Off-Road Emissions Control: Solutions for Unique Challenges

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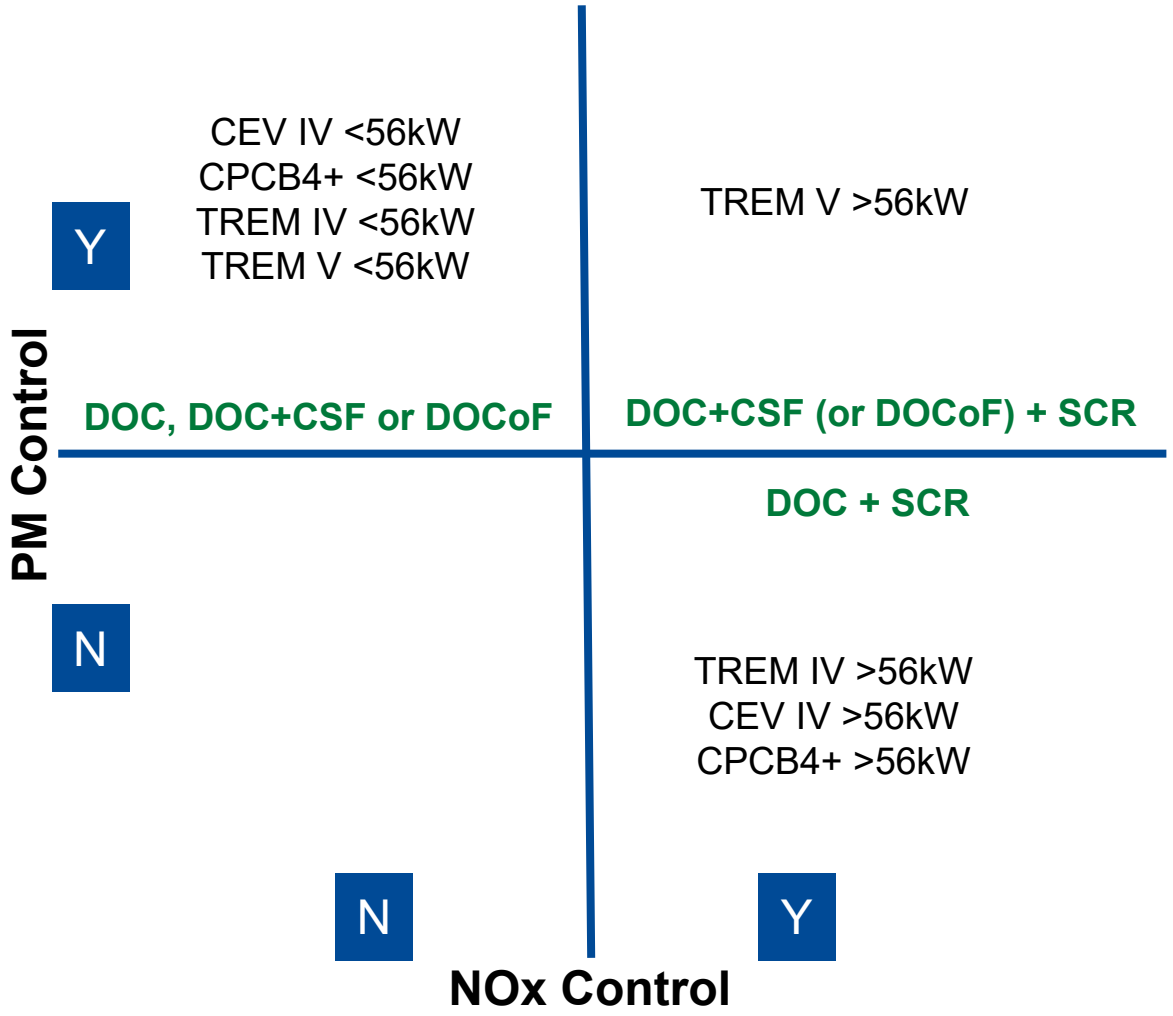
Complexity of Off-Road: Catalyst Needs

- Market segmentation drives various strategies for catalyst systems.
  - Segmented for:
    - NA vs TC engines
    - Passive vs active regeneration
- System design is strongly constrained by available footprints and off-road specific mechanical durability challenges



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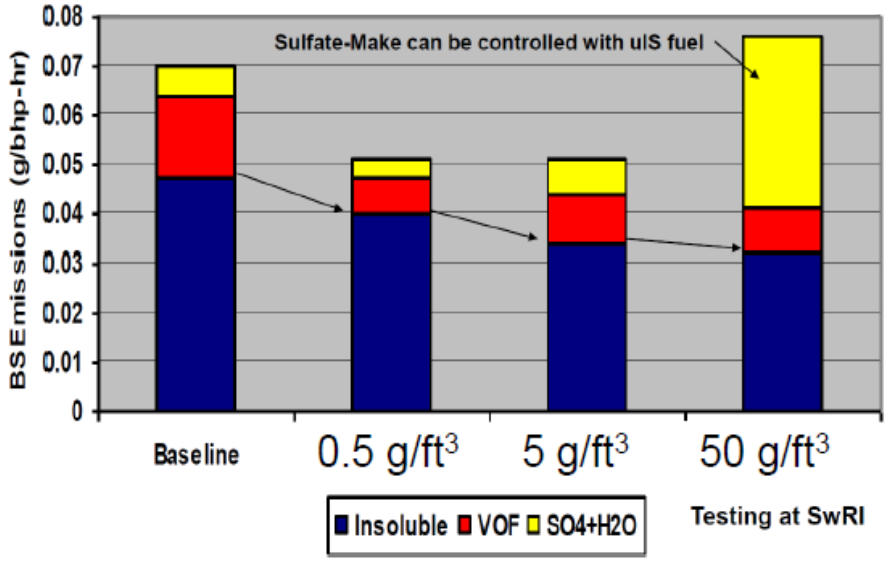
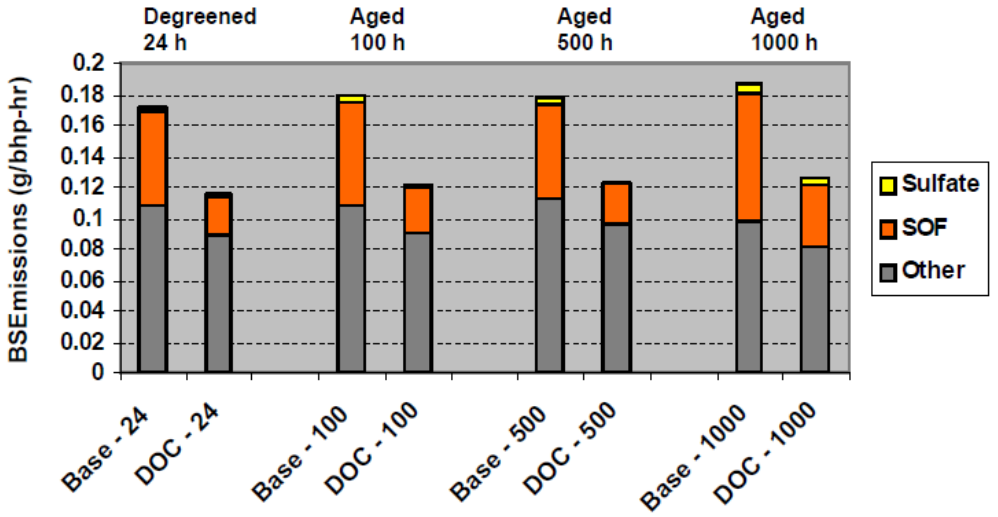
Low PGM DOC Only Solutions for PM Reduction

- DOC only solutions can achieve 20-30% PM reduction by reducing soluble fraction of PM.
- Increasing PGM loading on DOC can further reduce PM to a limit.
  - Sulfate-make can lead to an increase in PM.
- Durability of DOCs for PM reduction has been demonstrated over 1000 hrs.



MY98 HD engine tested with 350ppm S fuel



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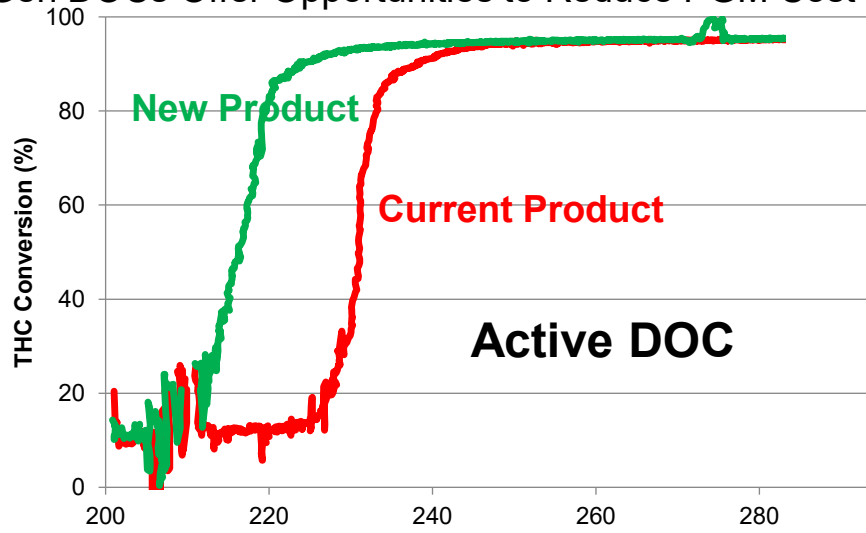
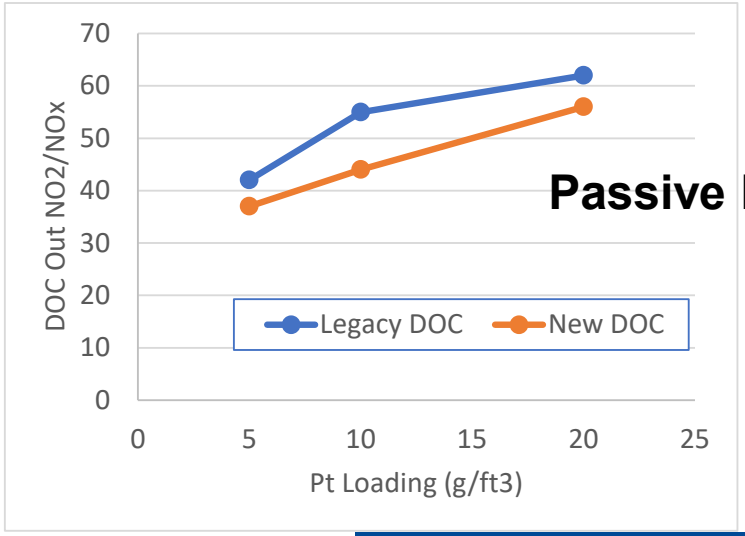
Passive and Active Approaches to CSF Regeneration

- Pt and Pd usage in DOCs and CSFs drives component costs.
- Active systems: Higher PGM (Pt & Pd) loading to enable fuel-burning.
  - DOC serves to make NO2 and burn-fuel for CSF regen
- Passive systems: Lower PGM (Pt only) with a tradeoff of more systems controls needed.
  - DOC serves to make NO2 for passive CSF regen

Next Gen DOCs Offer Opportunities to Reduce PGM Cost



20g/ft3 total PGM loading
HC lightoff on reactor at 1.2% HCs at SV=75k/h



DOC NO Oxidation on Engine
T=300C at SV=71k/h

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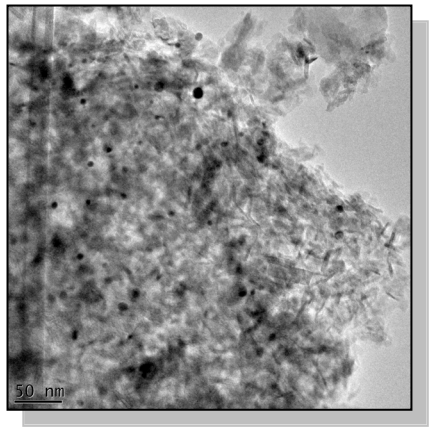
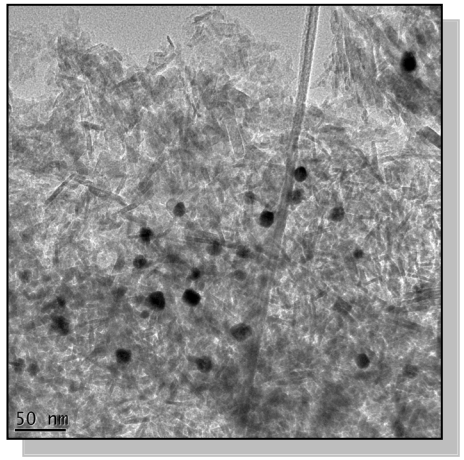
HT Aging Beyond Design Thresholds Will Impact DOCs

Pt Sintering due to HT Exposure on Passive DOCs

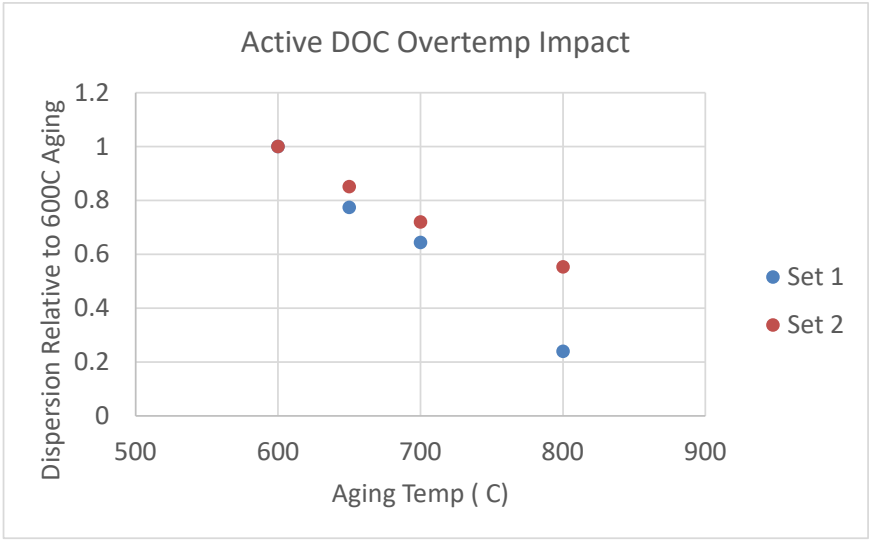
5hr 550C



200hr 550C



Active DOCs (Pt/Pd) Sinter at Temperatures Higher than Passive DOCs



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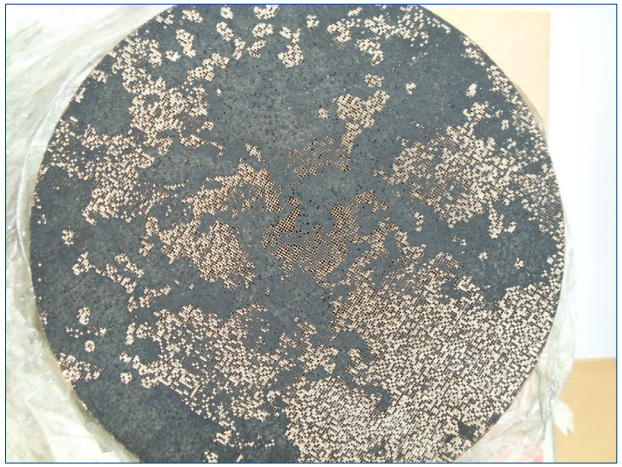
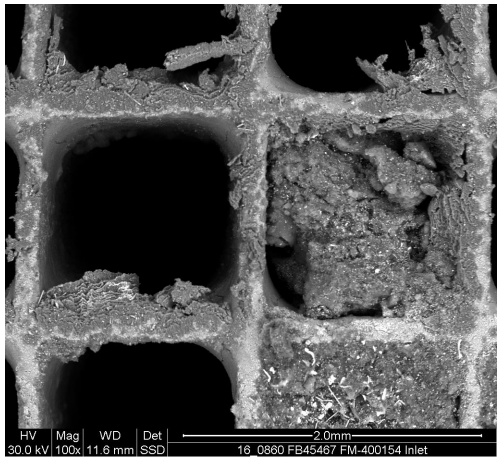
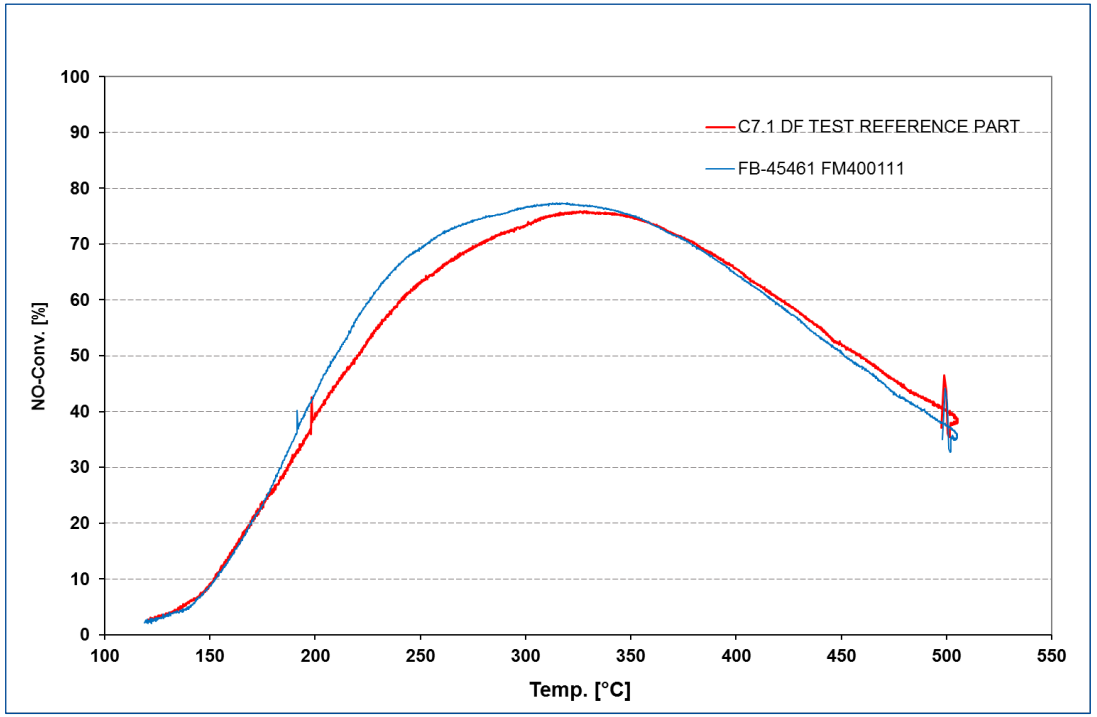
Off-Highway DOCs Can Have Unique Failure Modes





DOC inlet blocked with soft, white deposits consisting of Si, Mg, Ca & P.

Deposits formed as a result of contamination in the ambient air of the operating environment, a waste processing plant.



However, performance is fine when deposits are removed!

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Off-Road Applications:
Passive vs Active CSF Regeneration

	Active	Pseudo-Active	Passive	Passive with fuel Injection
Regeneration Initiation	250-275°C	300-325°C	NA	300-400°C
Regeneration Temp. (C)	525-650°C	500-575°C	400°C	450-500°C
Primary SCR Type	Cu Zeolite Fe Zeolite	Cu Zeolite Fe Zeolite	Vanadium	Vanadium Cu Zeolite Fe Zeolite
Max Sys. Temp (C)	750°C	750°C	550°C	550- 600°C
Sulfur Reg. Temp (C)	500°C	500°C	400°C	400 - 500°C
System Size	+	+	- -	-
PGM Cost	- -	-	+ +	+
Pros	Most Robust	PGM Cost	PGM Cost No active regeneration	More flexible than passive
Cons	PGM Cost Highest Fuel Consumption	Less flexible compared to active	No regen for urea deposit control No emergency reg NOx conversion has high sensitivity to NO_2 concentration	Increased fuel consumption compared to passive

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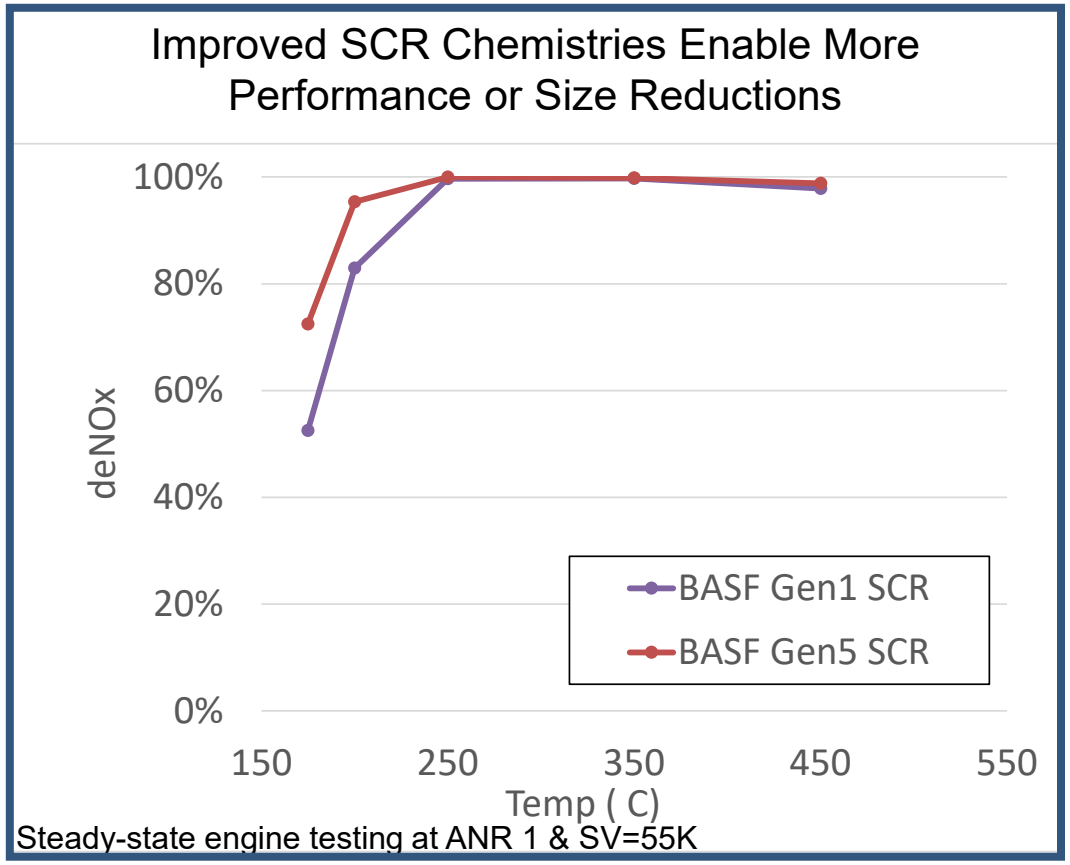
Options for Segments Needing NOx Control: Zeolite or V based SCR

Technology Attributes and Performance			
Type	Cu-Z	Fe-Z	VTi
SCR activity @ 200°	++	-	-
SCR activity @ 450°	=	+	=
SCR activity @ 550°	-	+	--
Thermal Stability	750°C	650°C	550°C
Sizing	++	=	=
Sulfur Sensitivity	-	-	+
Undesirable Compounds	=	=	-



Choice of active or passive soot regeneration drives the selection of an optimal SCR.

High performance Cu and V-SCR catalysts are available.

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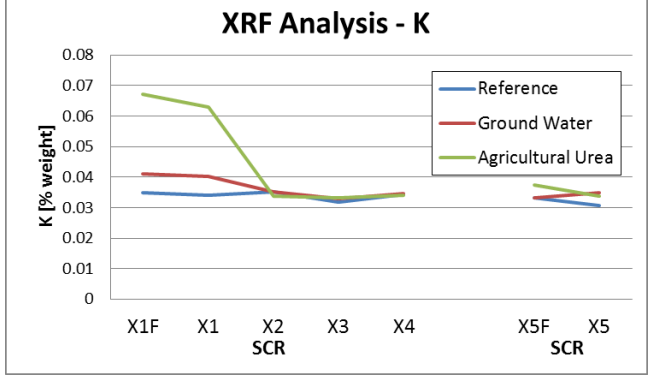
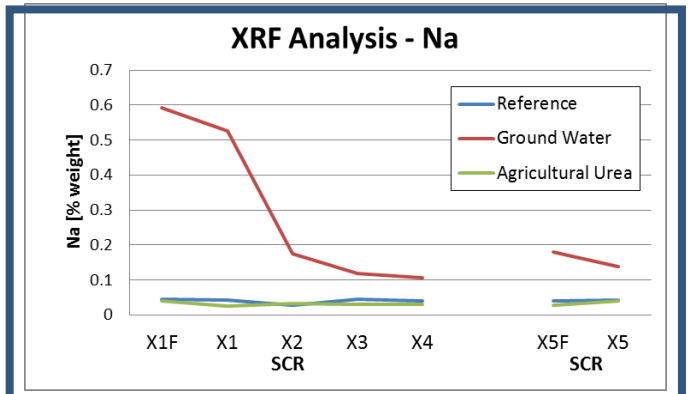
Challenges in Off-Road:
Use of biofuels and agricultural Urea

- Urea SCR infrastructure is available from BSVI introduction
- Biofuels and non-standard urea pose system level risks
  - Risk of agricultural urea or groundwater mix with urea
    - Introduces poisons of K, P and Na to the SCR.
  - Customer use of bio-fuels and non-ULSD fuels.
    - Alkali metal poisoning of components leads to deactivation.
    - Most OEMs utilize a planned replacement period based for biodiesel certified engines.



SCR exposed to agricultural urea shows significant poisoning by potassium.



SCR aged with urea/groundwater mixture shows significant poisoning by sodium.

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BASF Innovative Solutions for HD ICEs & Beyond

Fossil Fuel

Renewable / Sustainable Fuel

Technology

SCR advancement

DOC improvement

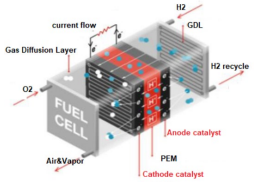
CSF PN improvement

ICE Fossil Fuel
- Euro VII & EPA 27 CO_2 reduction

ICE Non-Diesel Fuel
- Flexibility
- Sustainability

H_2-ICE

Alternate Powertrain



H_2 Fuel Cells

Towards zero carbon emissions

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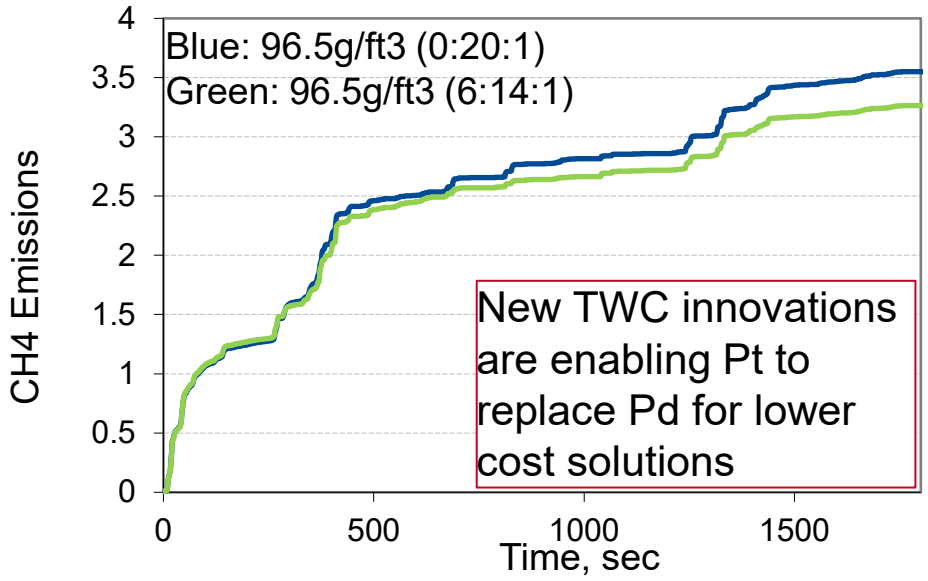
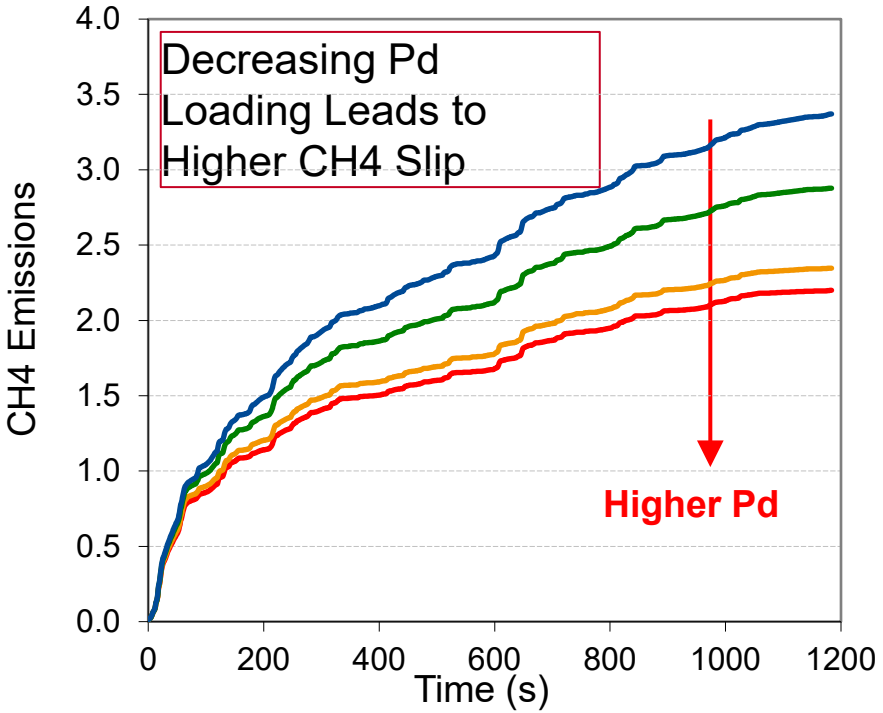
Three-Way Catalysts for Natural Gas

- Traditional approaches require high Pd and Rh loadings
- Transient reactor testing shows impact of PGM changes in CNG applications.





Low Rh/No Rh TWCs are coming. Stay tuned!!!

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Hydrogen ICE

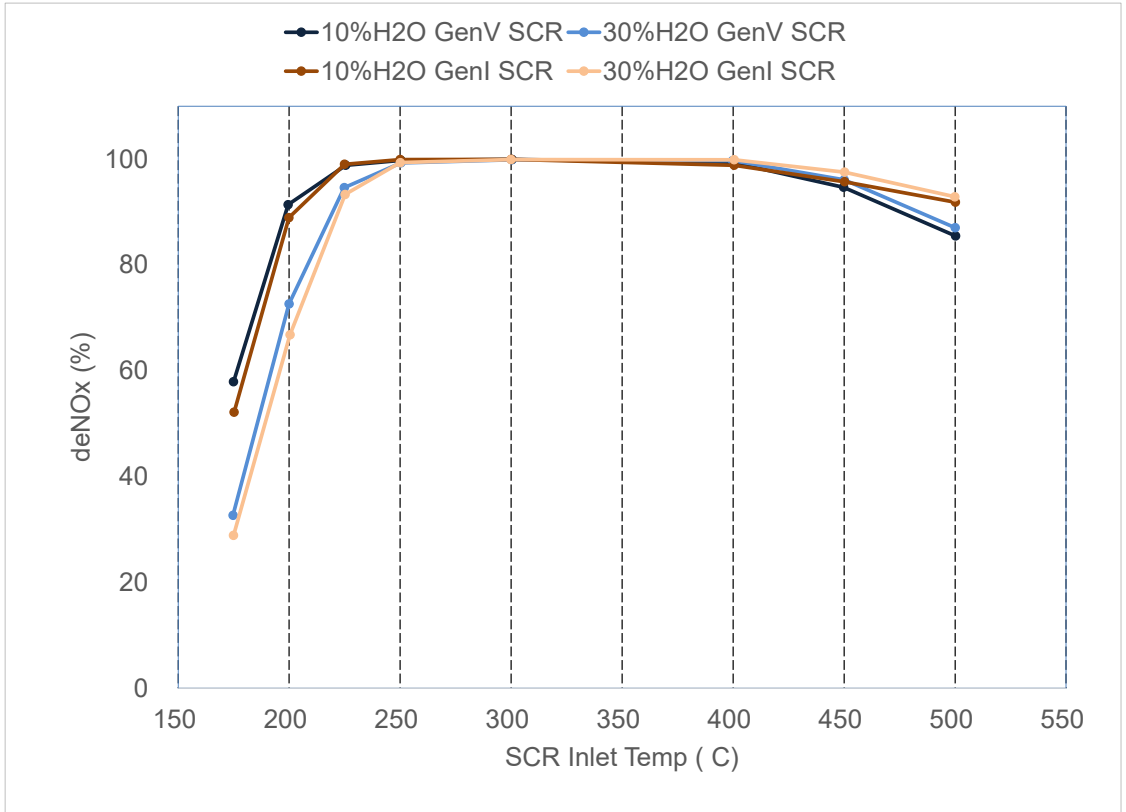
- Benefits of hydrogen fuel engines are well documented.

- Combustion of hydrogen also poses challenges to catalyst systems
  - High H2O content (20-30%)
  - Presence of H2 in exhaust gas

- H2-SCR is under investigation but current catalysts lead to significant N2O make.

- High H2O does lead to competition for active sites→reduced LT NOx conversion.

- Mid & high temperatures are not impacted by H2O content.



SV=60k/hr, 1000 ppm NO, ANR 1
Water content: 10 & 30%

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Summary

- Off-road segmentation and regulations in India is the most exciting market right now.
  - SO MANY OPTIONS AND NEW CHALLENGES.
  - From PM only to PM+NOx control, solutions are available.
  - Be ready for new and unseen failure modes.
- Beyond diesel, H2 ICE and natural gas powertrains are viable to meet emissions targets.

Thank you!

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