DOE/Cummins Heavy Truck Engine Program

Emissions and Aftertreatment Update

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Program Overview

- *DOE/OHVT Contract*
- *Achieve 45% Brake Thermal Efficiency at 2002 Emissions (Phase I)*
- *Achieve 50% Brake Thermal Efficiency at 2007 Emissions (Phase II)*

Program Work

- *Phase I*
  - *Evaluate SCR w/ Optimized HD Engine at ~75% NOx reduction*
  - *Develop NOx Aftertreatment components and systems to allow higher conversion rates for Phase II*
  - *Develop approaches for exhaust conditioning to allow adsorber/SOx trap regeneration*
  - *Develop PM filters and regeneration strategies for Phase II*
  - *Vehicle testing of engine/aftertreatment systems to assure performance and system integrity*

Presentation

- High-Efficiency ISX-SCR System FTP Results
- PM Filter Regeneration Strategies

2007 is NOT...

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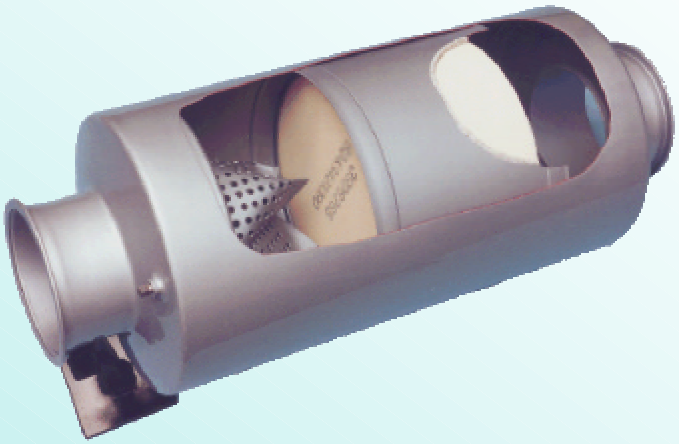
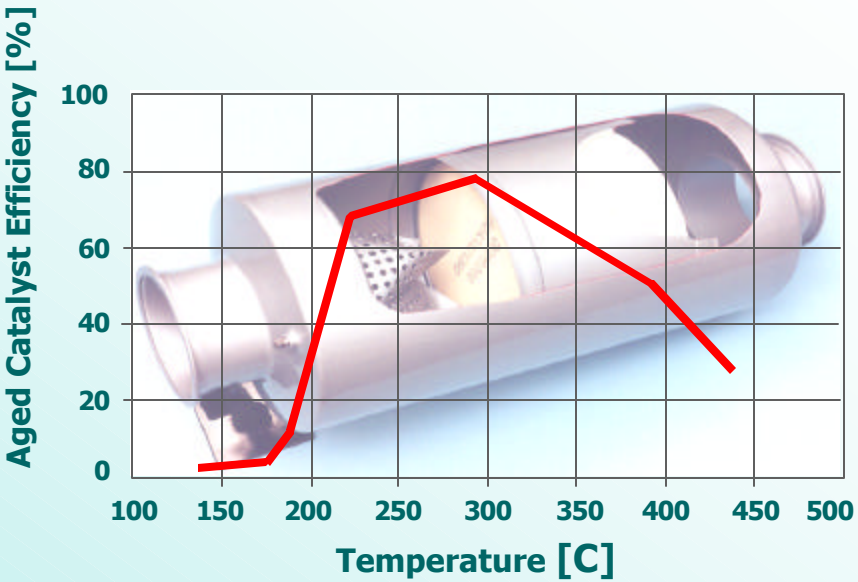


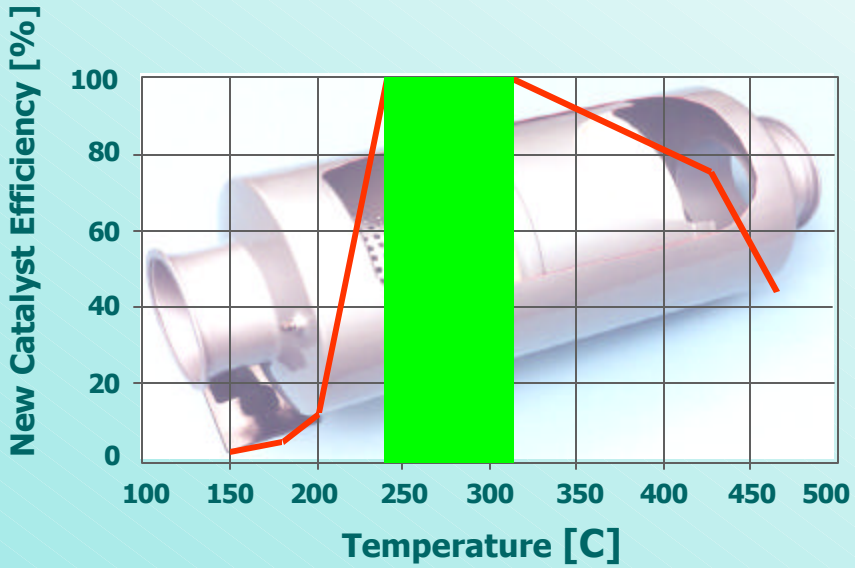
Tough Question to Answer…

- Can we meet the regulation?
  - Engineering Margin Calculation
    - Hardware Variability
    - Measurement Variability
  - Deterioration
    - Sulfur Regeneration
    - Oil Additives
    - Off design operation
    - Others



2007 / 2010 US Heavy Duty Hypothetical Case Study				
Species	Regulation [g/hp-hr]	Engineering Margin Target [g/hp-hr]	Catalyst Efficiency @ Full Life [%]	Design Engine-Out [g/hp-hr]
NO_X	0.20	0.14	94%	2.20
			90%	1.40
			80%	0.70
PM	0.01	0.008	90%	0.08
			80%	0.04

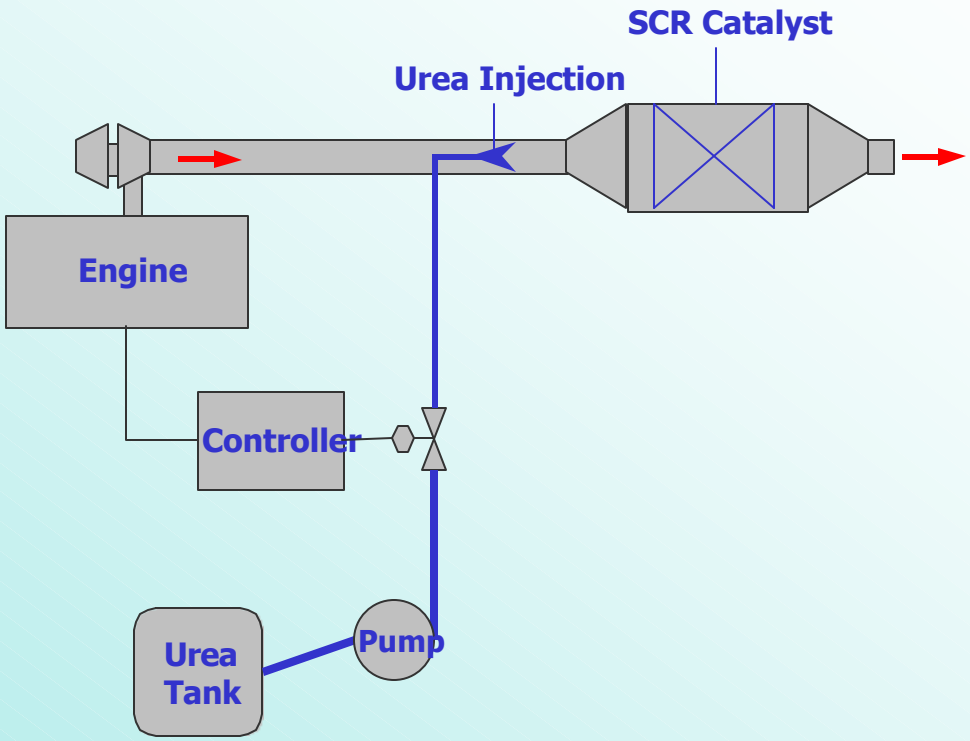
The Problem...


New Catalyst Efficiency [%]
100
80
60
40
20
0
100
150
200
250
300
350
400
450
500
Temperature [C]

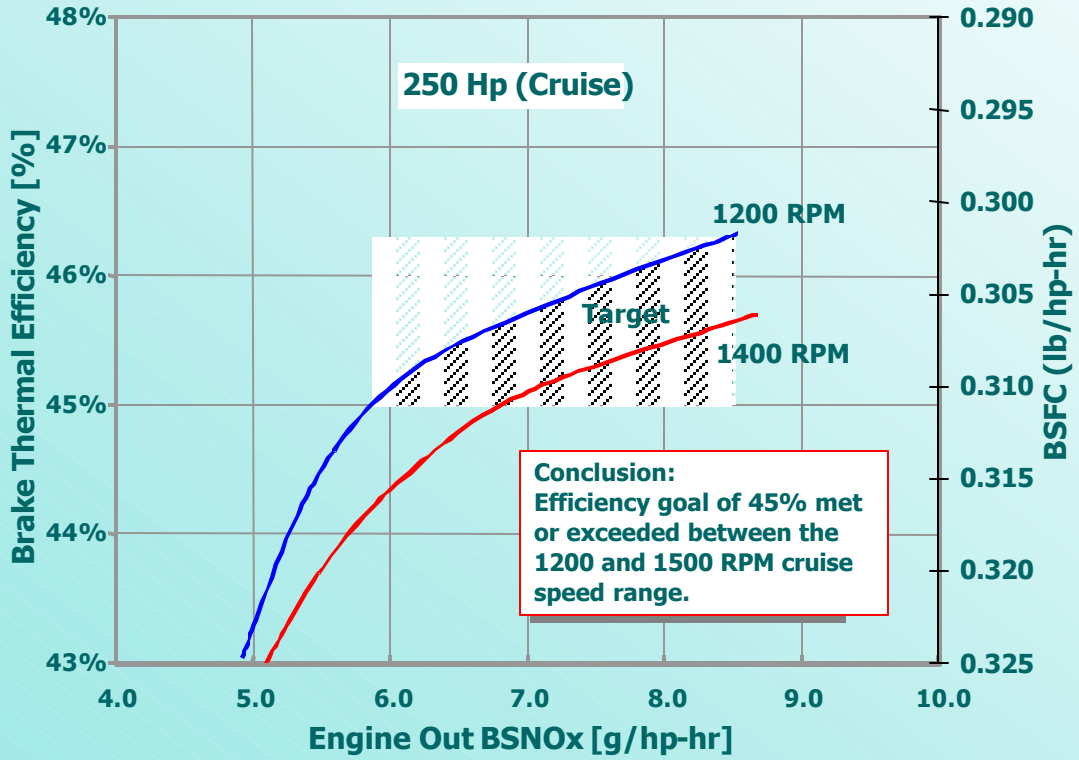
Exhaust Temperature [C]
450
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
1200
Time [second]

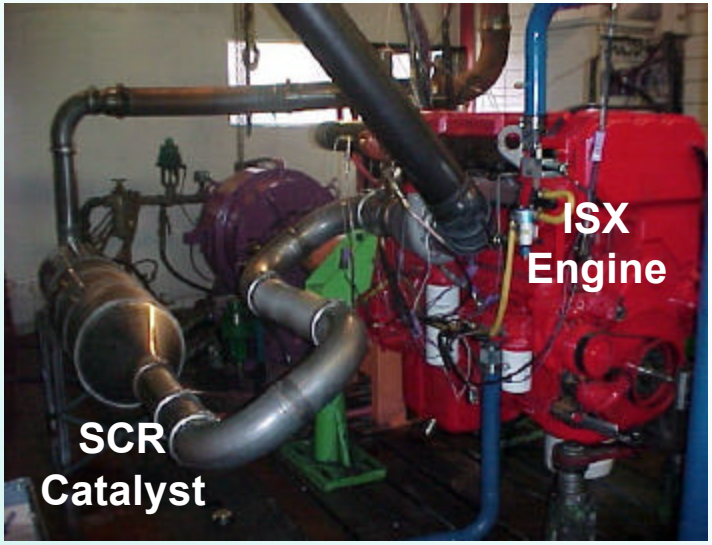
DoE Heavy Duty Truck Demonstration

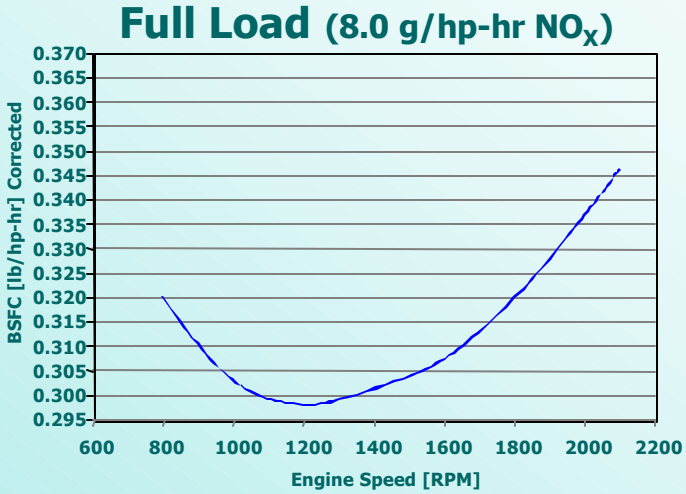
- *Selective Catalytic Reduction using Ammonia (aqueous urea)*
  - *Fuel Economy & Emission Demonstration*
  - *Goal:*
    - *45% BTE (0.310 lb/hp-hr BSFC) at cruise (250 Hp 1200 - 1400 RPM) while meeting 2002 Emissions*
- *Phase I Approach*
  - *8 g/hp-hr NO_X Engine Out*
  - *75% Efficient SCR Catalyst*
- *Status:*
  - *Completed steady state engine mapping and SCR controller development*
  - *Transient testing completed*
  - *Complete vehicle demonstration by 12/31/2001.*



Base Engine Development



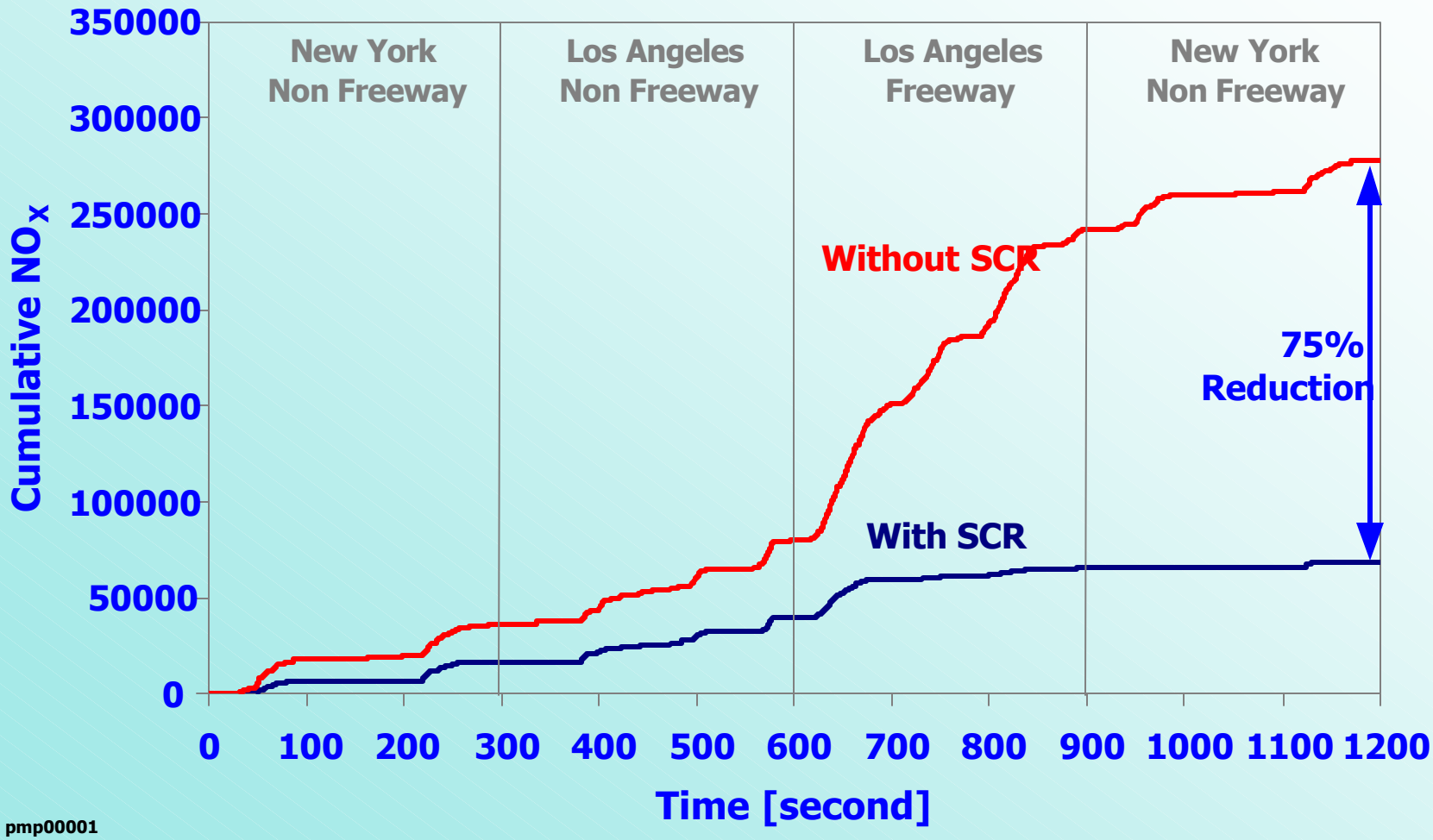




SCR FTP Results

Description - Cycle Type	Base Engine BS N0x (gm/hp-hr)	SCR Active BS N0x (gm/hp-hr)	NH_3 Slip Max / Average (ppm)	% Reduction
EPA Cold	6.1	2.2	15 / 1	64%
EPA Hot	6.2	1.6	36 / 4	75%
EPA Hot	6.1	1.4	40 / 4	78%
EPA Hot	6.1	1.3	40 / 4	78%
EPA Cycle Weighted Average (Hot = 6/7th, Cold = 1/7ths)	6.1	1.5	35 / 4	75%

Cumulative NO_X on the HD FTP Cycle with and w/o Urea Injection



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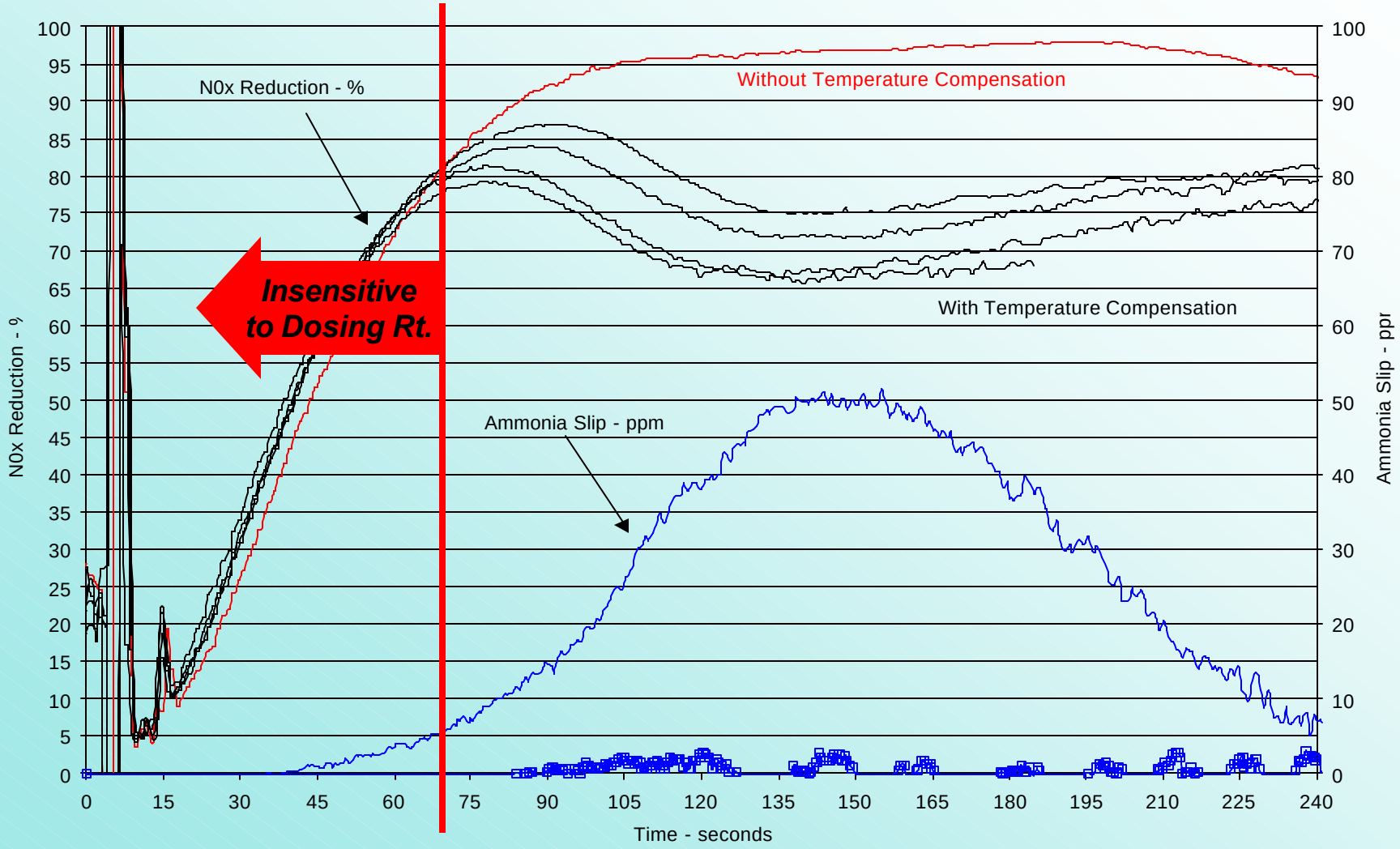
Catalyst Performance Test Data
Idle to Rated Acceleration - Snap Throttle Transient



SCR Limitations, Capabilities and Concerns

- *Steady State N0x Reduction 85-95% seems possible.*
- *Thermal lag in SCR catalyst and the FTP Cold Cycle may limit maximum N0x Reduction to 75-80% on the Transient FTP cycle.*
  - *The path to 90+% NOx reduction efficiency with this technology is not clear*

Catalyzed Diesel Particulate Filter Emission Reduction

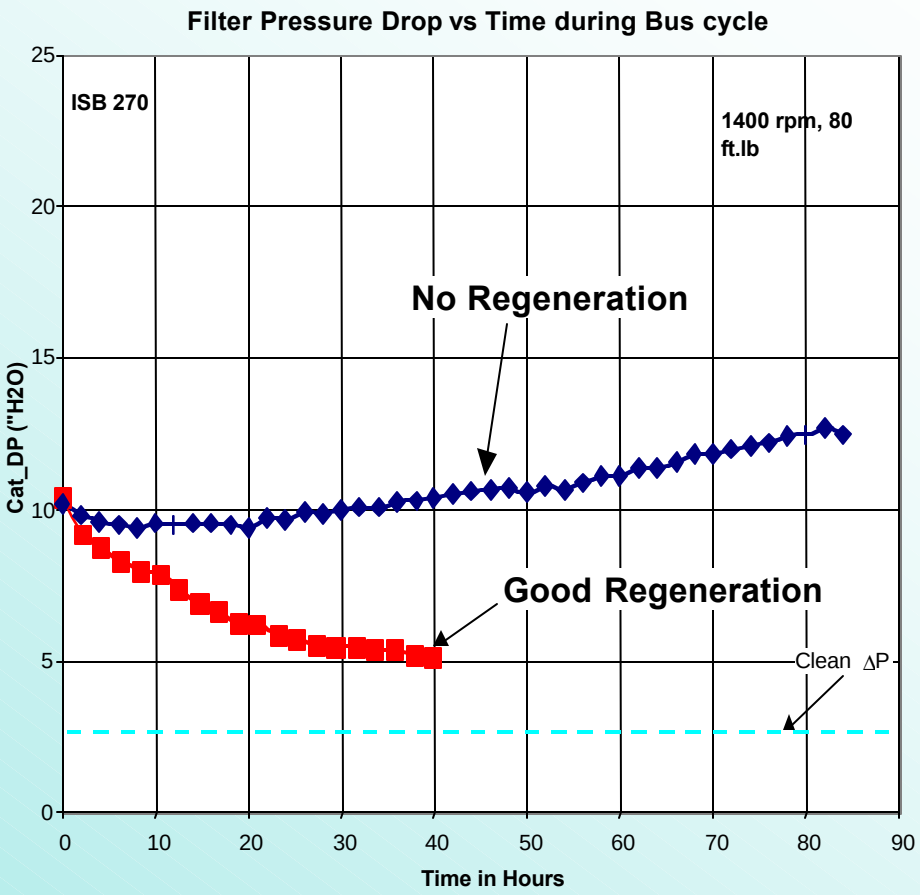
(US Heavy Duty Transient,10 ppm Sulfur, Hi Pt Catalyst)

	Emissions (g/hp-hr)			
Location	PM	HC	CO	NO_x
Engine Out	0.09	0.24	1.58	3.72
Filter Out	0.01	0.04	0.17	3.82
% Reduction	88.9	83.3	89.2	-2.69

DPF - Technology Assessment, Passive Filters

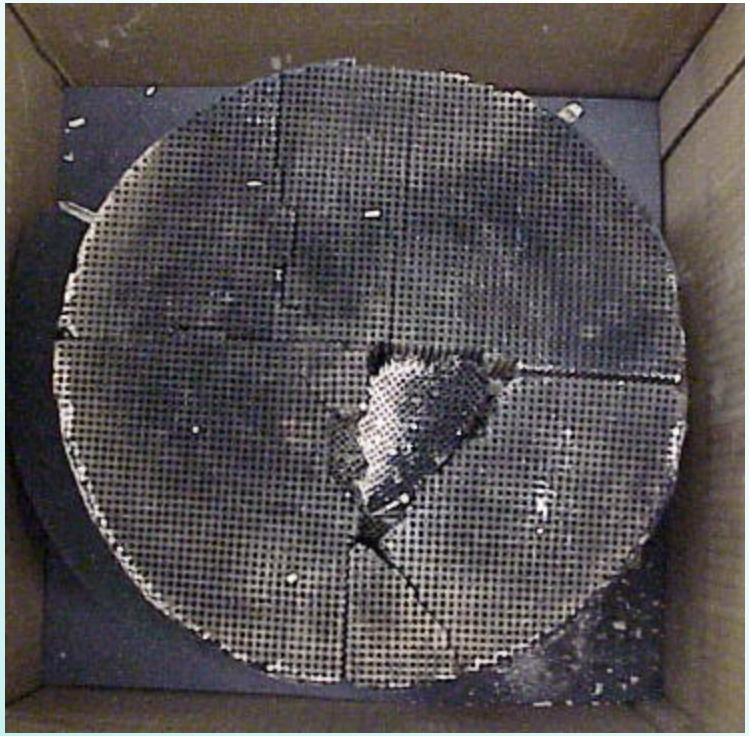
- Soot filters have been successfully applied
- Sensitive to:
  - Duty Cycle
  - Ambient Temperature
- Should successfully self-regenerate for most applications
- What about:
  - low ambient?
  - extended idle?
  - Urban stop and go?

Active Regen Needed!



Results of High Soot Loads

Excessive Peak Temperatures - Melting



Excessive Temperature Gradients - Fracture

DPF - Active Regeneration

Option 1 - Engine Management

- Heat for regeneration comes from engine
- Cost effective option
- Fuel penalty dependent on duty cycle

Option 2 - Exhaust Management

- Heat of regeneration comes from external device, e.g., Microwave, Burner, Grid Heater
- Higher initial cost
- Bypass system required
- Short regeneration period
- Fuel penalty dependent on duty cycle

Future Plans

- NOx Adsorber/Soot Filter/Engine System Architecture
- System Modeling and Simulation
- System Testing and Validation
- Vehicle Testing and Evaluation
- Advanced Combustion Research to Improve NOx/BSFC Tradeoff

Thanks….