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Performance Evaluation of the Delphi Non-Thermal Plasma System Under Transient and Steady State Conditions

8th Diesel Engine Emission Reduction Conference
San Diego, California
August 25-29, 2002

Joseph V. Bonadies, Joachim Kupe, Galen B. Fisher, Craig L. DiMaggio, David A. Goulette, Thomas W. Silvis, Mark Hemingway, William J. LaBarge
Delphi Corporation

Darrell R. Herling, Monty R. Smith, John G. Frye, Mark A. Gerber
Pacific Northwest National Laboratory

Acknowledgements

California Energy Commission
Diesel Emissions Carl Moyer Demonstration Program

Jerry Wiens

Test Vehicle Configuration
NTP Assisted Catalyst Evaluation

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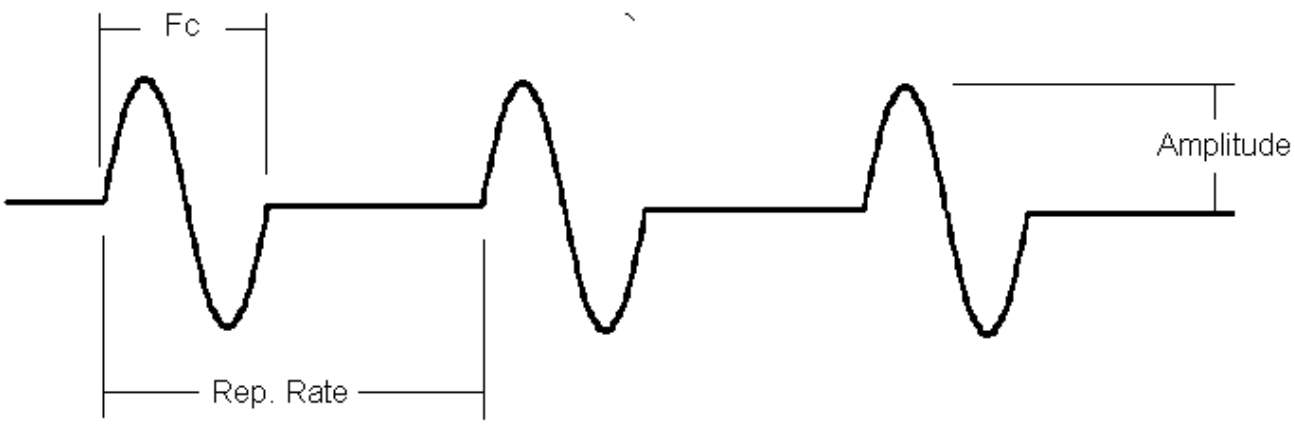
- 2000 European production vehicle with 2.2 L common rail engine
  - Delphi development EMS
  - Production FIE
  - Euro 3 emission certification
- System Configuration
  - DPF + Reactor + Catalysts
- 20 Cell Parallel Plate NTP Reactor
  - 15.4cc active area
- 2.5 liter SiC DPF (non-catalyzed)
- DeNOx Catalyst (Stabilized)
  - Ag Al2O3 (1.67L) (Catalyst 1)
  - Ag Ba-Y-Z (3.35L) (Catalysts 2 & 3)
  - Pt oxidation (0.98L) (Catalyst 4)
- Power Supply
  - 220VAC
  - Power control based on Speed/Load
  - 15KHz Pulse Density Modulation (PDM)
  - Power supply efficiency 80% from wall to gas

Pulse Density Modulation (PDM) Power Delivery Control

- Pulse density modulation power control
  - Fixed Amplitude (6kV peak)
  - Automatic resonant frequency control (Fc » 15 – 20 kHz)
  - Variable repetition rate based on speed/load

- US Patent 6,423,190 pulse density modulation for uniform barrier discharge in a non-thermal plasma reactor



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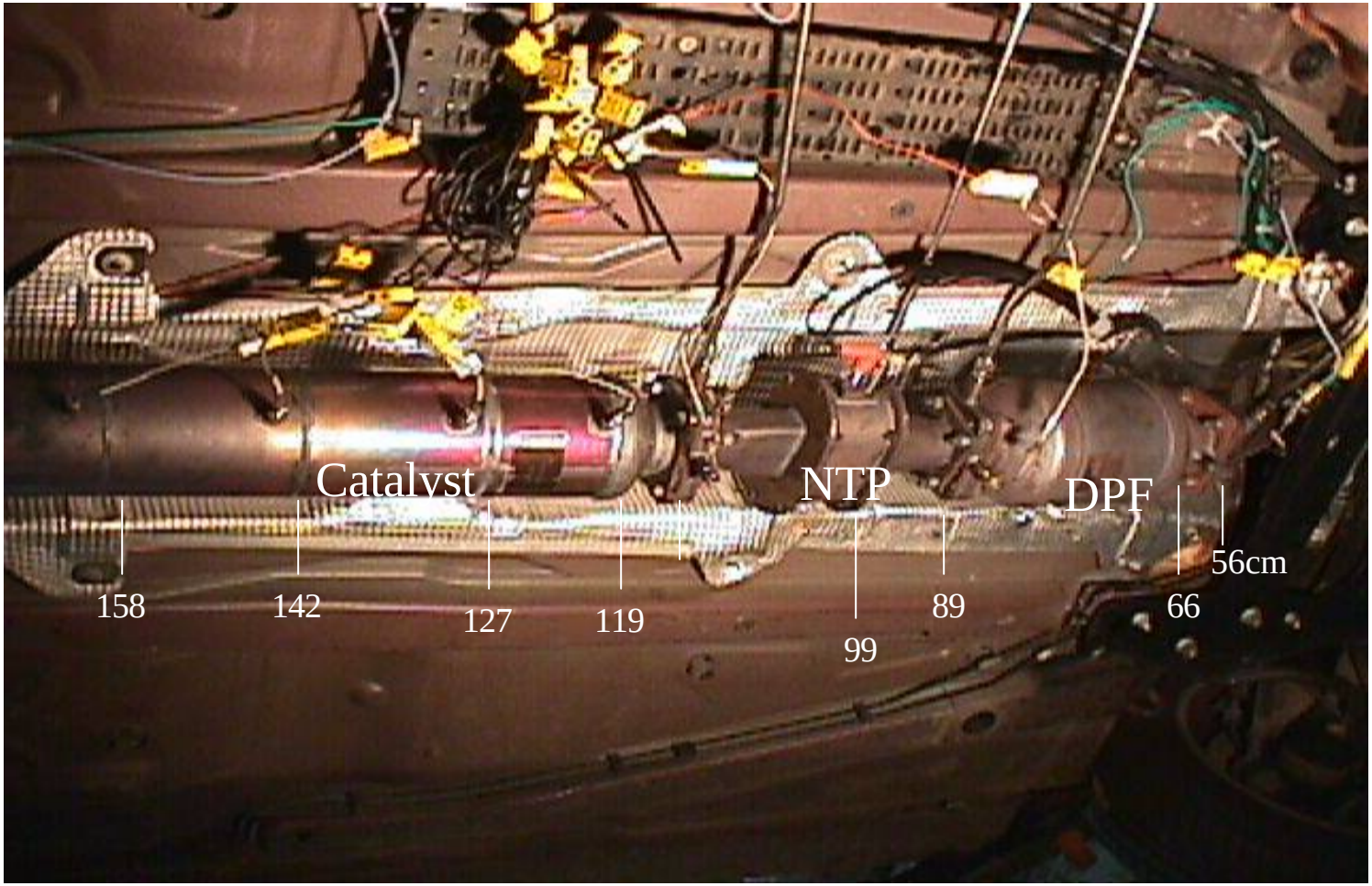
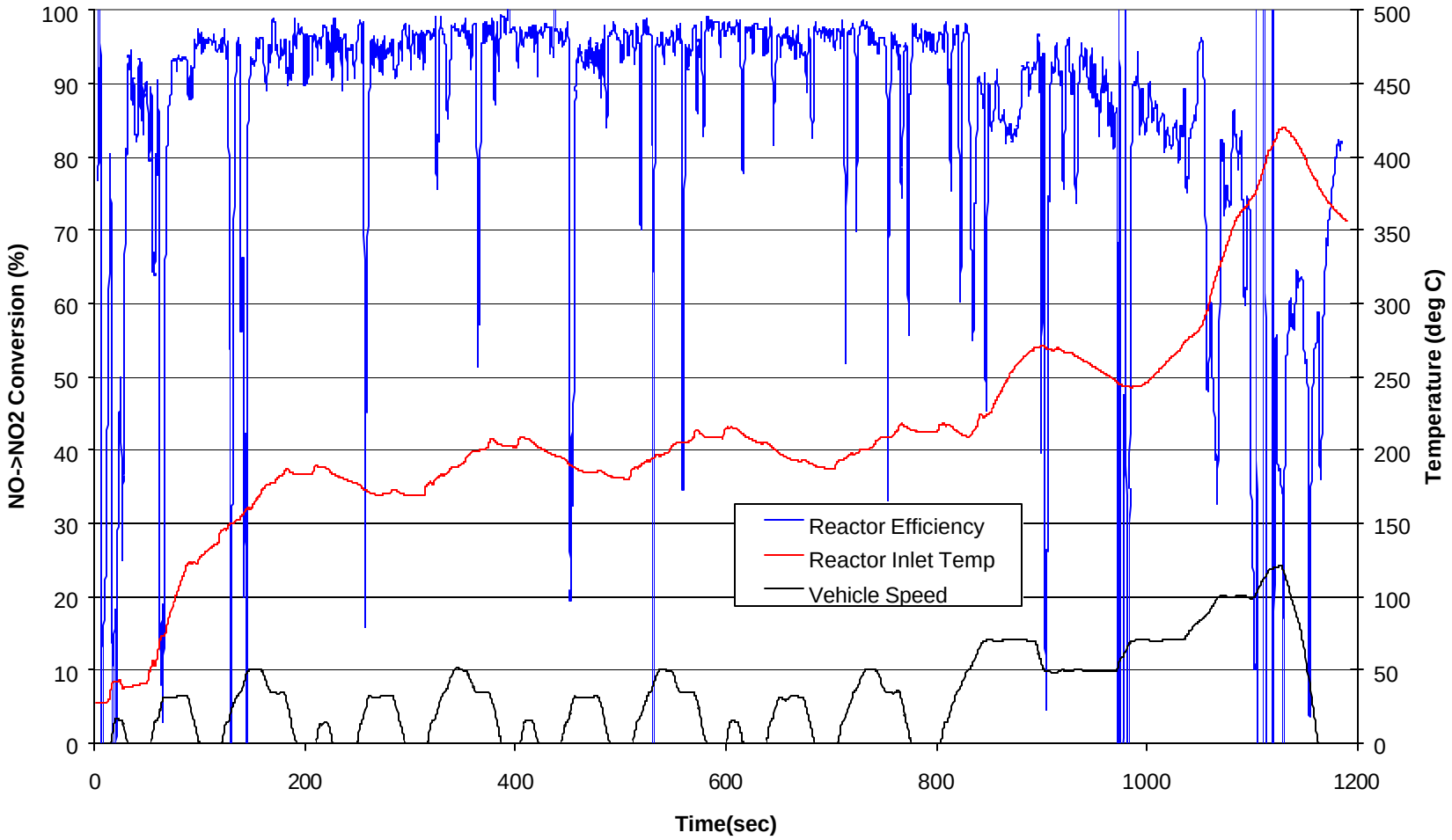
Vehicle Exhaust Configuration

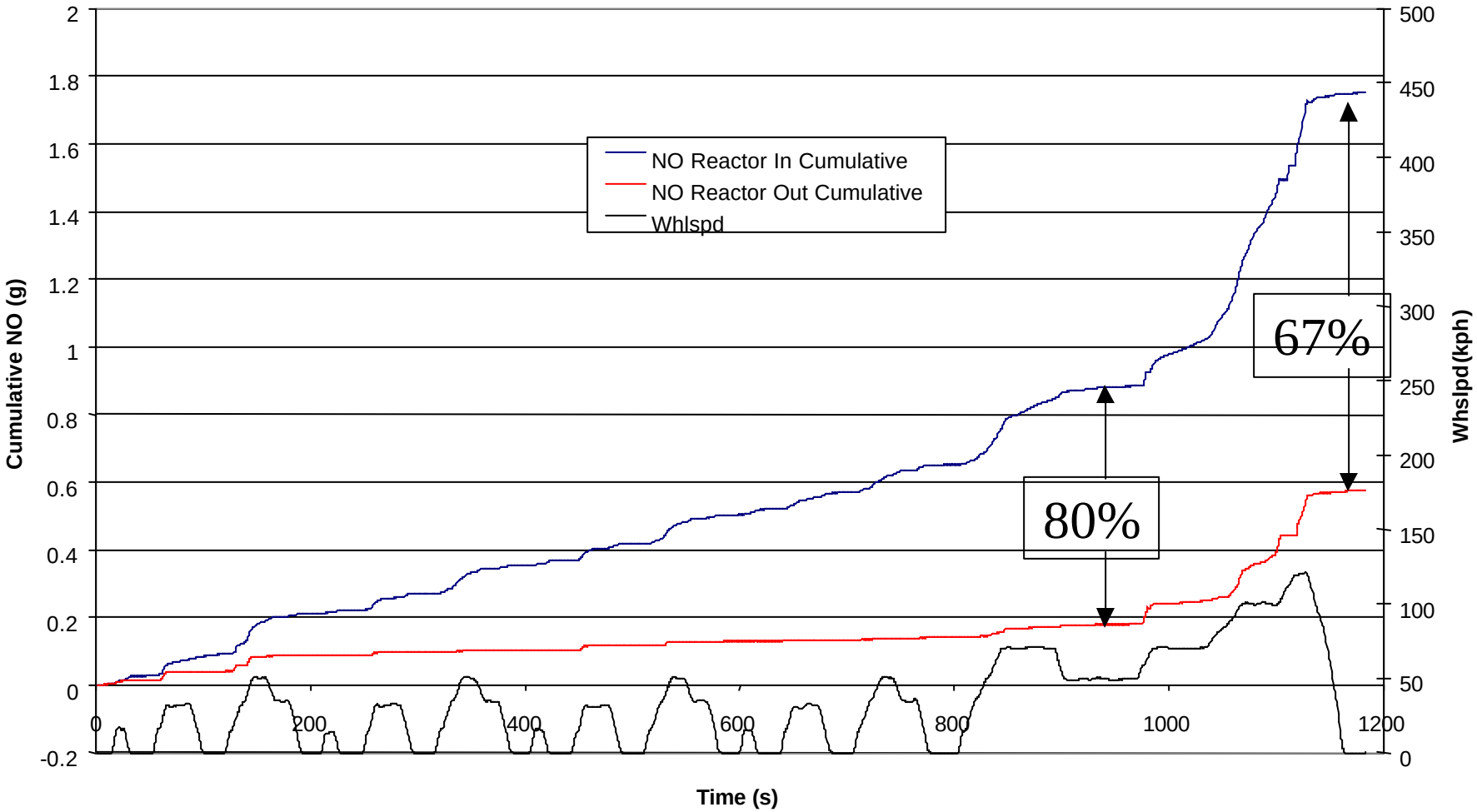


NTP Reactor Efficiency
MVEG Cycle



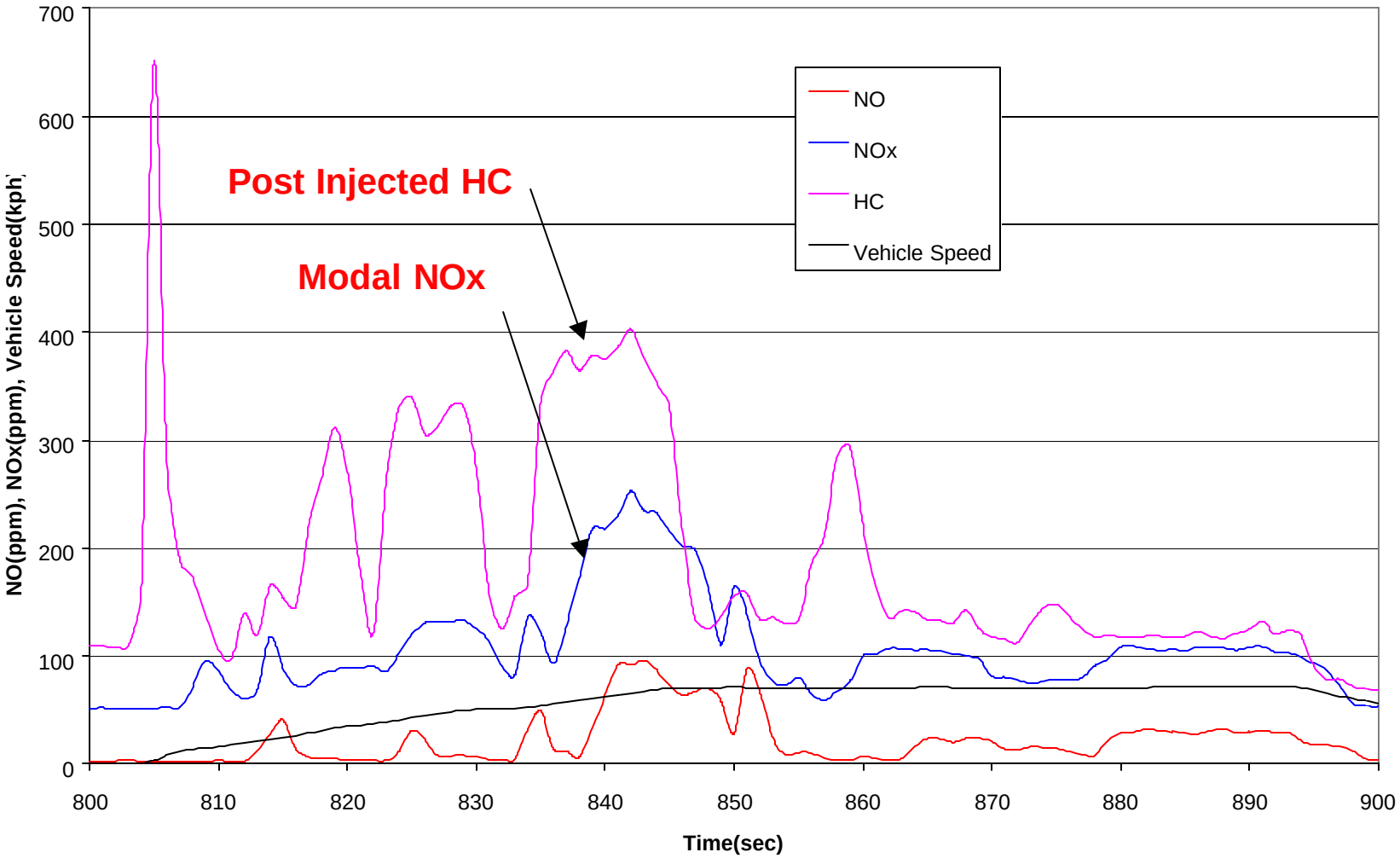
- NO to NO_2 conversion > 90% over ECE

Net NTP Reactor NO Conversion Efficiency



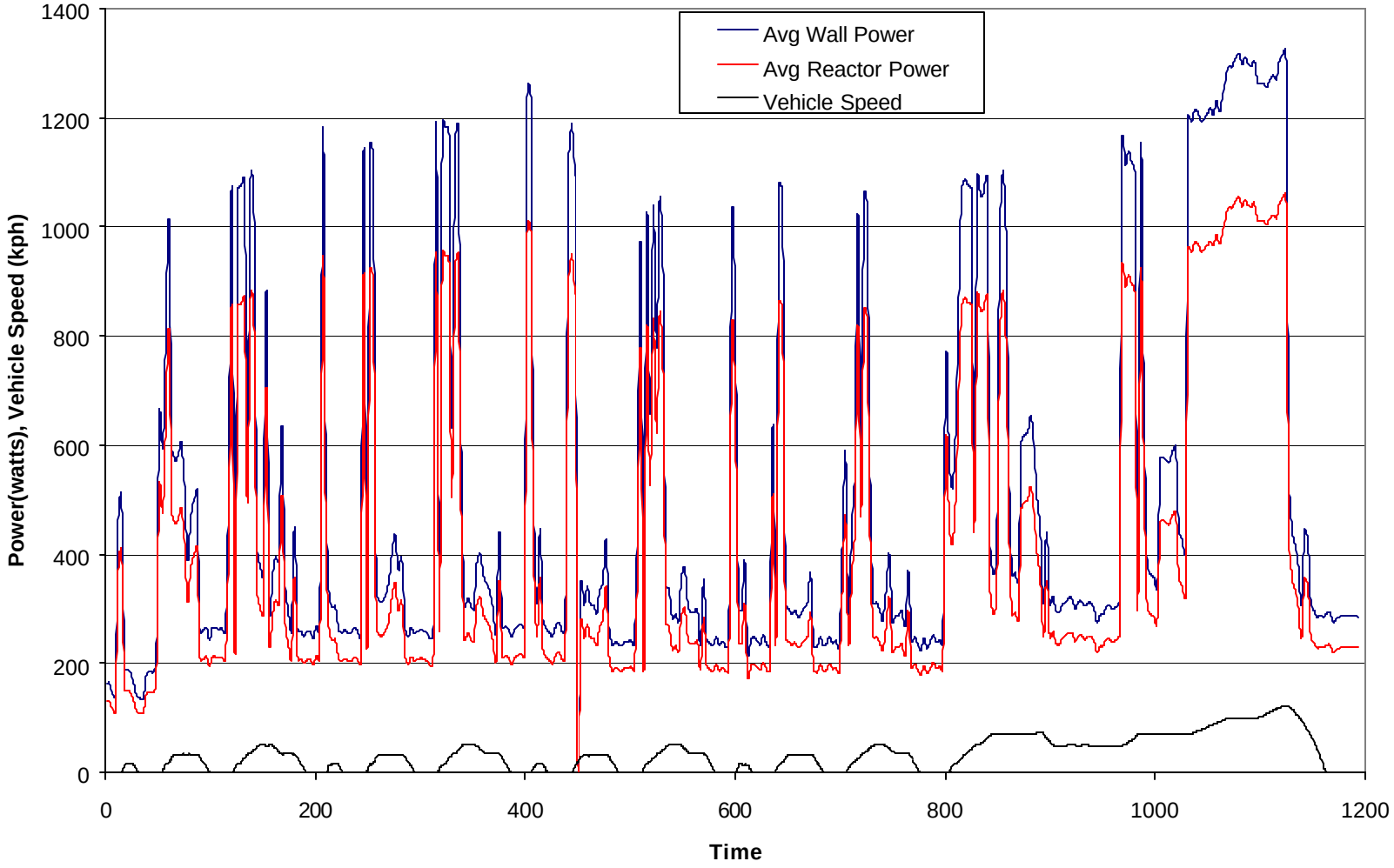
- 80% cumulative NO to NO2 conversion up to mid EUDC
- 67% cumulative NO to NO2 overall

In-cylinder Post Injection Timing
NTP Reactor Outlet



- Transient control provides HCs from post injection that arrive at plasma and catalyst ahead of NOx spike

NTP Power Consumption



- Transient control of NTP power demonstrated
- 350 Watt average over MVEG

Fuel Economy Penalty

- Power Consumption
  - **Fuel Economy Penalty: 5 %**
- Post Injected HC
  - **Fuel Economy Penalty: 3 %**
- Total Fuel Economy Penalty = 8 %

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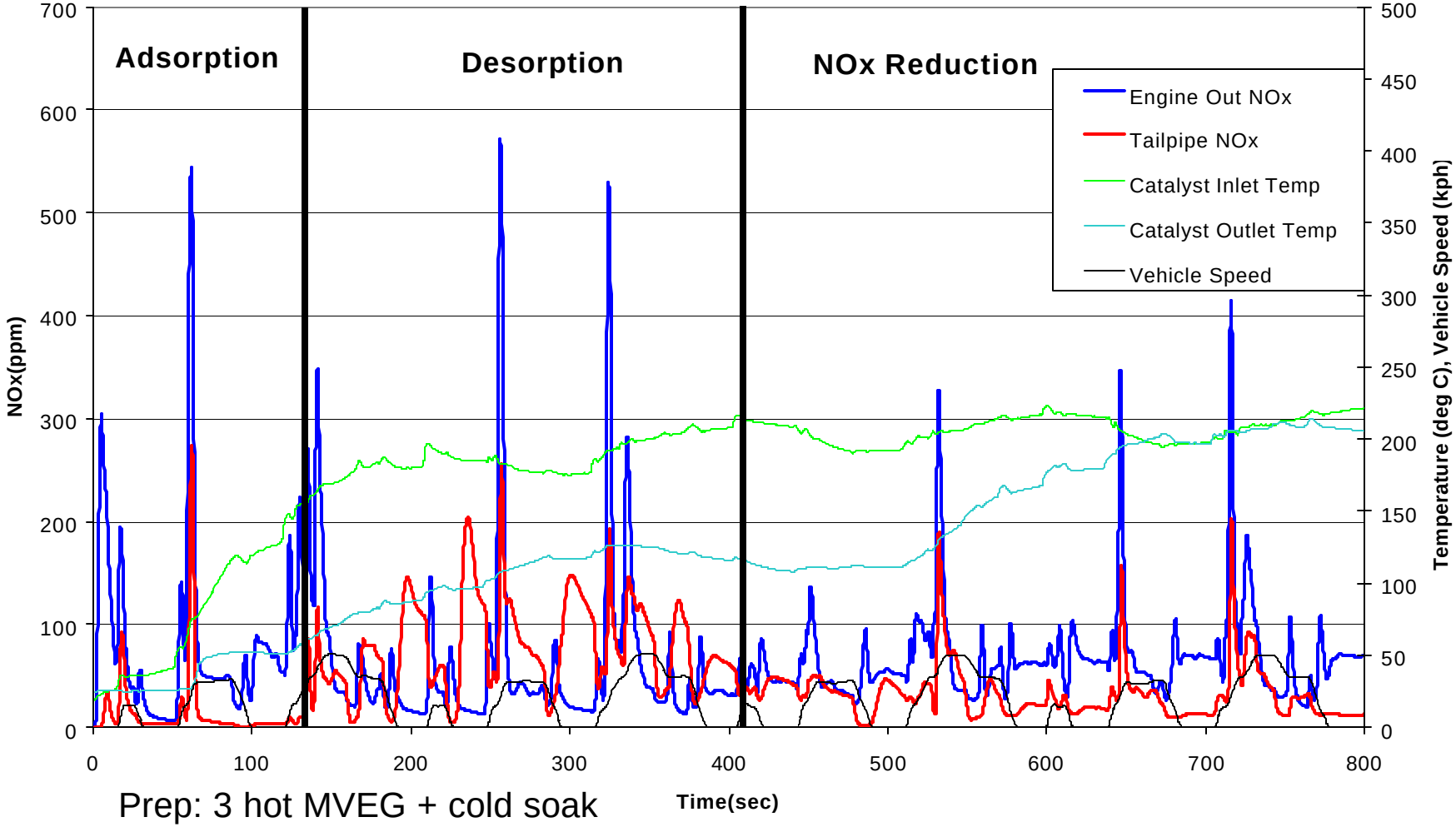
NTP Assisted Catalysis
NOx Performance

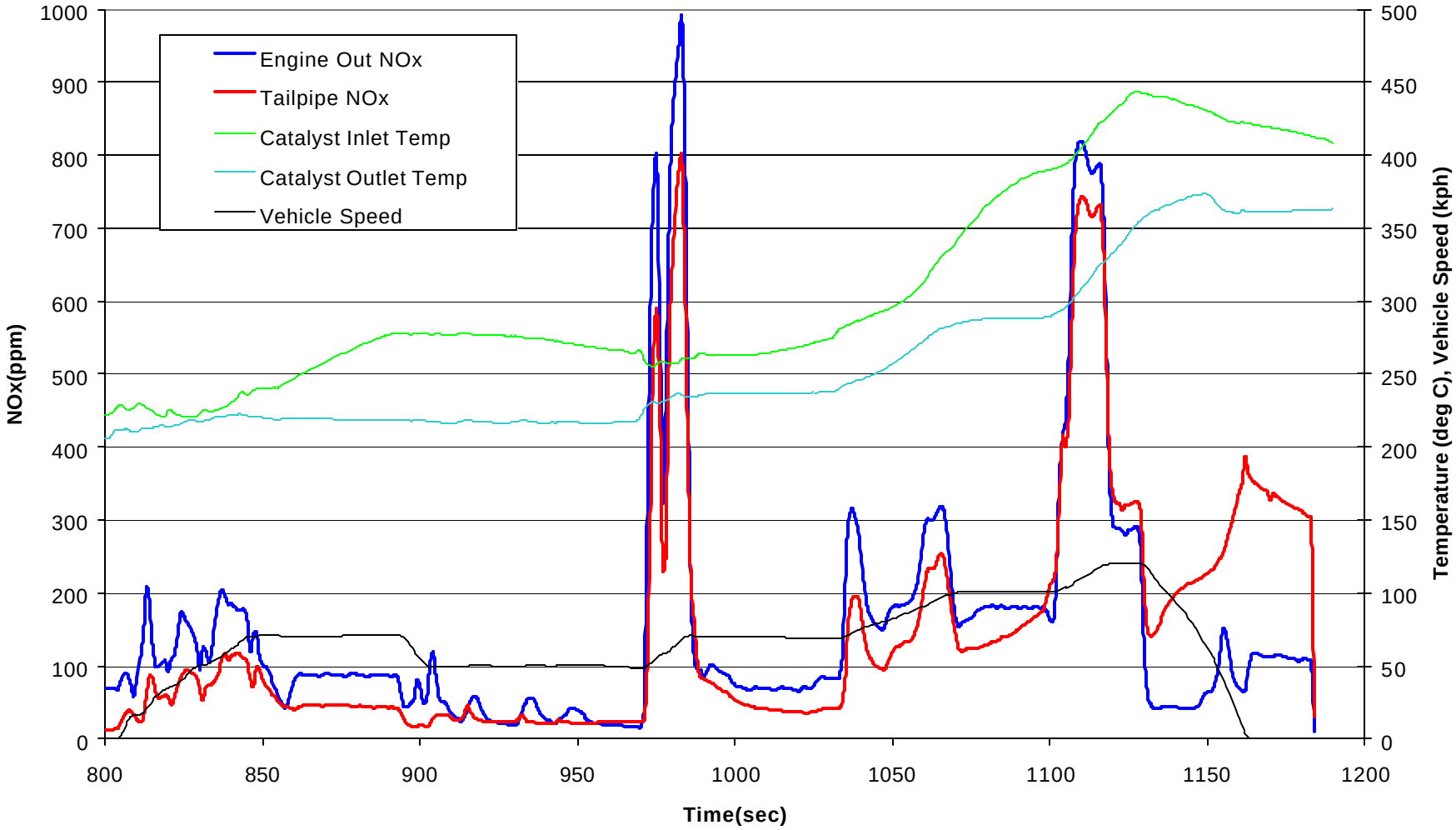
NOx Concentration ECE



Prep: 3 hot MVEG + cold soak

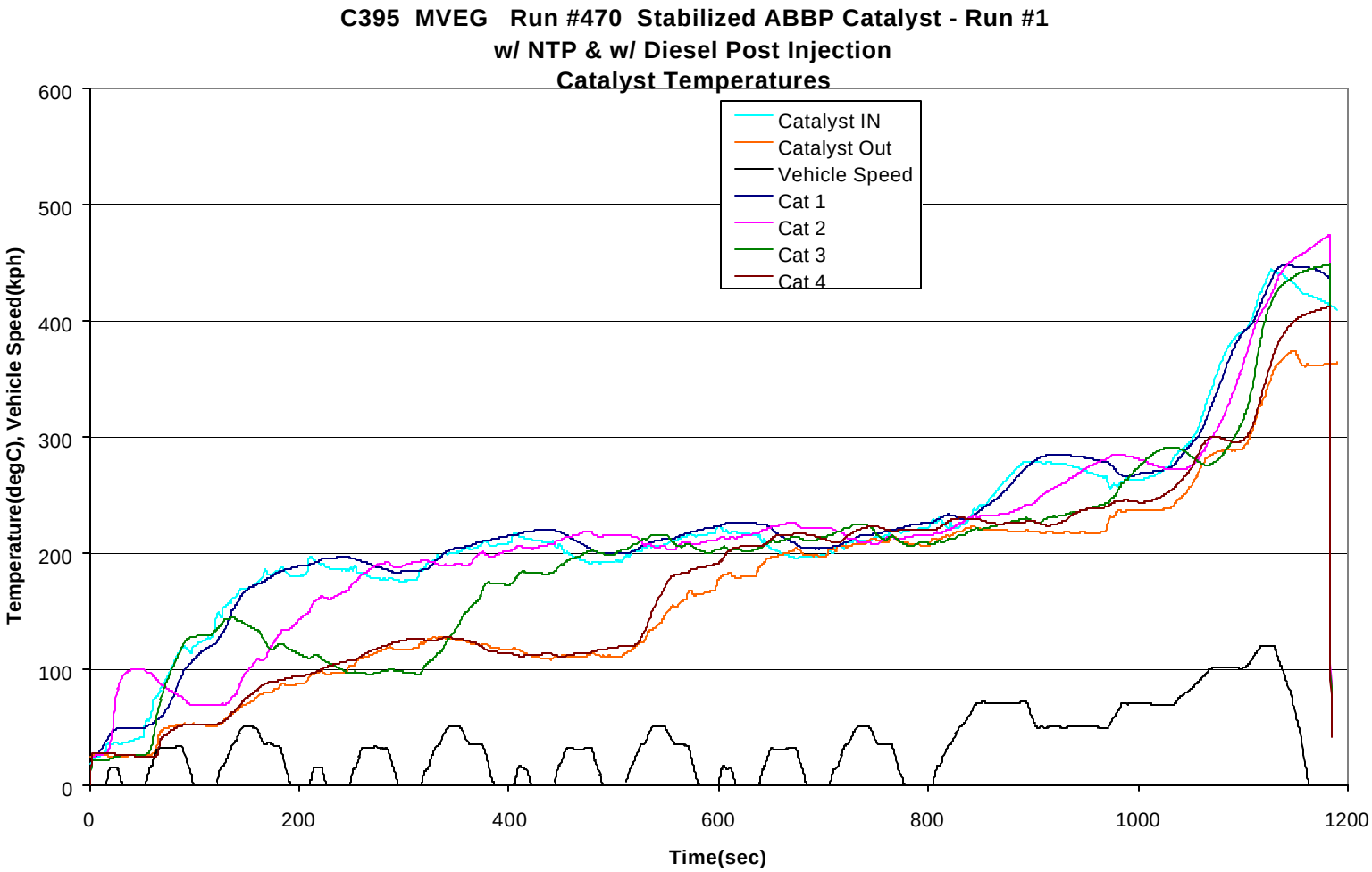
- NOx adsorption, desorption, and then reduction through ECE cycle

NOx Concentration EUDC



- Low NOx efficiencies during high speed portion of EUDC
- Large NOx desorption during final deceleration

Catalyst Bed Temperatures



- Catalyst bed temperatures stay below 300° C until last 100 s of MVEG
- Emphasizes the performance of the low temperature zeolite catalyst

Synthetic Gas Bench (SGB) Catalyst Performance

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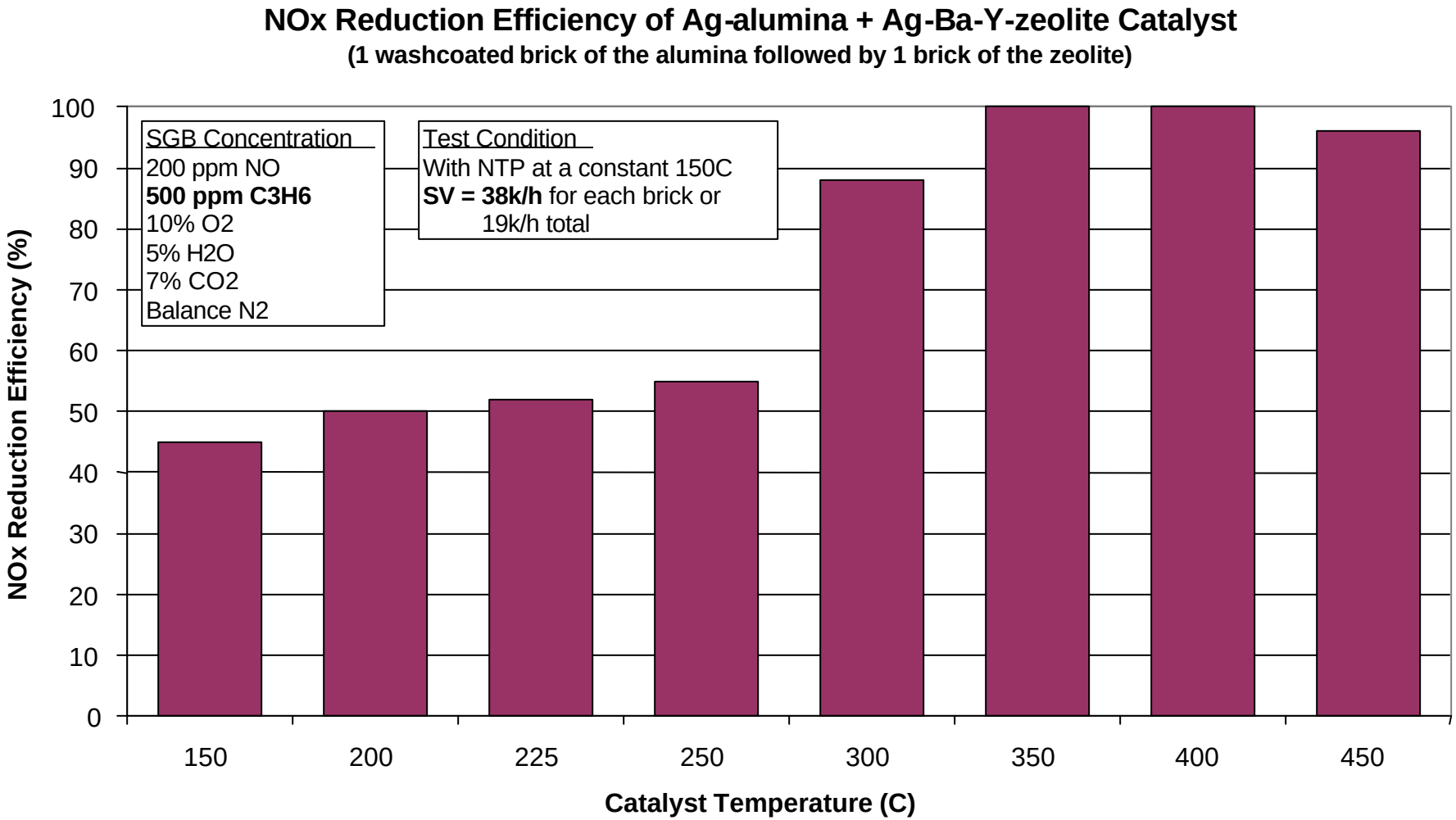
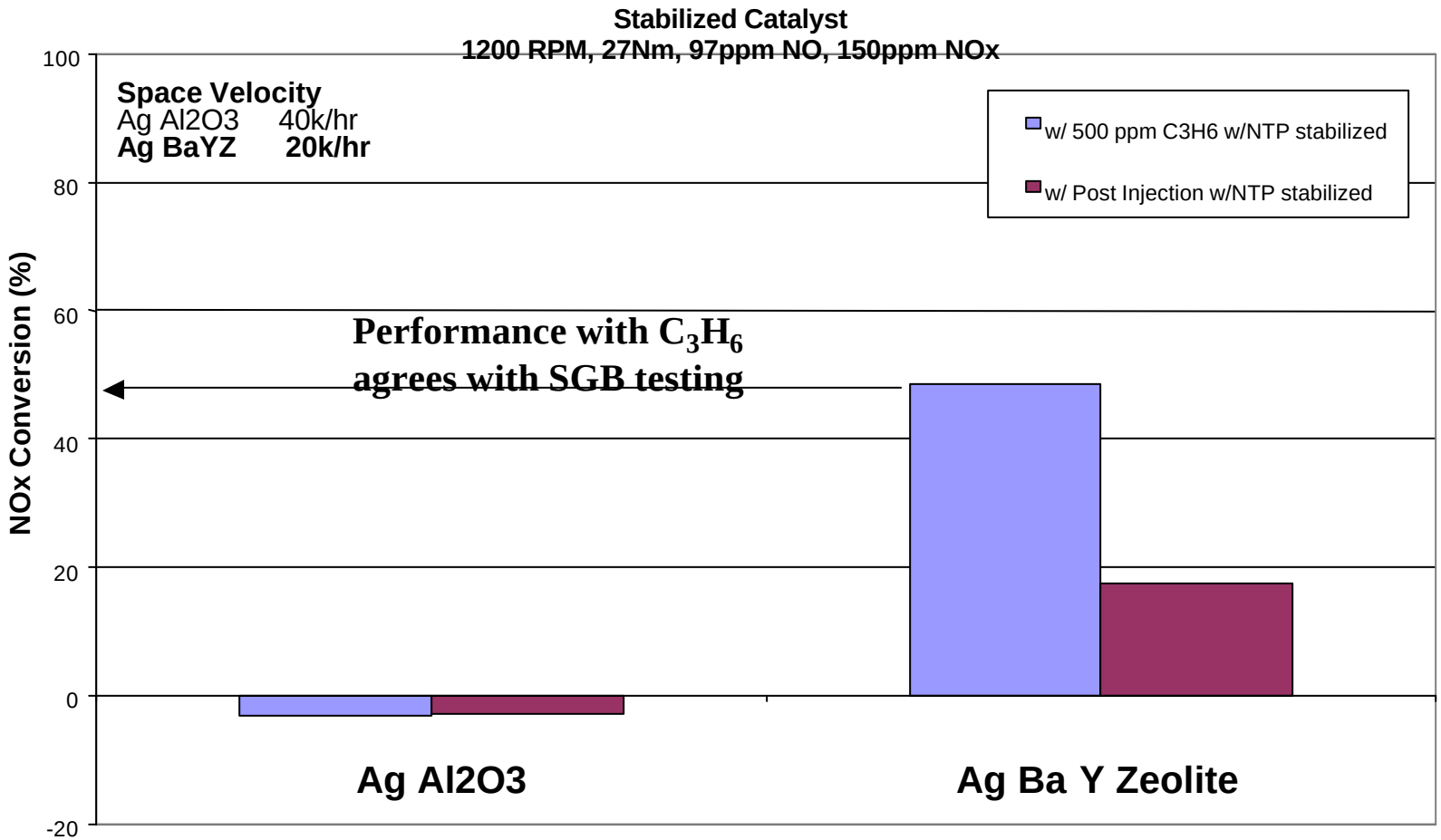


- Synthetic gas bench (SGB) testing used to identify candidate catalysts

Engine Dyno Steady State Performance C_3H_6 vs Post Injection - 150°C



- With HC from post-injection, <20% NOx conversion
- 50% NOx conversion similar on dyno and SGB with 500 ppm propene
- Near 15% with only propene & no NTP

Engine Dyno Steady State Performance C_3H_6 vs Post Injection - 350°C

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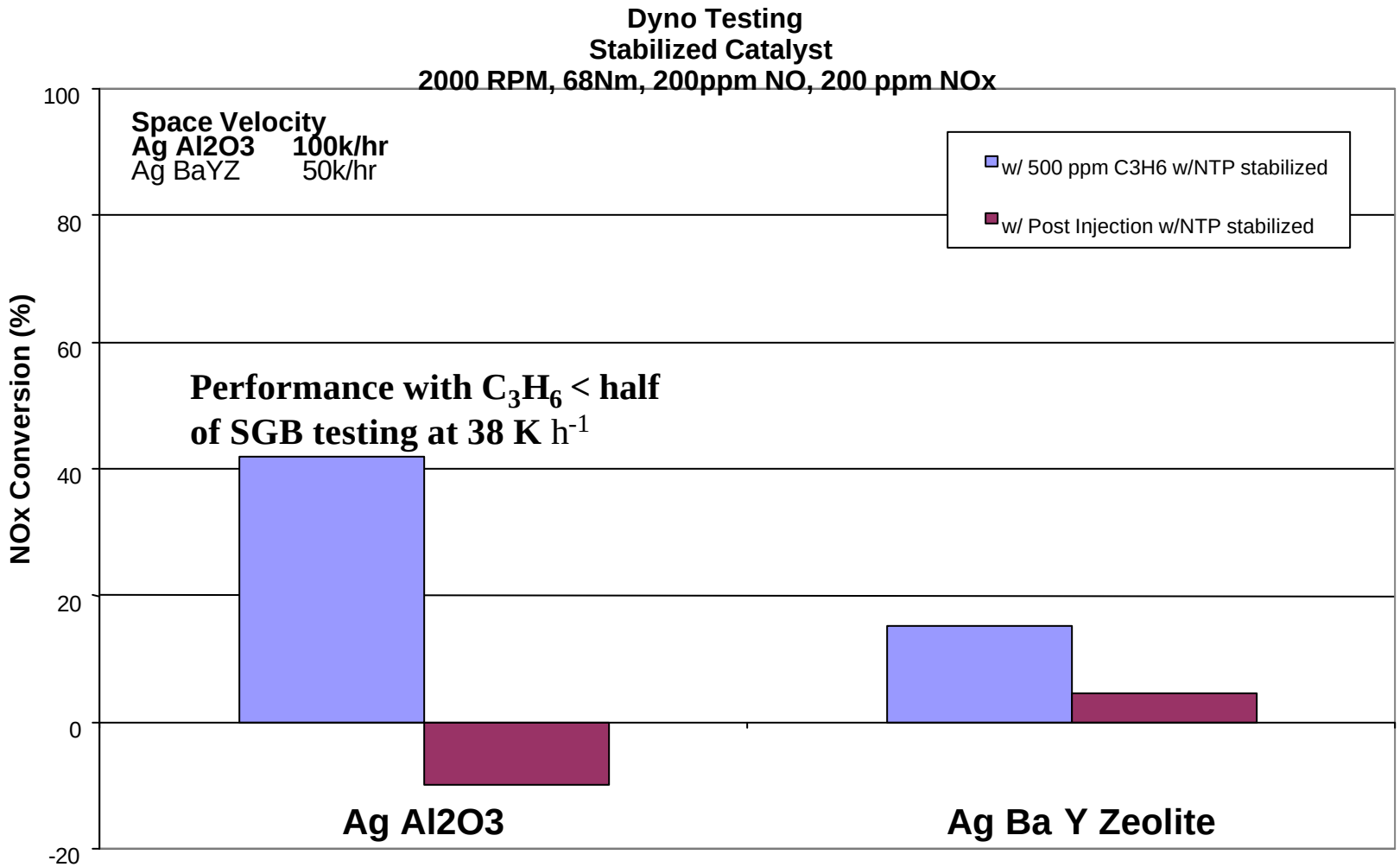

- With HC from post-injection, negative NOx conversion
- NOx conversion @ 100 K h^{-1} SV expected to be less than SGB data @ 38 K h^{-1}

NTPR Acetaldehyde Production
Engine Dyno Steady State

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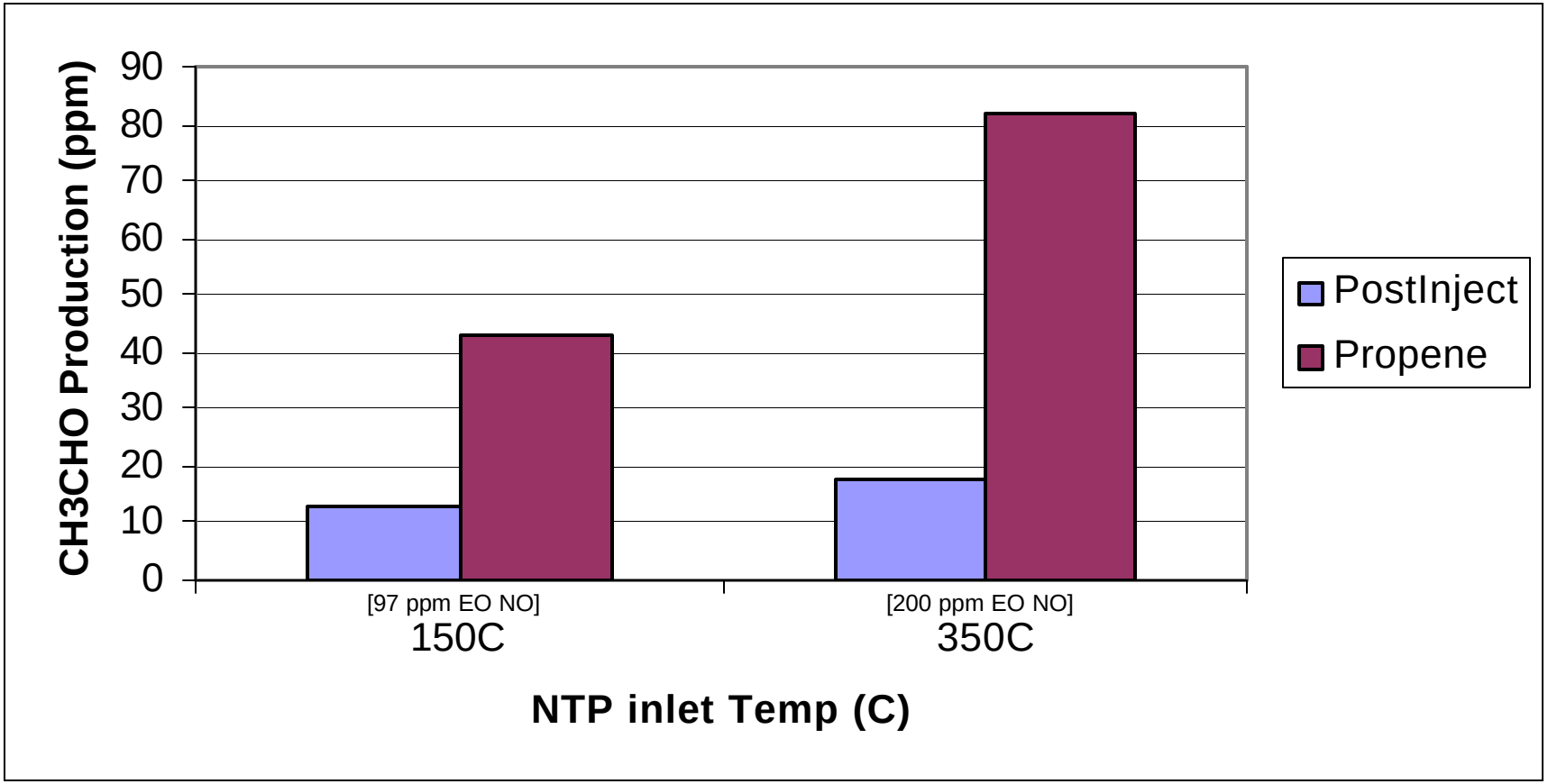
Acetaldehyde is the most efficient reductant used by these NOx catalysts



- With post injection, insufficient appropriate HC species exist in the exhaust to yield sufficient acetaldehyde

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Vehicle Test Summary

- 15 % NOx total system efficiency over MVEG cycle
  - 30 % ECE, 3% EUDC
  - NOx adsorption and desorption affected catalyst efficiencies
  - Ag Al_2O_3 catalyst not fully exercised due to low exhaust temperature
- Reactor exhibits good NO->NO_2 conversion
- Greater than 85% HC and 62% CO efficiency on cold MVEG with low temperature oxidation catalyst as rear brick
- Diesel post injection calibration improved reactor efficiency during transients
- Modest power levels are seen at low speed/load steady state operating points

DPF Regeneration

DPF Dynamometer Testing

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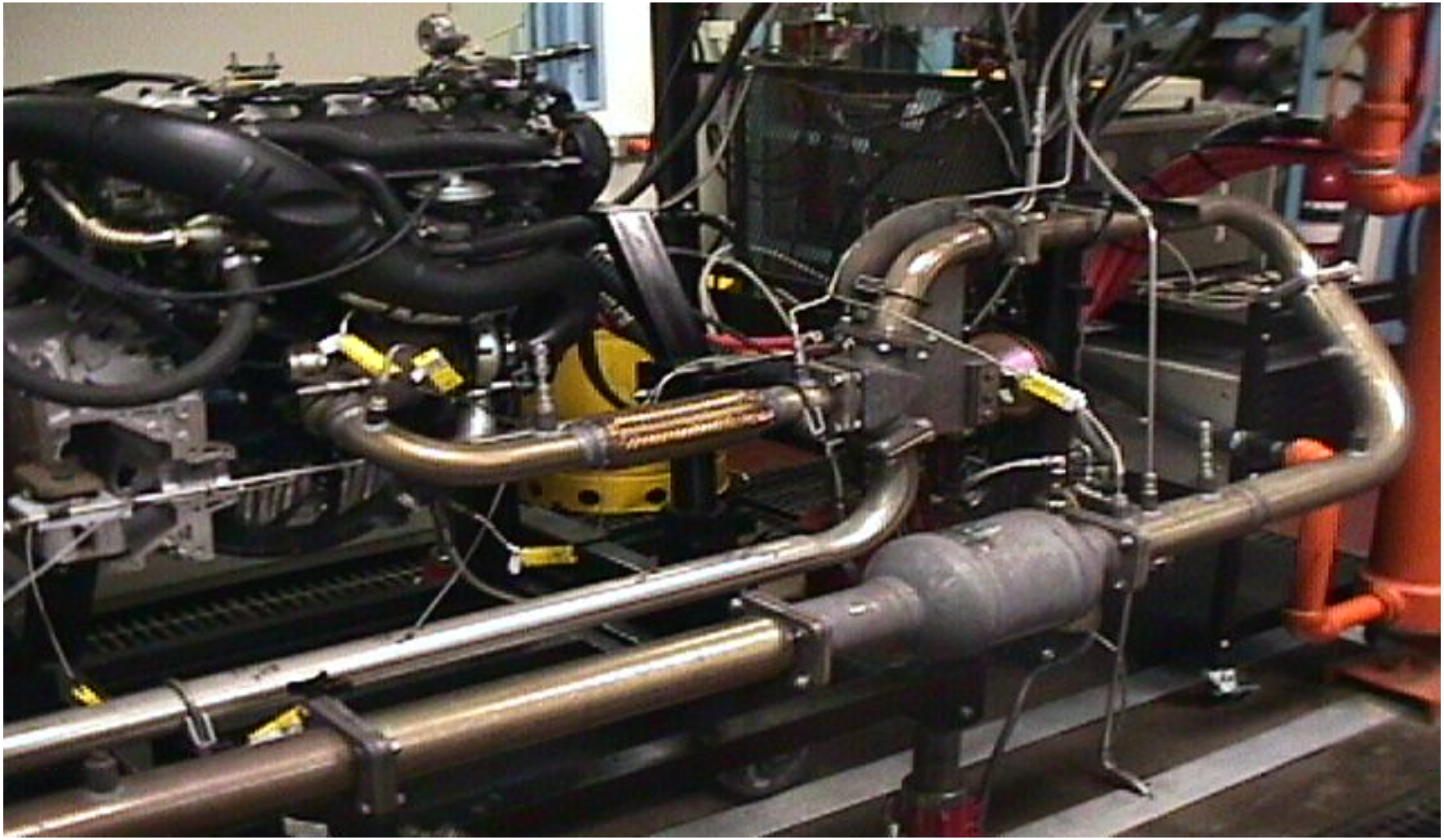
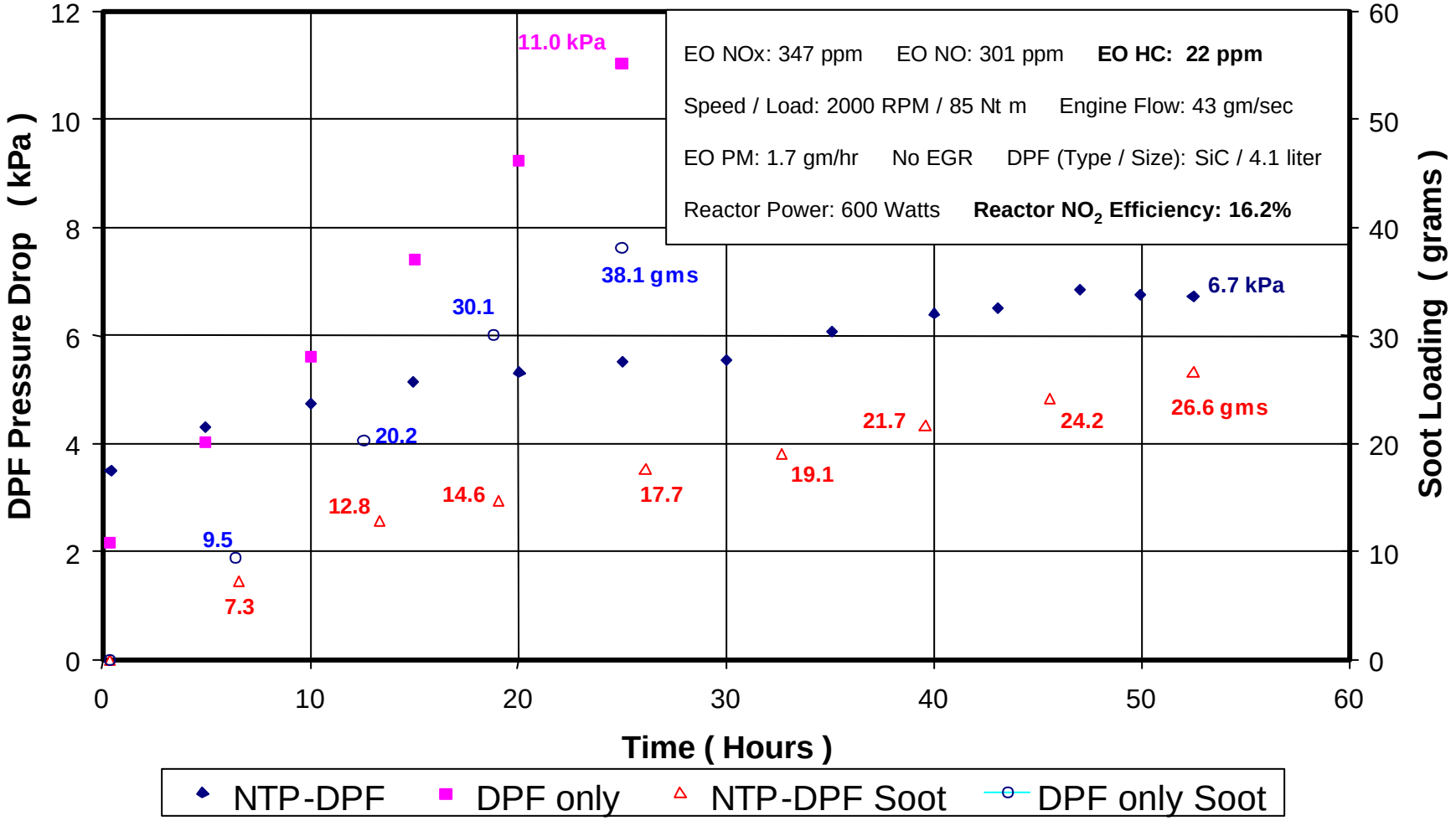


DPF Regeneration
305 C DPF Inlet Temperature



- Continuous regeneration occurs at 305 C with ~100 ppm NO_2 in exhaust
- DPF backpressure and soot loading reduced with NTP compared to DPF only

DPF Regeneration Summary

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- NTP reactor reduces exhaust PM mass 20% to 30%
- Continuous regeneration of a non-catalyzed DPF was demonstrated with the NTP reactor
- Three-way interaction exists between:
  - Soot loading
  - DPF inlet temperature
  - NO_2 concentration

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Conclusions

- NTP Reactor & Power Supply performance is acceptable
  - Potential to reduce power consumption with short pulse power supply
- NTP assisted catalysis has low NOx performance over transient MVEG emission cycle
  - Catalysts tested are too selective for the hydrocarbon species present in the exhaust
  - NOx adsorption and desorption is a major challenge
  - Catalyst durability and performance requires much more development resources
- NTP has the potential to enable continuous regeneration of a non-catalyzed DPF, given the proper levels of temperature, soot loading, and NO_2