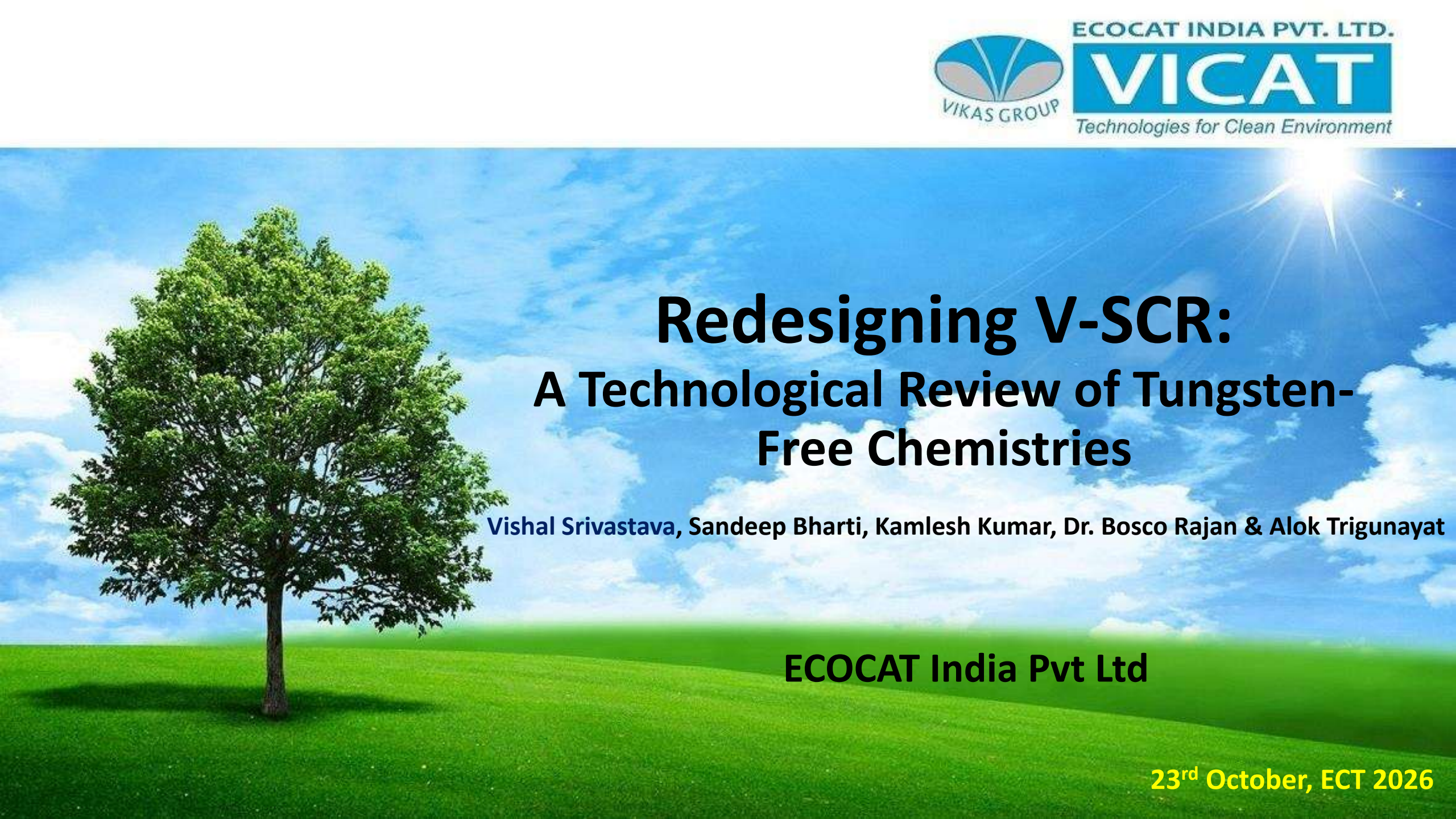




Redesigning V-SCR: A Technological Review of Tungsten- Free Chemistries

Vishal Srivastava, Sandeep Bharti, Kamlesh Kumar, Dr. Bosco Rajan & Alok Trigunayat

ECOCAT India Pvt Ltd

23rd October, ECT 2026

- **Introduction**
- **SCR Catalyst Technologies**
- **Conventional VWT SCR: SCR Benchmark Chemistry**
- **Conventional VWT SCR: SCR Reaction mechanism**
- **Why develop Tungsten-free V-SCR Chemistry?**
- **Next generation V-SCR: Design strategy**
- **Literature synthesis and proposed direction**
- **Modified V-based SCR Chemistry**

Introduction: NO_x Emissions

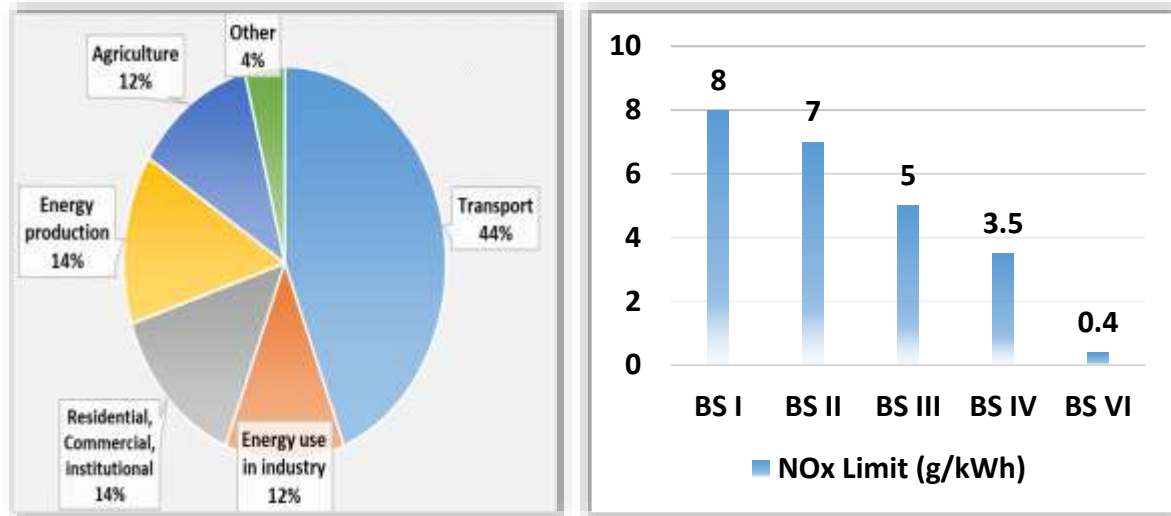


Fig 1: Sector Wise NO_x Emissions & increasingly stringent BS norms for NO_x Emissions

NO_x formation & why you should care?

- ❑ Gasoline and diesel combustion generates NO_x, primarily NO and NO₂.
- ❑ NO_x adversely impacts human health and contributes to environmental degradation.
- ❑ Increasingly stringent norms for NO_x reduction in EU7/upcoming BS7/CPCB4+ norms

NO_x in Diesel Exhaust is a particularly hard problem

Approaches for NO_x Reduction

- ❑ **Combustion Control:** EGR, Injection timing etc.
- ❑ **Exhaust After treatment Device** (LNT, SCR)
- ❑ Complex layout for Diesel Engines than Gasoline Engines (TWCS)

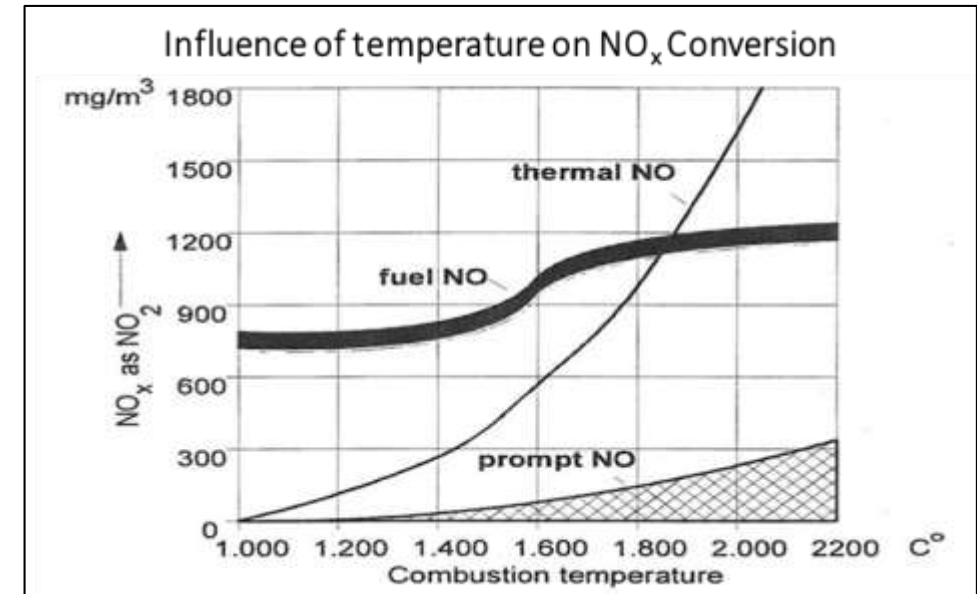


Fig 2: Vehicle NO_x, represented here by thermal NO, increases exponentially as combustion temperature increases. (UN-ECE, Task Force on Techno-Economic Issues)

NO_x formation in combustion process is unavoidable

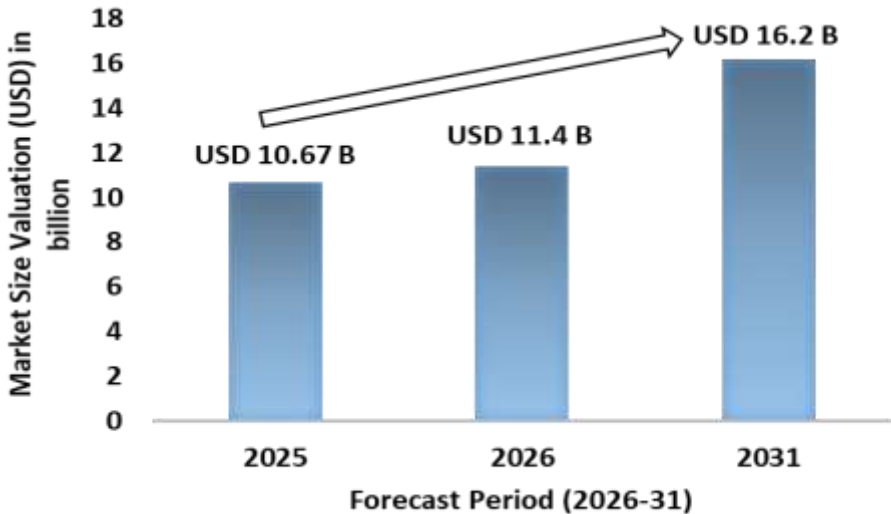


Fig 3: SCR market Size estimation from 2026-2031

- The Automotive SCR market size estimated to grow from USD 11.40 billion in 2026 to reach USD 16.26 billion by 2031.
- SCR adoption is accelerating with increasingly stringent NO_x emission regulations.



Fig 4: SCR Market Share by Catalyst Technology, 2025

- Cu-Zeolite Based SCR technology dominates SCR market.
- Vanadium-Based SCR remains widely established in stationary, marine and off-road applications.

Technology	Typical Catalyst	Application
Vanadium-Based SCR	V ₂ O ₅ -WO ₃ -TiO ₂	Stationary applications, Off-road, marine, some HD segments
Cu-Zeolite SCR	Cu-SSZ-13, Cu-SAPO-34	Modern Diesel Vehicles, HD trucks, off-road
Fe-zeolite SCR	Fe-ZSM-5, Fe-Beta, Fe-SSZ-13	High T-SCR applications, HD trucks

Source: 1. Mordor Intelligence (2025), Automotive SCR Market Size & Share Analysis: <https://www.mordorintelligence.com/industry-reports/automotive-selective-catalytic-reduction-market>
2. The European Commission (1991), Council Directive 91/441/EEC: <https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31991L0441>

Conventional VWT-SCR: Benchmark SCR Chemistry

V_2O_5 : 0.5-3%, WO_3 : 5-10%, TiO_2 : 80-90%

V_2O_5 / surface

VO_x

ACTIVE PHASE

$V^{5+} \rightleftharpoons V^{4+}$ redox
functionality
 NH_3 activation
 $NO_x \rightarrow N_2$ chemistry

WO_3

PROMOTER

↑ Acidity
↑ VO_x dispersion
↑ Thermal Stability
 TiO_2 stability

Anatase TiO_2

SUPPORT

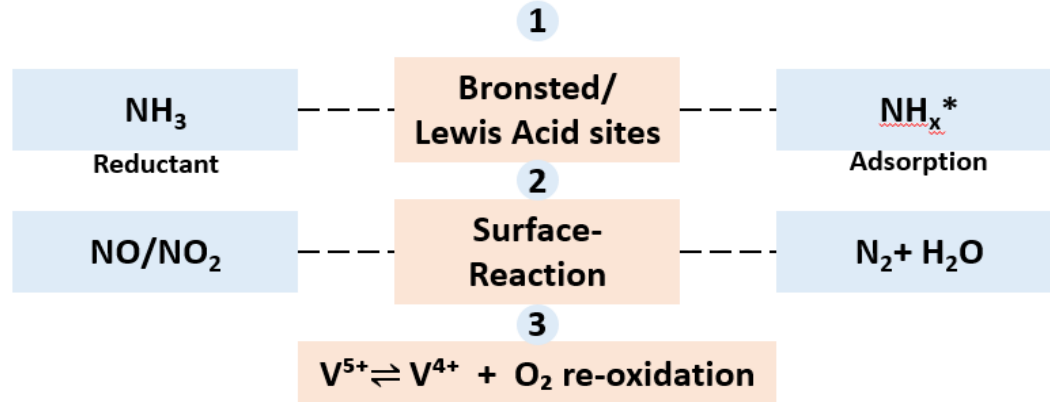
High surface area
Anchors VO_x / WO_x
Provides V-O-Ti
interface
Weak & Reversible
sulfation

Established technology to control NO_x emissions

- Mature, industrially proven chemistry
- Strong mid-temperature De NO_x activity
- High N_2 selectivity under suitable conditions
- Strong SO_2 resistance
- Tuneable V/W/ TiO_2 formulation

Automotive/off-road formulations can differ substantially by application

Bi-functional SCR mechanism



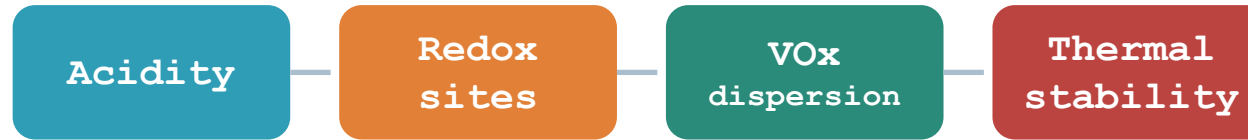
Main SCR reactions

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

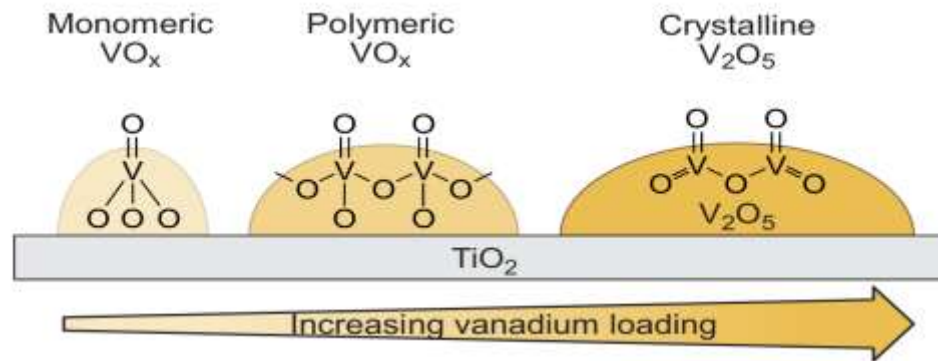
Fast SCR: $2NH_3 + NO + NO_2 \rightarrow 2N_2 + 3H_2O$

Key implication → A credible W-free formulation must replace several coupled functions:
Acidity + Redox tuning + VO_x stabilization + Hydrothermal durability

Key Parameters of SCR reaction mechanism



Widely recognized SCR reaction mechanisms: 1. Langmuir-H mechanism 2. Eley-Rideal Mechanism



Key surface
bonds
V=O

V-O-Ti

V-O-V

Increasing V surface density: ~~isolated~~ VO_x → polymeric VO_x → V₂O₅-like domains

- **Bronsted & Lewis Acid Sites:** Adsorption and activation sites of NH₃
- **Redox sites:** Vanadium Oxide species
- **VO_x Dispersion:** Availability of active centres

- **LH mechanism:** Reaction after complete adsorption of NH₃ & NO
- **E-R mechanism:** Reaction of adsorbed NH₃ with gas phase NO_x

The NH₃-SCR reaction mechanism is very complex, involving the valence & distribution of different elements, as well as transformation in the reaction process.

Conventional VWT-SCR: Benchmark SCR Chemistry

Study: VO_x surface coverage optimization by variation of Vanadium Loading & by Aging

DeNO_x Activity of 1.7-3.5wt% V₂O₅/WT: Fresh & Aged

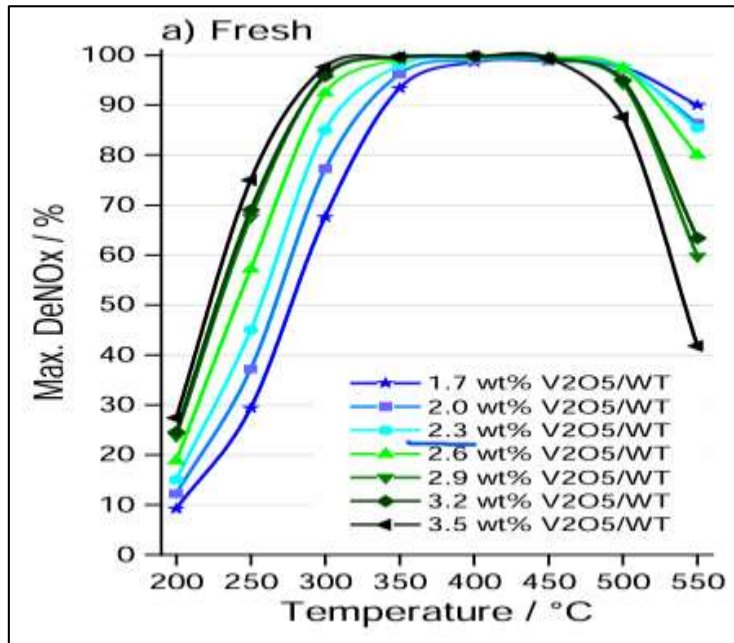


Fig 5: DeNO_x Activity of 1.7 & 3.5wt% V₂O₅/WT)

- In the fresh state, SCR activity increased with increasing V loading.

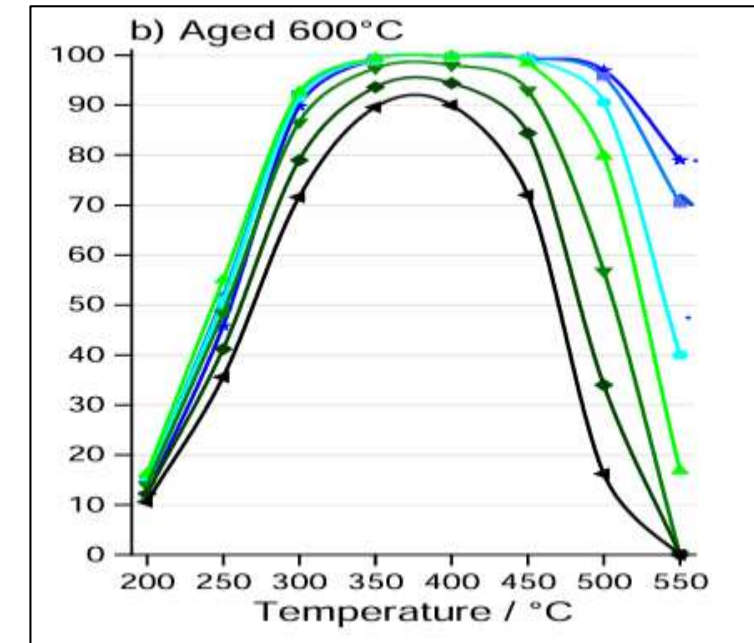


Fig 6: DeNO_x Activity over W free V-TiO₂ SCR (Fresh & Aged)

- Upon Aging, the catalysts with upto 2.3 wt% V₂O₅ exhibited higher NO_x reduction activity than fresh state.
- More than 2.6 wt%, showed increasing deactivation tendencies.

An Optimal Compromise between activity & hydrothermal aging resistance could be obtained only with Vanadium loading %

Why Develop Tungsten-Free V-SCR Chemistry?

Key challenges of conventional VWT

Low-temperature activity	Lower reaction rate / NH_3 activation during cold or low-load operation.
High-temperature durability	Hydrothermal exposure can alter VO_x dispersion and support properties.
$\text{SO}_2 \rightarrow \text{SO}_3$ oxidation	Can promote sulfate-related deposits / downstream concerns.
NH_3 oxidation & N_2O	Undesired pathways become important under unfavorable conditions.
VO_x aggregation	Excess V can shift isolated $\rightarrow$ polymeric $\rightarrow$ crystalline V_2O_5 -like species.
Poisoning	Alkali, alkaline-earth, P and other contaminants can neutralize active/acid sites.

China Wolframite Concentrate & APT Prices



Fig 7: Tungsten price surge (2025-2026)

Key Points

- Tungsten prices surged 622% between January 2025 and April 2026
- Need for SCR chemistry with wider effective SCR window
- Improving Low Temperature SCR performance
- Reduce dependence on W containing raw materials
- Retain hydrothermal & chemical durability

Research objective: Engineer the VO_x - TiO_2 interface, acidity & $\text{V}^{5+}/\text{V}^{4+}$ potential to widen De- NO_x window while reducing W and secondary emissions.

Next Generation V-SCR: Design strategy

Central question: Which tungsten-free chemistry can reproduce the functions of WO_3 —not merely replace its mass fraction?

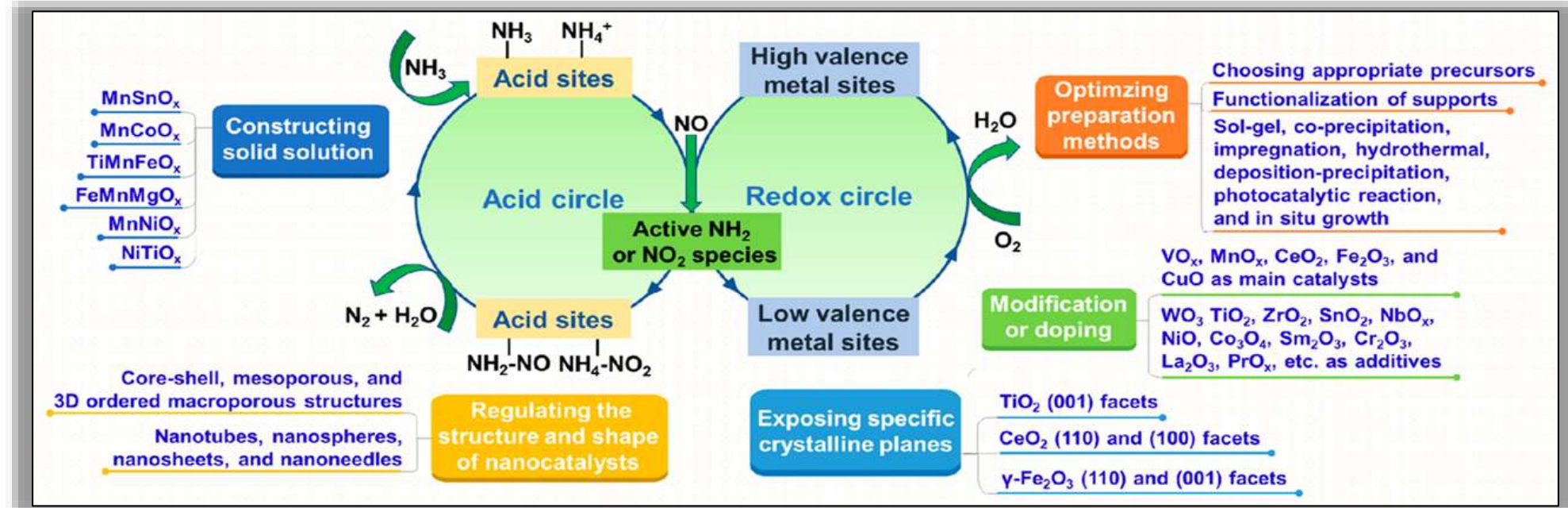


Fig 8: General Strategies of improving the acidity circle & redox circle of SCR catalysts

$$\text{SCR Activity} = f(\text{appropriate acidity, Accessible V redox Sites, highly dispersed } \text{VO}_x)$$

Key strategies

- Use of multi-functional promoters (transition metal oxides or rare earth metals).
- Engineer TiO_2 support itself.

- Optimizing synthesis methods
- Use of Novel supports
- Regulating the structure & shape of catalysts.

W-lean & W-free V-SCR Evaluation (Experimental)

SGTB Test Condition: NO_2/NO_x : 50%, ANR: 1.0, SV: 50K hr^{-1} , **Aging:** 600degCx15hrs, Hydrothermal

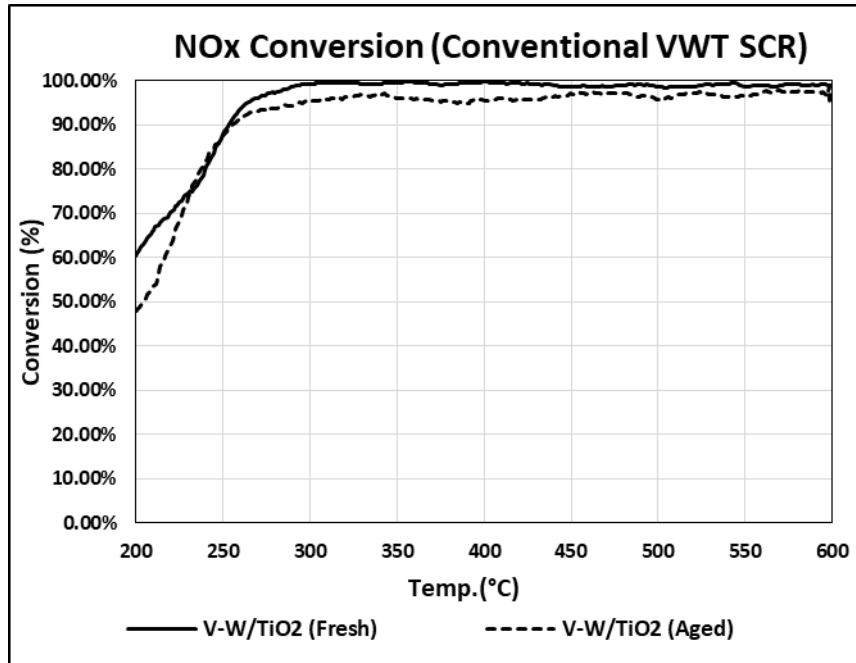


Fig 9: DeNO_x Activity over Conventional VWT SCR (Fresh & Aged)

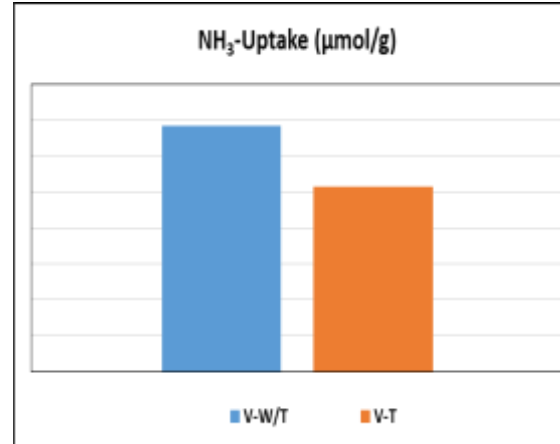
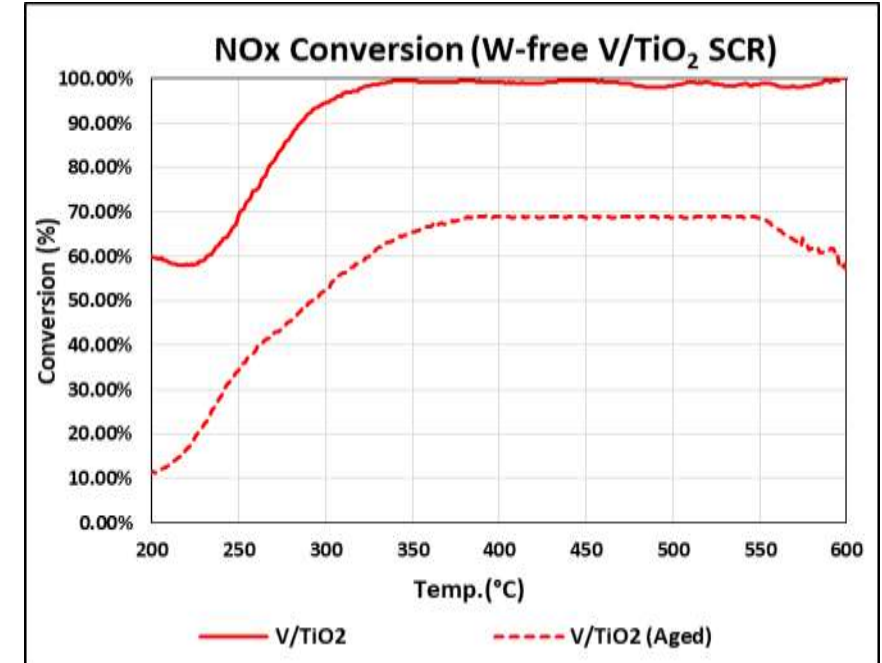


Fig 10: DeNO_x Activity over W free V-TiO₂ SCR (Fresh & Aged)

- Excellent NO_x conversion over wide temperature range.
- Little deterioration over HT aging
- HT aging sometimes improve light-off (due to surface redistribution of VO_x / WO_x species).

- Delayed T₁₀₀ observed
- Lower surface acidity without W (Tungsten)
- Poor Hydrothermal stability
- Anatase → Rutile transformation

Direct elimination of tungsten (W) results in reduced SCR activity and increased susceptibility to thermal deactivation.

Modified V-based Catalyst Chemistries: The Review

Reported NO_x conversion windows and representative reaction conditions

Catalysts	NO _x (or NO) Conversion	Temperature Range (°C)	Reaction Conditions (& GHSV)	Remarks
VWT	100%	300-400	0.05% NO, 0.05% NH ₃ , 5 vol% O ₂ , 25000 hr ⁻¹	V redox sites + Acidity
Cu-V/TiO ₂	>90%	225-375	0.05% NO, 0.05% NH ₃ , 5 vol% O ₂ , 26000 hr ⁻¹	Dual Cu/V redox couples
Cu-V/WTi	>84%	250-400	0.05% NO, 0.05% NH ₃ , 5 vol% O ₂ , 10,000 hr ⁻¹	Cu-V promotion on W-Ti support
VWCeCuTi	>80%	250-375	0.05% NO, 0.05% NH ₃ , 5 vol% O ₂ , 60,000 hr ⁻¹	Enhanced surface acidity & redox
VMoTi	>95%	200-400	0.05% NO, 0.05% NH ₃ , 5 vol% O ₂ , 25000 hr ⁻¹	Mo improves low-T redox activity
VMoWTi	>97%	190-450	0.05% NO, 0.05% NH ₃ , 5 vol% O ₂ , 26000 hr ⁻¹	Mo + W broaden window, improve thermal/structural stability
V/Ce/WTi	>95%	250-450	0.05% NO, 0.05% NH ₃ , 5 vol% O ₂ , 5% H ₂ O, 18000hr ⁻¹	Improved low T performance as compared to VWT
V-Ce(SO ₄) ₂ /Ti	100%	300-450	0.08% NO, 0.08% NH ₃ , 5 vol% O ₂ , 150000mL/g.h	Abundant reactive acid sites, tolerance to SO ₂ & H ₂ O
7%Ce-1%CuV/Ti	>97%	200-400	0.05% NO, 0.05% NH ₃ , 5 vol% O ₂ , 45000hr ⁻¹	Enhanced surface acidity & redox
V ₅ /Ce ₃₅ -Sb ₂ /Ti	>90%	225-400	0.1% NO, 0.1% NH ₃ , 3 vol% O ₂ , 45000hr ⁻¹	Superior catalytic performance & N ₂ selectivity
6%Nb-3%V/W-Ti	>90%	225-400	0.05% NO, 0.05% NH ₃ , 3 vol% O ₂ , 60000hr ⁻¹	Nb contributes to higher thermal stability
8%Ce-1%V/W-Ti	>80%	190-450	0.05% NO, 0.05% NH ₃ , 5 vol% O ₂ , 25000 hr ⁻¹	Low Temperature performance SCR

Review target: Chemistry with wide temperature range & high NO_x conversion

Reference: SCR of NO_x with NH₃ by using Novel Catalysts: State of the Art & Future prospects, Han et al (2019)

Recent progress on improving Low-Temperature Activity of V based catalysts for SCR of NO_x with Ammonia, Lian et al (2020)

Modified V-based Catalyst Chemistry: Conclusion

Literature synthesis & proposed research direction

Catalysts	Acidity	Redox	Thermal Stability	Review Interpretation
V-W/TiO ₂	High	High	Good	Benchmark: Balanced multifunctional promoter system.
V-Mo/TiO ₂	High	High	Moderate-good	Most Direct W-free starting point, optimize surface density.
V-Nb/TiO ₂	High	Moderate-high	Good	Interesting acidity/ poison-tolerance route, thermal stability.
V-Sb/TiO ₂	Moderate	Moderate	Promising	Strong candidate where aged dispersion/selectivity dominate.
V-Ce/TiO ₂	Moderate	High	Moderate	Useful low T redox promoter, sulphur durability is critical.
V(promoter)/Si-TiO ₂	Tuneable	Tuneable	Potentially High	Multifunctional route, separate structural & catalytic route

Conclusion: Prioritize V-Mo/TiO₂ as the closest functional replacement, while Si-stabilized TiO₂ + a second promoter is the strongest design direction when hydrothermal durability is central.

Modified V-TiO₂ formulations (Experimental)

SGTB Test Condition: NO₂/NO_x: 50%, ANR: 1.0, SV: 50K hr⁻¹, **Aging:** HT Aged (600degCx15hrs)

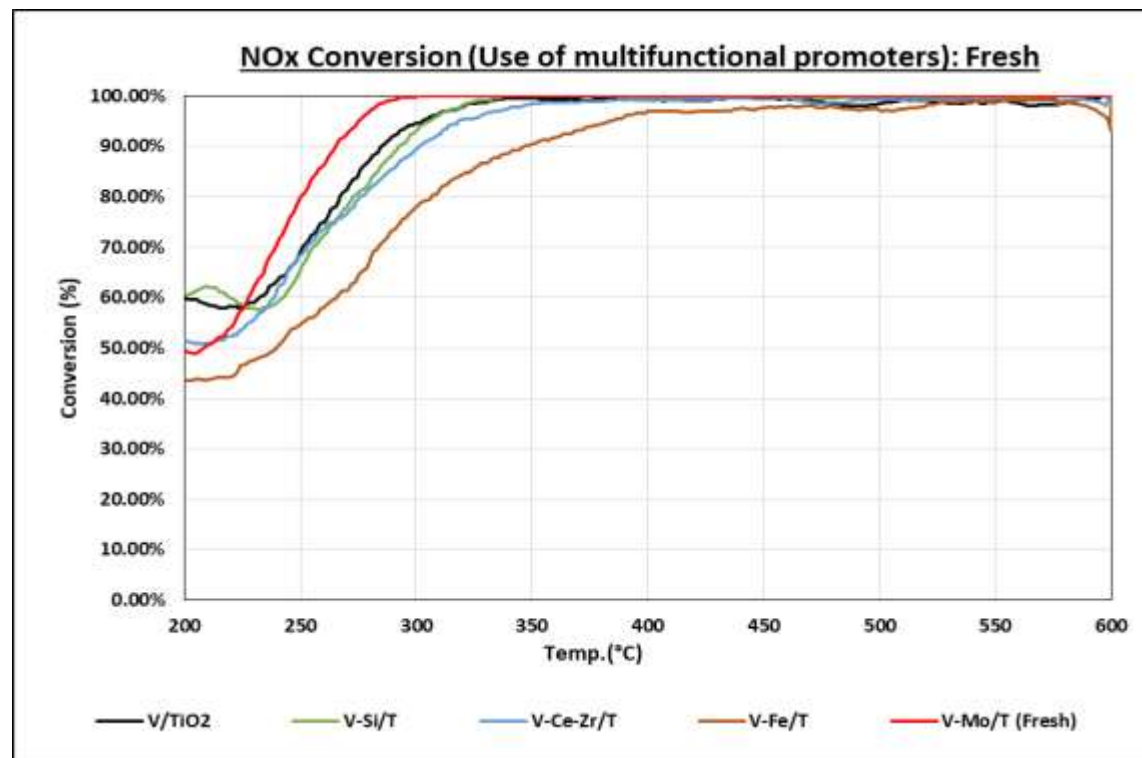


Fig 11: DeNO_x Activity over modified V-TiO₂ formulations (Fresh)

- Mo-based V-SCR is the closest analogue to VWT catalyst
- Modified TiO₂ support with SiO₂ can be optimized by V loading.
- With minimal change to V/Ti, Mo can preserve both acidity & redox potential

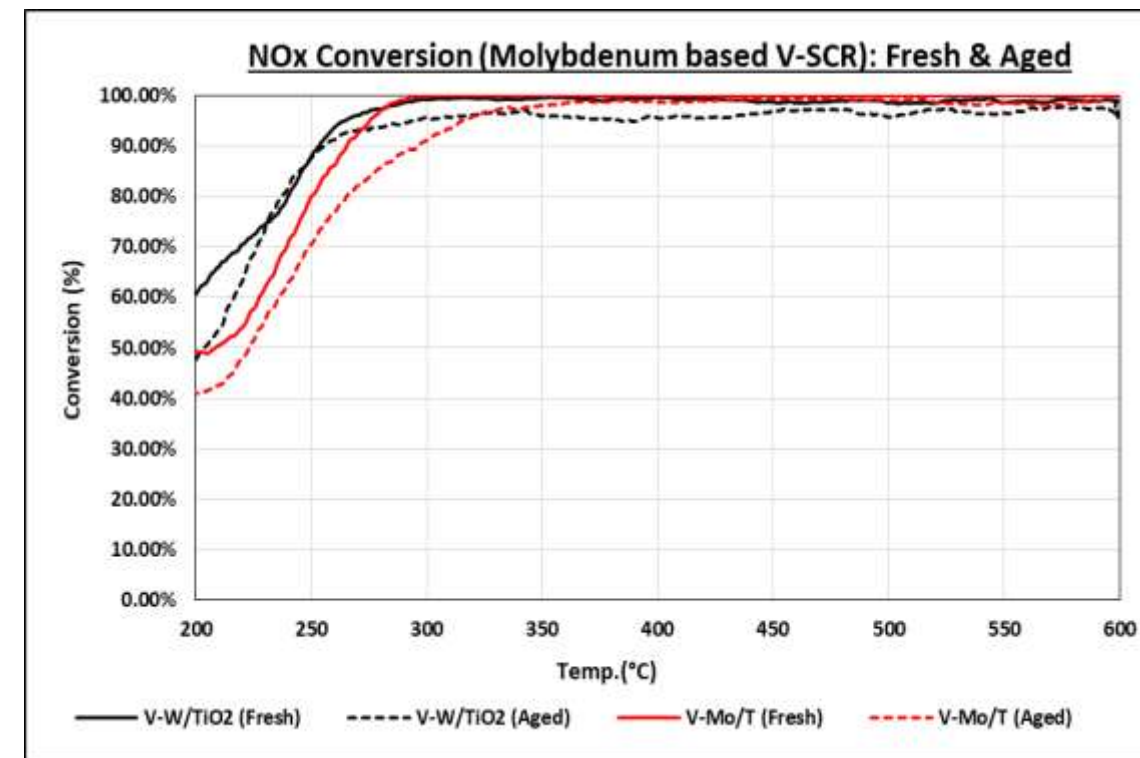


Fig 12: DeNO_x Activity Molybdenum based V-TiO₂ SCR (Fresh & Aged)

- T₁₀₀ is slightly delayed after extreme aging.
- Comparable performance wrt VWT SCR catalyst.
- Strong potential to replace W in VWT formulation.

Strategic use of multifunctional promoters can retain SCR performance without tungsten.

- **Rational design for V-Based Catalysts requires an improved fundamental understanding of the functions and interactions between the included components that affects the catalyst properties.**
- **Promising solutions have emerged with the implementation of promoters.**
- **Performance of the proposed materials under real engine exhaust conditions requires further evaluation.**
- **Further translation of the chemistry into monolith performance.**

THANKS