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

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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 Al_2O_3 (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

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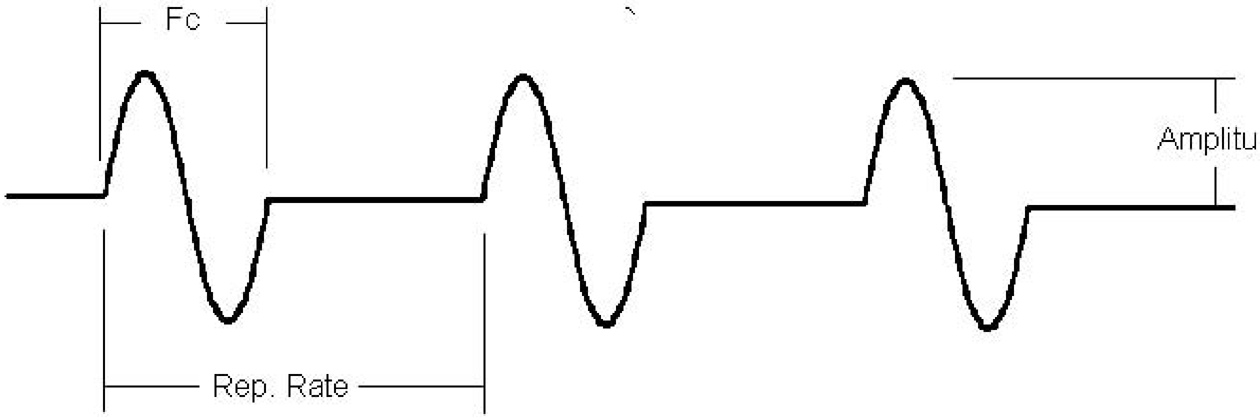
- Pulse density modulation power control
  - Fixed Amplitude (6kV peak)
  - Automatic resonant frequency control (Fc » 15 – 20 kHz)
  - Variable repetition rate based on speed/load

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



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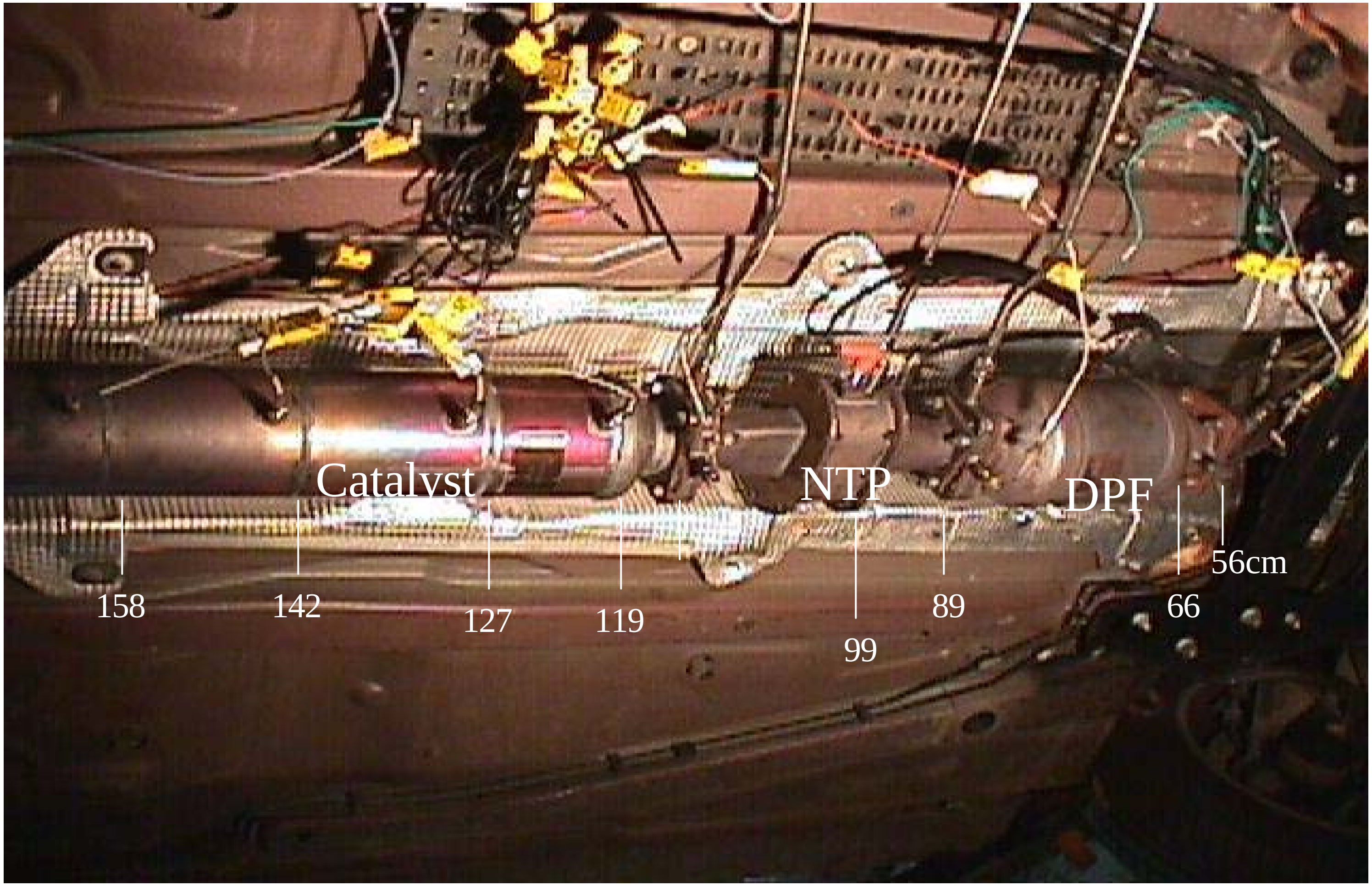
Vehicle Exhaust Configuration



NTP Reactor Efficiency
MVEG Cycle

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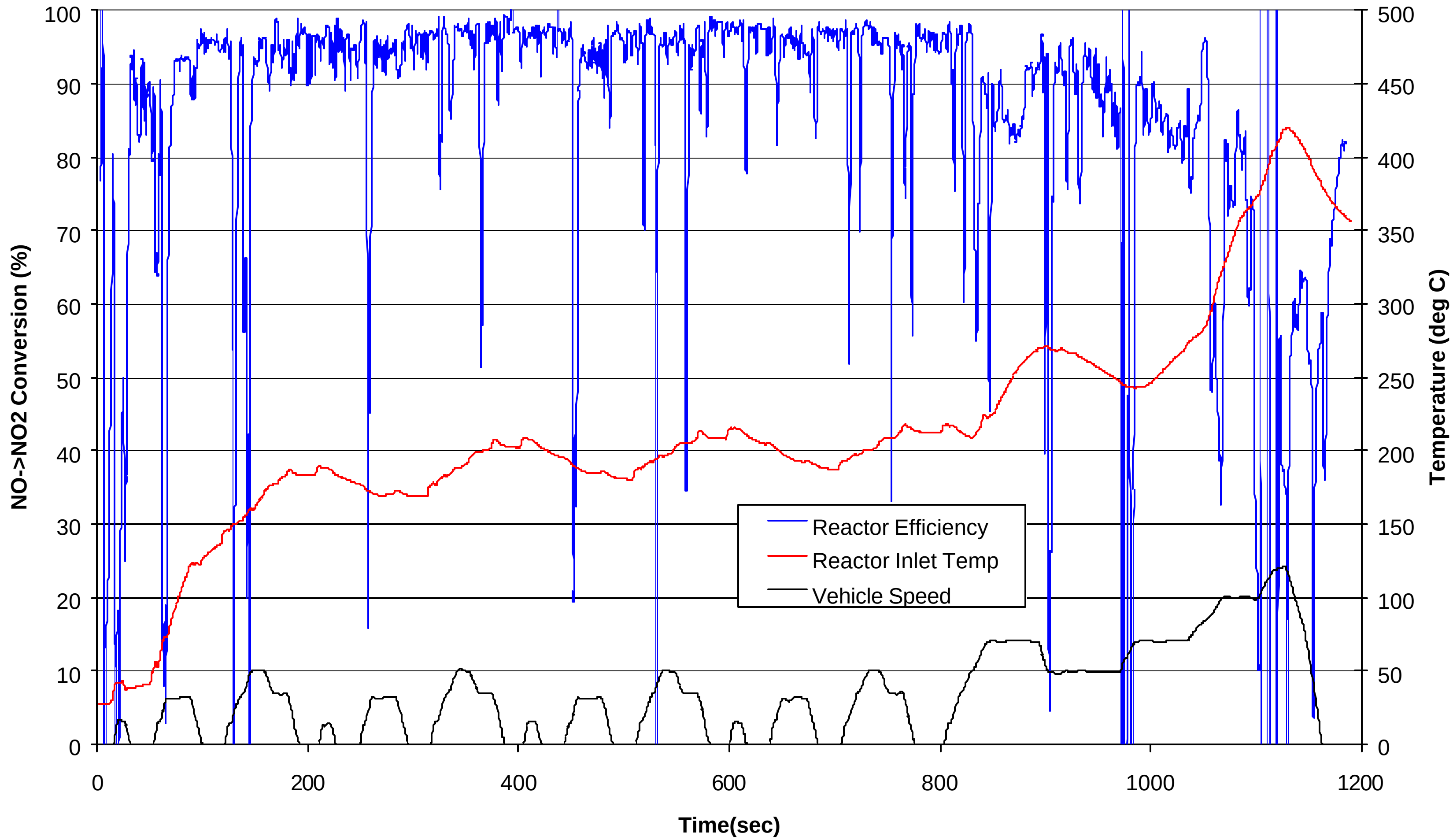
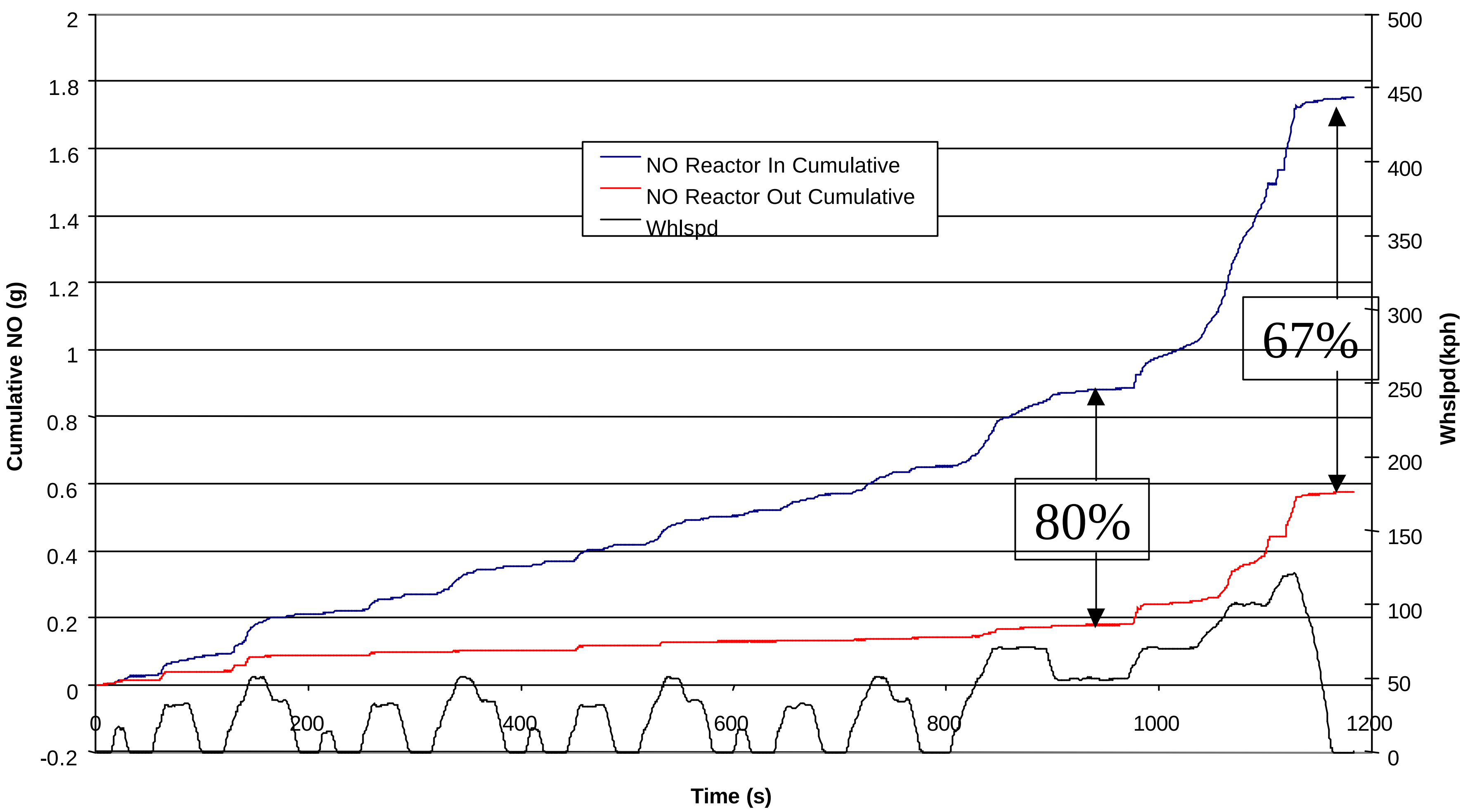


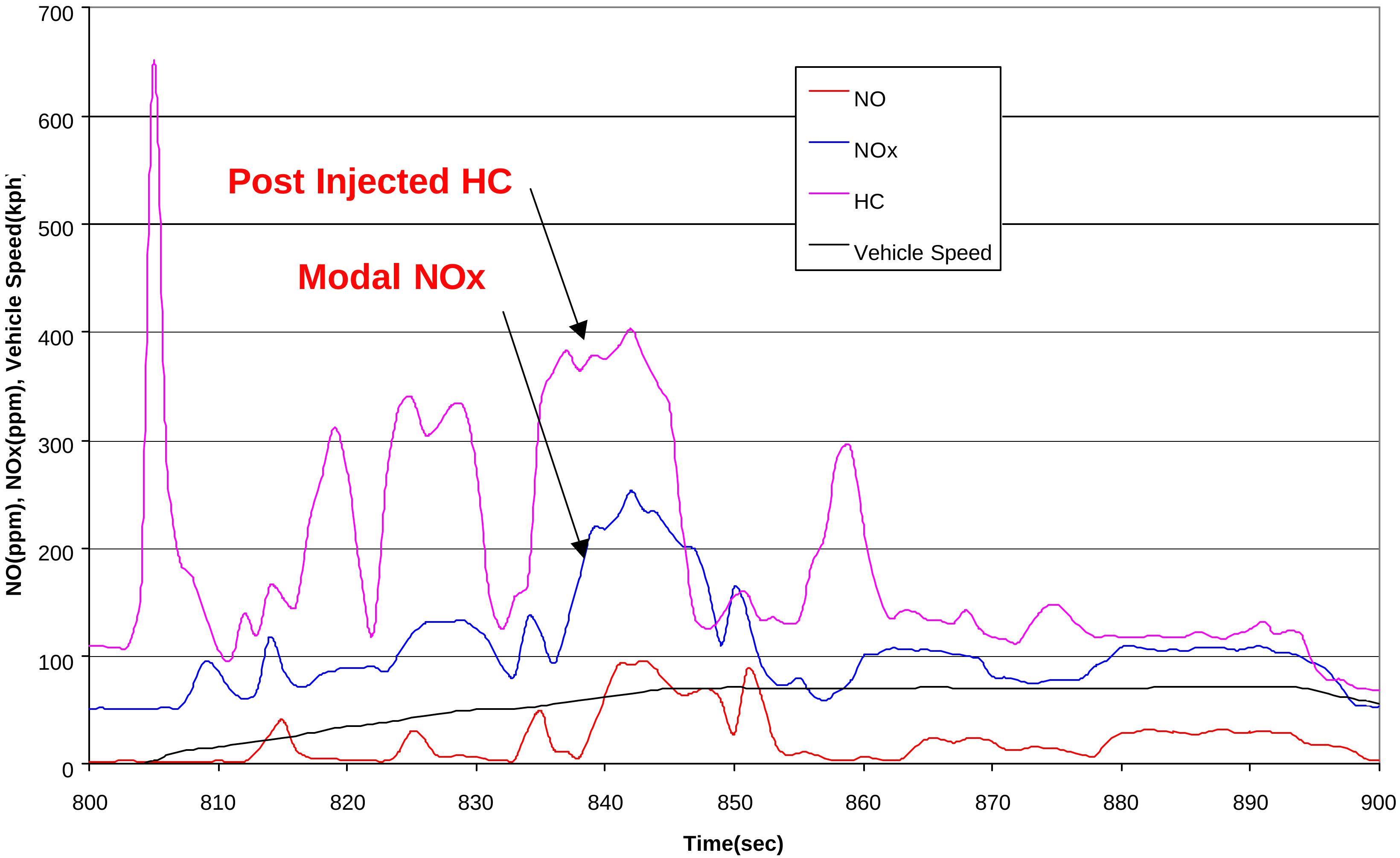
- NO to NO_2 conversion > 90% over ECE

Net NTP Reactor
NO Conversion Efficiency



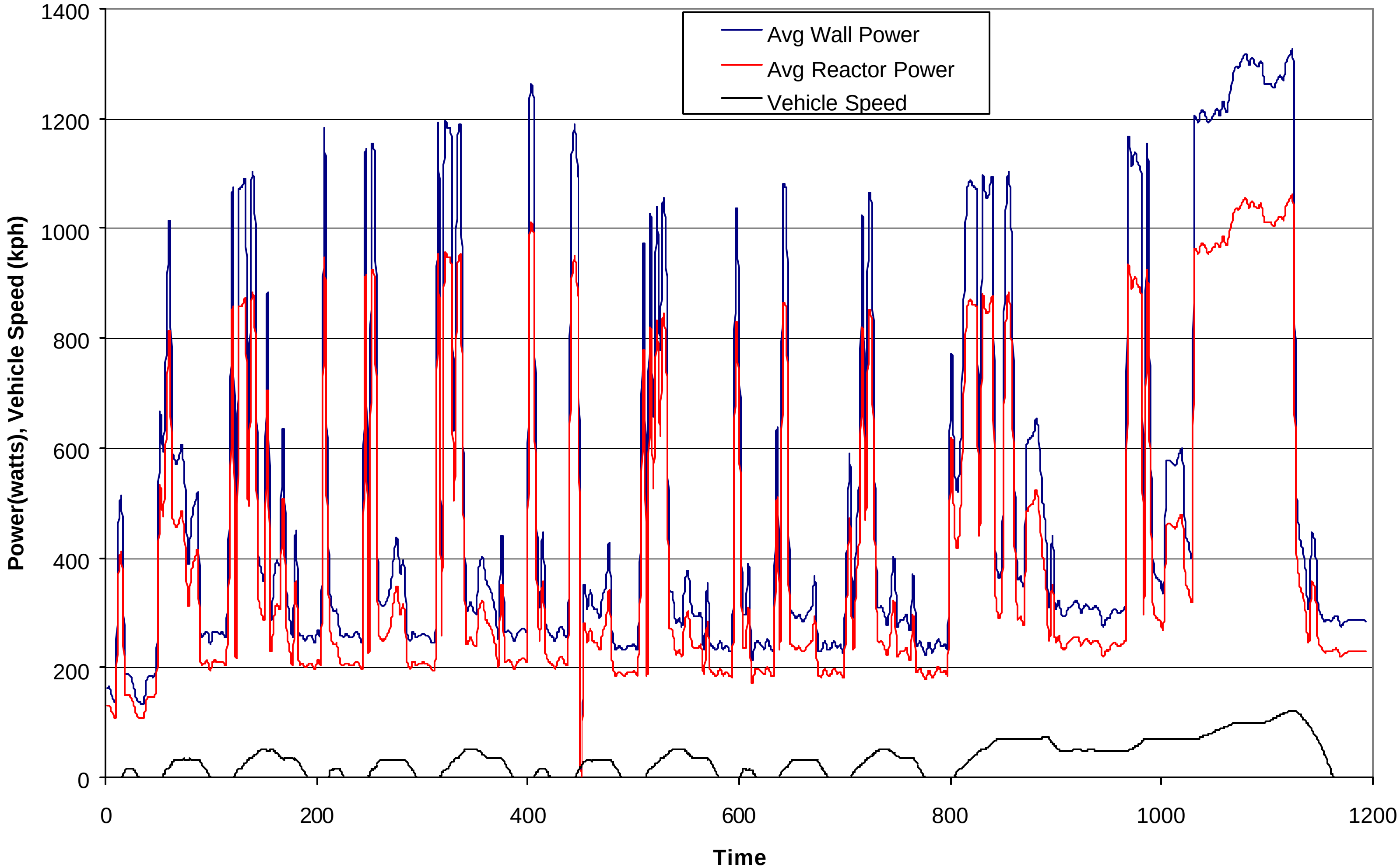
- 80% cumulative NO to NO2 conversion up to mid EUDC
- 67% cumulative NO to NO2 overall

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 %

NTP Assisted Catalysis
NOx Performance

NOx Concentration ECE

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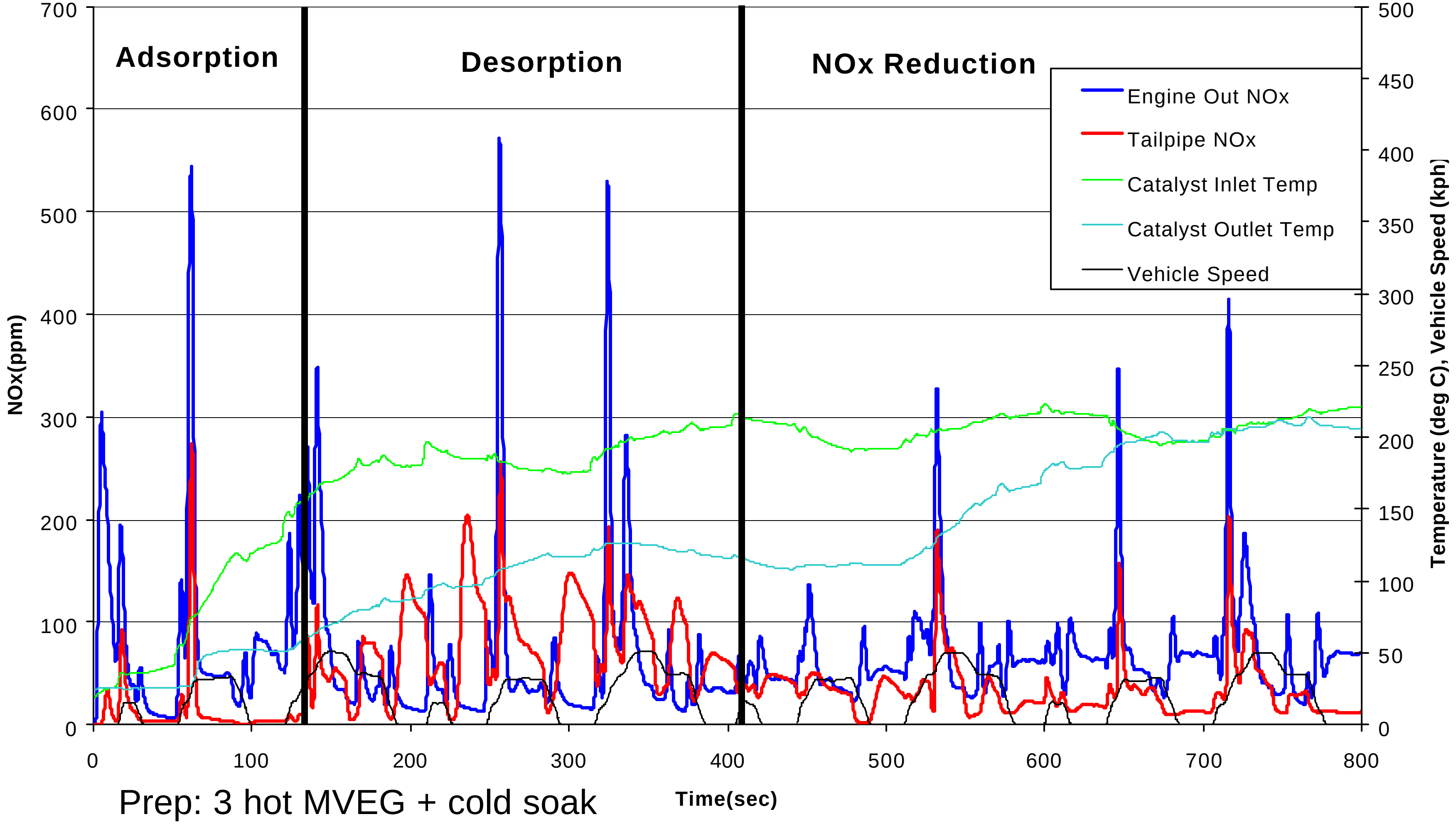
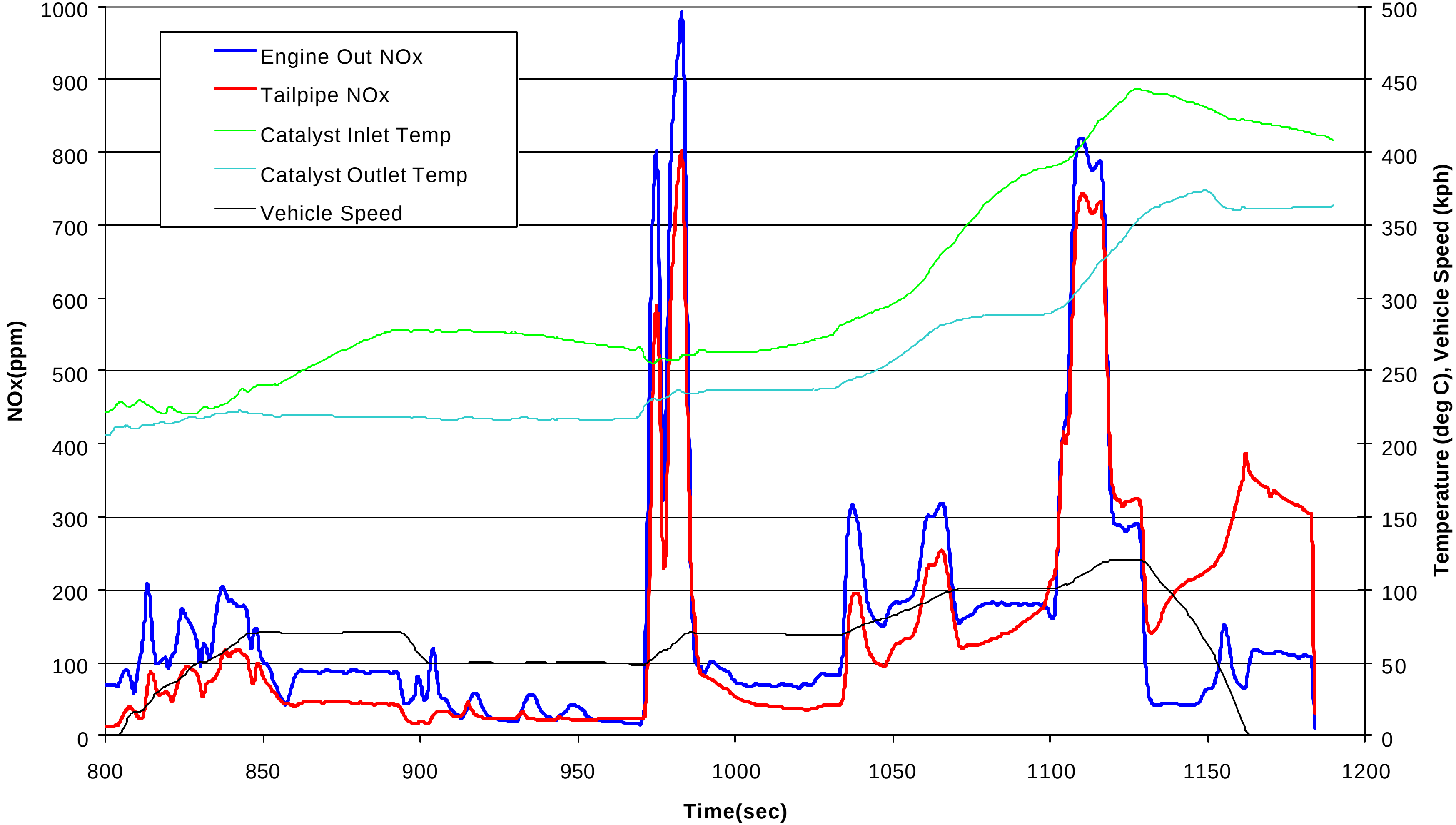


Prep: 3 hot MVEG + cold soak

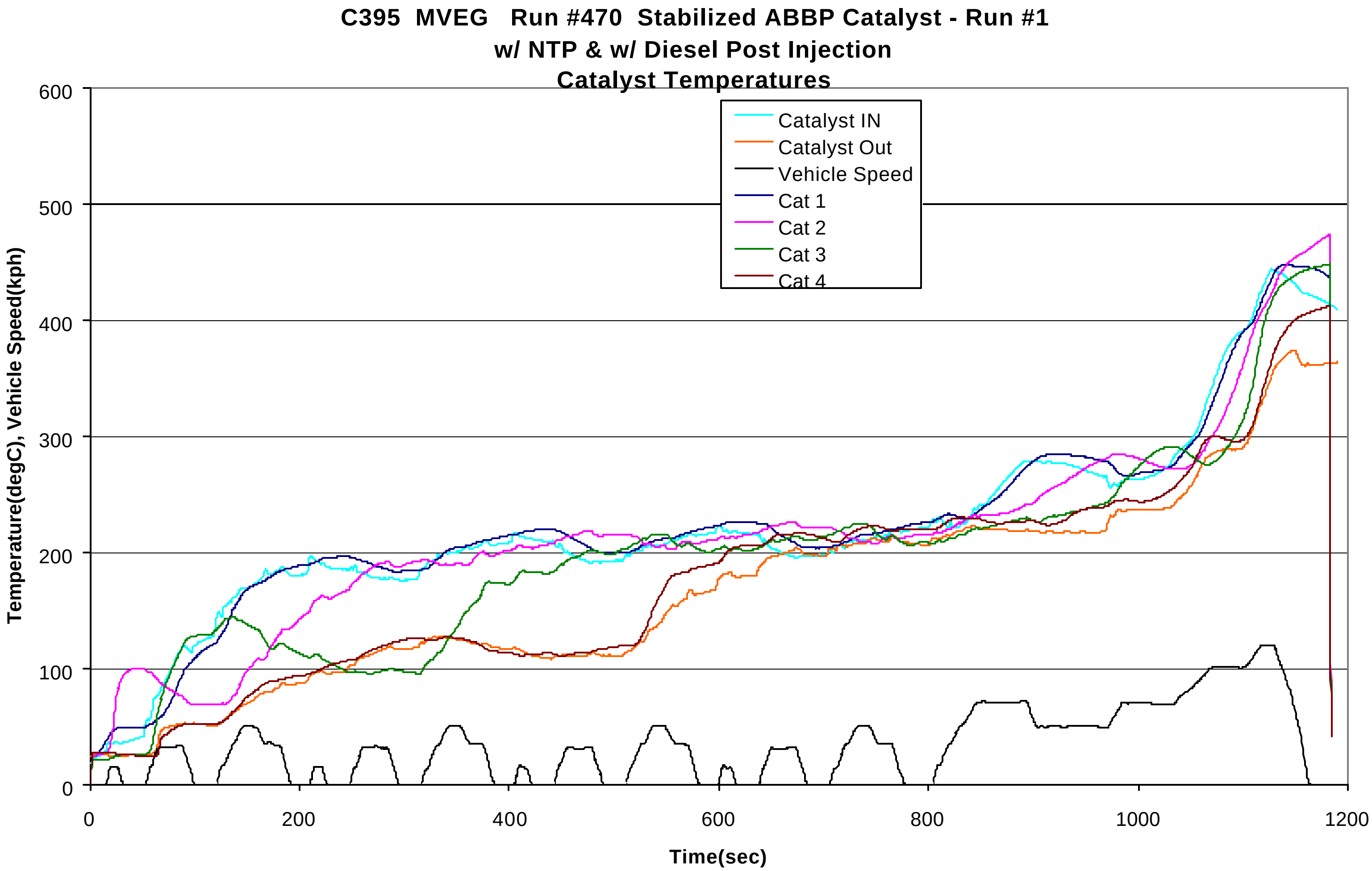
- NOx adsorption, desorption, and then reduction through ECE cycle

NOx Concentration EUDC



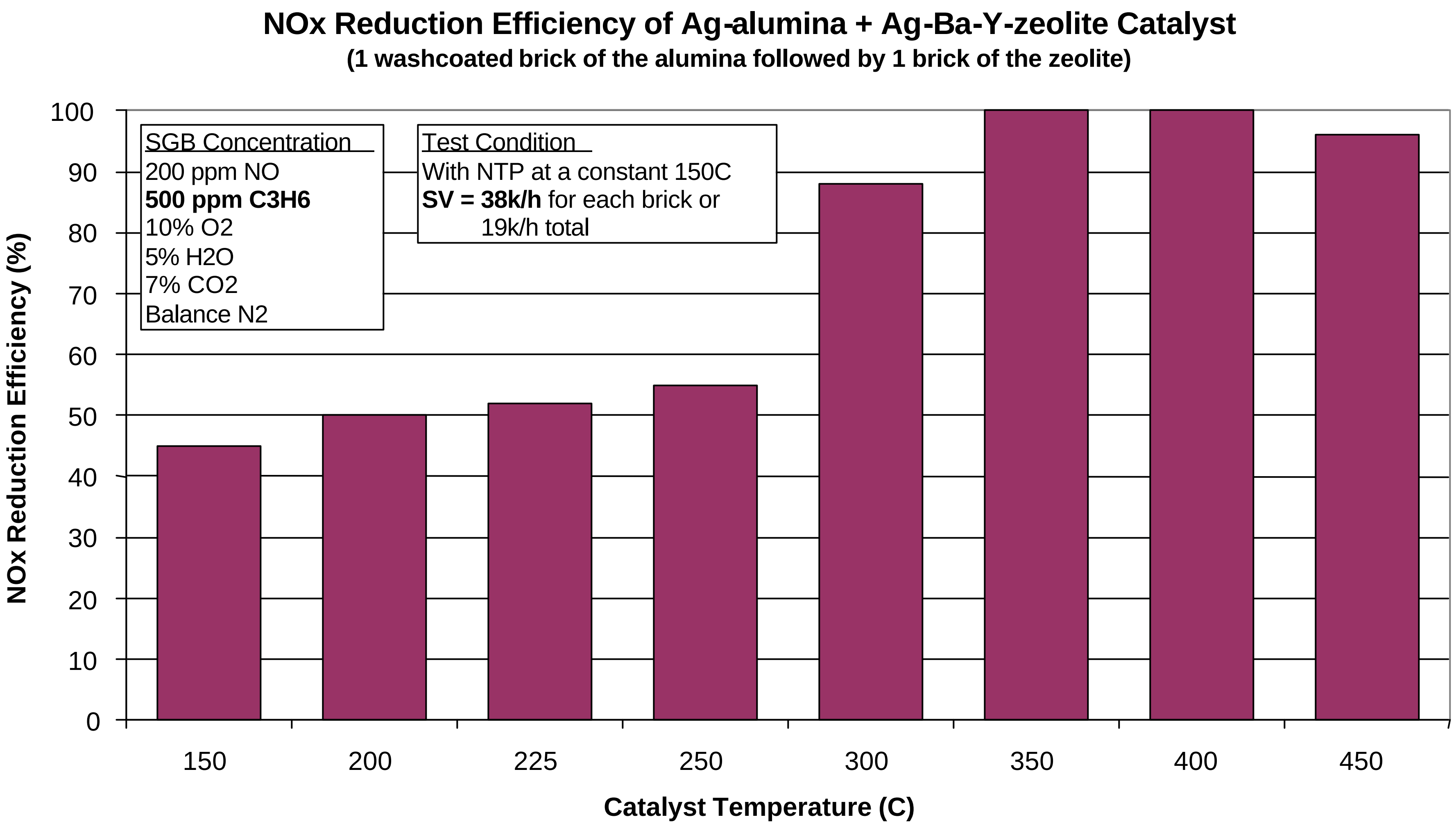
- Low NOx efficiencies during high speed portion of EUDC
- Large NOx desorption during final deceleration

Catalyst Bed Temperatures



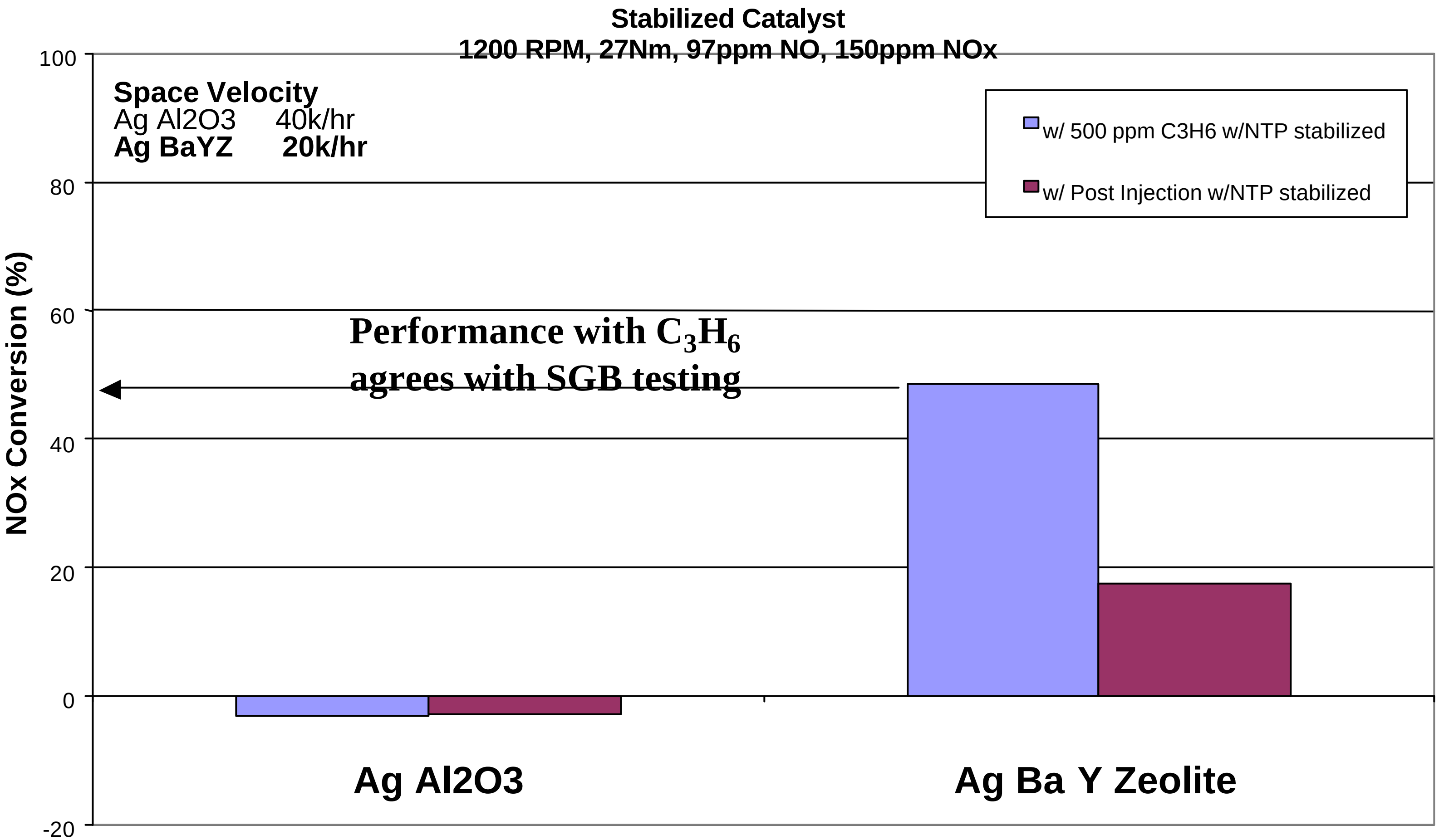
- Catalyst bed temperatures stay below 300° C until last 100 s of MVEG
- Emphasizes the performance of the low temperature zeolite catalyst

Synthetic Gas Bench (SGB) Catalyst Performance



- 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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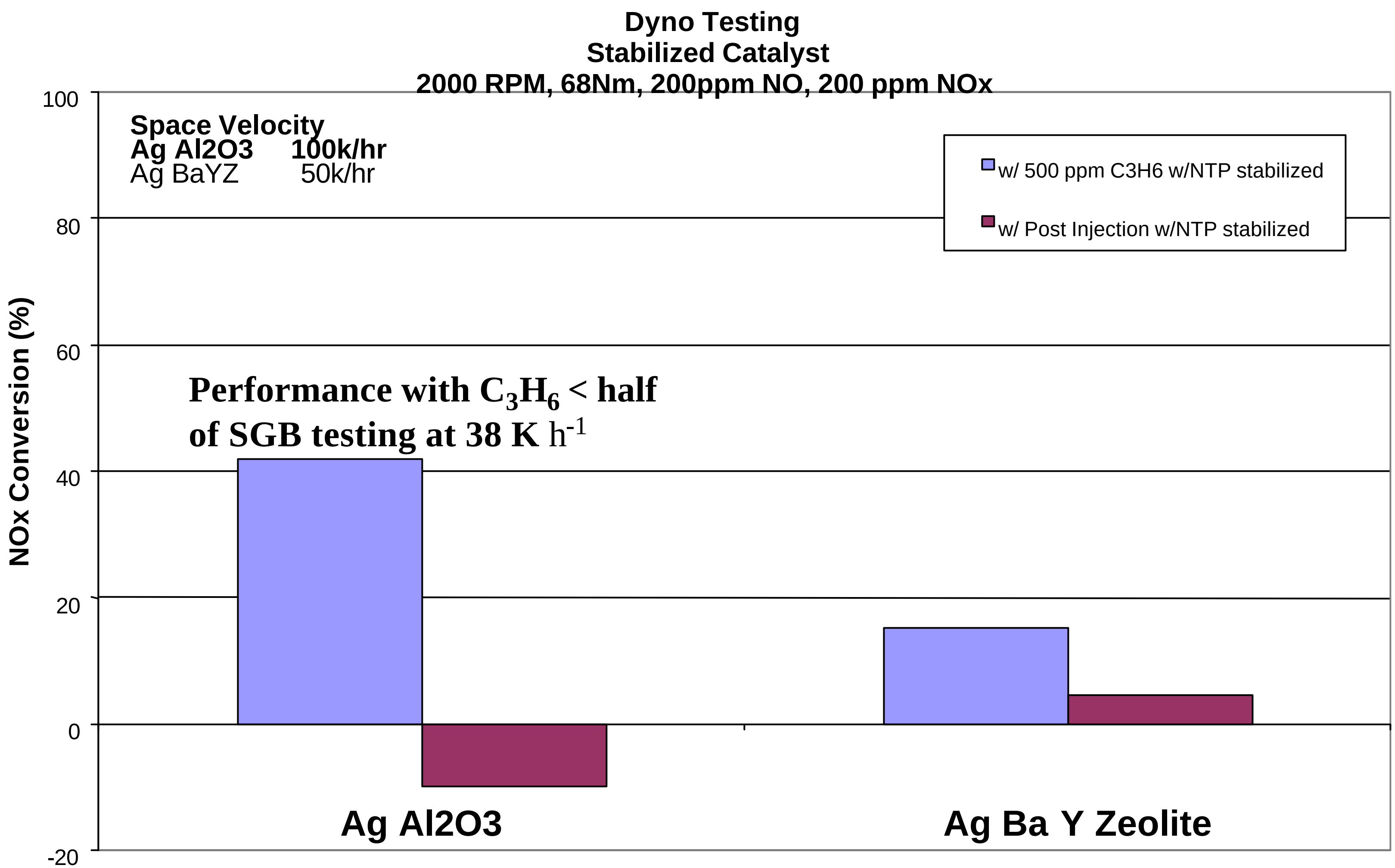
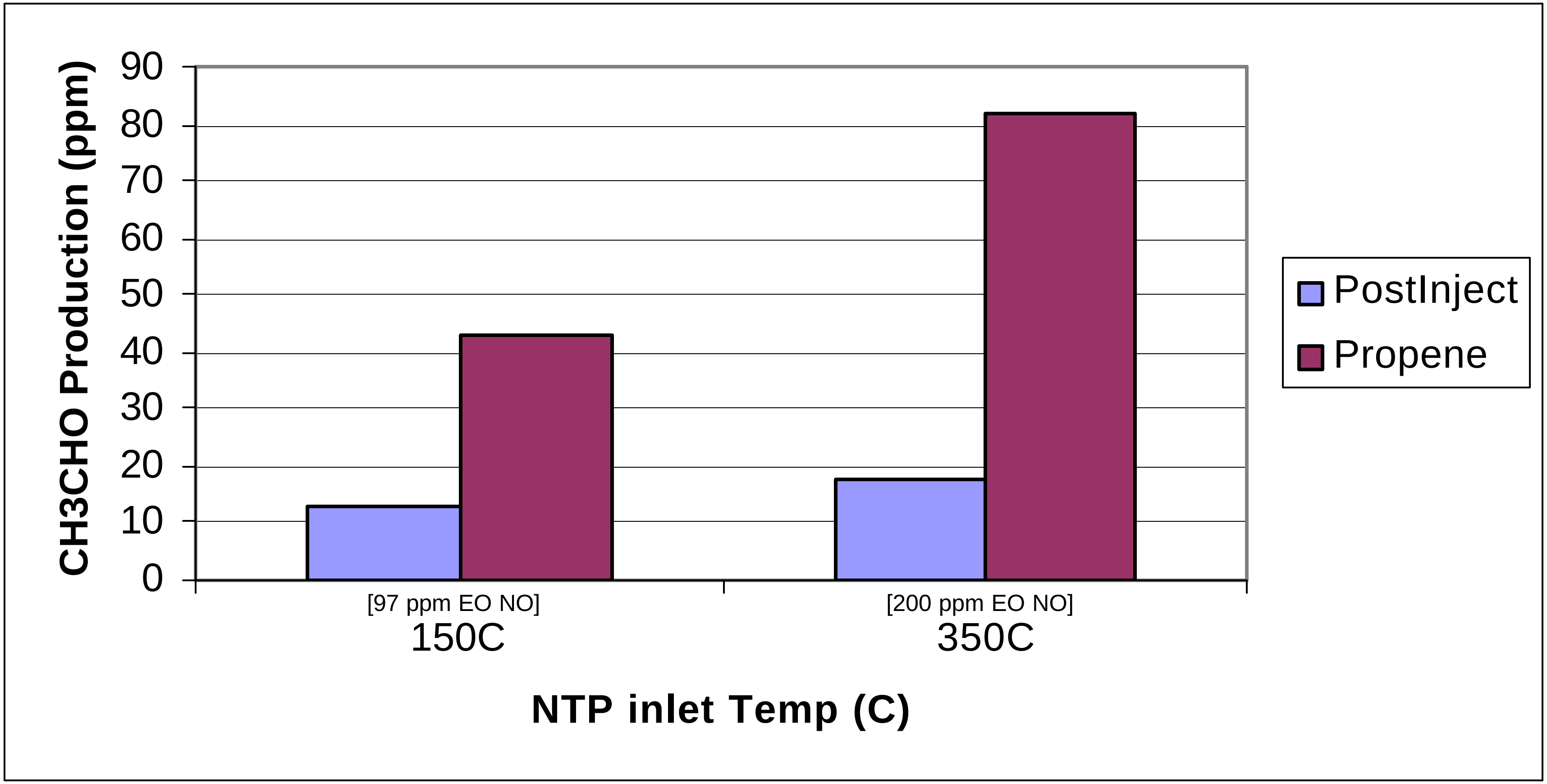


- With HC from post-injection, negative NOx conversion
- NOx conversion @ 100 K h^{-1} SV expected to be less than SGB data @ 38 K h^{-1}

NTPR Acetaldehyde Production
Engine Dyno Steady State

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

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

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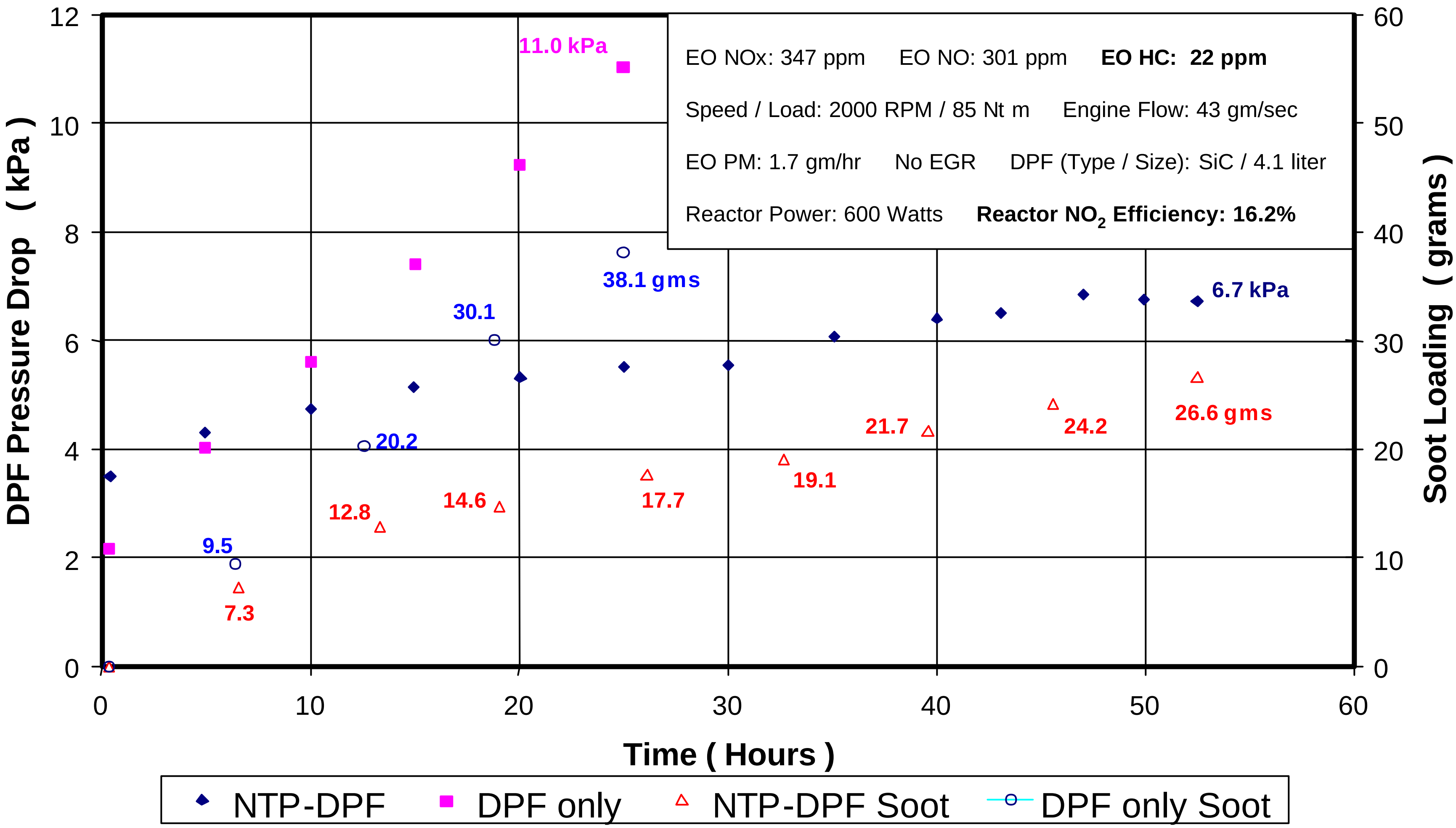

- Continuous regeneration occurs at 305 C with ~100 ppm NO_2 in exhaust
- DPF backpressure and soot loading reduced with NTP compared to DPF only

DPF Regeneration Summary

- 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

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