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Part of BASF Group

Advanced TWC Technology for FFVs (E22–E100) to Meet BS-7 Emission Norms

India Push Towards Flex Fuel

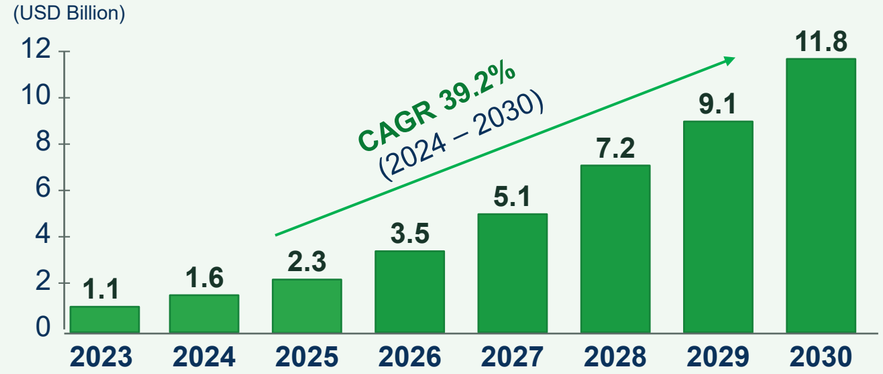
Import Substitution & Energy Security
- E20 reduces petrol's fossil component and supports lower crude-oil dependence
- Higher ethanol blends via FFVs can deepen domestic fuel substitution

Renewable / lower life-cycle
- Sugarcane ethanol: ~65% lower GHG than petrol
- Maize ethanol: ~50% lower GHG than petrol

Feedstock flexibility
- 1G: sugarcane juice / molasses, maize and eligible grains
- 2G: agricultural residues and lignocellulosic biomass
- Diversified feedstock supports rural value creation

Vehicle & Fuel Ecosystem
- Flex-fuel vehicles can operate across varying ethanol-petrol blends
- India's next step beyond E20 is higher blends and FFV scale-up
- Requires aligned vehicle calibration, materials, dispensing and consumer awareness

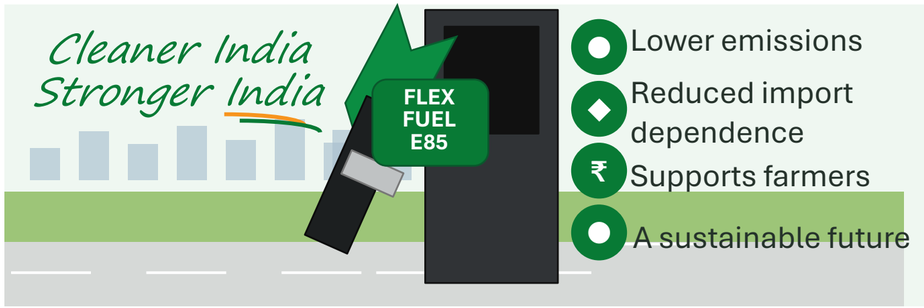
India Flex Fuel Market Size



Ethanol Blending Targets in India

E10 (2022) → E20 (2025–26) → E30? (by 2030)

Paving the way for a larger flex fuel market



From Farms to Fuels – Flex Fuel for a Stronger, Greener India

Note: Market size figures are estimates and may vary across sources.

BS-7 Flex Fuel: Catalyst Challenges and Opportunities

Potential

Durability Increase

1,60,000km ➔ 2,00,000km

US- Tier-3/Tier-4
Euro-7/ BS-7

BS-7 Flex Fuel

Challenges

Total THC In Consideration

BS-7- 100mg/km

Brazil NMOG + NOx for BIN30

Euro-7/BS-7
US- Tier-4

More Stringent Particulate Control

PN10 introduction.

Euro-7/BS-7 PN10
China CN-7 PN10

India vs Brazil Legislation for FFV

BRAZIL (PL-8)

- Flex-fuel centric legislation
- NMOG + NOx combined limit
- Oxygenated hydrocarbons included
- Aldehydes regulated separately
- BIN30 will be implemented from April 2029

Pollutant	mg/km
NMOG+NOx	50
PM	4
CO	600
Aldehydes	10

Technology Implication:

- Catalyst must efficiently convert ethanol-derived species.

INDIA (BS-6)

- Fuel-neutral legislation
- Separate THC and NOx limits
- Methane included in HC assessment
- India doesn't regulate aldehydes and oxygenated hydrocarbons
- Applicable to gasoline, CNG, LPG and flex-fuel vehicles

Parameter	Limit mg/km
CO	1000
THC	100
NMHC	68
NOx	60
PM	4.5
PN23 (GDI)	6.0×10^{11} #/km

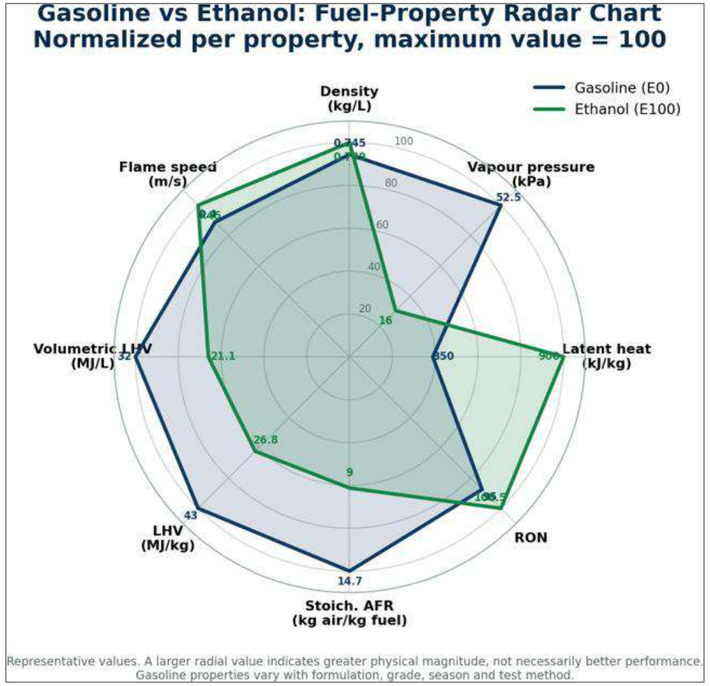
Technology Implication:

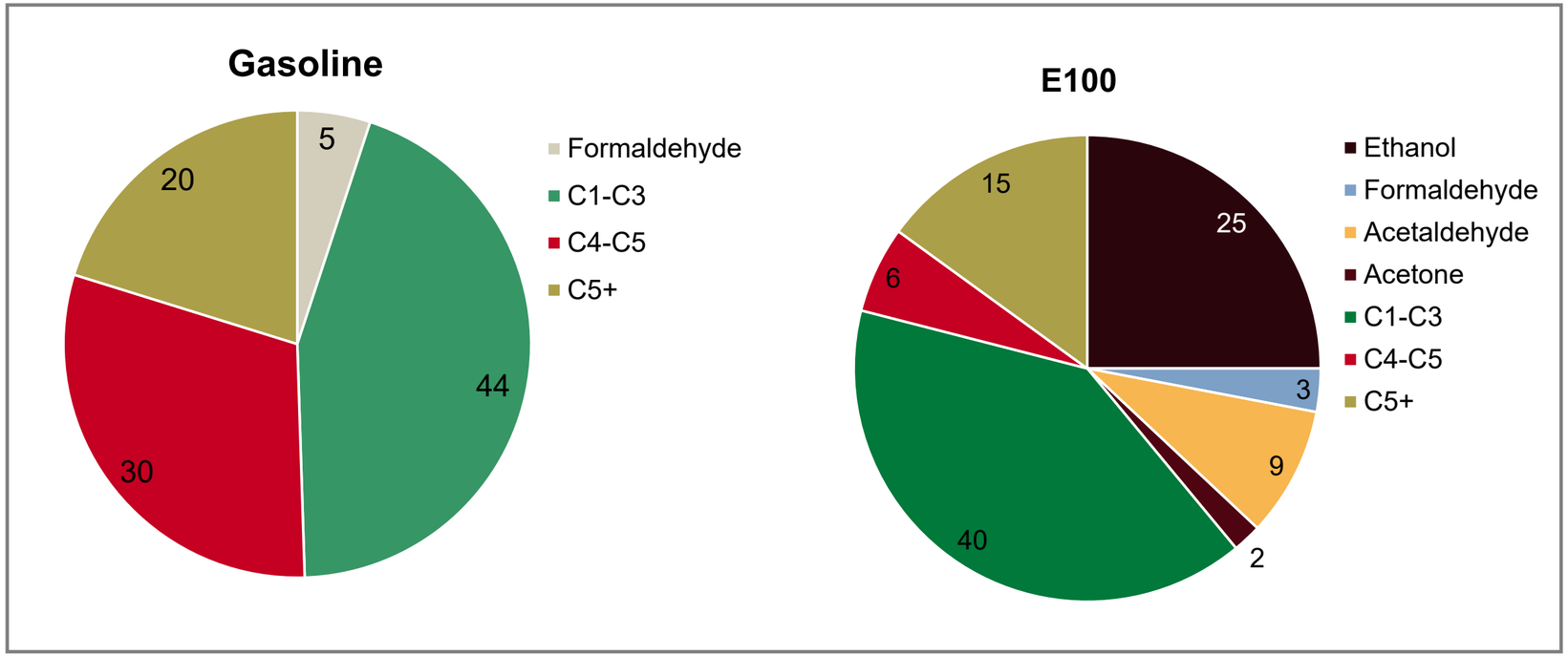
- Catalyst optimization strongly considers methane conversion.

Different Regulatory Drivers → Different Catalyst Strategies

Gasoline vs Flex Fuel: Comparison

- E100 engine out showed increased oxygenated and reduced medium (C4-C5) and large (C5+) hydrocarbon emissions;
- Catalyst performance would be affected.





Source: https://afdc.energy.gov/fuels/properties

Flex fuel: Emission Benefits and Aftertreatment Challenges

- Increasing ethanol reduces fossil-carbon, aromatic and particulate emissions, but shifts the critical challenge toward cold-start oxygenates and tighter catalyst control.

		E0	E20	E85	E100
EMISSIONS	Fossil CO_2 contribution	Baseline	Lower	Much lower	Lowest
	Engine-out CO	Baseline	Usually lower	Lower when warm	Lower when warm
	Conventional HC / aromatics	Baseline	Lower	Much lower	Lowest
	Ethanol slip	Negligible	Low	High	Very high
	Acetaldehyde / carbonyls	Low	Moderate	High	Very high
	NO_x sensitivity	Calibration-dependent	Lambda trim critical	High sensitivity	Highest sensitivity
	Particulate mass & number (GDI	Baseline	Lower	Much lower	Lowest tendency
	Evaporative-emission tendency	Baseline	Can increase	Generally lower	Low HC vapour
TWC CONTROL	Cold-start difficulty	Baseline	Moderate	High	Very high
	Catalyst light-off challenge	Baseline	Moderate	High	Very high
	Lambda-control sensitivity	Baseline	Higher	High	Very high
	Dynamic OSC demand	Baseline	Higher	High	Very high

Low | Moderate-low | Moderate | High | Very high

1 Clear emissions upside

Higher ethanol generally lowers fossil CO_2 contribution, aromatics, conventional HC and GDI particulate emissions.

2 E20 is mainly a control transition

Existing TWC architecture can remain effective, but ethanol recognition, fuel correction and lambda-bias calibration are essential for NO_x conversion.

3 E85/E100 need a dedicated strategy

Cold-start evaporation, ethanol slip and acetaldehyde dominate. Priorities are rapid thermal activation, Pd-rich oxygenate oxidation, accessible Rh and high-dynamic OSC.

Source: Microsoft Copilot AI-generated illustration.

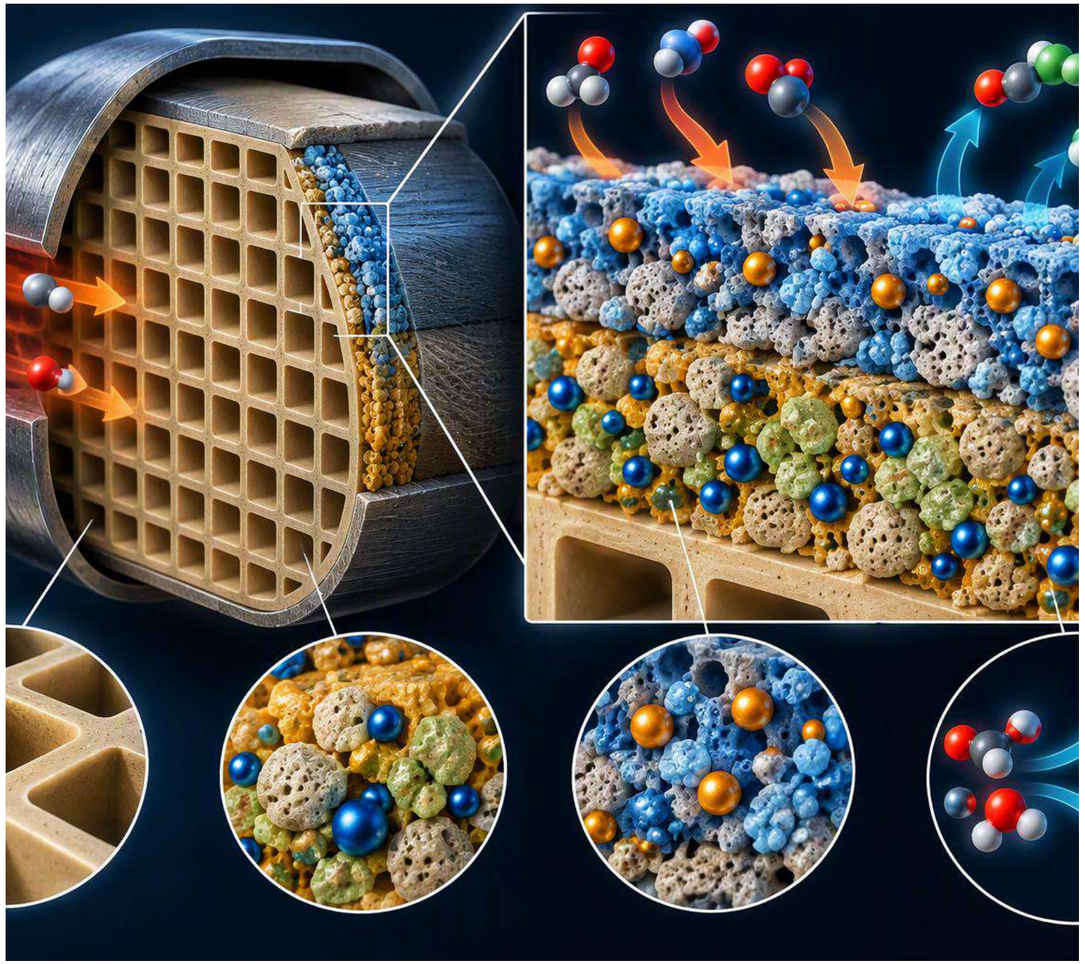
Main Reactions of Ethanol Conversion and Mechanisms

- Ethanol degradation via multiple pathways
- Some reactions produce secondary pollutants
  - Ethanol oxidation
    $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$
  - Ethanol decomposition
    $C_2H_5OH \rightarrow \mathbf{CH_4} + \mathbf{CO} + H_2$
  - Ethanol partial oxidation
    $C_2H_5OH + 1/2O_2 \rightarrow \mathbf{CH_3CHO} + H_2O$
    $C_2H_5OH + 3/2O_2 \rightarrow 2CO_2 + 3H_2$
  - Ethanol dehydrogenation
    $C_2H_5OH \rightarrow \mathbf{CH_3CHO} + H_2$
  - Ethanol dehydration
    $C_2H_5OH \rightarrow \mathbf{CH_2{=}CH_2} + H_2O$
  - Ethanol steam reforming
    $C_2H_5OH + 3H_2O \rightarrow 2CO_2 + 6H_2$
  - Ethanol oxidative steam reforming
    $C_2H_5OH + 2H_2O + 1/2O_2 \rightarrow 2CO_2 + 5H_2$

- Degradation of secondary pollutants from ethanol
  - Acetaldehyde decomposition
    $CH_3CHO \rightarrow \mathbf{CH_4} + \mathbf{CO}$
  - Ethylene oxidation
    $CH_2{=}CH_2 + O_2 \rightarrow CO_2 + 2H_2O$
  - Methane oxidation
    $CH_4 + 2O_2 \rightarrow CO_2 + H_2O$
  - Methane steam reforming
    $CH_4 + H_2O \rightarrow CO + 3H_2$
  - CO oxidation
    $2CO + O2 \rightarrow 2CO2$
  - CO water gas shift
    $CO + H_2O \rightarrow CO_2 + H_2$
- Ethanol and Acetaldehyde decomposition could be the root cause of CH4 and CO increase

McAtee et al.,Proc IMechE Part D: J Automobile Engineering, 2012, 226(11), 1536-1546

Flex Fuel Changes the TWC Operating Envelope



Cold start

Higher priority on rapid CO/HC and oxygenate clean-up before full catalyst light-off.

λ transients

Fuel composition changes engine-out chemistry; effective TWC control still depends on tight stoichiometric operation.

Water + Thermal

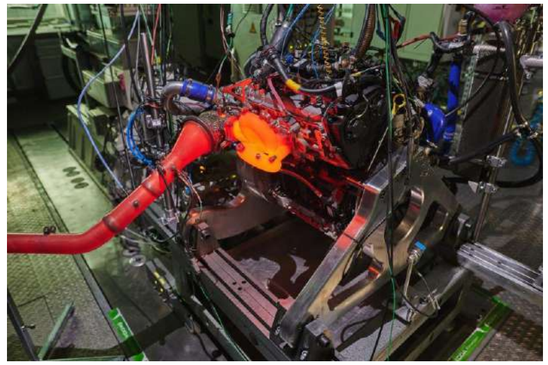
Hydrothermal stability and PGM dispersion become central durability screens.

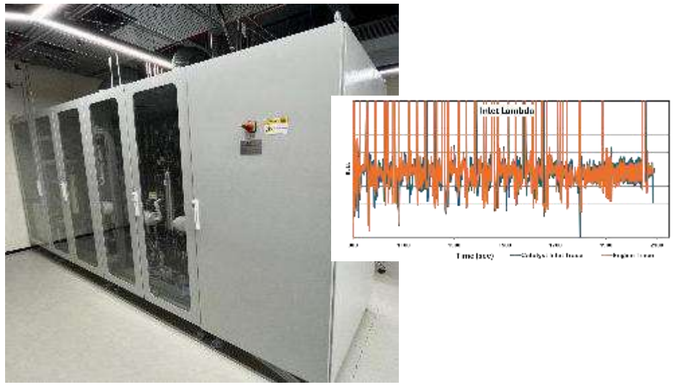
Secondary emissions

Track NH_3 and N_2O together with CO, THC and NOx during formulation screening.

Design implication: optimize spatial chemistry, not only total PGM loading.

Catalyst Evaluation Methodology





Catalyst formulation

- Different technologies, PGM ratios
- Core-size, representative of full-size

Engine bench aging

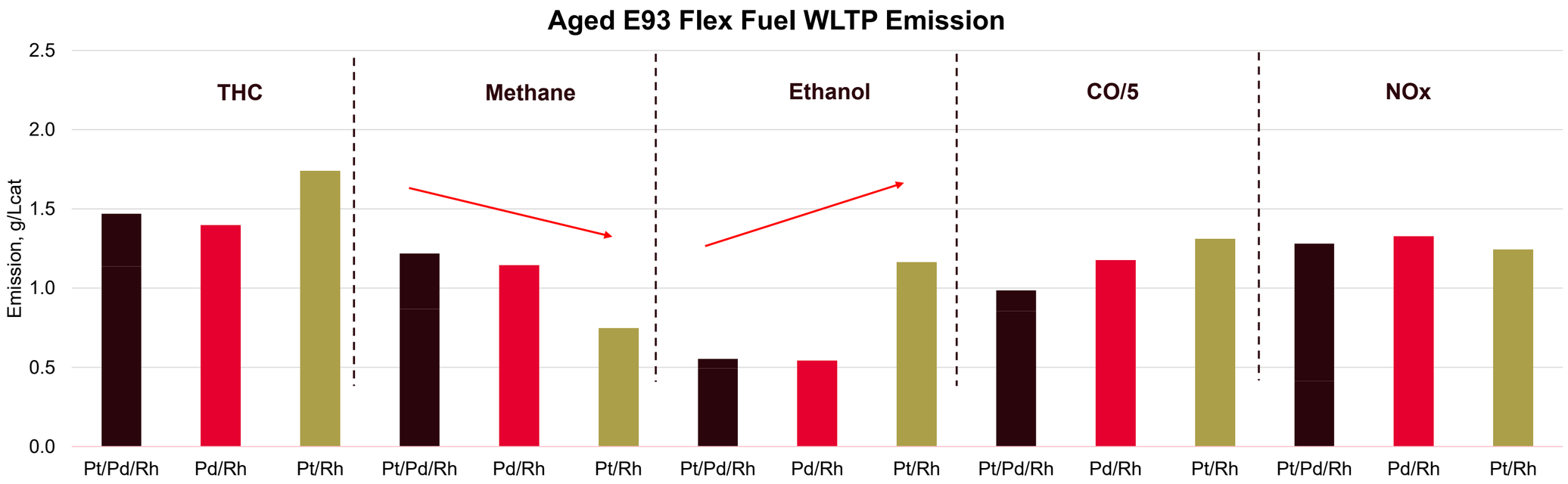
- Lean-rich aging for 50h

Evaluation on transient reactor

- Accurate reproduction of real-world driving cycles – temperature, gas flow and composition

Necessity of PGM Combinations in FFV

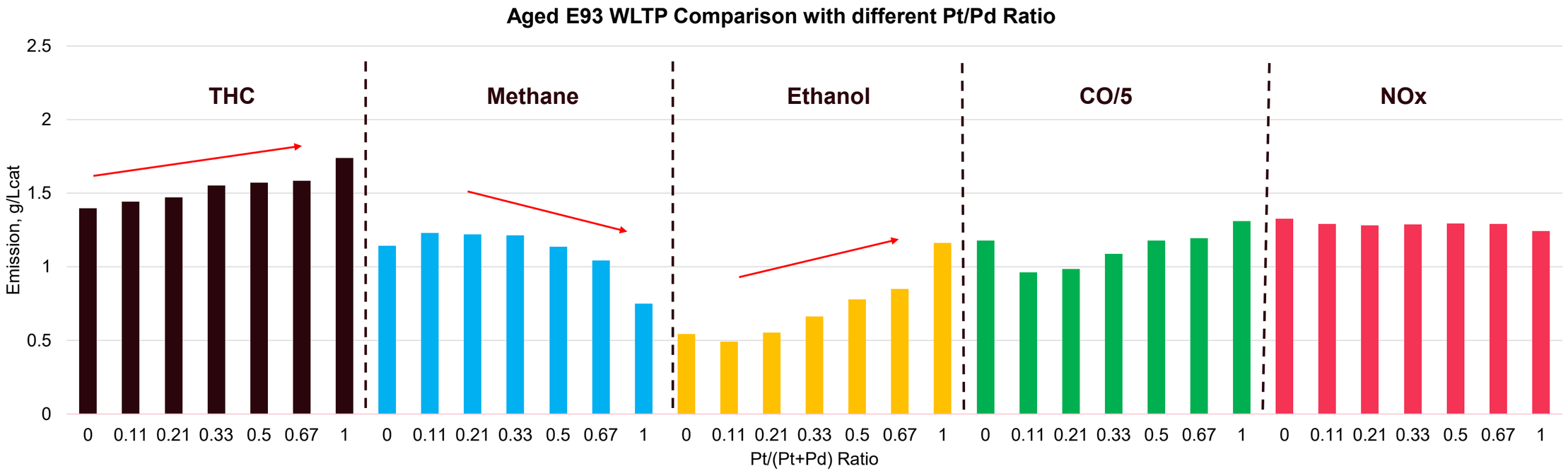
Pt/Pd/Rh	Pd/Rh	Pt/Rh
2.5/50/2.5	0/52.5/2.5	52.5/0/2.5



- Pd/Rh: Best THC & ethanol conversion
- Pt/Pd/Rh: Best CO conversion
- Pt/Rh: Lowest CH_4, highest THC & ethanol
- Pt benefit: Marginal overall improvement
- CH_4-ethanol trade-off suggests different reaction pathways

Engine Bench Aging – 50hr

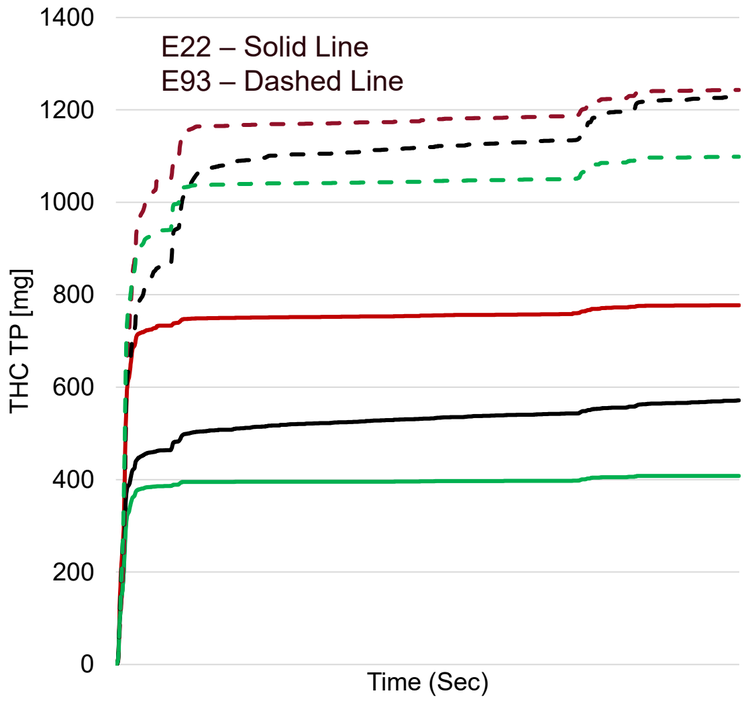
Effect of Pt/(Pt+Pd) Ratio on Flex Fuel Emission



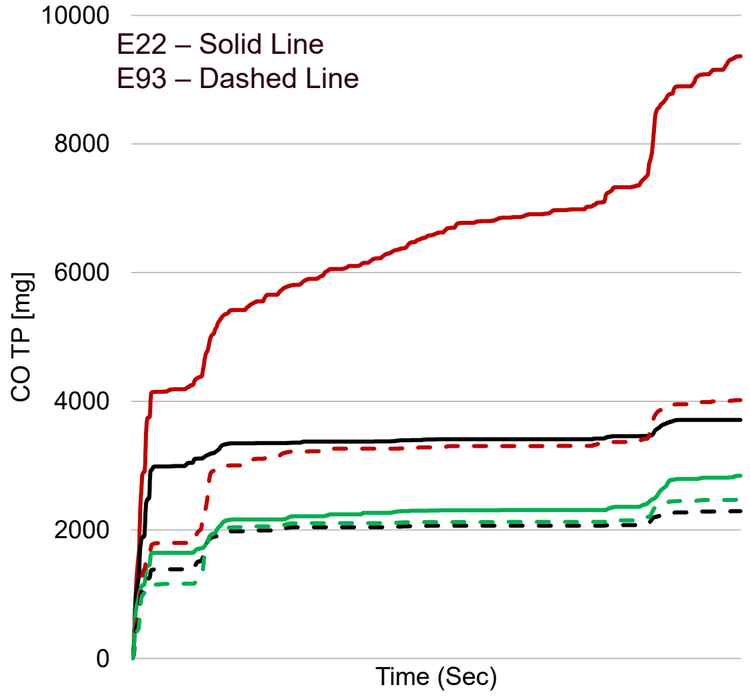
- Pd/Rh showed best performance for THC
- By increasing the ratio of Pt, THC continuously became worse. Ethanol and CO reached lowest emission with Pt/(Pt+Pd) ratio at 0.11
- NOx slightly improved with increasing Pt ratio
- The trend indicated Pd was active to convert ethanol to acetaldehyde and methane, leading to high emission of methane. On the contrary, with Pt rich, Pt is less active to convert ethanol to methane, leading to low emission of methane but high emission of ethanol
- Overall performance reached best at Pt/(Pt+Pd) = 0.11

Flex Fuel Catalysts Evaluation

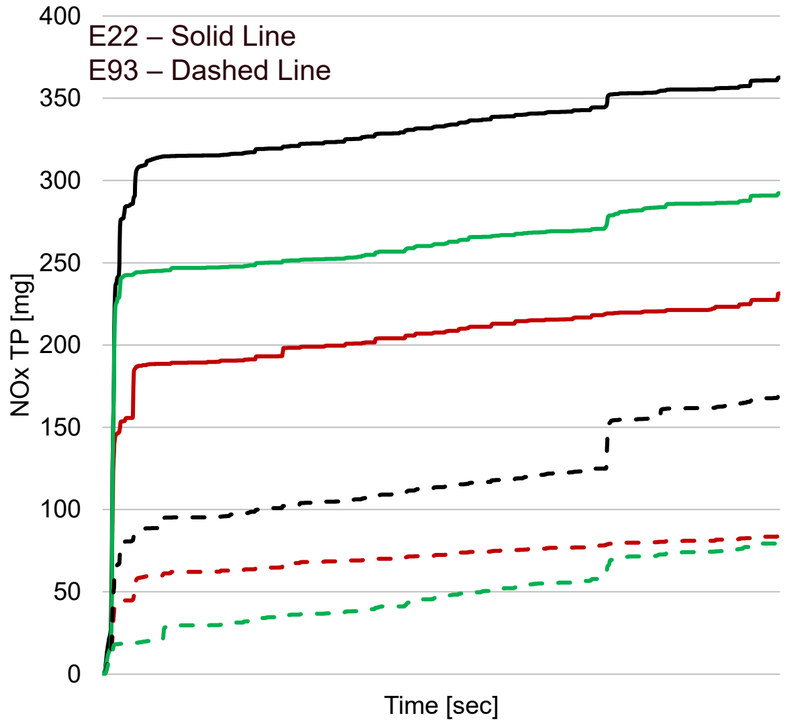
HC Performance TP



CO Performance TP



NOx Performance TP

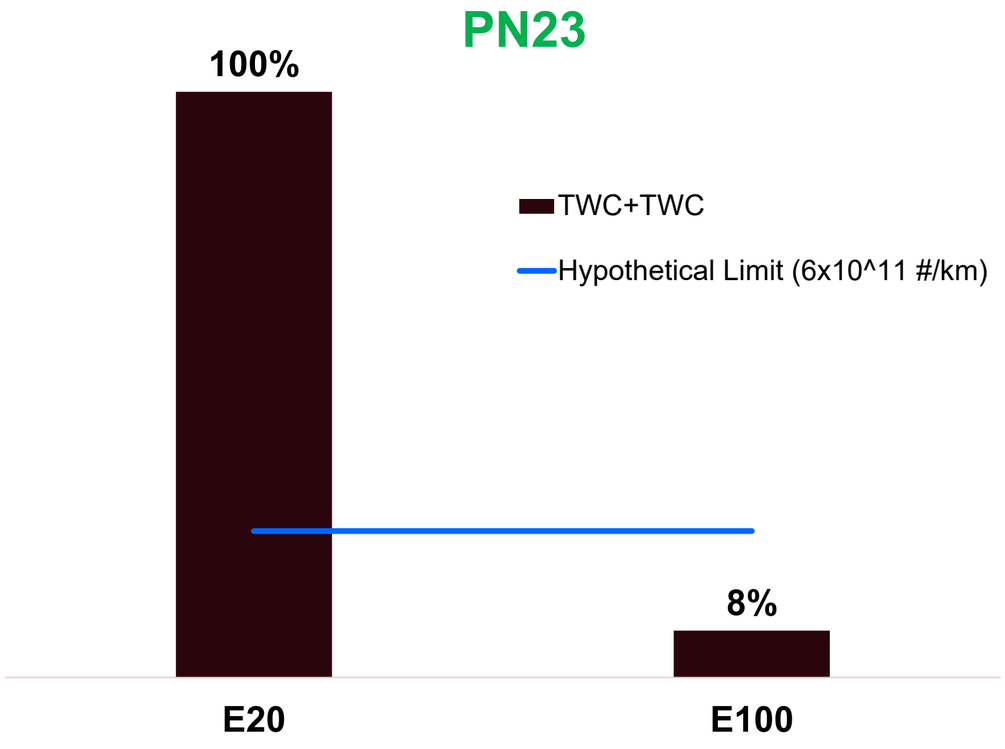


- Tail pipe THC emissions increased for E93 fuel compared to E22 fuel.
- Bi-metal design-2 showed the best THC and CO performance.
- Trimetallic catalyst achieved the lowest NOx emissions.
- The PGM cost of all catalyst designs kept same for evaluations.

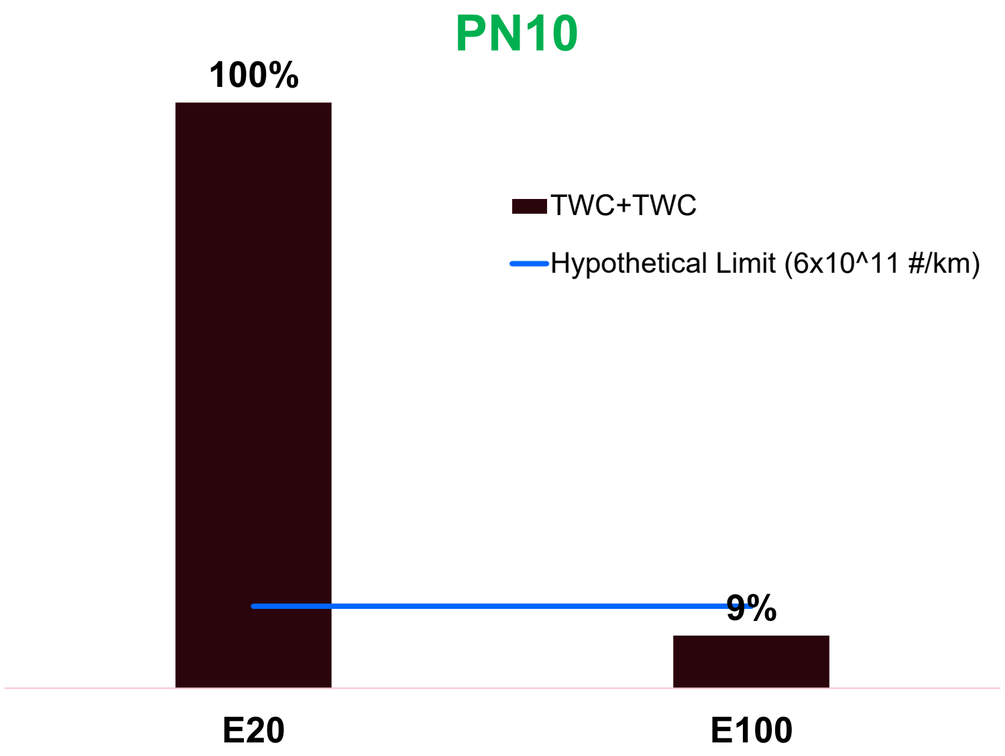
Engine Bench Aging – 50hr
Test Cycle – FTP-75

PN23 & PN10 Assessment

- E100 reduced PN23 emissions by ~92%, demonstrating a substantial decrease in solid particle formation compared with E22.



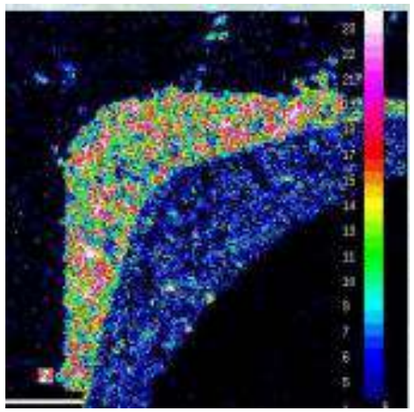
- PN10 emissions are ~1.8x higher than PN23
- E100 reduced PN10 emissions by ~91%, significantly lowering ultrafine particle emissions and enhancing future regulatory compliance margins.



1.5L GDI Vehicle
Test Cycle – WLTP

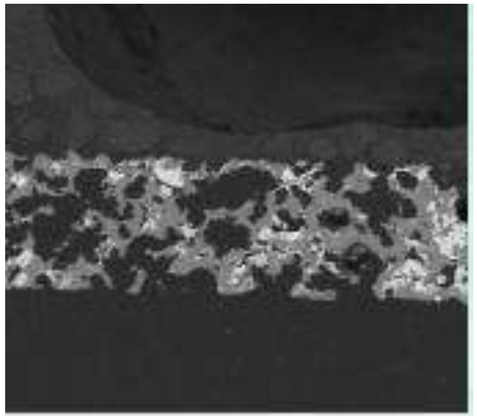
Gasoline Particulate Filters : FWC+

Euro-6 Gasoline Particulate Filter



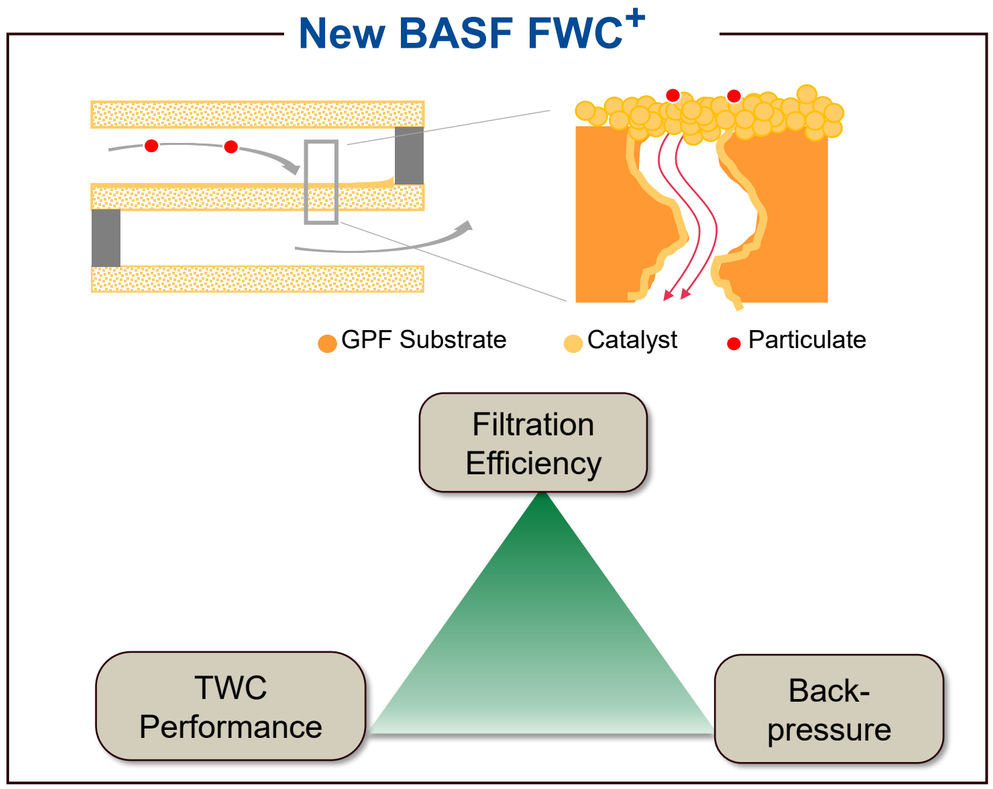
Four Way Catalyst

- Particulate Filtration
- Catalyst Activity



Four Way Catalyst +

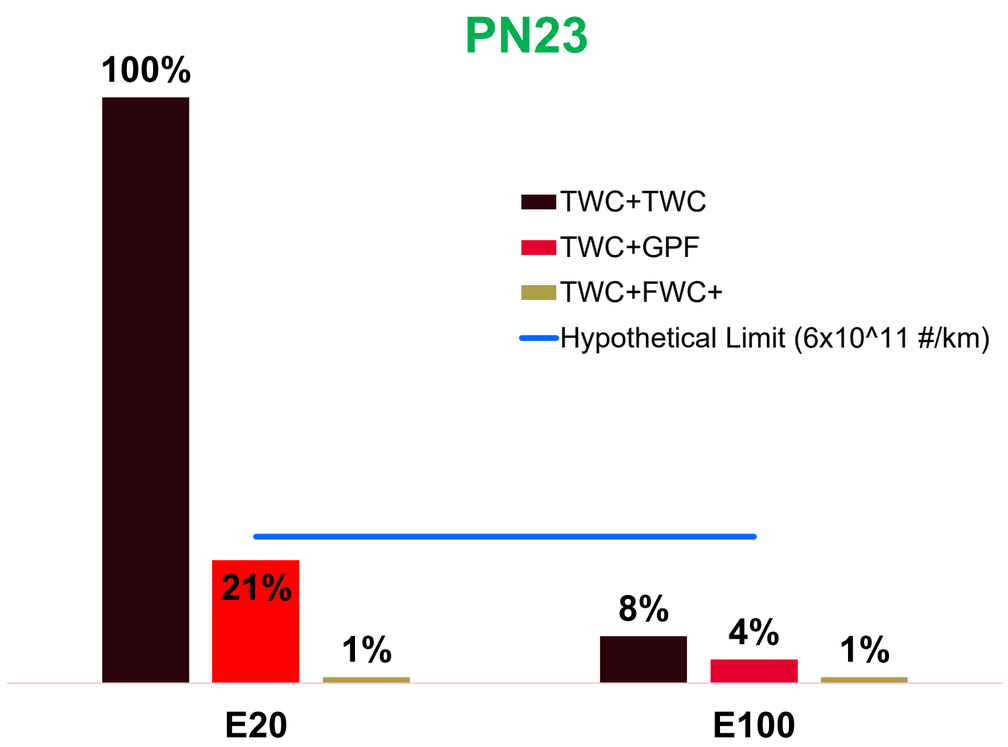
- Particulate Filtration
- Catalyst Activity
- Tailored to backpressure and Fresh Filtration requirement



PN23 & PN10 Assessment

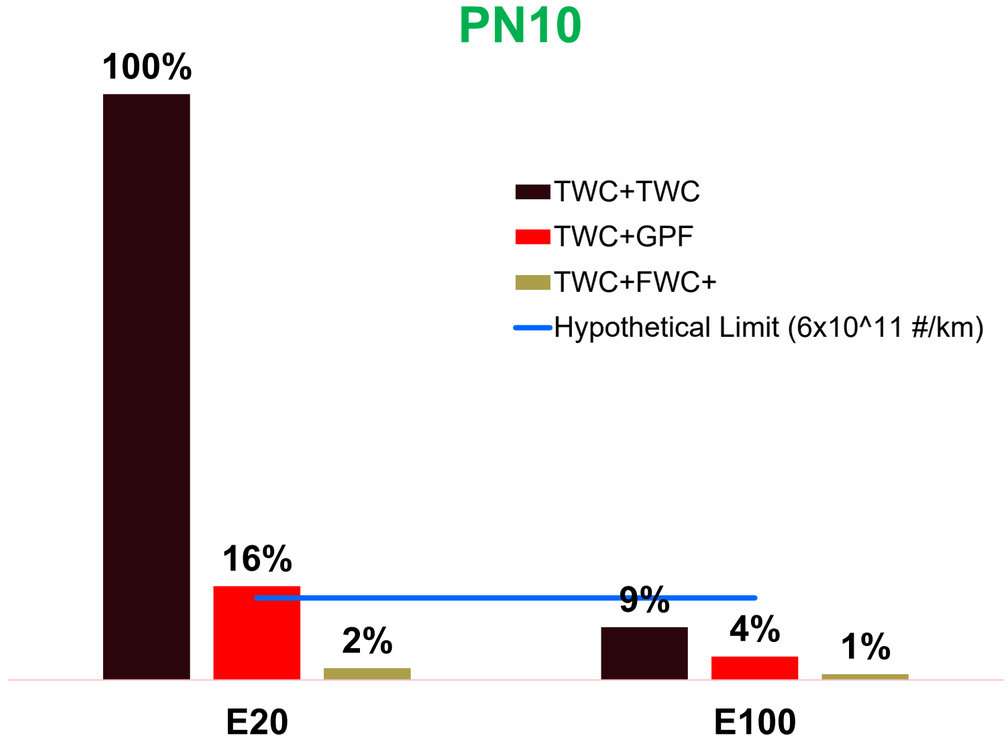
FWC reduced PN23 emissions to ~1% of baseline levels for both fuels.

- E100 significantly improves PN23 emissions.
- GPF delivers substantial PN23 reduction; however, remains close to the hypothetical limit for E20.
- FWC provides robust margin toward future PN23 limits.



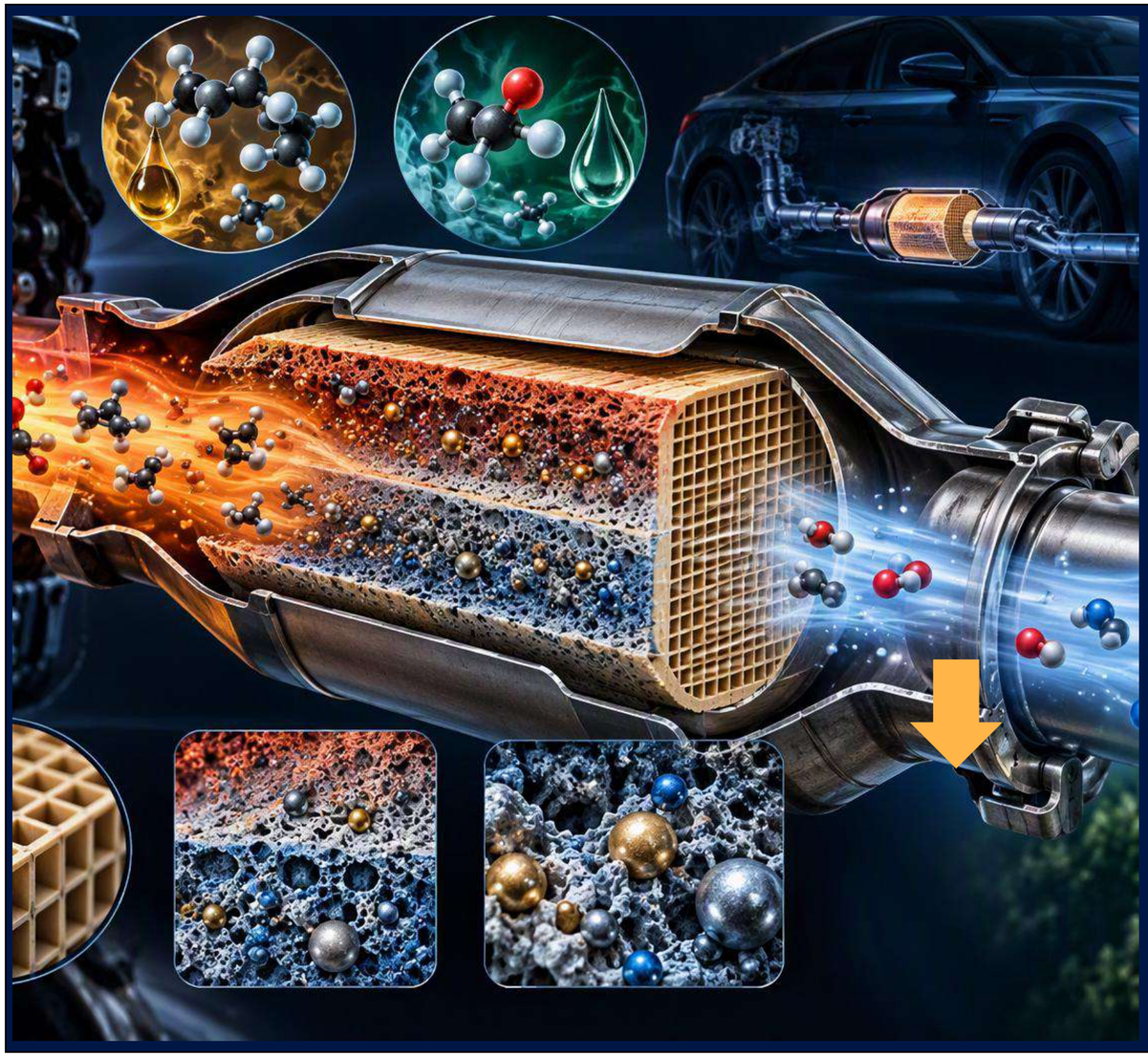
FWC reduced PN10 emissions to ~1-2% of baseline levels for both fuels.

- E100 significantly improves PN10 emissions.
- GPF delivers substantial PN10 reduction; however, operates at the hypothetical limit for E20.
- FWC provides robust margin towards future PN10 limits,.



1.5L GDI Vehicle
Test Cycle – WLTP

Metivo Advanced FFV Technology



OPTIMIZED Pt/Pd/Rh RATIO

For low-temperature activity / secondary-emission trade-offs/ strong thermal-aging resistance

OPTIMIZED TWC DESIGN TO ADDRESS

- Cold start requirement
- Better hydro-thermal stability
- Dynamic oxygen storage capacity

ADVANCED FOUR-WAY CATALYST +

Best catalyst activity tailored low backpressure and high fresh filtration efficiency > 90%

Metivo™

Part of BASF Group