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)

Air → Reformate → LNT (Generates Ammonia)
Fuel → DPF

Exhaust Valve → Selective Catalytic Reduction Catalyst (SCR)
### Operating Principle

<table>
<thead>
<tr>
<th>NOx storage</th>
<th>Regeneration</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx is stored on the LNT</td>
<td>Exhaust gas is bypassed around the LNT</td>
</tr>
<tr>
<td>Breakthrough NOx is converted by the SCR</td>
<td>Reformat is injected into the LNT</td>
</tr>
<tr>
<td></td>
<td>Stored NOx in the LNT is converted to NH₃</td>
</tr>
<tr>
<td></td>
<td>NOx in the exhaust is reduced by the SCR</td>
</tr>
</tbody>
</table>
Application

- 6.6L GM Duramax
  - 68 - 200+ gms/sec exhaust flow
  - Temperature range from 225 to 485° C
  - ~2.7 g/kWh NOx
  - 7.5L LNT, 120 gms/ft³ Trimetal, aged 16 hrs 700° 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% H₂, 24% CO, N₂ 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
Optimization Parameters

- Reformate delivery
  - Flow rate
  - Flow duration
  - Time between regenerations (period)
Minimal NOx during regeneration

• NOx burst occurs due to liberation of NOx prior to conversion to NH3
• If SCR has sufficient stored NH3 very little NOx breaks through (regen #5)
Minimal NOx between regenerations

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

• Time between regens. (period) affects the balance between NOx breakthrough 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)
More optimized regeneration

![Graph showing concentration over time with TNOX ppm and ENOX lines.](image-url)
Steady-state System Performance

FTP flows

13 Mode flows

System Eff (%) vs Temp (C)

DEER 24AU06 MDH
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, O₂, CO₂
  - Tail Pipe N₂O
- **DC Dynamometer**
  - Steady States (13 Mode)
  - Dynamic (FTP)
Preliminary NOx Reduction with Reformer: 13 Mode

Efficiency (%) vs. 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