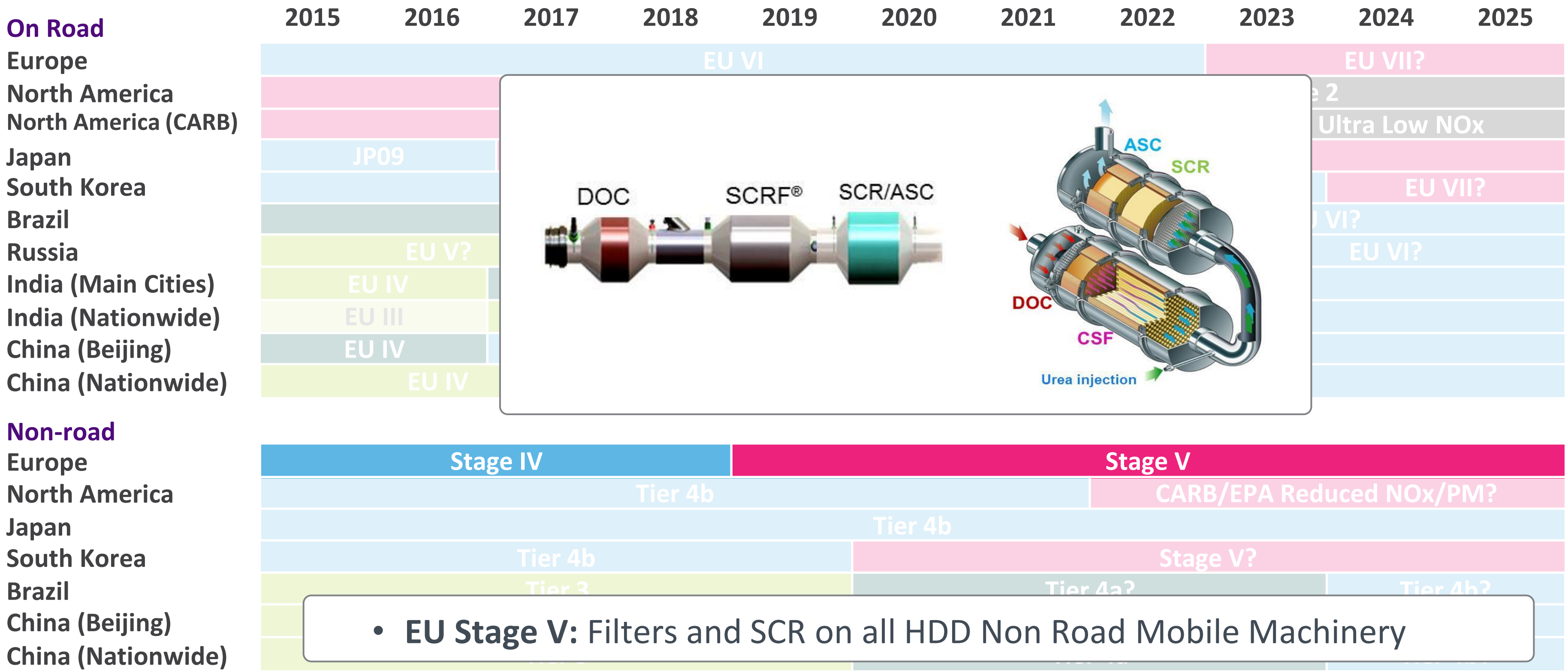
EU Non Road Stage V Mandates Filters via PN Regulation

HDD Emission Control Legislative Roadmap



- **EU Stage V:** Filters and SCR on all HDD Non Road Mobile Machinery

Transition to SCRT and SCRF systems increases requirements for installation and control strategies

China Non-road Regulations Require Emission Control

HDD Emission Control Legislative Roadmap

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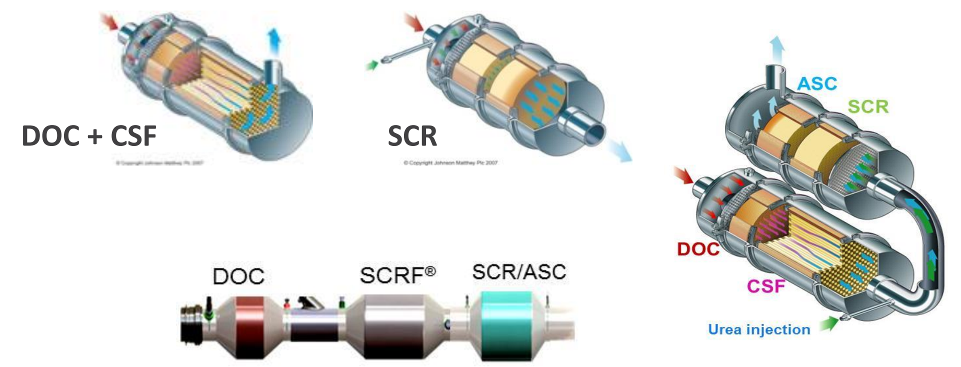
Non-road											
Europe											
North America											
Japan	Tier 4b										
South Korea	Tier 4b					Stage V?					
Brazil	Tier 3					Tier 4a?				Tier 4b?	
China (Beijing)	Tier 3			Tier 4a				Tier 4b?			
China (Nationwide)	Tier 3					Tier 4a				Tier 4b?	

- **China Tier 4a/b:** Filters and/or SCR on all HDD non-road mobile machinery



Introduction of emission control technology will enhance use of established knowledge

SCRF® Development Drivers

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SCRF Development

- On-road legislation
- Non-road legislation

	EuVI	EuVI+
PN (#/kWh)	6 x 10^{11}	6 x 10^{11}
PM (mg/kWh)	10	10

	Tier 4	Stage 5
PN (#/kWh)	No limit	1x10^{12}
PM (mg/kWh)	25	15

- PN introduction for Stage V is now filter forcing for ATS
- Space limation on non-road vehicles make SCRF an attractive option

Technical Drivers for SCRF®

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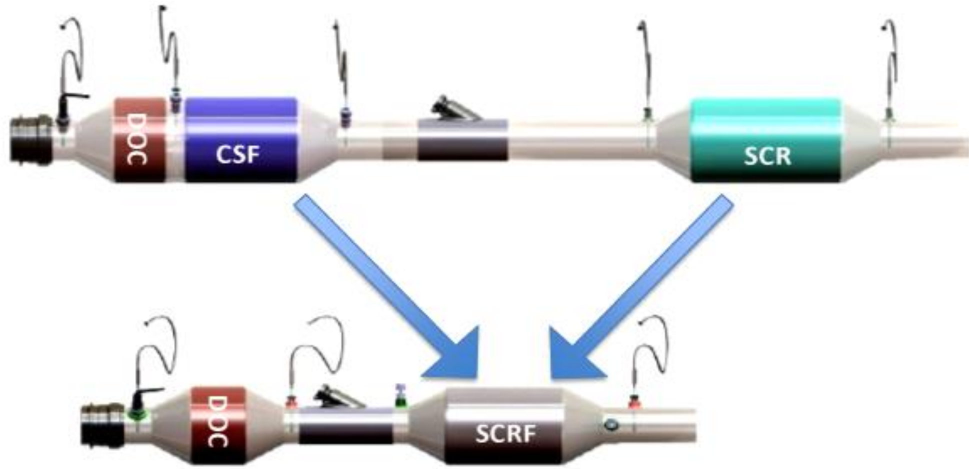
- Reduced system volume
  - More compact
  - Less space on vehicle
  - Muffler cost



- Faster heat-up of SCR coating
  - Cold start advantages
  - Improved low temperature performance

- Higher NOx conv. per unit system volume

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Technical features & challenges SCRF® application

SCR/ASC

SCR: NO_X reduction via reaction with NH_3

ASC: Removes ammonia slip after SCR & converts it to mostly N_2 and H_2O

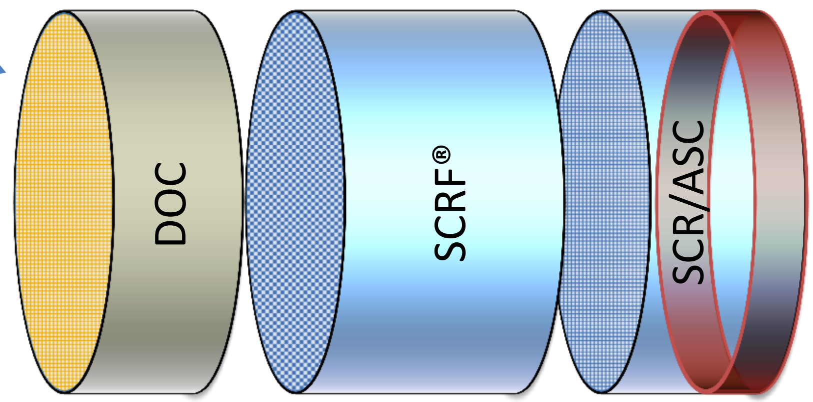
DOC

CO/HC oxidation

Exotherm generation

NO2 generation

Stability



SCRF®

NOx reduction + traps PM & PN compliant

Substrate cell density, porosity, wall thickness, MPS

Catalyst coating, loading, location, processing

HDD SCRF® Product Optimization

Finding the right balance between system functions

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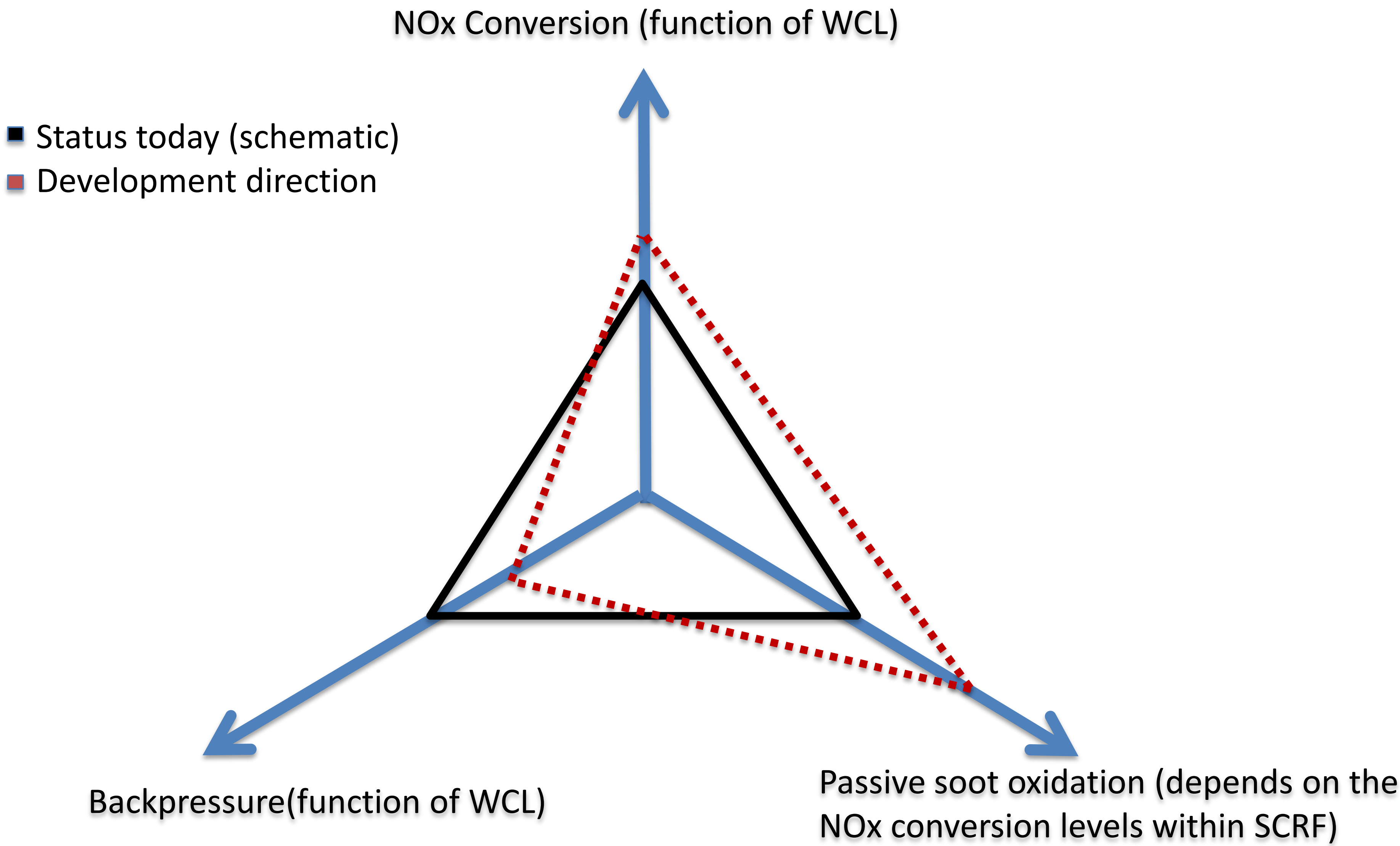

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SCRT® vs SCRF® System Comparison

WHTC NOx conversion, ageing at 700°C/100h

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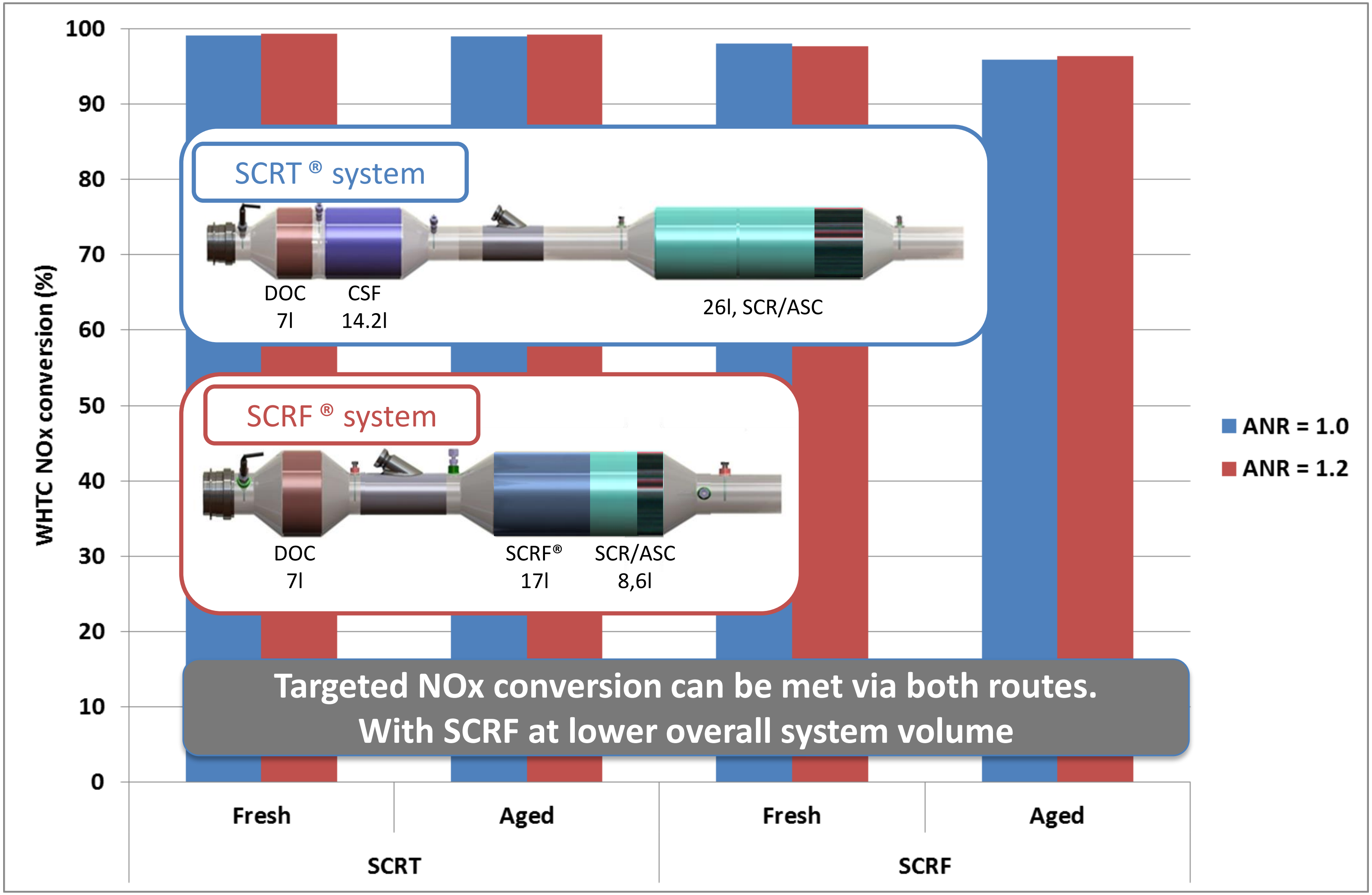
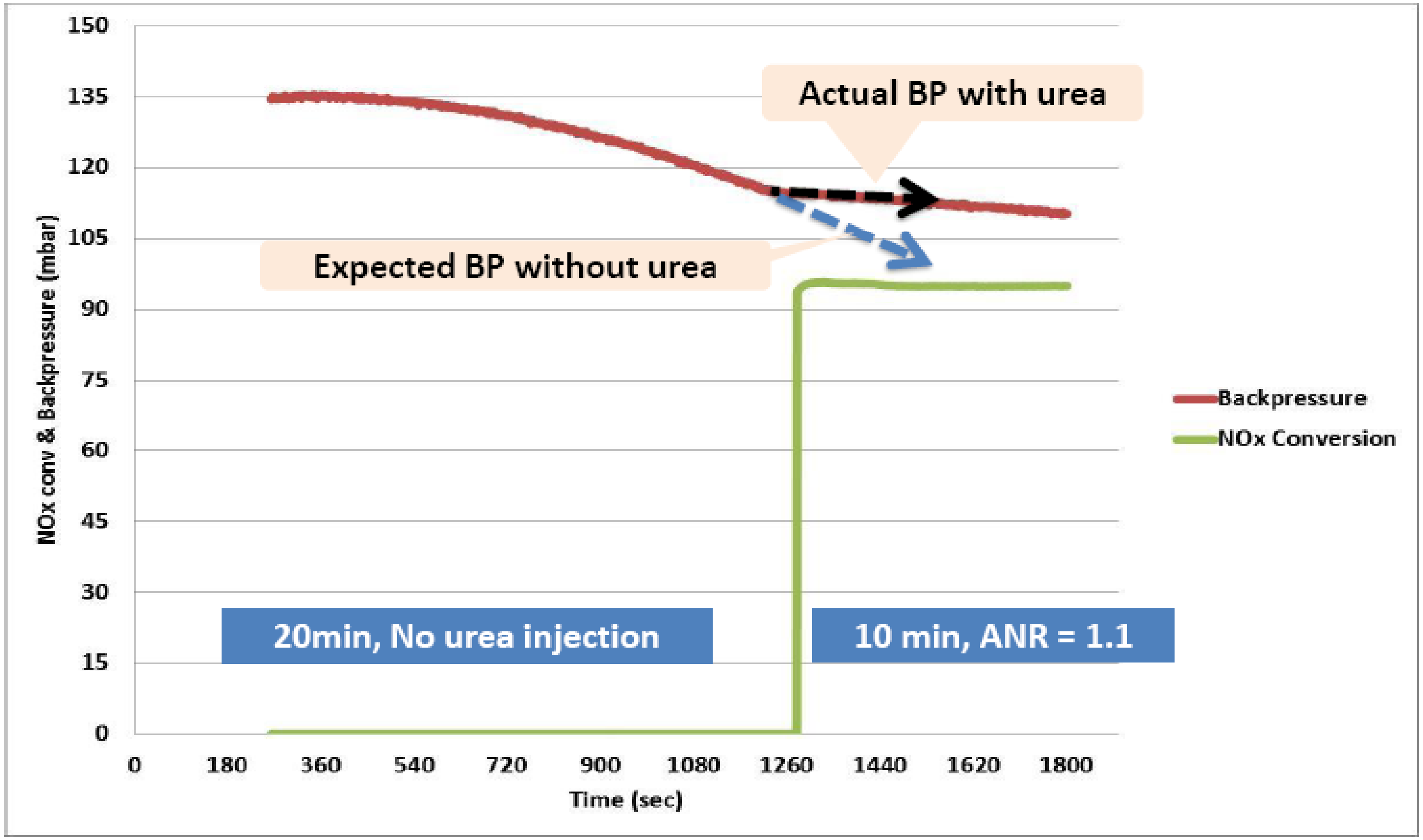
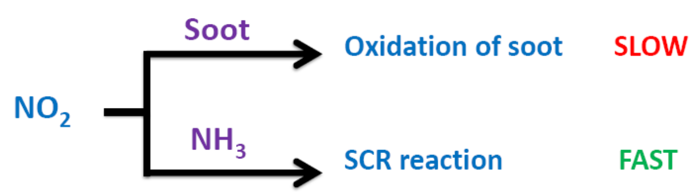


Influence of Urea Dosing on Passive Soot Regeneration

NO2/NOx ~ 40%, at 400ºC, 8g/l soot



Rate of soot oxidation drops with urea injection - NO_2 reacts preferentially via fast SCR reaction



Tailpipe PN Emissions

PN measured with urea injection

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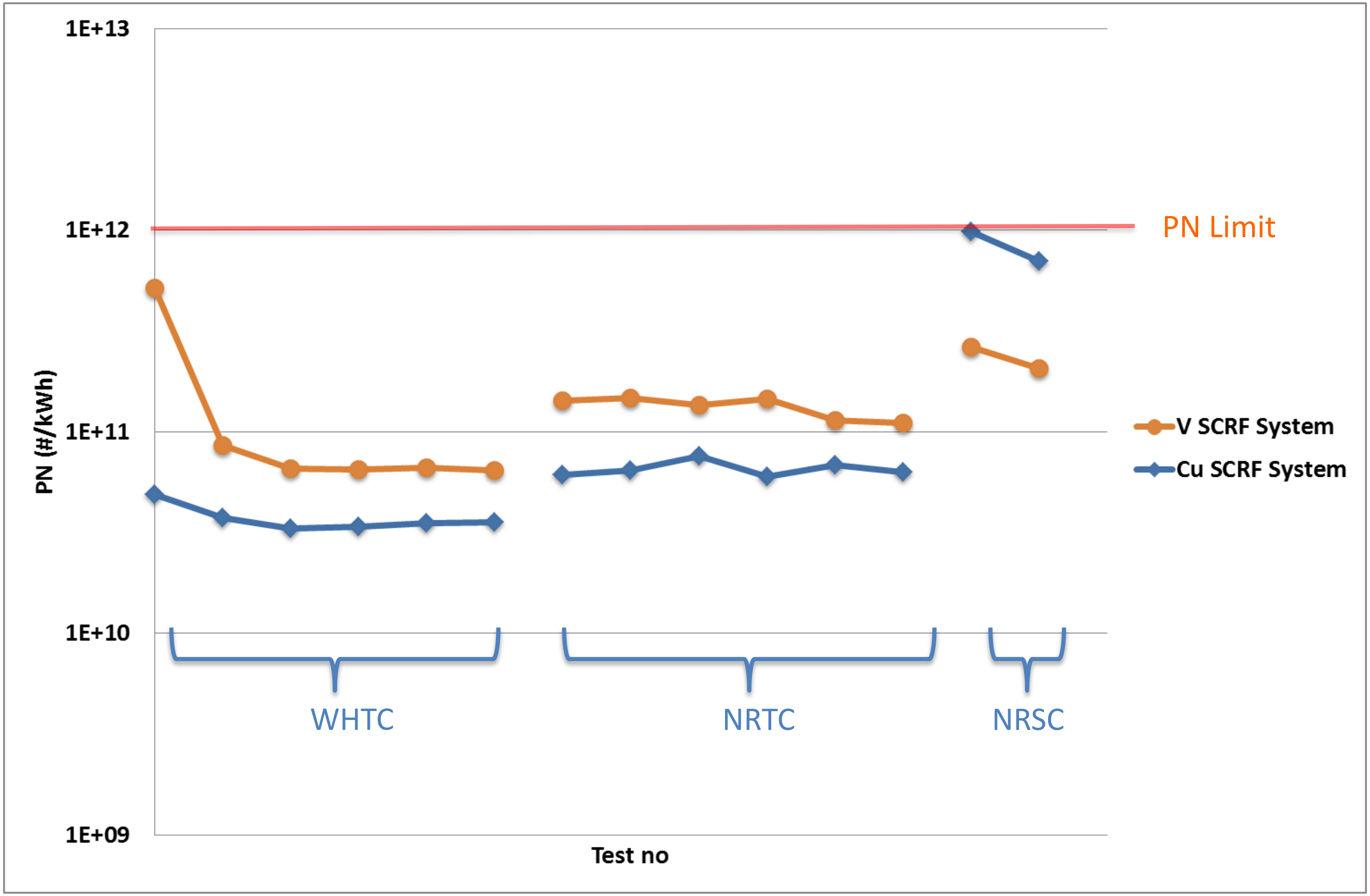

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Substrate definition affects SCRF® performance

Effect of cell density & porosity with soot & ash loading

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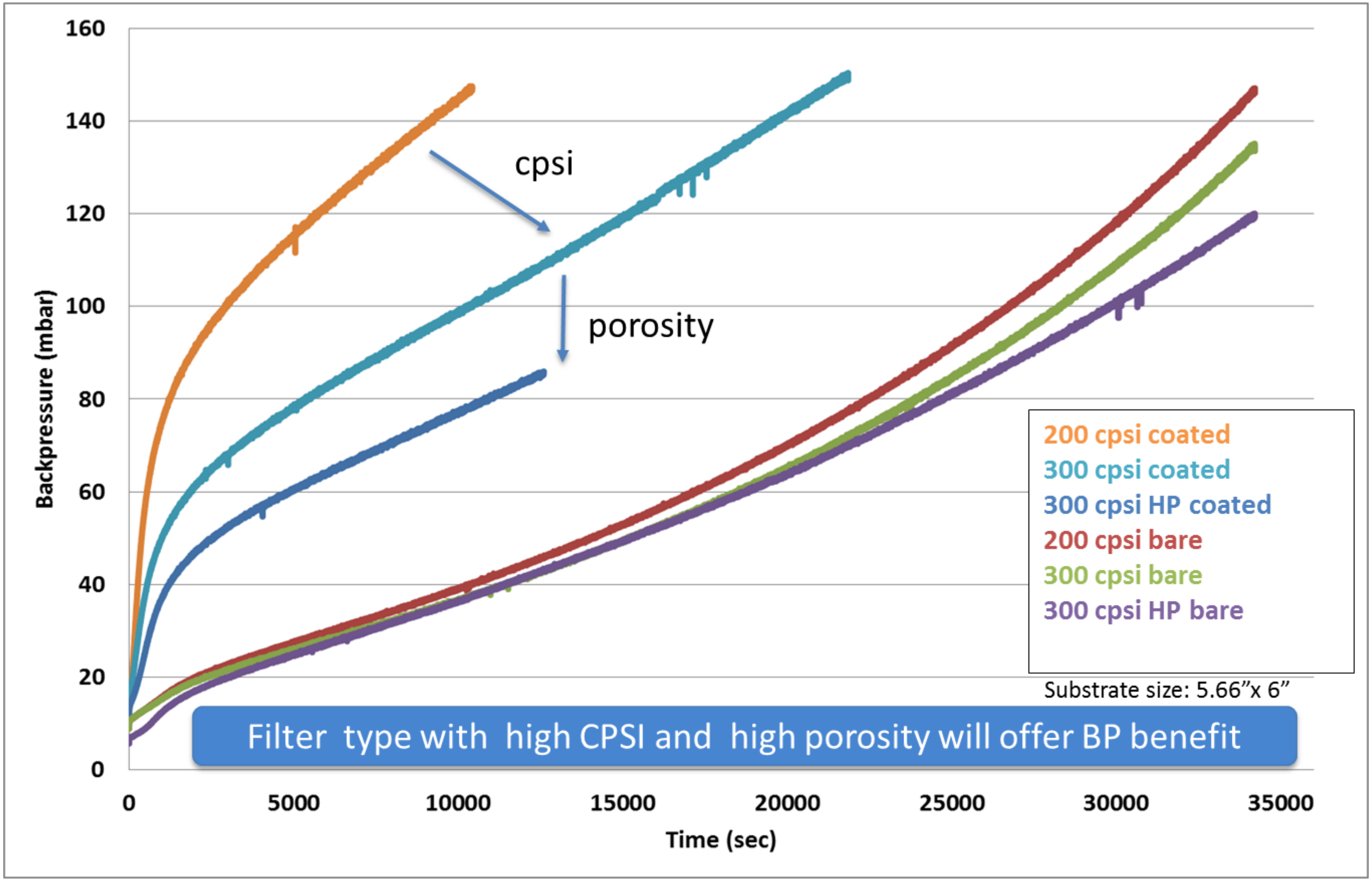

Substrate definition affects SCRF® performance

Effect of cell geometry on soot loaded backpressure

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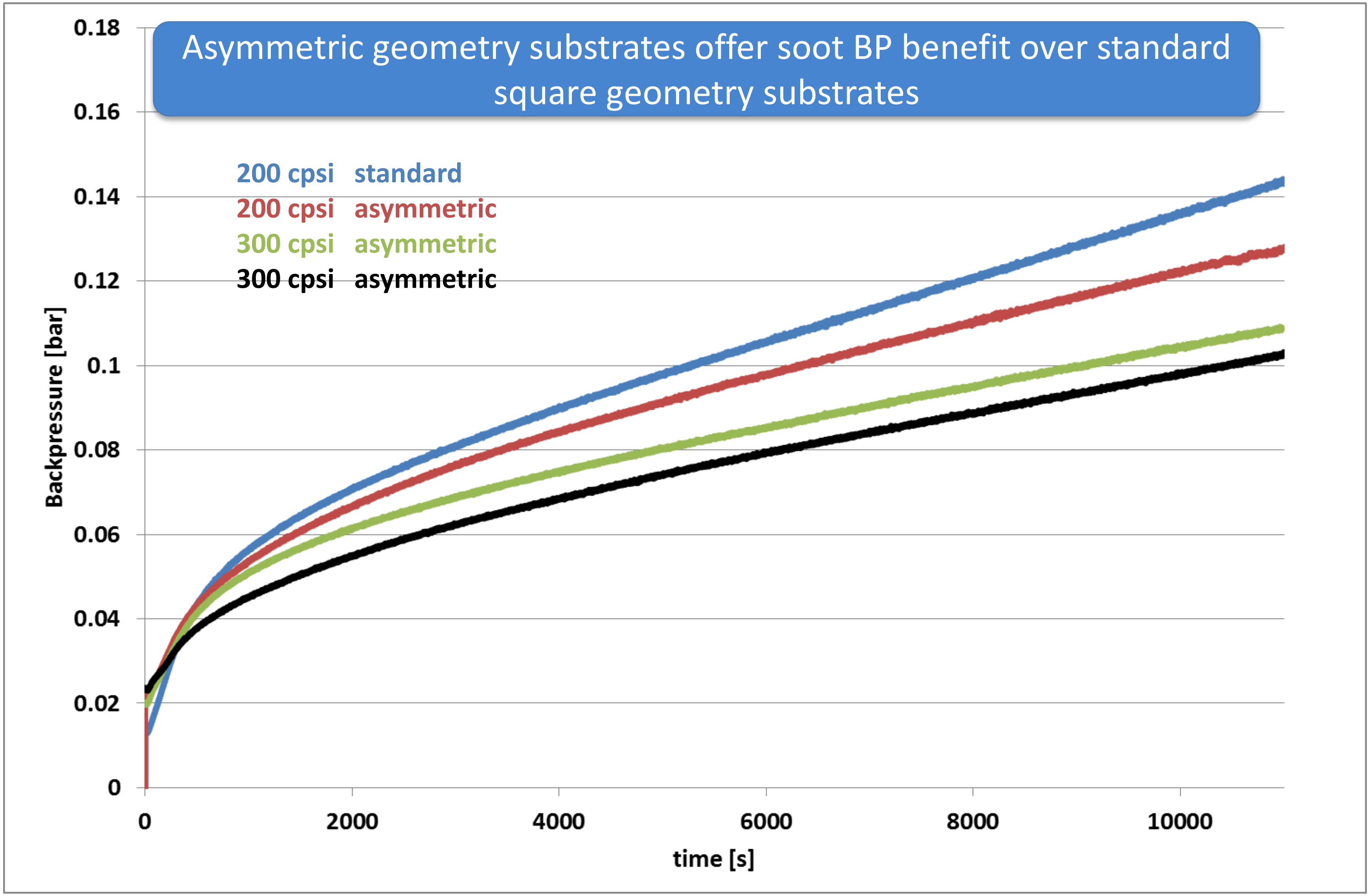

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Accelerated Ash Loading Study on Cu-SCRF®

High ash oil loading during 350 hrs of operation

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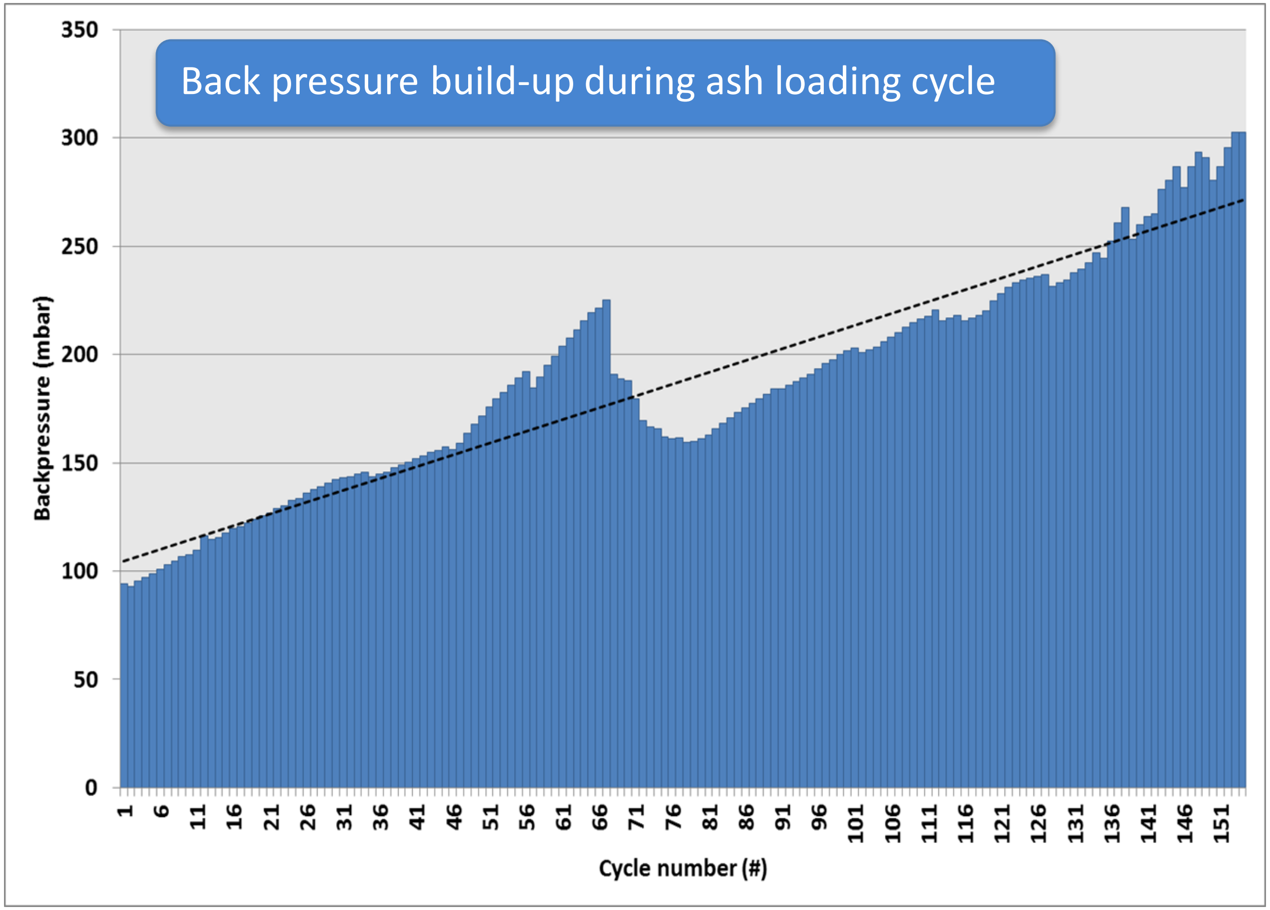
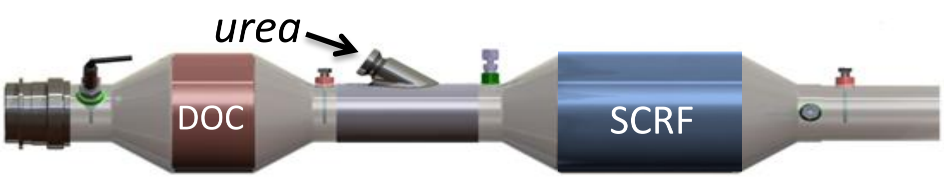


System was actively regenerated periodically at high temperatures to avoid soot build-up and form ash



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NRTC NOx conversion during ash loading

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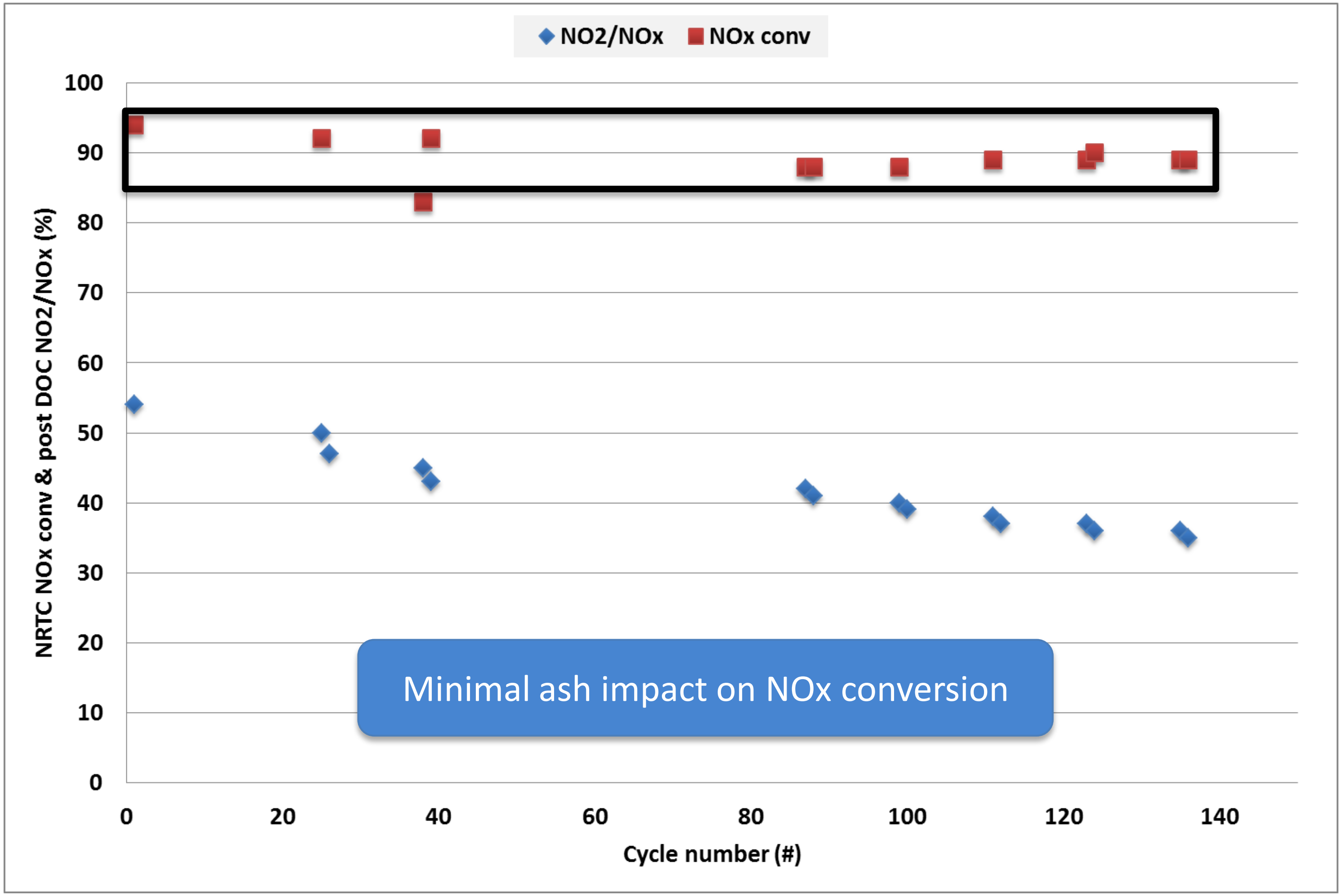

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Ash loading and Cleaning Study of Cu-SCRF®

Activity & BP before/after ash loading and after ash cleaning

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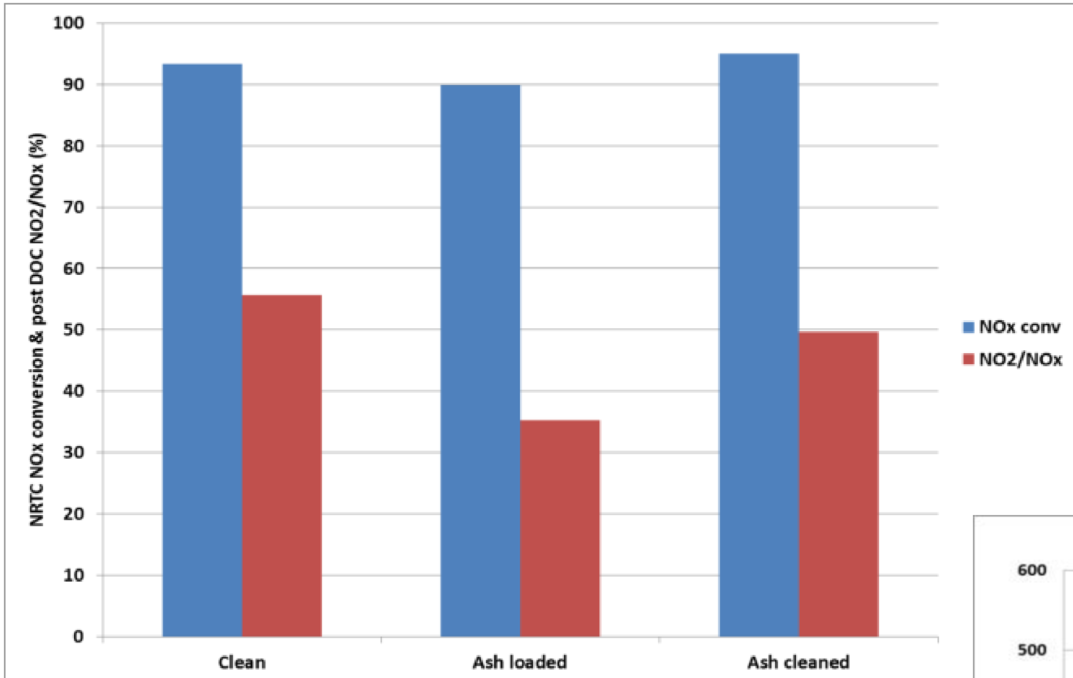
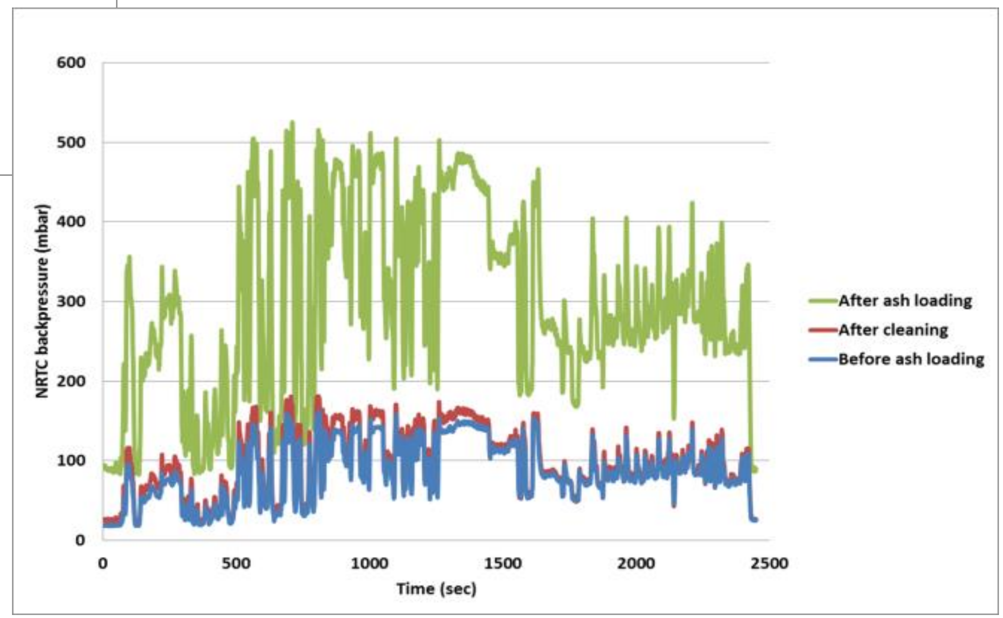


Following liquid based ash cleaning the component has equal performance to fresh & BP returns to its clean level



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Summary

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- System comparison tests have shown that SCRF® can be an alternative to SCRT® but at lower overall system volume which helps packaging and on vehicle installation

- Cell geometry optimisation and high porosity filters are enabling increased performance with low backpressure.

- SCRF® performance is dependent on catalyst washcoat optimization and substrate characteristics

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

- PN regulation and backpressure targets are met via optimised substrate cell density, porosity and catalyst washcoat technologies

- Study on ash loading and cleaning shows:
  - Ash accumulation does not have a significant effect on NOx conversion
  - Cu-SCRF® components can be cleaned, resulting in no loss in activity