Delphi On-board Ammonia Generation (OAG)

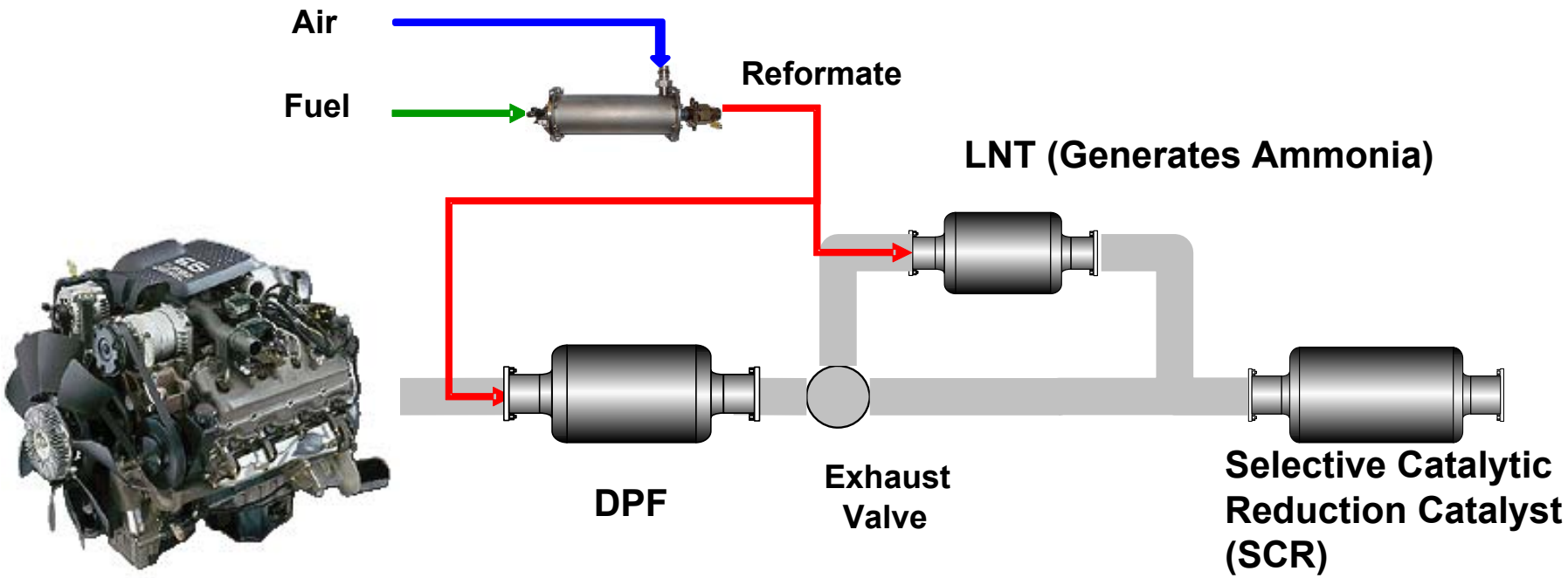
- Design targets
- Delphi OAG Based Exhaust System
- OAG Operating Principle
- Test Set-up
- System Optimization
- Engine Dyno. Testing w/ Delphi Diesel Fuel Reformer (DFR)
- Future Work
- Summary

Design Targets

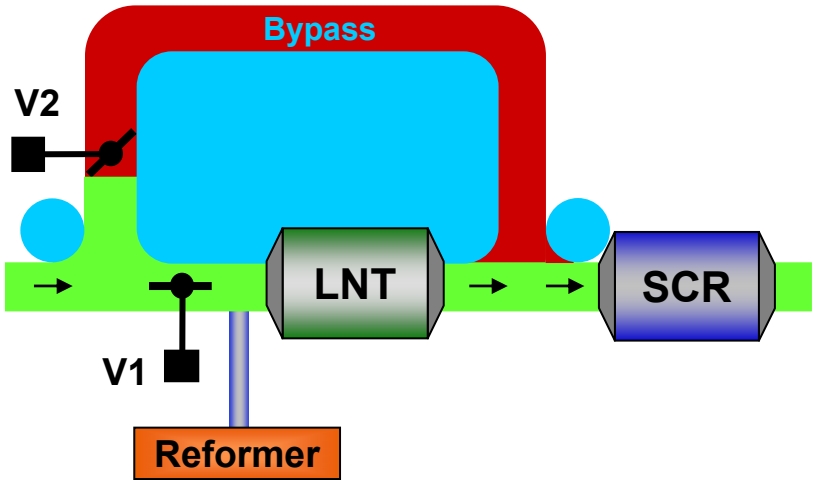
- High NOx conversion
- Wide operating temperature & flow windows
- Low fuel economy impact
- Minimize costs
  - simple
  - minimize use of PGM
- Minimize impact to engine
  - No post injection
  - No throttling
  - Minimal EGR
- No additional fluids
- LD to HD emission applicability
- Low sulfur sensitivity

Diesel LD & HD
Euro VI / US Tier 2 Bin 5 / US 2010

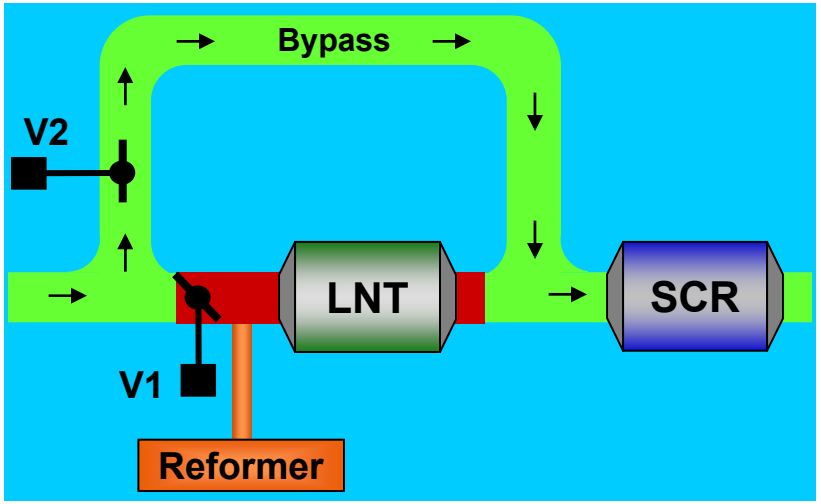
(On-board Ammonia Generation)



Operating Principle



- NOx storage
- **NO_x is stored on the LNT**
- **Breakthough NOx is converted by the SCR**



- Regeneration
- **Exhaust gas is bypassed around the LNT**
- **Reformat is injected into the LNT**
- **Stored NOx in the LNT is converted to NH_3**
- **NO_x in the exhaust is reduced by the SCR**

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Application

- 6.6L GM Duramax
  - 68 - 200+ gms/sec exhaust flow
  - Temperature range from 225 to 485^{o} C
  - ~2.7 g/kWh NOx
  - 7.5L LNT, 120 gms/ft^{3} Trimetal, aged 16 hrs 700^{o} C in steam
  - Bottled Reformate

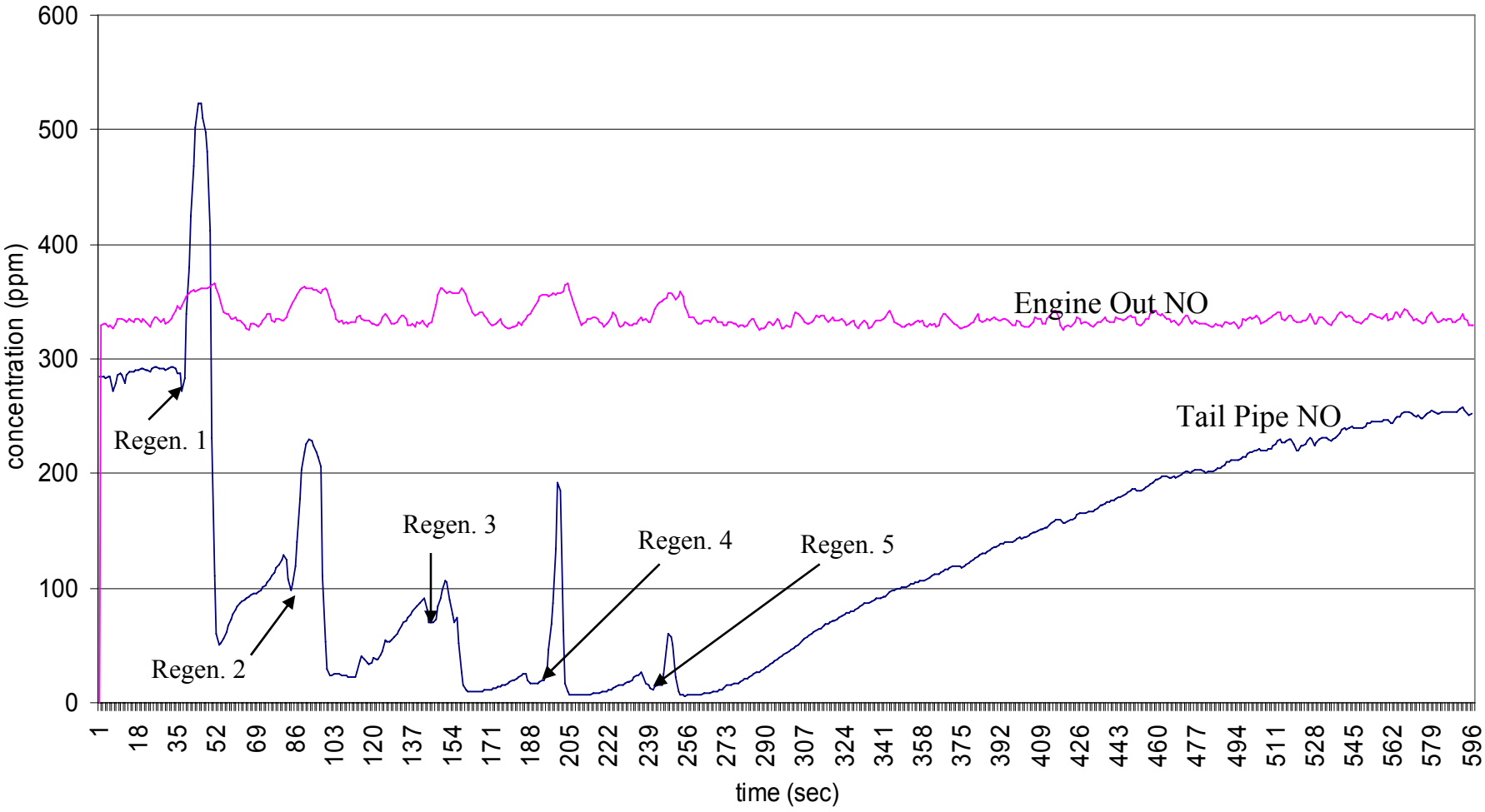
Optimization Goals

- Maximize NOx conversion efficiency
  - Wide temperature range
  - Wide flow range
- Minimize reformate volume
  - Lower cost reformer system
  - Minimal fuel economy impact
- Maximize SCR volume over LNT for lower costs

Test Procedure: Concept Evaluation

- Use bottled reformate: 21% H_2, 24% CO, N_2 Balance
- Set engine flow: 2 fixed points:68 gms/sec & 110 gms/sec
- Begin regeneration after tailpipe NOx level stabilizes usually 350-650 ppm
  - switch 3-way valve for flow through the bypass
  - inject reformate
  - return 3-way valve for flow through the LNT
- Wait a specified time interval, then repeat regeneration

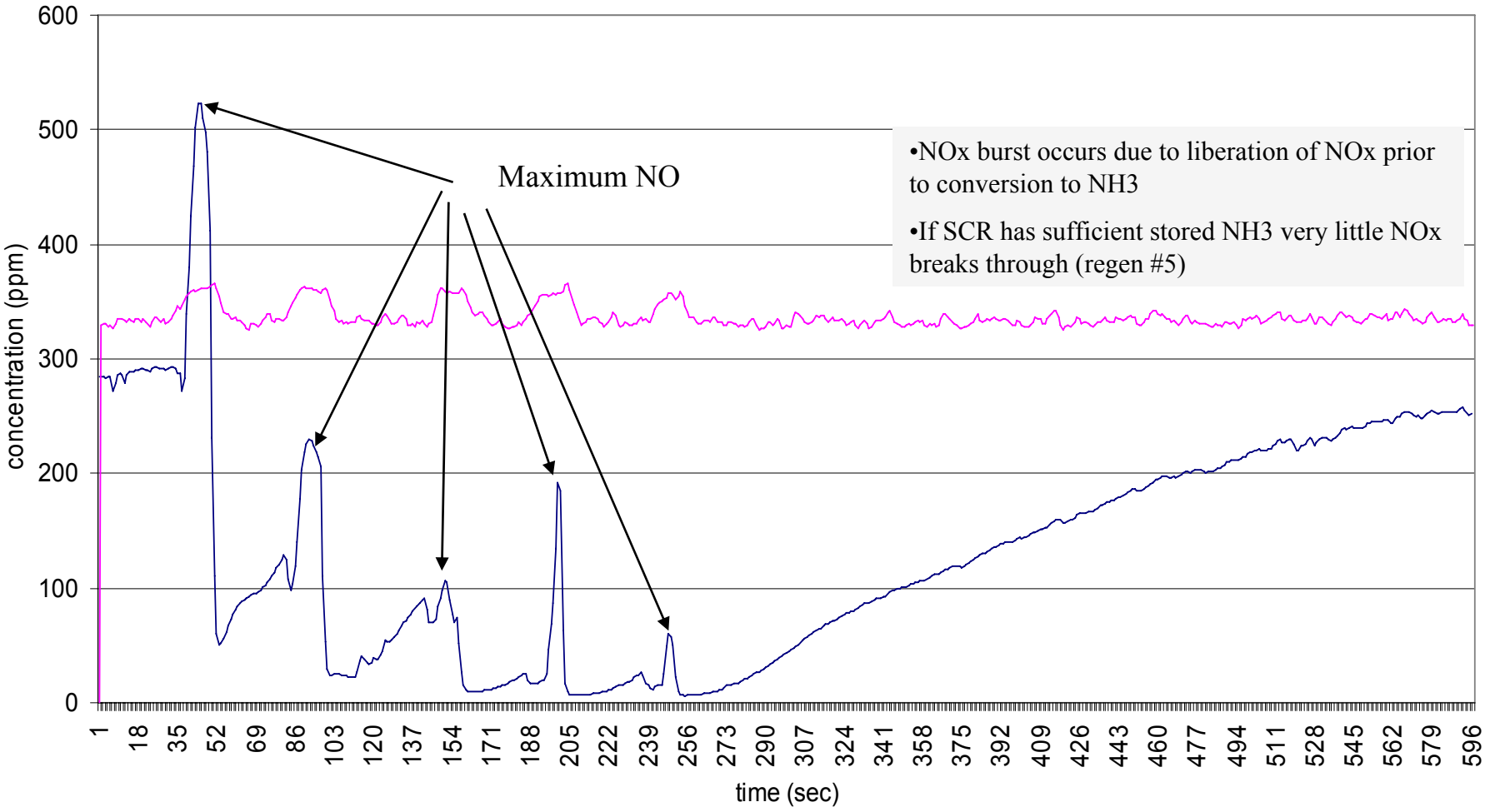
Initial Regeneration



Optimization Parameters

- Reformate delivery
  - Flow rate
  - Flow duration
  - Time between regenerations (period)

Minimal NOx during regeneration



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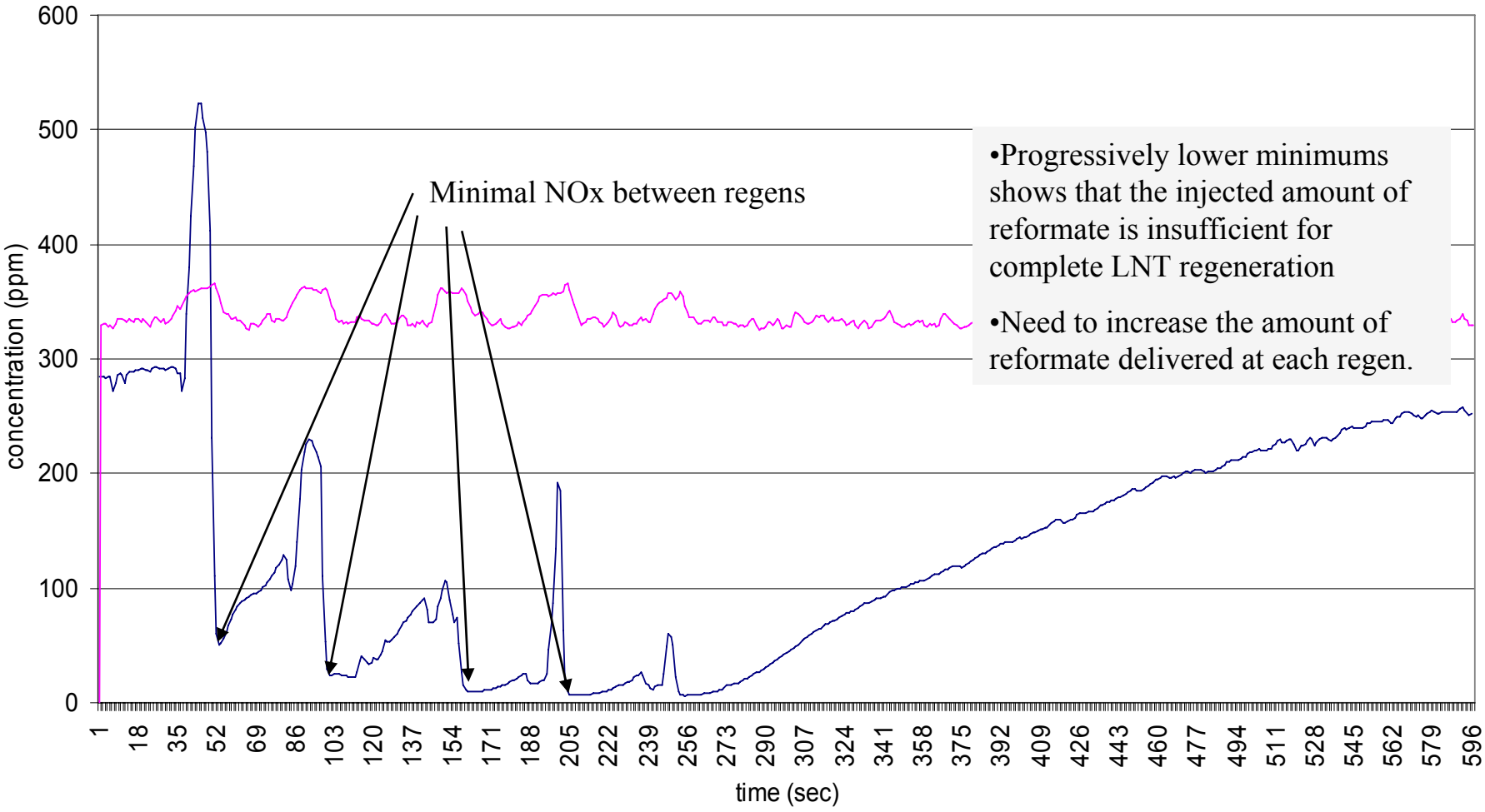
Minimal NOx between regenerations



- Progressively lower minimums shows that the injected amount of reformate is insufficient for complete LNT regeneration
- Need to increase the amount of reformate delivered at each regen.

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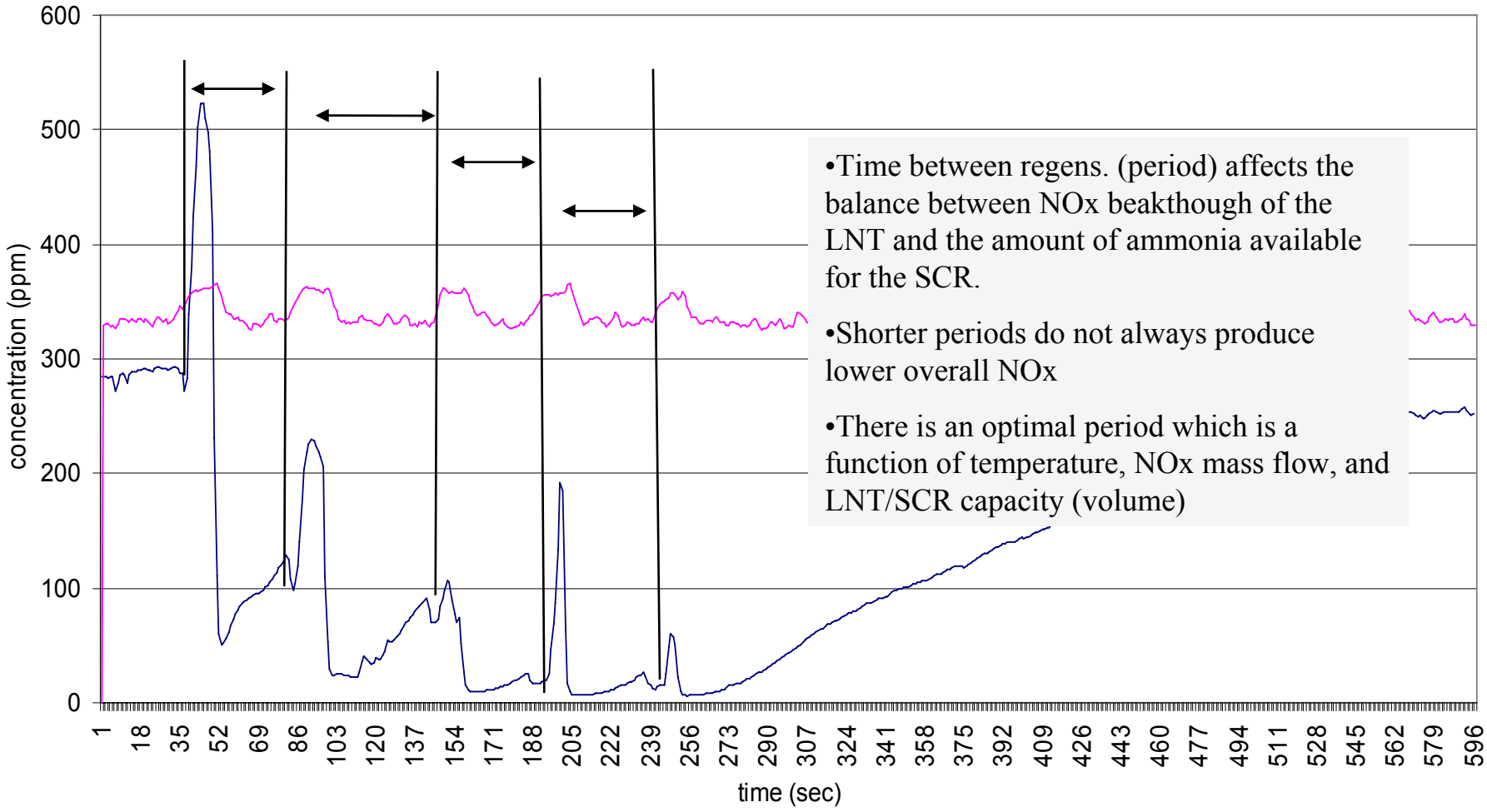
Period between regenerations



- Time between regens. (period) affects the balance between NOx beakthough of the LNT and the amount of ammonia available for the SCR.
- Shorter periods do not always produce lower overall NOx
- There is an optimal period which is a function of temperature, NOx mass flow, and LNT/SCR capacity (volume)

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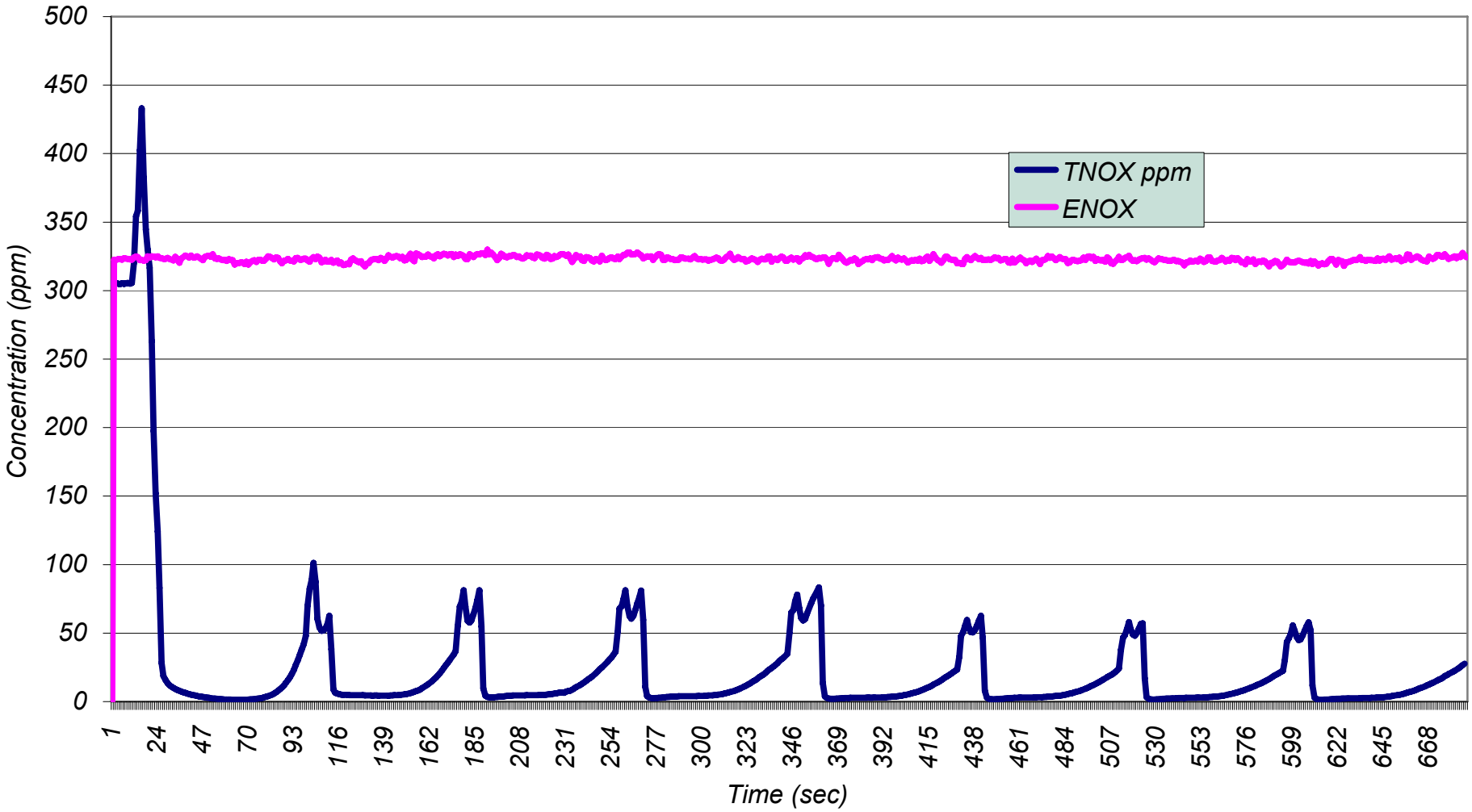
More optimized regeneration



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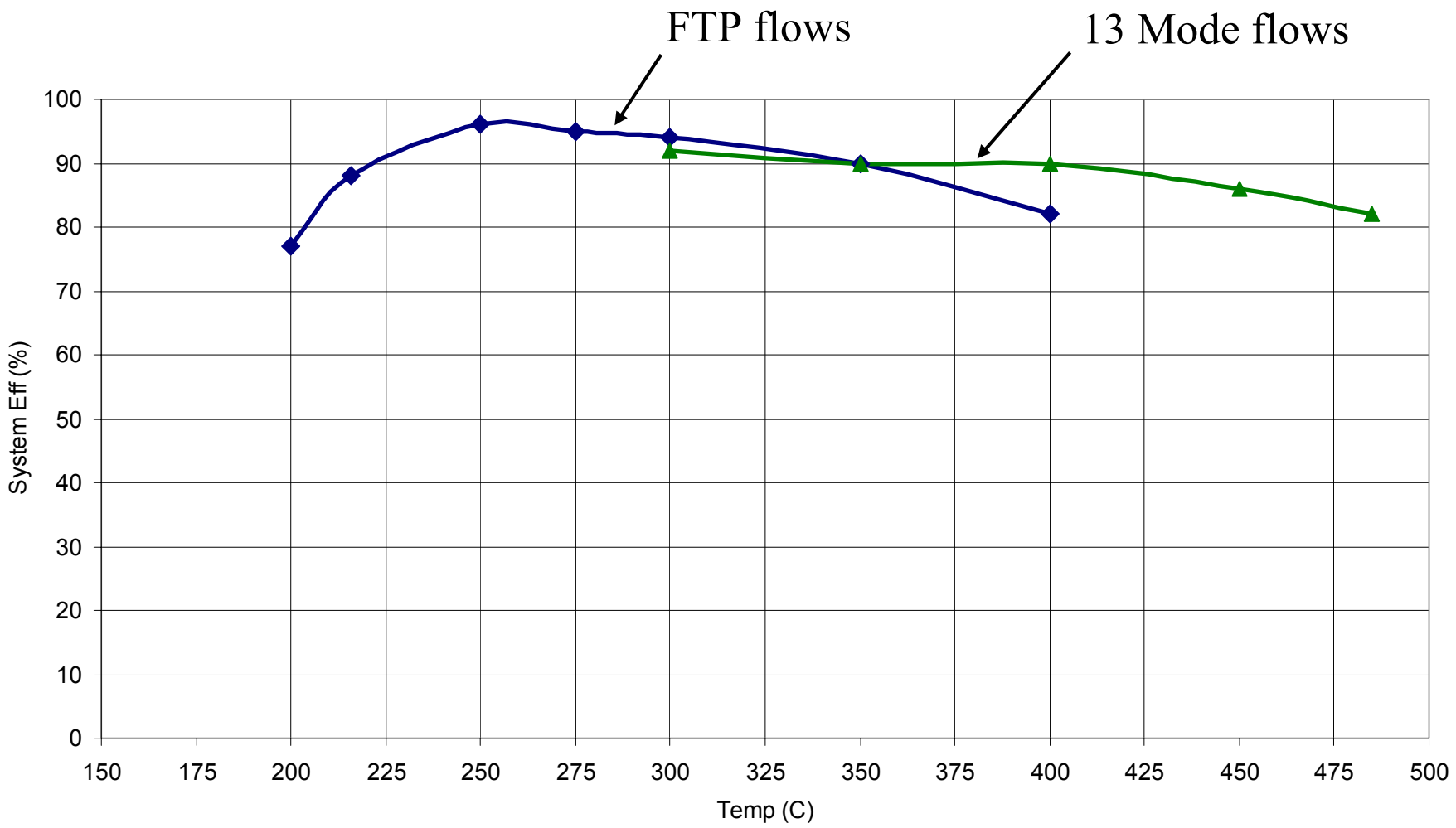
Steady-state System Performance



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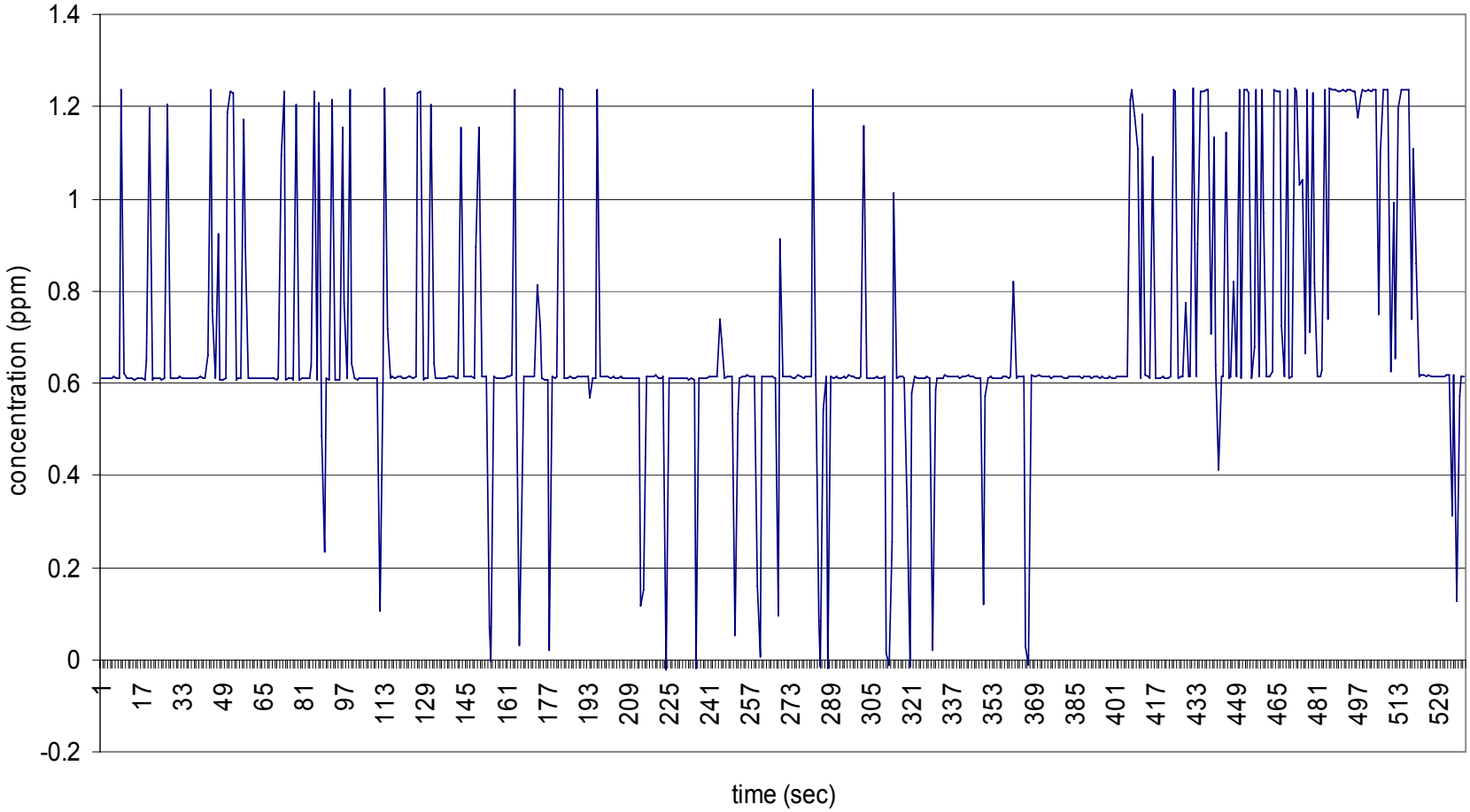
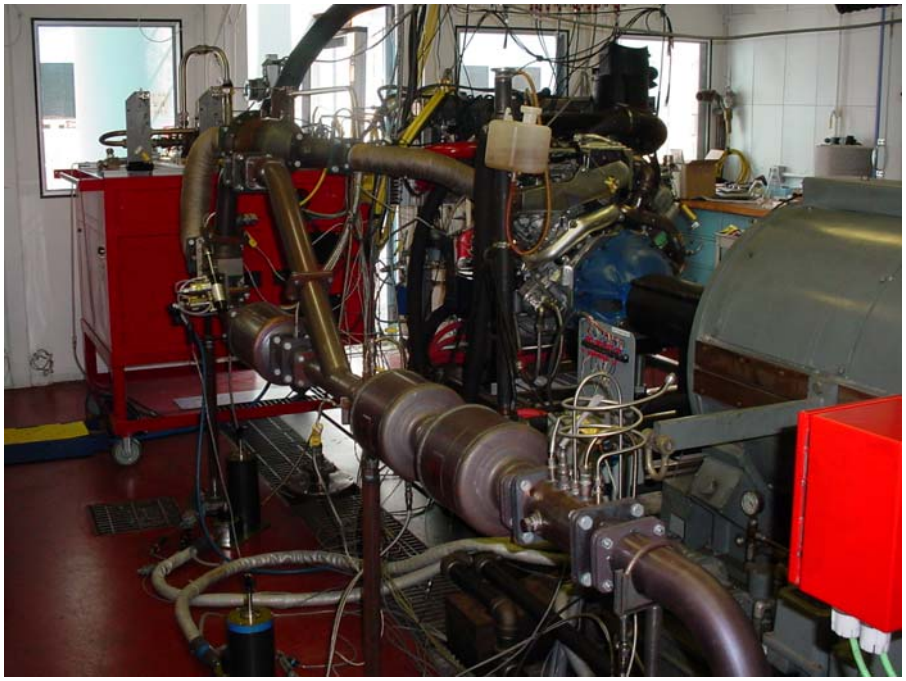
Ammonia Slip 7.5L LNT & SCR (350° C)



Delphi Diesel Fuel Reformer

- **Bottled Reformate testing gives a starting point to the Diesel Fuel Reformer (DFR) design performance specifications.**
  - **1 to 6 grams/second reformate flow (engine and application specific)**
  - **Operating in pulse mode up to 15 seconds burst at high flows above 2 g/s**
  - **Continuous operation below 1.8 g/s**
- **DFR is "off-line" so as to reduce fuel high fuel consumption rates for "in-exhaust" reforming.**
- **Allows for flexibility in injection points associated with Particulate Filter regeneration, LNT de-sulfurization, and enhanced cold starting emission performance.**

Delphi DFR Dynamometer Site



- **3 Emission Sampling System: Engine, intermediate, Tailpipe**
  - **HC, CO, NOx, O_2, CO_2**
  - **Tail Pipe N_2O**
- **DC Dynamometer**
  - **Steady States (13 Mode)**
  - **Dynamic (FTP)**

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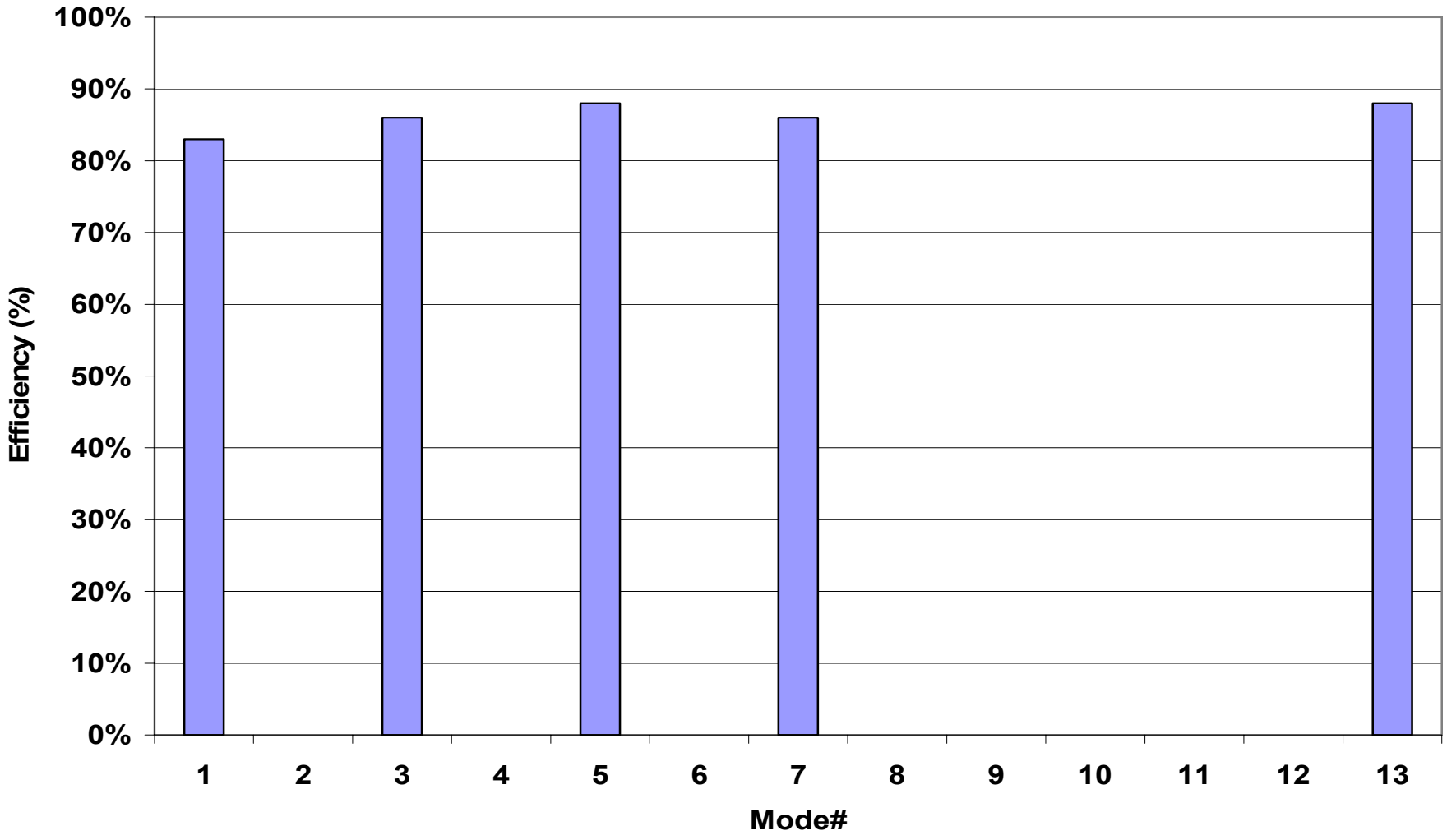
Preliminary NOx Reduction with Reformer: 13 Mode



Future Work

- **Complete initial 13 Mode Testing**
- **Optimize performance on 13 Mode**
  - **Better reformate scheduling**
  - **Balance between peak exhaust flow and SCR/LNT volumes**
- **HD FTP Testing**

Summary

- On-board ammonia generation gives high efficiencies over a wide range of test conditions
  - Temperature
  - Flows
  - De-sulfurization of LNT in the Delphi OAG can be done less frequently and with lower temperatures so as to minimize LNT degradation.
- The Delphi OAG system can also be used to regenerate a Diesel Particulate Filter (DPF) in a controlled manner so as to enable low cost cordierite use.
- Fuel economy loss is expected to be less than 4% including DPF regeneration.
- PGM costs are minimized
- Very little impact to the diesel engine operation
  - no throttling
  - no post injection
- Lower total exhaust system cost than Urea/SCR based system.

Delphi On-Board Ammonia Generation

- **Thank you for your attention**

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