



Technical Challenges ahead of BS VI Heavy Duty Diesel

Ashok Kumar

Corporate Research and Technology
Cummins Inc. USA

Sangati Seth

Cummins Emission Solution
India

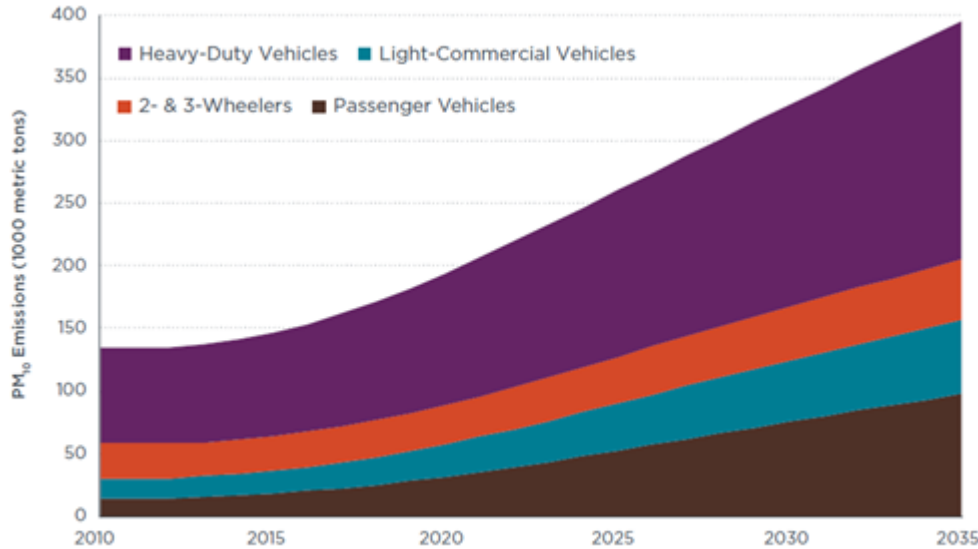
Oct 26, 2018

Outline

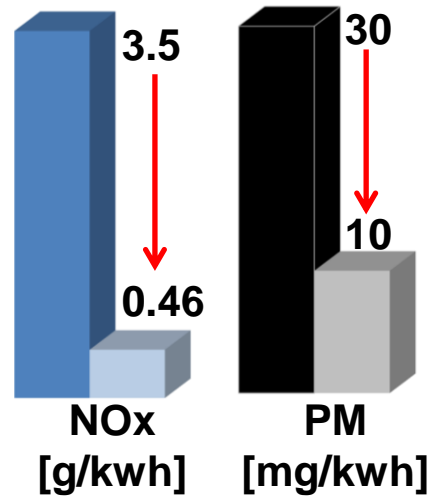
- BS VI emissions outlook
- Cummins aftertreatment experience
- Cu-SCR and DPF introduction in BS VI
- Challenges for BS VI
 - Fuel quality
 - AUS 32 quality
 - Lubricant quality
 - Maintenance and service
 - Low temperature operations
- Summary

Background: Why leapfrog to BS VI?

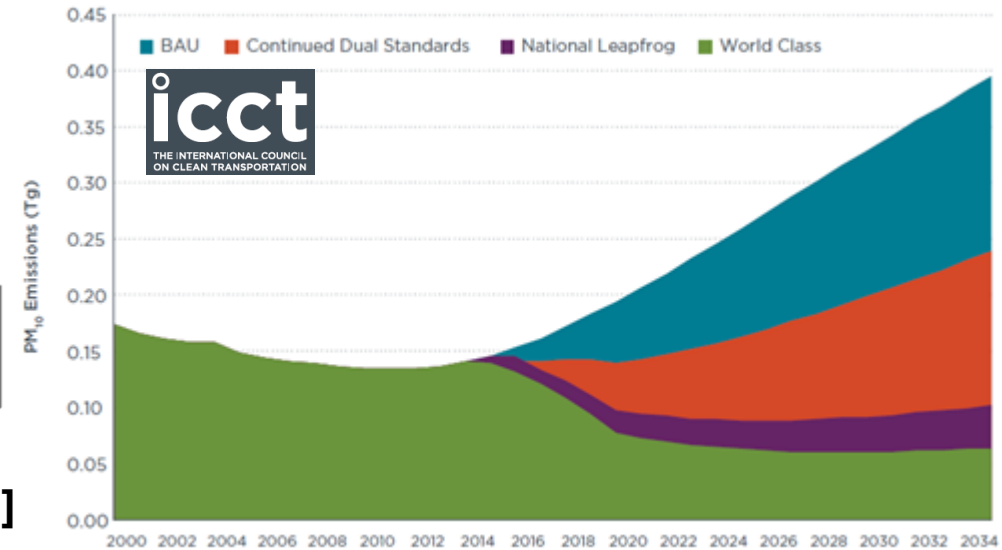
Projected total PM₁₀ emissions in the absence of further policy action



BS IV to BS VI



Projected total PM₁₀ emissions in the presence of further policy action



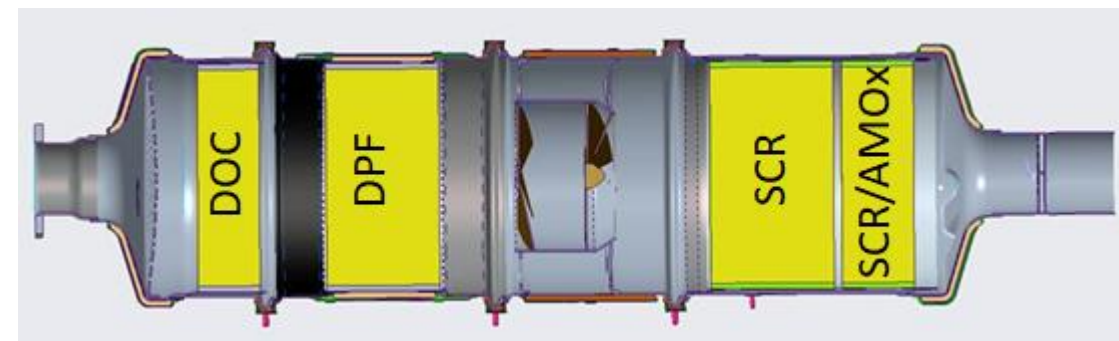
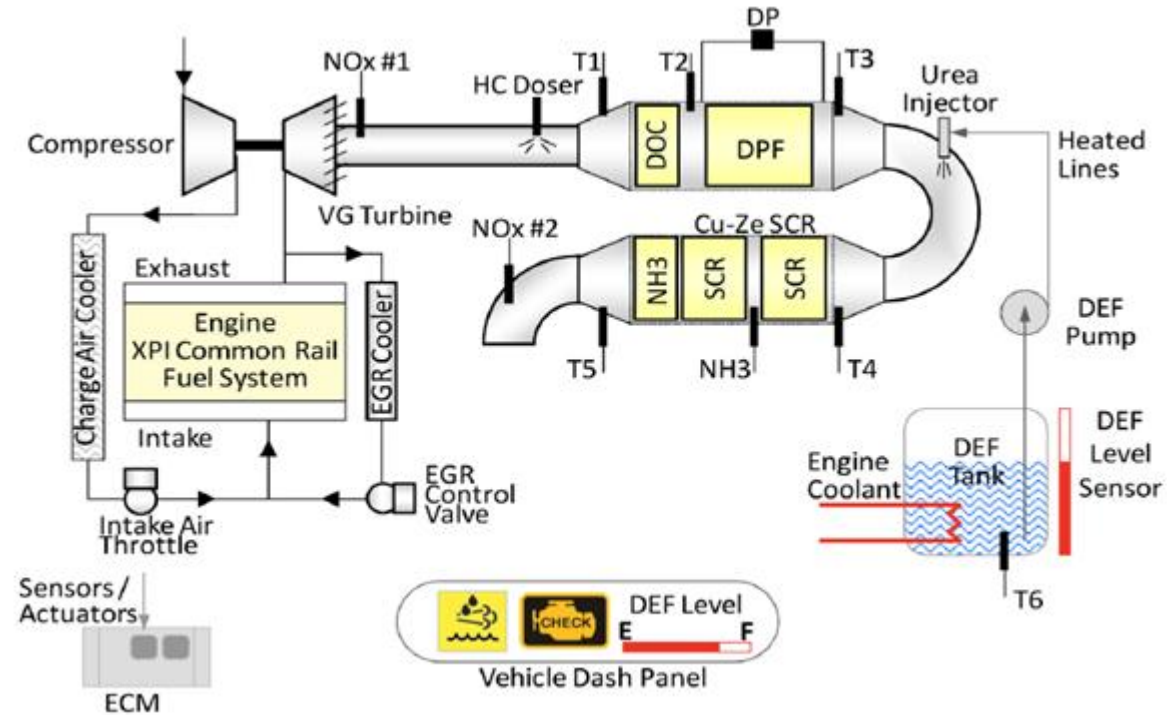
OVERVIEW OF INDIA'S VEHICLE EMISSIONS CONTROL PROGRAM, 2013

https://www.theicct.org/sites/default/files/publications/ICCT_IndiaRetrospective_2013.pdf

- India wide vehicular NO_x and PM₁₀ emission predicted to increase 260% between 2015 and 2035
 - HD vehicles predicted to account for 50% total vehicular PM₁₀ emissions and 38% NO_x emissions by 2035 and up to 40% PM₁₀ and 90% NO_x emissions in certain cities come from HD vehicles
- Early introduction of BS VI standards nationwide can help to reduce net emissions of NO_x & PM₁₀ by up to 86% by 2035
- Accelerated move to BS VI ambitious compared to historic European regulatory trajectory

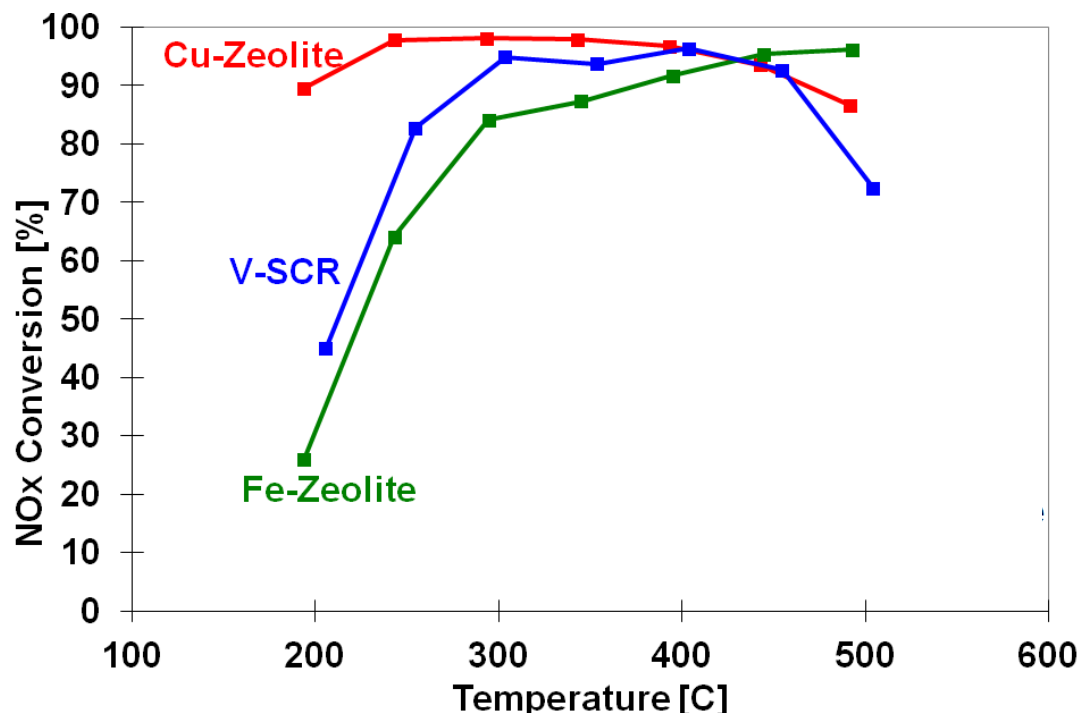
Cummins aftertreatment experience

- Over 20 years of aftertreatment systems and over 10 years of SCR experience
- Full range of aftertreatment solutions for
 - Euro IV, V, VI and equivalent markets
 - Stage IV, V
 - EPA 2010 and beyond
 - Tier III, IV ... and many more
- First HD OEM to introduce Cu-Zeolite SCR
- Cummins was able to meet US 2010 regulations, including OBD: 3 years ahead of schedule and before urea infrastructure became available: using LNT-based system for Dodge Ram 2500/3500 vehicles
- TWC- based systems for a range of natural gas-powered engines, including world's only 0.02 gNOx/hp-hr system
- Pro-active internal and collaborative RDE work



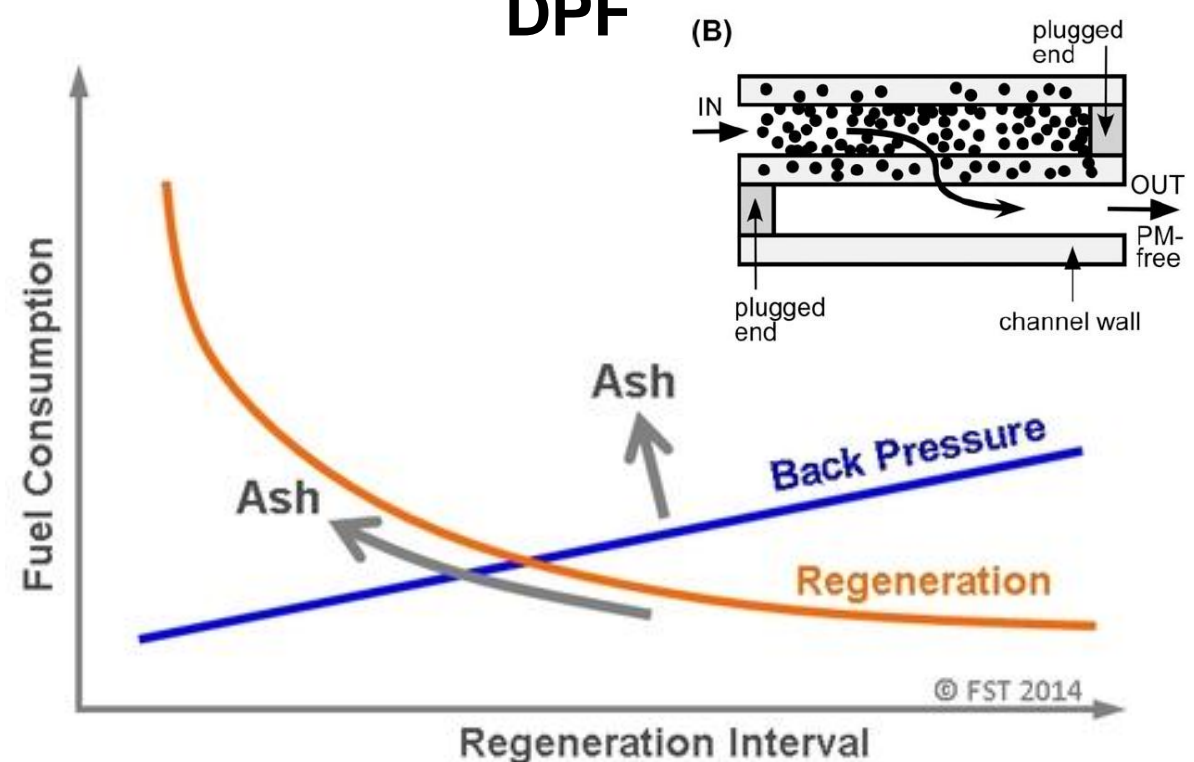
Introduction of Cu-SCR and DPF to BS VI HD systems

Cu-SCR



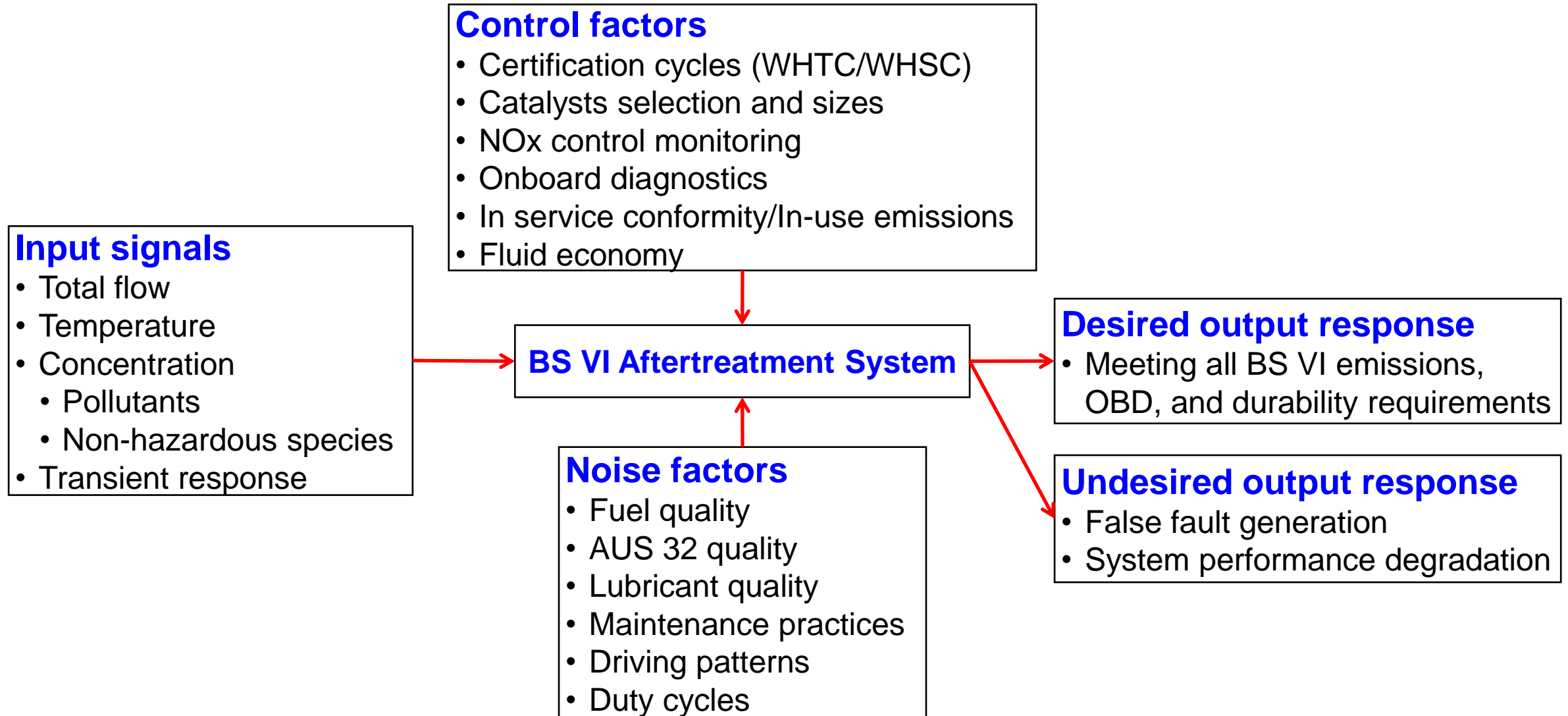
- Most of the BS IV systems are equipped with V-SCR and a fraction with DOC+DPF architectures
- Cu-SCR provides unparalleled low temperature NOx conversion that is critical for BS VI systems

DPF

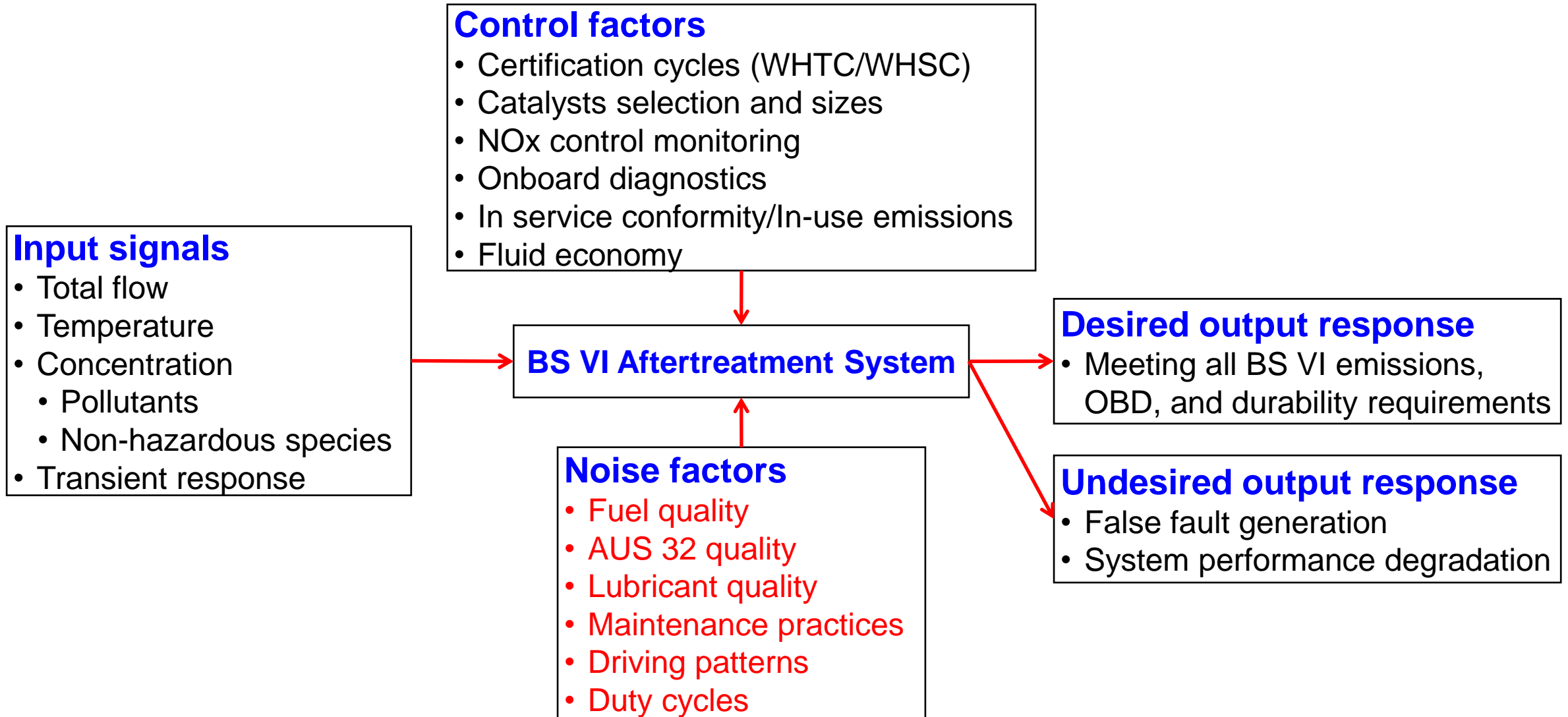


- DPF technology is very effective in meeting PM and PN regulations, but results in fuel penalty
- Regeneration strategy involves optimization of soot loading, back pressure, fuel penalty, and overall system performance

Parameter diagram for BS VI aftertreatment system



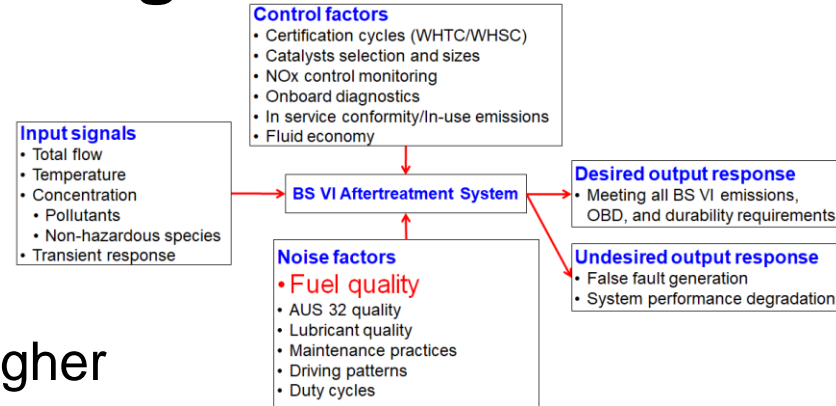
BS VI aftertreatment system challenges



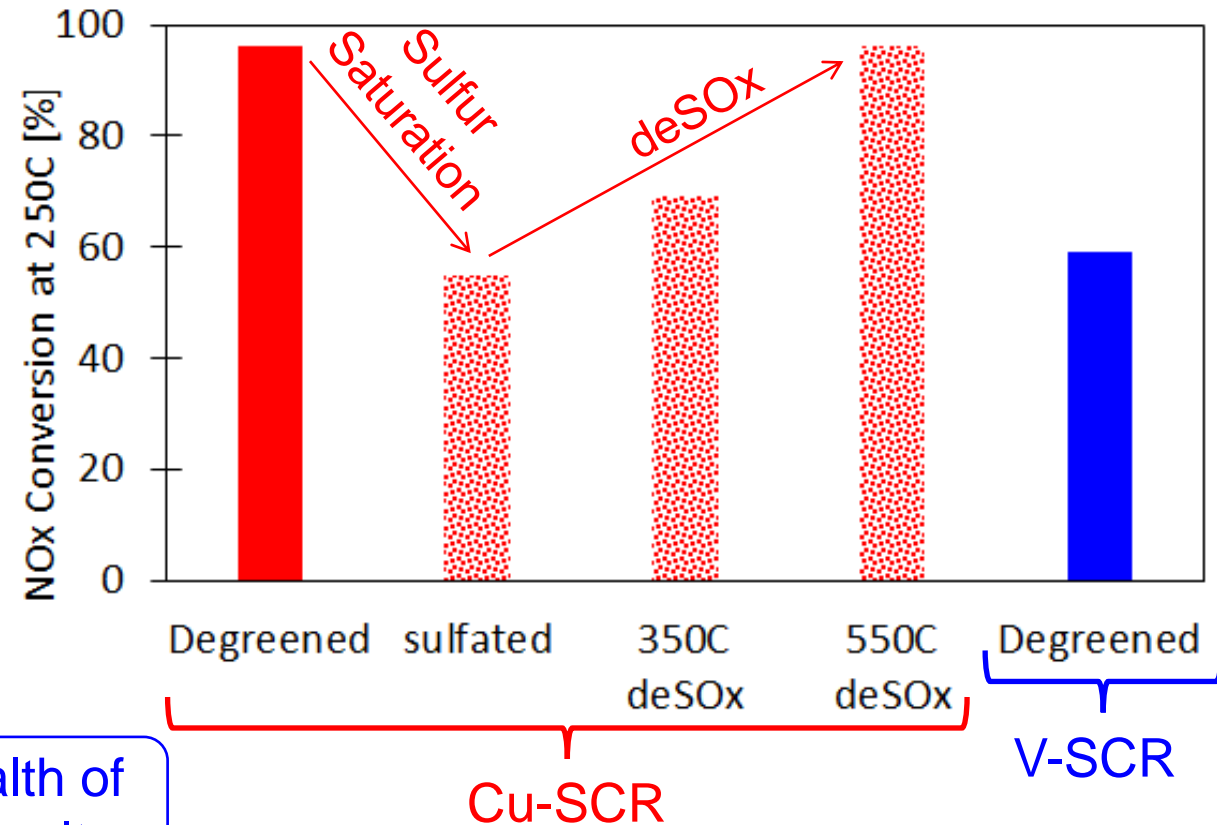
Fuel quality and its impact of high sulfur fuel



- BS VI systems are certified with ULSD, i.e., < 10 ppm sulfur fuel
 - Availability of certified fuel is essential for the health of aftertreatment system
- Performance of Cu-SCR degrades with higher levels of sulfur and requires regular deSOx
 - In spite of that, NOx conversion over sulfur-saturated Cu-SCR is similar to non-sulfated V-SCR
 - Usually with USLD, the deSOx syncs well with DPF regeneration and doesn't need any dedicated deSOx
 - Performance of Cu-SCR is completely recoverable upon regeneration
- In presence of high sulfur fuel, aftertreatment system may require more frequent regeneration to meet NOx emission requirements and may cause fuel penalty



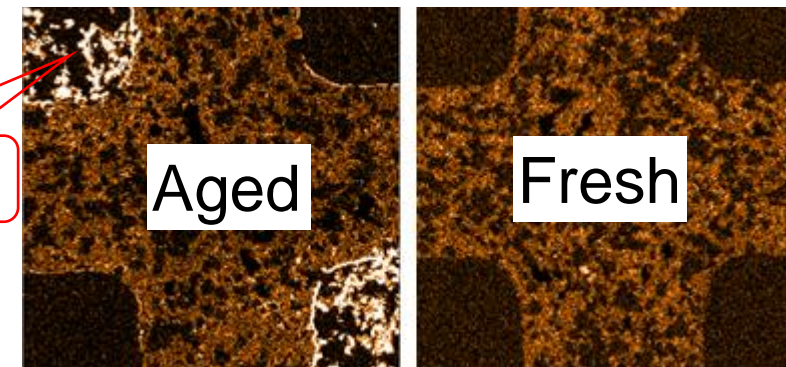
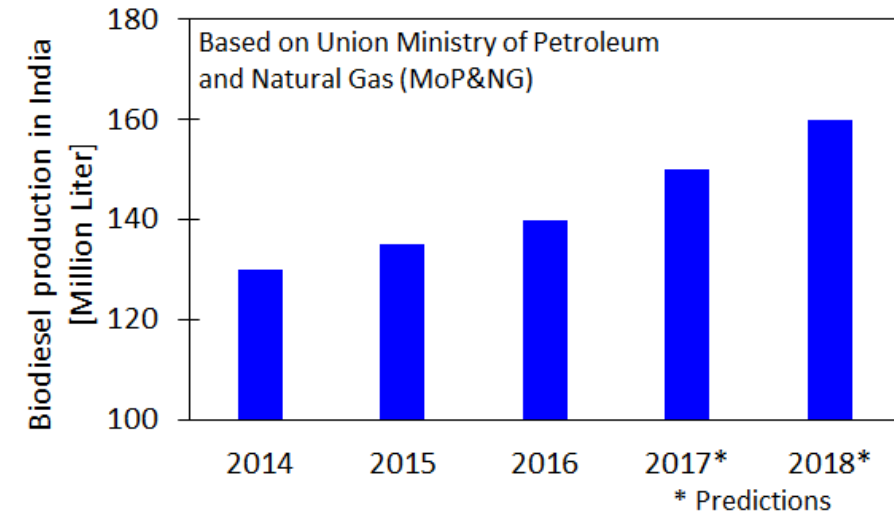
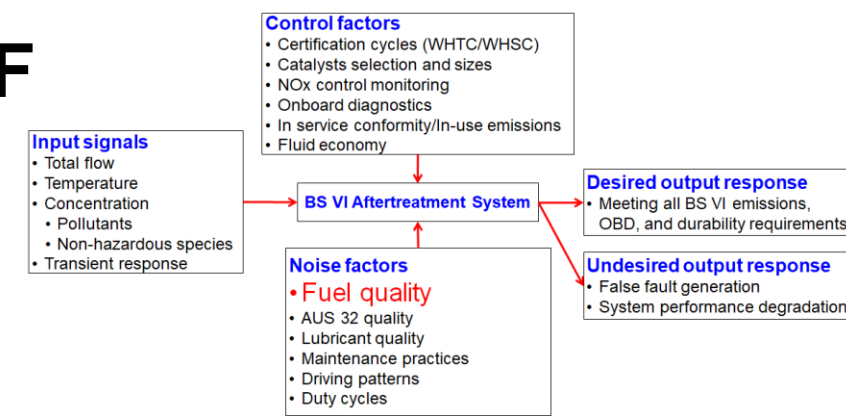
Regulations	Sulfur in Diesel [ppm]
BS III	350
BS IV	50
BS VI	10



Enforcing fuel quality is important to maintain health of BS VI aftertreatment system and to avoid fuel penalty

Biodiesel constituents and its impact on DPF

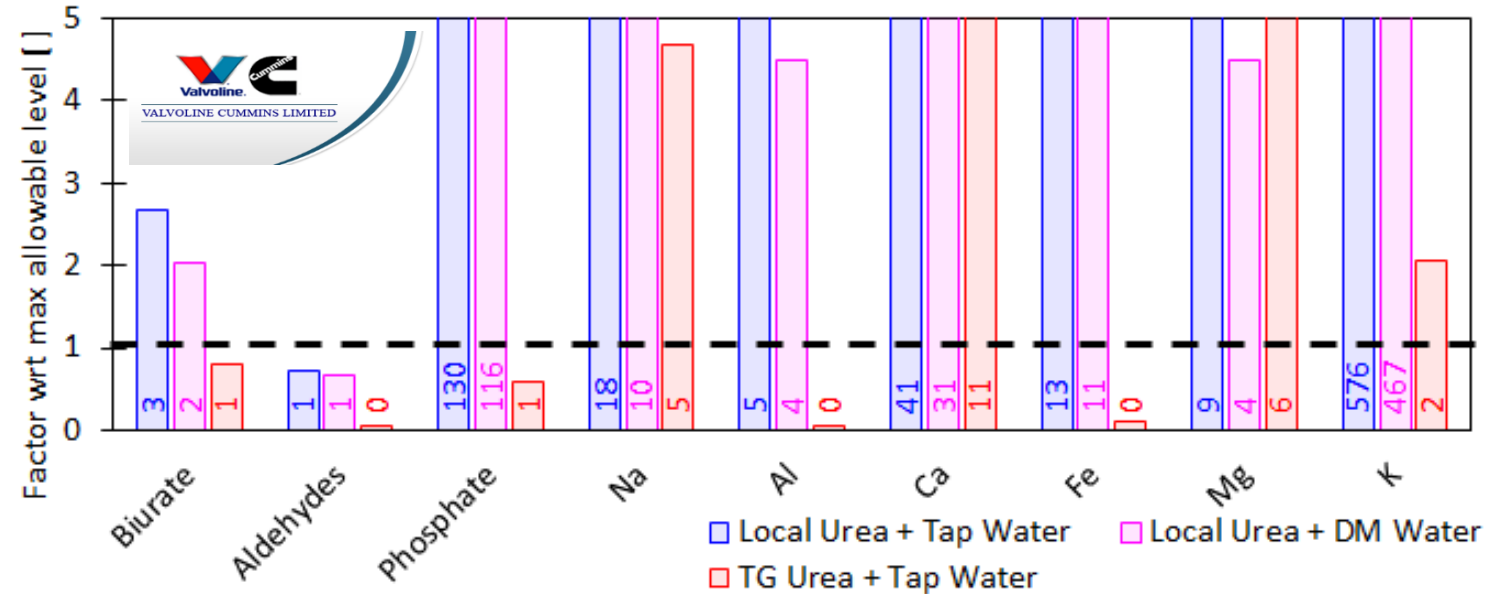
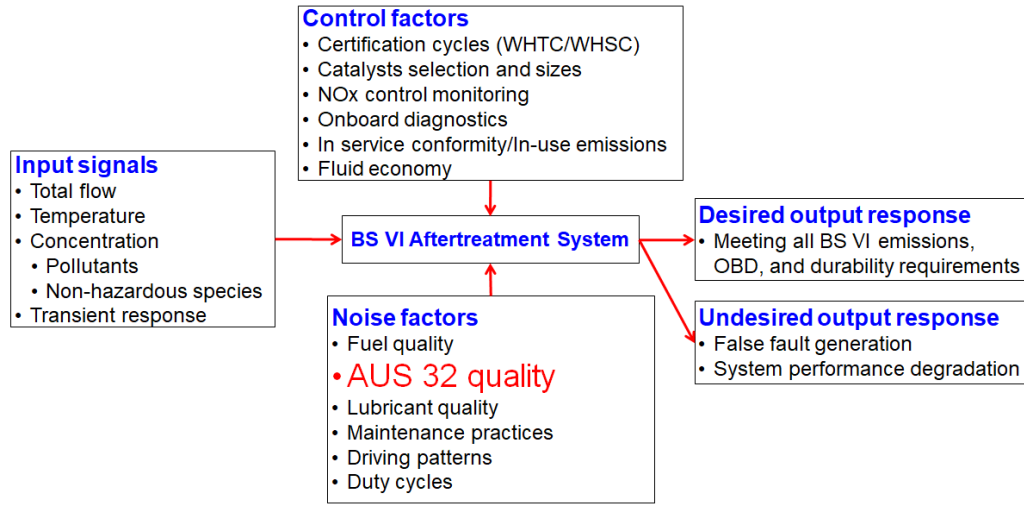
- Reference biodiesel blend for BS VI application is B7 (mixture of 7% biodiesel and rest regular diesel) **Draft Notification GSR 187(E)**
 - However, OEM can certify the vehicle up to B100 with certification testing using respective blends above 20%
- Raw material for biodiesel does not contain any metal (Na, K, etc.), but biodiesel preparation steps involve use of NaOH and KOH
- Regulative limit for biodiesel (B100, ASTM D6751)
 - Na + K < 5 ppm
 - Ca + Mg < 5 ppm
- Studies show that high Na (14x) in biodiesel accounts up to 80% of ash loading over DPF while other aftertreatment components didn't show any obvious impact
- Implication
 - Shorter maintenance interval for DPF
 - May affect catalytic functions of DPF



SAE 2016-01- 2322 (ORNL, Cummins, NREL)

Metal concentration in biodiesel needs to be regulated to limit ash cleaning interval

Aqueous urea solution (AUS 32) quality



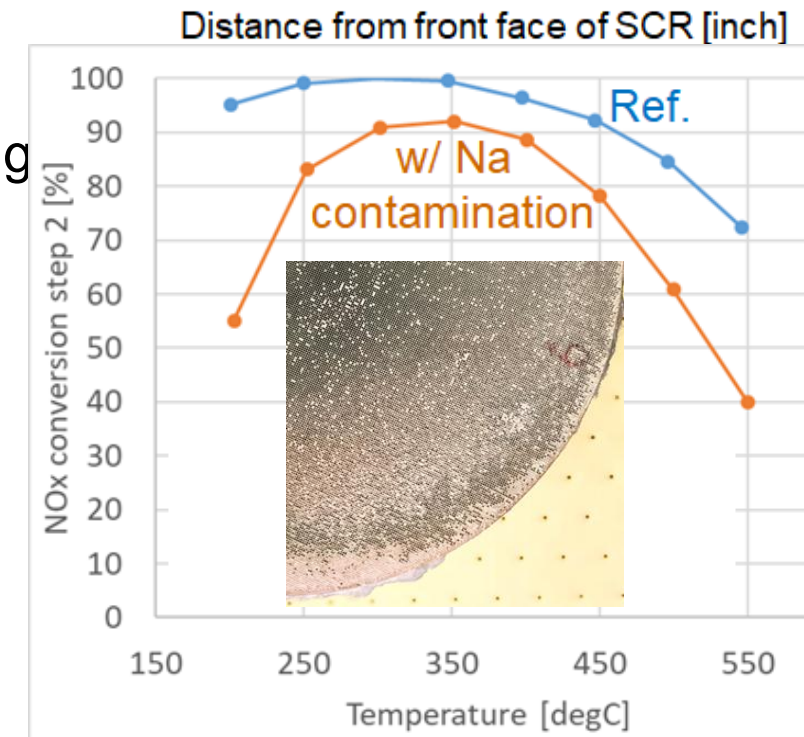
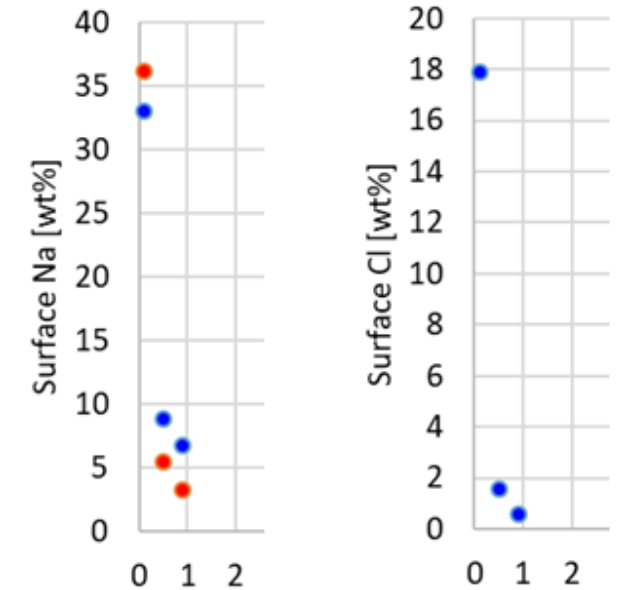
- BS VI systems require AUS 32 for NOx conversion over SCR irrespective of EGR or non-EGR based engines
- Certified AUS 32 for diesel aftertreatment systems is prepared with high quality urea and DI/DM water
- Contaminated AUS 32 may contain
 - From water: Na, Cl, K, Ca, Mg, etc.
 - Urea: Aldehydes, Biurate, Phosphate, K, etc.
- Uncertified AUS 32 and/or poor handling practices are key causes of AUS 32 contamination
- Certified AUS 32 availability at every fuel station and distribution network would be essential for BS VI



Impact of contaminated AUS 32 on A/T System

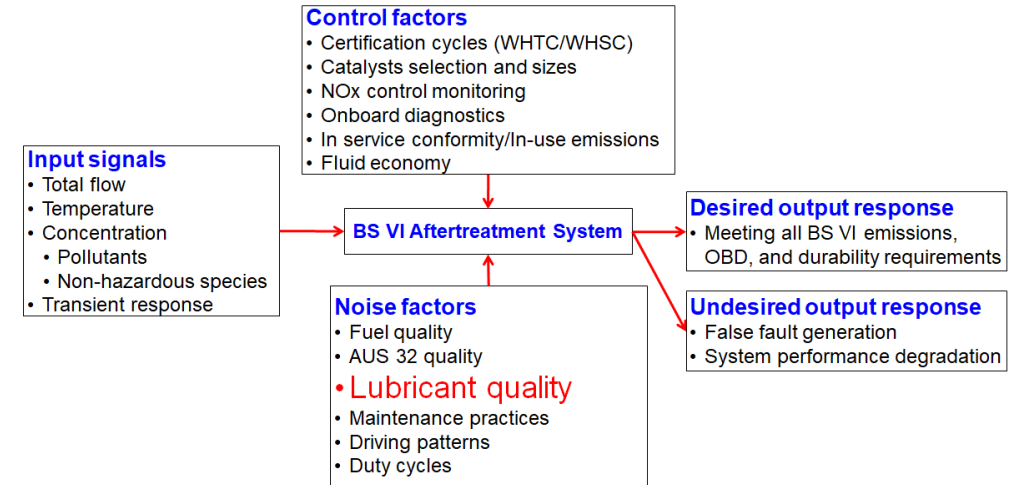
- **Face plugging of SCR or SCR/ASC parts:** BS VI SCR system design is optimized for high NO_x conversion efficiency, but it is susceptible for face-plugging when poor quality AUS 32 is used
 - This type of face-plugging is more difficult to remove compared to soot based face plugging
 - Loss in NO_x conversion
 - Increase in system back pressure
- Deactivation of metal zeolites due to active metal (Cu, Fe) leaching
- Damage/degradation to urea injection system
- Minerals deposition on mixer
- Fault code and may result in emission system failure

Contaminated AUS 32 was a big concern in Brazil (P-7) market and India/China also have similar concerns to some extent. Therefore, it is more important to enforce AUS 32 quality for BS VI systems as compared to BS IV

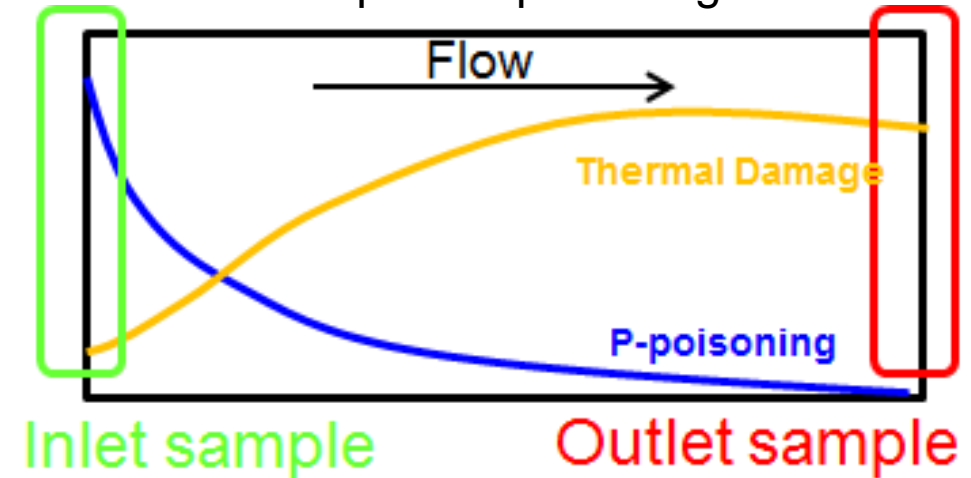


Lubricant additives and their impact on DOC and DPF

- Lubricant additives perform various function in diesel engine and are added to enhance
 - Wear reduction, e.g., ZDTP
 - Friction reduction
 - Piston cooling
 - Sealing
 - Corrosion prevention
- However, these additives may negatively affect aftertreatment catalysts
 - Phosphorus negatively affect performance of DOC
 - Zinc, Calcium, Silicon, Sulfur, etc. contributes to ash formation in DPF
- CJ4 and CK4 oils are recommended for BS VI application
 - These oils have low ash content and that is important to maintain longer cleaning interval for DPF



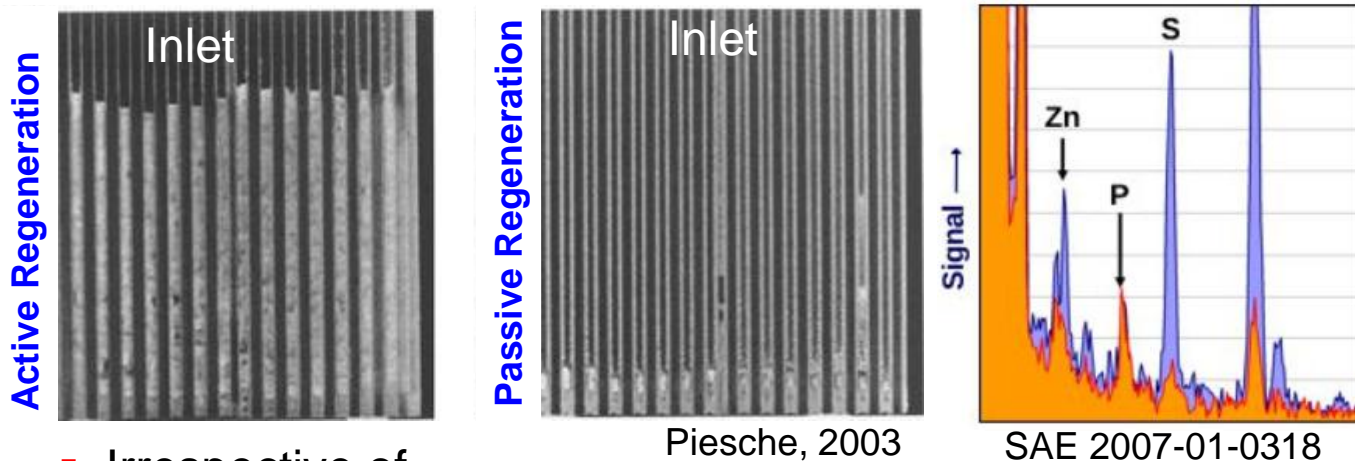
Typical distribution of thermal damage and Phosphorus poisoning in DOC



Availability of BS VI compatible engine oil is important to limit ash cleaning interval and to maintain high fuel economy of engine

Importance of maintenance and service diagnostics

DPF ash cleaning



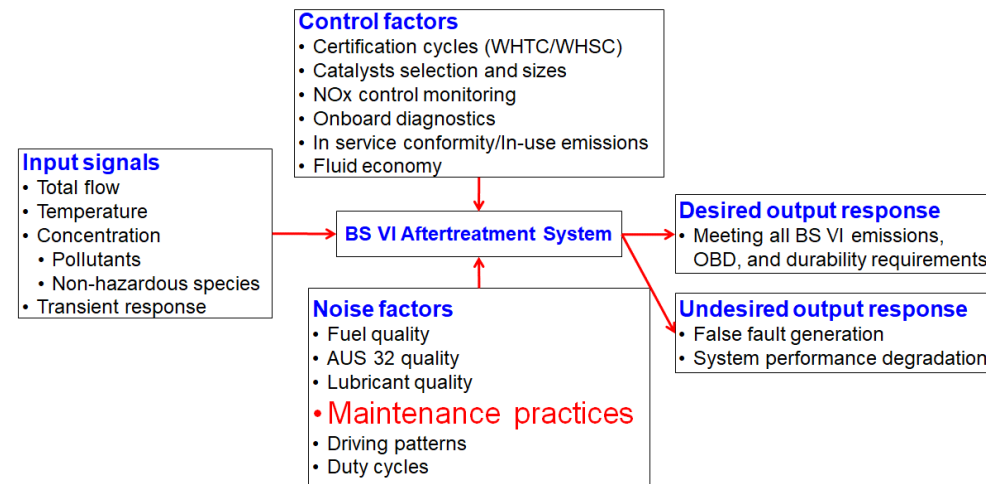
- Irrespective of
 - EGR vs non-EGR engine
 - Passive vs Active regeneration strategy

Ash management/cleaning over DPF would be required for lower back pressure and fuel economy

Truck Wash

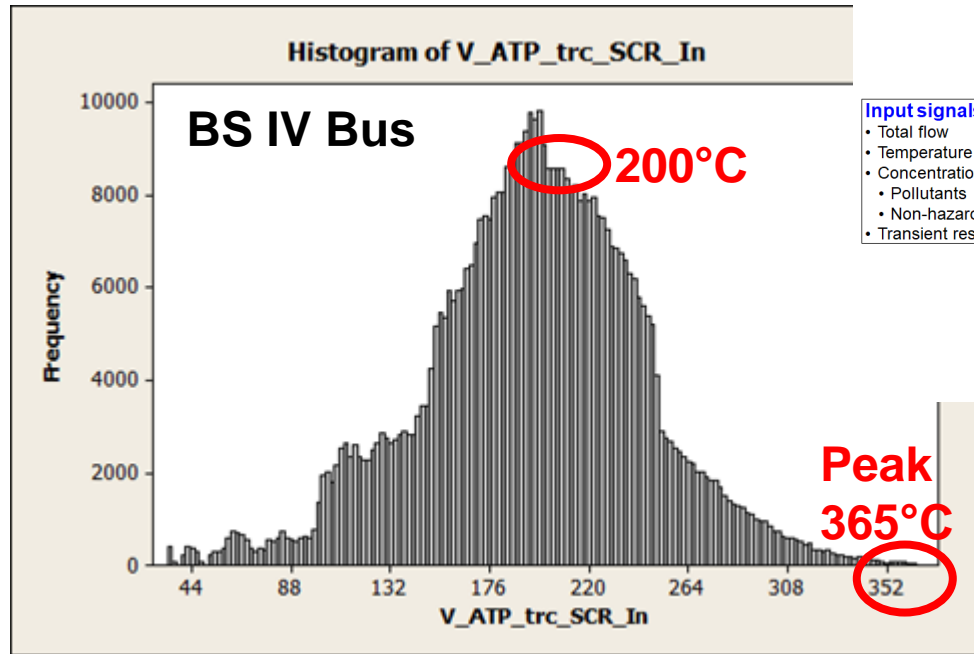
Need to ensure that water does not go through tailpipe

<https://www.youtube.com/watch?v=mkKLb7Wsxaw&feature=youtu.be>



- Capability to identify the fault and diagnose the fault would be more tedious for BS VI system because of complex architecture and would require effective service diagnostics
- Service center need to have right tools and processes to identify the faults and take necessary actions
 - DPF (stationary) regeneration for resetting the aftertreatment performance
 - Fuel and DEF sampling for quality
 - Ash cleaning

Duty cycles, driving patterns, and low temperature operations



Input signals

- Total flow
- Temperature
- Concentration
- Pollutants
- Non-hazardous species
- Transient response

Control factors

- Certification cycles (WHTC/WHSC)
- Catalysts selection and sizes
- NOx control monitoring
- Onboard diagnostics
- In service conformity/In-use emissions
- Fluid economy

BS VI Aftertreatment System

Desired output response

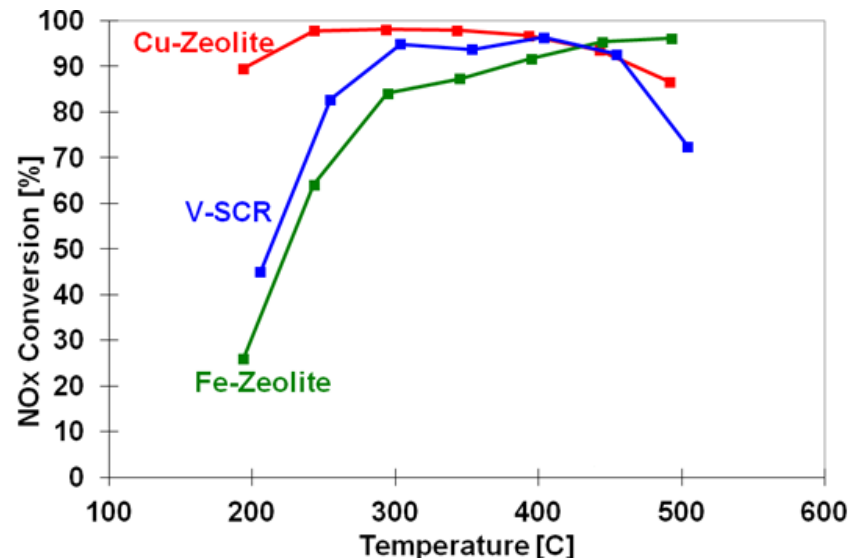
- Meeting all BS VI emissions, OBD, and durability requirements

Undesired output response

- False fault generation
- System performance degradation

Noise factors

- Fuel quality
- AUS 32 quality
- Lubricant quality
- Maintenance practices
- Driving patterns
- Duty cycles



- Advanced aftertreatment systems are challenged by low-T operations
 - Cu-SCR is technology of choice for low-T operations
 - DPF regeneration (both active and passive) can be challenging for such operations

Onboard Diagnostics (OBD) and compliance

Criteria Pollutant OBD Thresholds

OBD Threshold	BS IV OBD	BS VI-1 OBD 2020	BS VI-2 OBD 2023	BS VI Certification
NOx [g/kwh]	7	1.5	1.2	0.40 (WHSC) 0.46 (WHTC)
PM [g/kwh]	0.1*	0.025*	0.025	0.01
PN [#]				8 x 10 ¹¹ (WHSC) 6 x 10 ¹¹ (WHTC)

* Performance monitoring only as well not part of PEMS measurement in BS VI

- Enforcement of BS VI regulation is very crucial for its success as NOx emissions of one disabled system can be equivalent to 10 – 20 BS VI compliant systems. Example cases of BS VI systems under steady state

Engine	SO NOx Regulation	NOx Conversion Required	Effect of BS VI disabling
EGR 4 g/kwh	0.4* g/kwh (WHSC assumption)	90%	1 BS VI disabled vehicle = 10 compliant vehicles
Non-EGR 8 g/kwh		95%	1 BS VI disabled vehicle = 20 compliant vehicles

* OBD threshold and related definition for non-compliance are not considered to simplify the example

- As emissions regulations get tighter, high-emitters have an increasing environmental impact

Examples of Malfunction Indicator (MI)



AUS 32 Lamp
Need for assistance in achieving regeneration



High Exhaust System Temperature (HEST) Lamp
Active regeneration is underway

Summary

- BS VI system are designed for high NOx and PM/PN conversion efficiency while maintaining high fuel economy
- However, there are many noise factors that can negatively affect performance and/or maintenance interval of aftertreatment system
 - AUS 32 quality: Contamination/adulteration in AUS 32 can cause face-plugging of SCR system and may result in NOx conversion loss
 - High sulfur fuel: It causes faster deactivation (which is completely recoverable) and may result in fuel penalty
 - Lubricant: Right quality of lubricant must be used to limit ash formation and to achieve high fuel economy
- Cummins has good understanding of discussed noise factors and is well prepared to address BS VI challenges