Engineering approach for future OHW emission norms

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Engineering approach for future OHW emission norms

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II. Soot loading for different cycles
III. Summary

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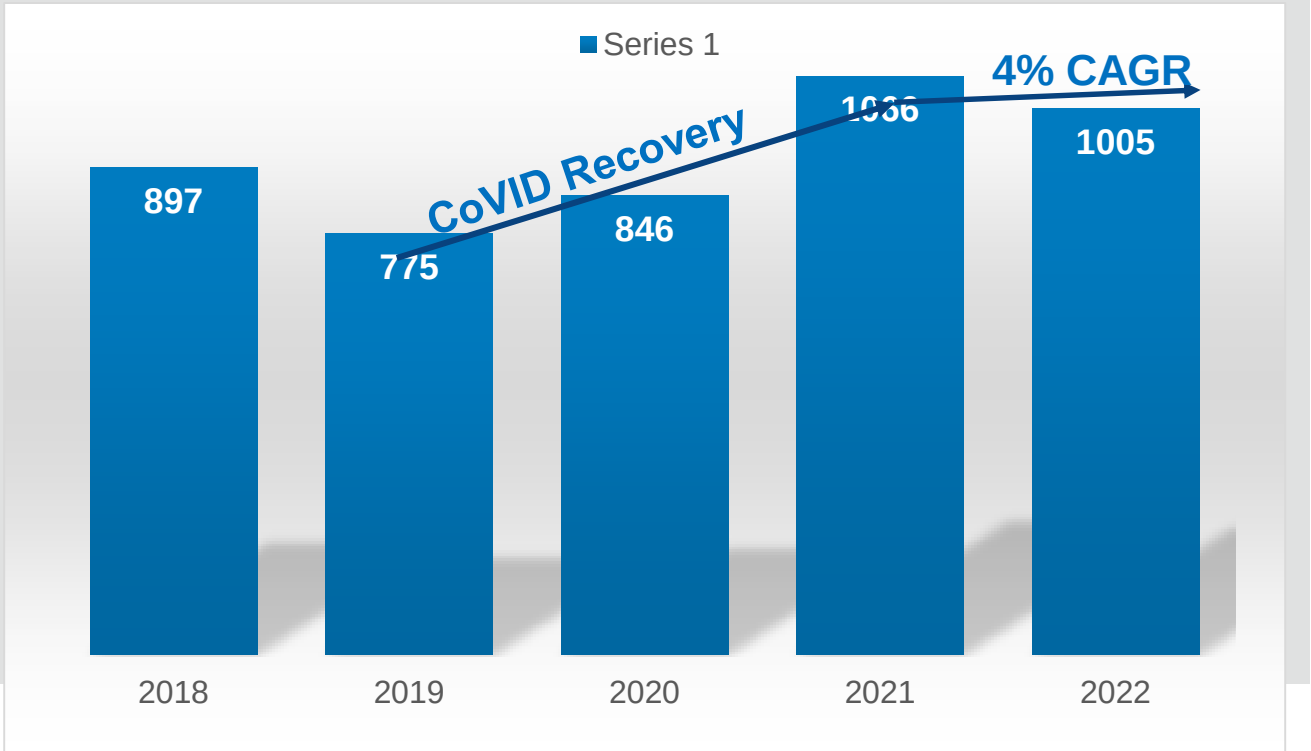
Off-Road Market Report – At a Glance

Cumulative Volume (x 1000 units)



Macroeconomic Indicators

2022

- India surpasses UK → 5th largest economy and JP → 3rd largest auto market. Car & LCV sales all time high.
- GoI push for infrastructure (physical & digital) supported CV & OR segment to grow, with demand in LCV, HCV & CEV.
- Rural sentiments positive due to ease of component supply, good kharif, procurement, rabi sowing and better water level in reservoirs → Strong demand for tractors.

2023

- Robust sales in several brands.
- Situation in rural economy looks good as Crop, Reservoir level, Price is favorable situation.

Consistent good monsoon, improved cash flow with farmers with better MSP for crops. continued momentum in Tractor Segment

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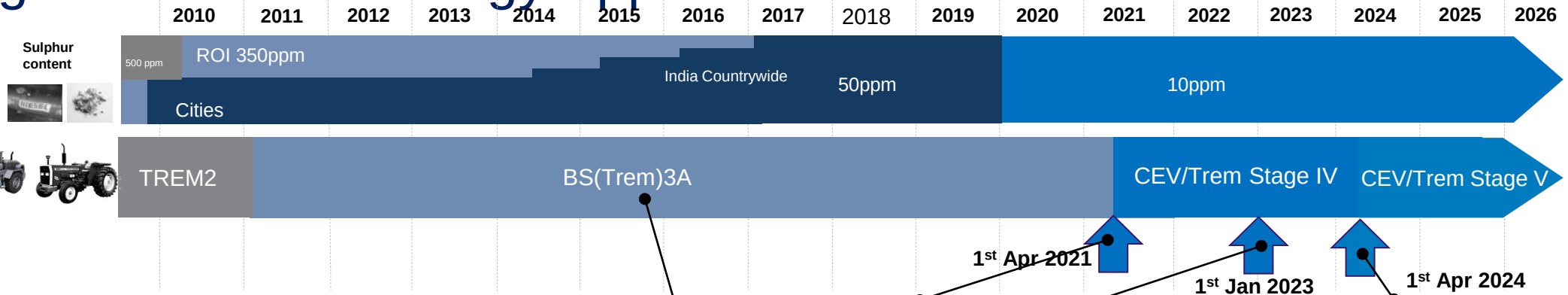
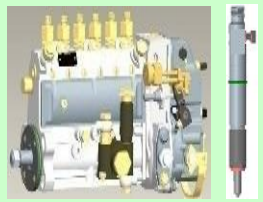
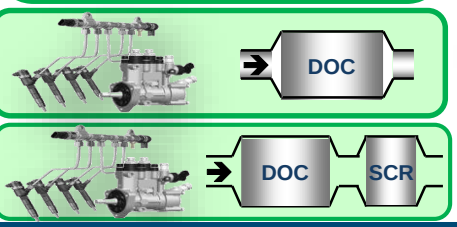
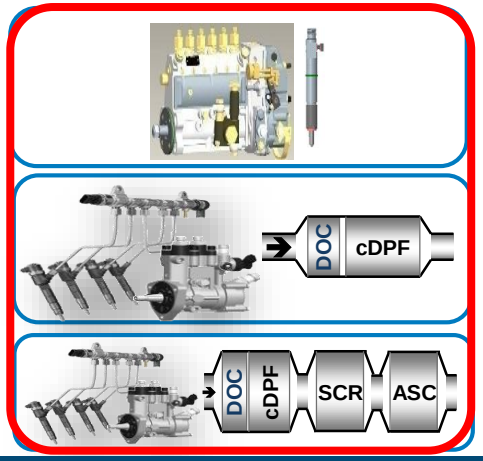
Regulation & Technology Approach – **Tractors & CEV**



P [kW]	BS3A	BS4	BS5	BS(Trem)3A	CEV	Trem Stage IV	CEV/Trem Stage V
0-8	7.5 / 0.8		7.5 / 0.4	Mechanical FIE			
8-19	7.5 / 0.6						
19–37			4.7 / 0.015 1X10^{12}				
37-56	4.7 / 0.4	4.7 / 0.025					
>56	4.0 / ≤0.3	0.4 / 0.025	0.4 / 0.015 1X10^{12}				







Bosch CRS Technology + EGT in Off-Road Segment → A key enabler to meet market KPI's & Customer value proposition
As CEV & Trem IV matures to SOP. Focus shifting to "Disruption Wave 2.0" → CEV & Trem V

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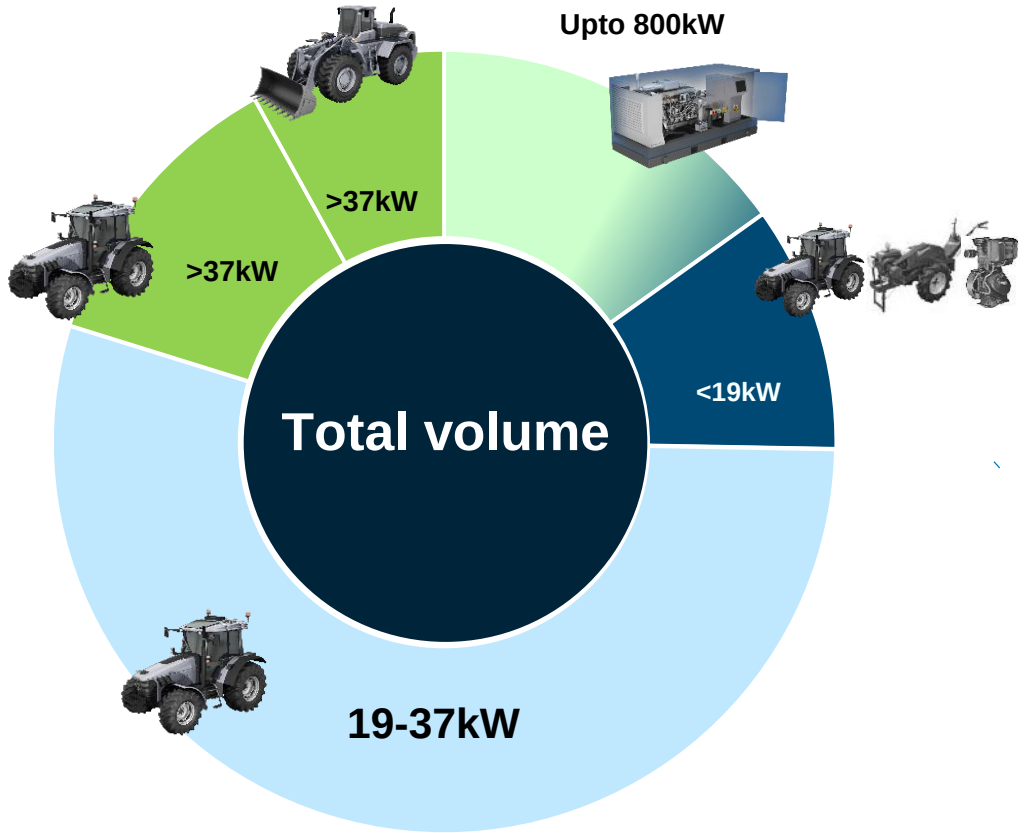
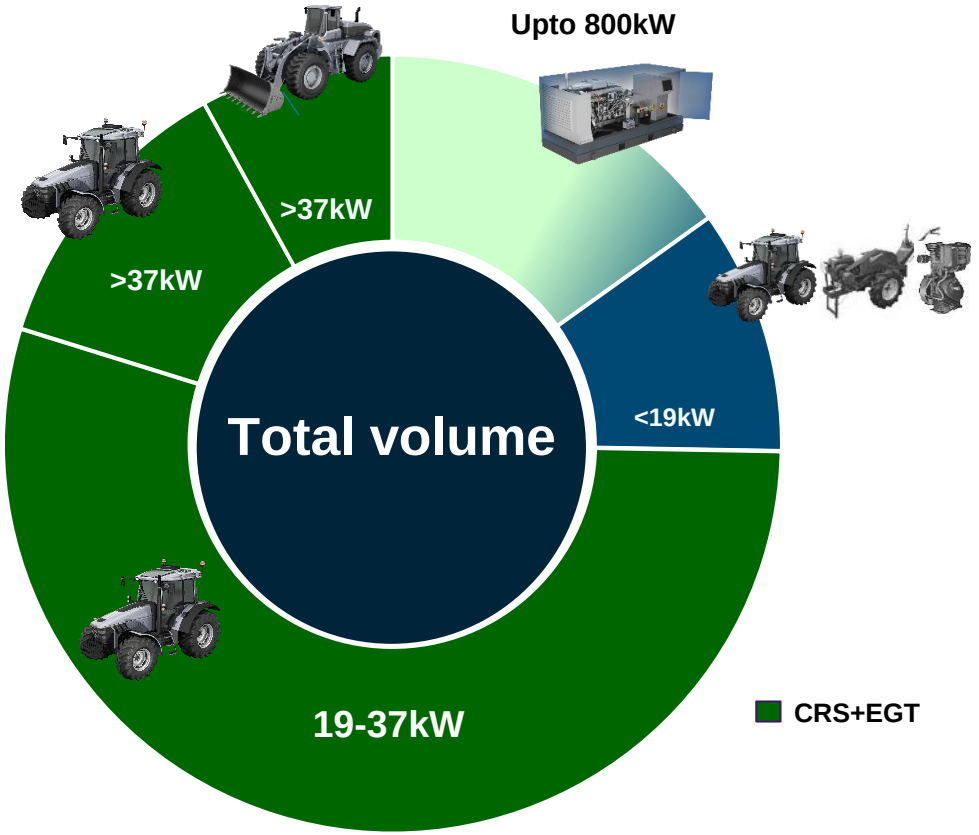
Off-Road Market At A Glance | **Disruption Wave**



Wave 1 | 2021-23 : CEV / Trem IV & CPCB4+



Wave 2 | 2024 : CEV / Trem V implementation

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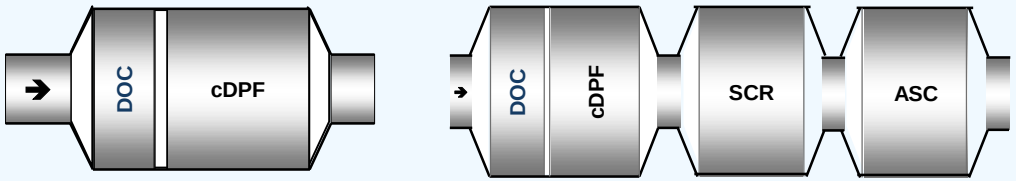
Trem V : **EGT Roadmap & Challenges**

Key challenges

Common EGT system definition



Challenges specific to EGT definition

- EGT experience with NA engines is low
- High exhaust temp, low lambda, system simplification, Catalyst selection
- DPF regeneration strategy definition
- Adequate engine out data available for EGT definition
- EGT packaging across various applications

Key Challenges: Experience on NA, High exhaust temp, low lambda, system simplification, packaging & full system solution

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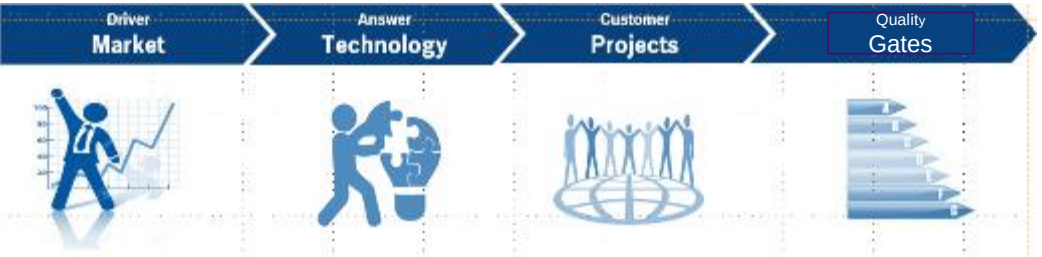
Off-Road India→ Leapfrogging into Productive Farm



CEV / Trem Stage V

- **Technical Approach**
  Tailored approach to suit Indian Domestic market proposed to OEM's New Generation Engines .
- **Fuel System + Controller + Calibration**
  Indigenized FIE, ECU's along with Custom built SW & FIS capable up to meet address various new requirements for Off-Road applications and requirements
- **EGT-System Integration**
  A unique & First of a Kind EGT system Integration approach helped OEM's to Define, Plan & Release Programs with EGT first time right.
- **Quality Gates**
  Ensures project delivery in terms of quality, time & customer satisfaction

A new journey toward CEV / Trem Stage V has just begun…
….. with many teams but one mission.

Off-Road market moves CRS way…

Bosch vision is to become a preferred & trusted technology partner in Off-Road transformation & Growth

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Engineering Approach for Future NRMM Emission
Sensor & Actuator Layout | **Trem V | <56KW | NA Engine**

FIE : CRI2-16 OHW

Pressure : 1600bar

Well accepted by market.

TVA

- Benefits in NA engine for both normal and DPF mode

Airmass Sensor

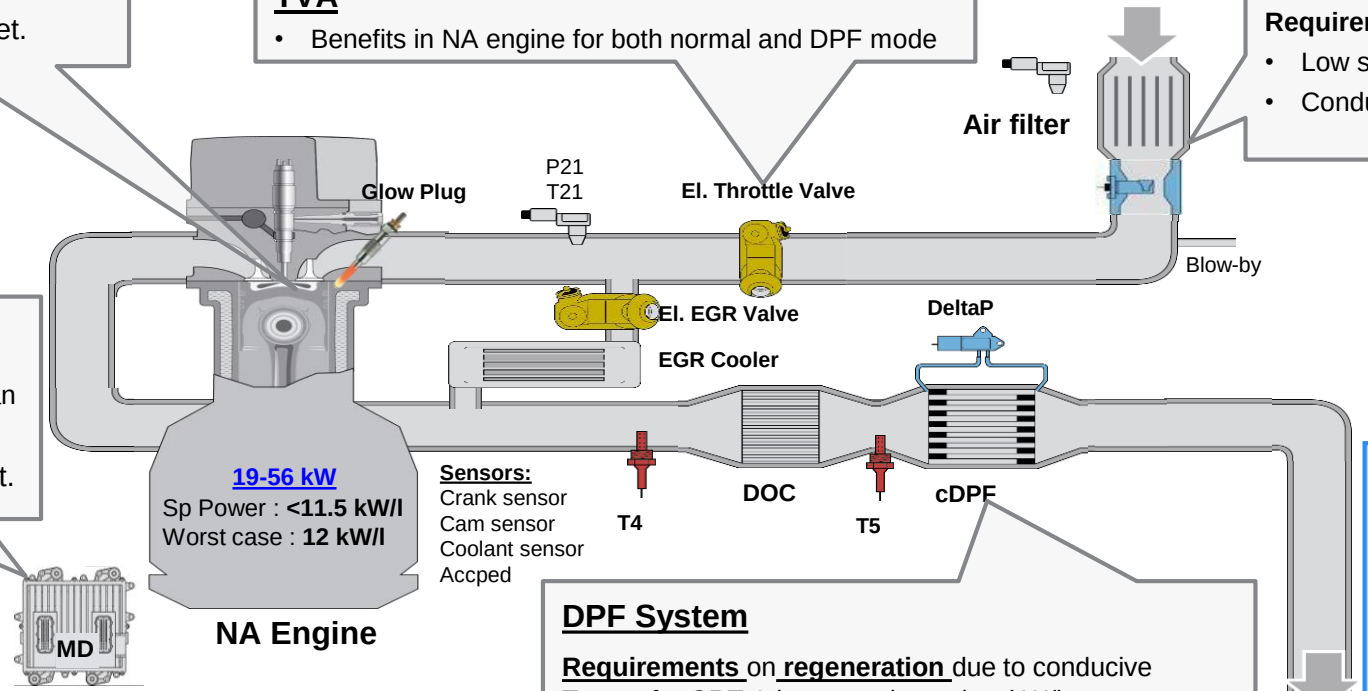
Requirement considering…

- Low soot impact [low kW/l] to external noise.
- Conducive passive regeneration field conditions.

ECU : MD1CS162

Tailored controller with lean SW / HW / CAL.

Well accepted by market.



DPF System

Requirements on **regeneration** due to conducive $T_{Exhaust}$ for CRT & low soot due to low kW/l.

Key Market Demand :

- **System Simplification**
- **Different View existing in market.**

Requirement engineering air mass sensor and DPF regeneration priority for successful TREM V system definition.

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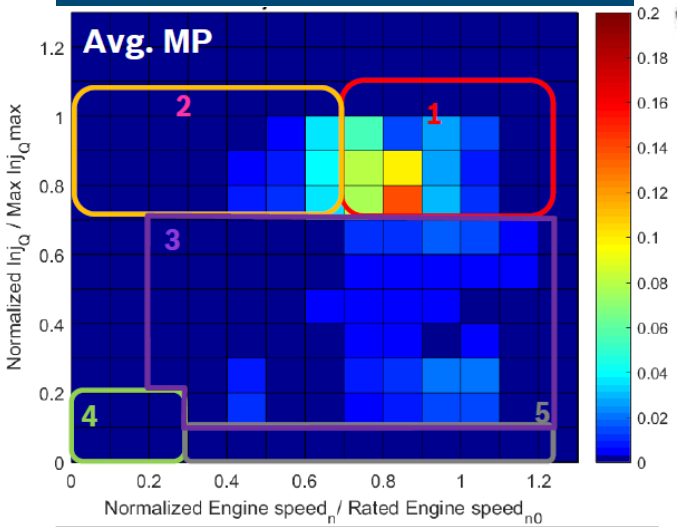
Off-Road Applications | **Mission Profiles** | Trem IV Applications

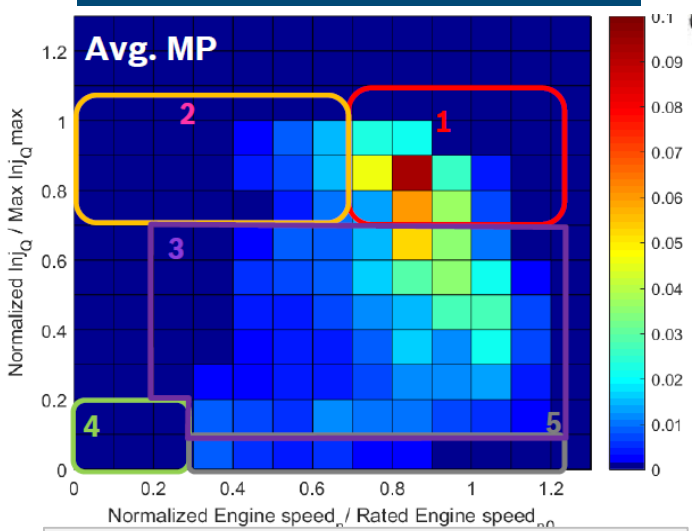
Power : 26.85-32kW



Rated speed : 2000-2700rpm
Specific power: 9-11.5kW/l
Naturally aspirated engines

Zone1-3
~75%

Power : 41-56kW



Rated speed : 2000-2300rpm
Specific power range: 11.5-13kW/l
Naturally aspirated engines

Zone1-3
~75%

Demonstrator engine

→ A representative of engine from mass market from respective P_{Class}.

Configuration	Engine 1	Engine 2
Power Class	19-56kW	19-56kW
Air system	NA, cEGR	NA, cEGR
Sp. power [kW/L]	9, 11.5	13
EGT	DOC+ cDPF	DOC+ cDPF

Most operations at high loads, in CRT zone / Active RGN zone → Motivation for "key ask" on REGEN Strategy.
Bosch Approach → Critically review low load, high transient operation of engine soot, exhaust temperature & robustness before industrialization.

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Off-Highway requirement engineering for TREM V

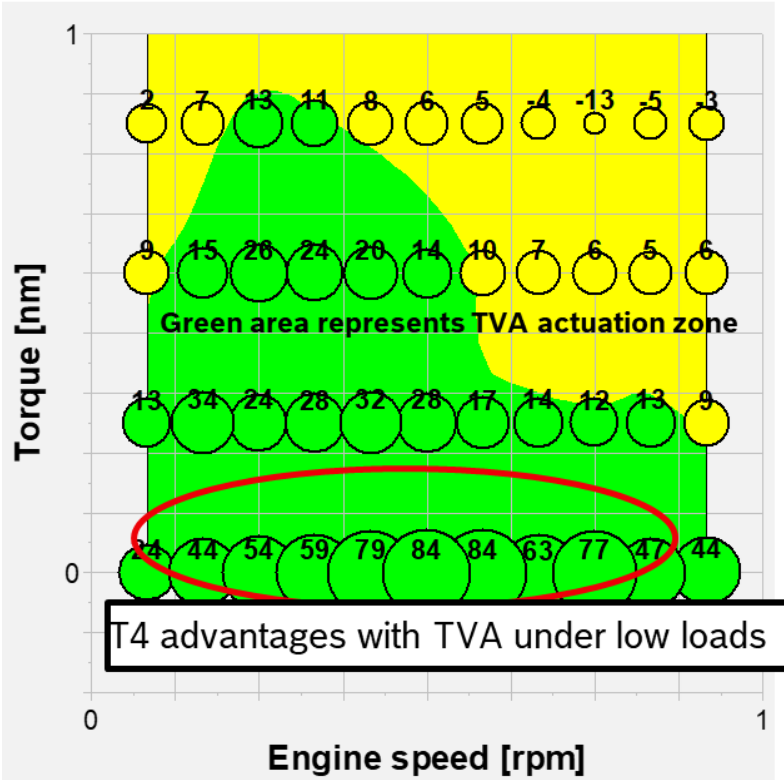
TVA Benefits

Off-Highway requirement engineering for TREM V

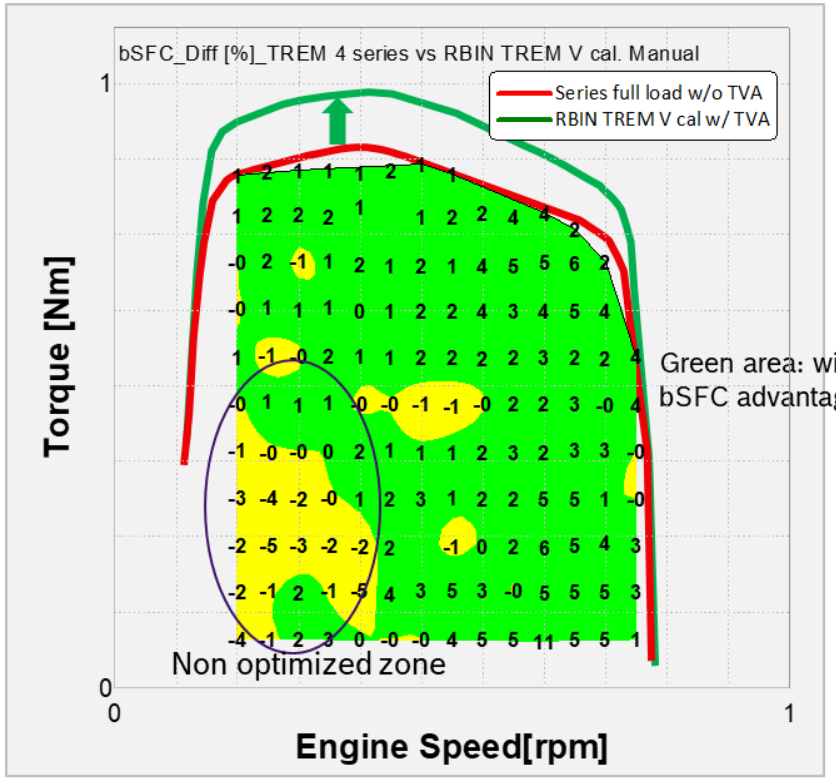
<56 kW NA TREM V: Benefits of TVA

Why TVA beneficial?

T4 difference w/ & w/o TVA [˚C]



bSFC advantage with TVA



TVA offers upto 50-60˚C higher T4 temp. → Robust field behavior over lifetime, under adverse ambient conditions, bSFC advantage

Advantages: Normal mode bSFC improvement with TVA, higher full load [EGR & NOx opt. in low & high load within legal boundary]

Throttle Valve supports lower soot entry, bSFC advantage, exotherm capability at low DOC Ui/massflows and overall robustness of system.

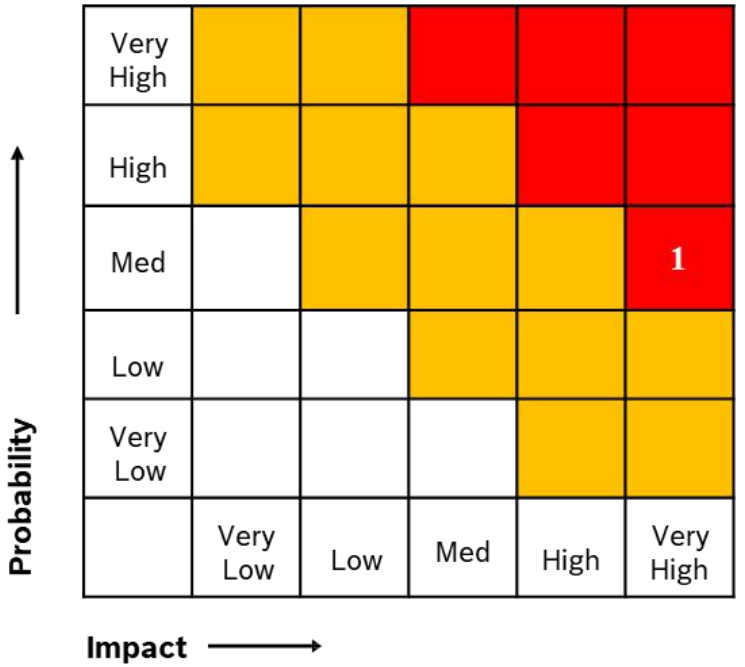
Off-Highway requirement engineering for TREM V

Air Mass Sensor and DPF Regen requirement

Off-Highway requirement engineering for TREM V

Air mass sensor removal impact analysis

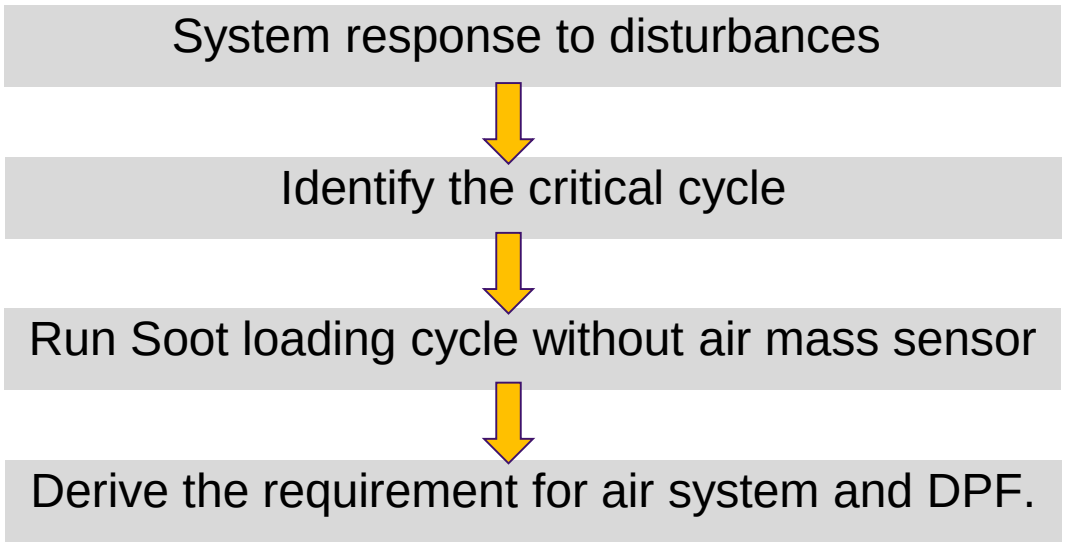
Emission component	Relevant functions	Impact on type Approval [TA]	Impact on field
Engine out emissions	EGR Close looping	**Close loop EGR not possible** → Higher emission spread against tolerances.	Less robust against system disturbances/ prod. tolerances Faster DPF soot filling, frequent RGN/ DPF failure.→ **Field issues**
	Smoke limitation	Not critical considering DPF	Not critical for NA Critical, to be assessed, for TCIC



Critical field cycles to be assessed for DPF KPIs for impact analysis

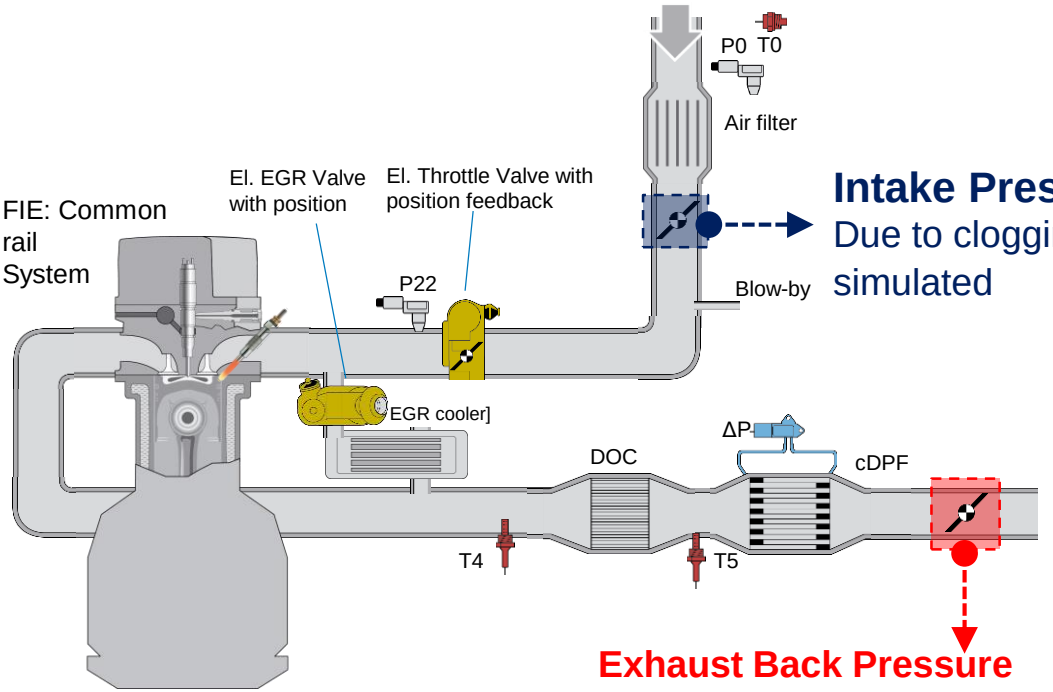
Off-Highway requirement engineering for TREM V

DPF regen. Requirement evaluation flowchart



Off-Highway requirement engineering for TREM V

Test matrix



Intake Pressure
Due to clogging of Air filter simulated

Exhaust Back Pressure
considering Max. BP sample

Base → Empty DPF, no Intake depression, Mean Injectors.

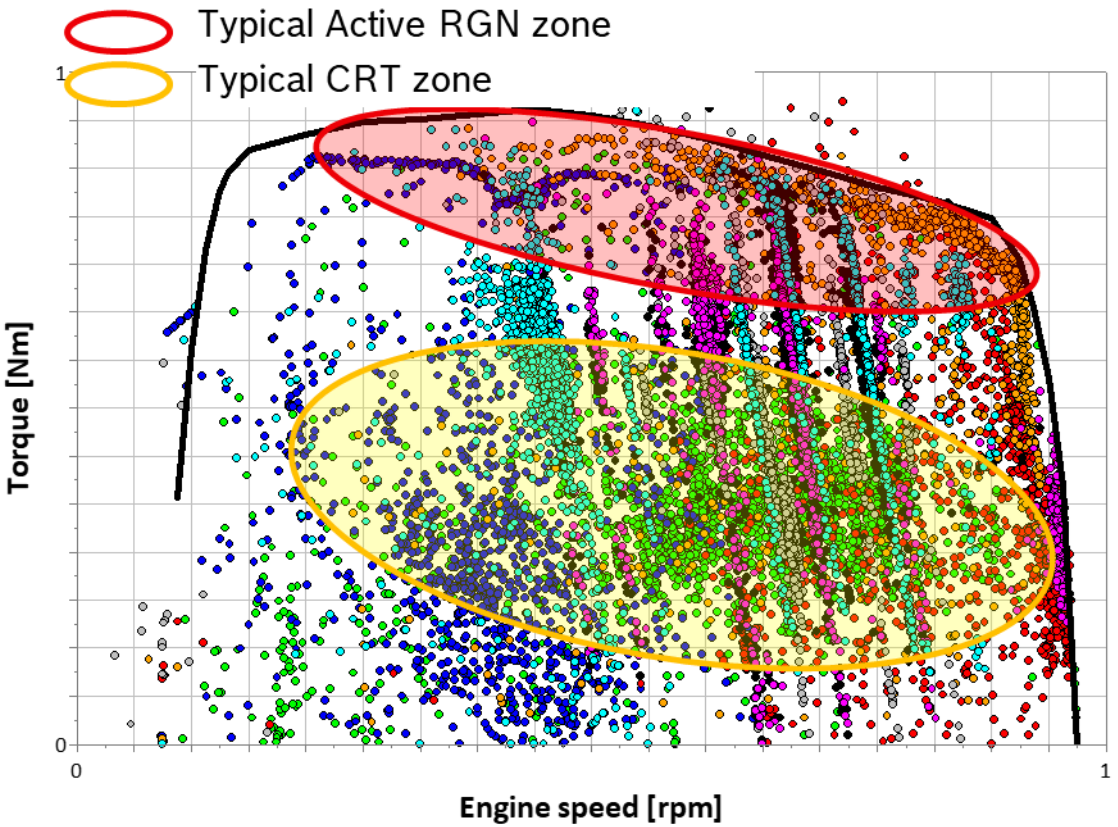
Intake depression –
Intake depression is taken for analysis as average use case.

Exhaust Back Pressure
DPF corresponding to Max. Back pressure from production

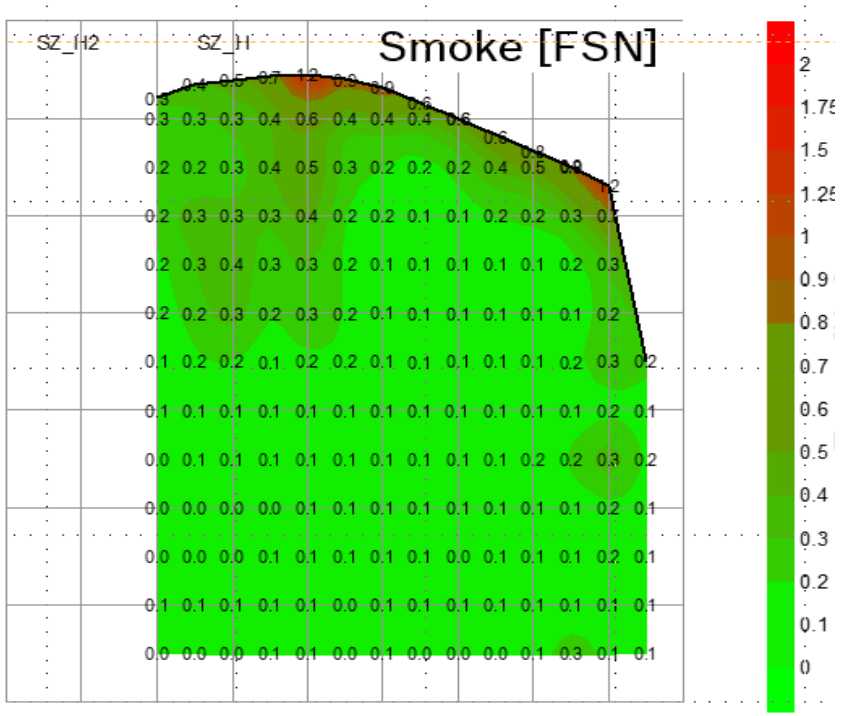
Off-Highway requirement engineering for TREM V

Tractor load collectives from field

Typical tractor load collective from field



Typical TREM V smoke emission[FSN



Most of the load collectives fall under either CRT zone with very little eng. Out soot or under active regeneration zone.

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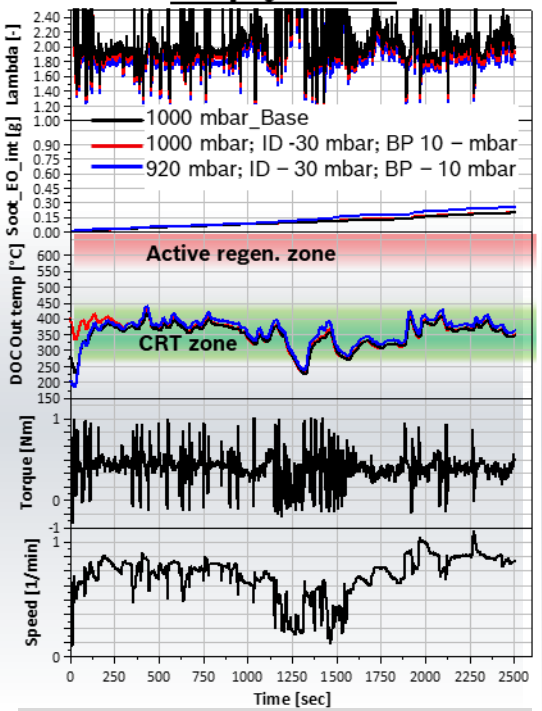
Off-Highway requirement engineering for TREM V

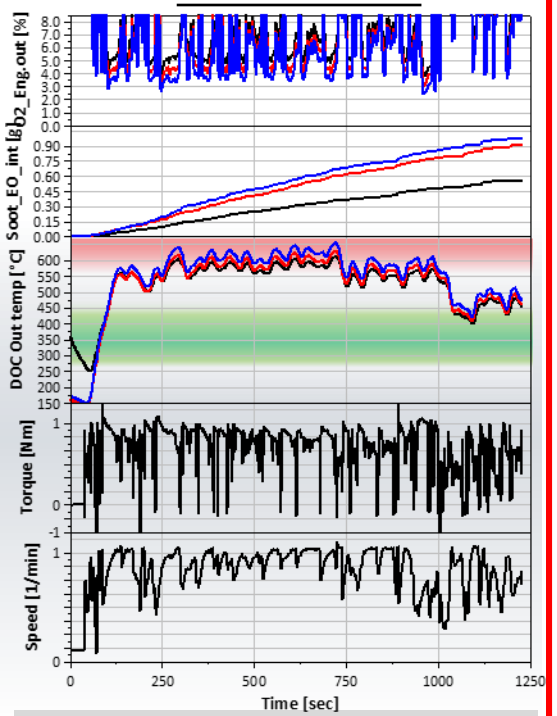
Critical cycle analysis

Empty trailer



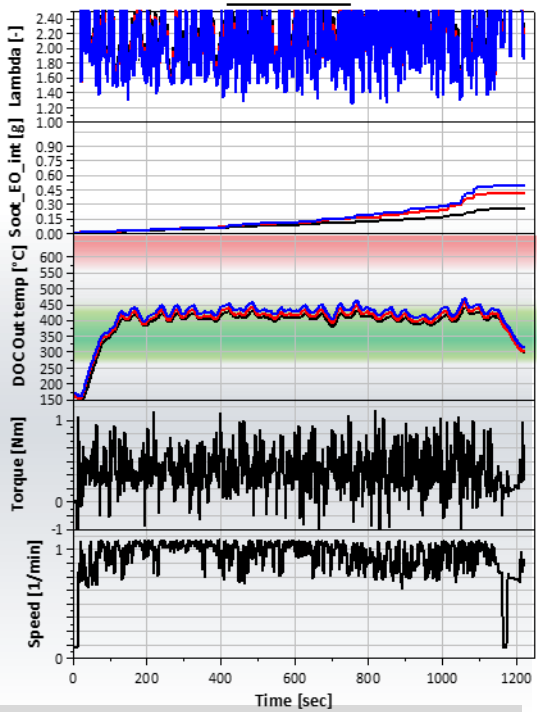
- Low load operations leading to better lambda and lower Engine out Soot levels.
- Exhaust temperature between 250-300˚C Optimal for CRT.

Loaded trailer



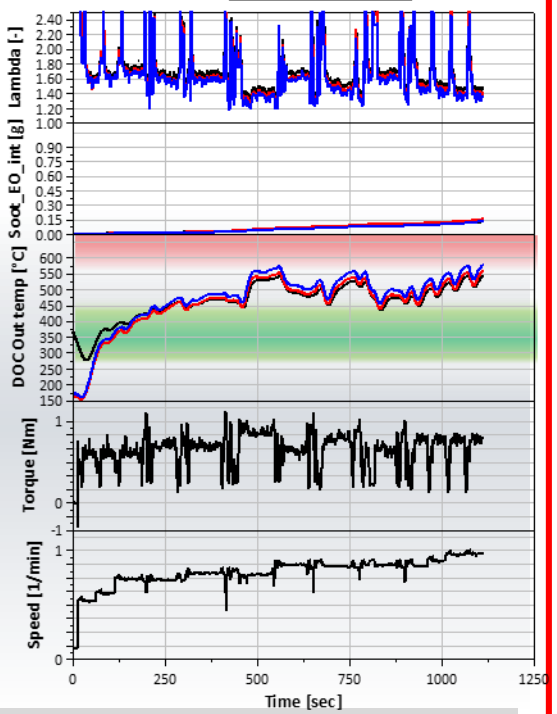
- High load, transient operations → critical lambda and Very high Engine out Soot levels.
- Exhaust temp mostly >550˚C & O2>3% → Active regen. use case.

Loader



- High load, transient operations → Relatively high Engine out Soot.
- Exhaust temp between 400-450˚C → Upper threshold of CRT zone

Ploughing



- Medium load, transient operations → Relatively low Engine out Soot.
- Exhaust temp between 400-550˚C & CRT?

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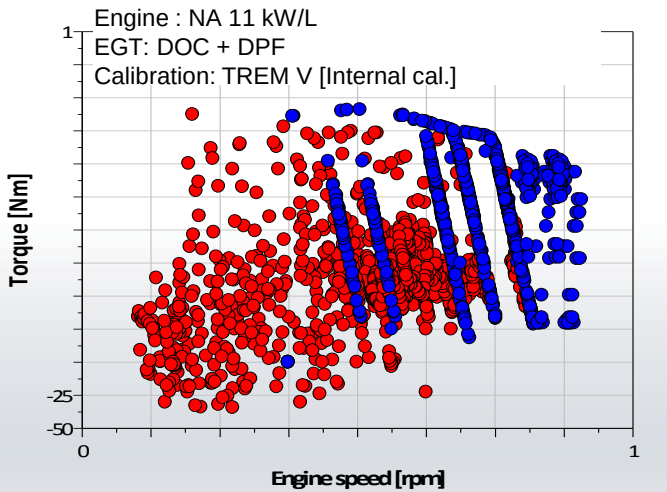
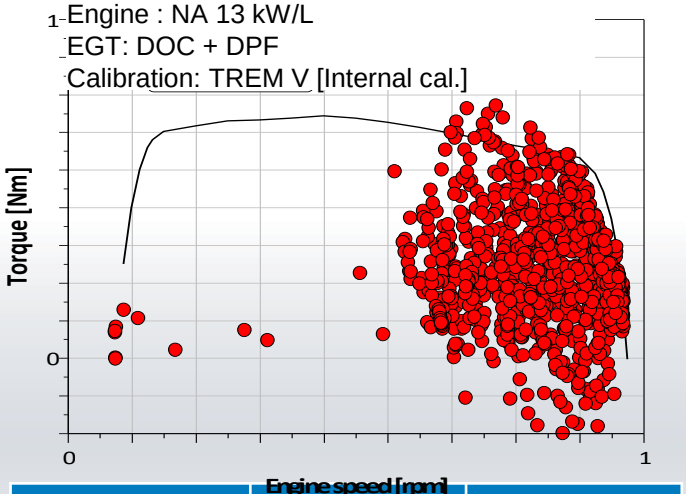
Critical soot load cycles

Ploughing cycle1



Cumulative hours run (hrs)	DPF Soot entry_MSS [g]	Physical Soot mass in DPF (g)
0	0	0
20	5	1.8
40	11	2.88
60	~19	3.98

Loader Cycle



Cumulative hours run (hrs)	DPF Soot entry_MSS [g]	Physical Soot mass in DPF (g)
0	0	0
20	~24	4.7
40	~50	7.5
60	~80	9.3

Conclusion

- ~75% Soot burn off in critical cycles → combined Passive and active regenerations.
- **DPF RGN interval > 100 hours** under nominal system disturbances → Model air mass, without EGR close loop, **suffices** the requirements.
- Project specific use cases, trial matrix and field trials necessary.
- Robust open loop EGR functional performance required.

Off-Highway requirement engineering for TREM V

DPF regeneration strategy for <56 kW NA TREM V segment

	1. Only Passive regeneration	2. Passive + Service regen.	3. Active regeneration
Advantages	• **Most economical** – EGT overall cost and development cost reduction.	• **Economical** and **practical** option for OEMs - Both EGT and development. • High Pt with low Pd. • Limited-Service regeneration as backup → More **robust solution** to market.	• **Most robust solution** compared to Option 1 & 2. • High Pt with high Pd • **Can cover critical load collectives** with high soot loading requiring frequent regeneration (especially in cold altitude conditions) without driver intervention
Risks	• **No back up** in case of DPF soot load / failure due to DOC's in-efficiency to active regen. • Reliability of such DOC over lifetime with exposure to high temperatures [NA]	• End customer education on service regen., implications of nonadherence. • Auto active regen. Not feasible in entire engine operating zone • Complex EGT design to cater requirements of Passive, service regen. & reliability over lifetime.	• **High EGT cost and development cost**. (post implementation, feedback from field and currently adapt with efficient development methods)
Conclusion	• **Not recommended currently,** as there is no backup in case active regeneration is required and all use cases coverage.	• **Feasible solution** • Prerequisite - Low engine out soot, good NO2 to soot ratio and EGT designed for passive and O2 based regen	**Most Robust solution.**

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Thank you for your attention...

Questions?

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