# *An Improvement of Diesel PM and NOx Reduction System*


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**TOYOTA MOTOR CORPORATION**

# Contents

1. Current status of DPNR

2. Improvement of NOx storage and reduction efficiency

   (a) How to realize effective rich condition
   - Rich combustion
   - Multiple injection
   - Additional fuel injection

   (b) How to maintain activated state
   - Improvement on thermal deterioration
   - Improvement on sulfur poisoning – New concept DPNR

   (c) How to treat unexpected products
   - Clean-up catalyst (including NOx slightly reduced)

3. Future prospective of the next generation DPNR

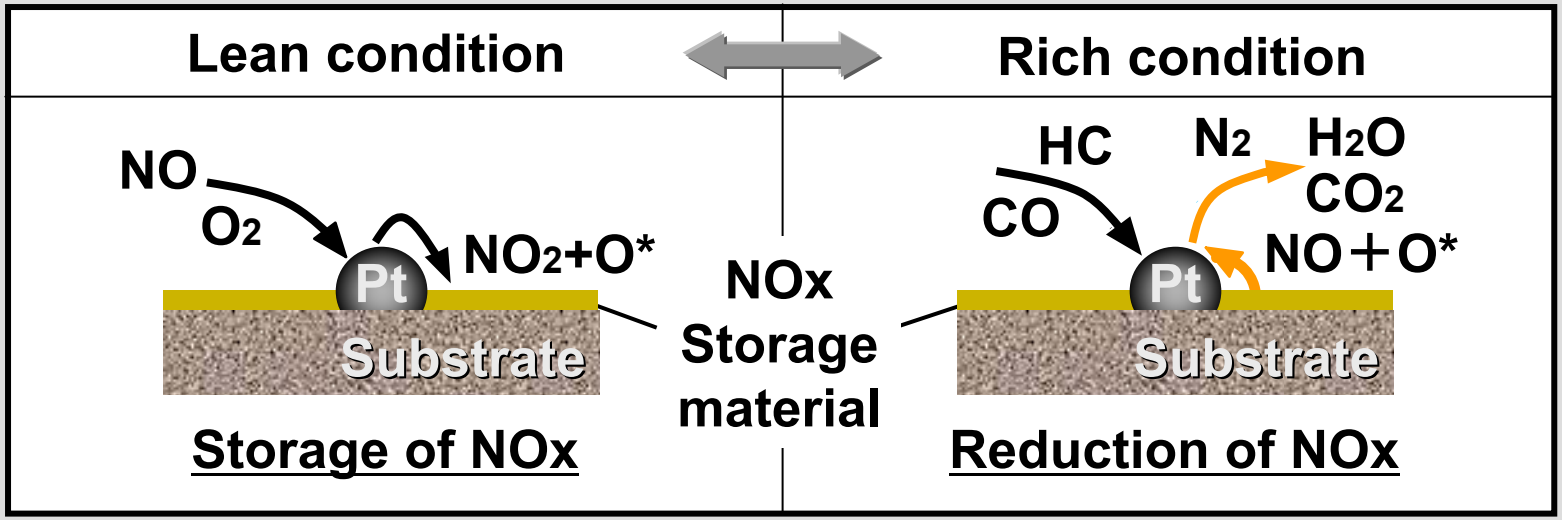
4. DPNR(NSR) or UREA-SCR ?

# Current Status of DPNR

## NSR Catalyst

- NSR (NOx Storage Reduction Catalyst)
- LNT (Lean NOx Trap)

NOx purification mechanism of NSR




1992 Patent application

1994 Start of production

2003 Start of diesel engine application : DPNR

# Introduction of DPNR

2002 | 2003 | 2004 | 2005 | 2006 | 2007

Field trial

60 cars, 7 countries

Clean power concept

(Paris show)

Wide scale introduction

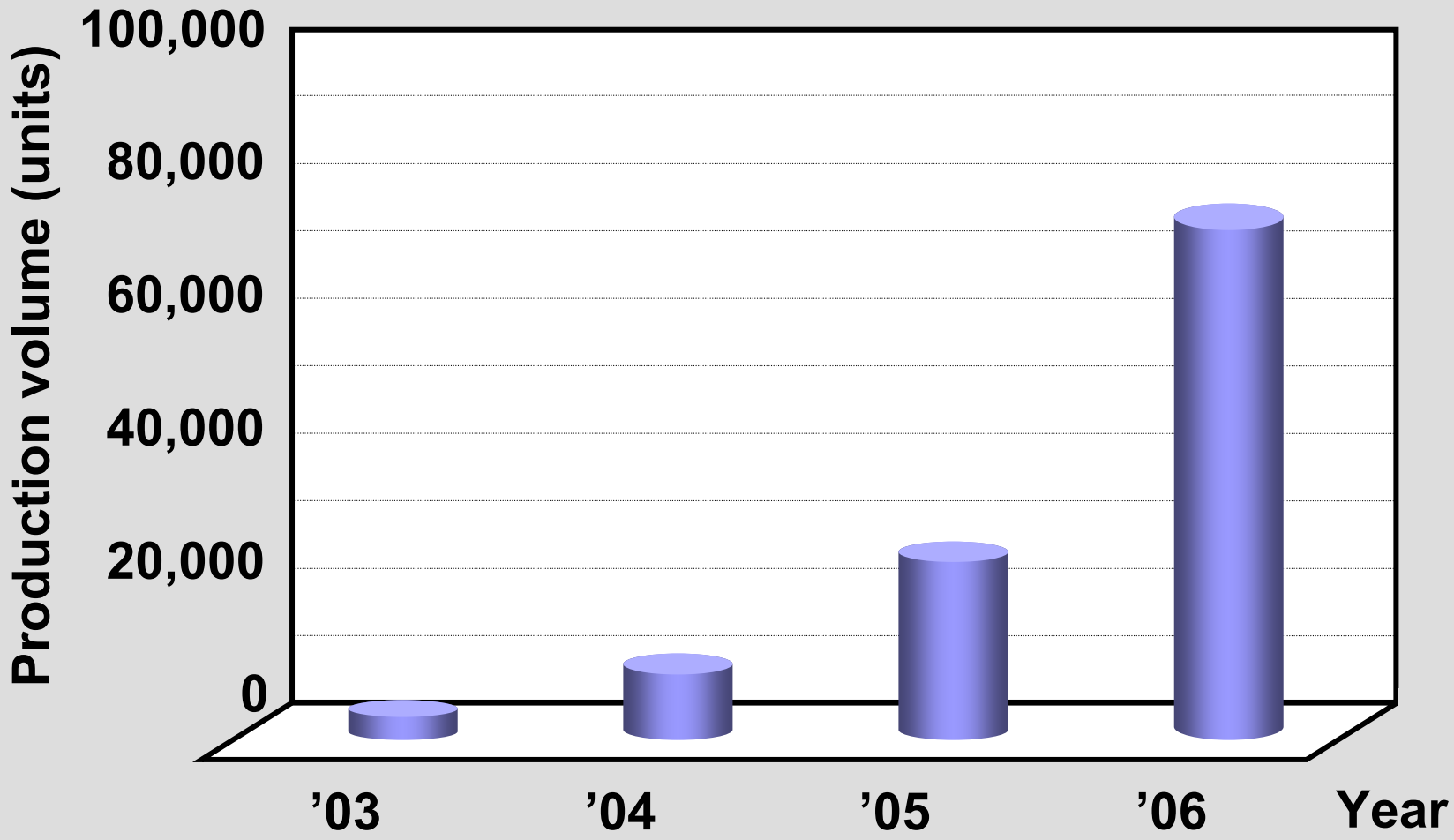
(EU-wide)

1st Introduction

(for selected countries)

low sulfur diesel fuel

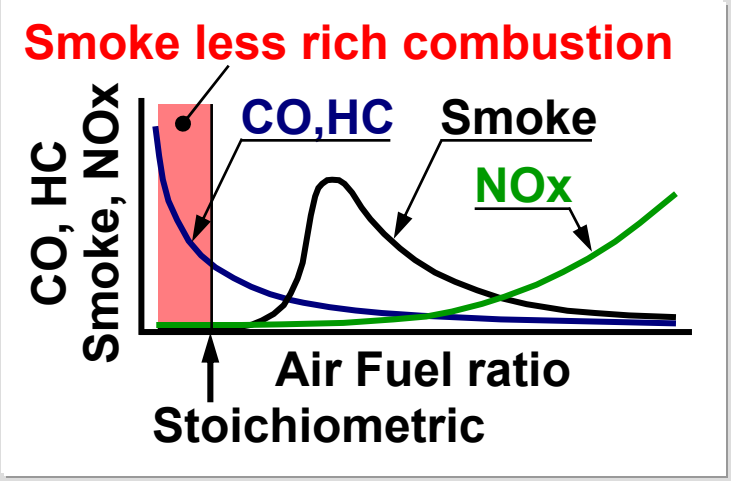

# Production Volume of DPNR



# Contents

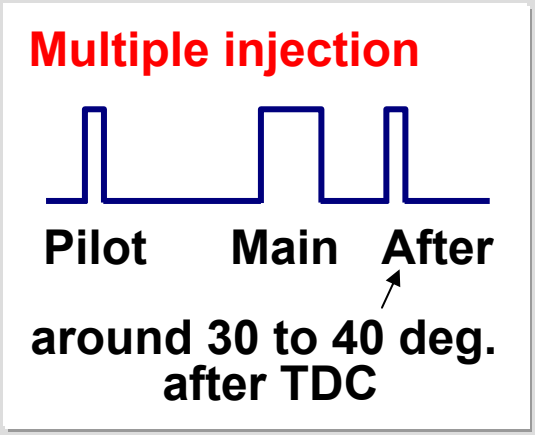
# (a)How to Realize Effective Rich Condition

## Comparison of three methods




➢In cylinder

- Smokeless rich combustion
  - ++Very high NOx conversion efficiency by CO
  - − CO emitted from catalyst under rich condition
  - − Very limited operation area
- Multiple injection
  - + High NOx conversion efficiency by CO
  - − Limited operation area by smoke and oil dilution
  - − Fuel economy



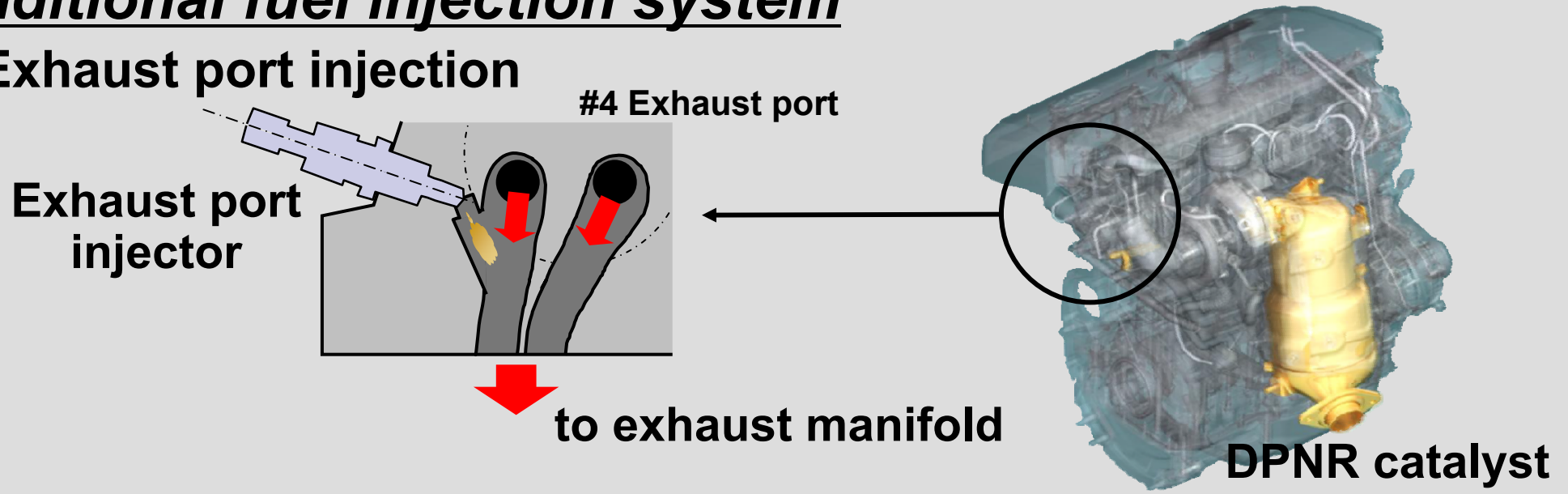

➢On catalyst

- Additional fuel injection
  - + High NOx conversion efficiency by local rich condition on the catalyst
  - ++No limitation of operation area
  - − Additional injector

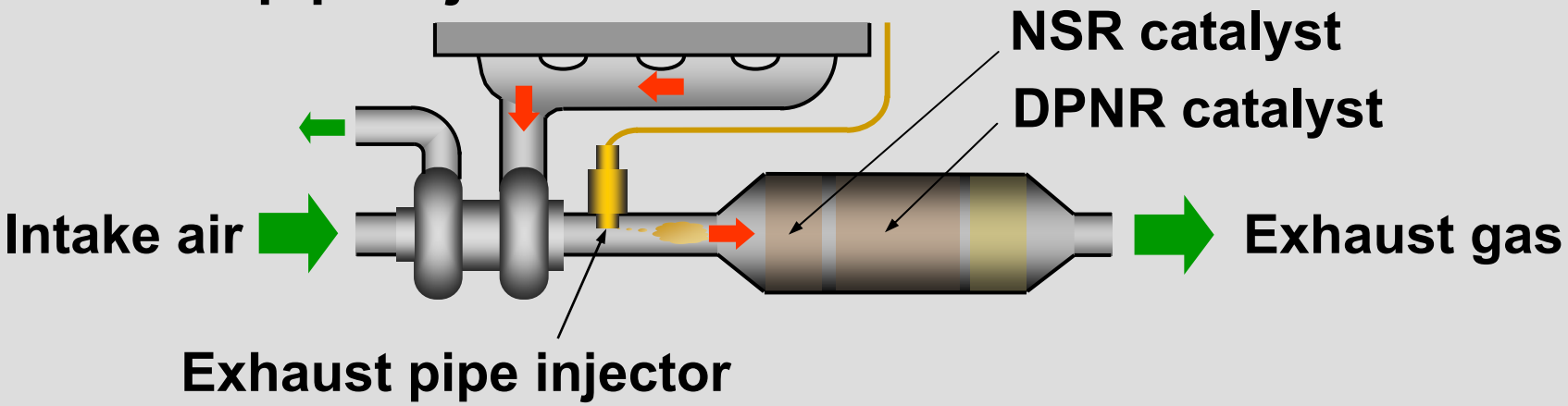
# Methods for Rich Pulse

## Additional fuel injection system

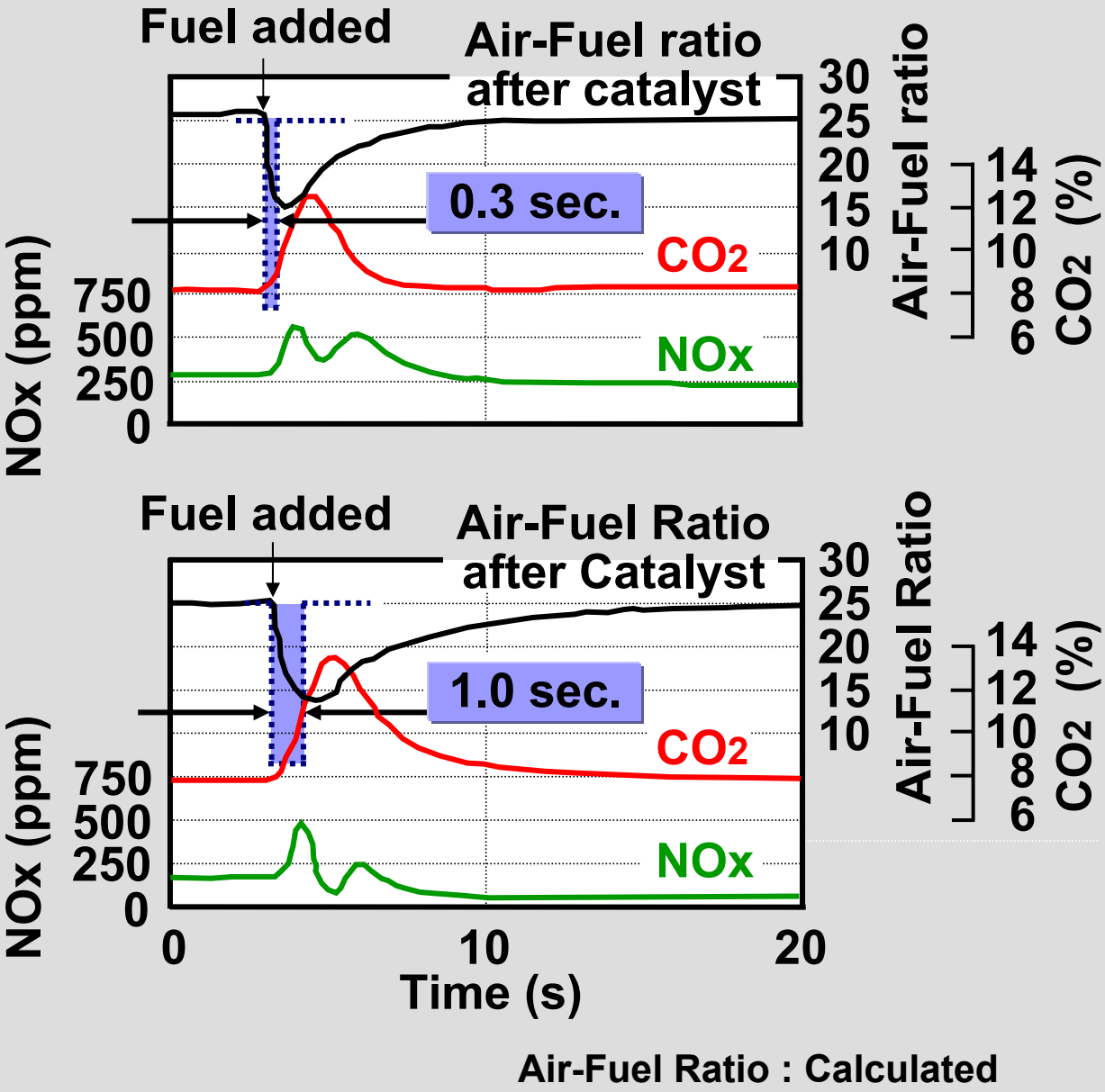
- Exhaust port injection




- Exhaust pipe injection



# Key Technologies for Rich Pulse



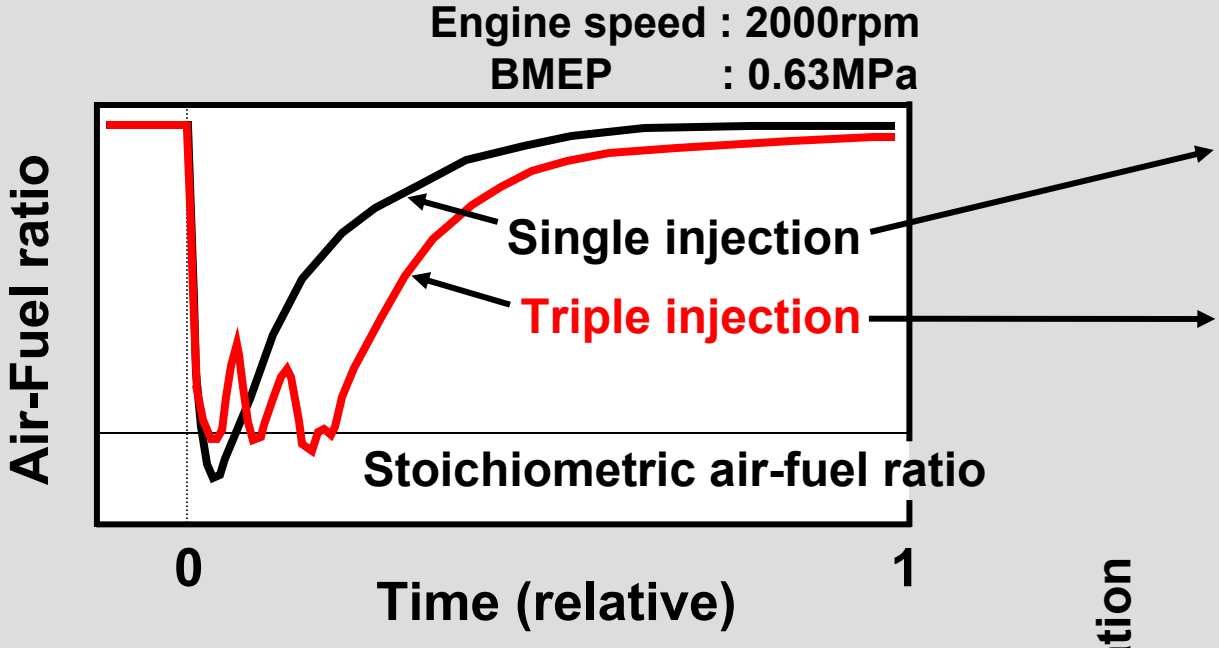

Air-Fuel Ratio : Calculated

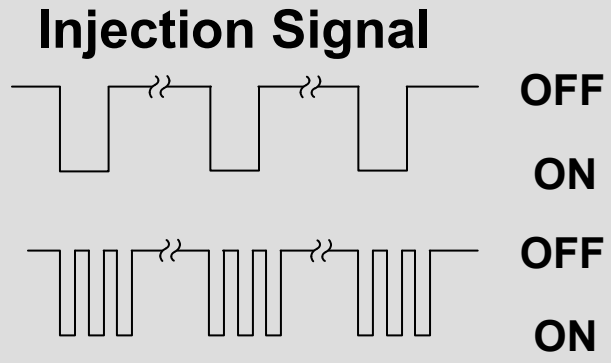
- Short rich pulse duration
  - Low NOx reduction efficiency

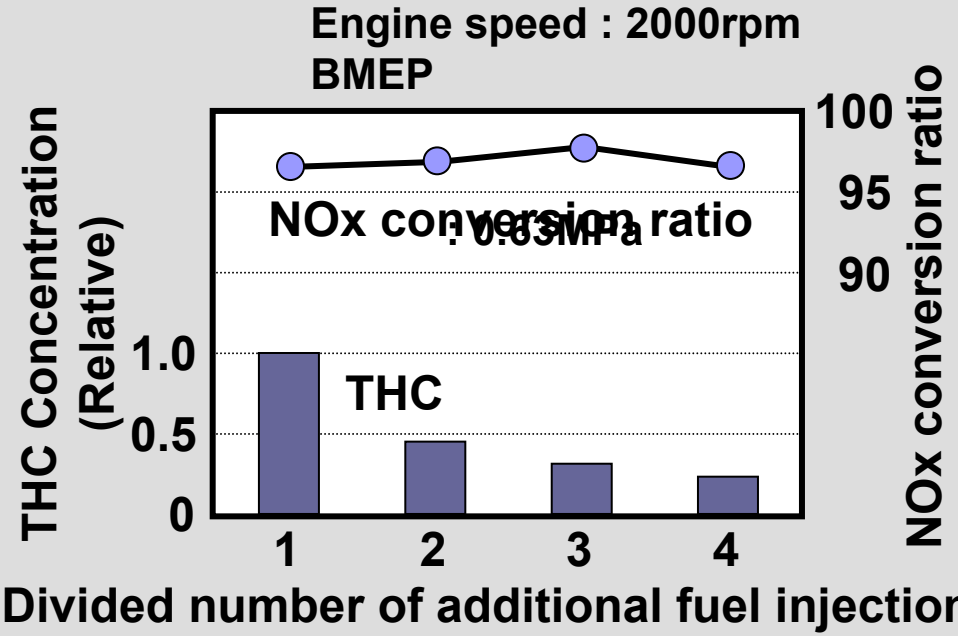
- Extended rich pulse duration (0.3 → 1.0sec.)
- Increased quantity of additional fuel
  - \+ Higher NOx reduction efficiency
  - Increased fuel penalty
- Simple increase of additional fuel is not favorable.

# Key Technologies for Rich Pulse

## Effect of multiple injection by additional fuel injection



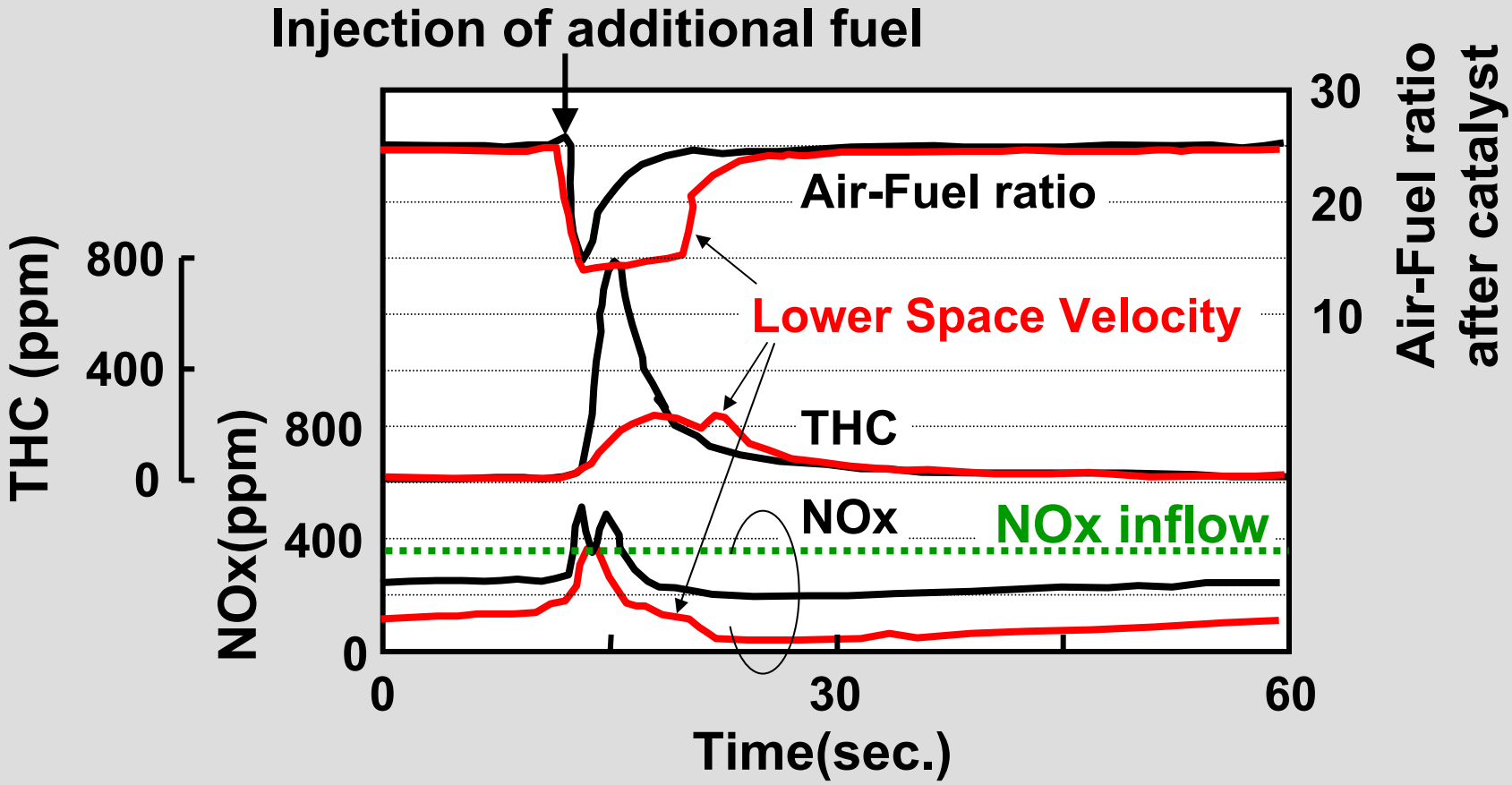




- Deeper rich pulse + Higher NOx reduction
  - Higher HC emission
- Multiple rich pulse + High NOx reduction
  + Lower THC emission

# Key Technologies for Rich Pulse

## Advantage of low space velocity




- Low SV can prolong rich pulse duration and results in lower NOx and HC emission

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**(b) How to maintain activated state**
- **Improvement on thermal deterioration**
- **Improvement on sulfur poisoning – New concept DPNR**

(c) How to treat unexpected products
- Clean-up catalyst (including NOx slightly reduced)

3. Future prospective of the next generation DPNR

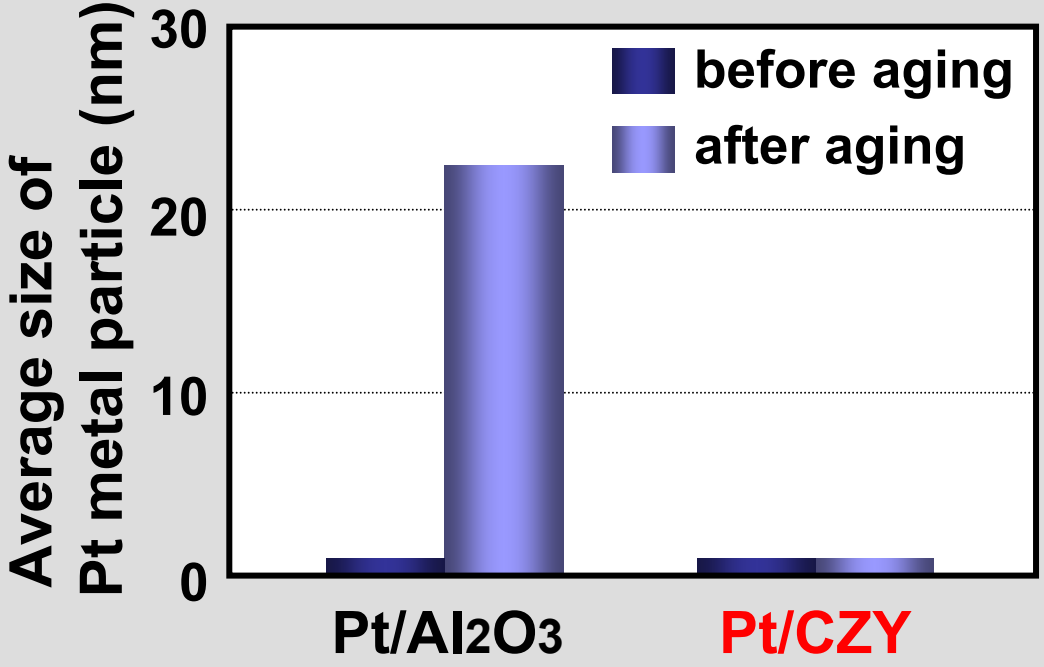
4. DPNR(NSR) or UREA-SCR ?

# Improvement on Thermal Deterioration

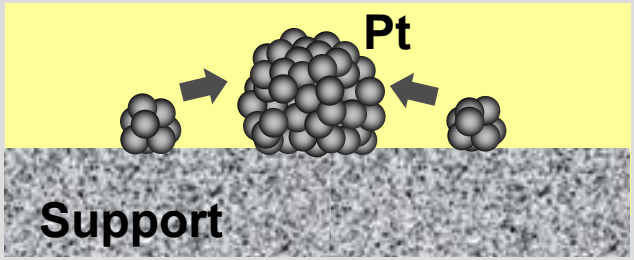
## Effect of support material of TWC* for sintering of Pt.

*TWC:three way catalyst

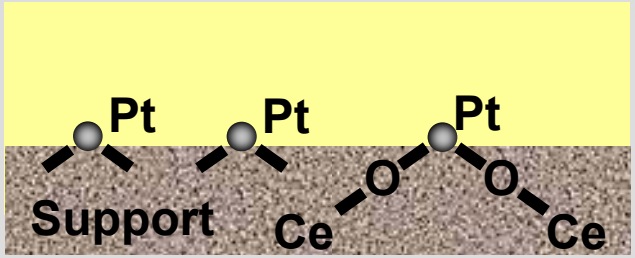
Measured by the low temp. CO pulse method
Aging condition:800 deg.C x 5hours




Support : γ-$Al_2O_3$




Support : CZY
($CeO_2$-$ZrO_2$-$Y_2O_5$ solid solution)

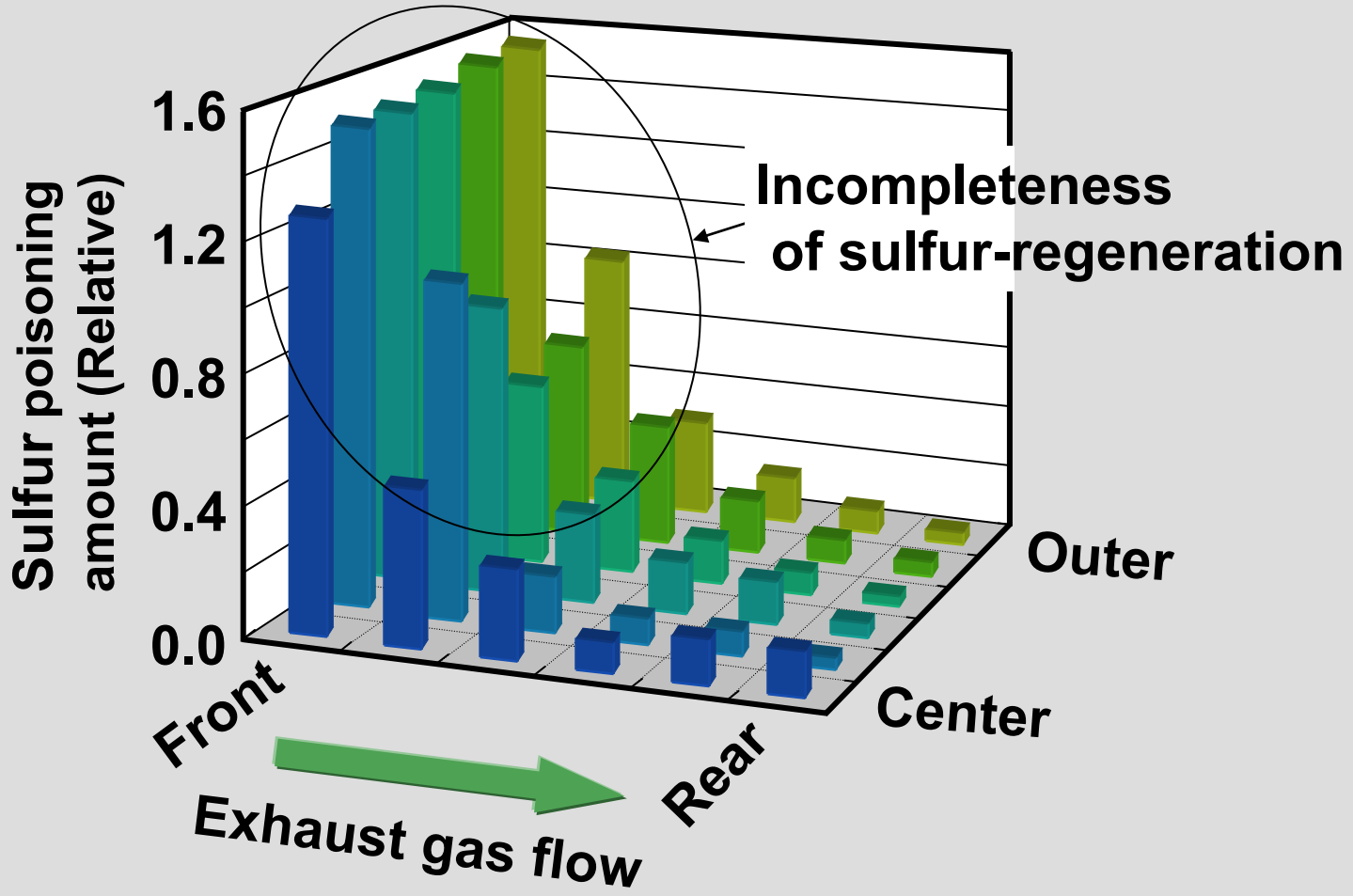



- Pt particles on ceria-based catalysts do not sinter at all.
- Pt-Support interaction (Pt-O-Ce) is the key point for the inhibition of Pt sintering.

SAE 2006-01-0413

# Improvement of Sulfur Poisoning

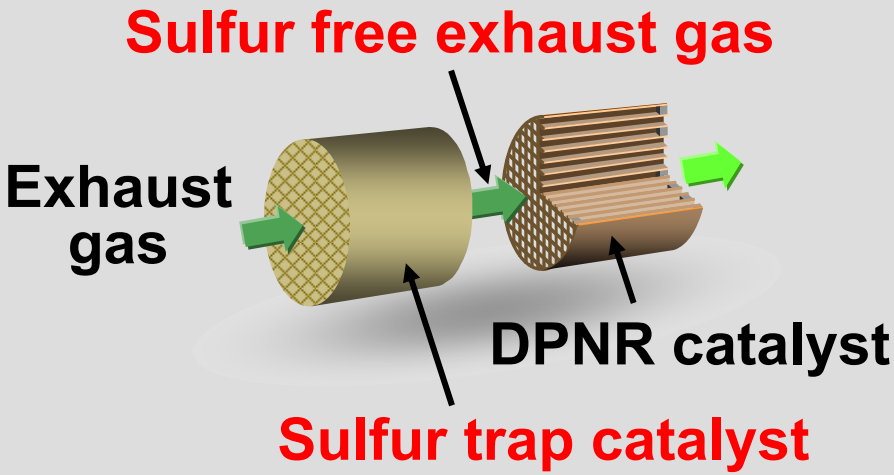
## An example of incompleteness of sulfur regeneration of NSR catalyst



# One of New Concept DPNR (S Trap DPNR)

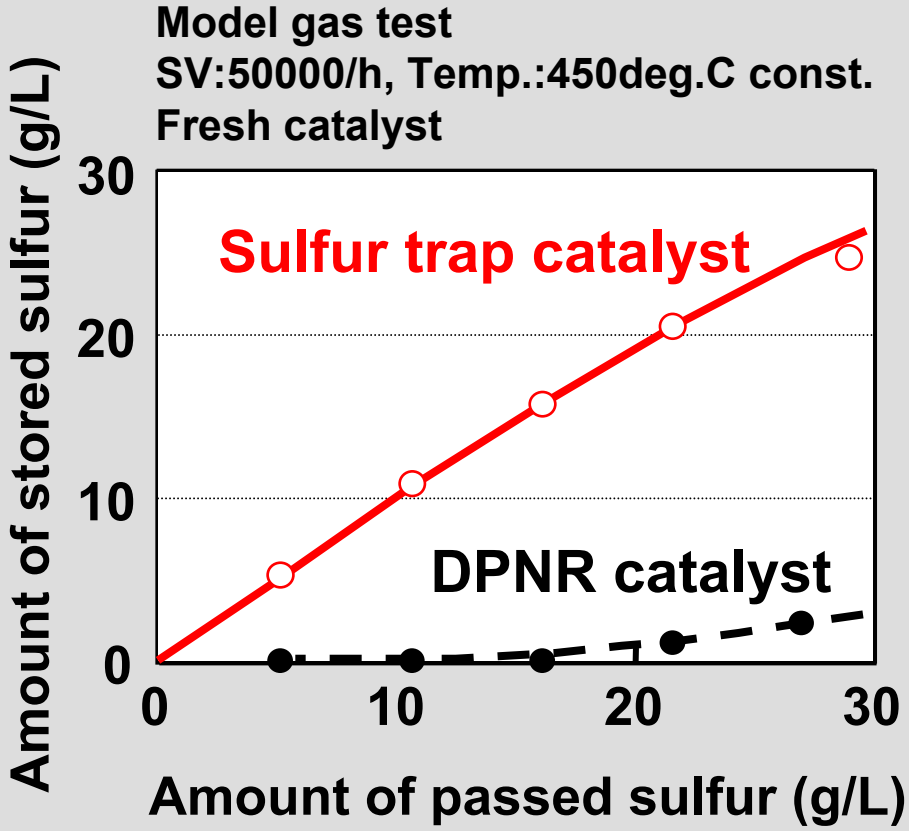
## S Trap DPNR

### Concept of S Trap DPNR



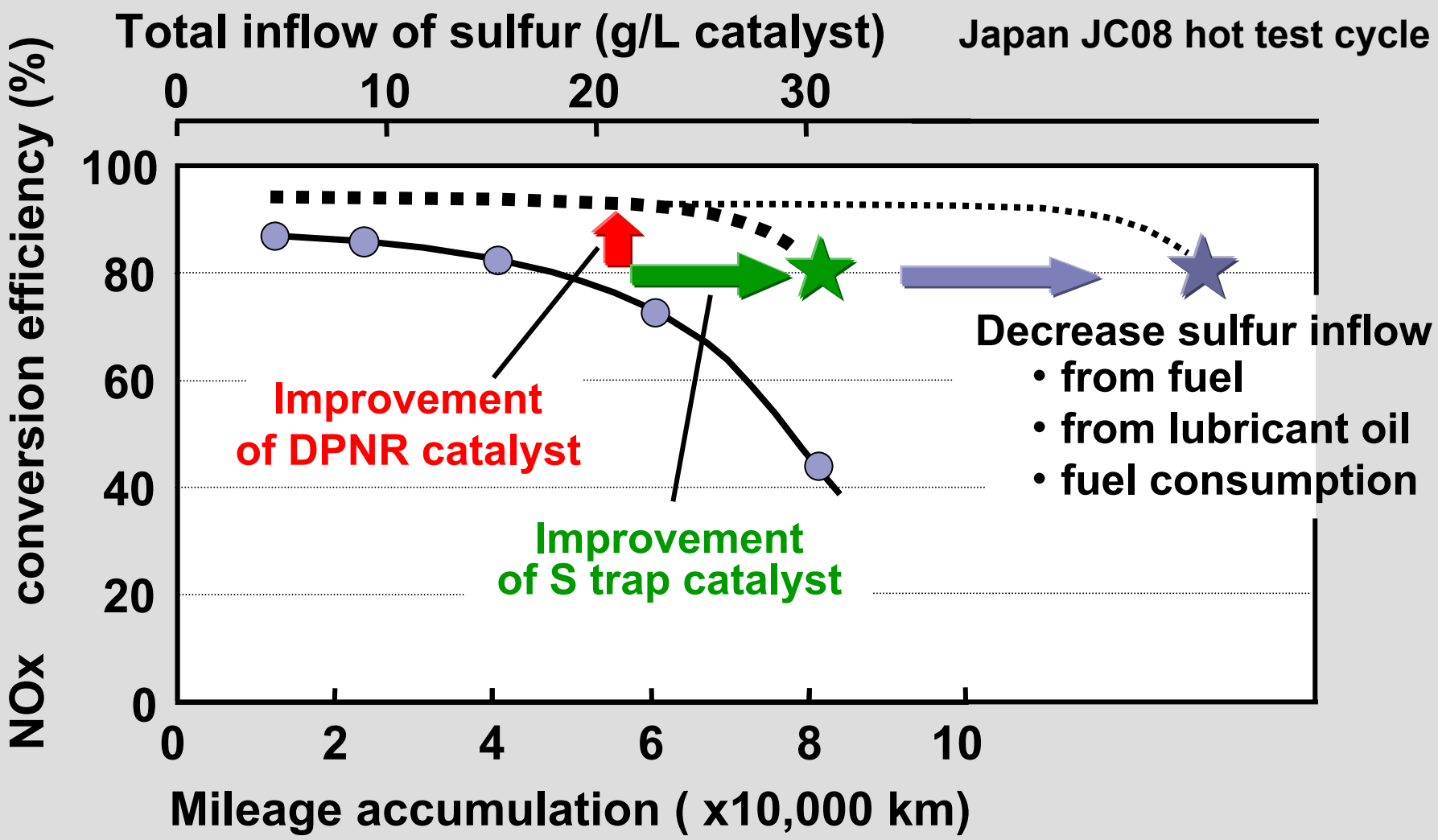

- Sulfur poisoning of the DPNR catalyst is suppressed.
- Thermal deterioration caused by sulfur discharging control can be reduced.

### Sulfur poisoning of DPNR catalyst with sulfur trap catalyst



# One of New Concept DPNR (S Trap DPNR)

## Results of durability test



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- **Clean-up catalyst (including NOx slightly reduced)**

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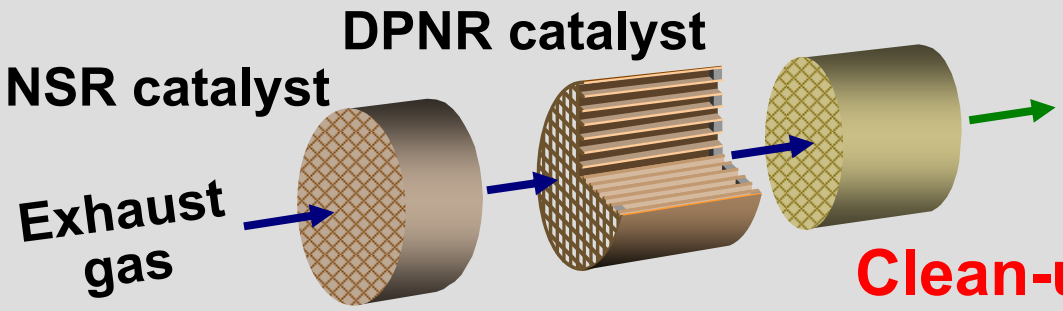
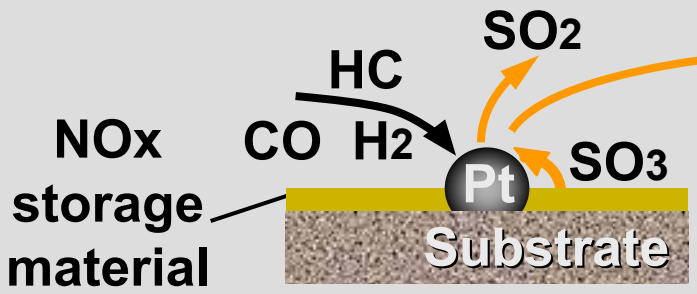
# Clean-up Catalyst for DPNR (NOx slightly reduced)



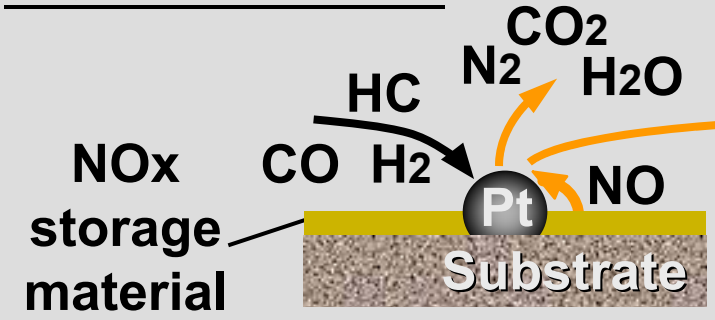

## Regeneration from sulfur poisoning




$H_2S$, HC, CO → $SO_2$, $H_2O$, $CO_2$

- $H_2S$ emitted during sulfur regeneration control can be converted to $SO_2$

## NOx reduction

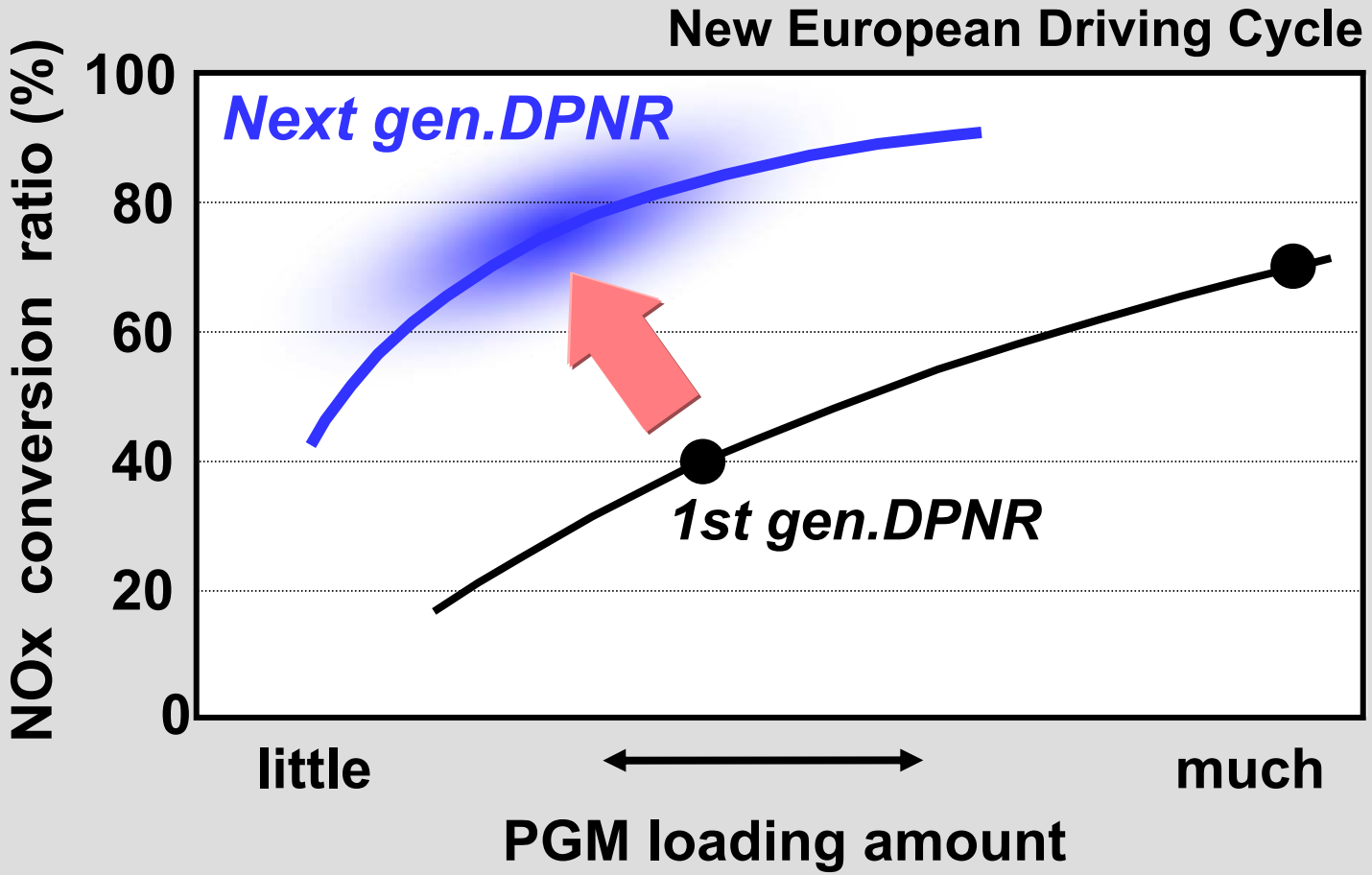



NO, HC, CO $NH_3$ ····· → $N_2$, $H_2O$, $CO_2$

- NOx is slightly reduced by $NH_3$ and HC

# Contents

# Future Prospective of Next Gen. DPNR



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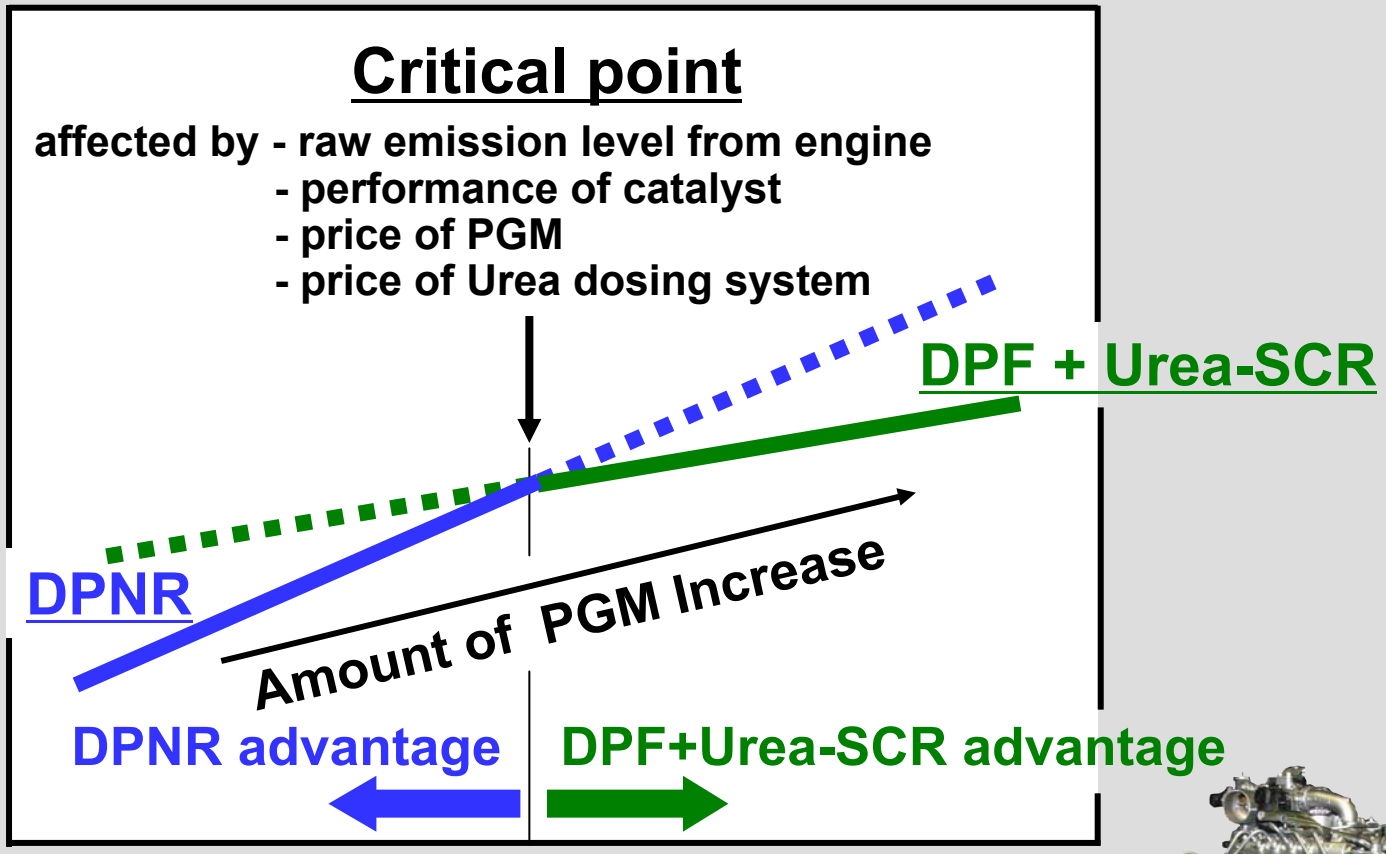
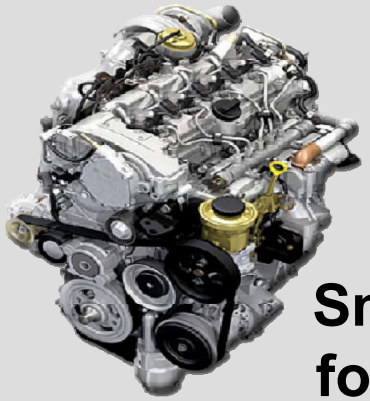
# DPNR(NSR) or UREA-SCR ?

√ advantage

| | DPNR (=NSR) | UREA-SCR |
|---|---|---|
| NOx purification performance | 70% - = | 70% - |
| Maintenance | √ | Refilled up by every oil exchange |
| Installation for PC and LDT | √ | Urea tank Number of catalysts |
| Fuel consumption penalty | NOx reduction, Desulfurization | √ |
| Desulfurisation | Needed periodical desulfurisation | √ |
| Anti tampering | √ | Urea lack measures |
| System cost | √ for PC | √ for HDT |
| Loading quantity of PGM | | √ |
| Low sulfur fuel | <15ppm | √ |
| Urea supply infrastructure | √ | |
| Choice | PC, LDT | MDT, HDT |

# DPNR(NSR) or UREA-SCR ?



Small L4 engine for compact car

Large V8 engine for SUV

# Conclusions

## 1.For the improvement of NOx storage and reduction efficiency

NOx reduction

- High reduction efficiency of additional fuel injection system can be realized by multiple injection and/or lower space velocity with low HC emission and fuel consumption.

Catalyst improvement

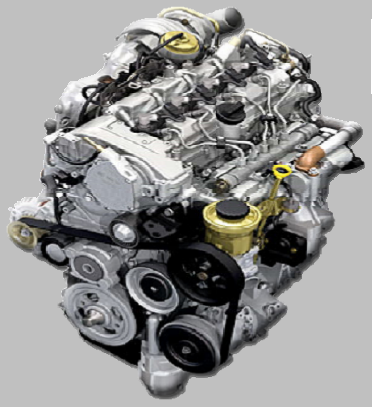
- Ceria based support is effective for suppression of thermal deterioration.
- S-trap DPNR will be one of the promising system which can restrain the deterioration by sulfur poisoning.

## 2. Future prospective of the next generation DPNR

- It will be able to realize over 70% of NOx purification ratio with less PGM in the next generation DPNR.

## 3. DPNR(NSR) or UREA-SCR ?

- We should choose DPNR(NSR) for smaller engines of swept volume and Urea-SCR for larger ones.

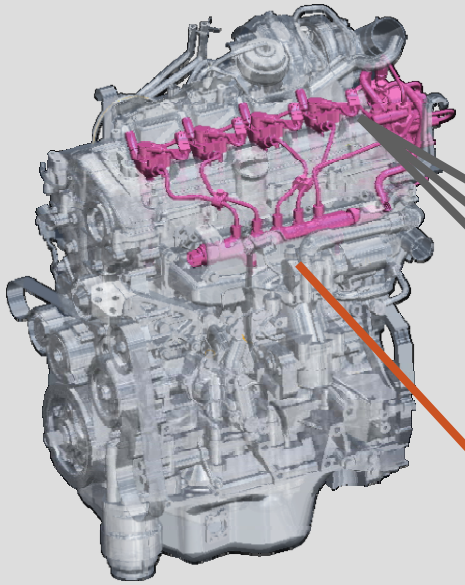


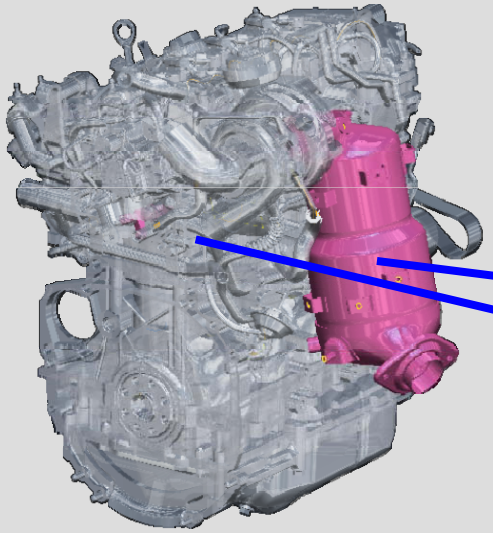
***2AD-FHV 2.2L L4  w/DPNR***

***1VD-FTV 4.5L V8  Just Introduced!***

*Thank you for your attention*

# TOYOTA Diesel Clean Advanced Technology system





## TOYOTA D-CAT

**Fuel Injection System**
New generation CR injection syste
・Piezo Injector
・High pressure injection 1800bar-
・Multiple injection

**Combustion**
・Low compression ratio
・Smokeless rich combustion
・High efficiency EGR cooler
and temperature control

**After treatment**
DPNR
・Original DPNR caralyst
・Exhaust port/pipe injector
DPF

**Engine management**

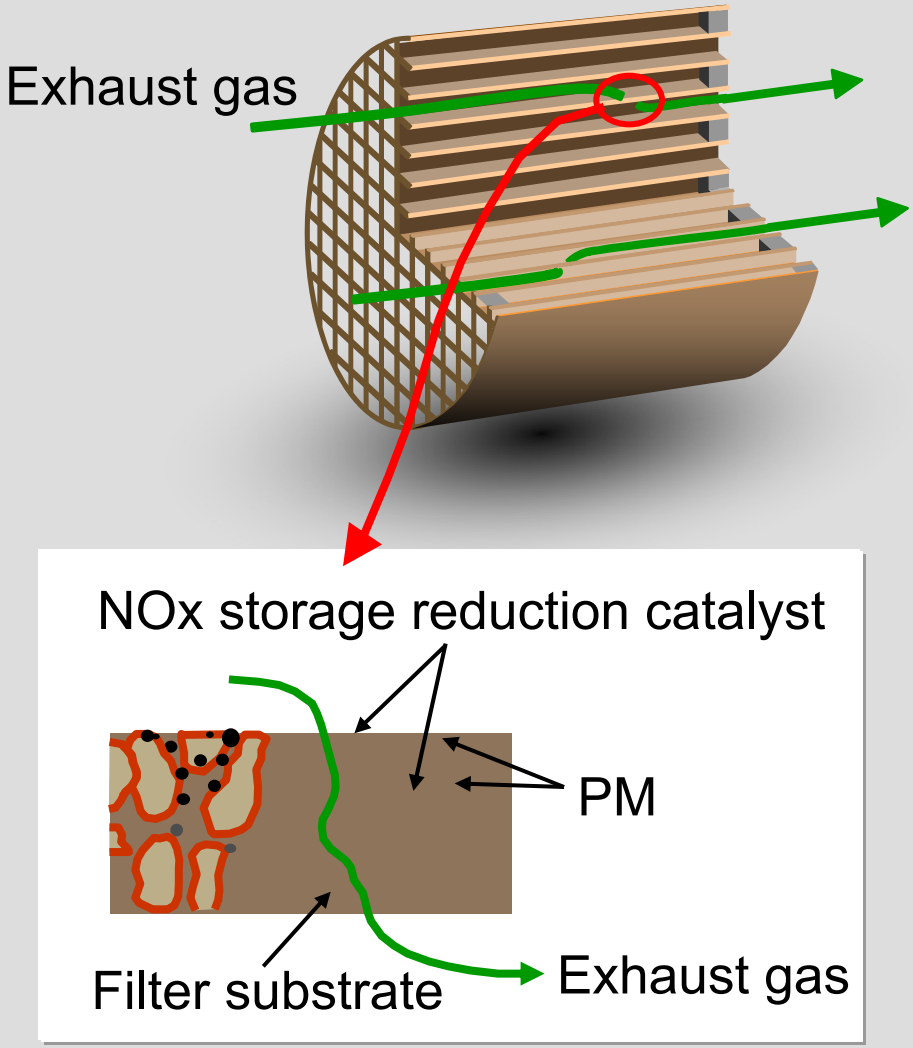
**Low emission**

**Low fuel consumption**

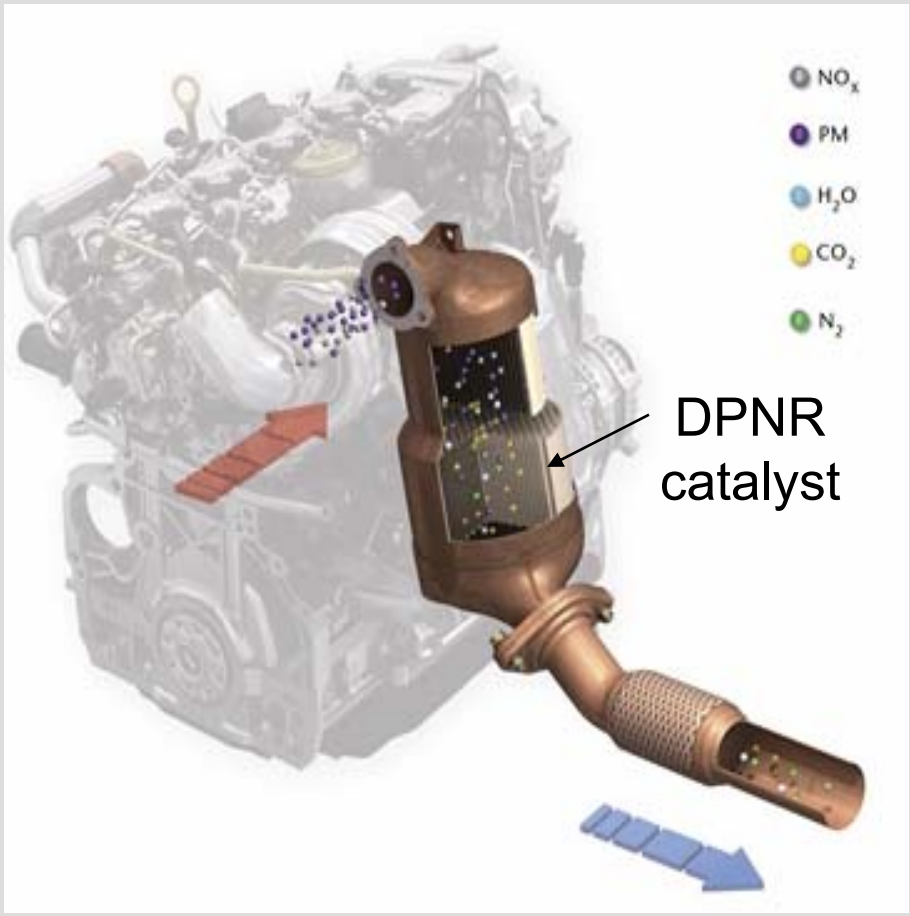
**High power & torque**

# DPNR (Diesel Particulate-NOx Reduction System)

Configuration of DPNR catalyst

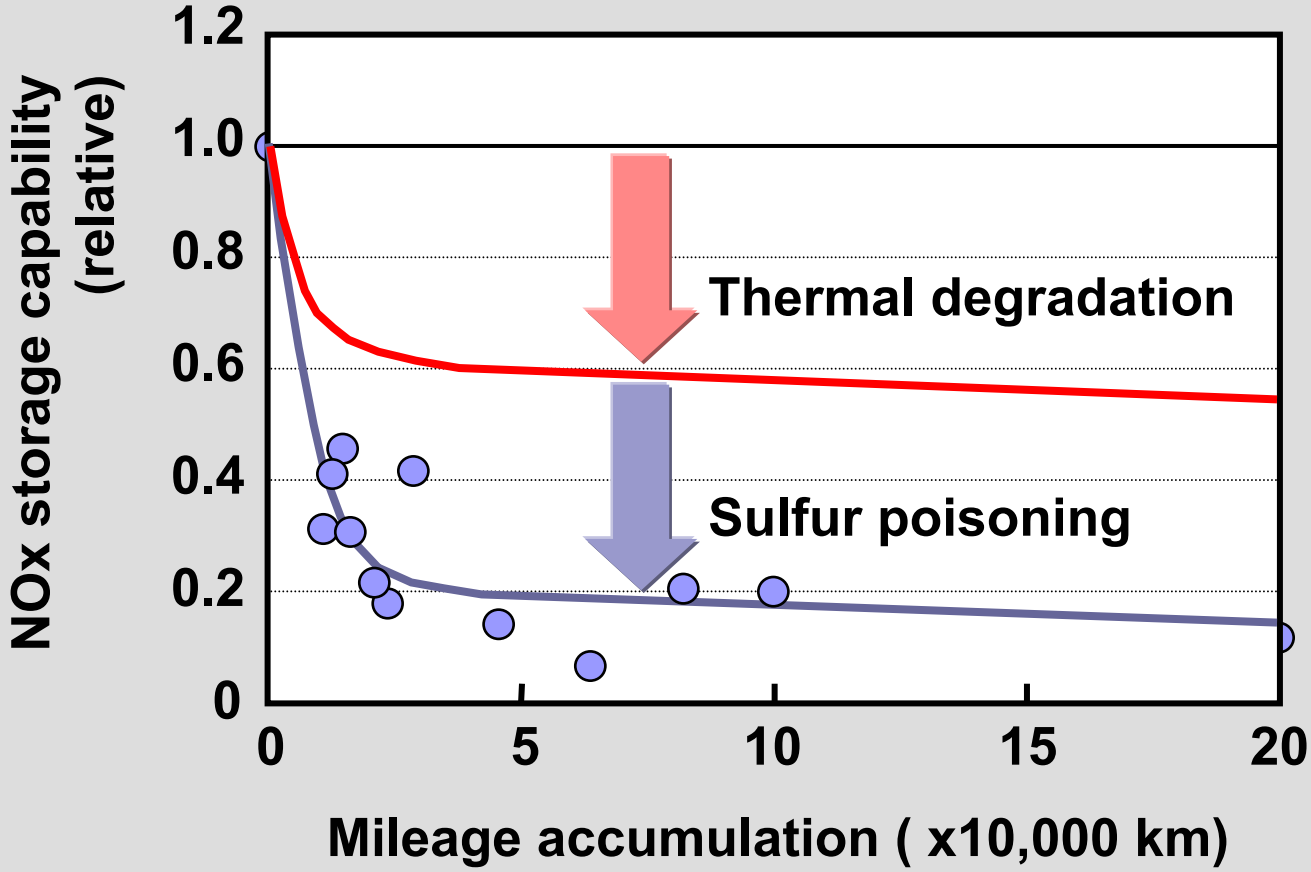



Application for current 2AD-FHV engine



# (b) How to Maintain Activated State

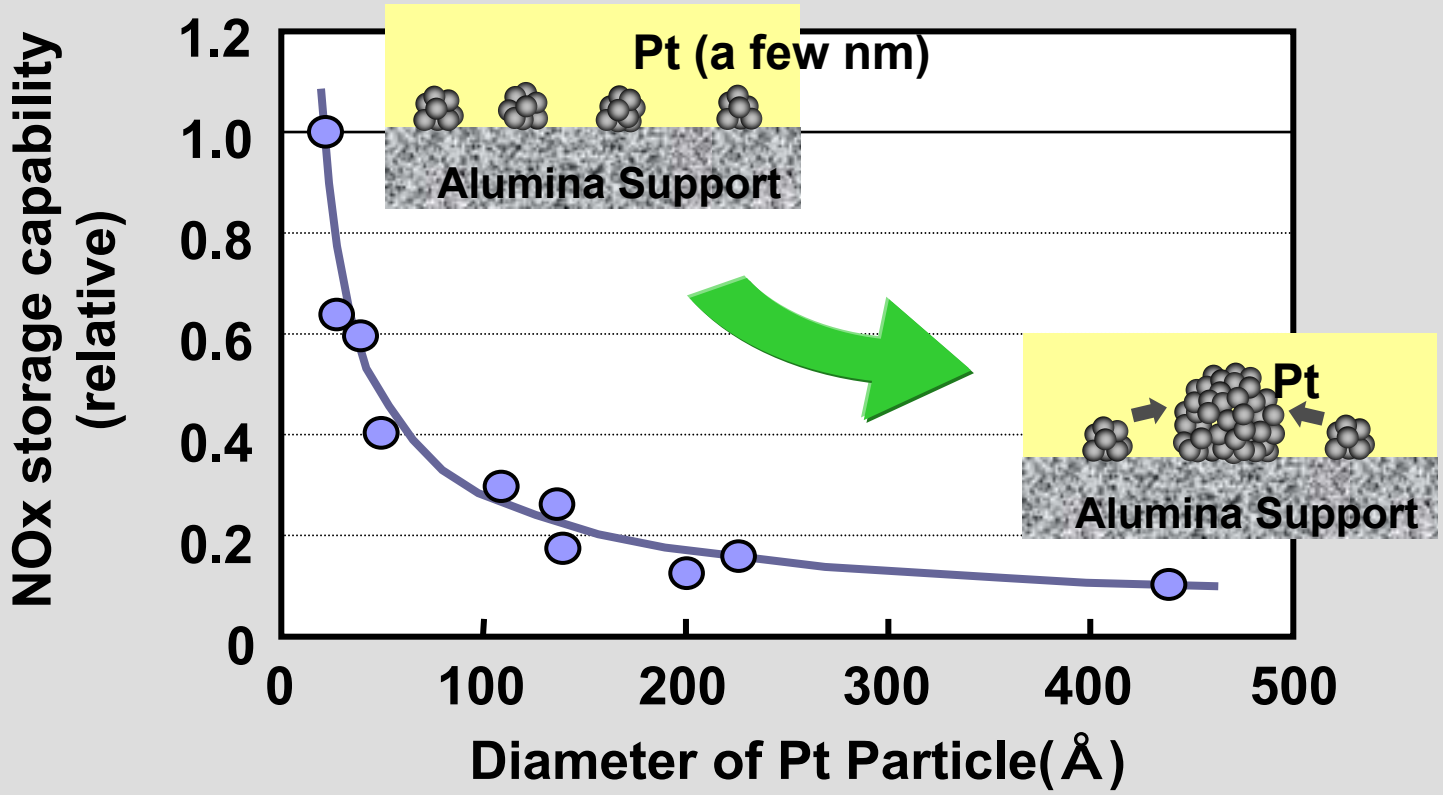
## Degradation of NOx storage capability




**NOx storage capability is Decreased by thermal deterioration and sulfur poisoning**

# Improvement on Thermal Deterioration

## Relation between NOx storage capability and sintered Pt diameter




➢Pt particle sintering : Main cause of deactivation

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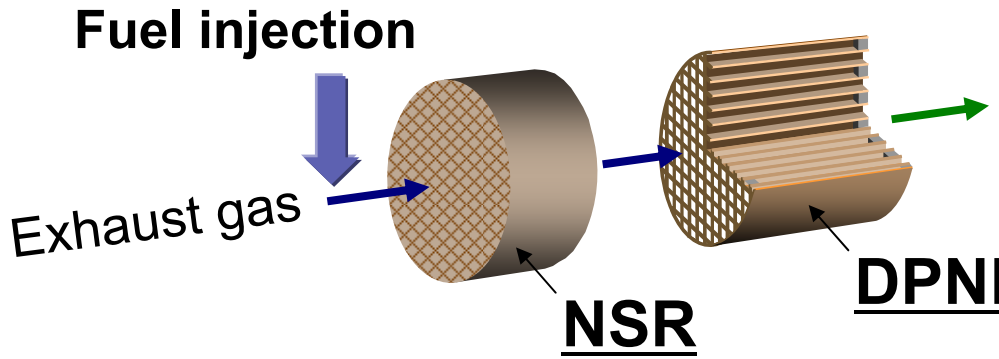
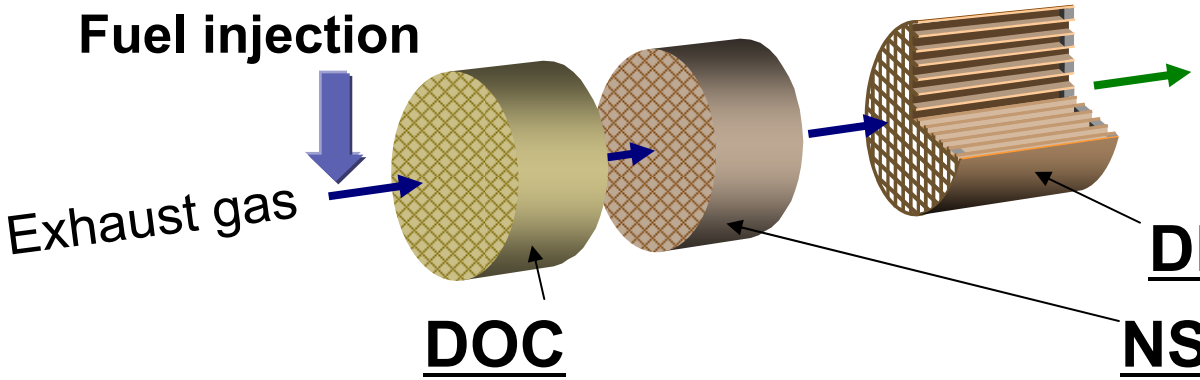
# Improvement of Sulfur Regeneration




- NOx storage/reduction
- Raise gas/catalyst temp.




- Raise gas/catalyst temp.
- NOx storage/reduction