The QuadCAT
Four-Way Catalytic Converter

An Integrated Emission Control System for Diesel Engines

presented to the:

California Air Resources Board

February 3, 2000

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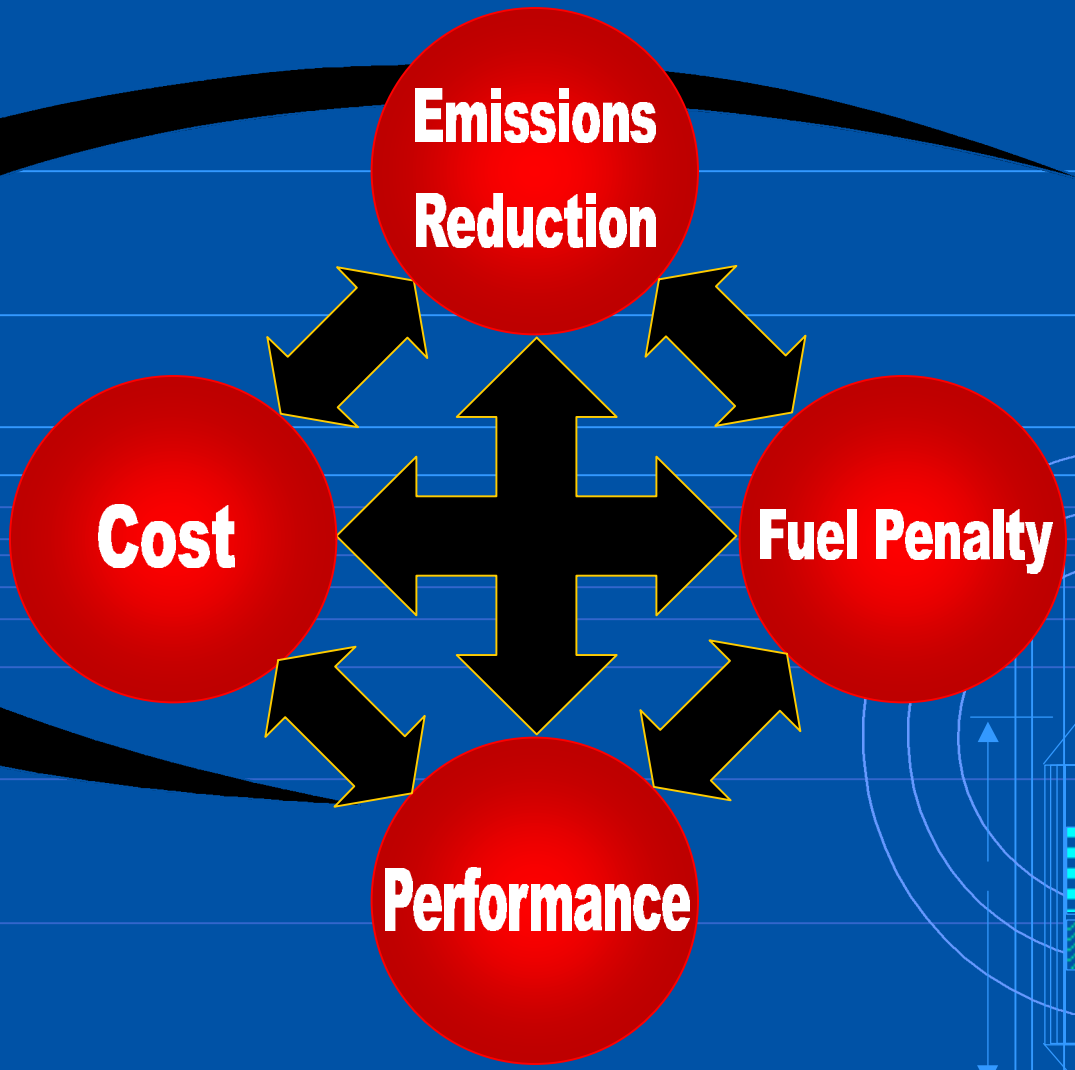
Ceryx Vision

Systems that balance *Cost*, *Performance*, *Emissions Reduction*, and *Fuel Penalty* to make the economics of pollution control viable



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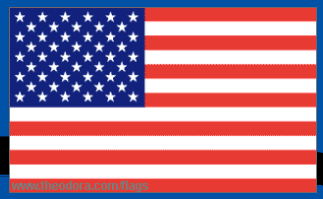
Emission Standards

U.S. and Europe



	HC	CO	PM	NOx
	grams per brake horsepower hour			
1998 Baseline	1.3	15.5	0.1	4.0
2004 U.S. Federal (2002)	0.5 (62%)*	15.5 (0%)	0.1 (0%)	2.0 (50%)
Euro IV (2005)	0.4 (69%)	1.1 (93%)	0.015 (85%)	2.6 (35%)
ULEV (Clean Fleet Program)	N/A	7.1 (46%)	0.05 (50%)	2.8 (30%)

**Percent reduction in relation to baseline*

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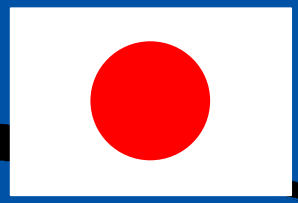
Emission Standards: Japan



	CO	HC	NOx	PM
	grams per kilometer (mean)			
Passenger Cars				
<1265 kg (1997)	2.10	0.40	0.40	0.08
<1265 kg (2002)	0.63	0.12	0.28	0.052
Commercial Vehicles				
2,500-12,000 kg (1997/98)	7.40	2.90	4.50	0.25
>12,000 kg (2004)	2.22	0.87	3.38	0.18

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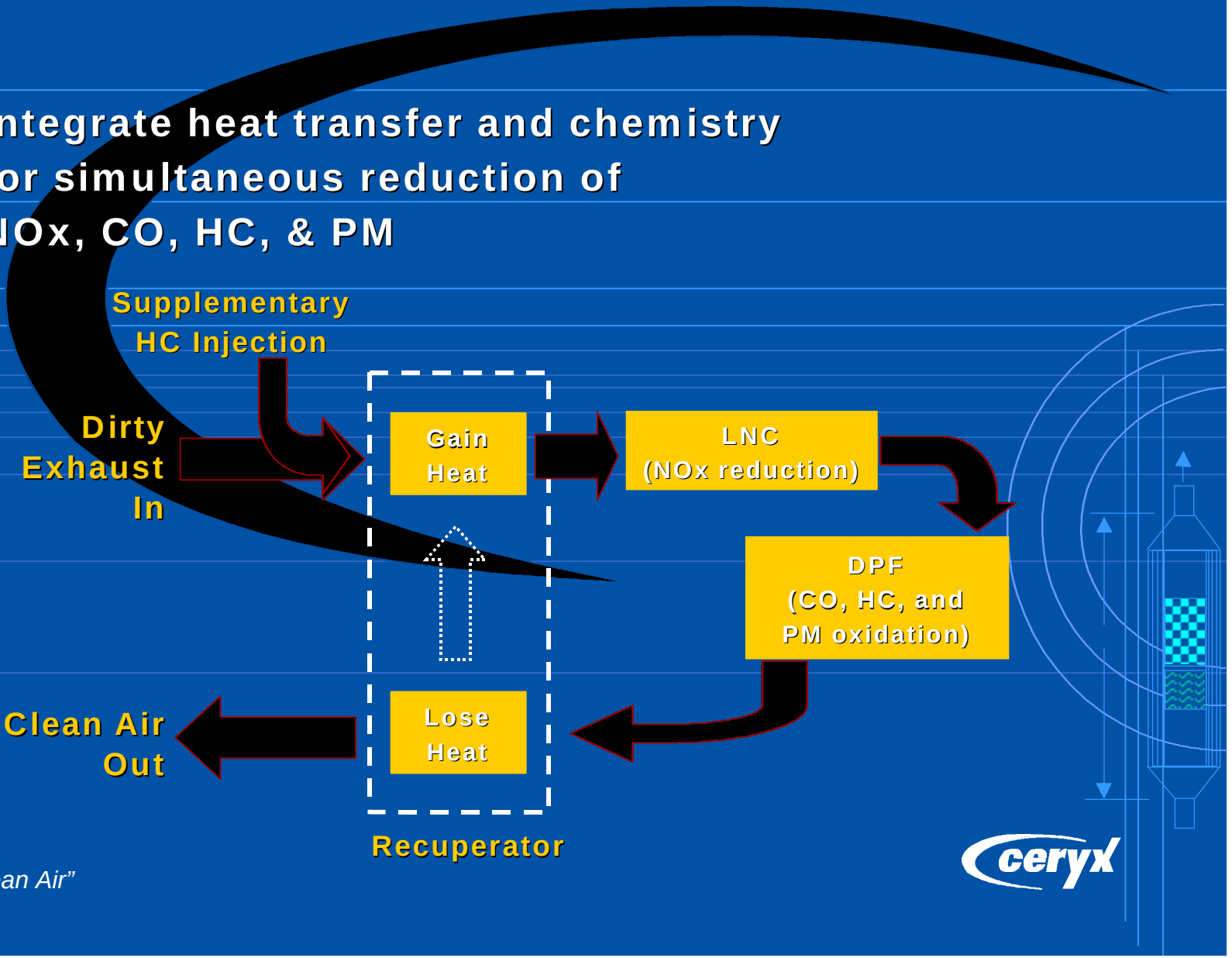
QuadCAT Flow Schematic

- Integrate heat transfer and chemistry for simultaneous reduction of NOx, CO, HC, & PM



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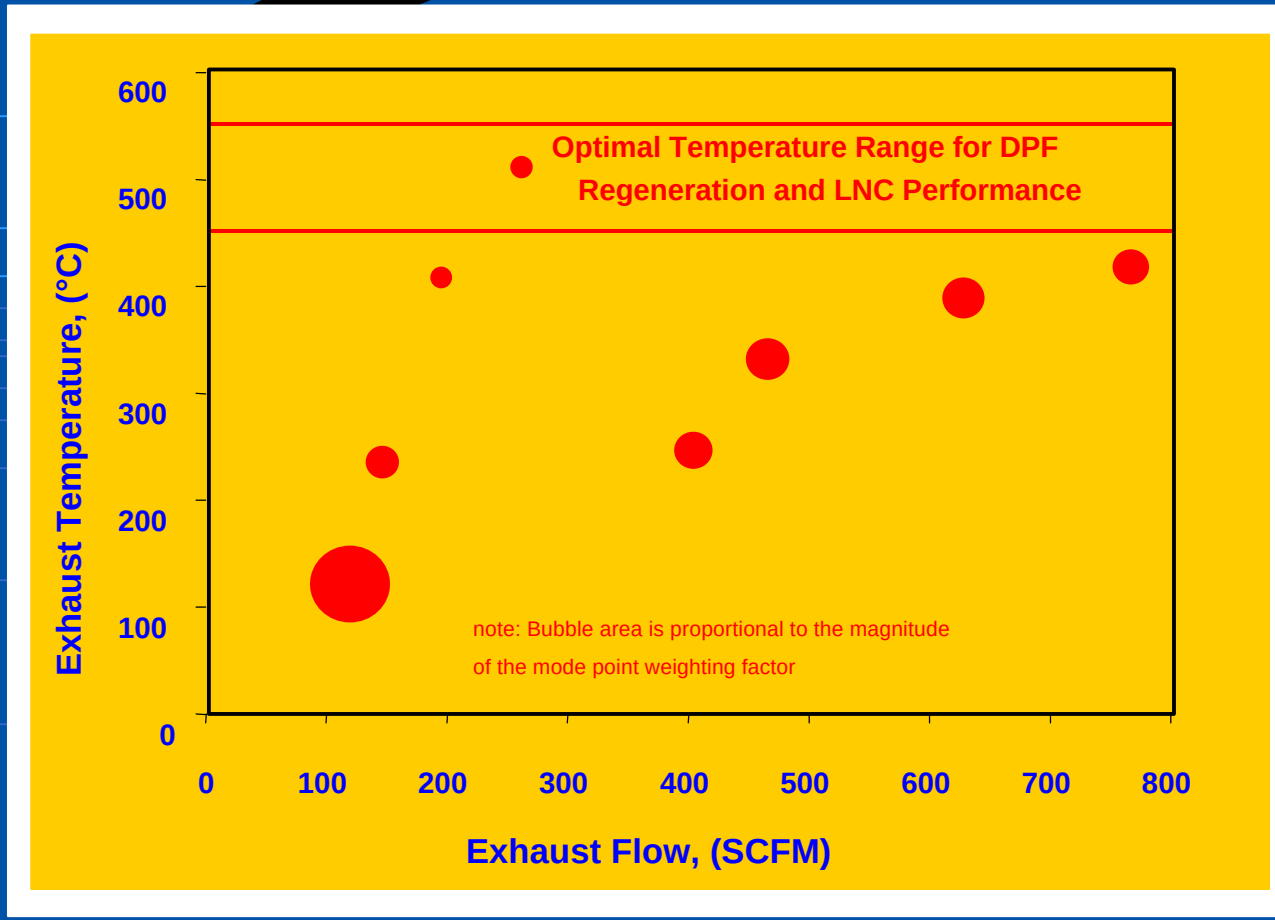
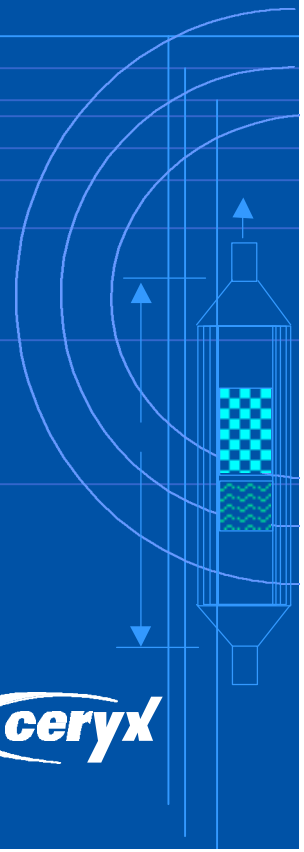
Temperature Profile Over 8-Mode Heavy-Duty Cycle





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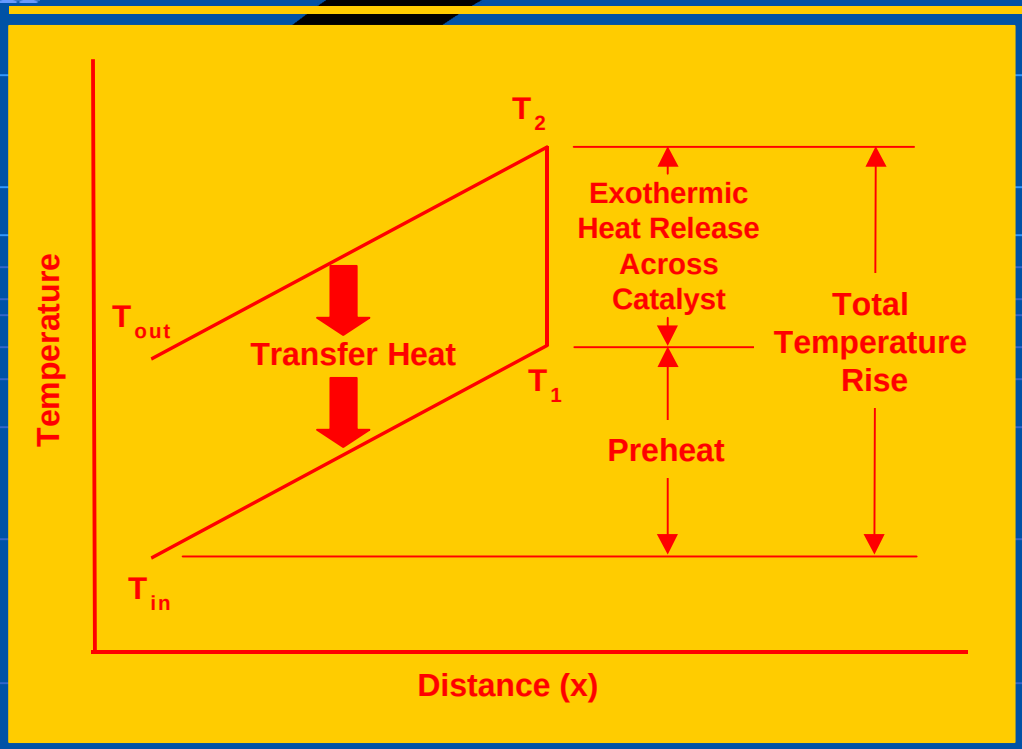
Chemical Reactor Platform



- Recycle heat from exothermic reactions
- Increase catalyst temperature
- Effectiveness defined as:

$$\eta = (T_1 - T_{in})/(T_2 - T_{in})$$

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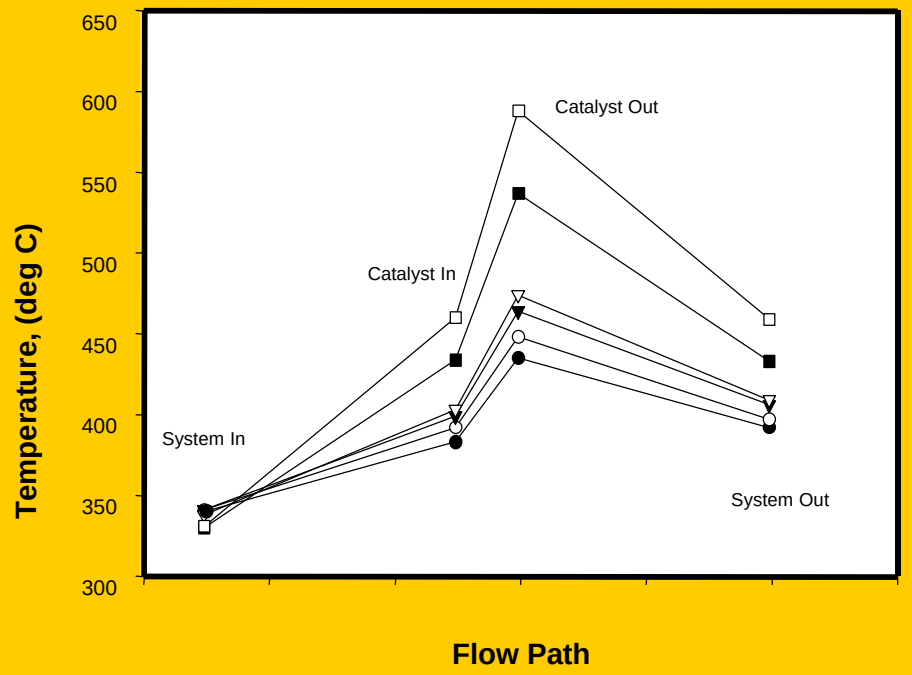
Experimental Data with Light-Duty Prototype on 200 Hp Engine



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Integration Makes Full Use of Resources

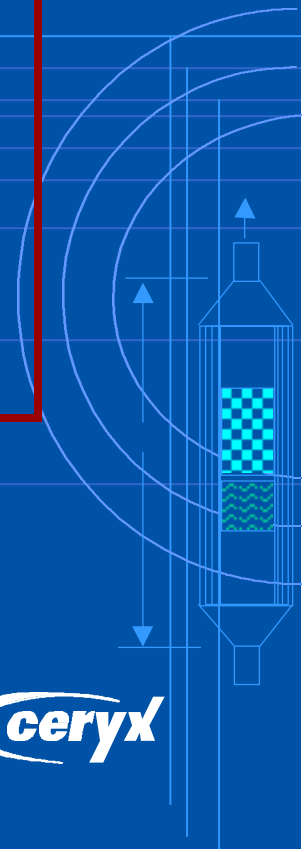
Injecting supplementary HC provides:

Energy source for DPF regeneration

$$HC + O_2 \rightarrow Heat$$

Reducing agent for NOx catalyst

$$HC + NOx + O_2 \rightarrow CO_2 + H_2O + N_2$$



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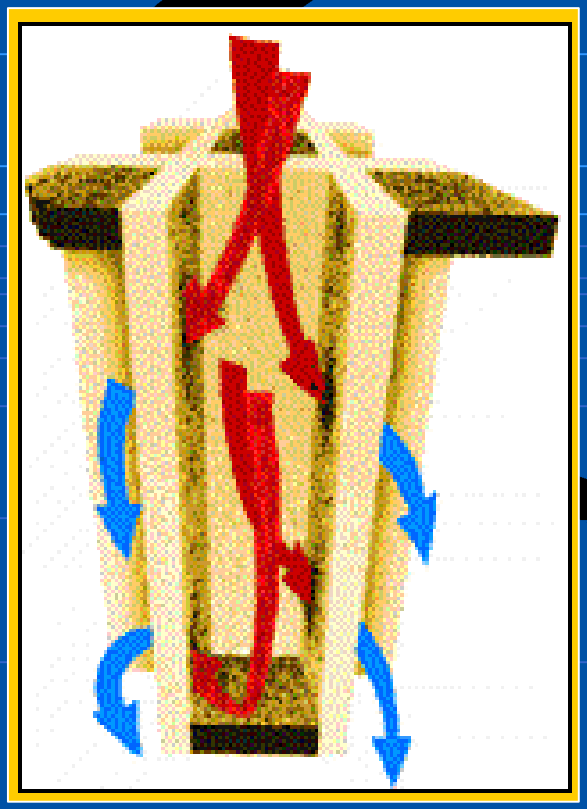
Diesel Particulate Filters



- Very high filtration efficiency (>90%)
- Variety of configurations
- Regeneration requires elevated temperatures to oxidize PM:
  - 550°C-650°C Uncatalyzed
  - 380°C-450°C Catalyzed
  - 200°C-400°C with fuel borne additives such as cerium or platinum

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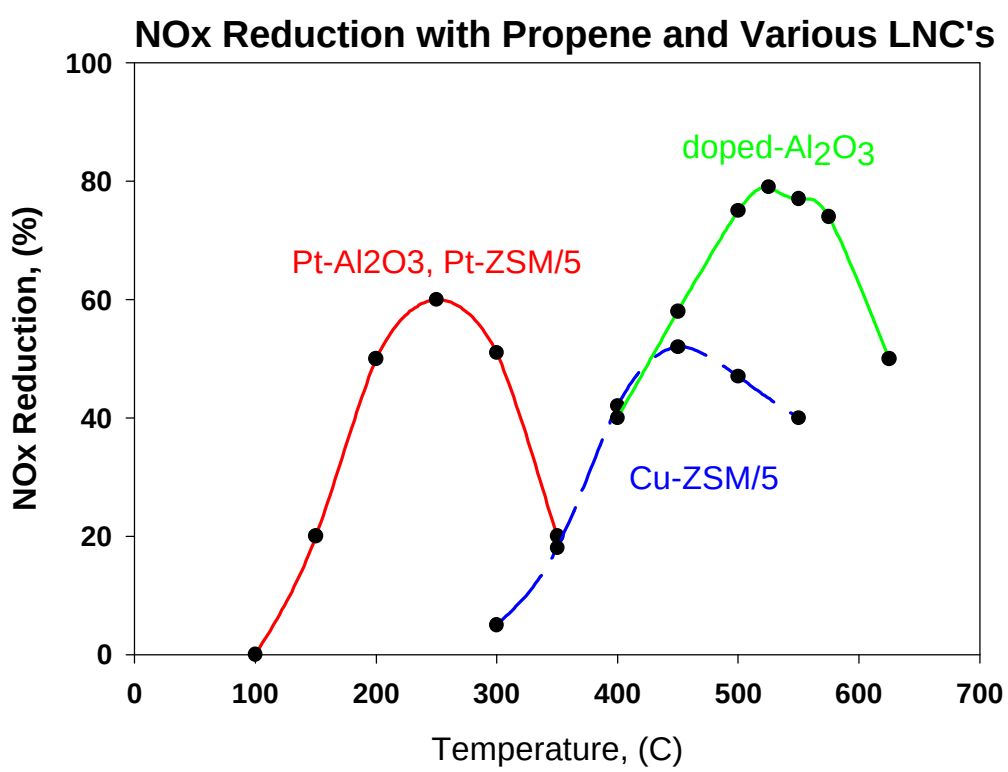
Lean NOx Catalysts



- Many formulations with various temperature windows
- Best reductions at elevated temperatures
- Low-cost, non-precious metal based catalyst are durable and sulfur tolerant
- Could benefit from QuadCAT recuperative approach

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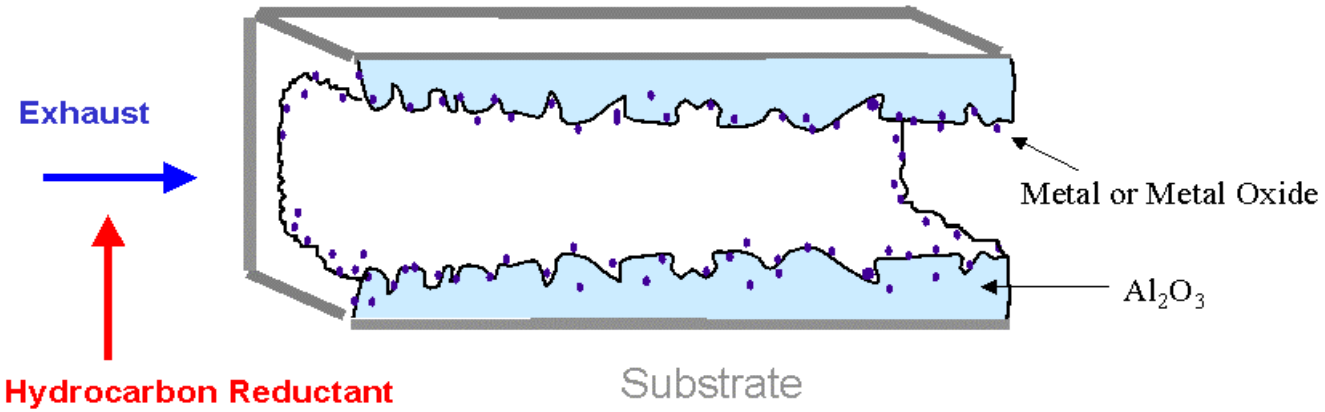
Lean NOx Catalyst Mechanism

Lean-NOx Catalytic Mechanism



(1)	$NO + O_2 \rightarrow NO_2$	Active Catalyst Site
(2)	$NO_2 + HC + O_2 \rightarrow N_2 + CO_2 + H_2O$	Alumina Site

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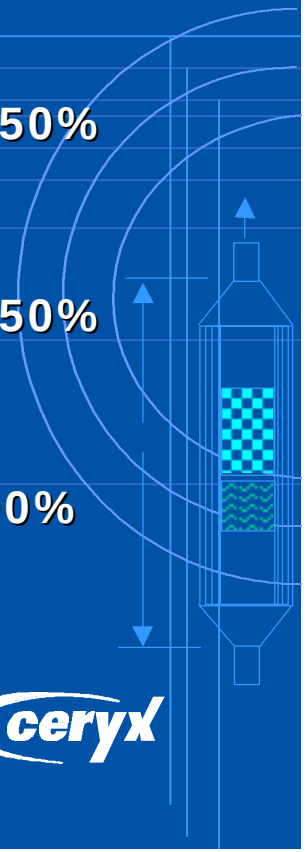
Ceryx Offers Multiple Configurations in a Single Platform

Product	HC	CO	PM	NOx
◎ **LeanCAT™** (Lean NOx Catalyst +DOC)	>90%	>90%	>30%	30-50%
◎ **QuadCAT™** (Lean NOx Catalyst + DPF)	>90%	>90%	>90%	30-50%
◎ **QuinCAT™** (NOx Trap + DPF)	>90%	>90%	>90%	>90%



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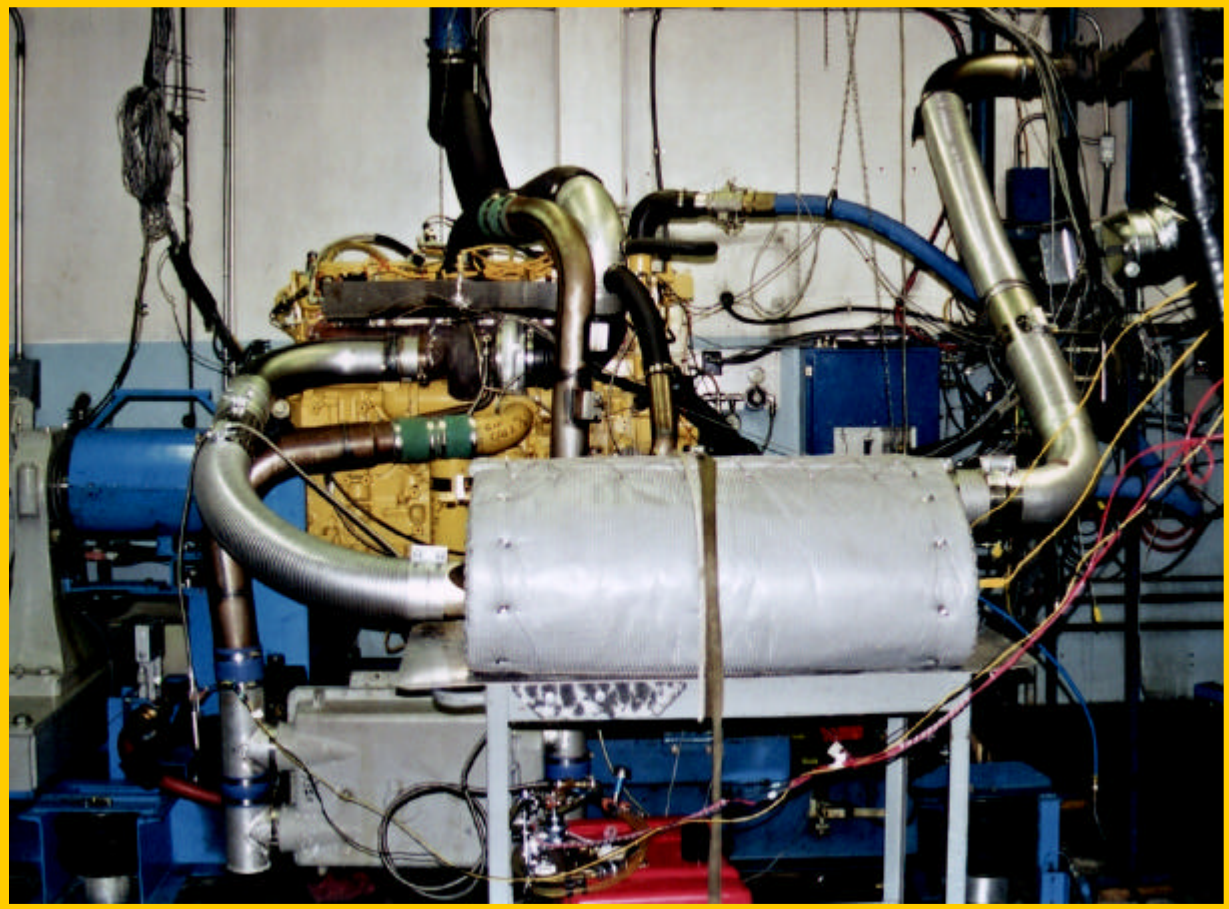
QuadCAT Prototype Testing



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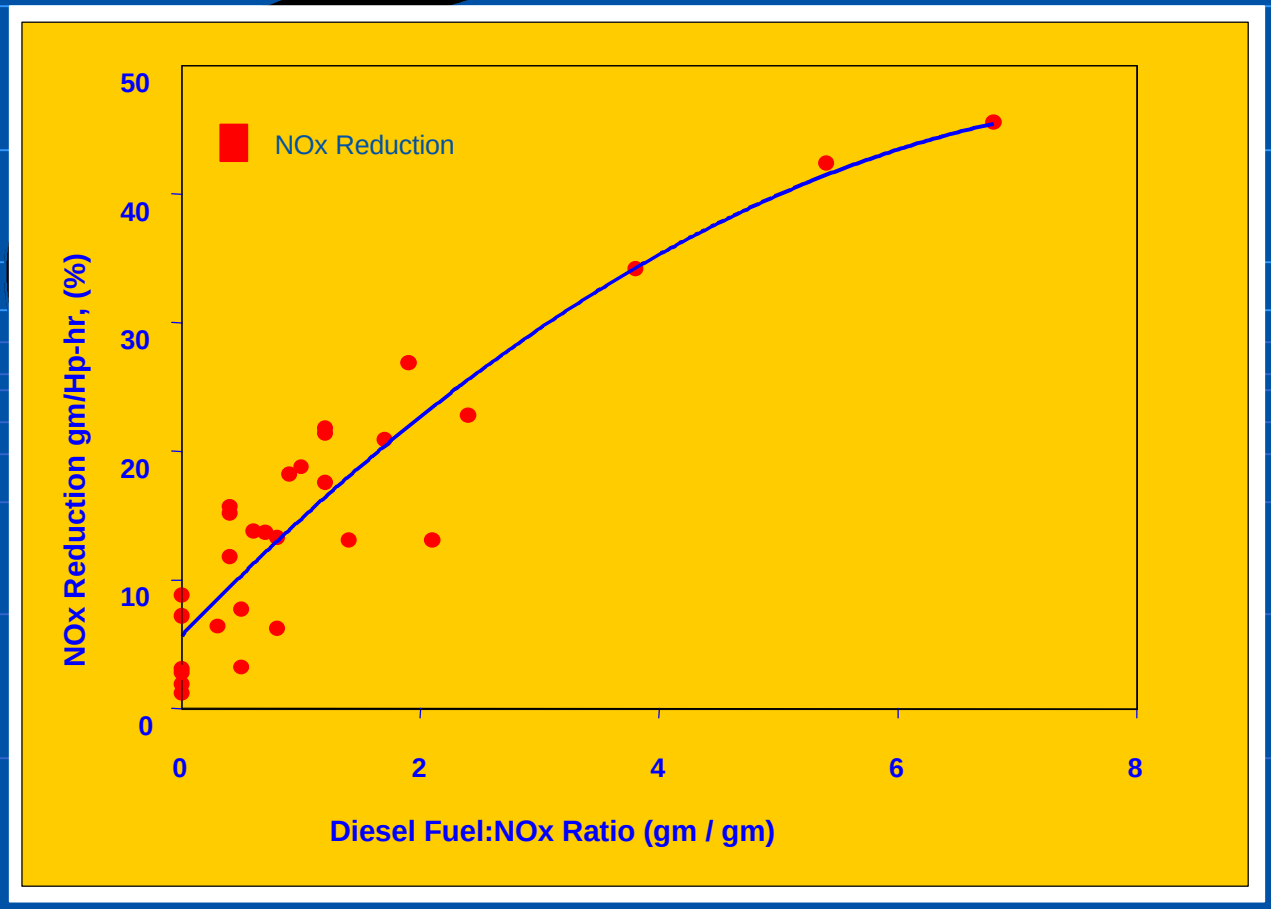
Results: NOx Reduction



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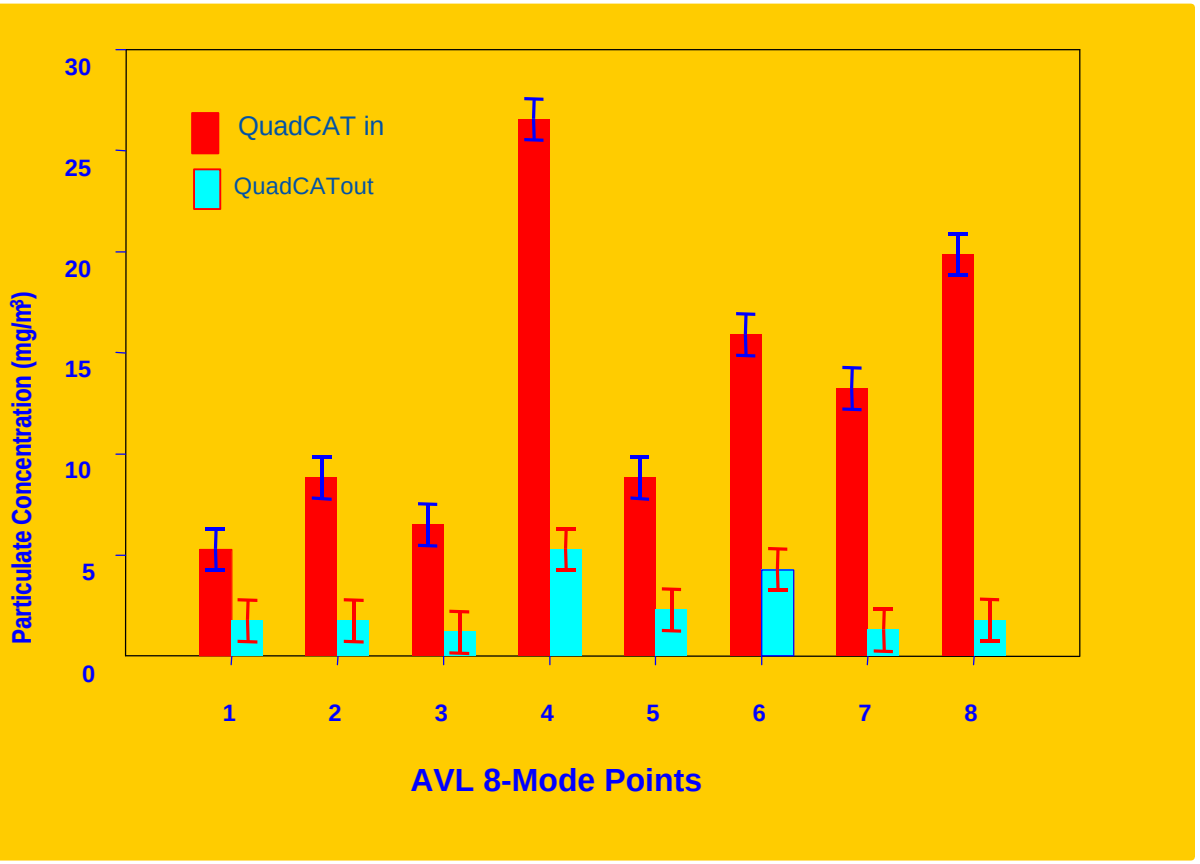
Results: PM Reduction



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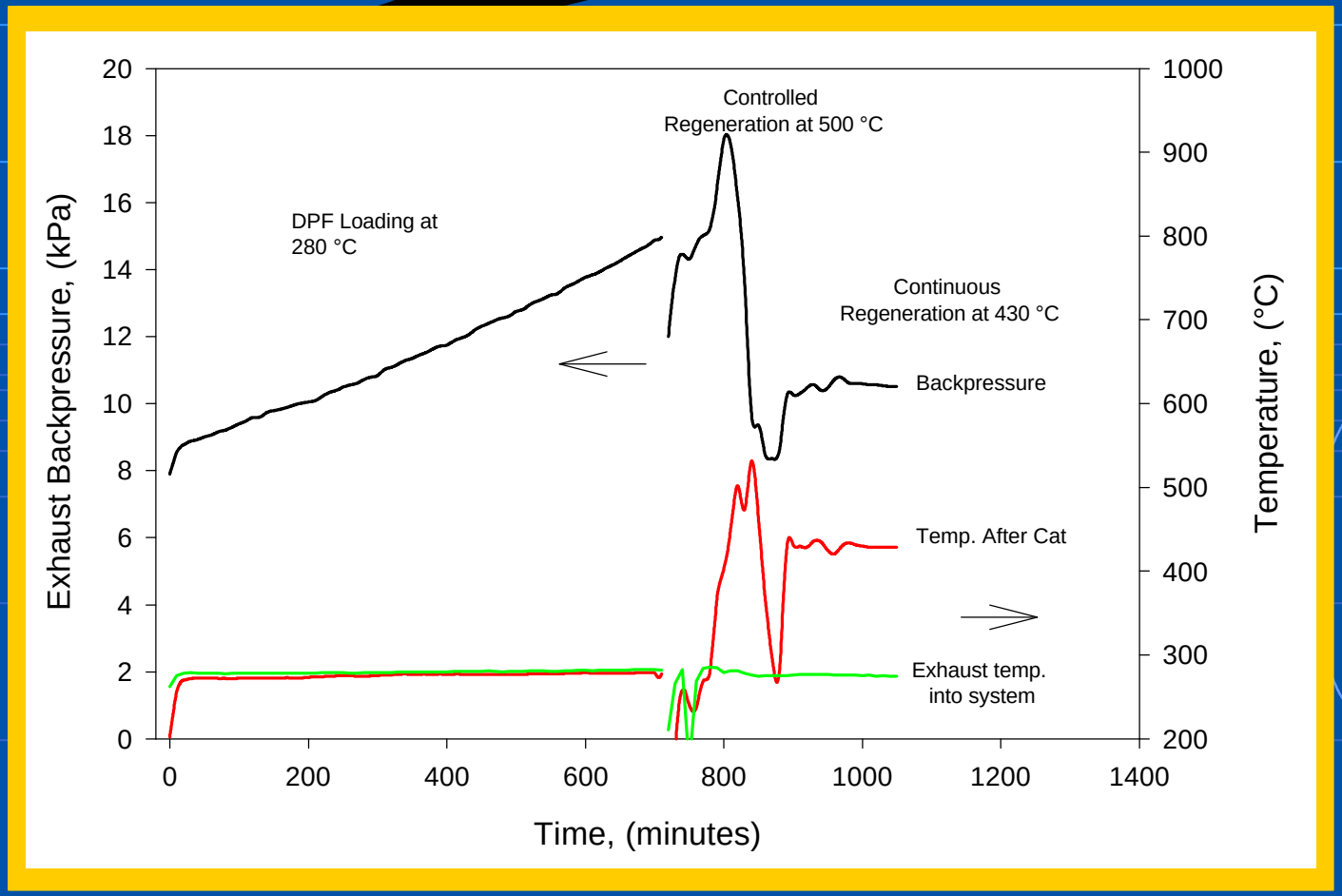
DPF Regeneration Data



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The QuadCAT System

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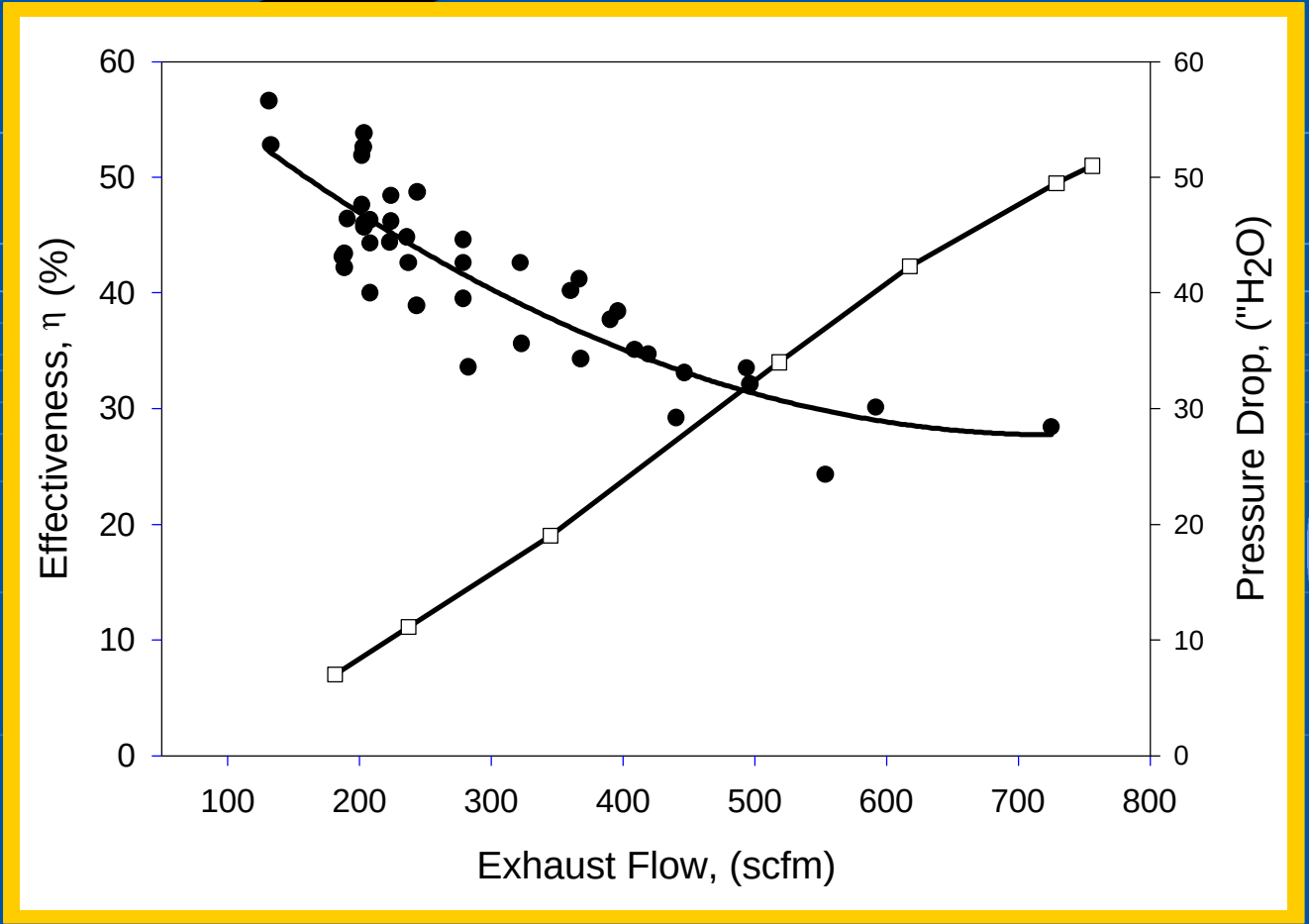
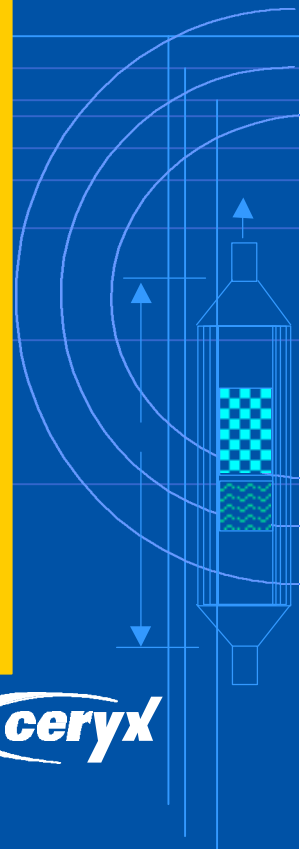
Heat Recovery & Pressure Drop

Recuperator and Catalyst





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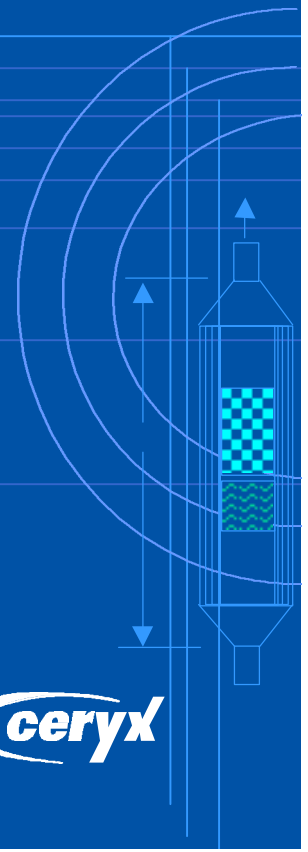
Summary of Testing

- ‘Proof of concept’ demonstrated
- 30-60% heat recovery
- Acceptable back-pressure
- > 95% reduction of CO and HC
- > 80% PM reduction
- Up to 45% NOx reduction depending on amount of fuel injected



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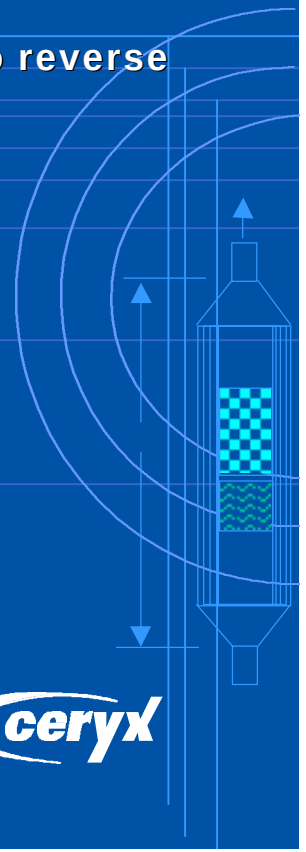
Summary: The QuadCAT 4-way Catalytic Converter

Elements	Features
◎ Recuperator	➢ Elevate catalyst temperature by recycling heat ➢ Noise abatement (replaces muffler/silencer)
◎ Fuel Injection and Control System	➢ Simultaneous oxidation & reduction with controlled HC injection ➢ Rich cycling and high temperature cycling to reverse sulfur poisoning ➢ Regenerate DPF on demand, OR ➢ Optimize for NOx reduction
◎ Lean NOx Catalyst	➢ Reduce NOx with HC as a reductant ➢ Non-precious metal based
◎ DPF/DOC	➢ Filter and oxidize PM ➢ Oxidize CO and HC ➢ DOC is non-precious metal based



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Light-Duty QuadCAT Converter

- A QuadCAT Converter field unit installed on a Ceryx test vehicle

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