

Advanced Catalyst Technologies for Fulfilling upcoming Standards

Paving the way to a Sustainable Future

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BASF Environmental Catalyst and Metal Solutions

 **BASF**

We create chemistry

A BASF Standalone Division

BASF Environmental Catalyst and Metal Solutions (ECMS)

Mobile Emissions Catalysts



Emissions control catalysts for cars, trucks, motorcycles, non-road vehicles

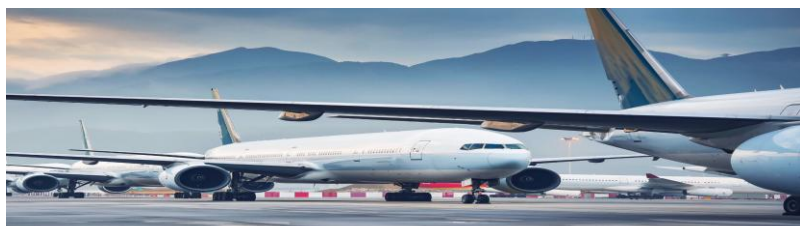
Precious Metal Services & Recycling



Trading



Recycling



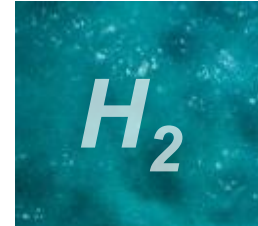
Catalysts for ozone and VOC removal for aviation industry



Precious Metal Chemicals



Temperature Sensing



Solutions for hydrogen value chain

4,500 employees

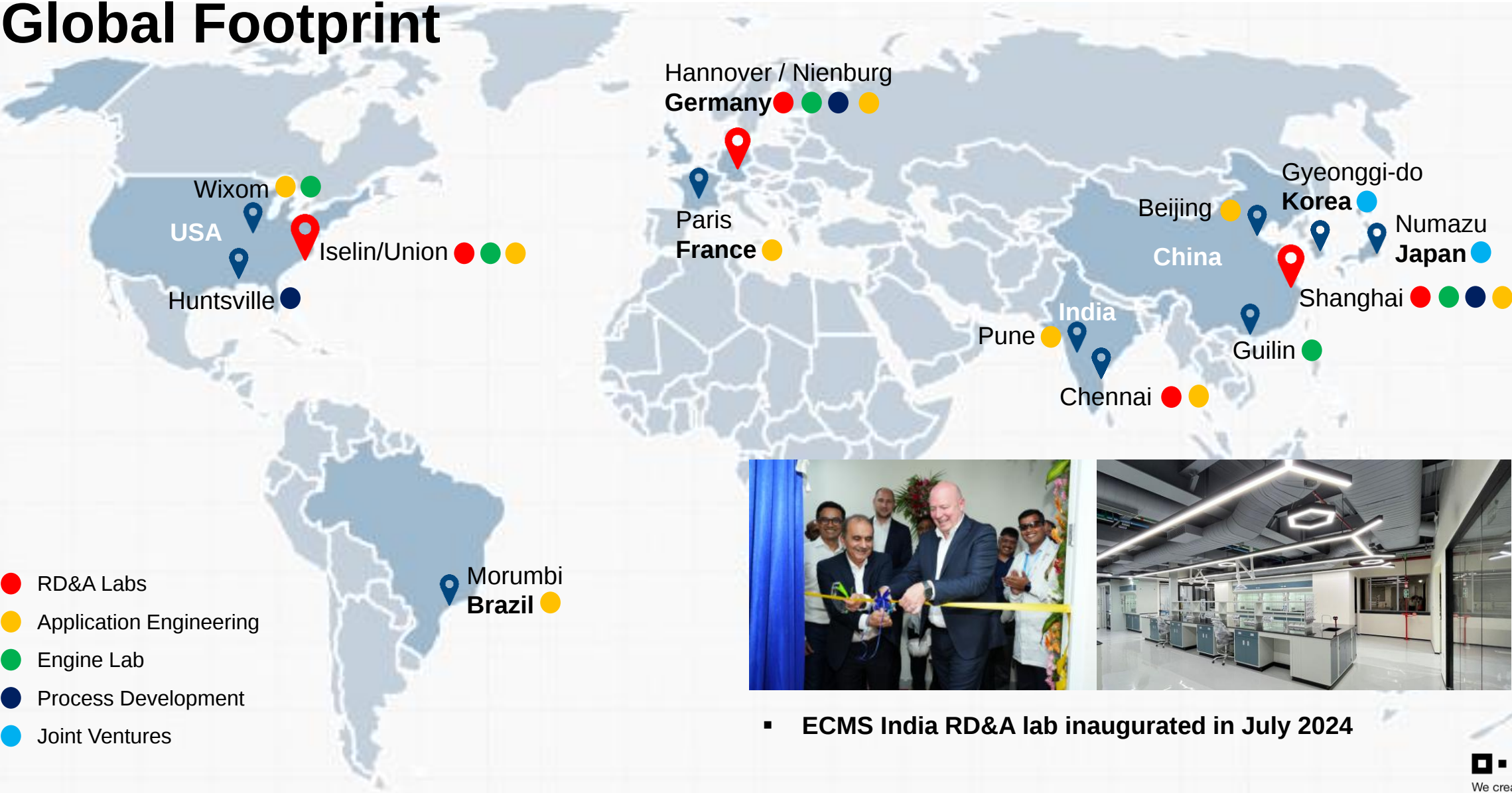
30 Sites

- 20 Manufacturing
- 10 R&D
- Others

in 14 countries globally

7.0bn € sales 2024

ECMS RD&A (Research, Development and Application) Global Footprint



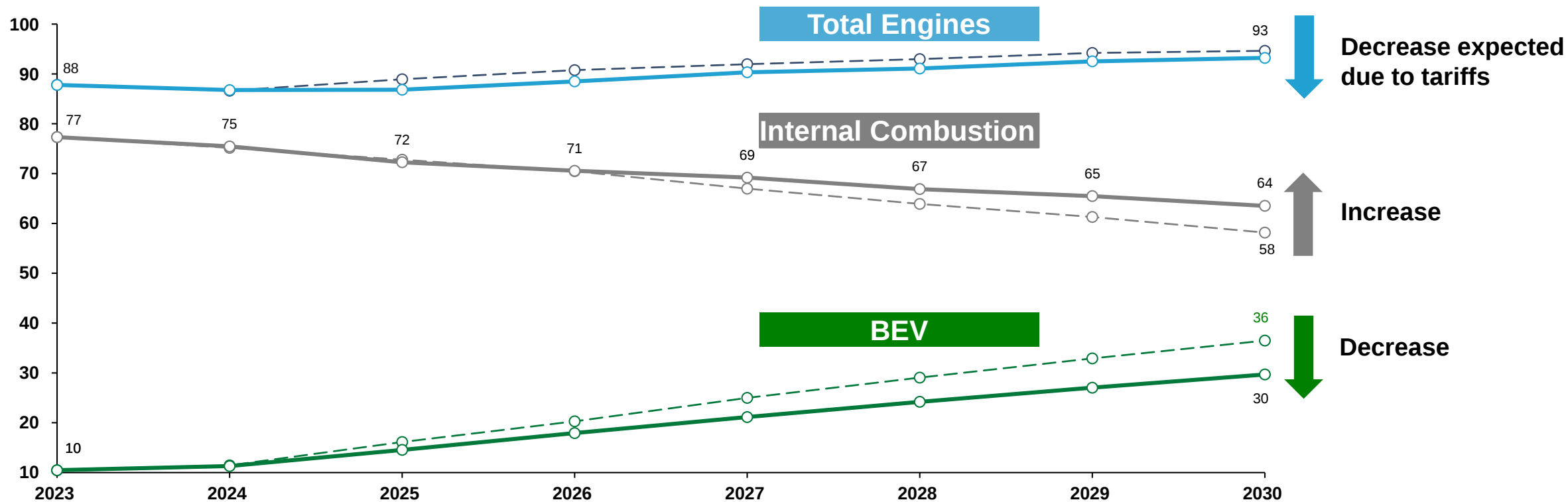
▪ ECMS India RD&A lab inaugurated in July 2024

Global Light Vehicle Production

BEV penetration has slowed down

Vehicle production
[m unit engines]

Solid lines: 2025-03
Dotted lines: 2024-07



* Y-axis starts from 10m unit engines.

Source: IHS 2025-03 vs 2024-07 LV forecast (0-3.5t, all powertrain)

Global Light Duty Gasoline Emission Regulations



- **Tier4** with phase-in by 2032
- **PM** limits: 0.5mg/mile
- Lowest global NMOG + NO_x limits



- PL8 started 2025
- High **Ethanol** usage
- Focus on NMOG+NO_x



- **Euro 7** starting 2026
- **PN₁₀** at 6x10¹¹ #/km
- **OBM** (On-board monitoring)



- High share of PHEV & REEV
- **China 7** expected 2029
- **PN₁₀** & **NH₃** limits likely



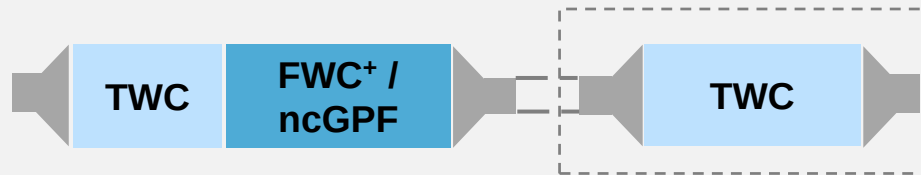
- WLTP (3P) in 2027
- **BS7** likely to take over aspects from Euro 7 and China 7 earliest 2029
- **CNG** and **Biofuels**

*PM = Particulate Mass
*PN = Particulate Number
*NMOG = Non-Methane Organic Gases
*PHEV = Plug-In Hybrid Electric Vehicle
*REEV = Range-Extended Electric Vehicle

Light Duty Gasoline Future Catalyst Layouts



- Highly porous flow-through substrates & PGM zoning for CC1 TWC
- Filter introduction for particulate mass (PM) control
- Higher thermal durability required (no enrichment)



*ncGPF = not coated Gasoline Particulate Filter



*TWC = Three-Way Conversion Catalyst

*FWC = Four-Way Conversion Catalyst = coated GPF

*AMOX = Ammonia Oxidation Catalyst

Europe

- High filtration efficiency filter for PN treatment

China

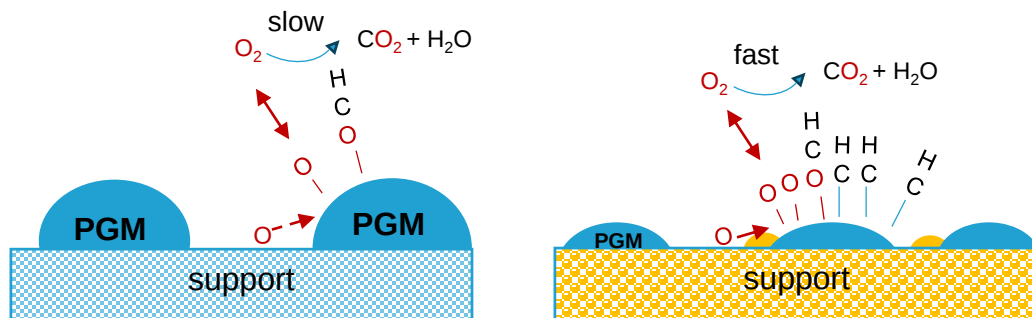
- Focus on close coupled system due to limited available space in PHEVs/REEVs
- High filtration efficiency filter for PN treatment
- AMOX and low-NH₃-make-TWC likely



Euro VII technologies to be tailor-made for India BS7

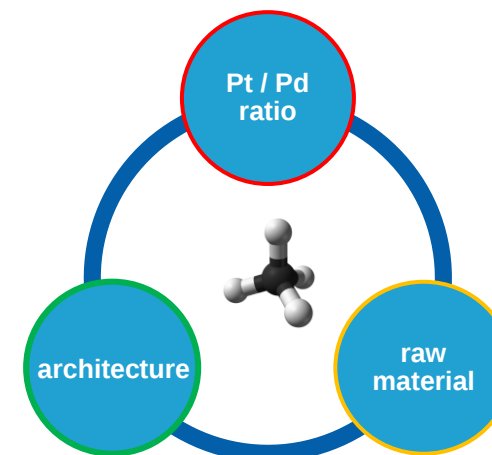
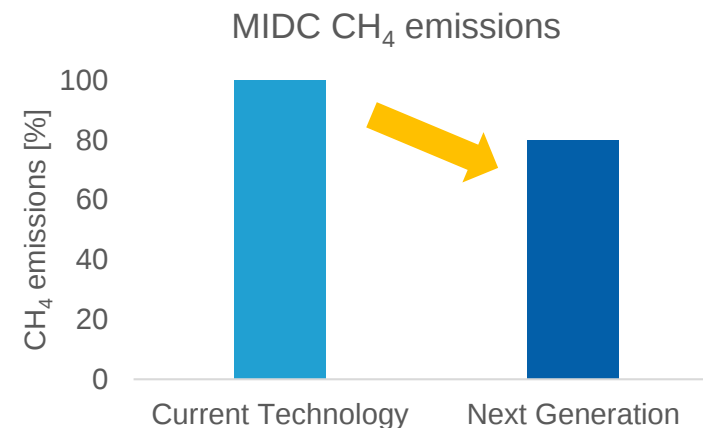
Tailor-made TWC for Stricter Regulations

Gasoline

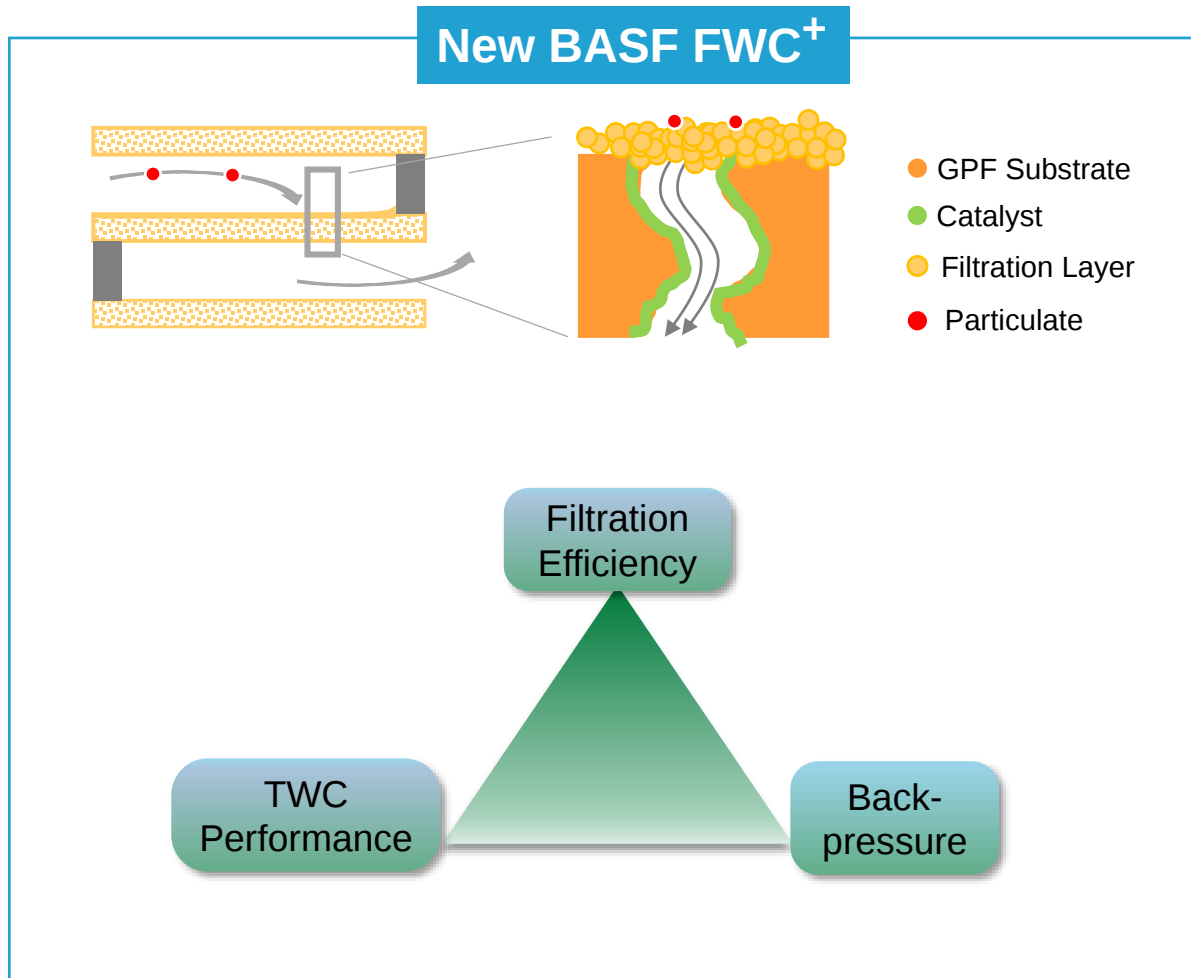


- High Rh efficiency required due to recent price trend
- Rare-Earth package for optimal OSC function and supply security
- PGM anchoring for high thermal durability
- Selectivity optimization for low NH_3 make and low CH_4 make in FlexFuel applications

Bi - Fuel



Filter Solutions for Stricter Regulations



FWC

- Contributes to overall **emission robustness** due to PGM containing catalyst coating
- **Full oxidation of soot** to CO₂ during regeneration
- **Lower onset temperature** for soot regeneration
- Better **space utilization**

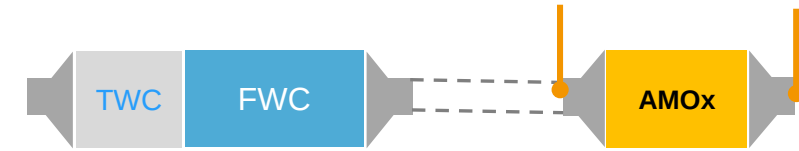
FWC⁺

- **Ultra-high Fresh Filtration Efficiency (FFE)** possible for PN₁₀ (and PM, PN₂₃)
- **Low backpressure** due to low layer thickness
- Layer can be **tailor-made** based on requirement
- Low and linear soot-loaded-backpressure due to soot cake formation at low loadings / **Calibration friendly**

*FWC = Four-Way Conversion Catalyst = coated GPF

*FWC⁺ = FWC with additional measures for high Filtration

Ammonia Control for Gasoline

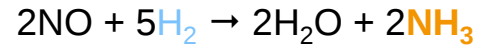


Ammonia oxidation



Ammonia oxidation catalyst

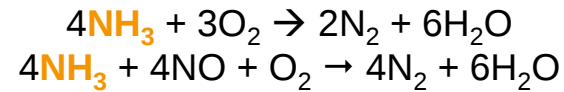
Formation of NH_3 during periods of rich operation ($\lambda < 1$)



Minimize NH_3 formation

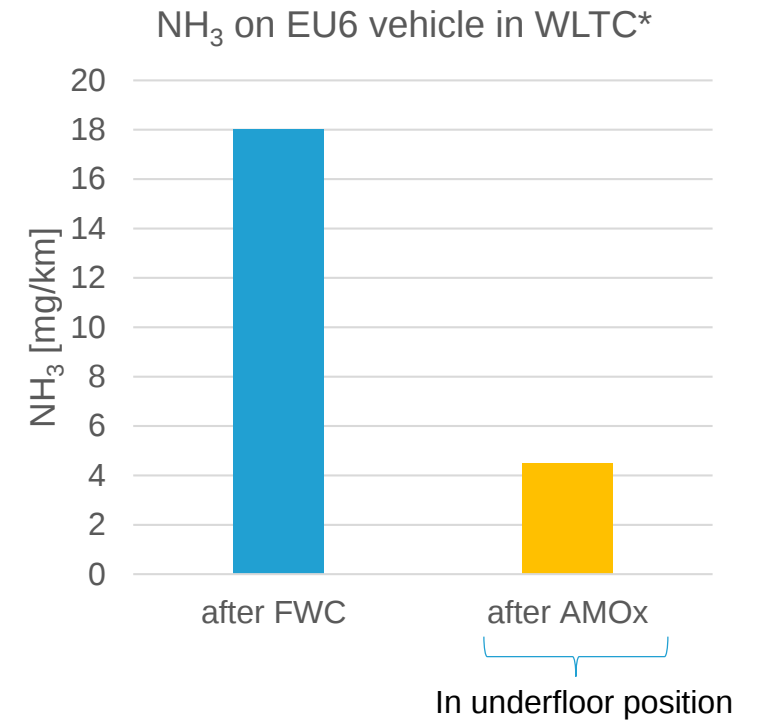
- Optimized TWC for low NH_3 make
- Improved calibration / λ -control
 - Less / shorter rich phases

AMOx can oxidize NH_3 to N_2



- High thermal stability needed under lean and rich environment

Example

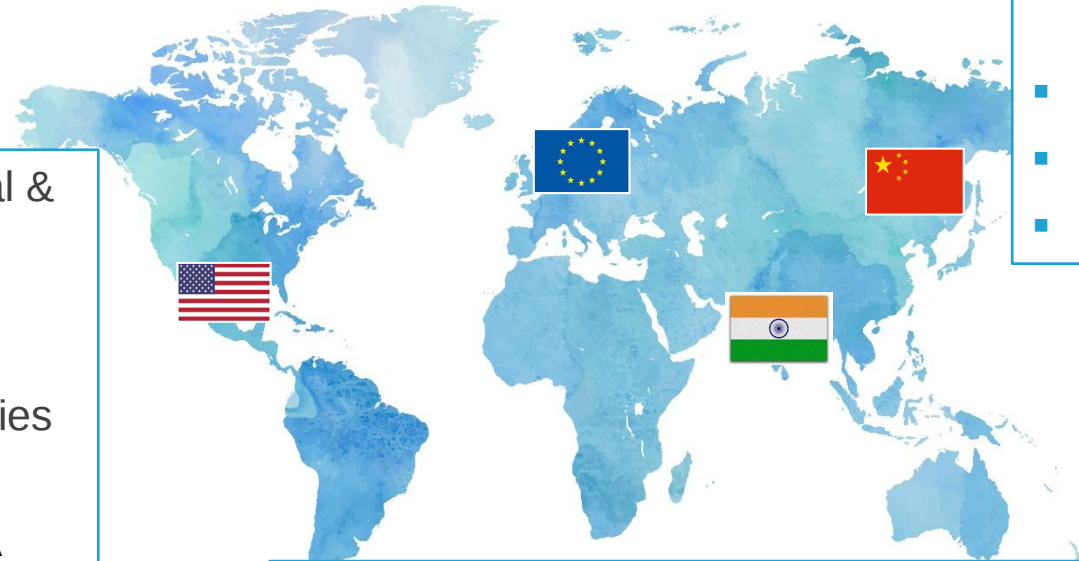


*engine bench aged system

Global Heavy Duty Emission Regulations

- **Euro VII:** Implementation second half of 2028
- Easier to achieve than initially proposed (Clove)
- Some OEMs continue with dual dosing

- **EPA27** on-road: Both dual & single dosing and Cu & V systems
- Development continues despite political uncertainties
- Off-highway ARB Tier 5 is proposed, pending at EPA

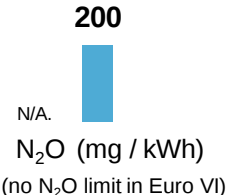
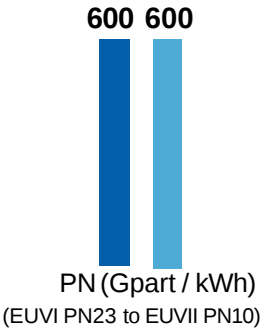
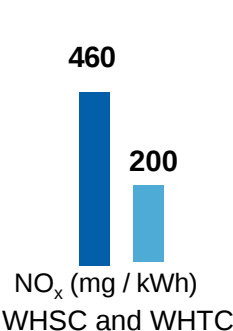


- **NS VII:** To be finalized in 2025. Expected to be more stringent than Euro VII
- Dual dosing is prime path for N3 platforms
- Cu-SCR is preferred
- CNG: filter for PN control may be needed

- **BS VII:** Expected to follow Euro VII requirements
- **Trem V:** Further delayed, possible dilution
- CPCB IV+: Low power engines → DOC only; high power engines → DOC+SCR+AMOX

Future On-Road Heavy Duty Regulations

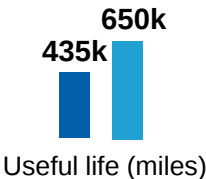
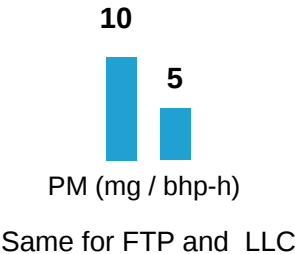
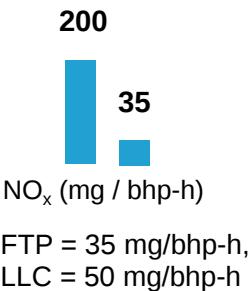
Euro VII relaxed from the initial proposal



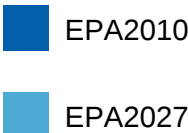
Finalized April 12, 2024



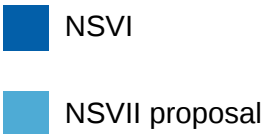
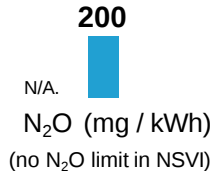
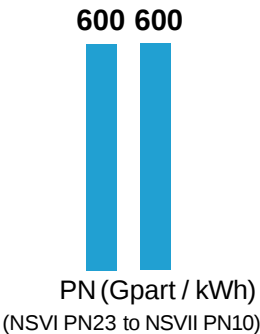
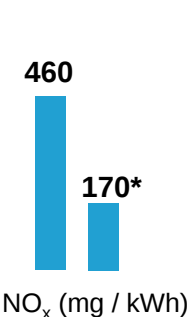
EPA27
Ultra-low NO_x
Engine useful life



Finalized Dec 21, 2022



NSVII
proposal
(stricter than Euro VII)



Cu-Zeolite SCR Technology Roadmap

Zeolite R&D



Zeolite Lab
Synthesis



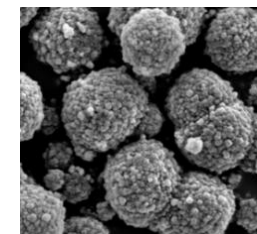
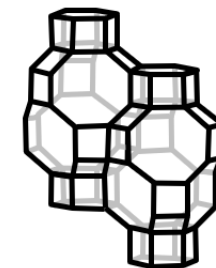
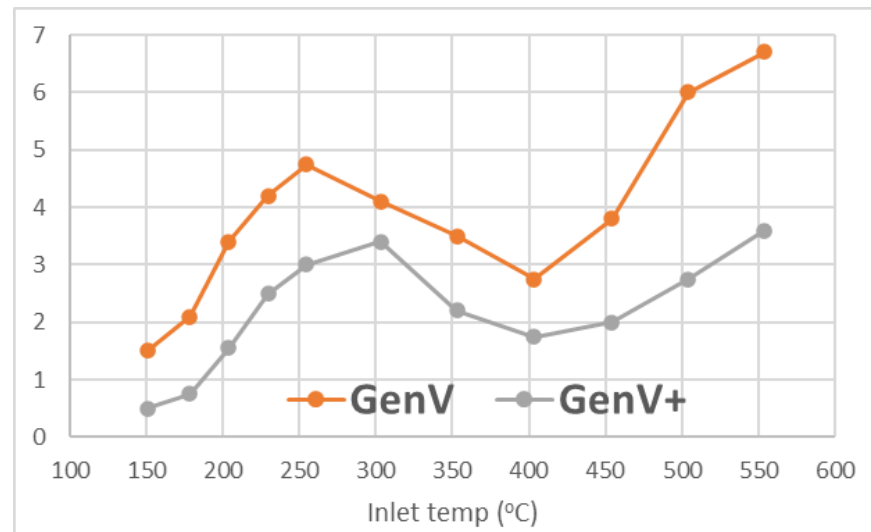
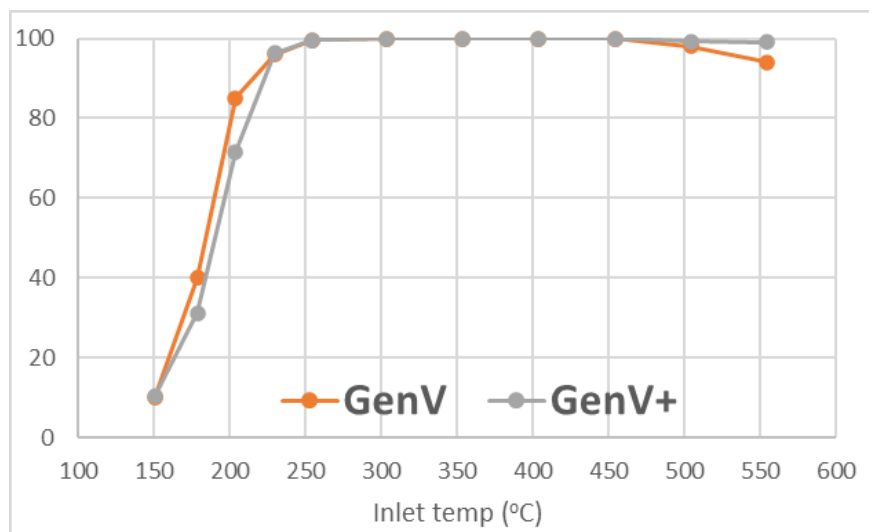
Zeolite
Production



Zeolite
Application



- **GenV** launched in India and other markets
- **GenV+** with significant N₂O reduction and will be commercialized for MY27 platforms
- **NextGen** under development with higher DeNO_x and significantly lower N₂O than GenV+



Diesel Oxidation Technology Development



Design requirements

- High NO oxidation
- Low-temp hydrocarbon oxidation / fuel-burn
- Minimum change from fresh to aged

Field learnings

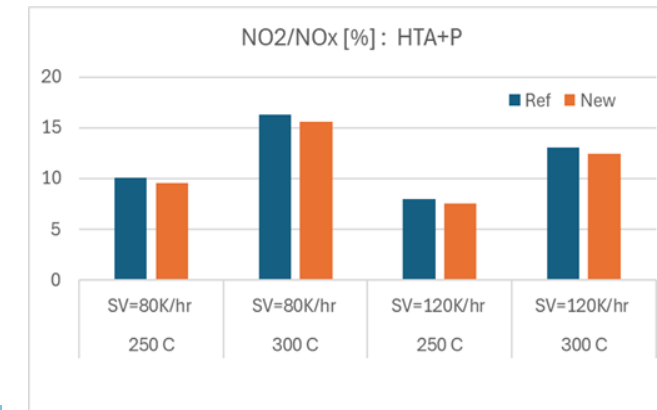
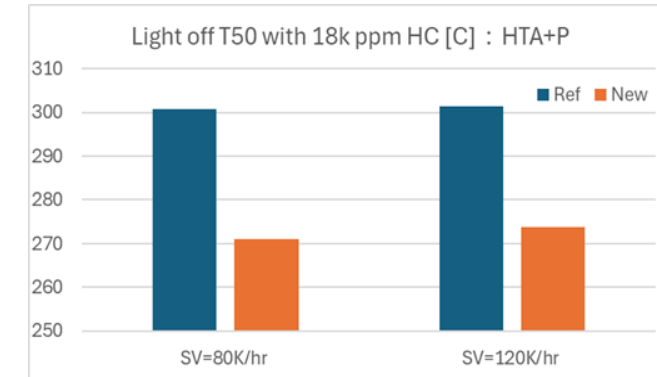
- On-road use experience
- Off-road DAAAC* aging part characterization

Catalyst design levers

- Zoning and washcoat architecture
- PGM loading and ratio
- Support materials for better and stable PGM dispersion
- Strategies for field robustness

Reduced
PGM usage

Enhanced
robustness

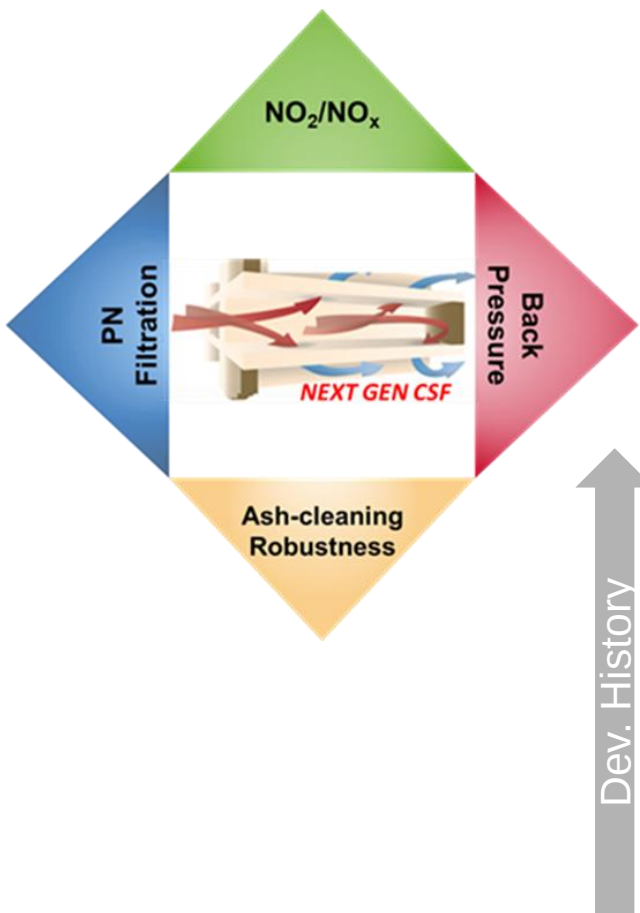


*New oxidation catalyst formulation at 25% lower PGM loading has been developed and validated on engine

Simulated EUL aging

*DAAAC = Diesel Aftertreatment Accelerated Aging Cycles

Advanced Particle Filtration Solutions

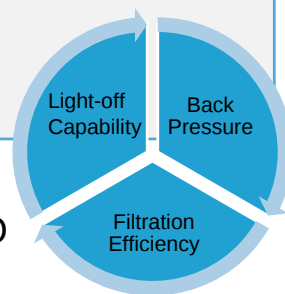
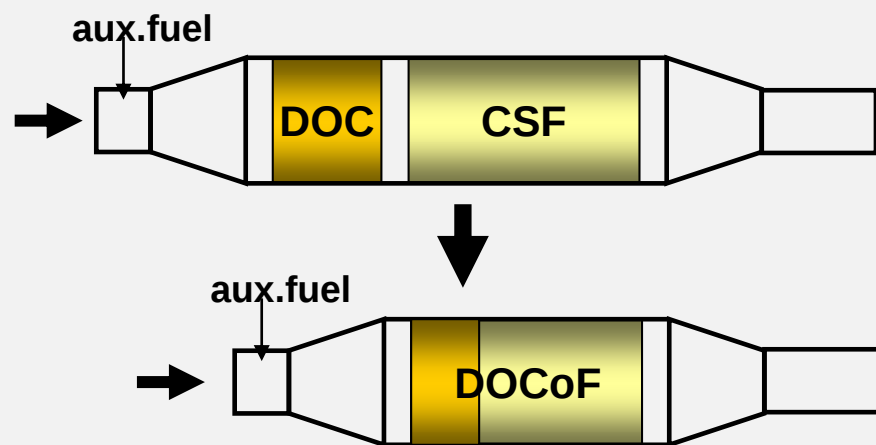


Technology	PN Performance (RDE Cycle*)	PN Performance (FFE^)	Ash-cleaning Durability
	90% MAW GigaPN10/kwh	BASF PN Test at Fresh	BASF PN Test after Simulated Ash- cleaning
AdvCSF Design 1	~10	~90%	~85-90%
AdvCSF Design 2	~50	~80-85%	~80-85%
CSF+	~20	~90%	~60-65%
CSF Conventional	>1000	~55-65%	~55-65%

- Technology options are available to address the needs for both the current filtration efficiency improvement (e.g. some off-road applications) and the anticipated PN10 requirement in future BSVII.

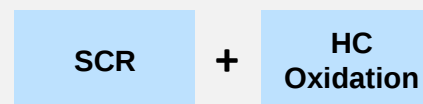
Unique 2-in-1 Catalyst Solutions

DOC on Filter (DOCoF)

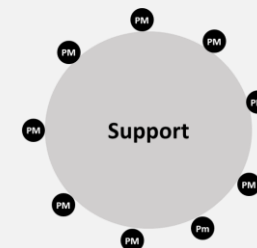


- DOCoF Functionality
 - Conversion of HC (including slip) & CO
 - Soot removal
 - L/O injected fuel for active filter regen.
 - $\text{NO} \rightarrow \text{NO}_2$ (soot combustion & “fast” SCR)
- Unique catalyst design enables durability, as seen in DAAAC testing

Multi-Function Catalyst (MFC)



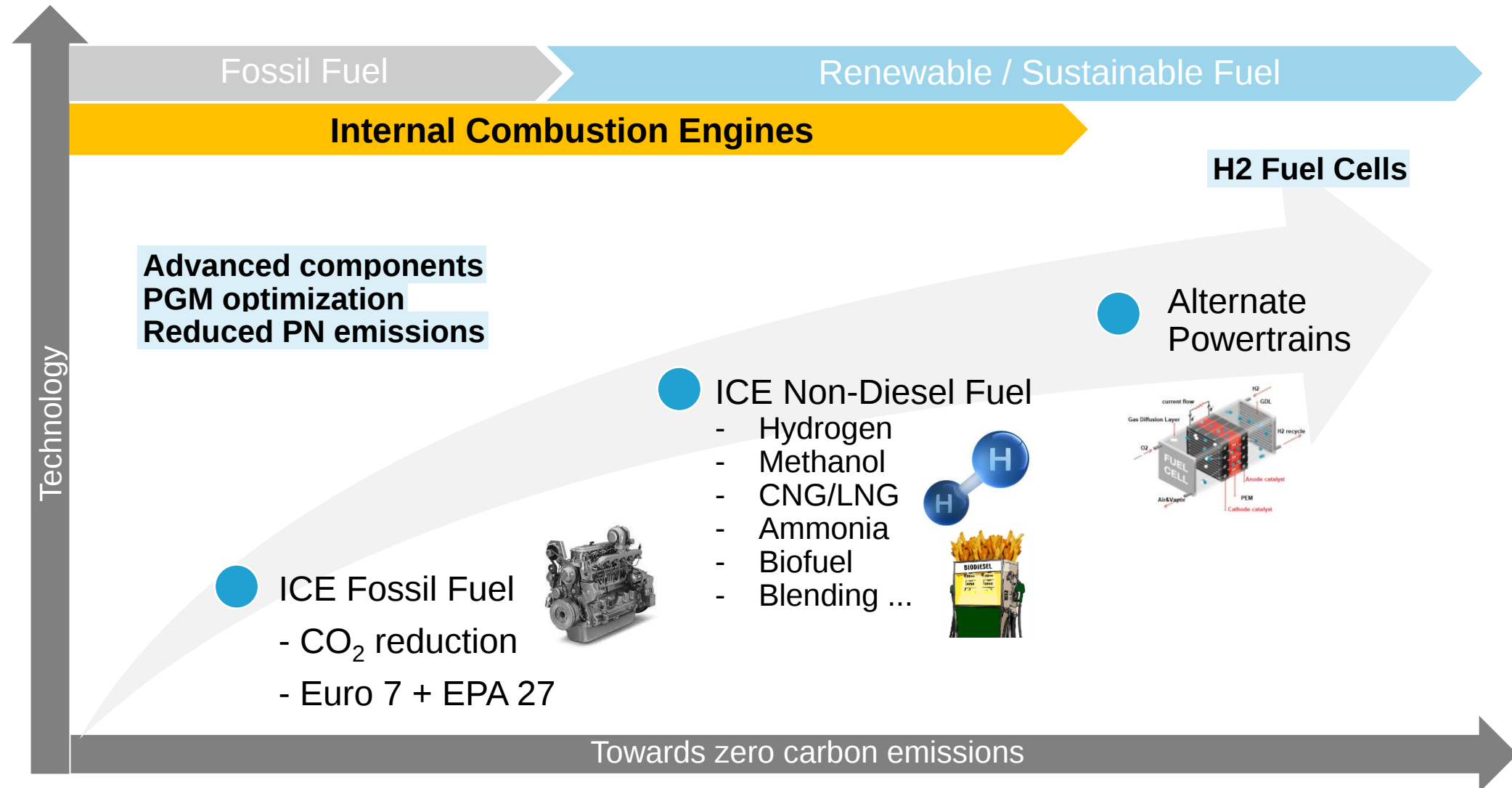
Cu-zeolite



Supported Pd

- Comprehensive data package for GenV+ MFC
 - SCR and fuel L/O performance
 - HC masking robustness
 - Sulfur effect
- DAAAC demonstrated at SwRI

BASF ECMS partners with customers to develop a portfolio of solutions





Paving the way to a Sustainable Future

- Long and proven track record of advanced catalyst development and application experience
- Technologies ready for India BS7
- Building on long history of partnership with OEMs in India
- BASF ECMS dedicated to strong technology delivery to Indian customers

More to come...

Advancing Emission Control through Hybrid Catalyst Technologies

• Bhabani Panigrahi

After-Treatment Catalysts for Gasoline Hybrid Vehicles

• Yogesh Shinde

Motorcycle Emission: Future of Legislation & Catalyst

• Rajesh Shankaranarayanan



We create chemistry