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

DOE and Ford Motor Company Advanced CIDI Emission Control System Development Program

(DE-FC26-01NT41103)

Robert Hammerle

Diesel Engine Emission Reduction Conference

August 25, 2002

FEV

Research

ExxonMobil Research and Engineering

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 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 NOx conversion from 150° to 600°C with low N_2O 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

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FEV

Philipp Adomeit, Eric Koehler, Dean Tomazic

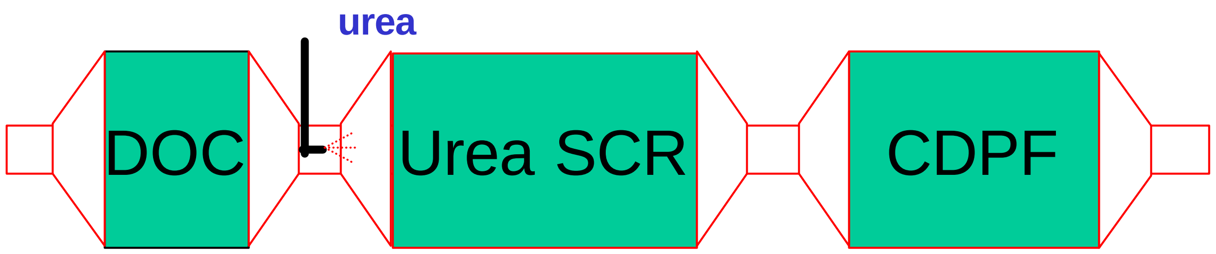
Exxon Mobil

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

Initial Configuration Choices

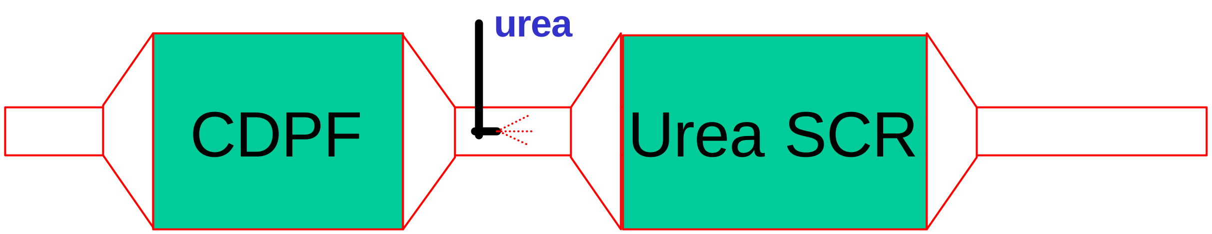
for Tier II Bin 5

Selected configuration



Oxidize HC, CO, NO **Reduce NOx** **Control PM**

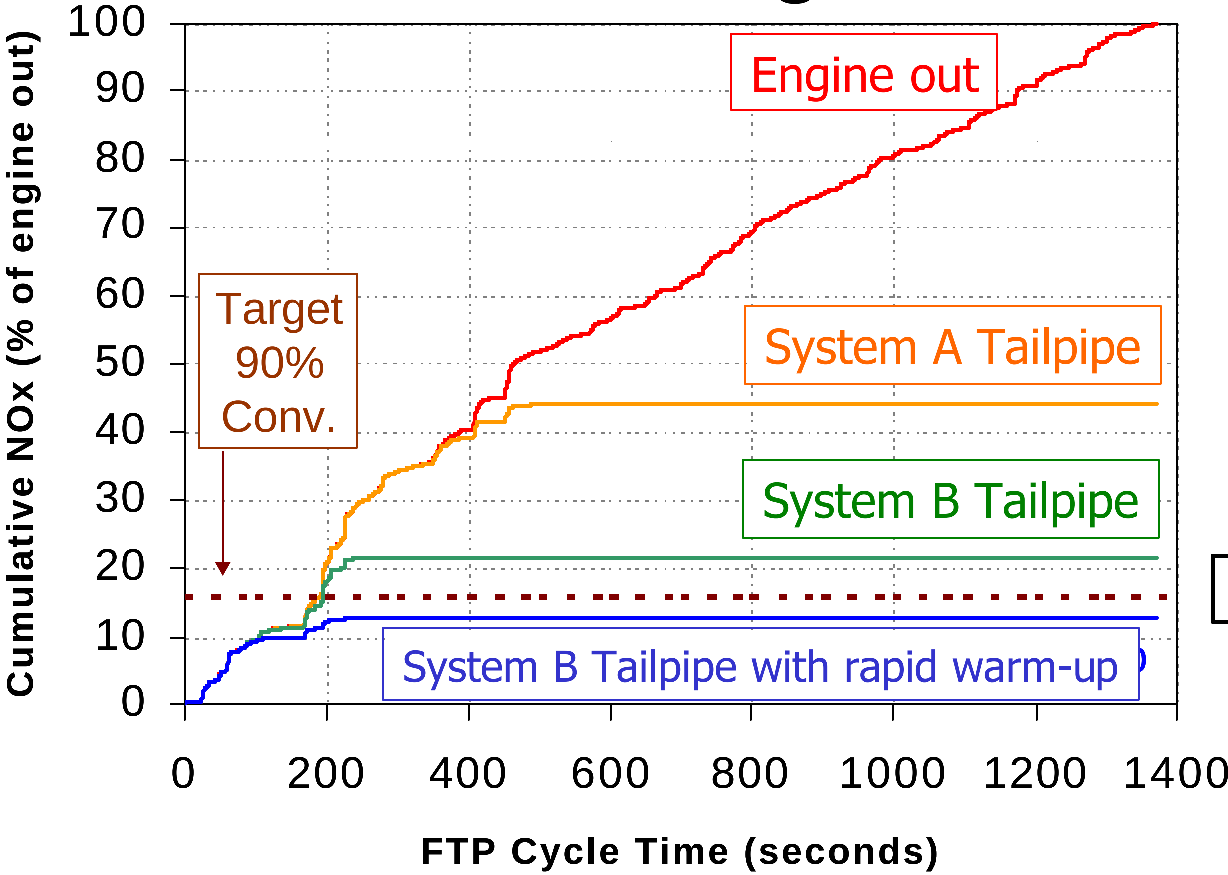
Unacceptable configuration

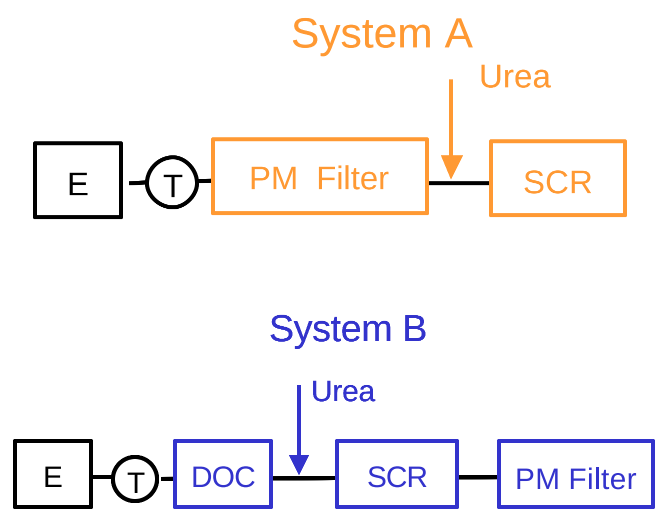


Oxidize HC, CO, NO
Control PM

Reduce NOx

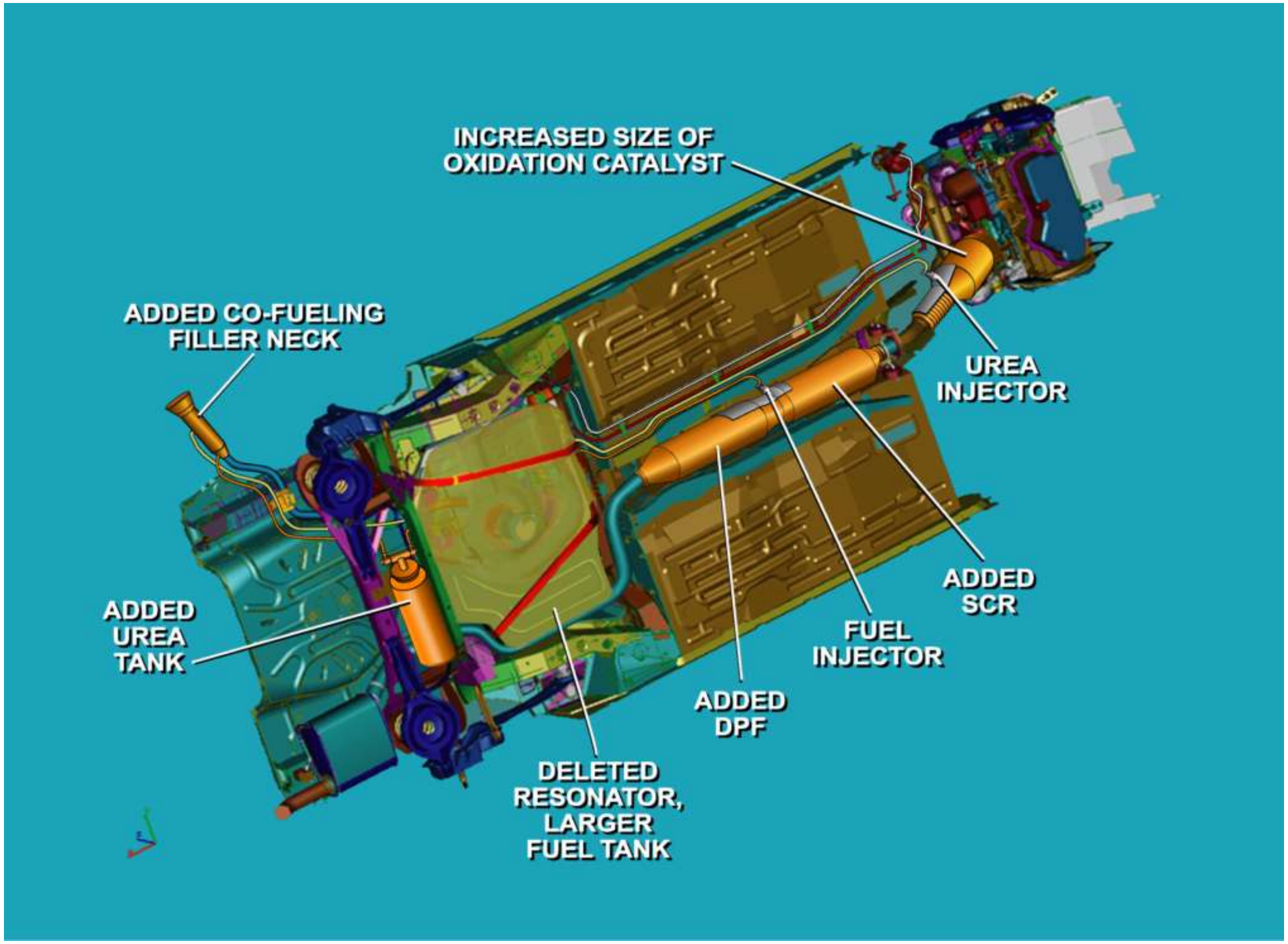
Urea SCR Model Prediction of Tailpipe NOx for Configuration Alternatives





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

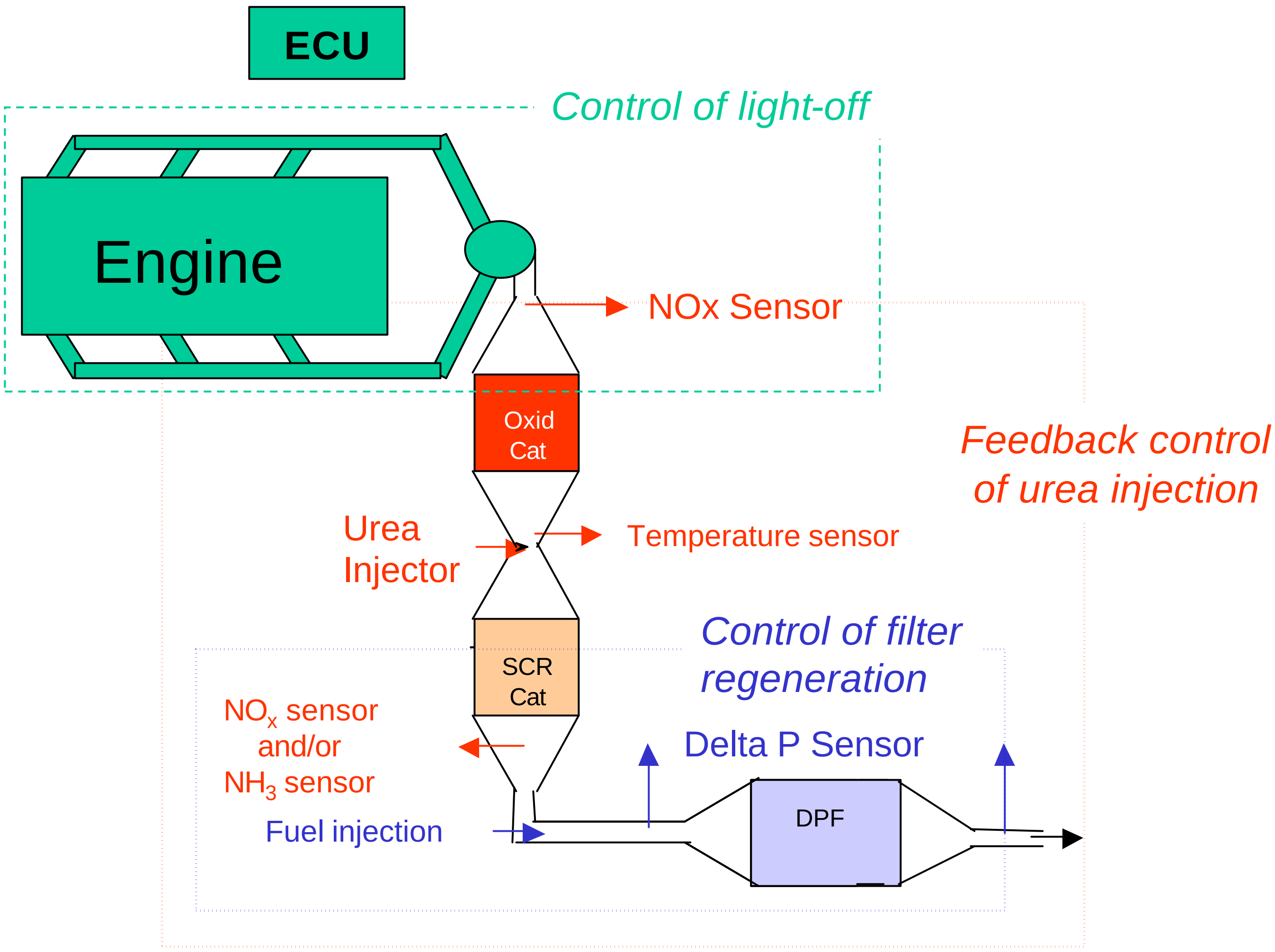


Ford Research Laboratory showed Focus results using fresh catalysts:

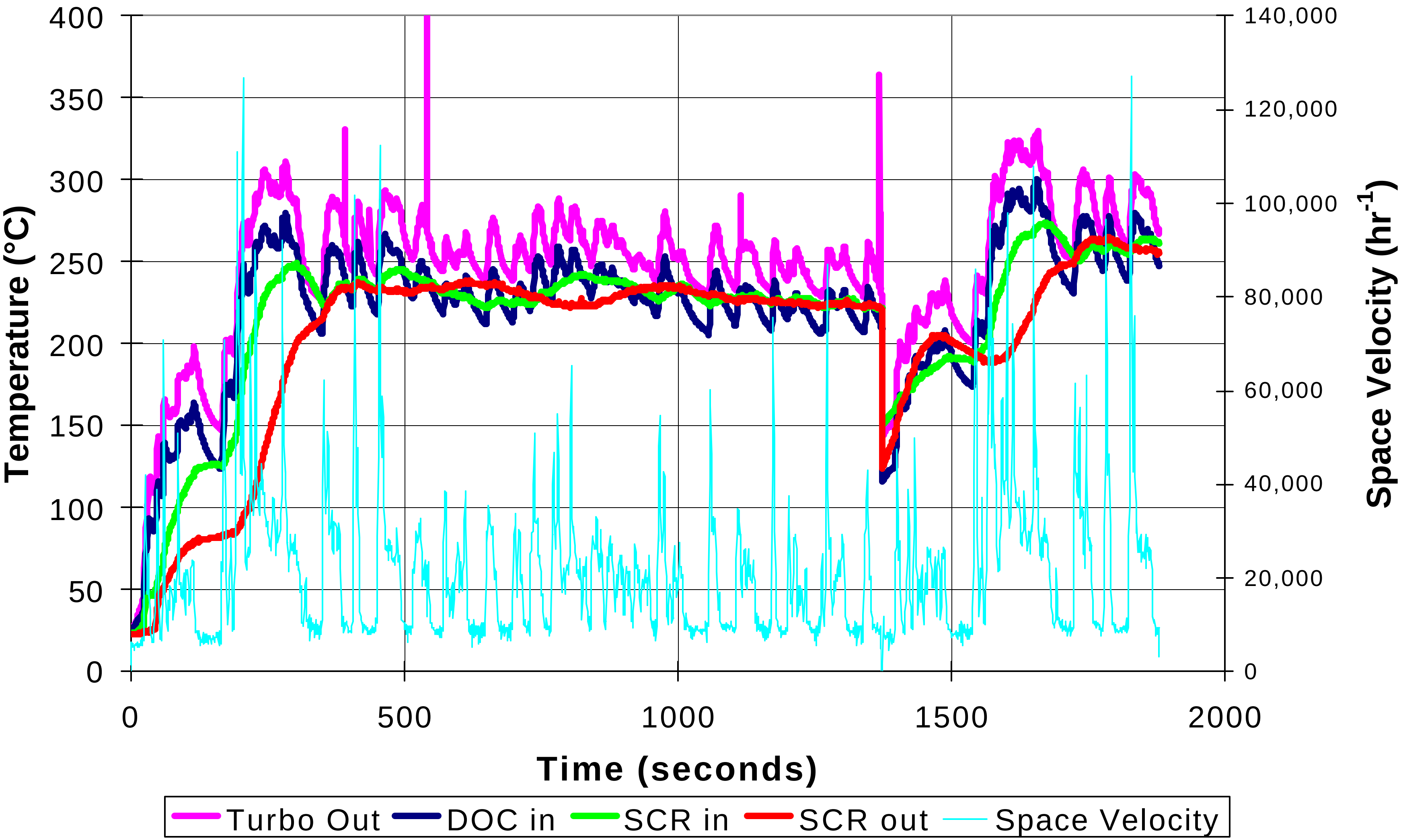
FTP conversion for NOx is ~90% and PM is ~98%.

US06 conversion for NOx+HC is ~92%.

Light-Duty Truck Exhaust System



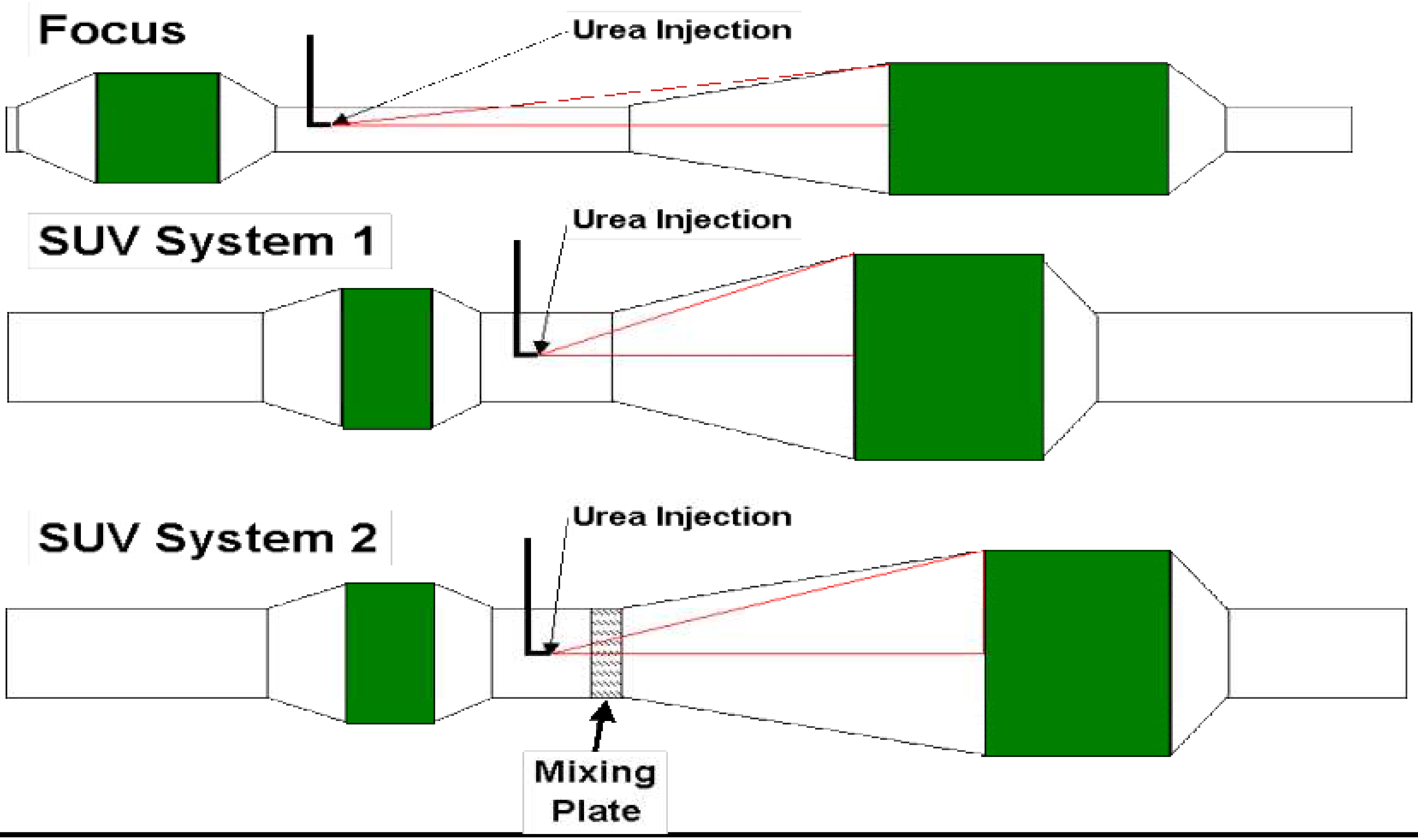
Temperatures and Space Velocity
EPA-75 Test



Vehicle Testing

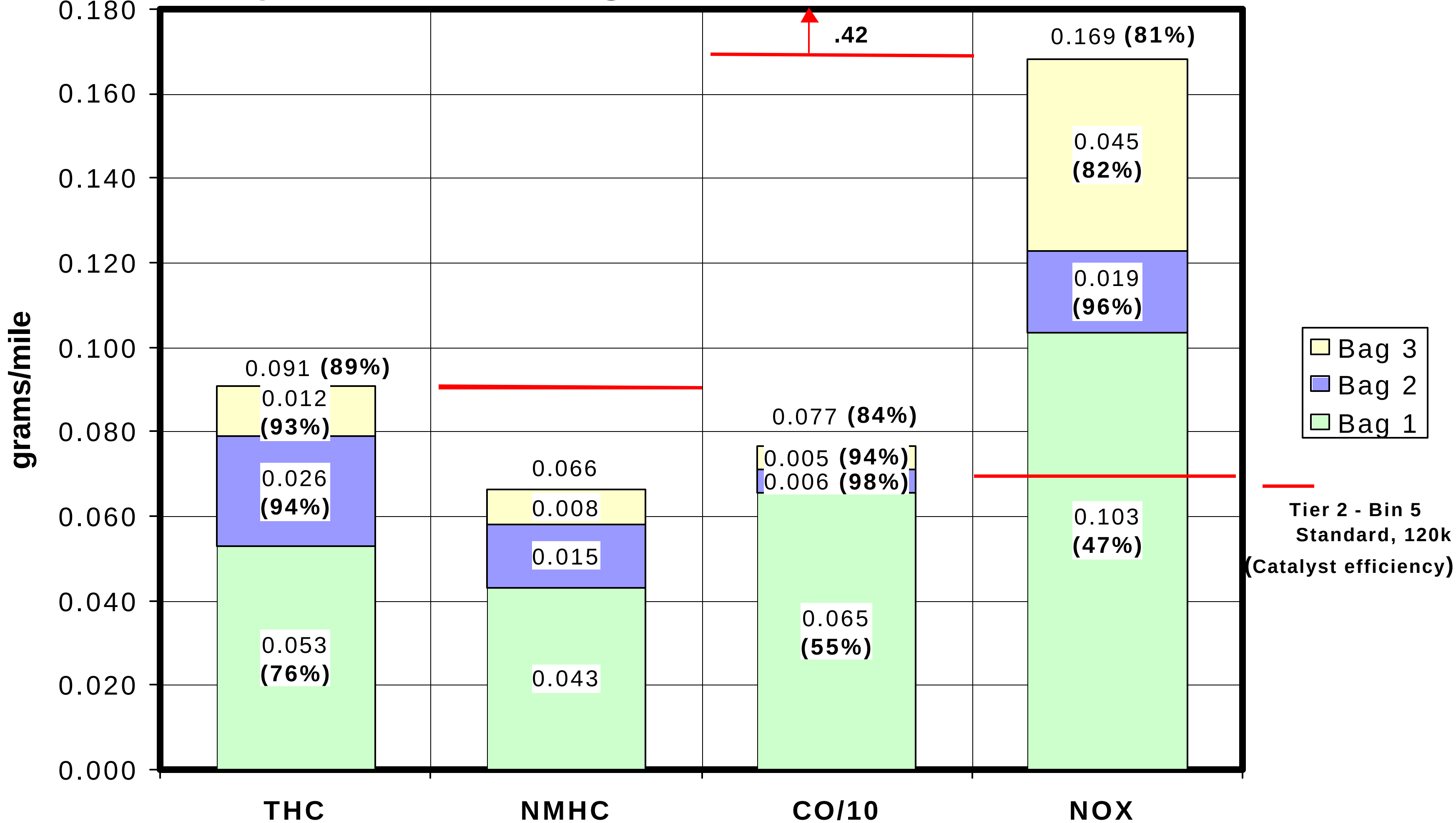
- With initial system 1, 35% NOx conversion and high NH3 slip.
- Suspected poor urea distribution caused low NOx conversion.
- Developed new system 2 for improved urea distribution
- System 2 has increased length of the SCR entrance cone and mixing plate.

Urea Distribution on SUV & Focus



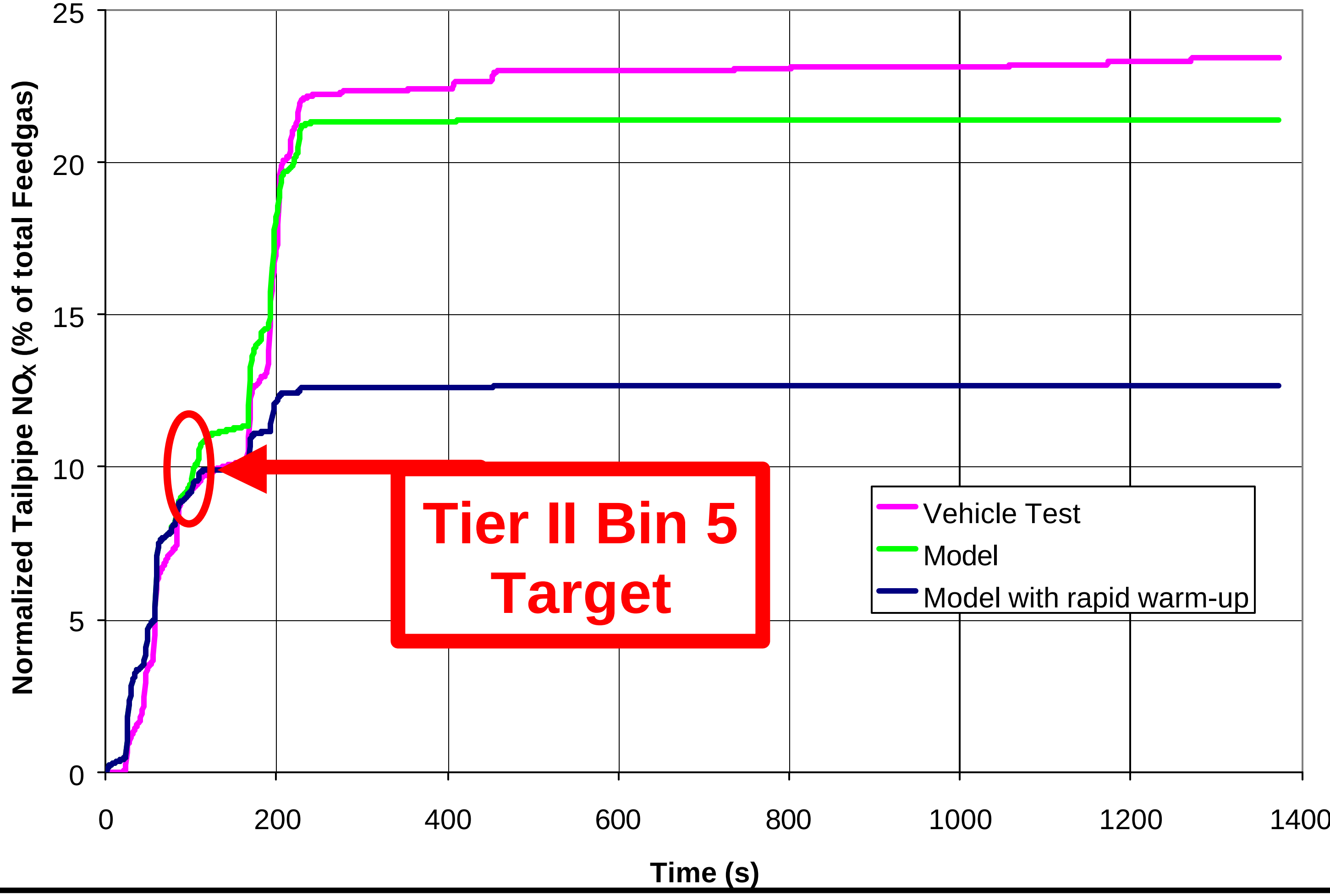
Sport Utility Vehicle Testing

System 2 - Weighted EPA-75 Emissions

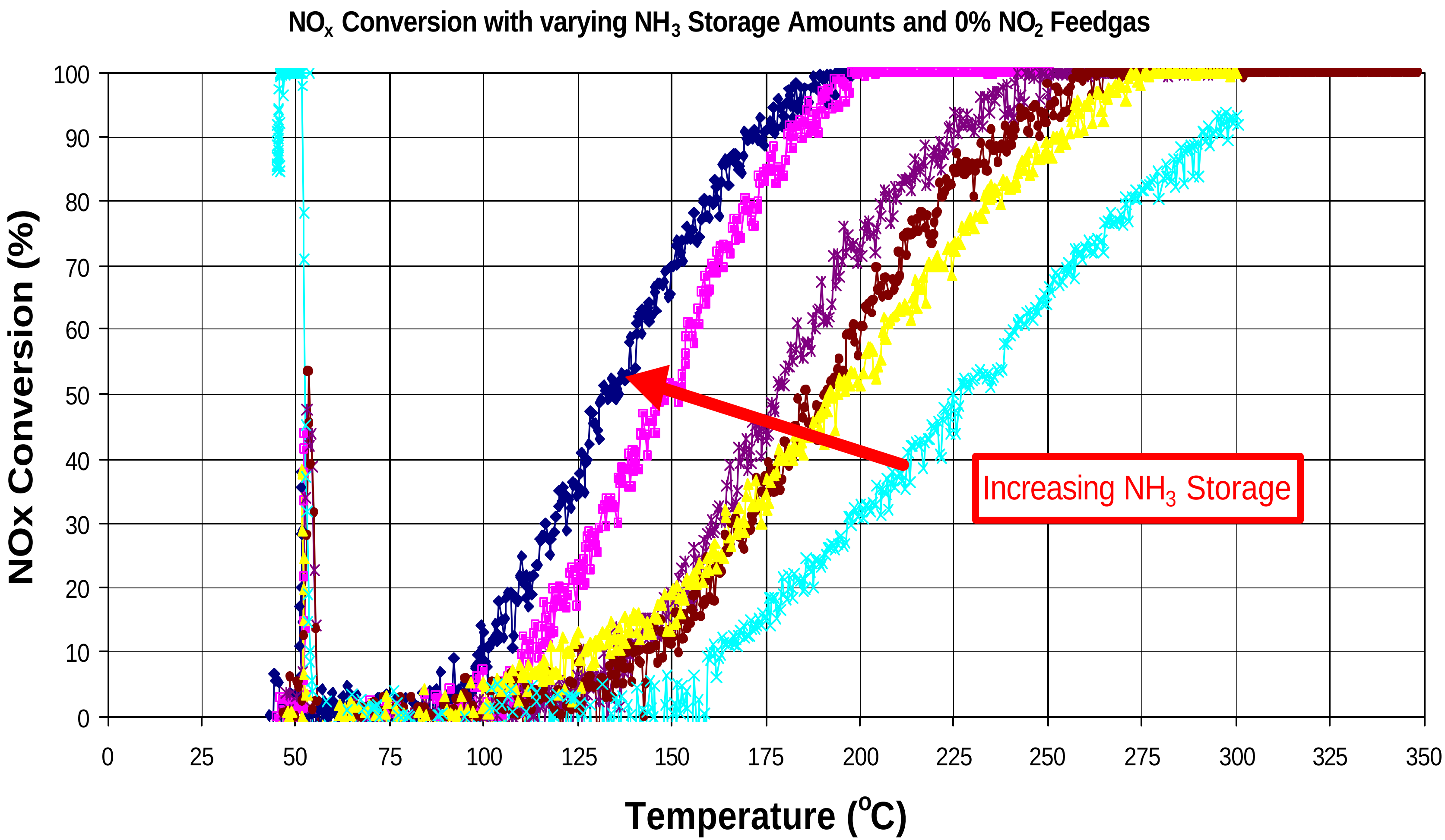


SUV Testing

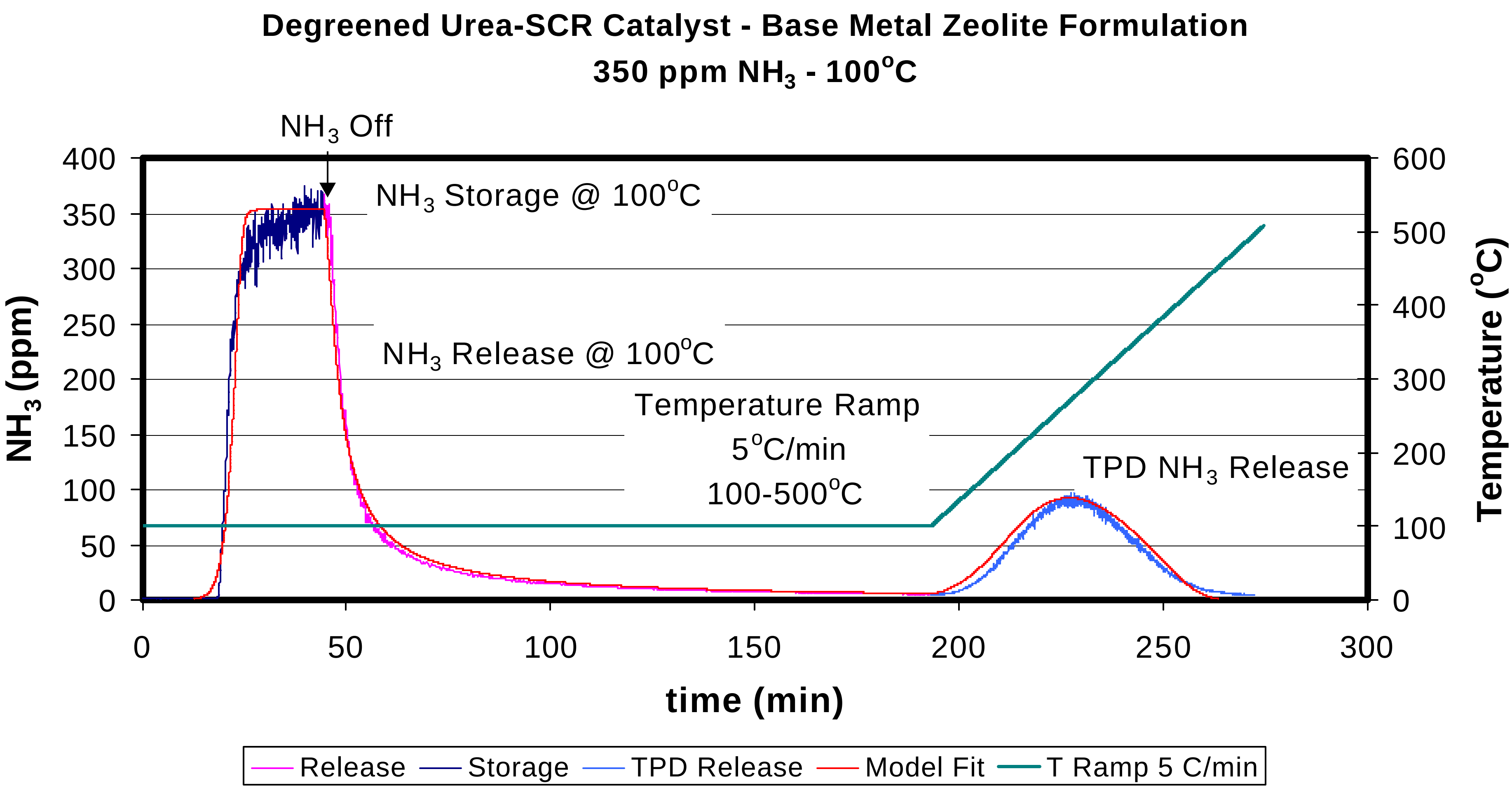
Accumulated NO_x (Bags 1-2)



Effect of NH_3 Storage on NO_x Conversion



NH_3 Adsorption/Desorption Model



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

NOx Sensor Development

Amperometric - O2 and NOx Pumping

- Prototype NOx 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_2 with similar sensitivity

Issues:

- To limit thermal shock cracking, response time remains about 0.7 sec.
- Cross sensitive to NH_3 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

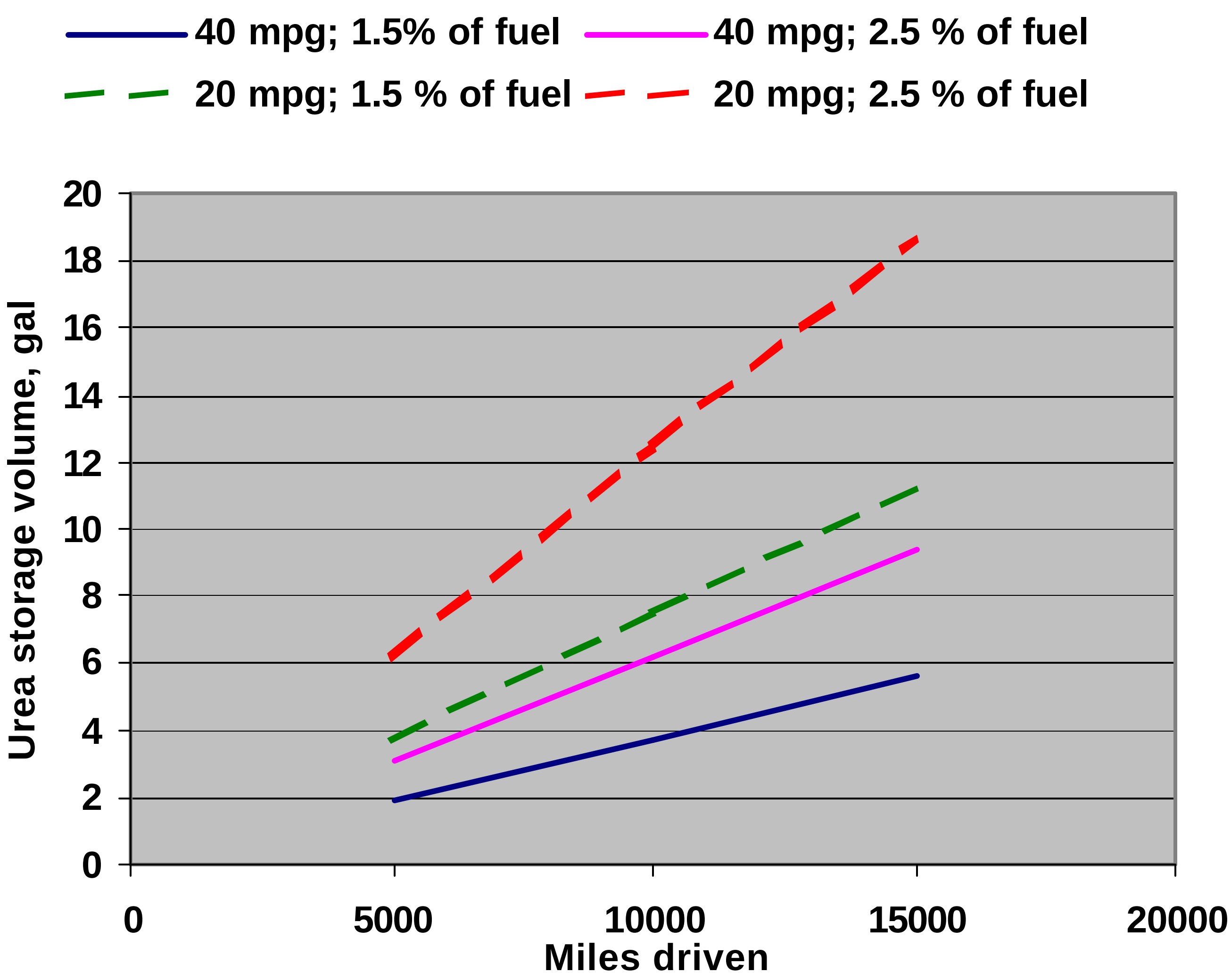
1. Which vehicles can carry sufficient urea on-board?
2. Which customers will use professional service stations?
3. Which customers will carefully re-fill urea by themselves?
4. What warnings will be positively perceived rather than negatively?
5. Will incentives work (free urea, free oil changes, etc.)?
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?

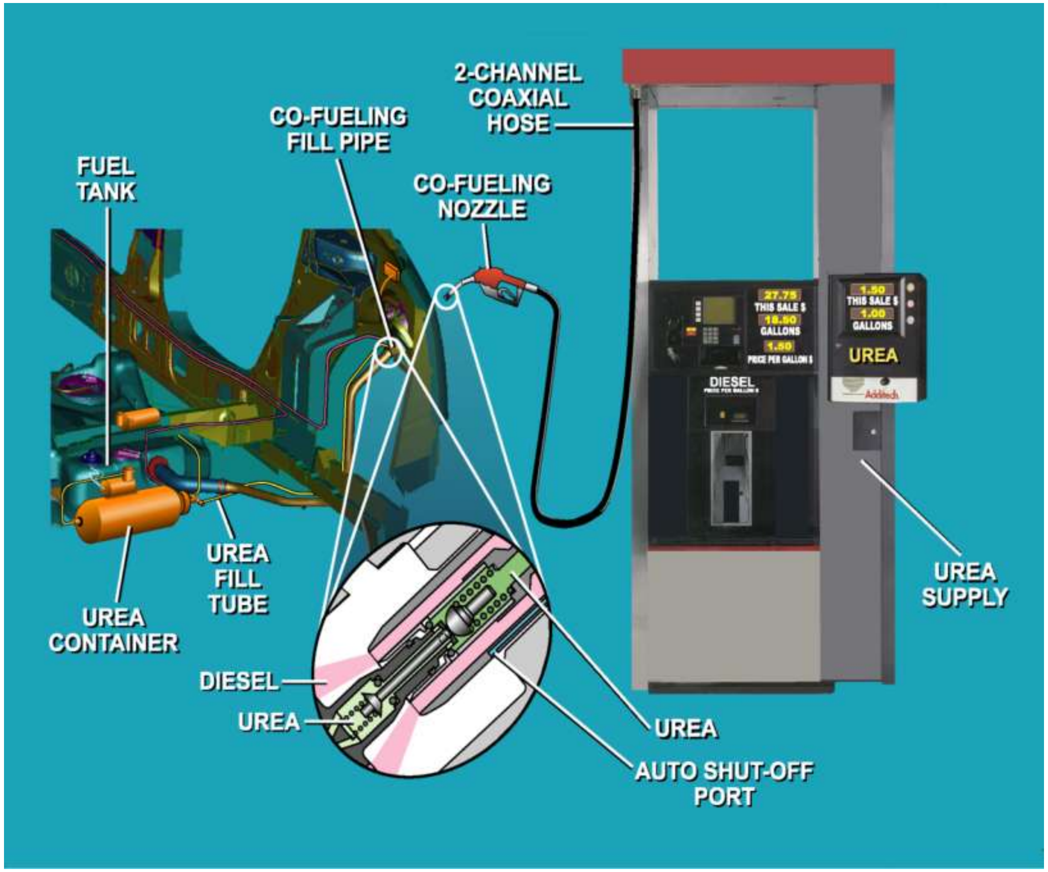
To be successful, a low-cost urea supply infrastructure must be developed that is convenient and does not impose a significant burden onto customers.

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 (12ºF, -11°C)
- Freeze point additives must not be toxic or poison catalyst
- Heated system may be required for colder climates

Co-Fueling Design Requirements

Design Requirements	Current Design
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 NOx Control Development

- Achieved 96% NO_x conversion on FTP when SCR catalyst is above 200°C.
- Need warm-up within ~1 min. to meet target.
- Need to optimize NH_3 storage for best cold-start NO_x control, but must control urea injection to prevent NH_3 slip.
  - control model for optimizing urea injection
  - durable NO_x and NH_3 sensors
- Need more durable NO_x catalyst to use DOC for DPF regeneration.
- Urea supply infrastructure remains a major issue.