12th International Conference & Exhibition - Nov. 14-15, 2019, Pune, India

Development of Advanced Catalytic Solutions to Meet Tightening Regulations: BS 6 and Beyond

ECT-2019 International Conference

Event Organised by:

ECMA

Emission Controls Manufacturers Association, New Delhi, INDIA

Saeed Alerasool, Ph.D.

Vice President
Environmental Catalysis Research
BASF

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We create chemistry

- ❑ Company introduction
- ❑ Review and perspective
- ❑ Advancement for LDV
- ❑ Advancement for HDD

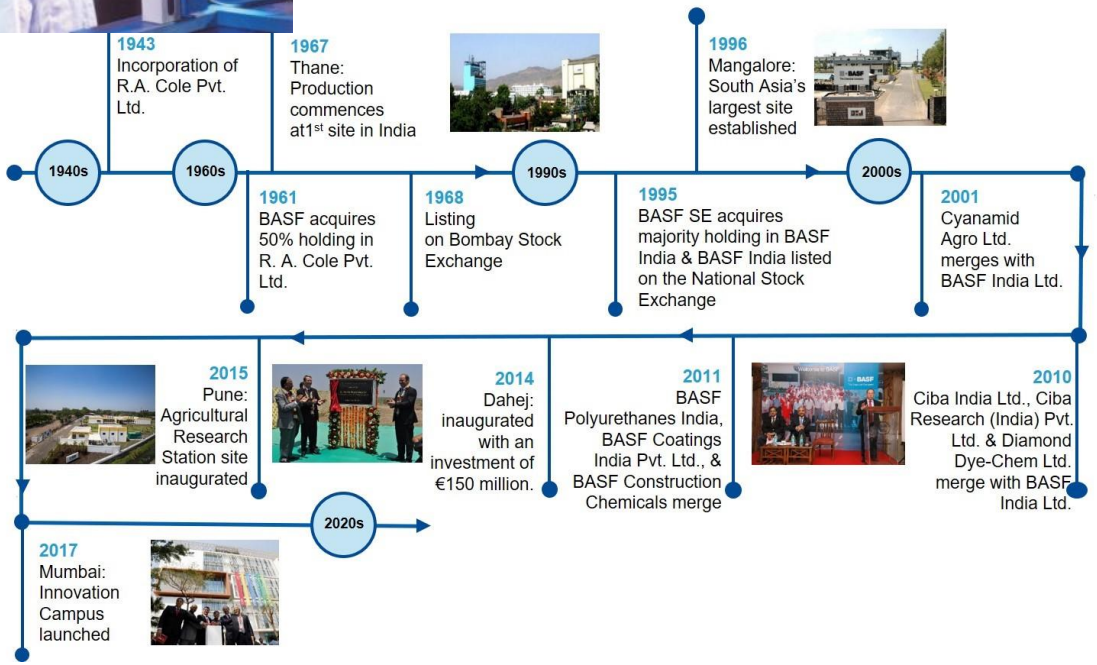
Agenda

- Company introduction
- Global regulation review and market trend
  - BS6 aftertreatment solutions and on-going challenges
- Catalyst advancements for LDV
- Catalyst advancements for HDD
- Summary

BASF Group At A Glance

- Celebrated **150** years in 2015
- Our chemistry is used in almost all industries
- We combine economic success, social responsibility and environmental protection
- Sales 2018: **€62,7** billion thereof **€11,6** billion to automotive
- Employees as of Dec. 31, 2018: **122,404**
- **6** Verbund sites and **355** other production sites

75 years in India



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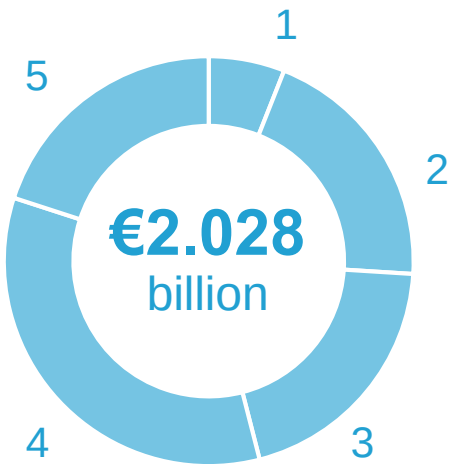
Research & Development Is a Major Growth Driver for BASF



2018

1	Chemicals	6 %
2	Performance Products	20 %
3	Functional Materials & Solutions	20 %
4	Agricultural Solutions	34 %
5	Corporate Research, Other	20 %

Research for the future: With our innovative products and processes, we provide sustainable solutions for global needs.

- Expenditures for research and development €2,028 million
- Around 11,000 employees worldwide involved in research and development
- Around 3,000 research projects
- Around 900 new patents filed

Champion in the chemical industry

- Consistently high expenses for R&D
- Sales of around € 9 billion from innovations that we have launched in the past five years

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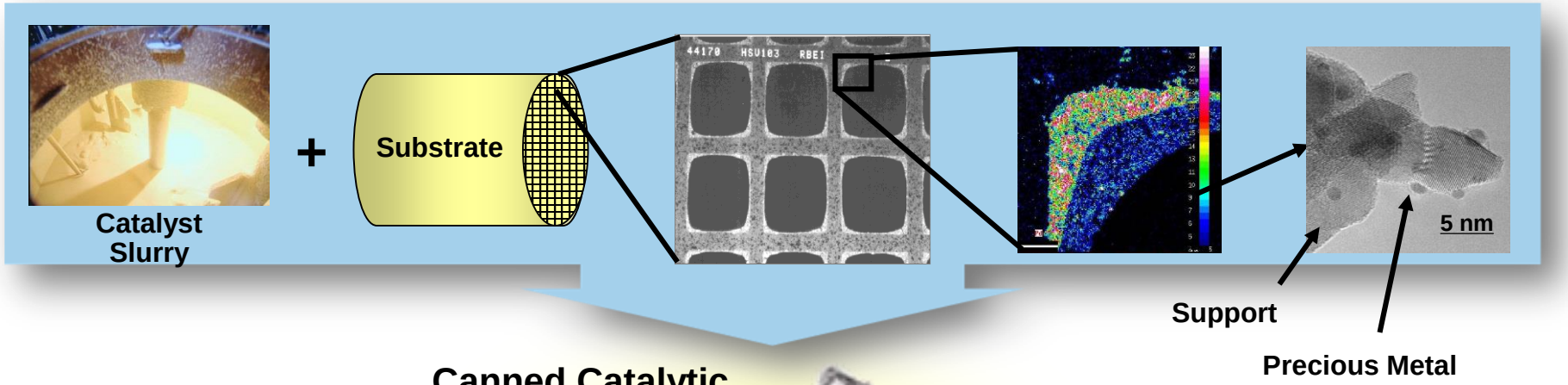
The No.1 Chemical Supplier To The Automotive Industry

Top 100 global automotive suppliers (2018)

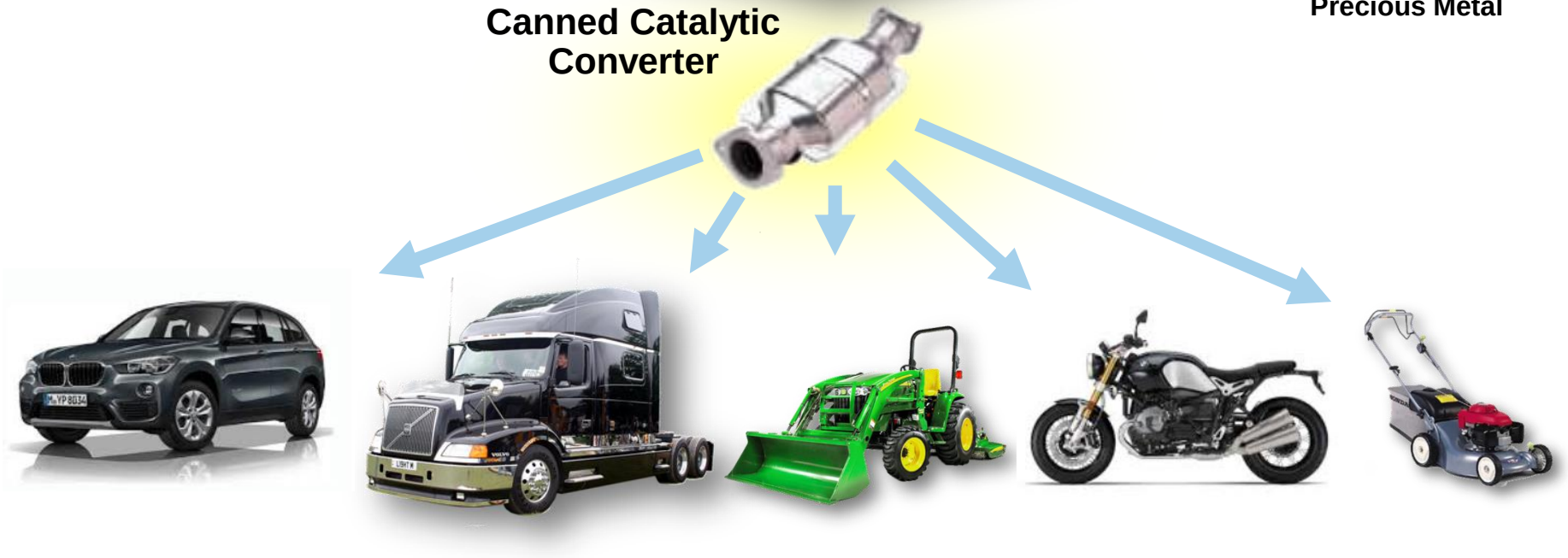
Rank	Company	Sales (in $ billion)
1	Bosch	49.5
2	Denso	42.8
3	Magna	40.8
…		
19	**BASF**	**12.9**
…		
69	Dupont Trans & Industry	3.2

*Source: Automotive News, June 25, 2019
*Based on the magazine's statistics, not including precious metals

Catalytic Solutions for Broad Range of Applications

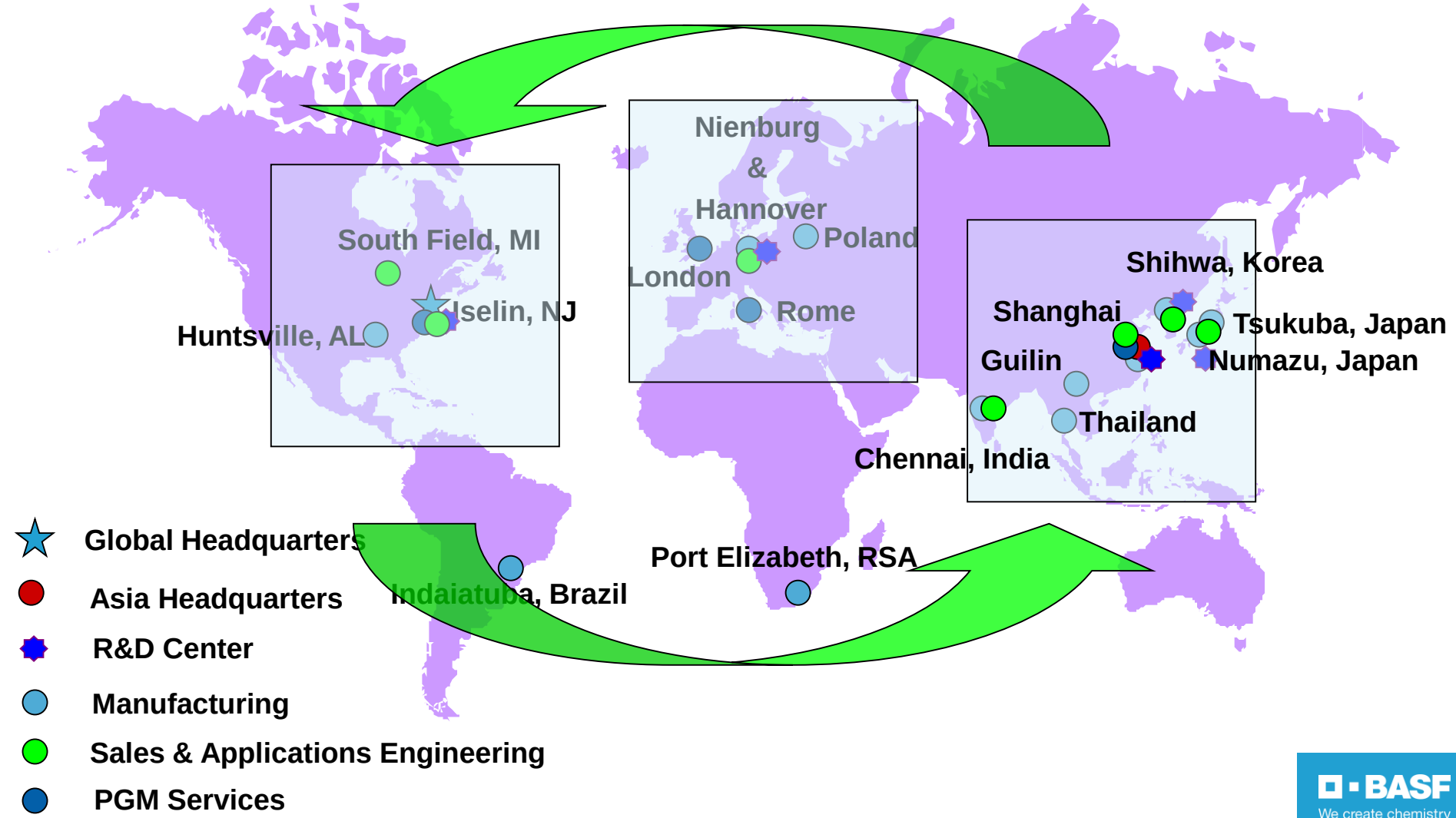


Canned Catalytic Converter



Global Platform To Share Technology/Experience/Knowledge

World Leading Expertise, Local Focus



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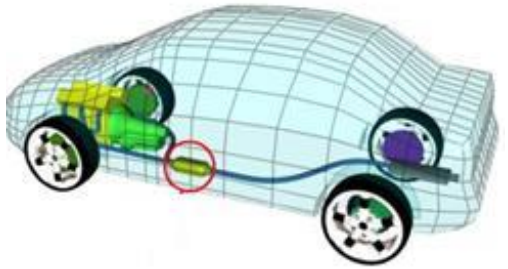
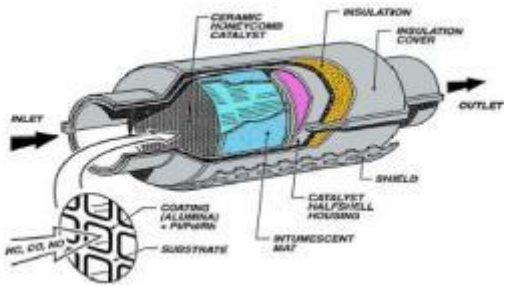
- ❑ Advancement for HDD

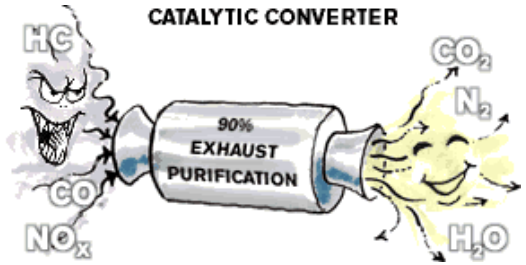
Catalysts as The Enabler for Clean Air We Are Breathing

L.A.
USA
(Accomplished)



New Delhi
India
(In-Progress)





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Driver for Advancement in Emissions Control Technology

New Regulations

- EU LDD 6d & RDE
- US LDG LEV III
- **BS 6!! BS 7??**

CO_2 Mandates

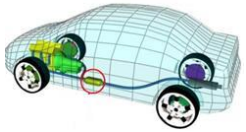
- Engine measures that
- Decrease exhaust temp.
- Increase emissions

Cost Reduction

- Reduce PGM usage
- Reduce catalyst volume
- System integration

Emissions Control Catalysts Technologies

Comparison of LDV and HDD Emission Regulations

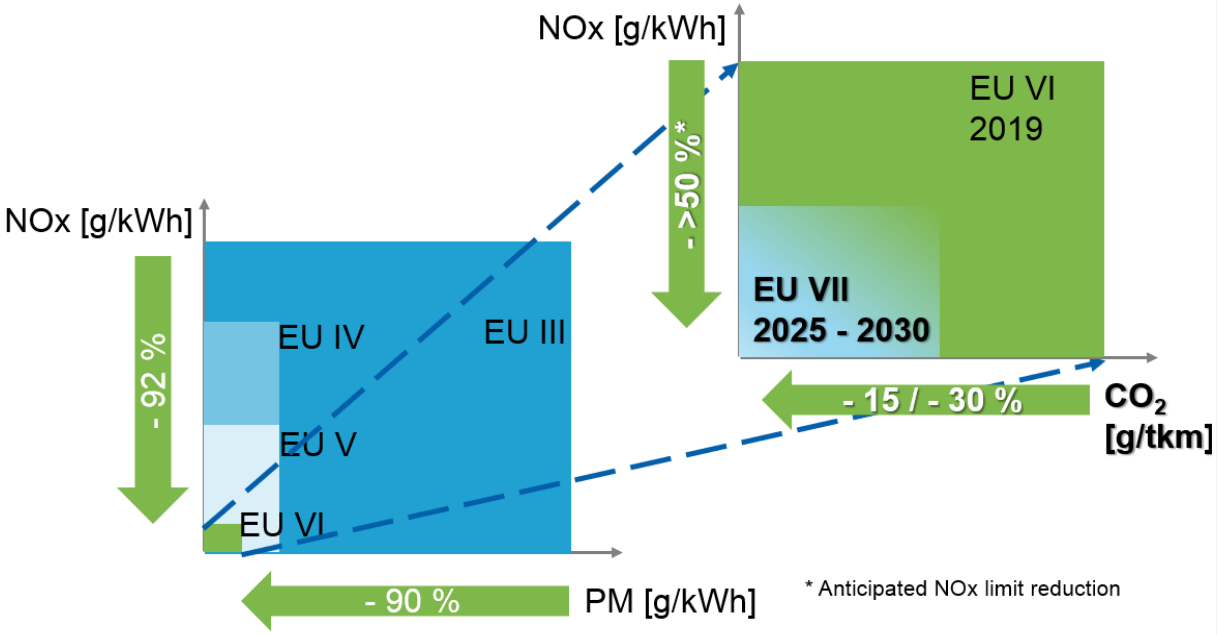


LDV (g/km) // WLTP				
Norm	**BS6**	**EU 6c/d**	**NS6a**	**NS6b**
CO	**1.0**	**1.0**	**0.7**	**0.5**
HC	0.1	0.1	0.1	0.05
NMHC	0.068	0.068	0.068	0.035
NO_x	**0.060**	**0.060**	**0.060**	**0.035**
PM	**0.0045**	**0.0045**	**0.0045**	**0.0030**
PN	**$6x10^{11}$**	**$6x10^{11}$**	**$6x10^{11}$**	**$6x10^{11}$**

HDD On-Road (g/kwh)				
Norm	**BS VI**	**EU VI**	**NS VIa**	**NS VIb**
CO	4.0	4.0	4.0	4.0
HC	0.16	0.16	0.16	0.16
NO_x	0.46	0.46	0.46	0.46
NH_3	10ppm	10ppm	10ppm	10ppm
PM	0.01	0.01	0.01	0.01
PN	$6x10^{11}$	$6x10^{11}$	$6x10^{11}$	$6x10^{11}$

- Same limits in India and China as Europe for HDD, some variations are seen with Indian LDV
  - NEDC certification cycle with a peak speed of 90 km/h
  - PN&PM apply to only GDI engines, not MPI

Stricter Regulations Mandate Higher Efficiencies, Lower emissions and Increased Robustness



Global challenges

- Green House Gases
- Fuel Efficiency
- Ultra High DeNOx
- Robustness
- System Cost

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BASF History of Delivering Innovative Solutions

1976 – Developed the first three-way auto emissions catalyst

1982 – Awarded the United Nations "Award of the Decade" for environmental innovation and achievement

1995 – Earned first US EPA Urban Bus Retrofit certificate

2000 – Commercialized the first catalyst system for destroying ozone

2003 – Awarded the National Medal of Technology for Three-Way Catalysts development

2004 – Commercialized the first catalyzed soot filter

2010 – Earned Edison Patent Award for advanced zeolite SCR catalyst

2011 – Commercialized first emissions catalyst for non-road diesel engine applications

2013 – Announced FWC™ catalyst to remove 4 pollutants with 1 component from gasoline-engine exhaust

2014 – Introduced CSF.4 which can eliminate one catalytic component from diesel-engine exhaust systems

Pre-1974

100 of today's cars to equal the pollution from 1 pre-1974 car

Today

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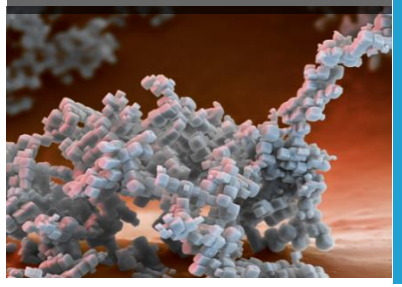
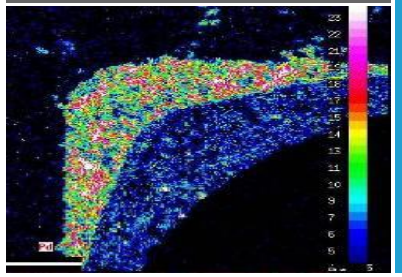
Innovative Material and Process Development Enable New Solutions

Material Innovation



- New zeolites
- Novel synthesis
- Materials with new functionalities

Advanced Coating Process



- Innovative design concepts
- Multi-functional catalysts

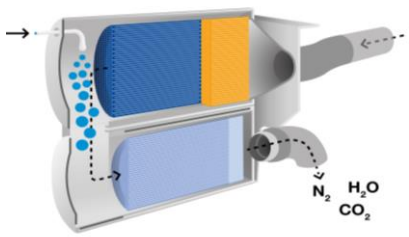
BASF Toolbox

- Superior deNOx activity / selectivity
- NOx storage
- Selective oxidation

Improved Functionality

- Modeling & Simulation
- Performance & Robustness Validation

Application Development



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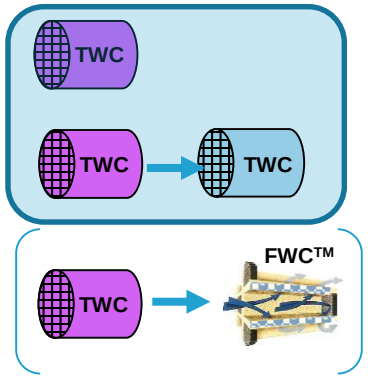
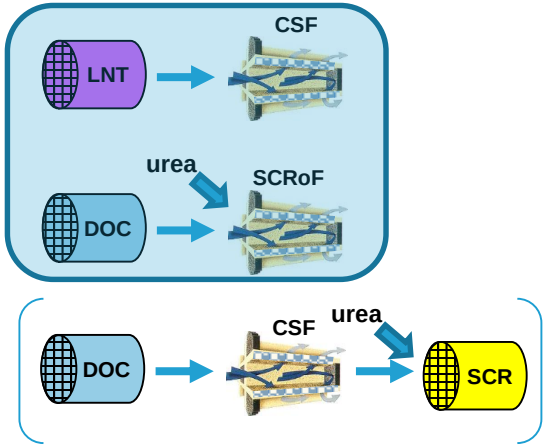
Catalyst Systems Used in Upcoming BS 6 / TREM IV

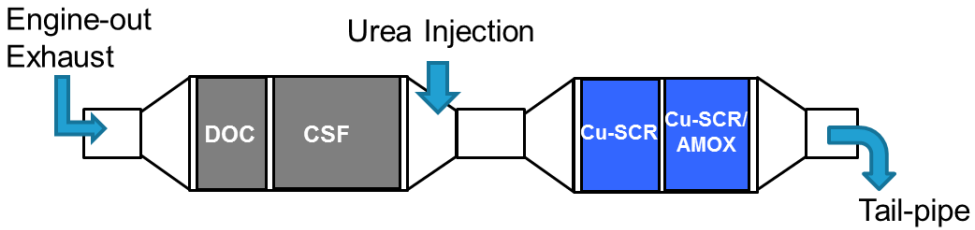
LDG



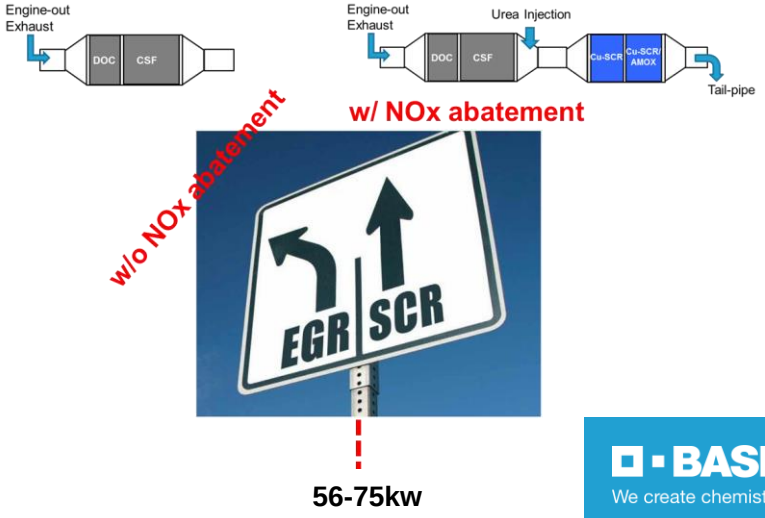
LDD



HDD-on



HDD-off



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Catalyst Advancements for LDV
– Addressing future regulation and cost challenges

Market Needs

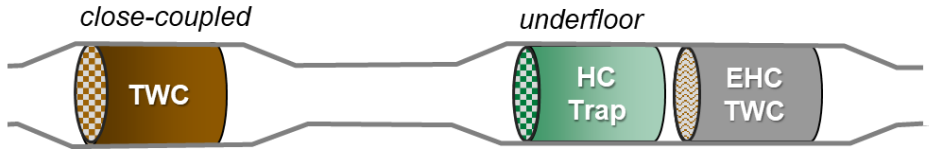
- Emission & CO_2 reduction
  - Cold start & lower exhaust temperature
  - Alternative fuel: e.g. CNG
- Cost effectiveness
  - Rising precious metal prices, esp. Pd
- Future requirement
  - PN for GDI engine
  - IRDE in 2023

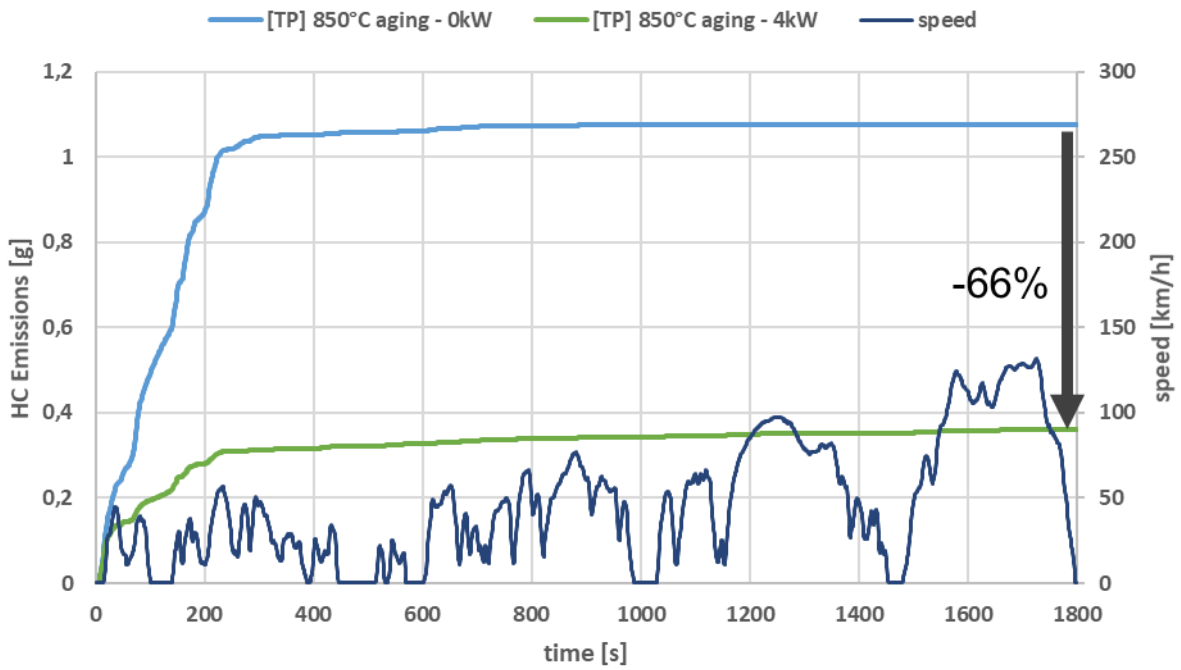
BASF Solutions

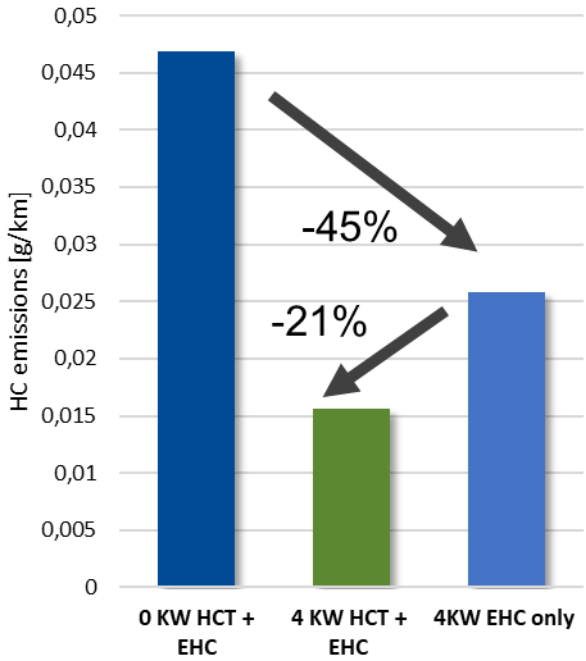
- Emission and CO_2 reduction
  - EHC – Hydrocarbon trap combination
  - Tailored CNG TWC technology
- Cost efficiency
  - Tri-Metal TWC development
- Future requirement
  - Advanced fresh filtration efficiency
  - Tailored cycle development for IRDE

Cold Start Solutions

Hydrocarbon Trap and EHC: System Performance*







- HC tailpipe emissions are reduced by about 66% after 850°C oven aging by using HC trap and TWC-EHC
- Significant contribution in the light off phase by hydrocarbon trap observed

***After hydrothermal oven aging (16h, 850°C)**

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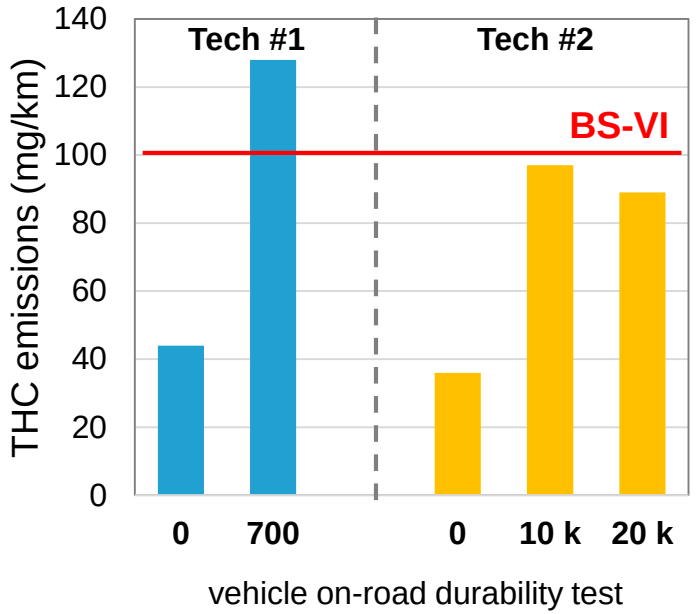
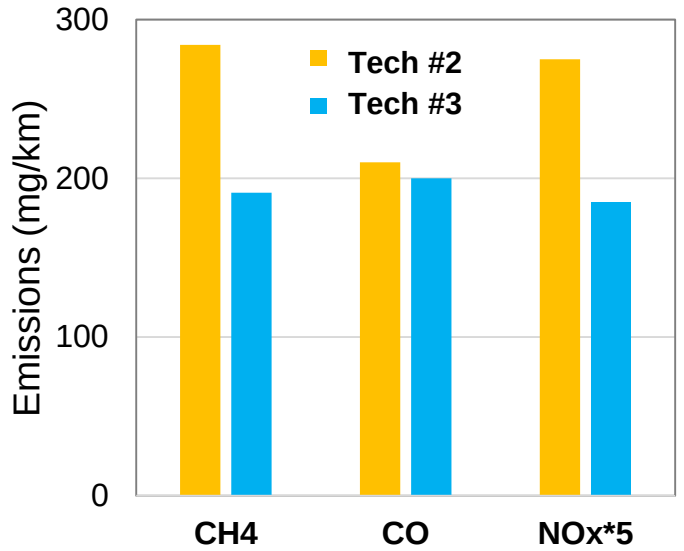
Tailored CNG TWC Development for India

Tech #1 Reference → **Tech #2** Improved sulfur durability → **Tech #3** Improved thermal durability



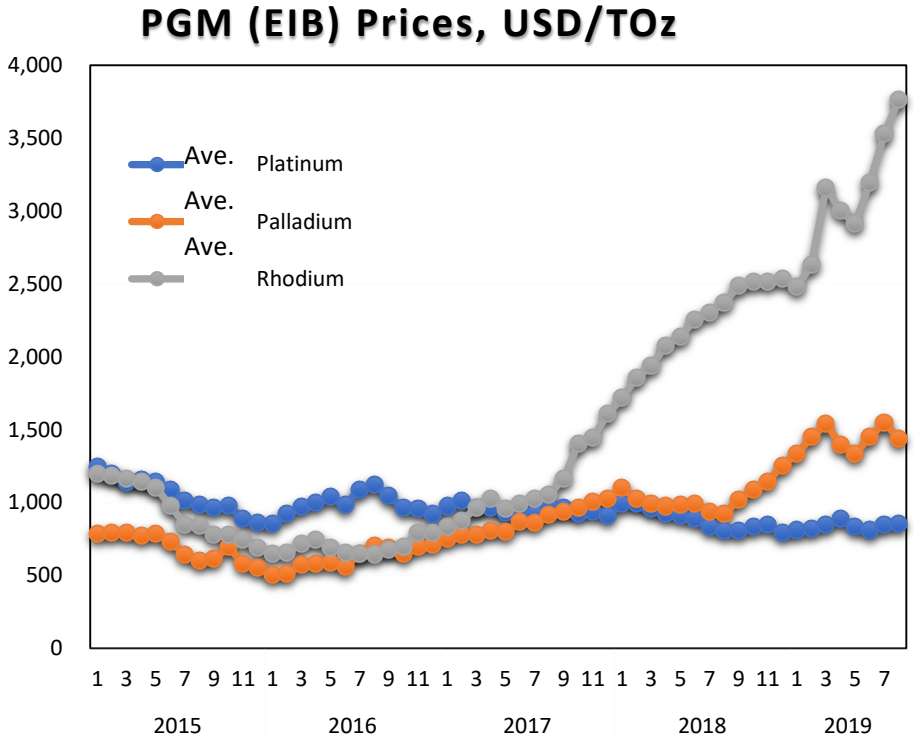
vehicle on-road durability test



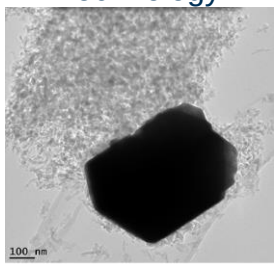
Aged testing on @VSS

- PGM distribution
- Support and promoter
- OSC level
- Tri-metal

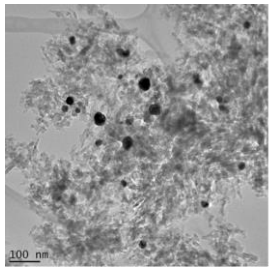
Tri-Metal TWC Development to Deal with Rising Pd Price



Conventional Pt Technology

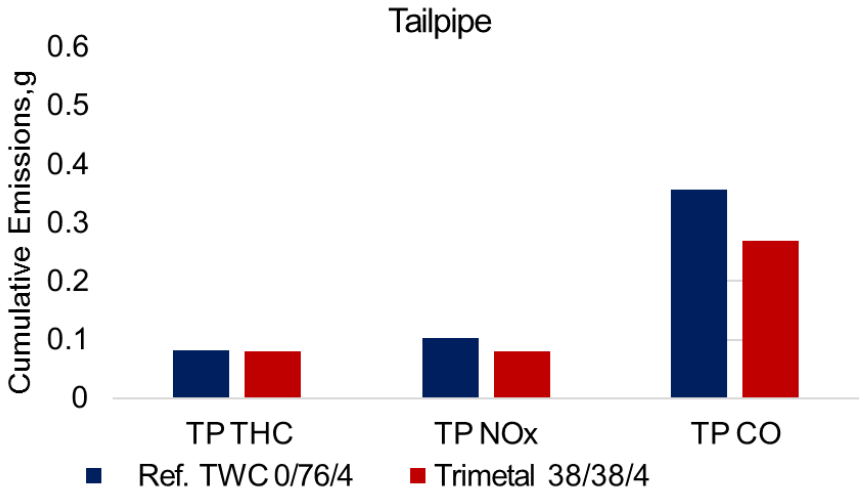


New Pt based Technology



- Increasing Pd prices leads to substantial cost increase
- Pt prices are seeing a downtrend in recent times
- New Pt based technology could save 10-20% cost, depending on PGM content

Performance equivalency after high temp. aging (maximum bed temp. 1030°C)



- Simple replacement of Pt with Pd will not work
- Strong metal-support interactions (SMSI) to countermeasure against Pt sintering
- Pt on SMSI support benefit demonstrated
- Cooperation with two Indian OEMs underway

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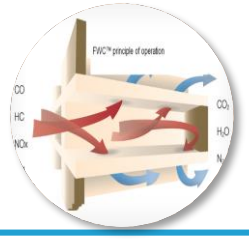
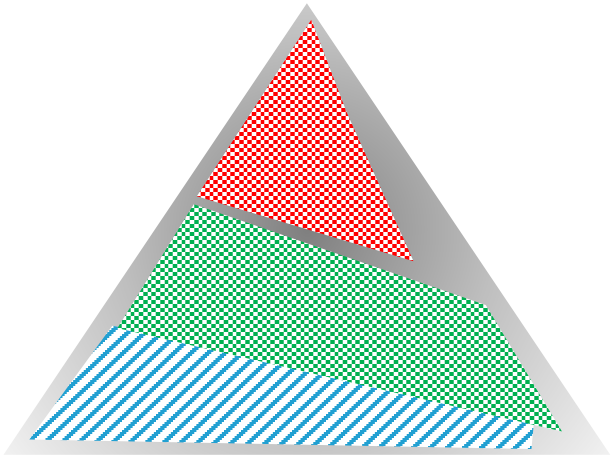
FWC™ Portfolio for High Porous Substrates

Customized Solutions for Different System Configurations



Maximize fresh filtration efficiency (FFE)



Minimize backpressure

Maximize gas phase activity

Generation 1
- low backpressure
- reduced fresh filtration efficiency

Generation 2
- increased filtration
- backpressure penalty

Generation 3
- high filtration
- minimal backpressure penalty

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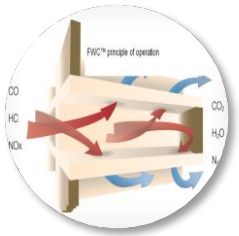
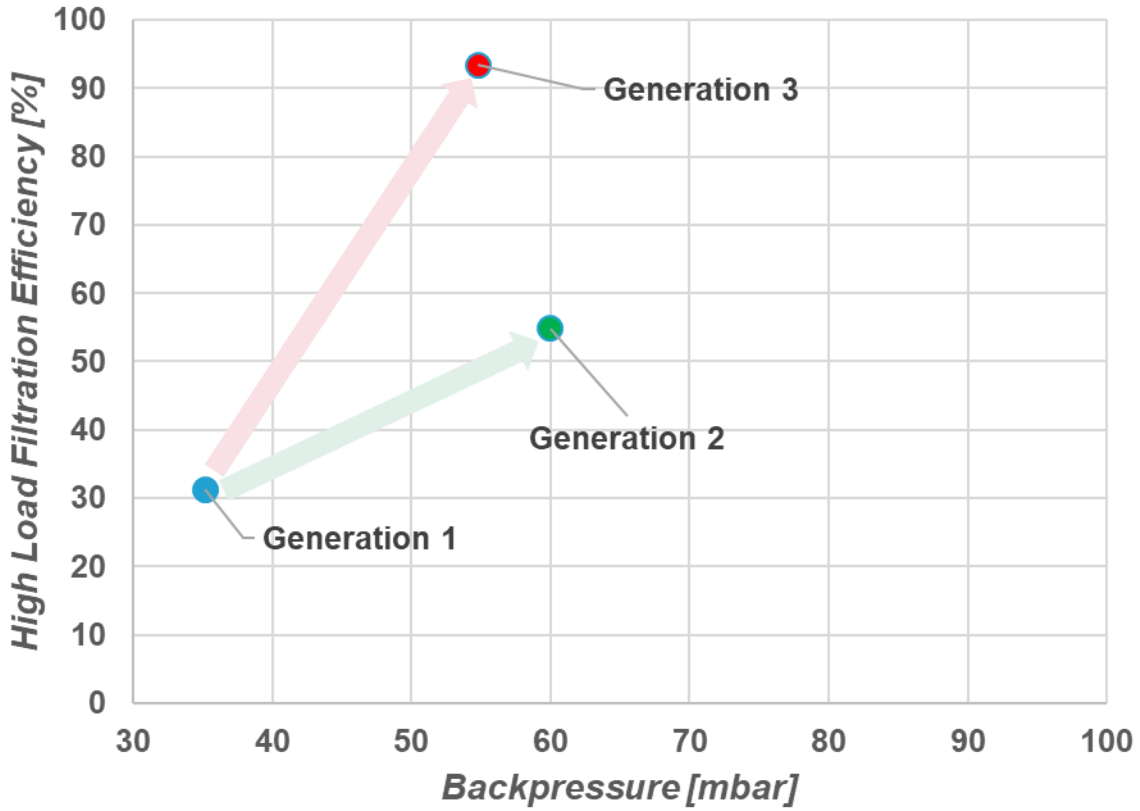
Filtration Efficiency Measured for Different FWC Generations

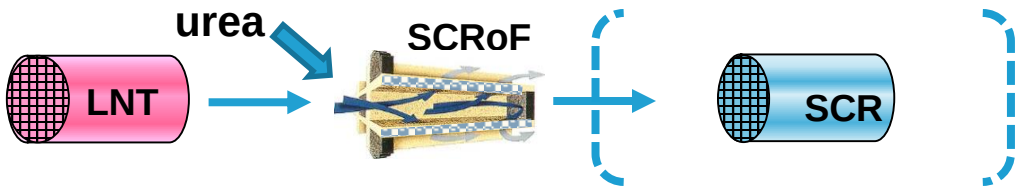
- Generation 1 FWC shows lowest fresh filtration efficiency
- Generation 2 increases fresh filtration efficiency, but has also negative impact on backpressure
- Generation 3 shows fresh filtration efficiency >90% at reasonable backpressure increase

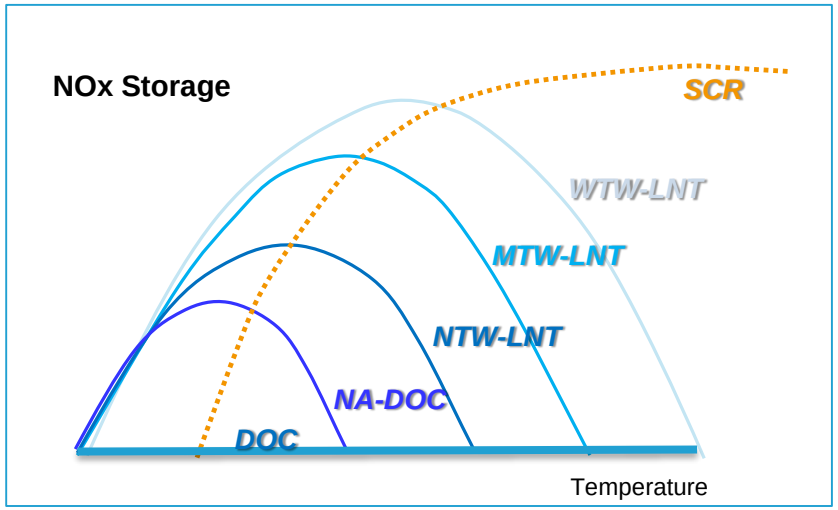




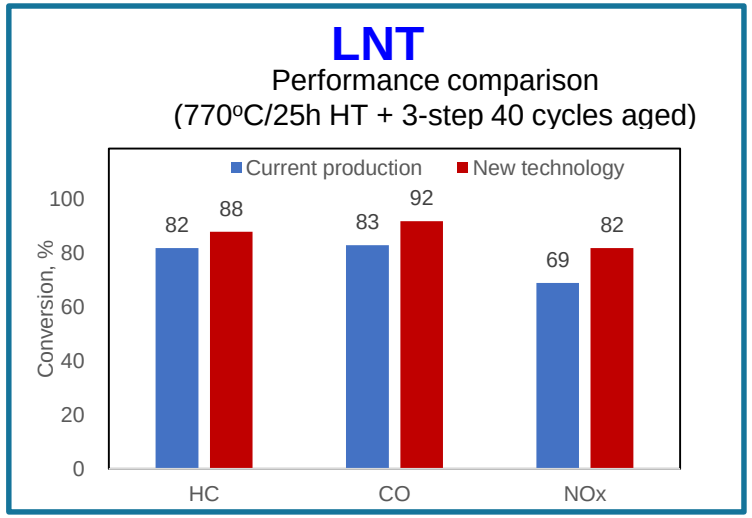
Tailored Diesel Component for Indian Driving Conditions

Combi system with LNT + active SCRoF

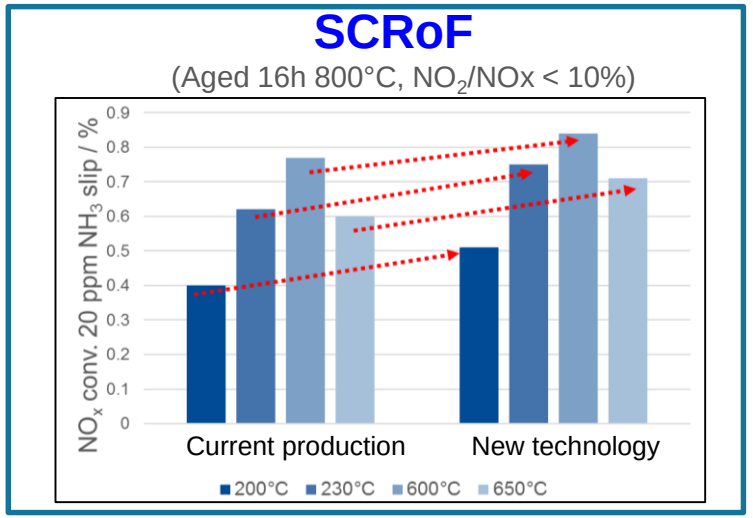




Tailored NOx Storage Capacity of LNT



Improved LNT technology



Improved NOx conversion on the SCRoF

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Meeting Strict RDE Requirements for LDD

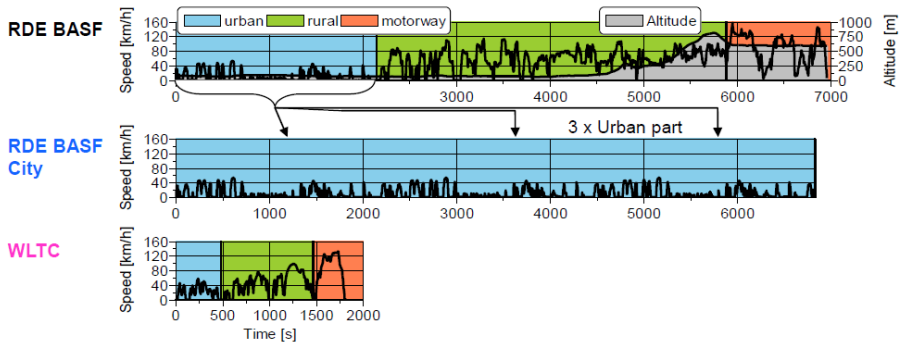
Specific Challenges of the Exhaust Aftertreatment Systems of Euro 6d RDE Applications in Different Driving Scenarios

Landsberg, D., Zink, U., Müller-Stach, T., Albarracin-Caballero, J.-D.
BASF Catalysts Germany GmbH
Wittka, T., Fiebig, M., Wilkes, T., Schönen, M.
FEV Europe GmbH

7th International MinNO$_x$ Conference
June 19-20, 2018, Berlin

Lowest Emission Levels Achieved in all Cycles

Chassis Dyno Test Results

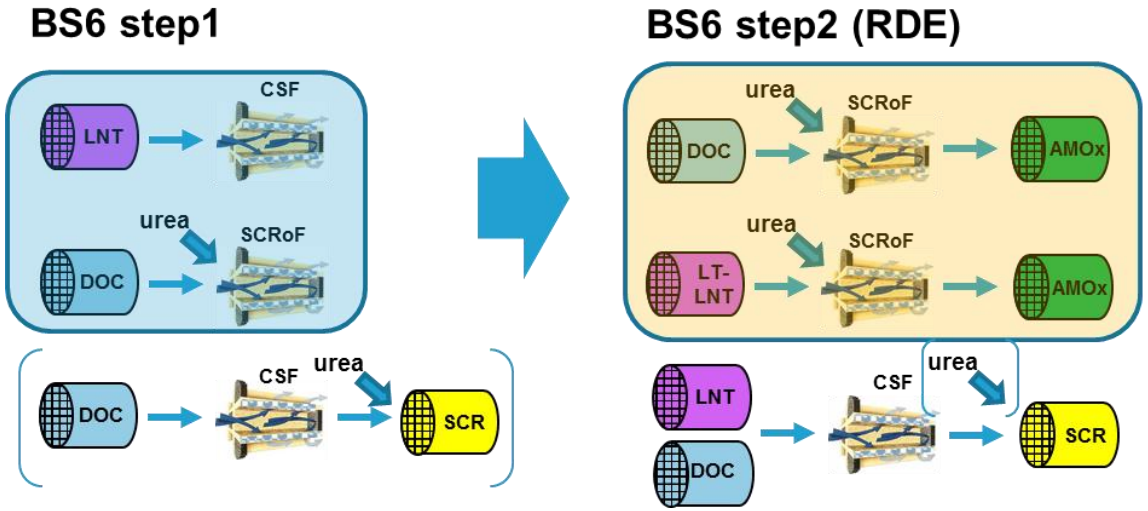


NO$_x$ Tailpipe
28 mg/km
36 mg/km
24 mg/km

- Target window < 60 mg/km achieved for all RDE trip profiles
- Even under very challenging conditions with low load / temperature city driving 36 mg/km NO$_x$ tailpipe were realized

FEV BASF We create chemistry

13



- Technology and experience can be transferred from European market and adapted for India application

- All evaluated cycles reached the target of < 60 mg/km NO$_x$ Tailpipe
  - In demanding urban driving profile 36 mg/km observed!

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Catalyst Advancements for HDD
– Addressing future regulations and cost challenges

Market Needs

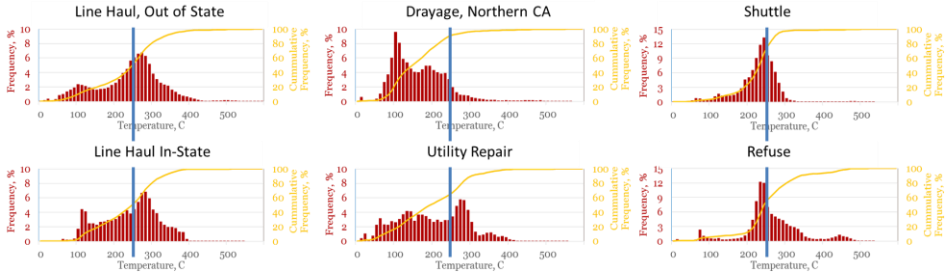
- System robustness/durability
  - Risk averse design
- HDD on-road beyond BS6
  - PN (tighter CF or/and 23->10nm)
  - Lower T/P NOx emission limit
  - System considerations
- HDD Off-Road beyond Trem IV
  - Cost and packaging concerns

BASF Solutions

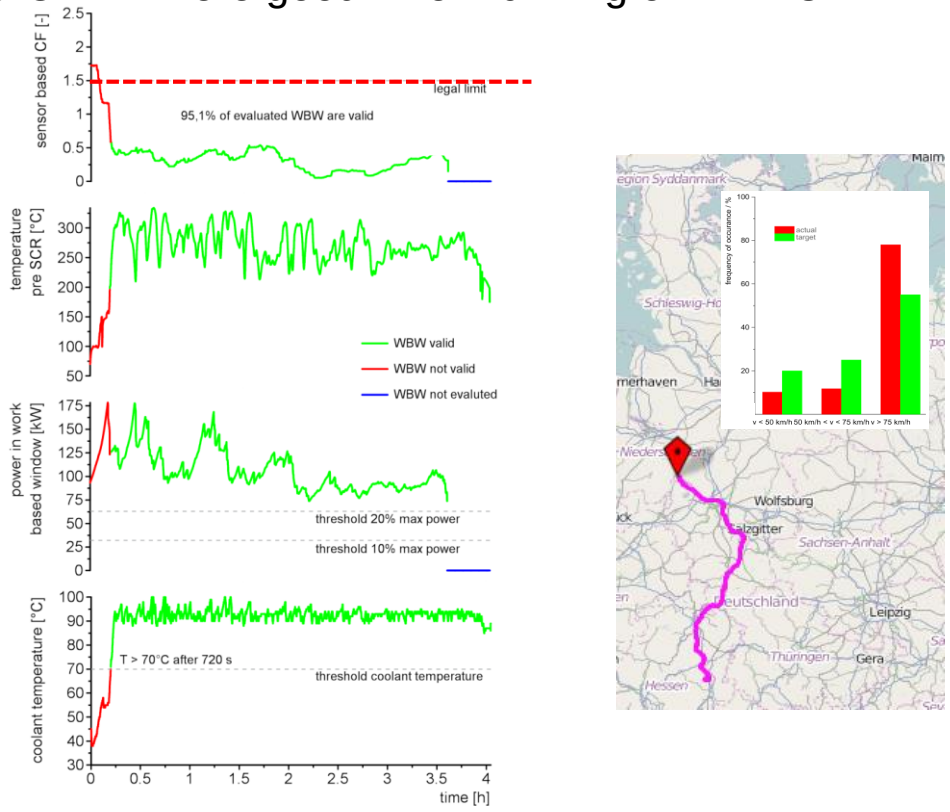
- System robustness/durability
  - Leverage Europe/US experience
  - Advances in component durability
- HDD on-road beyond BS6
  - New generation Cu-zeolite SCR
  - Innovative ccMFC
- HDD Off-Road beyond Trem IV
  - Two-into-One solutions

US/EU Experience Indicates Low-Temp NOx Challenges

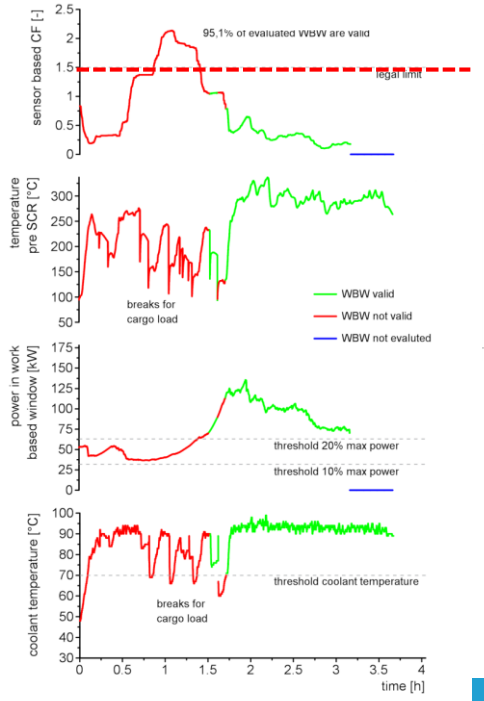
- US: CARB vehicle fleet SCR-in temp showed quite large portions below 250 C

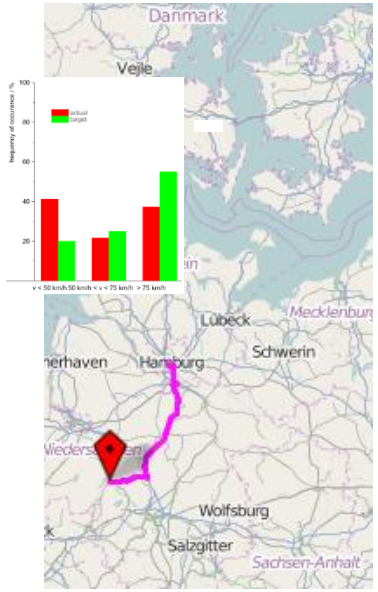


- EU CF: All were good when running on HWYs



- EU CF: Some challenges found when driving in city road





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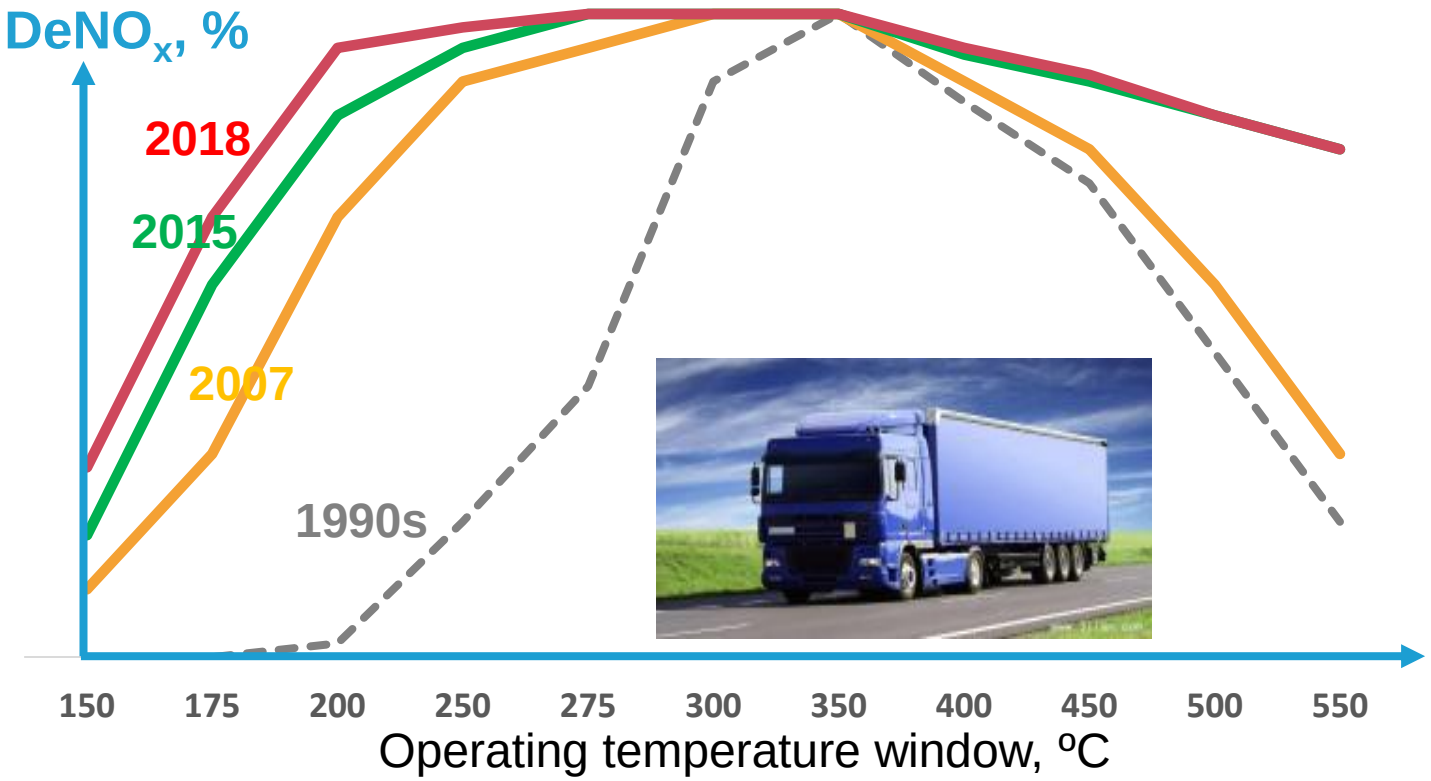
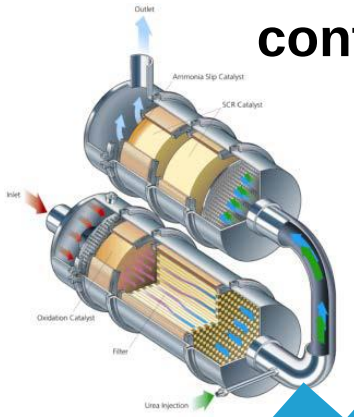
Cu-SCR Technology Advancement for HDD

Continuous advancement of Cu-zeolite SCR technology with better DeNOx performance over wide temp. window



Evolution of HDD emission control from 2010 to 2019



today's compact aftertreatment systems are 40% lighter, 60% smaller, and substantially less expensive

*MECA June 2019 report on meeting HDD Low NOx standards (www.meca.org)

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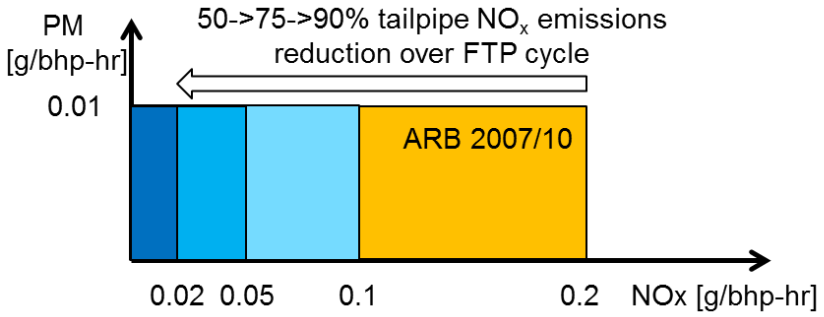
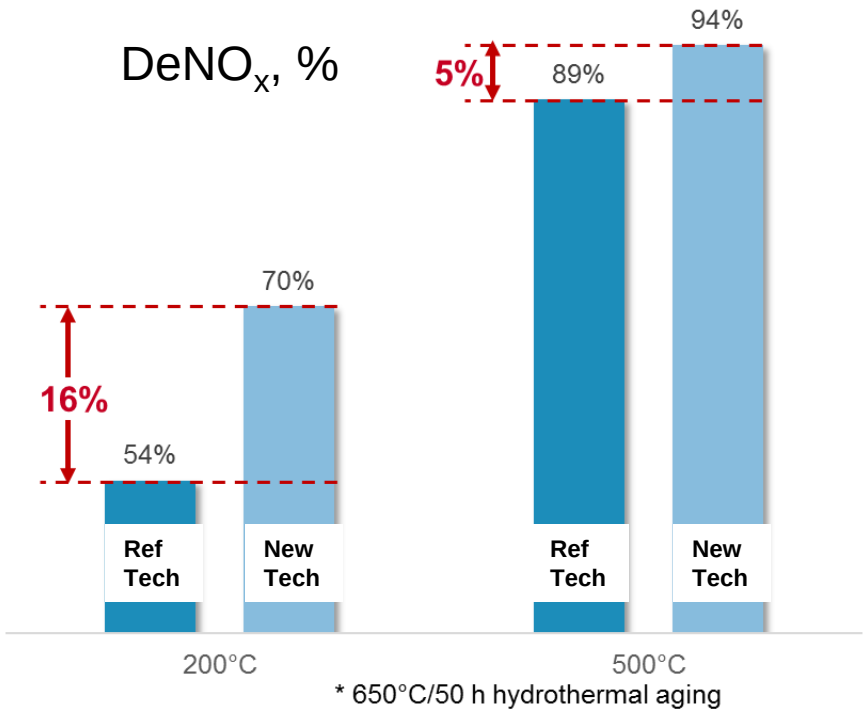
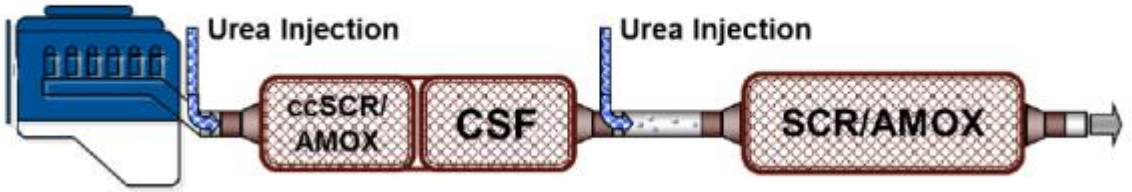
Next Generation of Cu-SCR For Future ULNOx Requireme





Possible application for ULNOx system scenarios



Potential sulfur issue with the close-couple SCR needs to be addressed

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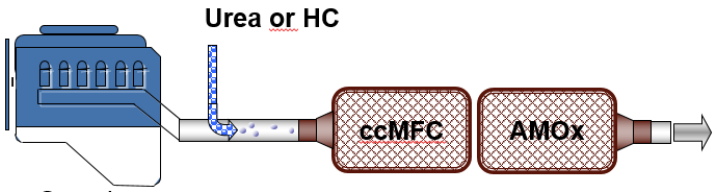
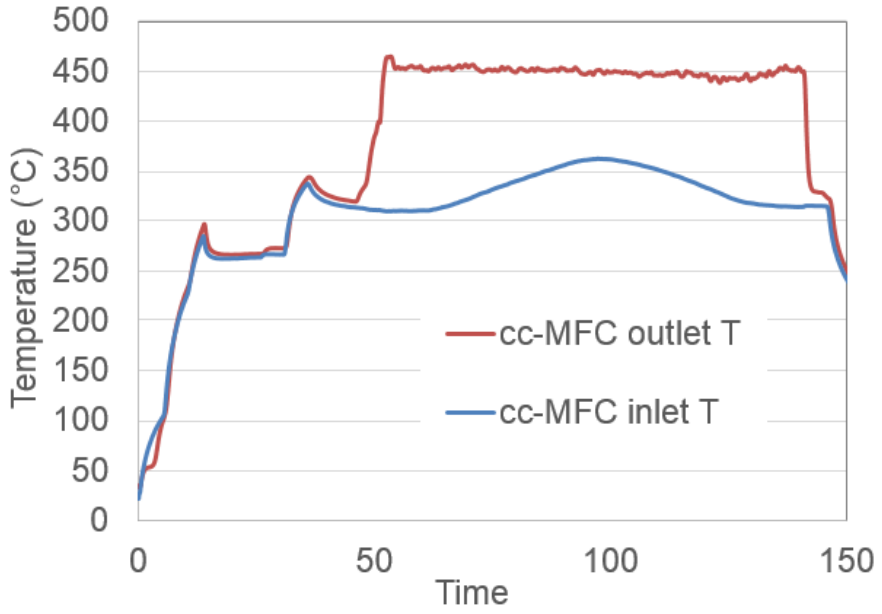
Innovative ccMFC with DeNOx and Self-DeSOx Functions

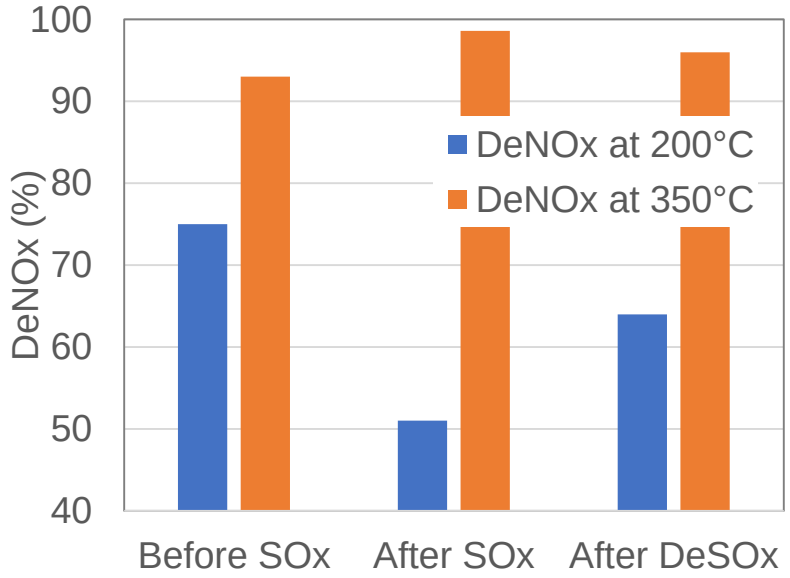
- ❑ ULNOx triggers new catalyst design as 1st component.
- ❑ cc-Multi-Functional Catalyst (cc-MFC) are customized per specific customer engine requirements.
- ❑ BASF demonstrated cc-MFC example to meet EU/NA customer requirements.
  - Fuel injection to achieve 450°C
  - Recovery after sulfation possible



cc-MFC fuel light-off



cc-MFC SCR Recovery from DeSOx



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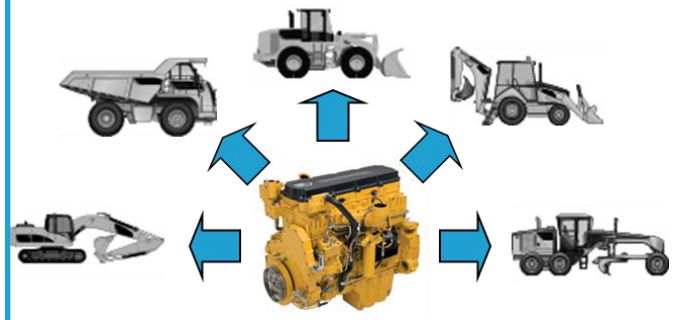
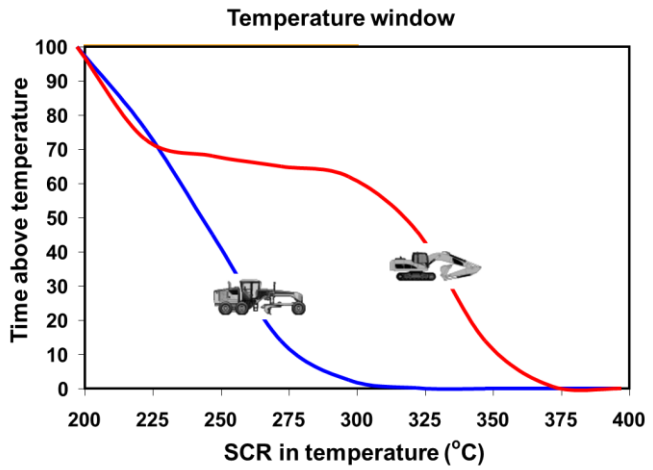
- ❑ Company introduction
- ❑ Review and perspective
- ❑ Advancement for LDV
- ❑ Advancement for HDD

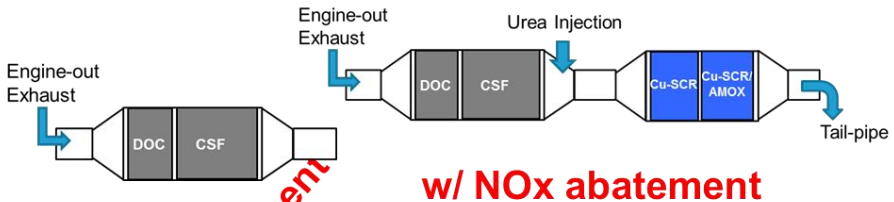
Off-Road Aftertreatment Challenge and Solution

Challenges



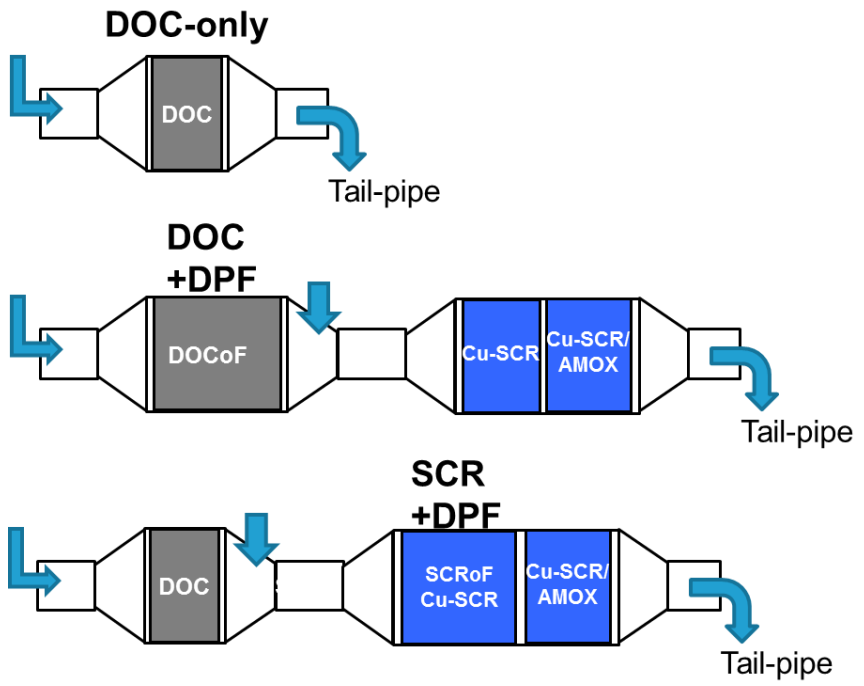


Current Solution for Trem IV



56-75kw

Future Cost Effective Solutions



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Summary

- Advanced catalytic solutions are the enablers to meet tightening vehicle emission regulations in India

- Emission and CO_2 reduction
  - EHC – Hydrocarbon trap combination
  - Tailored CNG TWC technology
- Cost efficiency
  - Tri-Metal TWC development
- Future requirement
  - Advanced fresh filtration efficiency
  - Tailored cycle development for IRDE

- System robustness/durability
  - Leverage Europe/US experience
  - Advances in component durability
- HDD on-road beyond BS6
  - New generation Cu-zeolite SCR
  - Innovative ccMFC
- HDD Off-Road beyond Trem IV
  - Two-into-One solutions

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