

# Urea SCR and DPF System for Diesel Sport Utility Vehicle Meeting Tier II Bin 5

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DOE and Ford Motor Company Advanced CIDI Emission  
Control System Development Program  
(DE-FC26-01NT41103)

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Diesel Engine Emission Reduction Conference

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# DOE Ultra-Clean Fuels Program

Outline of Ford's program to achieve Tier II emission standards for 2007 using low sulfur diesel fuel as an enabler for a high efficiency aftertreatment system.

## Primary Contractor

*Ford Motor Company*

## Subcontractors

**ExxonMobil**

*Research and Engineering*

**FEV**

## Catalyst Suppliers

**ENGELHARD**

JM

Johnson Matthey

**OMG**  
OM Group

Phase I - Initial build/test phase (12 mos.)

Establish baseline emission control system

Deliver engine dynamometer NOx and PM test results

Demonstrate and deliver prototype vehicle NOx and PM test results

Deliver urea delivery (infrastructure) prototype

Phase II - System/component optimization phase (18 mos.)

Define final system hardware components

Deliver NOx and PM performance data

Demonstrate emission control system (includes NOx and PM data)

Phase III - Durability/Demonstration phase (18 mos.)

Definition of durability test procedure

Final NOx and PM emission levels

Define fuel sulfur limits for emission control system

Final report for the completed program

**FEV**

**Research**  
*Ford Motor Company*

**ExxonMobil**

*Research and Engineering*



# FEV Program

## Concept Design

- CFD Modeling including urea injection

## Engine Dynamometer

- Baseline and rapid warm-up testing
- Urea SCR/DPF optimization
- Transient FTP/US06 testing

## Vehicle durability

- 120,000 miles or 5000 hours



# ExxonMobil Program

Intellectual property discussion delayed program for 9 months; program was then accelerated to contain original objectives.

## SCR urea catalyst development

- Durable, high NO<sub>x</sub> conversion from 150° to 600°C with low N<sub>2</sub>O make.

## Urea infrastructure studies

- Co-fueling
- Low temperature urea solution

## Fuel development

- Make and use fuel, which will be typical of 2007 production with 15 ppm sulfur cap.

# Acknowledgements

## Contributions to this program

### Ford

Karen Adams, Dick Baker, Will Belanger, Brendan Carberry, Dick Chase, Dave Kubinski, Paul Laing, Christine Lambert, Mike Levin, Chris Mazur, Cliff Montreuil, Rick Soltis, Paul Tennison, Devesh Upadhyay, John Vanderslice and Scott Williams

### FEV

Philipp Adomeit, Eric Koehler, Dean Tomazic

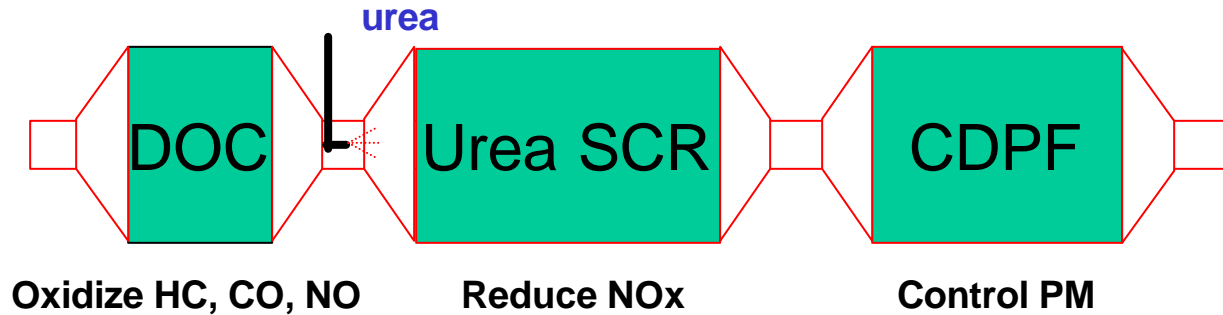
### Exxon Mobil

Joan Axelrod, Jeff Beck, Bill Blazowski, Owen Feeley  
Marcus Moore, Mike Noorman and David Stern

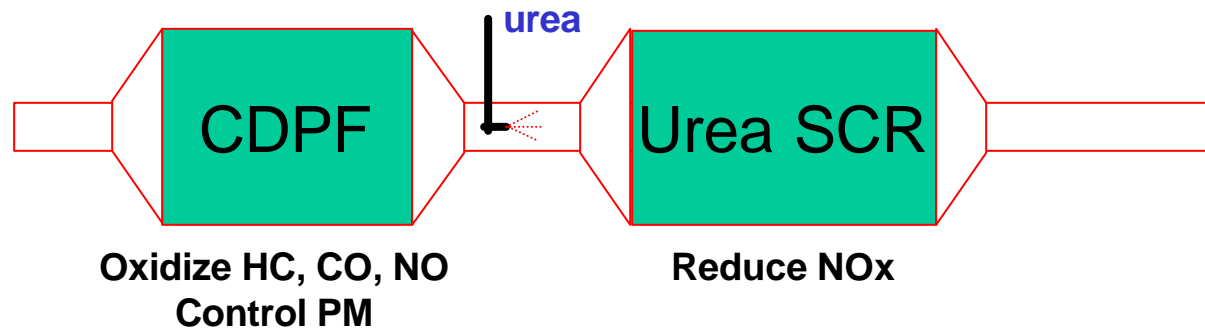


# Initial Configuration Choices for Tier II Bin 5

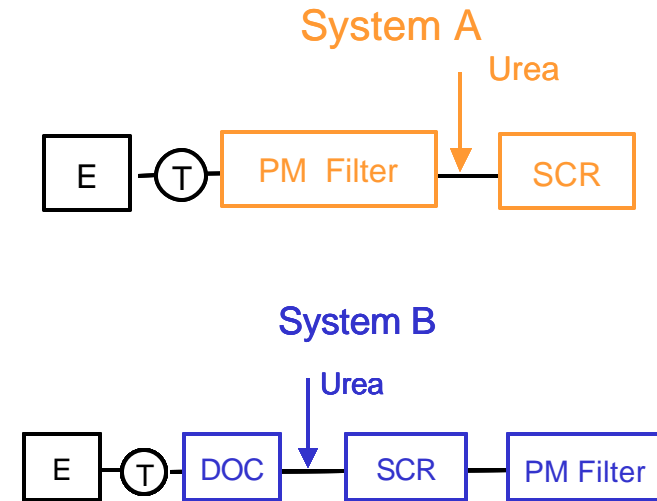
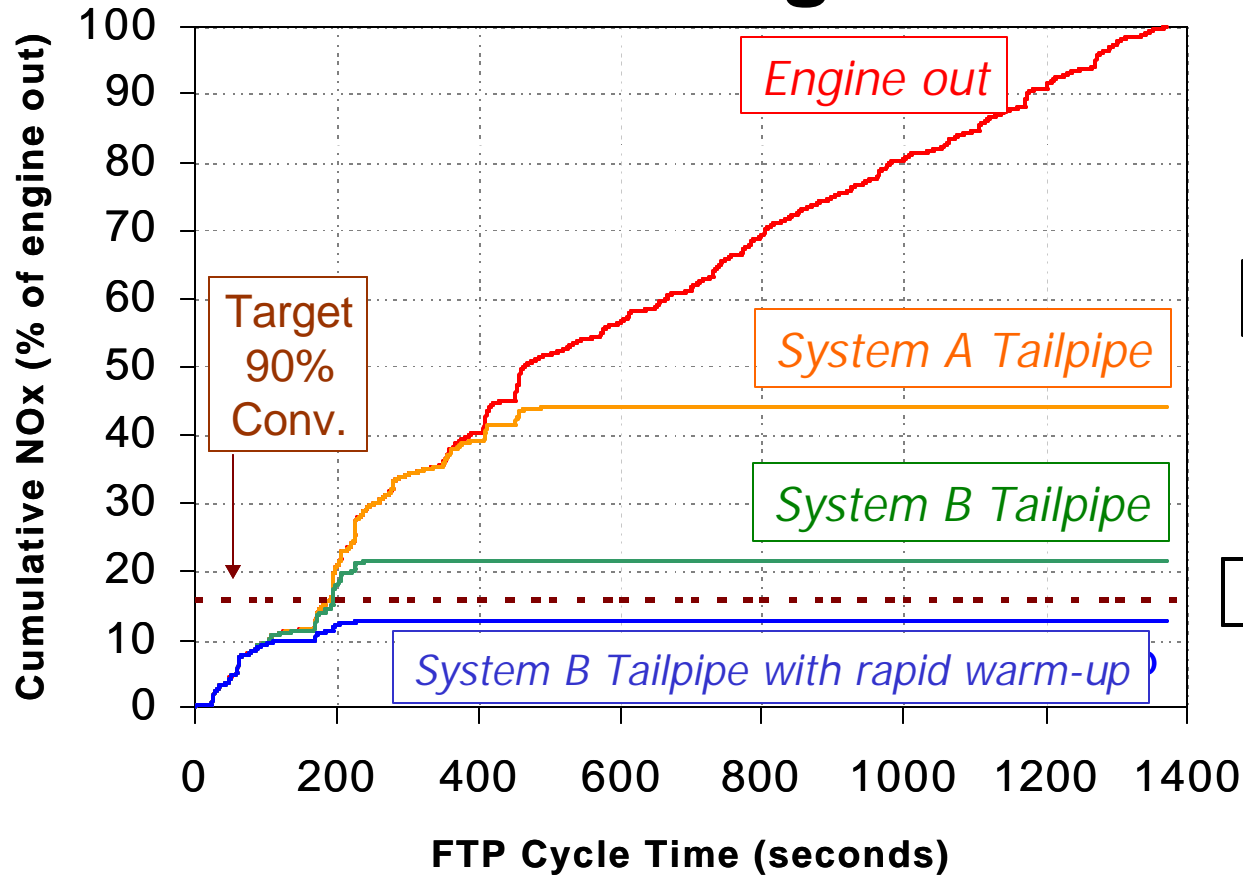
## Selected configuration



## Unacceptable configuration

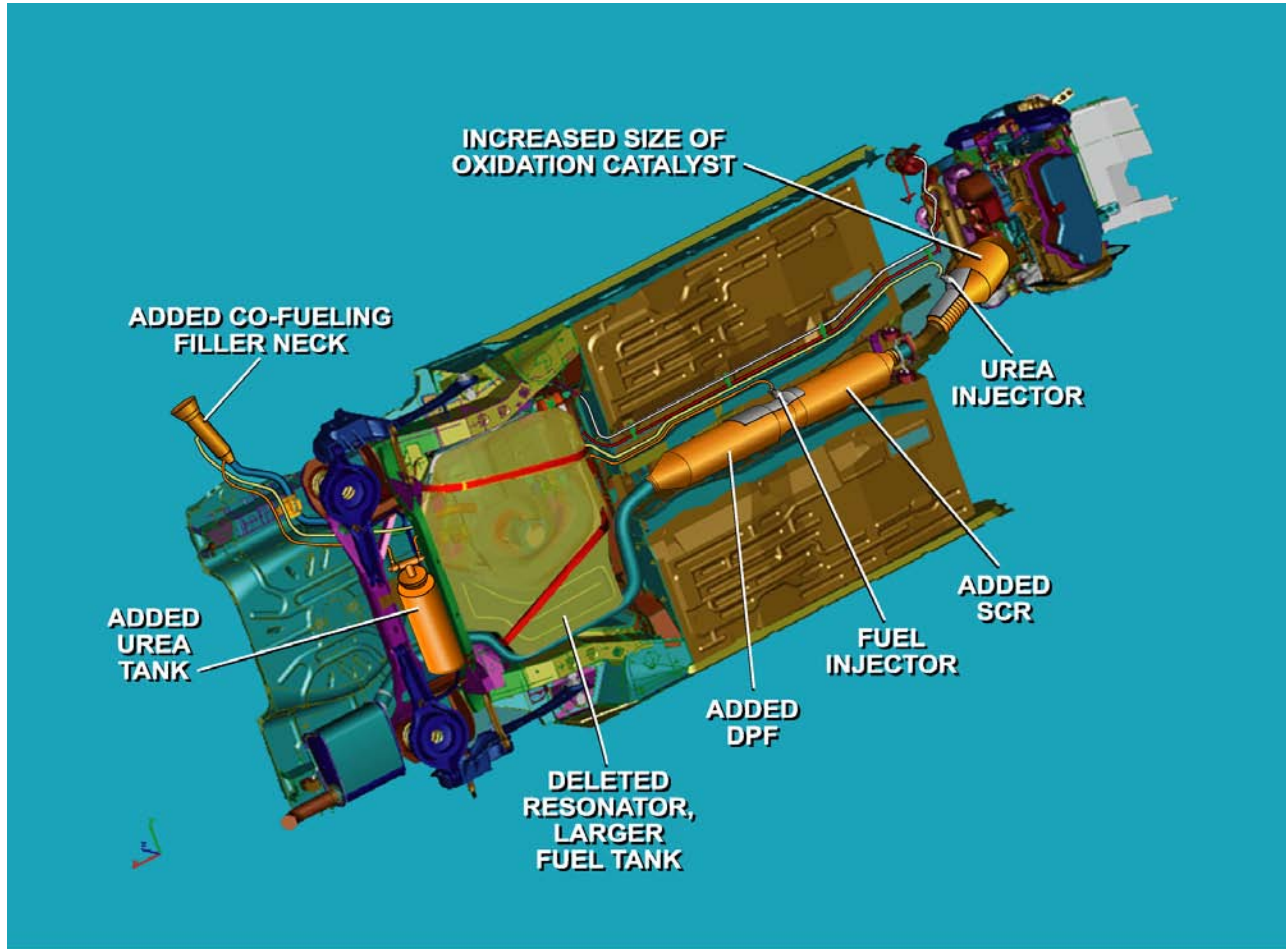


# Urea SCR Model Prediction of Tailpipe NOx for Configuration Alternatives



*Rapid warm-up = extra 50°C ramped in over first 30s of test and off at 200s.*

# Using Fresh DOC/SCR/DPF System, Focus Achieved ULEV II / Bin 5



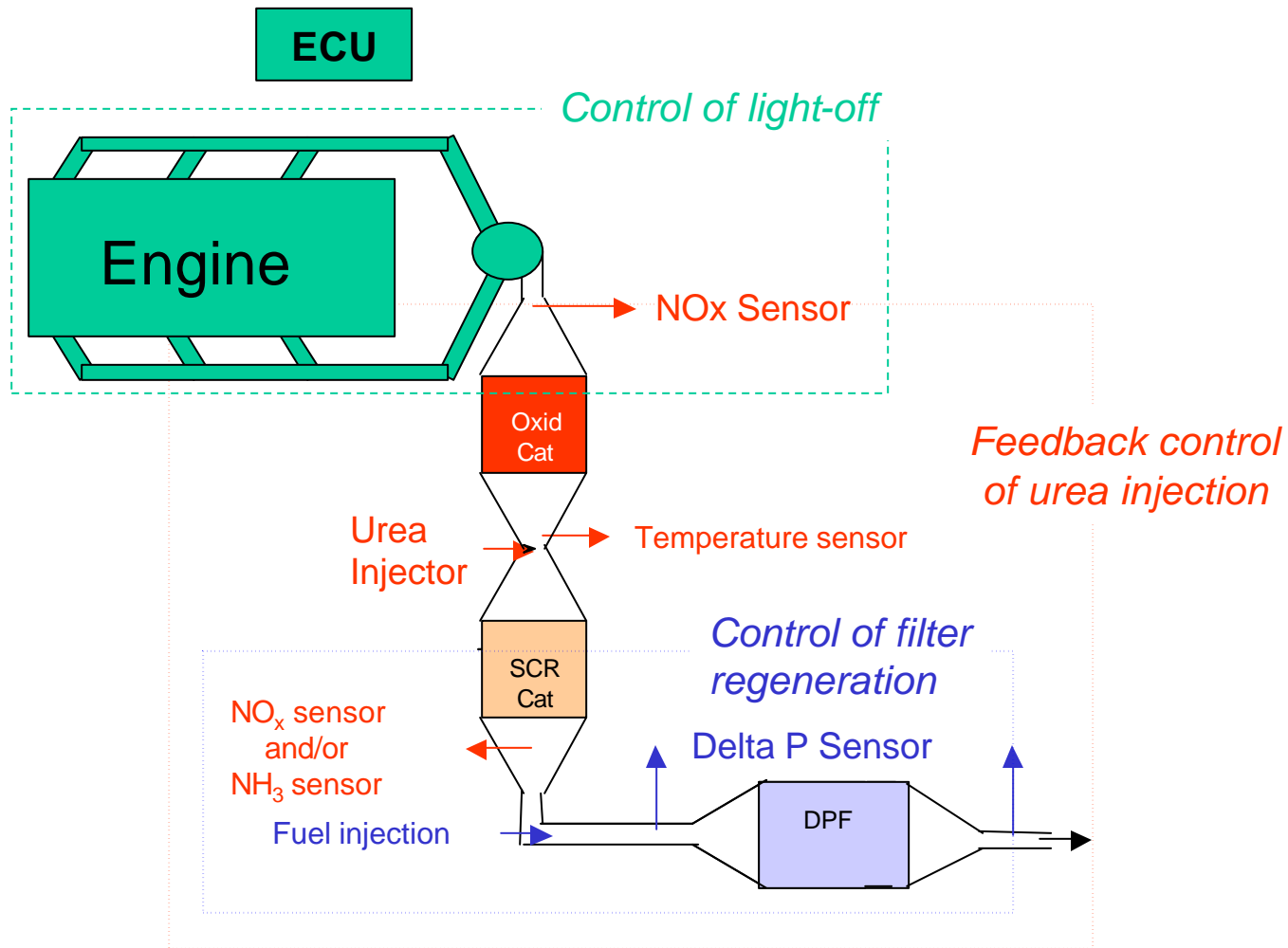
Ford Research Laboratory showed Focus results using fresh catalysts:

FTP conversion for NO<sub>x</sub> is ~90% and PM is ~98%.

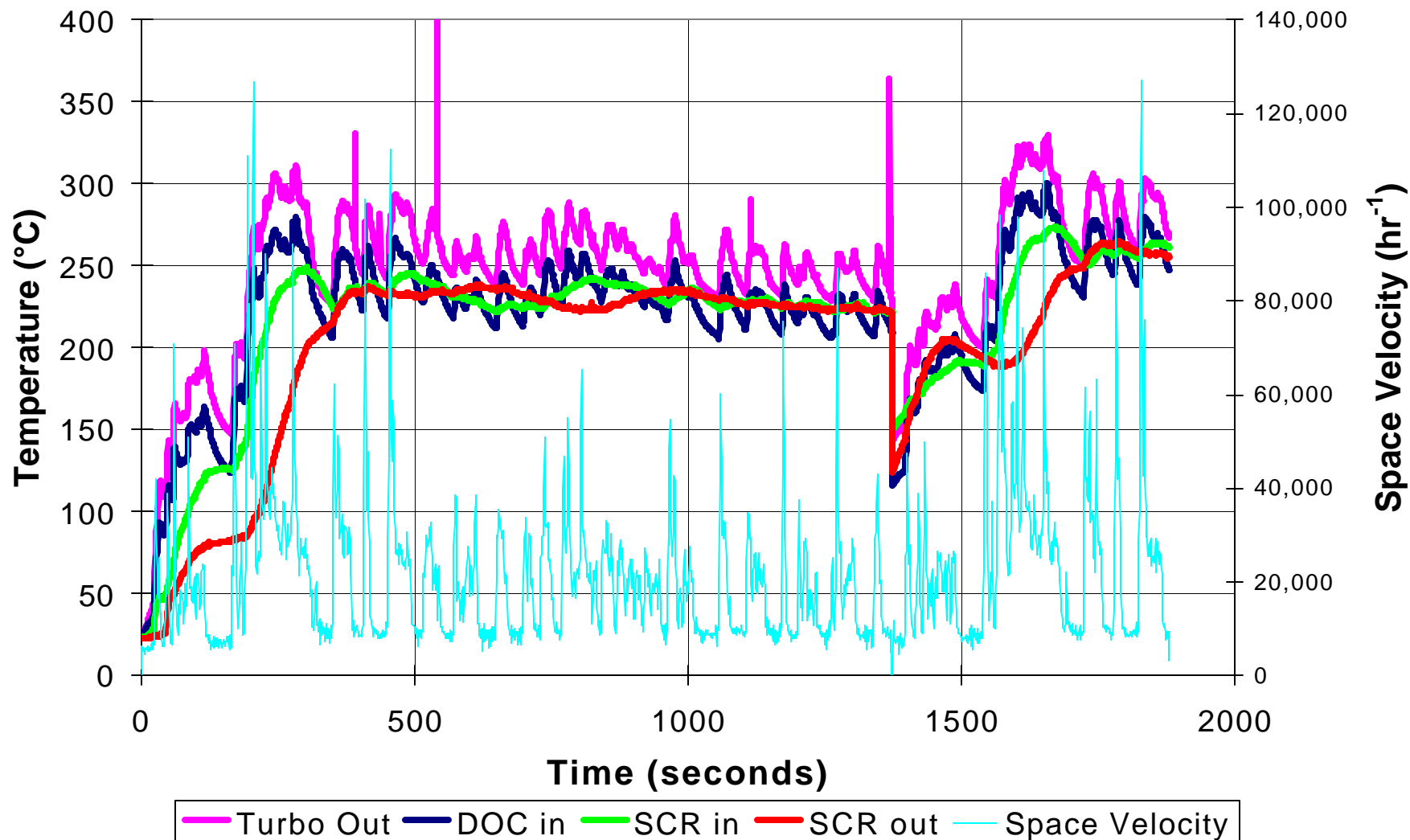
US06 conversion for NO<sub>x</sub>+HC is ~92%.



# Light-Duty Truck Exhaust System



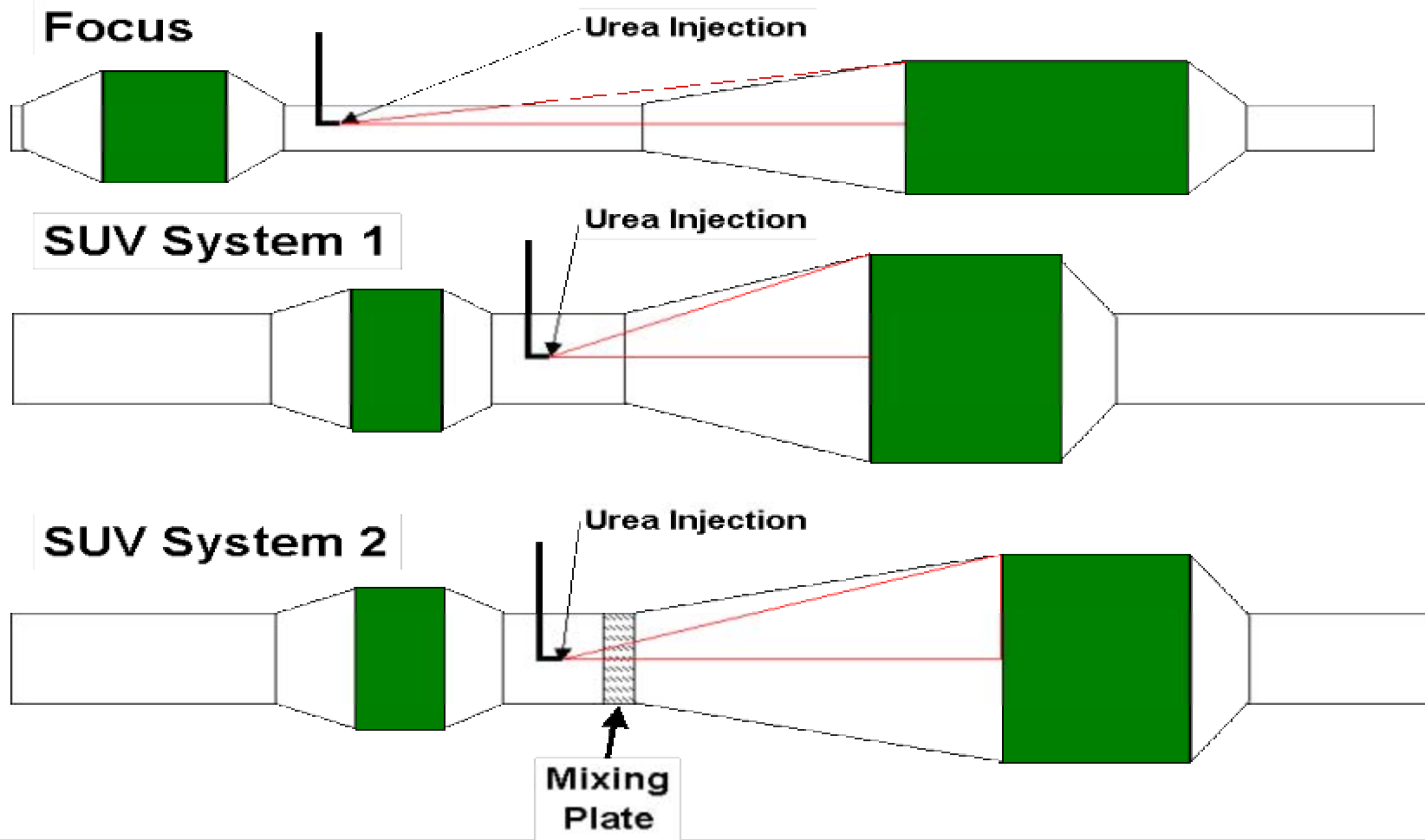
# Temperatures and Space Velocity EPA-75 Test



# Vehicle Testing

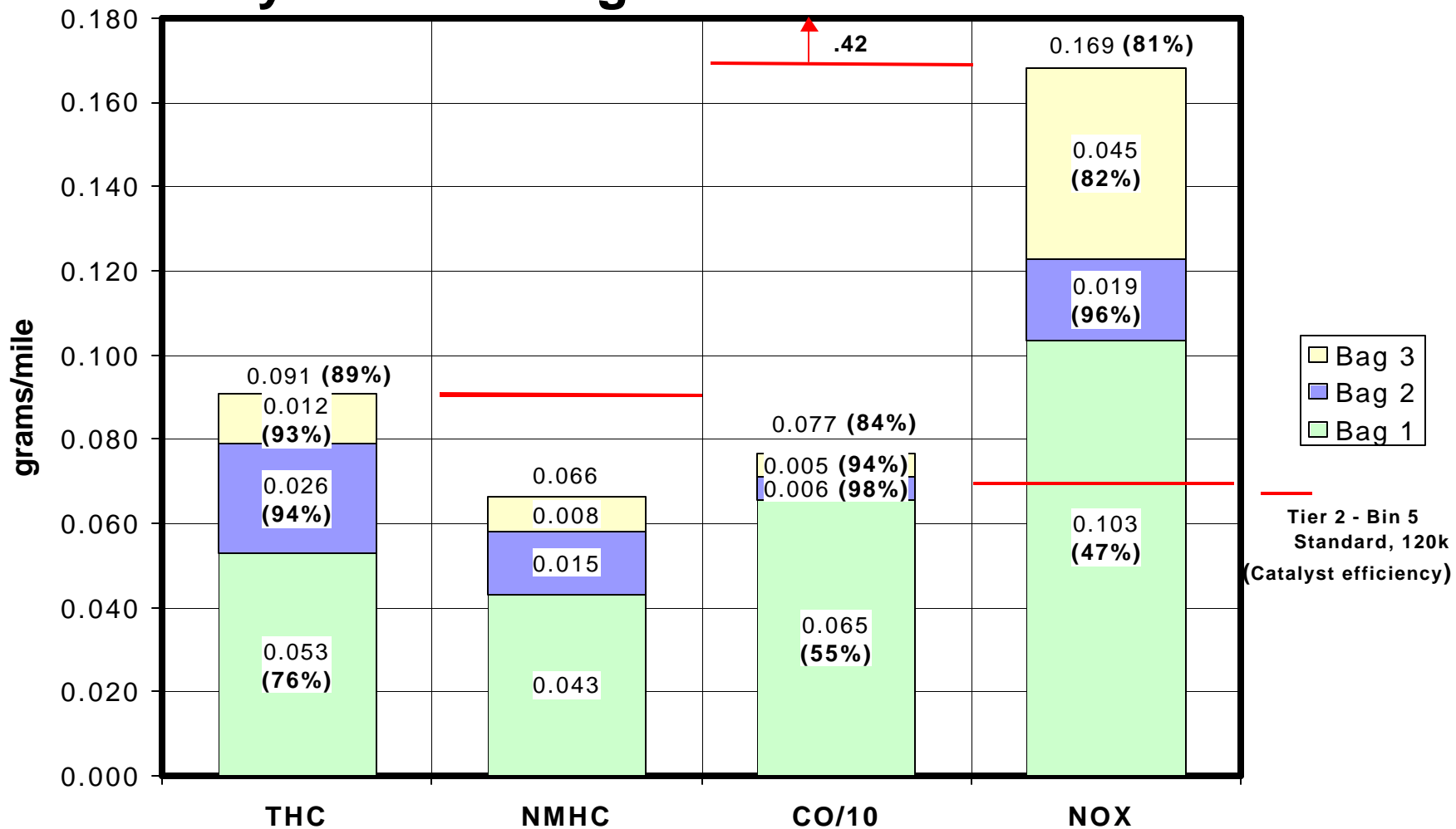
- With initial system 1, 35% NO<sub>x</sub> conversion and high NH<sub>3</sub> slip.
- Suspected poor urea distribution caused low NO<sub>x</sub> conversion.
- Developed new system 2 for improved urea distribution
- System 2 has increased length of the SCR entrance cone and mixing plate.

# Urea Distribution on SUV & Focus



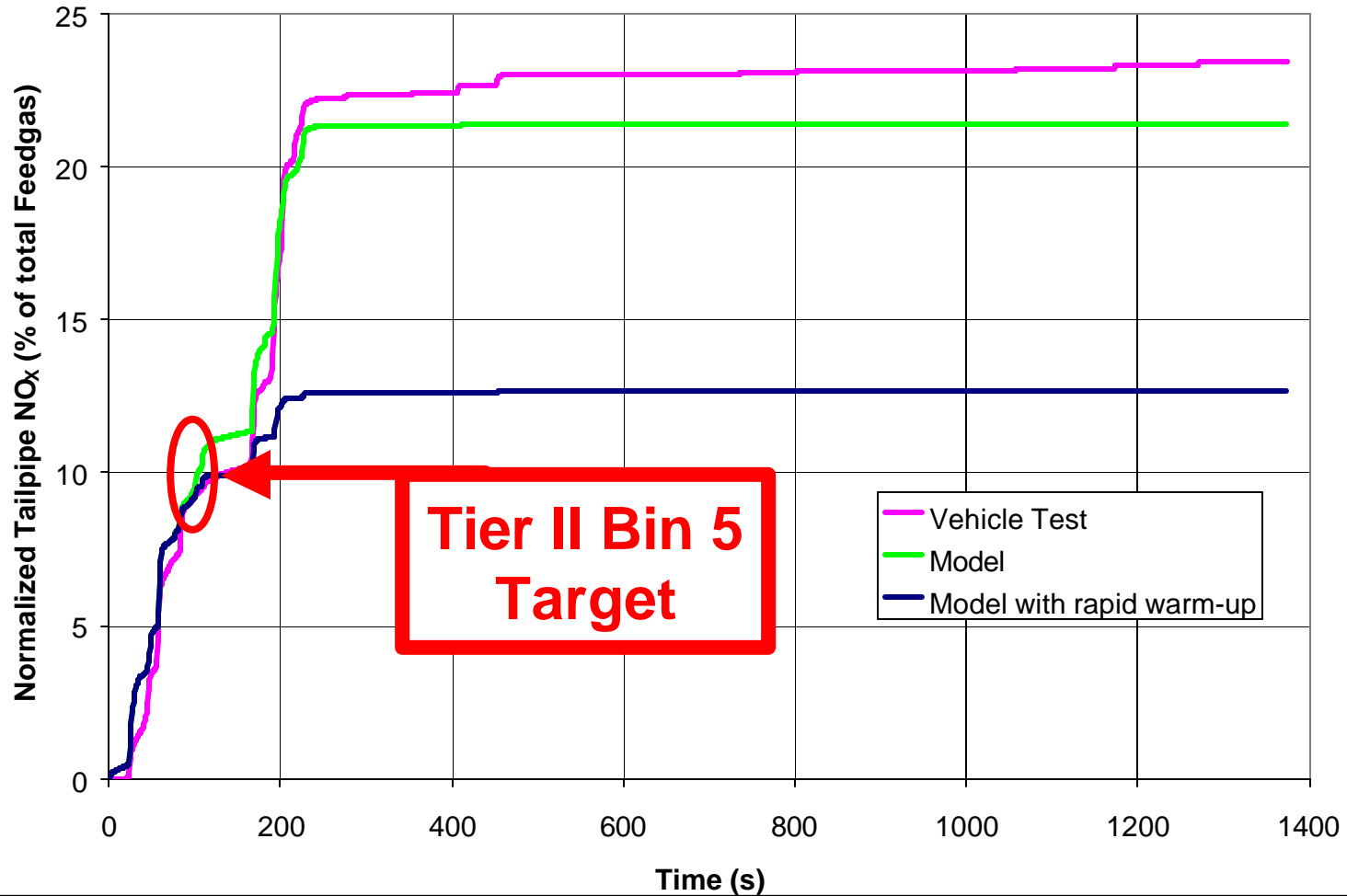
# Sport Utility Vehicle Testing

## System 2 - Weighted EPA-75 Emissions



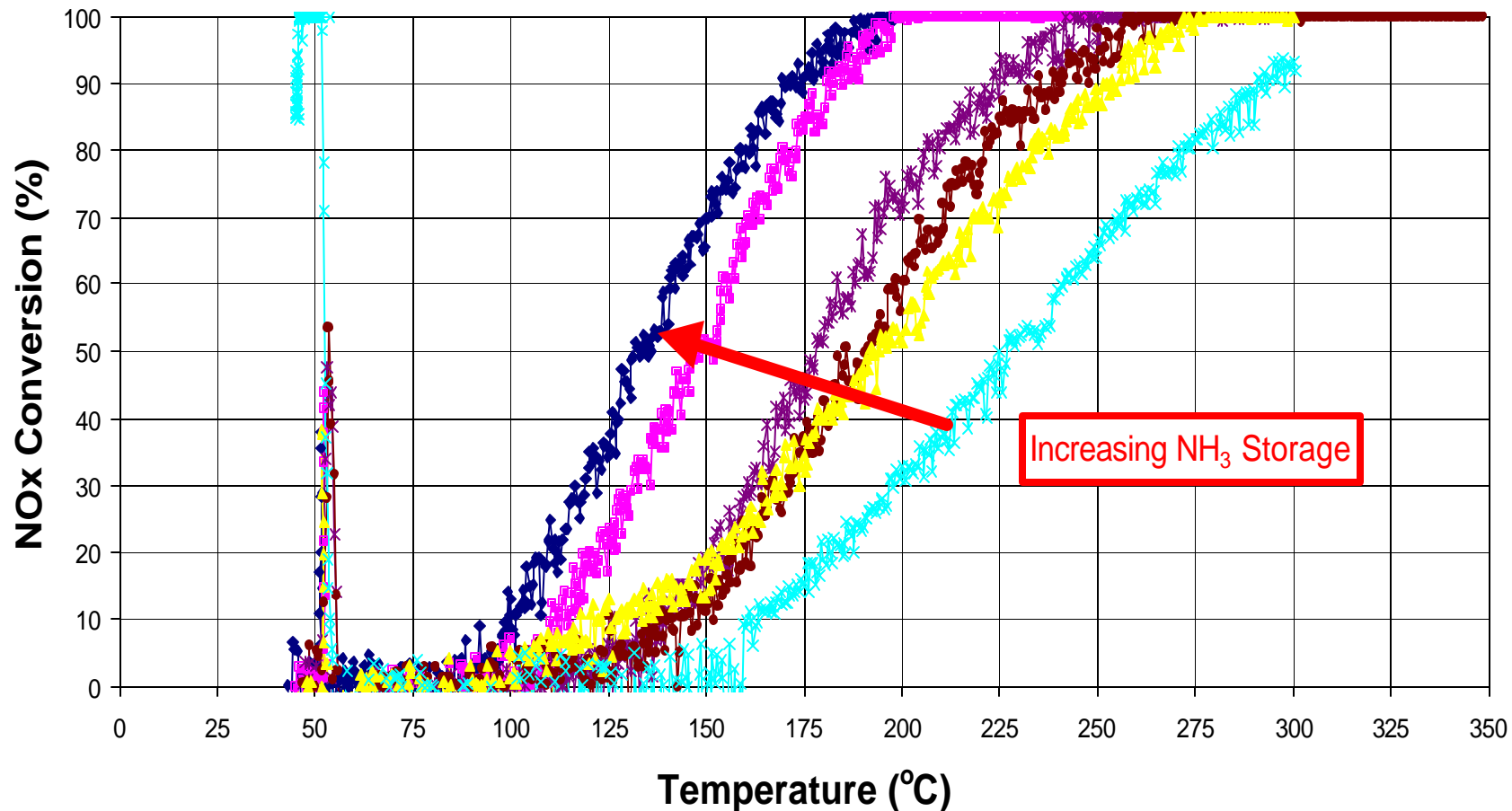
# SUV Testing

## Accumulated NO<sub>x</sub> (Bags 1-2)



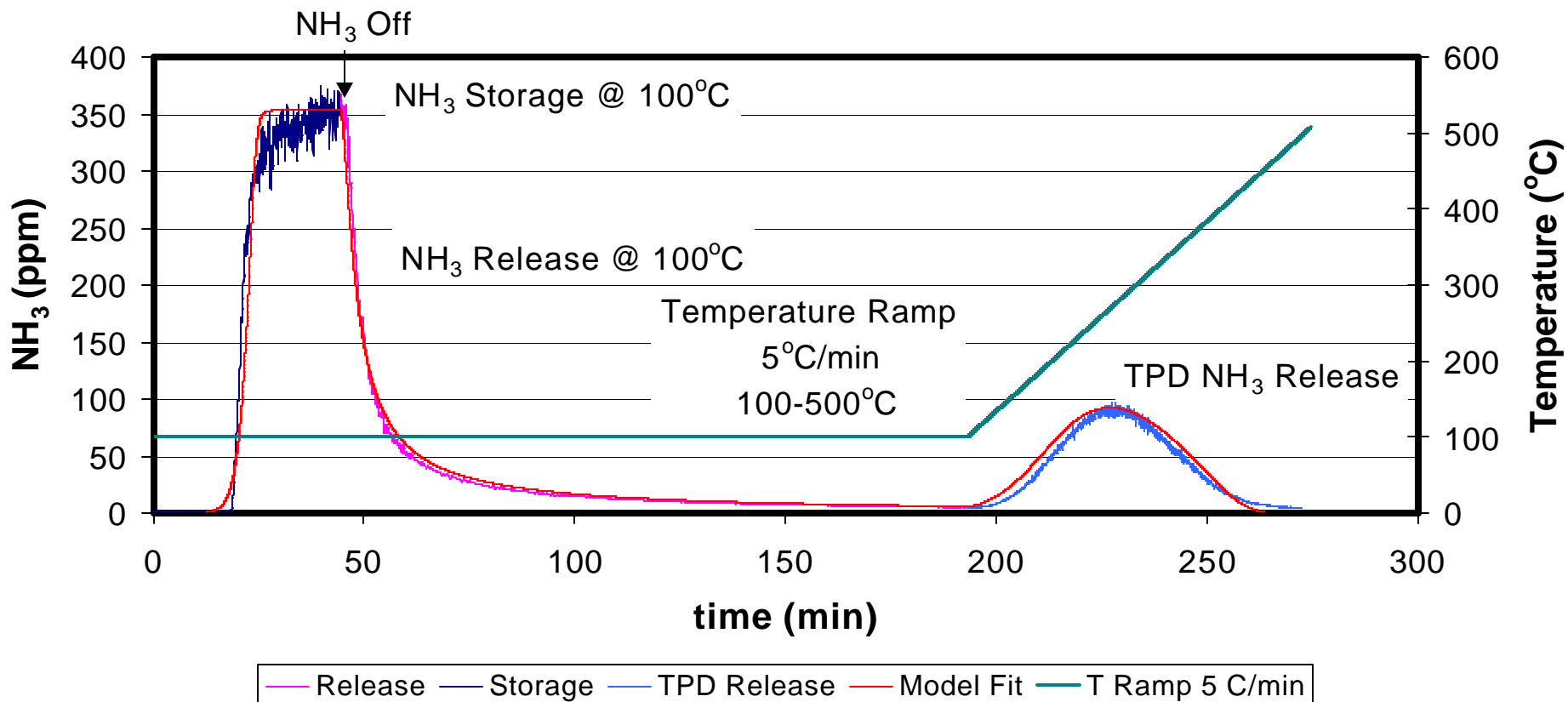
# Effect of $\text{NH}_3$ Storage on $\text{NO}_x$ Conversion

$\text{NO}_x$  Conversion with varying  $\text{NH}_3$  Storage Amounts and 0%  $\text{NO}_2$  Feedgas



# NH<sub>3</sub> Adsorption/Desorption Model

Degreened Urea-SCR Catalyst - Base Metal Zeolite Formulation  
350 ppm NH<sub>3</sub> - 100°C



- Good prediction of adsorption/desorption levels and positions versus time



# NOx Sensor Development

## Amperometric - O<sub>2</sub> and NO<sub>x</sub> Pumping

- Prototype NO<sub>x</sub> sensors from NGK Locke

### Status:

- Start of production 4Q/2001
- Range 500 or 2000 ppm +/- 10 ppm
- Valid for A/F from 10 to 8
- Detects NO and NO<sub>2</sub> with similar sensitivity

### Issues:

- To limit thermal shock cracking, response time remains about 0.7 sec.
- Cross sensitive to NH<sub>3</sub> giving ~60% NO response
- Costly

- Other suppliers (NTK, Denso, Delphi, Bosch)

## Other sensor types:

- Resistive (NASA/Makel)
- SiCFET (NASA Glenn)
- Electrochemical mixed-potential

# Ammonia Sensor Development

- Four technologies are being evaluated:
  - 1) Mixed potential (two suppliers)
  - 2) Zeolite (Dornier, Daimler-Chrysler, Temic)
  - 3) SiC-based FET (S-Sense, Linköping U.)
  - 4) Metal oxide resistors (SUNY)
- Collaborative development of the four technologies
  - 1) Vehicle testing of prototype sensors
    - Initiated mixed potential sensor testing on vehicle
- Will select the most promising from these four technologies.

# Urea Infrastructure Choices

## A. Fill Aqueous Urea during Oil Change Service

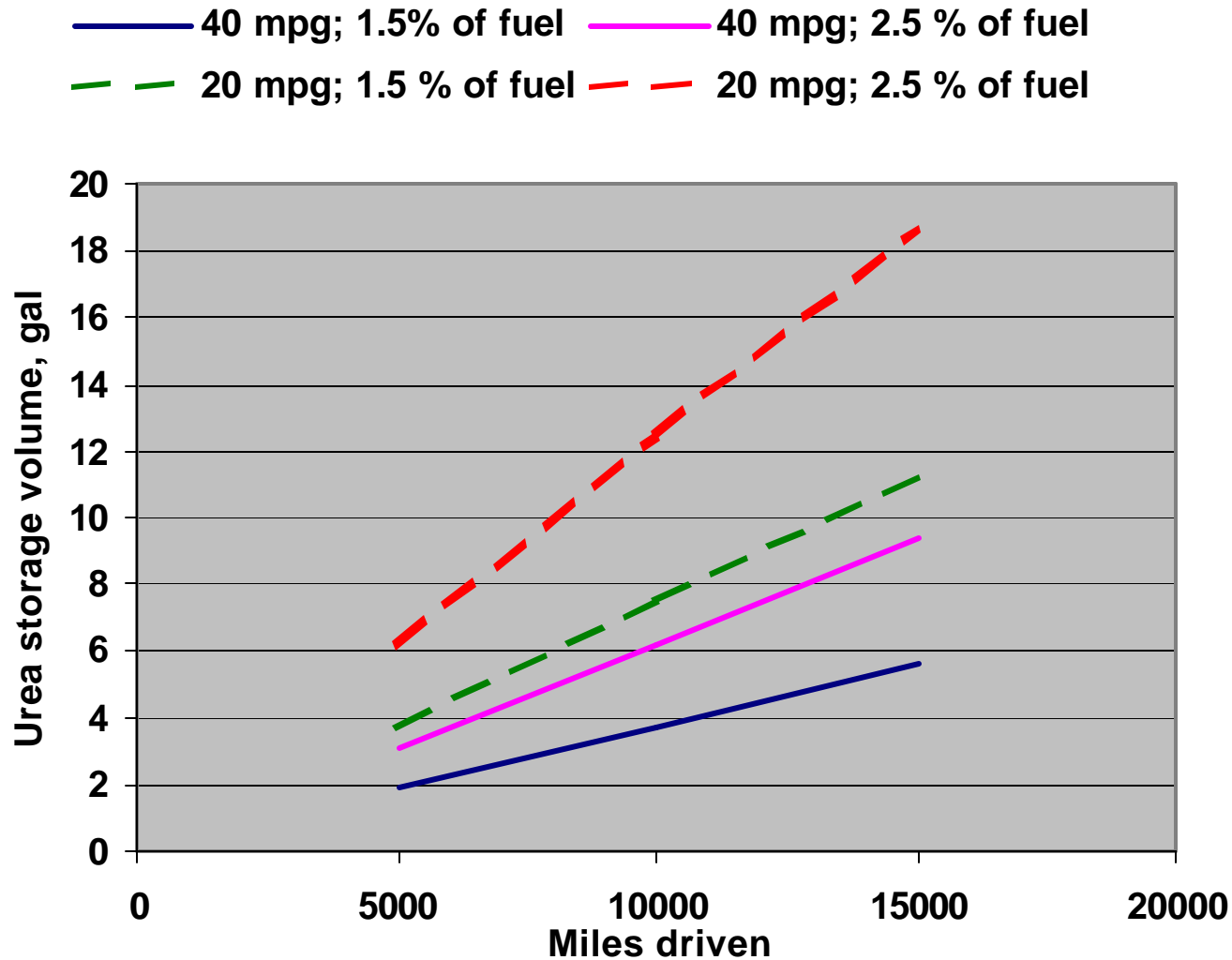
1. Which vehicles can carry sufficient urea on-board?
2. Which customers will use professional service stations?
3. Which customers will carefully re-fill urea by themselves?
4. What warnings will be positively perceived rather than negatively?
5. Will incentives work (free urea, free oil changes, etc.)?
6. Can this approach start infrastructure for key truck stops & fleets?

## B. Fill Aqueous Urea during Fueling

1. Which vehicles have limited package space for urea?
2. Which customers are unlikely to follow directions for periodic service?
3. Can urea be added during fueling with no extra actions? Co-fueling.  
Note: Concept for co-fueling was presented at DEER 2001.
4. How could co-fueling be introduced to general public?

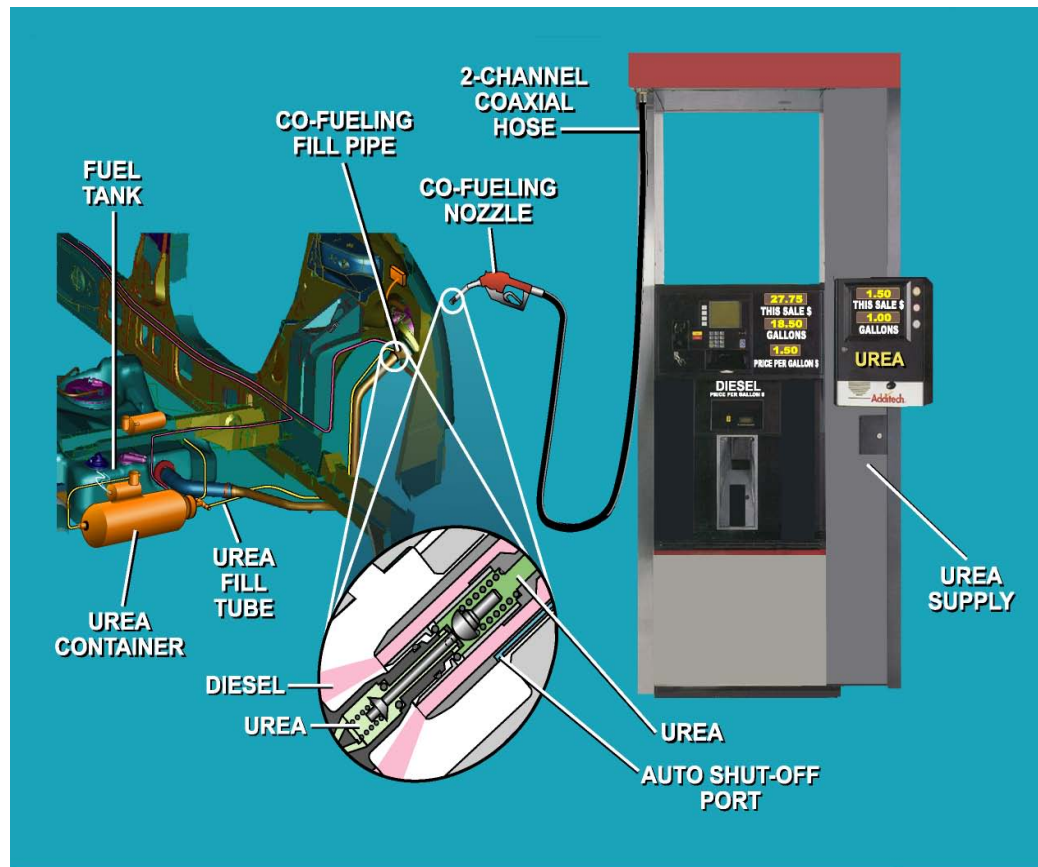
To be successful, a low-cost urea supply infrastructure must be developed that is convenient and does not impose a significant burden onto customers.

# On-Board Urea Storage Volume



# Urea Infrastructure

## Aqueous urea co-fueling for light-duty vehicles



### Aqueous urea delivery for light-duty vehicles

- requires no extra consumer actions
- co-fueling with diesel into separate tanks may be possible

### Formulation of aqueous urea

- Concentration– 32.5 wt% has lowest freeze point (12°F, -11°C)
- Freeze point additives must not be toxic or poison catalyst
- Heated system may be required for colder climates

# Co-Fueling Design Requirements

| <u>Design Requirements</u>                | <u>Current Design</u> |
|---|-----------------------|
| 1. Deliver urea during diesel fueling     | ✓                     |
| 2. Independent on / off                   | ✓                     |
| 3. Prevent dispensing diesel without urea | ✓ ?                   |
| 4. Avoid cross-contamination              | ✓ ?                   |
| 5. Easy to operate / no training needed   | ✓                     |
| 6. Backward compatibility                 | ✓                     |
| 7. Minimize investment                    | ✓ ?                   |
| 8. Avoid dry out, plugging                | ✓ ?                   |
| 9. Manage freezing                        | ✓ ?                   |

“ ✓ ” = requirements met. “ ✓ ? ” = issues remain.

# Status of NO<sub>x</sub> Control Development

- Achieved 96% NO<sub>x</sub> conversion on FTP when SCR catalyst is above 200°C.
- Need warm-up within ~1 min. to meet target.
- Need to optimize NH<sub>3</sub> storage for best cold-start NO<sub>x</sub> control, but must control urea injection to prevent NH<sub>3</sub> slip.
  - control model for optimizing urea injection
  - durable NO<sub>x</sub> and NH<sub>3</sub> sensors
- Need more durable NO<sub>x</sub> catalyst to use DOC for DPF regeneration.
- Urea supply infrastructure remains a major issue.