Ammonia Sensor For SCR NOX Reduction

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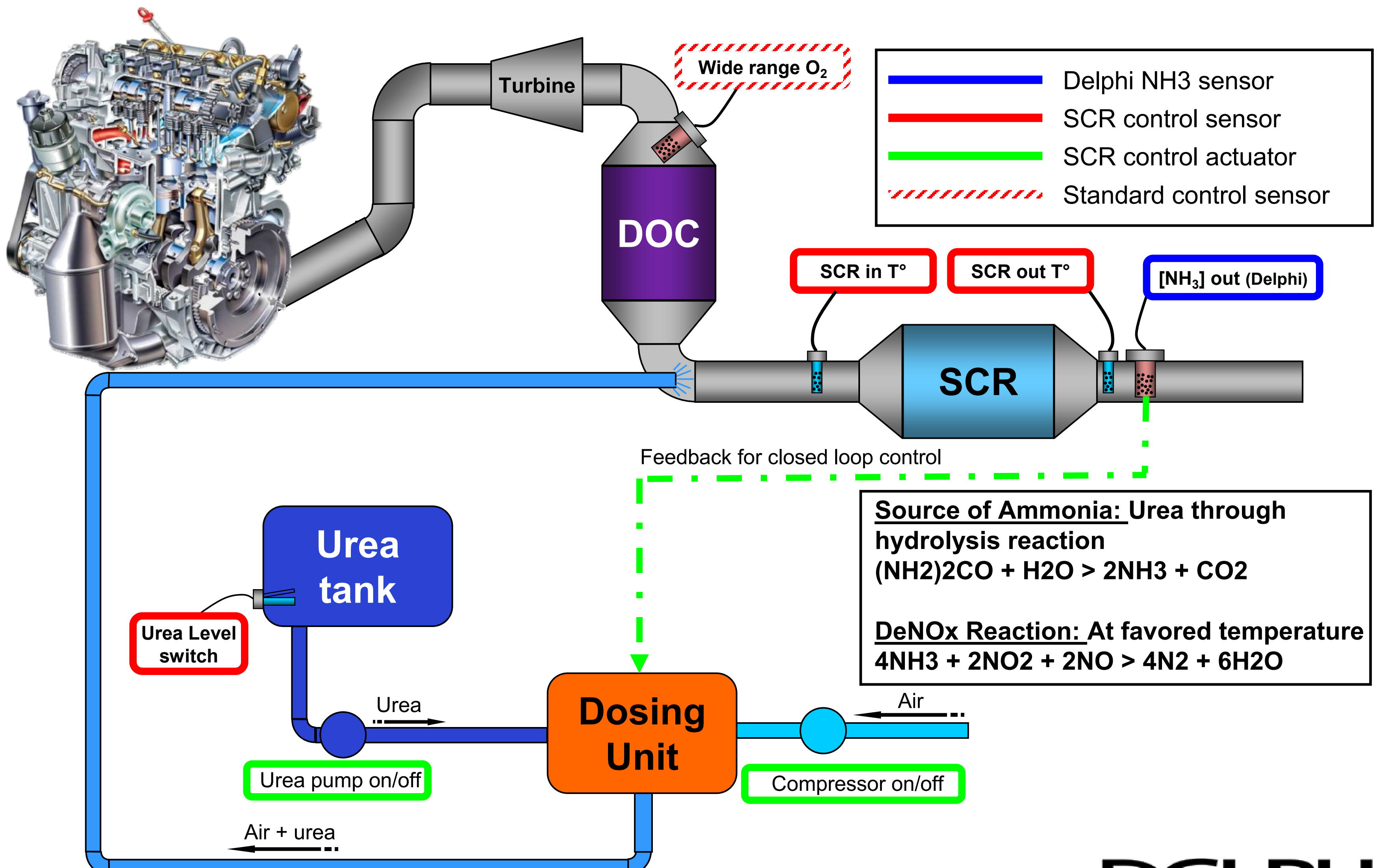
Agenda

- NH_3 Sensor Usage in SCR system
- Overview NH_3 Sensing Technologies
- Functionality of NH_3 Sensor
- NH_3 Sensor Design
- Test Results
  - Cross Sensitivity
  - Test results
- Close Loop Control of the SCR System with a NH_3 Sensor - System Advantages
- Summary

Diesel SCR System



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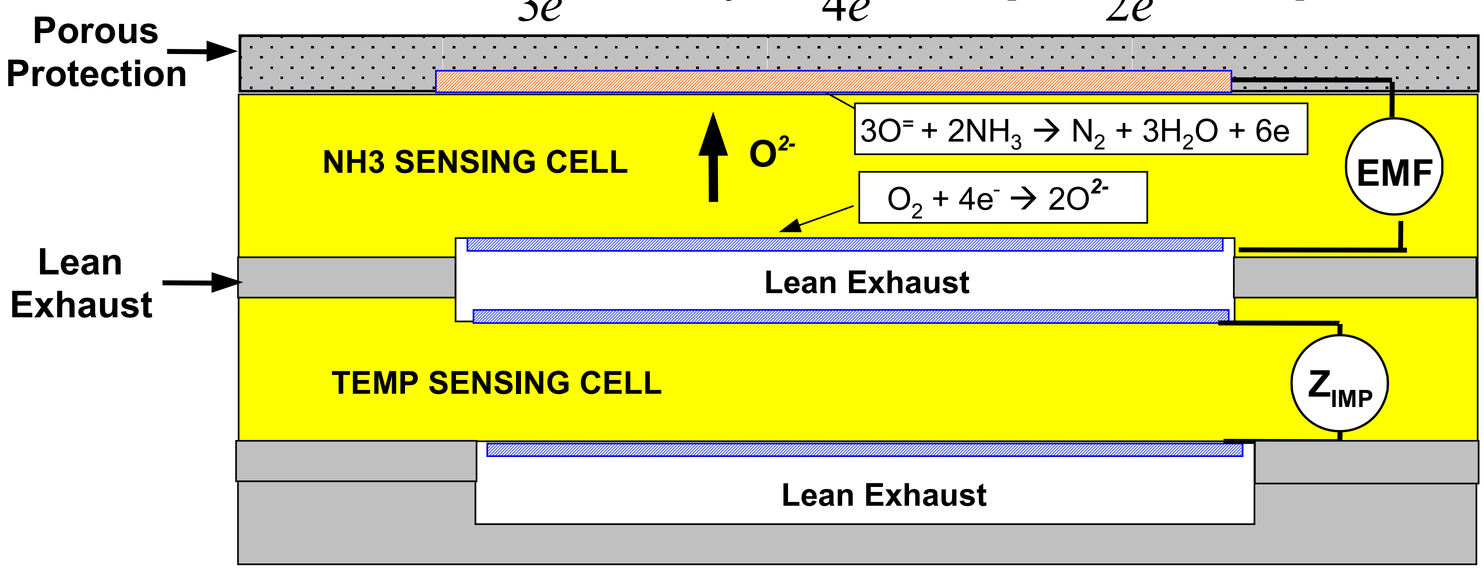
Sensing principle

- **Non-equilibrium electrochemical sensing principle**
  - Proprietary NH3 sensing electrode materials
  - Both sensing and reference electrodes exposed to the engine exhaust
  - Solid oxide electrolyte used as the sensor body

$$EMF \approx \frac{kT}{3e} Ln(P_{NH_3}) - \frac{kT}{4e} Ln(P_{O_2}) - \frac{kT}{2e} Ln(P_{H_2O})$$



• *(Heater circuit not shown)*

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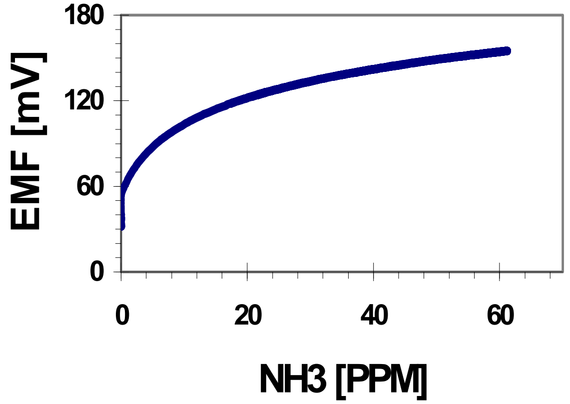
Theory

- **Semi-log output of EMF versus NH_3 concentration**

$$EMF \approx \frac{kT}{3e} Ln(P_{NH_3}) - \frac{kT}{4e} Ln(P_{O_2}) - \frac{kT}{2e} Ln(P_{H_2O})$$



  - **Interference effect due to H_2O and O_2 concentrations changing due to combustion can be self-compensating**
  - **The concentration of H_2O and O_2 vary in opposite directions as function of A/F ratio minimizing effect**

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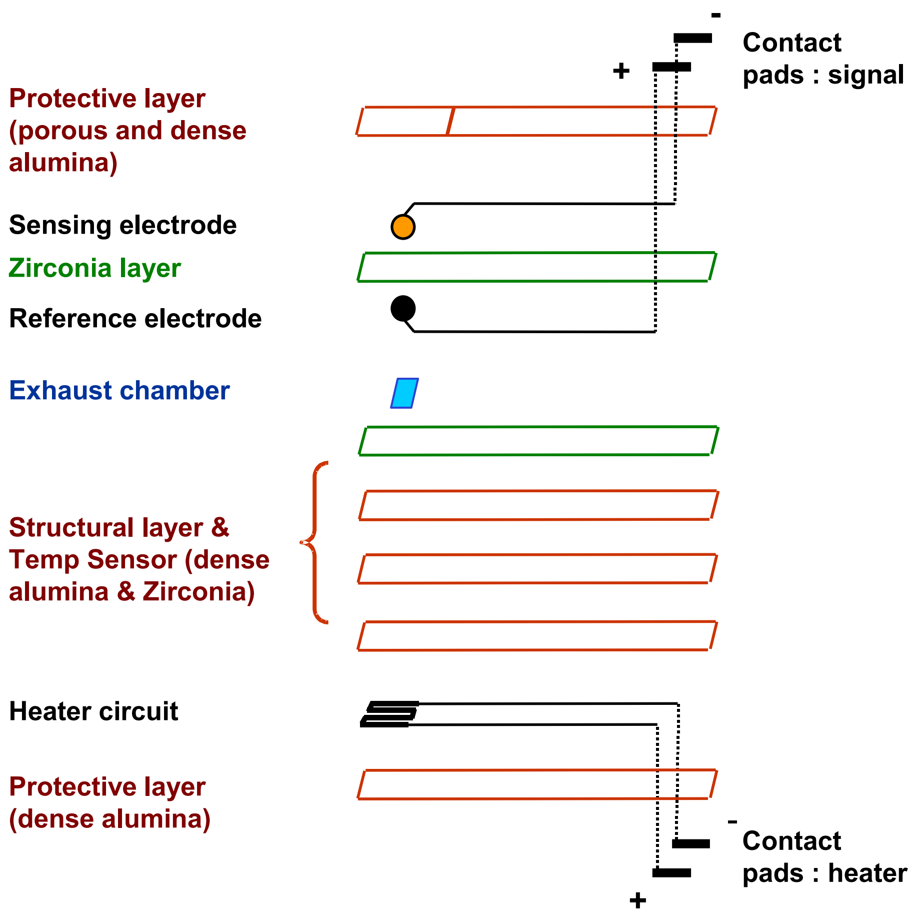
Sensor structure



- **Planar structure**
  - Co-fired zirconia and alumina layers with NH3 sensing, platinum reference electrode and heater circuit
- **Key Features**
  - Integrated heater provides fast time to activity
  - Temperature sensor included
  - No air reference
  - Alumina layers provide electrical isolation between heater and sensor circuits
  - Porous protection provides excellent exhaust poison resistance
  - Small size

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Sensing Element

- **Finished sensing elements**
  - **Monolithic thick film multi layer composite substrate**
    - **Alumina / Zirconia composite**
    - **Alumina provides toughness - Zirconia electrolyte**
  - **Integral Heater and Temperature Sensor for heater control**
  - **Compatible with existing sensor packaging technology**
- **NH3 electrode material applied on substrate surface**
- **A poison protective material is applied over the NH3 electrode**

➩ **Finished sensing element looks like exhaust oxygen sensing element**

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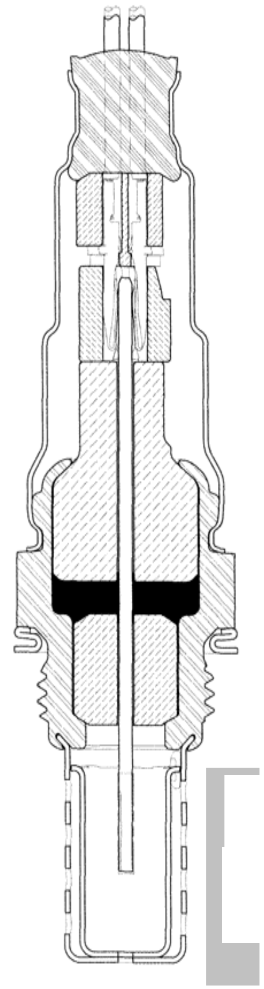
Sensor package

- Based on proven robust production planar sensor packaging
- Package has capability beyond diesel exhaust temperatures
- Lower shielding can be modified according to customer application



NH_3 Sensor System Mechanization

- **Mechanization**
  - **Early systems being developed for commercial vehicle applications**
  - **Stand-alone electronic interface with CAN link to vehicle**
  - **A-sample hardware shown below.**
    - » **A-Sample systems provide either Analog or CAN message output**

Advanced Development Hardware

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NH_3 Sensor Performance Targets

- **Measurement range: 0 – 100ppm NH_3**
  - Tolerance: ± 5ppm NH_3 at 10 ppm NH_3.
  - Acceptable gas content without interference: NO, HC, CO, N_2O.
  - Acceptable gas content with cross sensitivity: O_2, H_2O.
- **Temperature range:**
  - Functional: 200 ºC to 450 ºC
  - Non functional: - 40 ºC to 700 ºC
- **Durability target:** 5.000hours / 250.000km
- **NOx Exhaust gas content:** 0 to 500ppm (sensor performance within spec)
- **H2O exhaust gas content:** 1% to 8% by mass (sensor performance within spec)
- **Response Time:** T_{60} = 3 s
  T_{90} = 5 s
- **Thermal Shock**
  - Two layers of protection
    1. Double layer protective shield
    2. System algorithm to disable sensor when liquid water is possible in the exhaust
  - Heated ceramic sensors must be protected from contact with liquid water to prevent damage do to thermal shock

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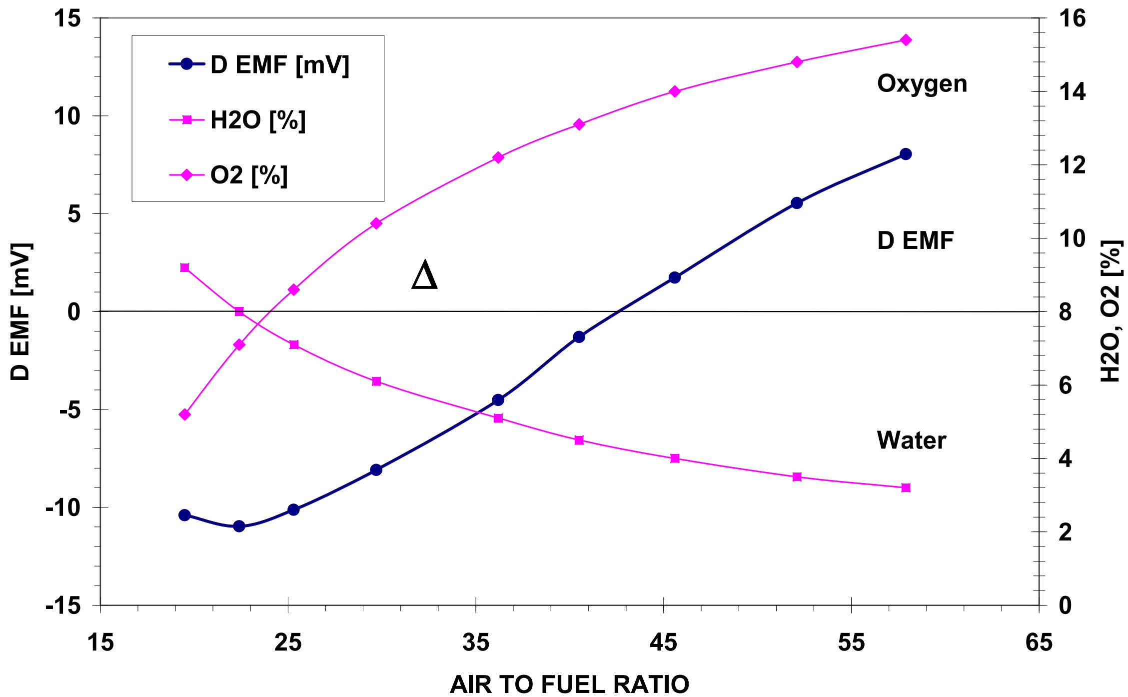
NH_3 Sensor Interface Electronics

- **Environment**
  - Ambient Temperature (electronics): - 40 ºC to 105 ºC
- **Electrical**
  - Sensor system compatible with either a 12V or 24V vehicle electrical system
  - Sensor system communicates to vehicle over a CAN bus
- **Mounting/Installation**
  - Sensor mounts directly to exhaust pipe via a M18x1.5 threaded boss
  - Sensor must be mounted 10 º above horizontal to prevent pooling of water in shield

Water and oxygen interference effect

- Water and oxygen have opposite interference effect
- Self compensation effect is possible in a narrow range as shown in following figure (confirmed by lab gas bench too)
- Climate air humidity difference is a main concern but can be handled by calibration
- Model based correction is also possible if A/F ratio and air humidity information is available



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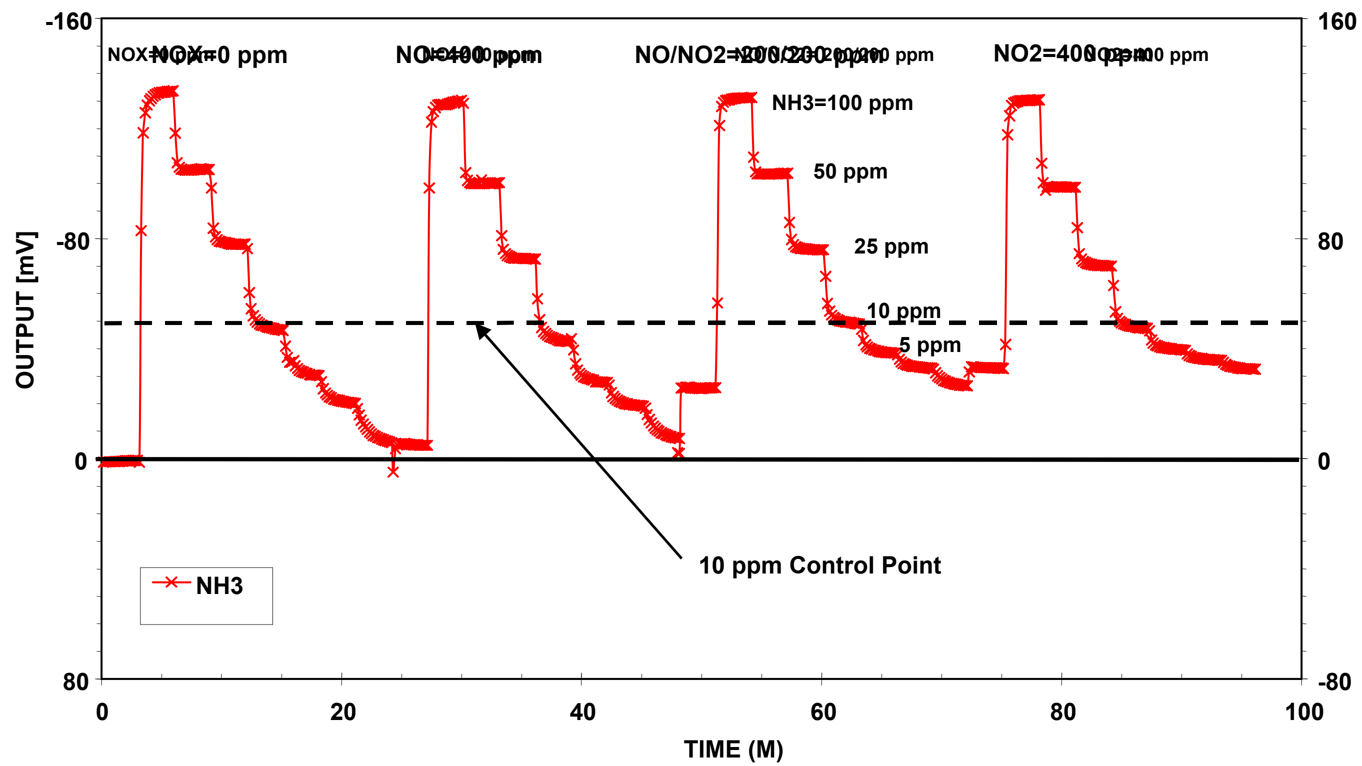
NH_3 Output in the Presence of NO_X

- **Basic function demonstrated in gas bench testing**
  - NH_3 signal free from NO_X interference
  - Some interference below 10ppm set point



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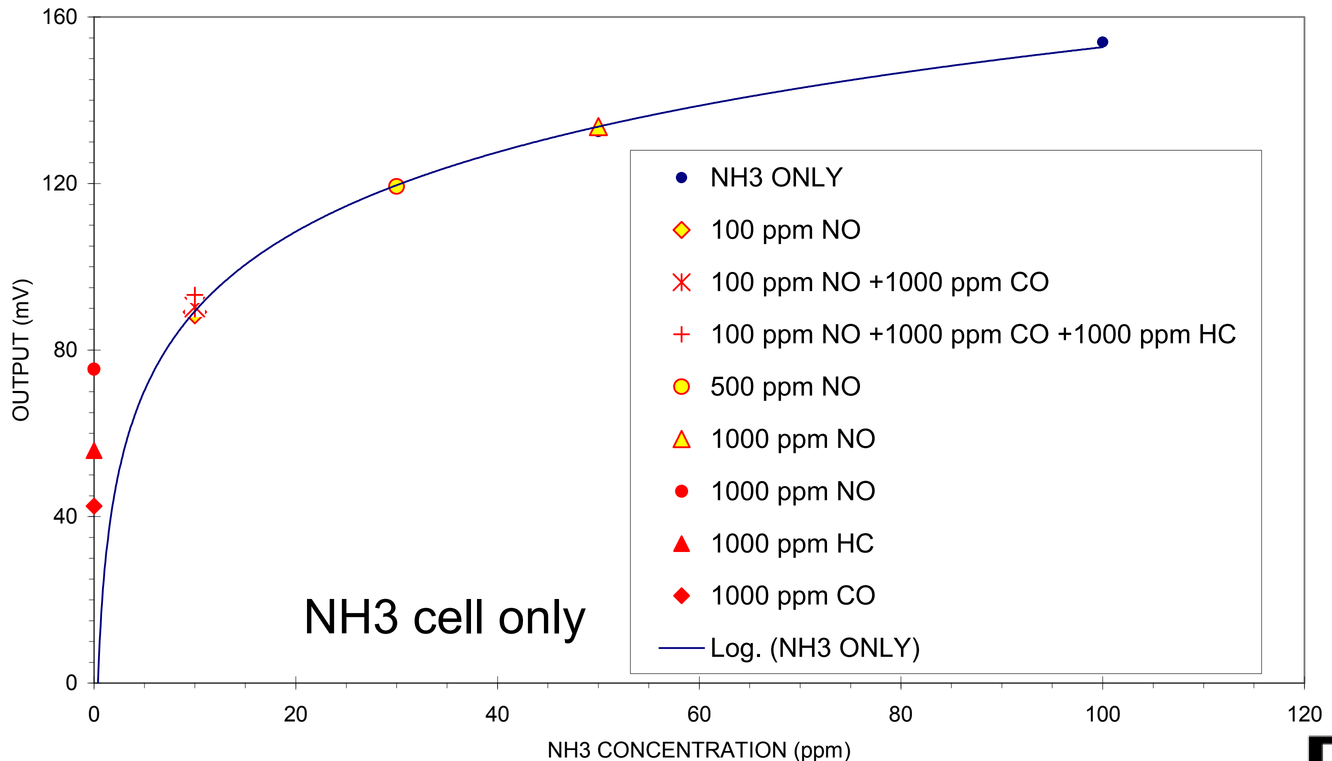
Sensor performance cross interference

- NH_3 sensing accords to the theory prediction (semi-logarithms equation)
  - Data obtained at lab gas bench, 14% O_2, 1.5% H_2O
- Interference from NO, CO, and HC is negligent



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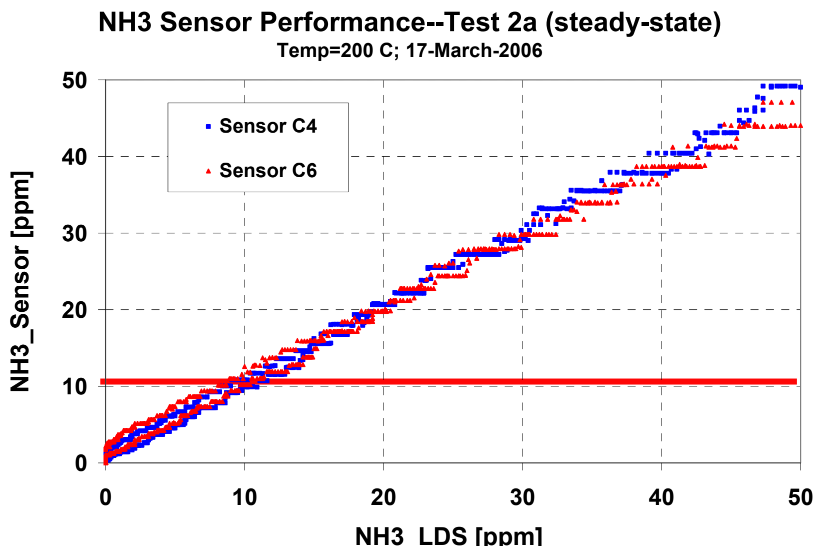
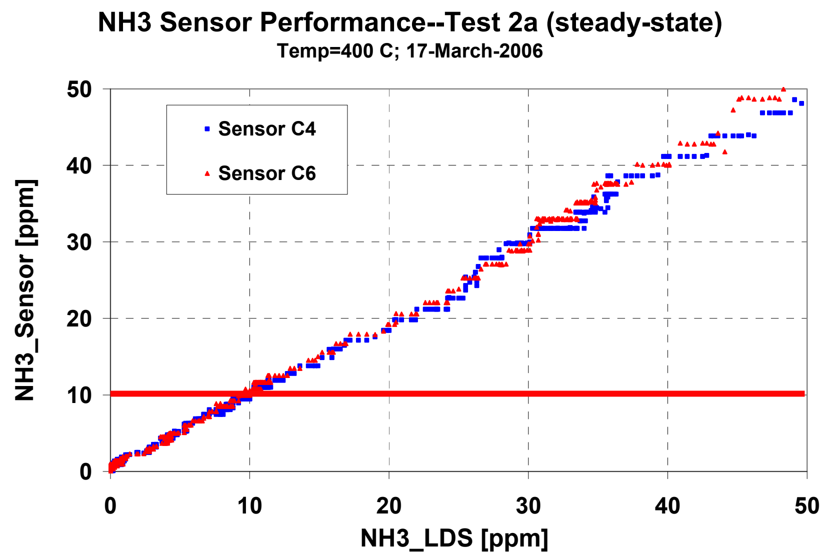
Engine Test Stand Performance
Steady State Test





- **Sensor data**
  - **Steady state performance on HD diesel engine**
  - **Test stand fitted with SCR aftertreatment system**
  - **Sensors tested at 200 C & 400 C steady-state exhaust gas conditions**
  - **Ammonia slip between 0 and 50 ppm**
  - **Chart shows sensor output plotted against LDS instrumentation NH3 output signal**
- **Result**
  - **Sensor accuracy within specification limits (+/- 5ppm at 10 ppm control point)**

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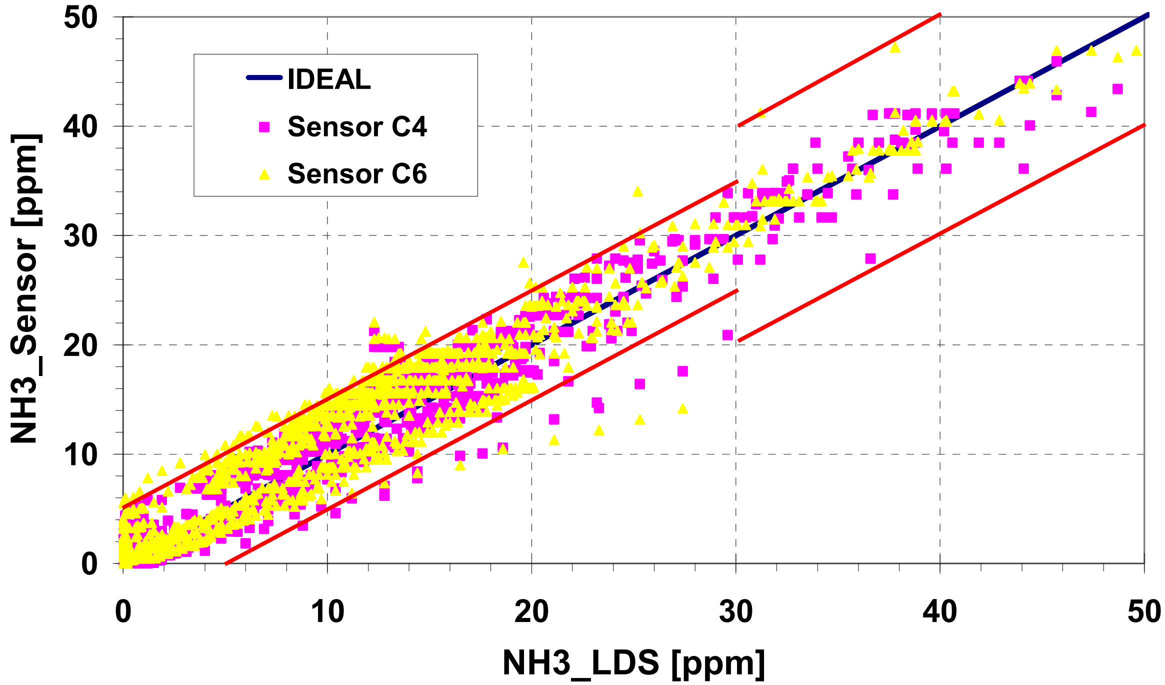
Engine Test Stand Performance ESC Cycle

- **NH_3 Sensor output during an ESC cycle on the engine test stand**
  - **NH_3 sensor output tracks LDS instrumentation over a dynamic test cycle**

NH3 Sensor Perfromance Test--Test 2b

ESC Engine cycle; 17-March-2006



No poison effects after 700h test cycle without DPF

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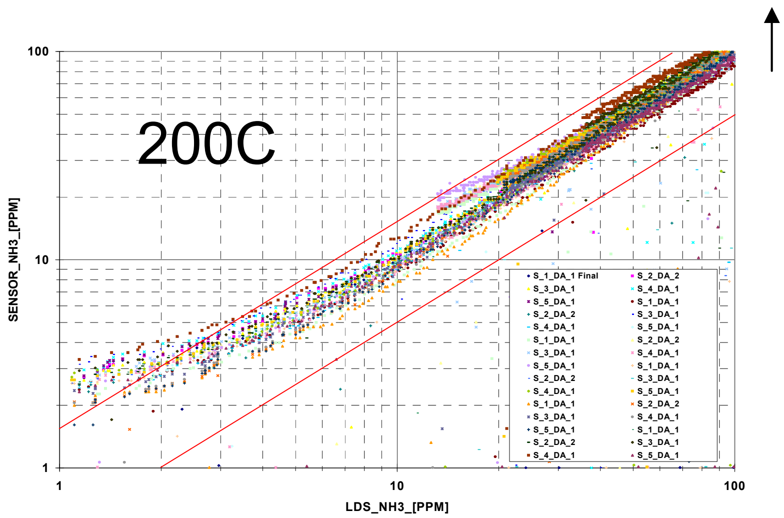
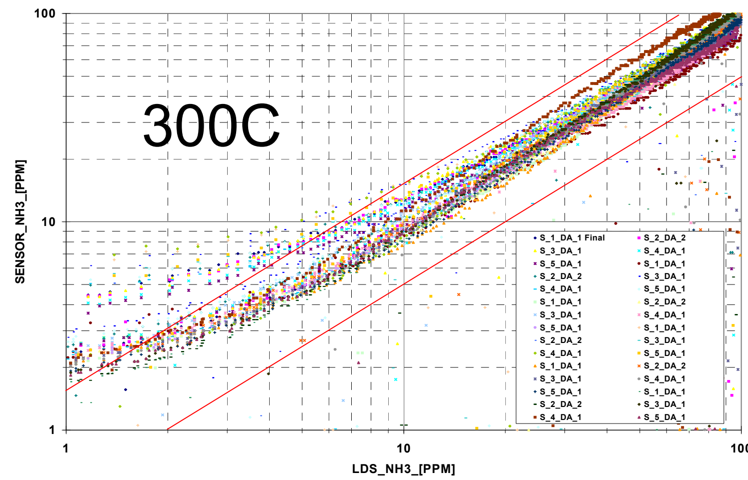
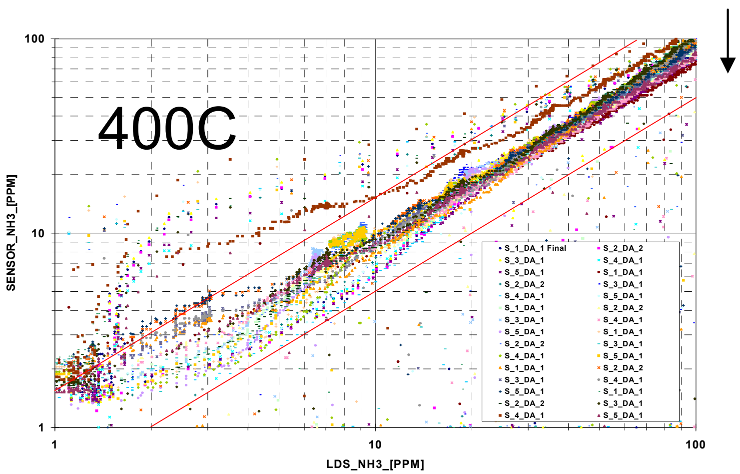
Sample to Sample Variation







- 30 sensors
- Same conversion equation
- No water-oxygen adjustment
- No air humidity adjustment
- Red lines mark ±50% at 10 PPM NH3

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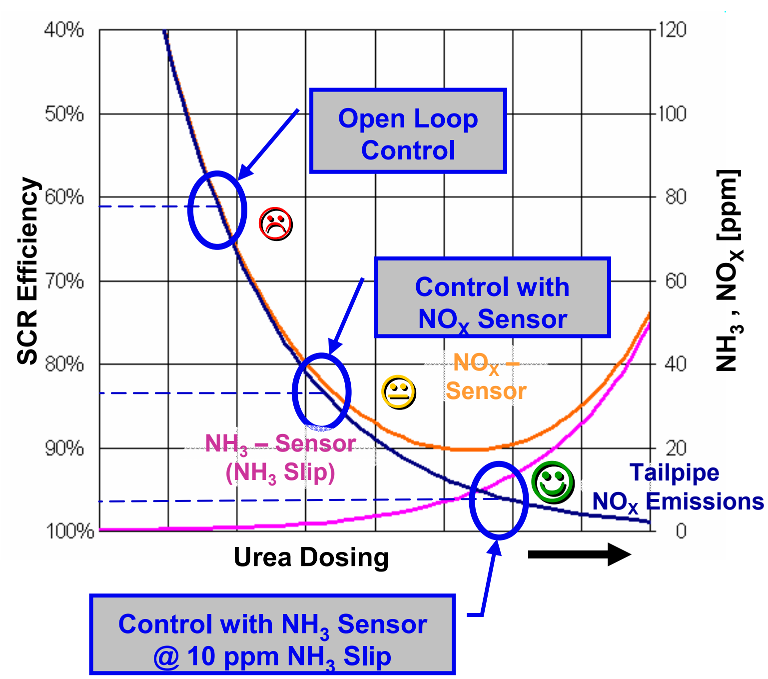
Exhaust Ammonia (NH3) Sensor
- Optimized Performance of an SCR Converter

Graphical Representation of Key Factors to SCR Control



- **Euro 4 limits can be achieved by using open loop control urea dosing**
  - SCR efficiency approximately 65%
- **The realization of maximum NOx conversion (without using a post oxidation catalyst) is only possible with closed loop controlled Urea dosing:**
  - A NOx based SCR control does not enable the use of the maximum NOx conversion because of NH3 cross sensitivity of NOx sensor.
  - The NH3 based SCR control enables operation at the conversion limit of the catalyst:
  - >90% NOx conversion possible for highwa driving conditions
  - Minimal catalyst volume

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Conclusion

- Sensor demonstration has been done
  - NH_3 sensing accords to concept
- Interference with NO, HC, CO is not significant
- O_2 and H_2O have opposite interference effect (minimum compensation through calibration)
- Air humidity and air to fuel ratio information is required for model based correction of the interference effects of O_2 and H_2O (only required if highest accuracy is demanded)
- Response time T_{60} < 3 second, T_{90} < 5 sec
- Sensors are built on existing Delphi exhaust oxygen sensor technology
- NH_3 Sensor provides an opportunity for improved SCR dosing control and system diagnosis

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Thank You!