Strategies and Challenges in Exhaust Aftertreatment Systems to meet upcoming OH Emission Regulations of India

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OUTLINE

- Off Road Emission Legislation and potential ATS configurations
- Emission & Exhaust After-treatment Technologies
- Emission Development Strategies
- After-treatment Challenges in Off Road systems
- Summary

- **Off Road Emission Legislation Road Map**
- Emission & Exhaust After-treatment Technologies
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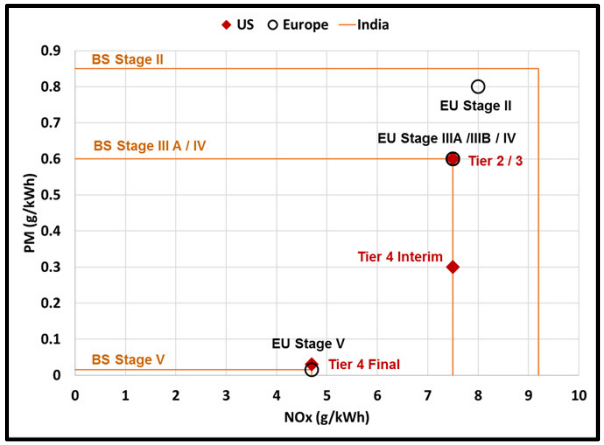
World Wide OH Regulation

Country	Engine Range - Power (kW)	Apr-11 Apr-12 Apr-13 Jan-14 Oct-15 Apr-16 Apr-17 Apr-18 Apr-19 Oct-20 Apr-21 Apr-22 Apr-23 Apr-24 Apr-25 Apr-26 Apr-27
US	37 < P < 56 56 < P < 75 75 < P < 130 130 < P < 560	Tier 4 Int / Stage 3 B — Tier 4 Final / Stage 4
Europe	37 < P < 56 56 < P < 130 130 < P < 560 560 < P	Stage III B — Stage IV — Stage V
China	37 < P < 56 56 < P < 75 75 < P < 130 130 < P < 560	Stage II — Stage III — Stage IV / Tier IV
India	8 < P < 56 56 < P < 75 75 < P < 130 130 < P < 560	Stage III A — Stage IV — Stage V

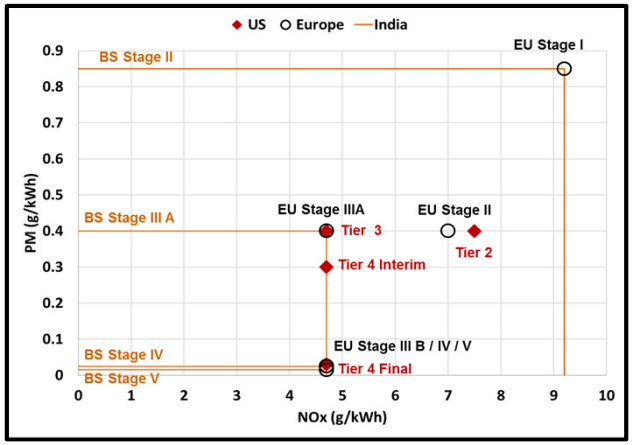
Off Highway Emissions

19–37 HP Scenario

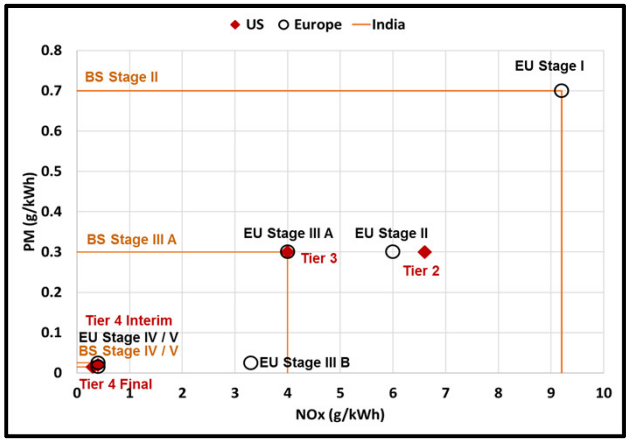


Europe and India has Stringent norms at Stage V and PN included

37–56 HP Scenario



56 HP and 130 HP



Tier 4 Final has Stringent NOx requirement compared to Europe and India.

PN limits are included in EU / BS Stage V

OH ATS potential configurations of Catalyst Elements

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Bharat OH Emission standards								
Engine Power	CO	HC	NOx	PM	PN	NH3	Test Cycle	ATS Configuration
kW	g/kWh				#/kWh	ppm		
Bharat OH Stage IV - October 2020								
P < 8	8	7.5*		0.4	-	-	NRSC	**No ATS**
8 ≤ P < 19	6.6	7.5*		0.4	-	-		**No ATS**
19 ≤ P < 37	5	4.7*		0.025		-		**No ATS**
37 ≤ P < 56	5	4.7		0.025	-	-	NRSC and NRTC	**DOC (optional)**
56 ≤ P < 130	5	0.19	0.4	0.025	-	10		**DOC + SCR**
130 ≤ P < 560	3.5	0.19	0.4	0.025	-	10		**DOC + SCR**
Bharat OH Stage V - April 2024								
P < 8	8	7.5*		0.4	-	-	NRSC	**No ATS**
8 ≤ P < 19	6.6	7.5*		0.4	-	-		**No ATS**
19 ≤ P < 37	5	4.7*		0.015	1 × 10^12	-	NRSC and NRTC	**DOC+DPF**
37 ≤ P < 56	5	4.7*		0.015	1 × 10^12	-		**DOC+DPF**
56 ≤ P < 130	5	0.19	0.4	0.015	1 × 10^12	10		**DOC+DPF+SCR**
130 ≤ P < 560	3.5	0.19	0.4	0.015	1 × 10^12	10		**DOC+DPF+SCR**
P ≥ 560	3.5	0.19	3.5	0.045	-	-	NRSC	**DOC**

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Engine & Exhaust After-treatment Technologies for OH

Legislation	Fuel S level
➢Tractor application : Stage- IIIA	Current : 50 ppm

Current Engine Technologies

➢< 19kW : 1-2 Cylinder , NA , M-FIE

➢< 37kW : 3-4 Cylinder , <3 liter displacement , NA / TC , M-FIE / E-FIE

➢< 75kW : 3-4 Cylinder , <5 liter displacement , NA / TC , , M-FIE / E-FIE , Cooled EGR

Engine Technologies

➢Combustion changes , E-FIE , CR ,
➢High pressure Fuel injection , High CR
➢Turbocharging
➢ EGR

After-treatment Technologies

➢Diesel Oxidation Catalyst (DOC)
➢Partial Filter (PFF)
➢Diesel Particulate Filter (DPF)
➢Selective Catalyst Reduction (SCR)

Fluid Technologies

➢Low Sulfur fuel , 10ppm eta 2019
➢Low SAPS Lubrication Oil – CJ4 , CK4

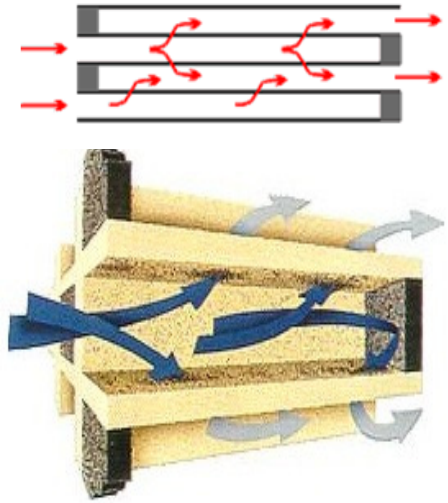
Control System Technologies

➢Engine Control System (ECU)
➢After Treatment Control system (ACU)

Tenneco Particulate Matter Abatement Technology : DOC + DPF

TENNECO

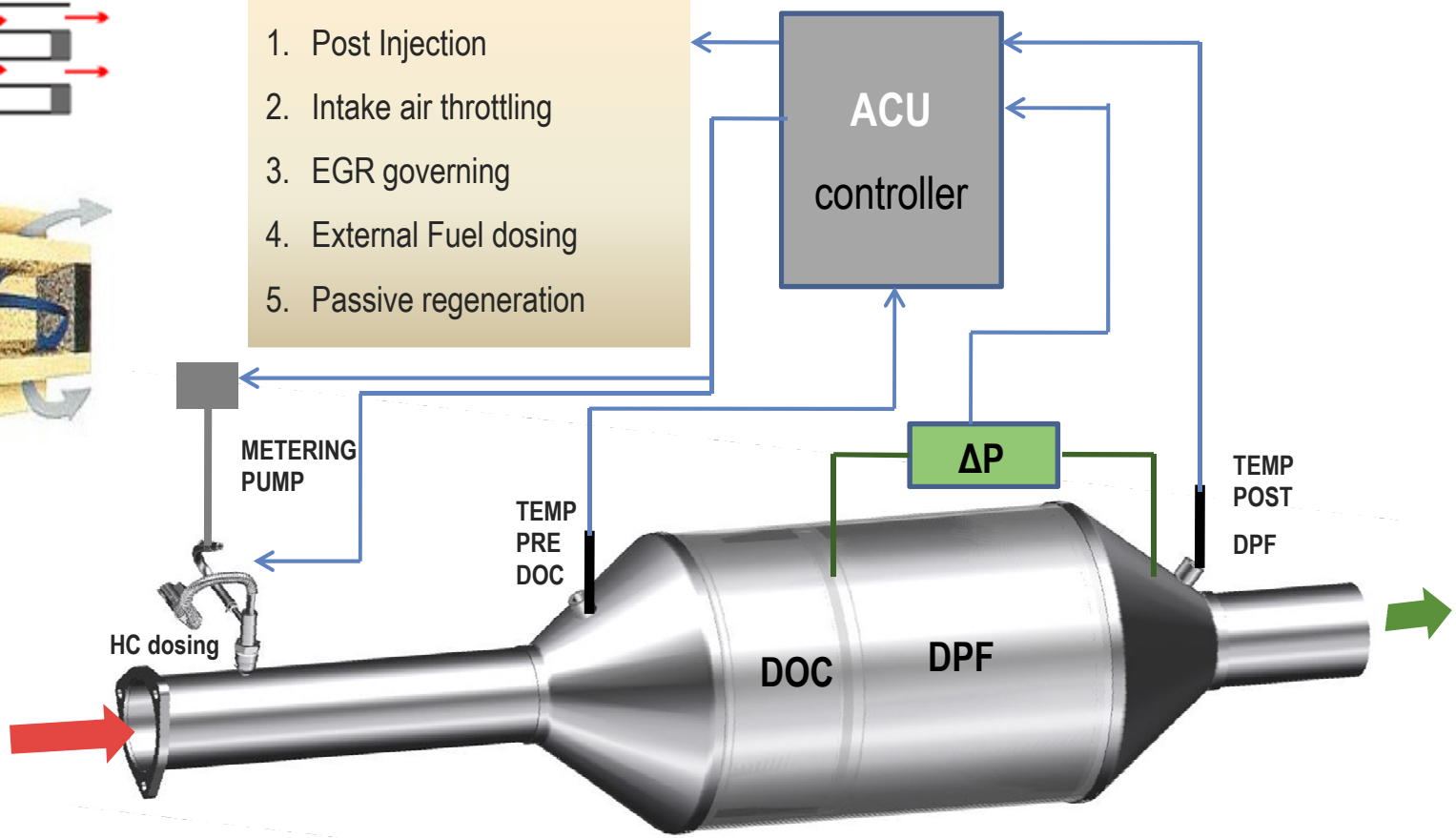
➢Capable of more than 95% PM conversion



Source :www.dieselnet.com

DPF REGENERATION

1. Post Injection
2. Intake air throttling
3. EGR governing
4. External Fuel dosing
5. Passive regeneration



NO2 Formation : $NO + ½O_2 \leftrightarrow NO_2$

HC & CO Reduction : $HC + O_2 \rightarrow CO_2 + H_2O$

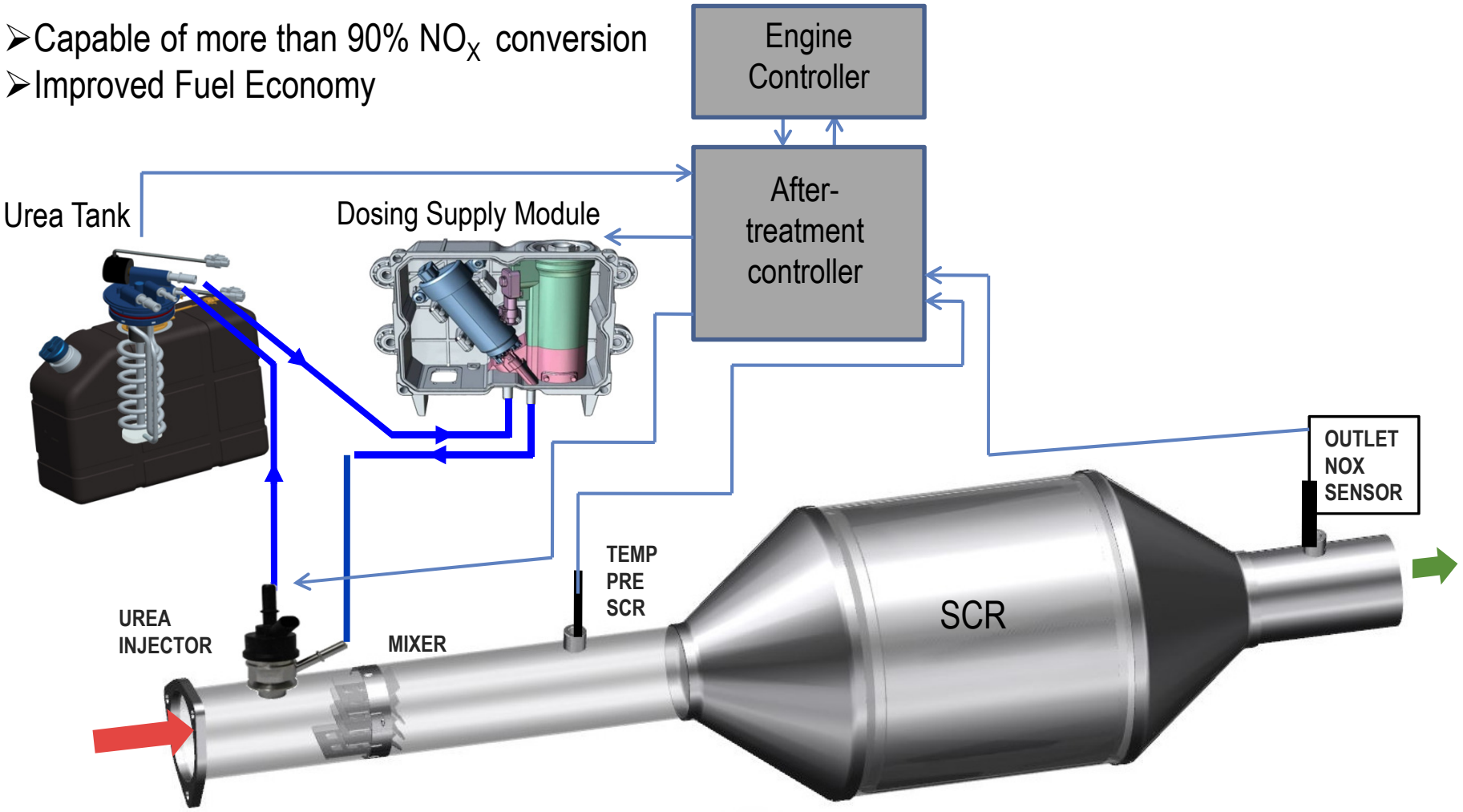
$CO + 1/2O_2 \rightarrow CO_2$

Passive Regeneration : $NO_2 + C \rightarrow NO + CO$

Active Regeneration : $C + O_2 \rightarrow CO_2$

Tenneco NO_X Abatement Technology : UDS + Mixer + SCR

- Capable of more than 90% NO_X conversion
- Improved Fuel Economy



Thermolysis: $(NH_2)_2CO \rightarrow NH_3 + HNCO$

Hydrolysis: $HNCO + H_2O \rightarrow NH_3 + CO_2$

Standard Reaction: $4NH_3 + 4NO + O_2 \rightarrow N_2 + 6H_2O$

Fast Reaction: $2NH_3 + NO + NO_2 \rightarrow 2N_2 + 3H_2O$

Slow Reaction: $8NH_3 + 6NO_2 \rightarrow 7N_2 + 12H_2O$

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- After-treatment Challenges On Off Road Vehicles
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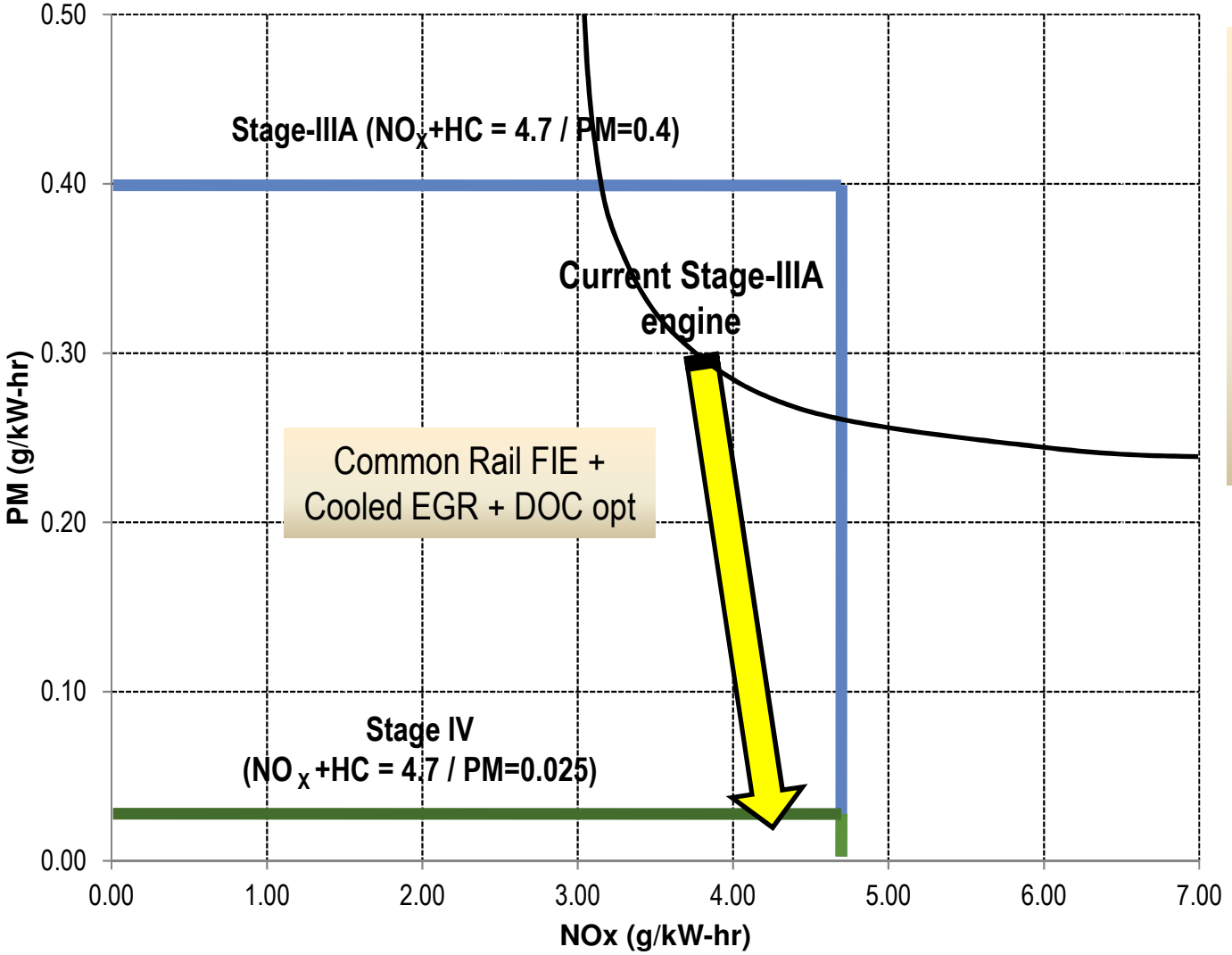
Potential Engine + After-treatment Development Strategies for 37kW ≤ P < 56kW , India Stage-IV off-road

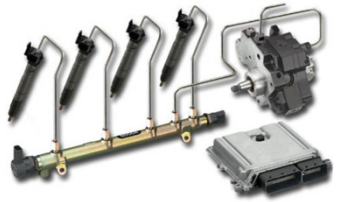


Strategy

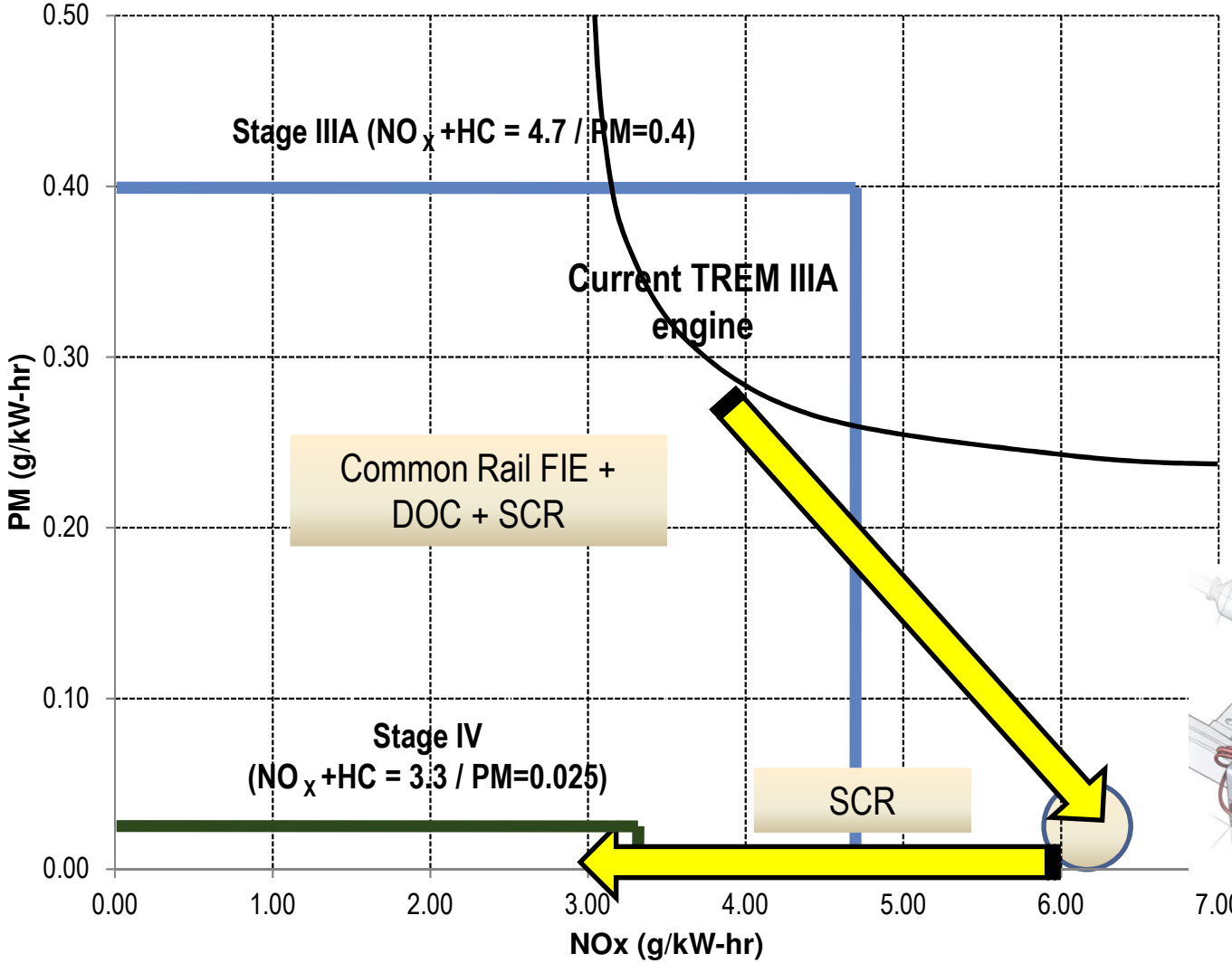
E-FES

+

Tenneco DOC aftertreatment system



After-treatment Development Strategies
56kW ≤ P < 75kW – India Emission Legislation



Strategy

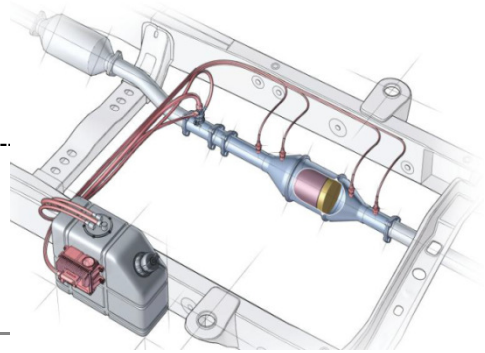
E-FES

+

Tenneco DOC+ SCR aftertreatment

+

Tenneco XNO$_X$® dosing system



Next emission norm is assumed to be Stage IV

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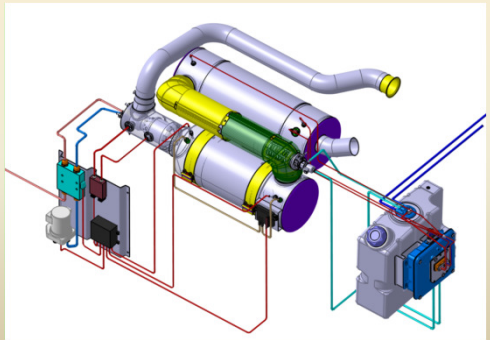
Challenge : End Customer / User requirements

High Performance

Low Initial Cost

EXHAUST AFTER-TREATMENT TECHNOLOGY SELECTION



Low Fluid consumption – Fuel, Urea, Oil

Low Maintenance

Extended maintenance interval

Design To Repair & Reuse

Ease In Service (DPF cleaning / urea filter replacement)

Limited Use Of Electronics

Challenge : Diversity of Equipment & Application

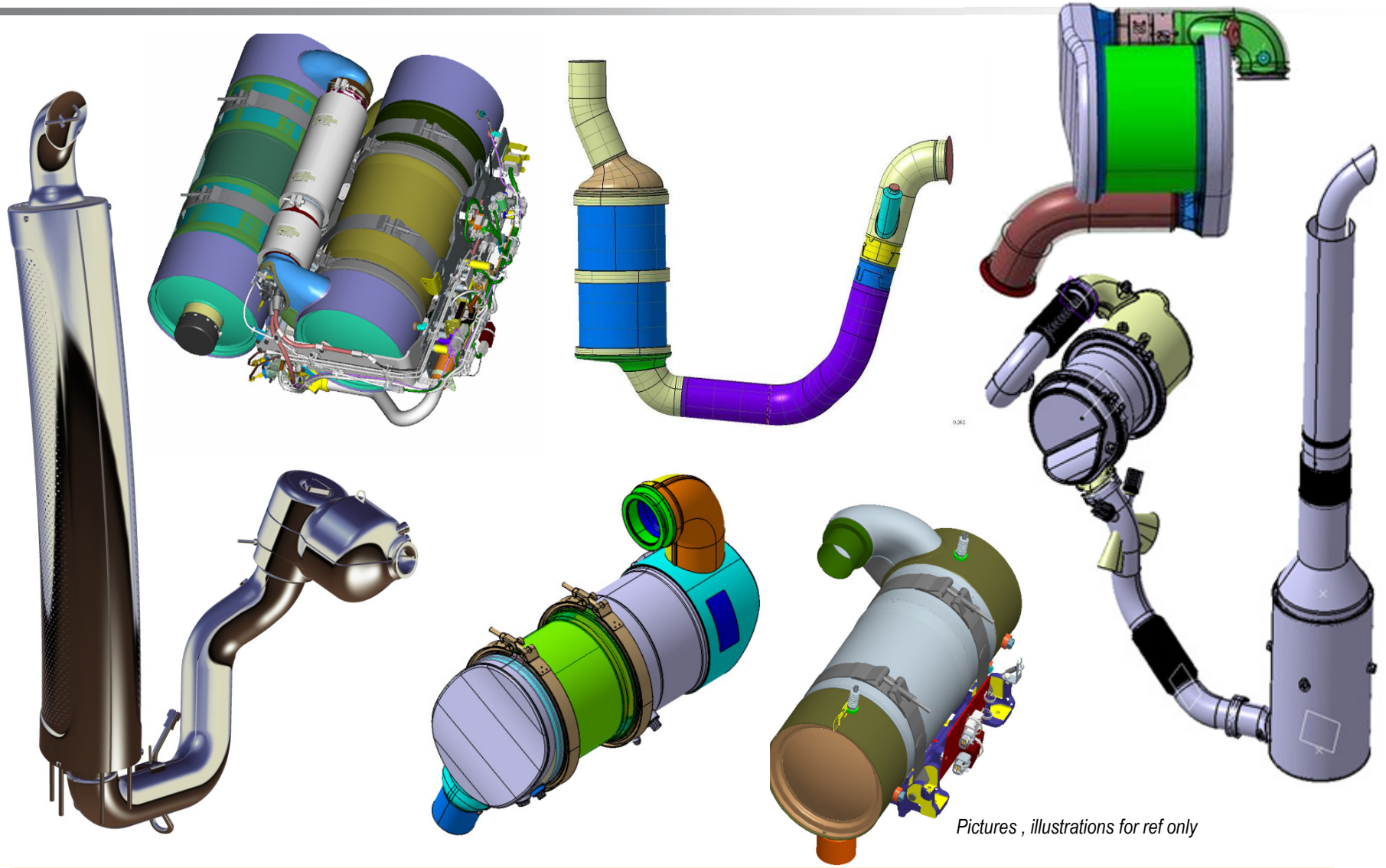
Sector	Application
Tractors/ Agri Machines	➢Ploughing ➢Puddling ➢Haulage ➢Harvesting ➢PTO driven
Earthmoving Equipment	➢Backhoe Loader ➢Compact Loader ➢Loader ➢Dozer,
Transportation	➢Ground support equipment in airports
Material Handlers	➢Fork-lift ➢Crane

Tenneco offers a variety of aftertreatment system designs to address the diversity of applications.

Challenge : After-treatment Packaging

Integration of Tenneco after-treatment systems in existing packaging space is unique for each application

Off Road After-treatment Systems

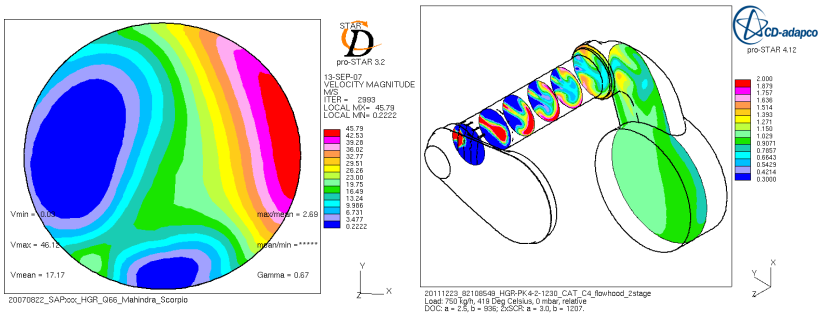


Pictures , illustrations for ref only

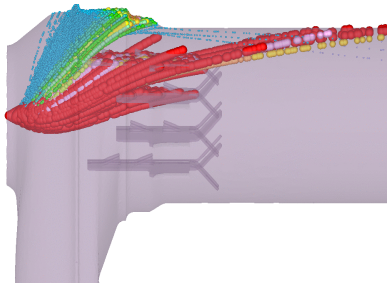
This packaging concern drives complex geometry of exhaust system designs

Challenge : System Integration Requirements

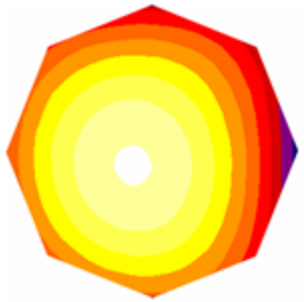
- Uniform Flow & Urea Vapor Distribution



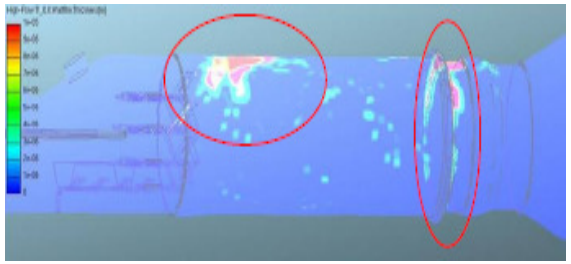
Spray Propagation

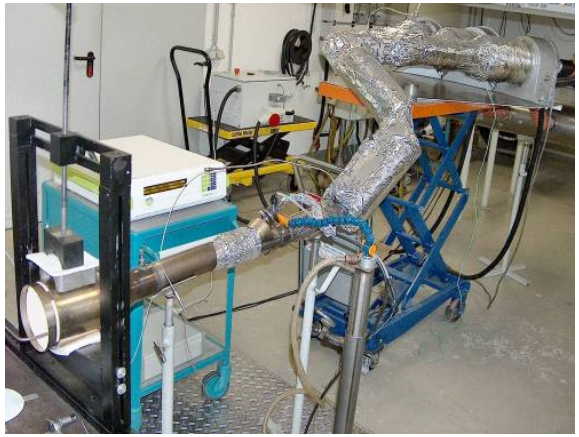


Uniform Temperature Distribution



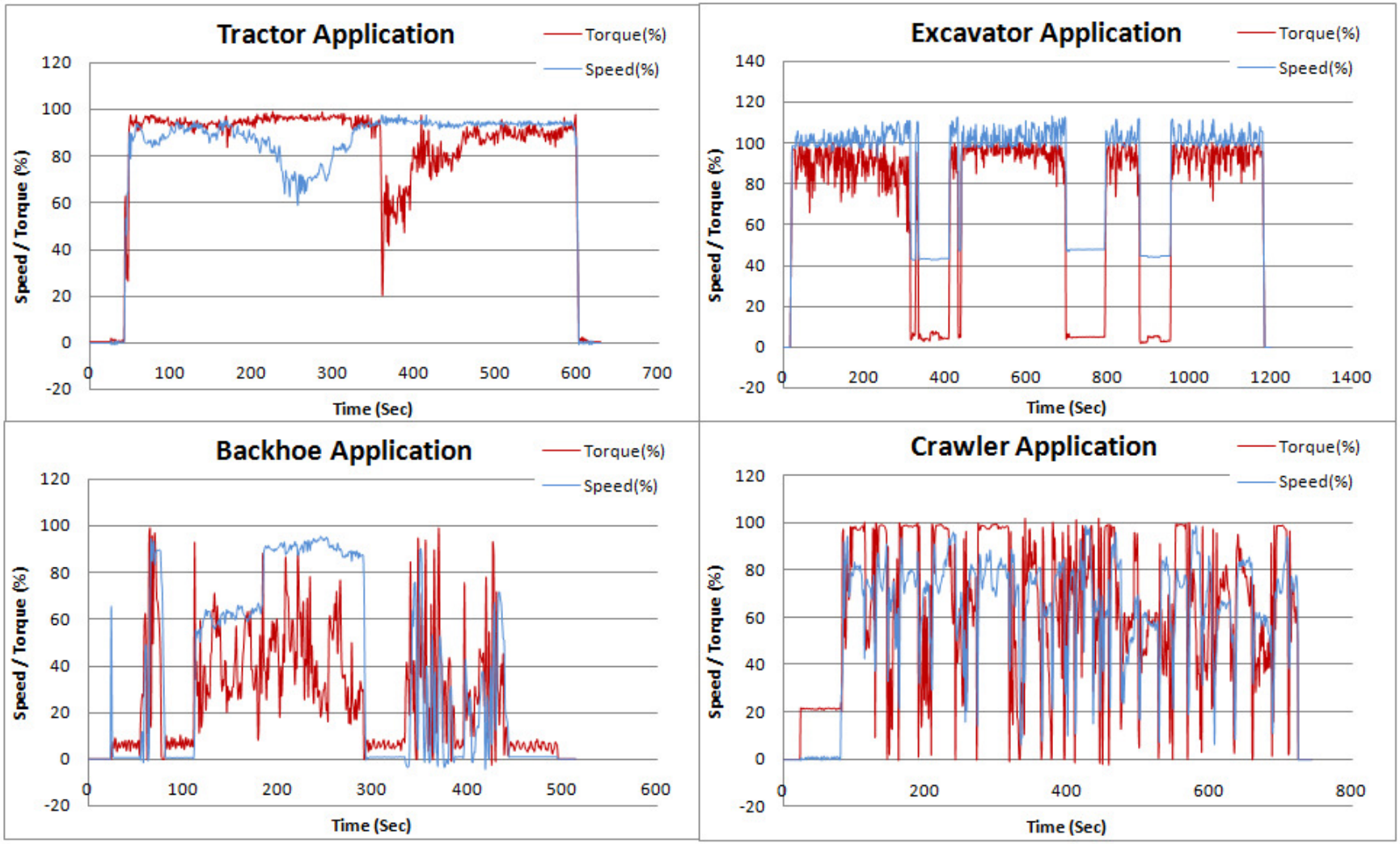
- Wall wetting , Urea deposits & conversion efficiency





All Tenneco systems are designed to achieve optimum distribution of exhaust flow & urea atomization in complex exhaust layouts ensured by multiple loops of virtual and physical validation

Challenge : Equipment Duty Cycle Variation



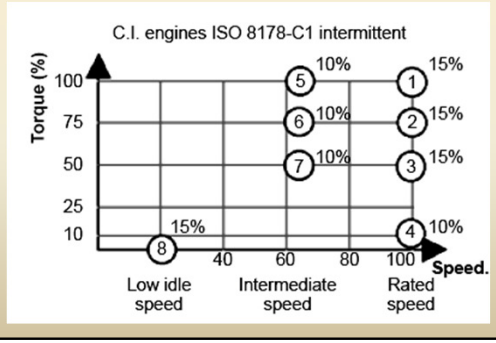
Source : www.epa.gov

Tenneco Aftertreatment Systems are designed for every duty cycle application

Challenge : Transient Emission Cycles

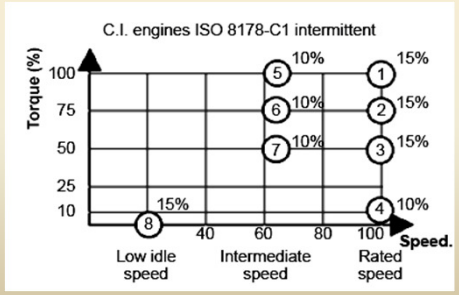
Emission Cycle - IIIA

ISO 8178 -4 “C1” -
8 mode cycle study state cycle

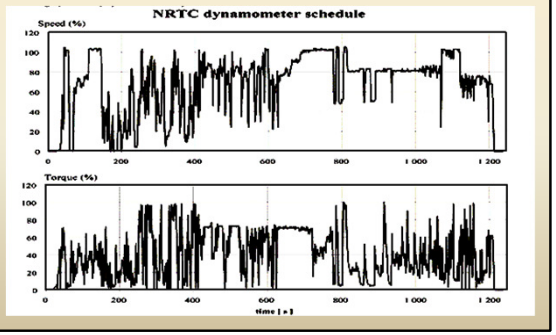


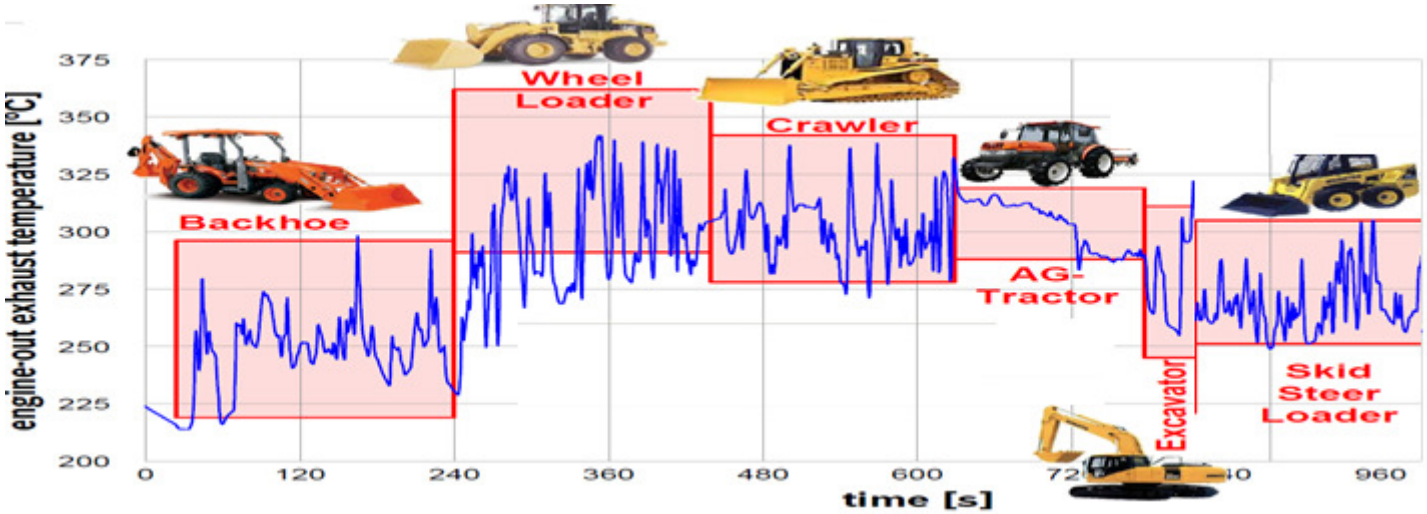
Next Emission Level

ISO 8178 -4 “C1”
8 mode cycle study state cycle



NRTC
Non Road Transient cycle





Tenneco systems can adopt unique calibration strategies for every application

Challenge : Reliability & Durability Requirements

- Higher useful life expectancy as compared to on-road vehicles
- Expose to high level of dust and debris
- Vibration and shock load
- Extreme weather conditions
- Overload operation
- Urea adulteration and contamination.
- Urea storage and handling
- Technology awareness
  - End Customer
  - Service

Tenneco systems are designed and tested to work in severe and harsh usage conditions.

Challenge : Fluid (Fuel,Adblue,Oil)

- Fuel Regulation : Low Sulfur availability
  - Catalyst deactivation due to high sulfur fuel
  - Sulfate formation leads to increased in particulate matter emission
  - NO_2 generation capability reduced impacting SCR performance
  - Sulfuric acid creation leading to corrosion in exhaust system

- Oil Technology : Low Sulfated Ash , Phosphorus & Sulfur (SAPS)
  - Change to CJ4 / CK4 from current CH4/CI4 oil

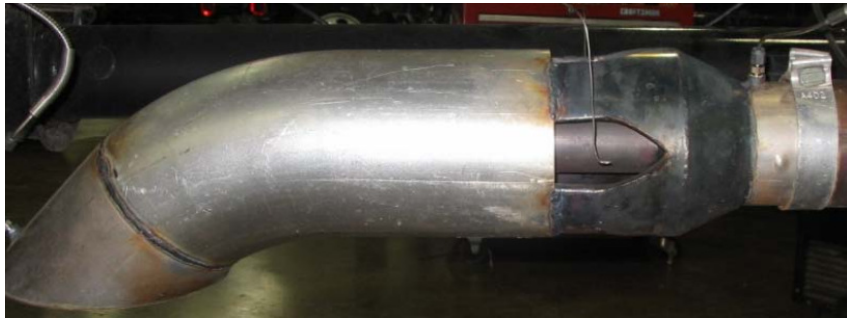
- Urea infrastructure
  - Adblue/DEF availability in OH regions
  - quality
  - cost

Low sulfur fuel , low SAPS oils & Adblue/DEF quality are key for after-treatment performance

Challenge: Low Exhaust Skin Temperature Requirement

- Low skin temperature
  - Heat shield (heat retention) design & packaging
  - Heat shielding

- Tail pipe temperature mitigation
  - Use of heat diffusers / aspirators to mitigate high exhaust gas temperatures exiting from tailpipe.



Skin temperature and exhaust thermal management is a paramount factor for safe operation, that all Tenneco systems are developed with.

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Summary

- Technology path is dependent on Power Category.
- Tenneco offers tailored solutions addressing all challenges.
- Several potential solutions are possible and Atertreatment system integration is essential for effective handshaking with engine.
- Future emission regulations for off-road would require a combination of DOC , DPF & SCR technologies integrated together.

Thank you !