Powertrain Sensors & Actuators

General Presentation
Smart NOx Sensor

October 2009

Smart NOx Sensor
Product

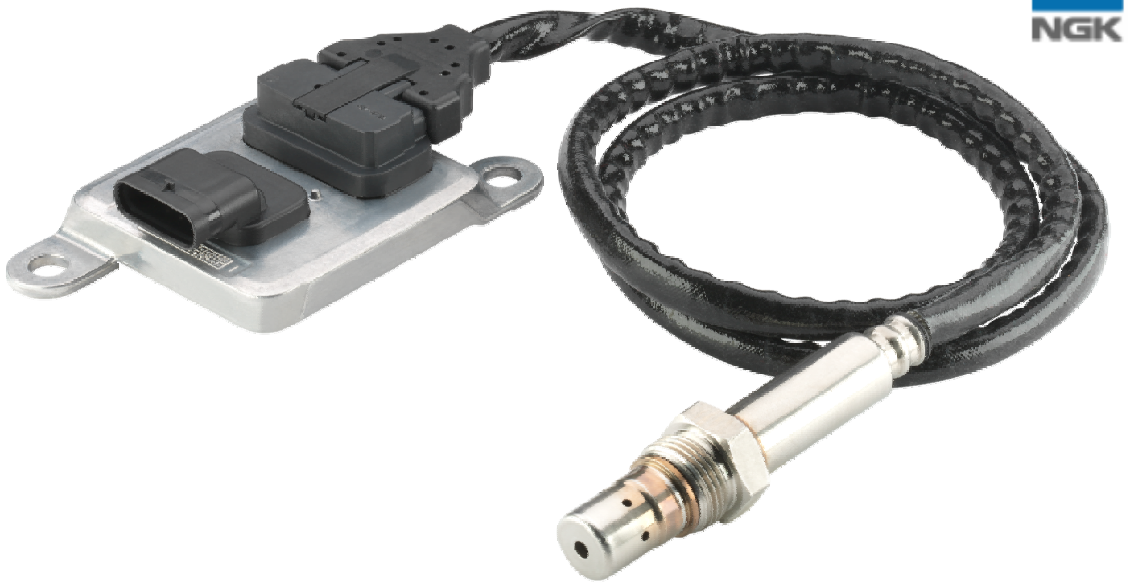
Control electronics by

Continental

Sensor element by

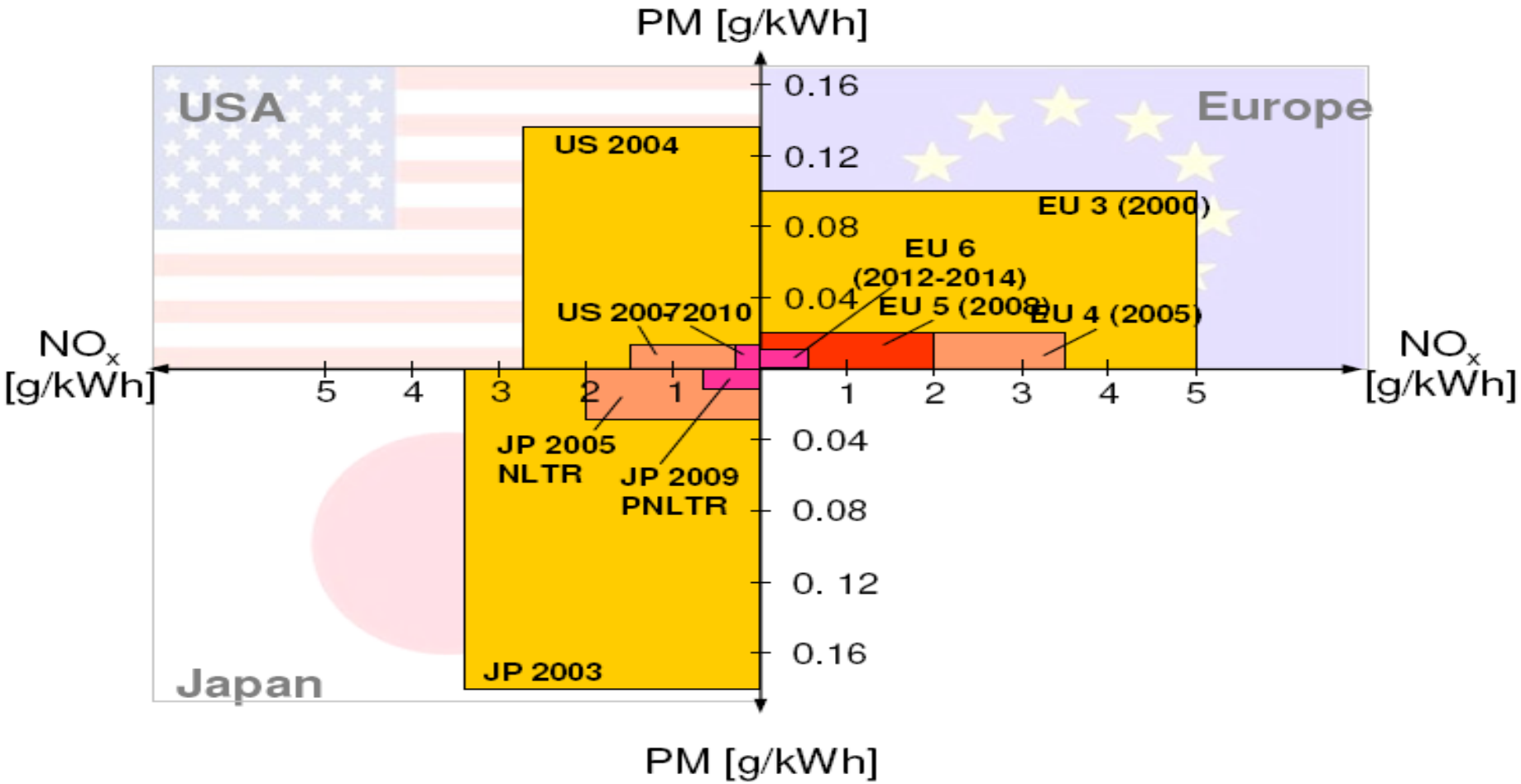
NGK

NGK Insulators, Ltd.



- The SMART NOx-sensor (SNS) is a common development by Continental AG and NGK Insulators.
- The sensor element is produced and assembled by NGK Insulators in Nagoya, Japan.
- The production of the electronics and the final assembly and calibration are done at Continental AG in Regensburg, Germany.

Smart NOx sensor
Emission regulations (Heavy Duty Diesel exemplary)



Smart NOx Sensor Applications

Gasoline Applications:

Passenger Cars

- Usage in combination with leanburn technology for gasoline passenger cars (GDI/FSI/HPDI)
- Smart NOx-Sensor is used to control the regeneration cycle of the NOx storage catalyst (NSC)

Diesel Applications:

Passenger Cars and Light Duty Trucks

- Usage in combination with exhaust aftertreatment systems for diesel passenger cars
  - SCR (Selective Catalytic Reduction)
  - NSC (NOx Storage Catalyst = “NOx trap”)

Heavy Duty Trucks

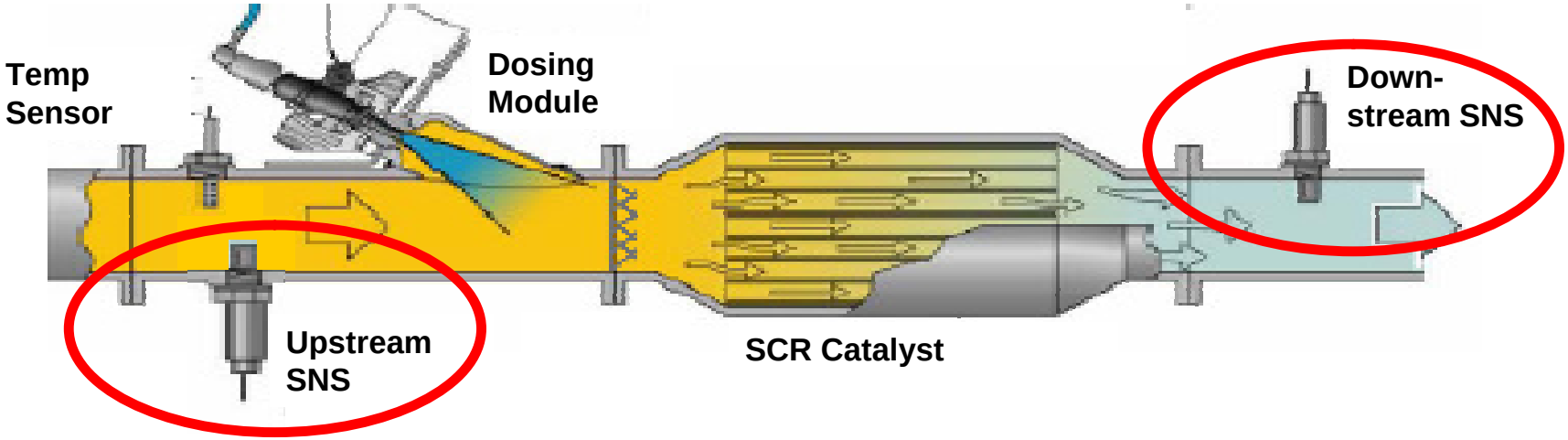
- Smart NOx-Sensor could be used for control and OBD of
  - SCR (Selective Catalytic Reduction)

Smart NOx Sensor
SCR-Application

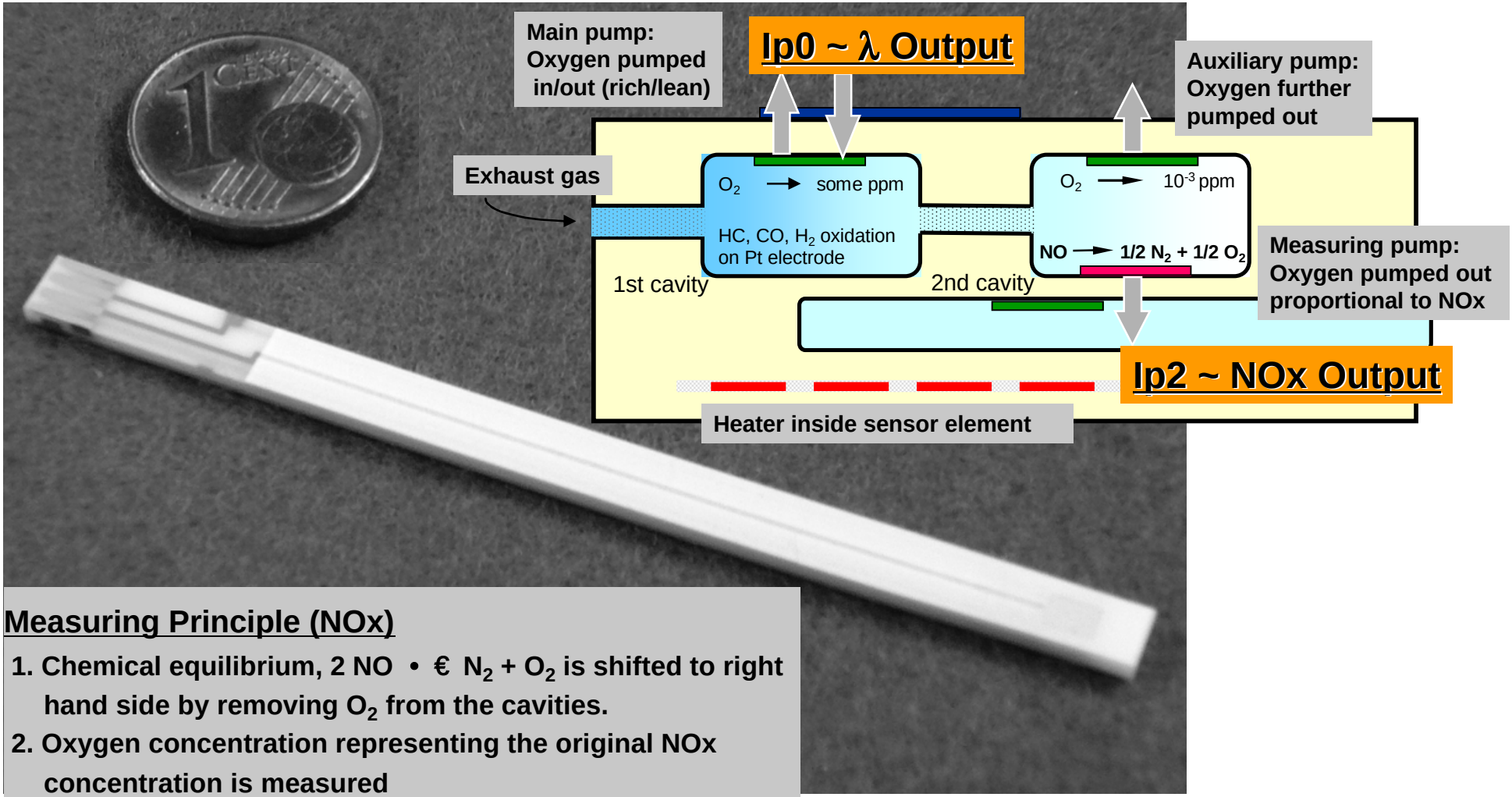
- **NOx sensor application in SCR system**
  - EU5 => OBD => 1SNS downstream SCR
  - EU6, JP09, US10 => OBD+ closed loop => 1SNS downstream, 1SNS upstream SCR

- **Customer benefit upstream sensor**
  - Closed loop control for SCR-system
  - Optimized urea injection
    => extended urea mileage
  - Optimize catalyst size

- **Customer benefit downstream sensor**
  - Fulfill legal requirements for
    OBD (on board diagnosis)
  - Detection of Urea/ammonia slip



Smart NOx Sensor
Measurement principle NOx and O_2



Measuring Principle (NOx)

1. Chemical equilibrium, 2 NO • € $N_2 + O_2$ is shifted to right hand side by removing O_2 from the cavities.
2. Oxygen concentration representing the original NOx concentration is measured

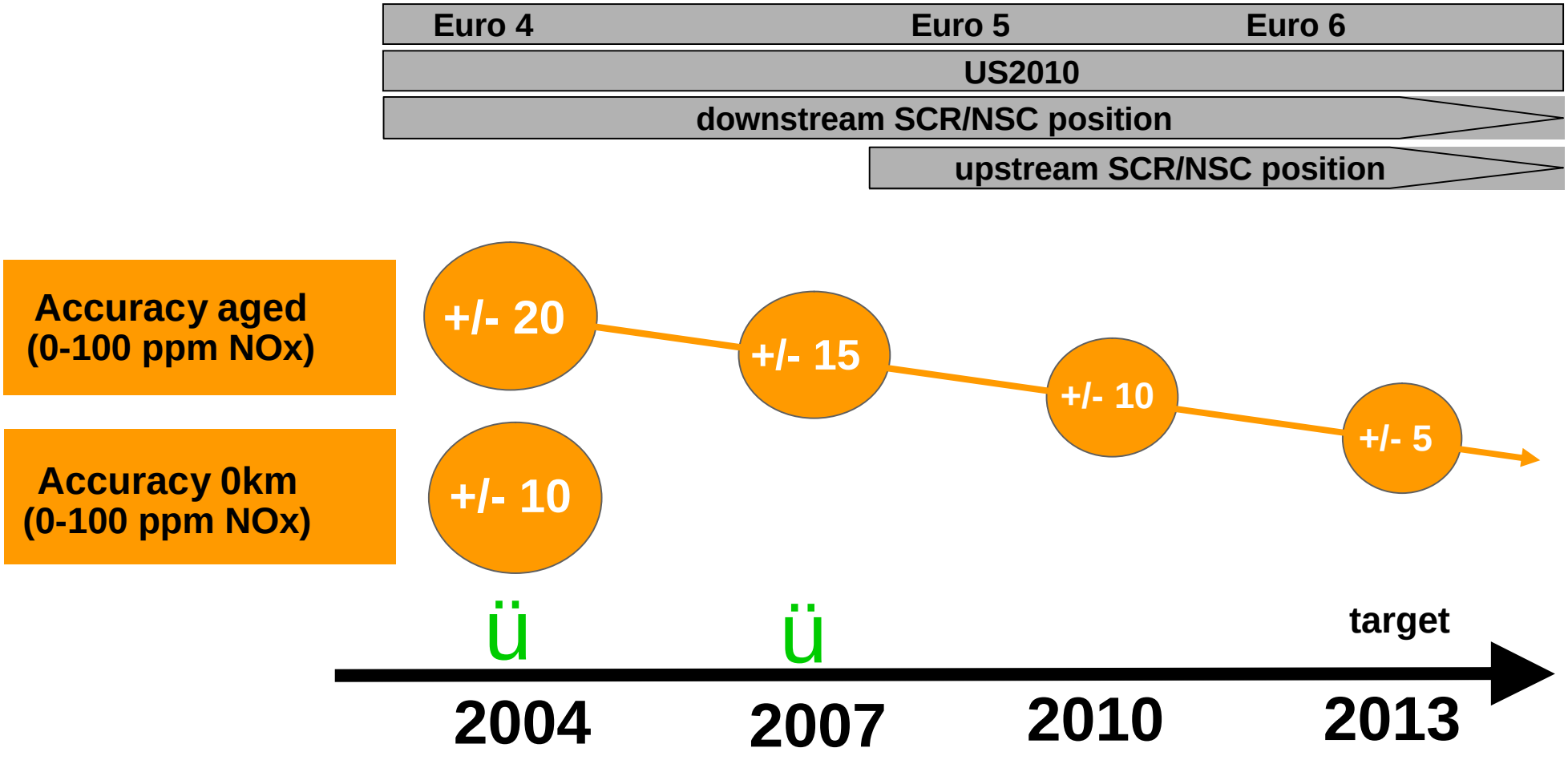
Smart NOx sensor
Signal output

Signals provided via CAN-link (CAN 2.0 / CAN SAEJ1939)

- **NOx signal**
  - NO (basic calibration)
  - NO_2, NH_3 (additive sensitivities)
- **Linear • // O_2-concentration**
  - 1000/• (CAN2.0)
  - O_2-concentration in % (SAEJ1939)
- **Binary •**
  - Nernstian step function in mV

Status of operation	Status byte indicates readiness of the sensor
Electrical errors	Electrical self diagnosis of shorts and open wires for connection ECU – sensor probe
Sensor identification parameters	SW-version, part-number,
Element temperature	Element temperature calculated by heater resistance

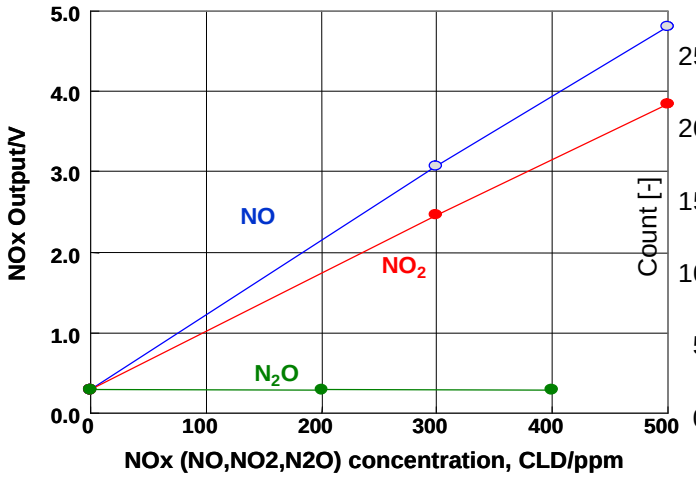
Smart NOx Sensor
Accuracy – Development road-map



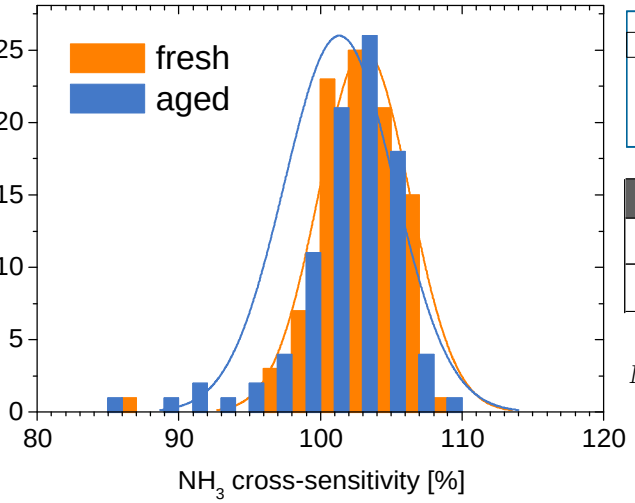
Smart NOx Sensor
Cross Sensitivities

Considerable Sensitivities to:

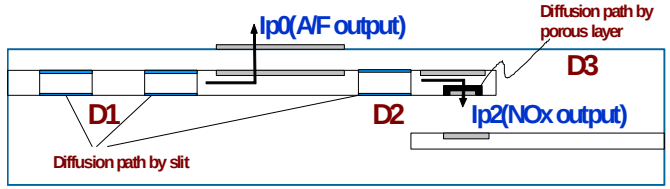
NO_2



NH_3



Pressure



Diffusion type	Static pressure dependency	Output
Molecular diffusion	Low pressure dependency	Lambda
Knudsen diffusion	High Pressure dependency	NOx

$$NOx_{P0} = NOx_P * \left[\left(\frac{P0}{p} - 1\right) * \alpha_{NOx} + 1\right] \qquad \alpha_{NOx}: 0..1 \text{ typical } 0{,}4\text{-}0{,}6$$

No cross sensitivity to N_2O

Low cross sensitivities to O_2, CO, SO_2, HC, CO_2 and Tgas

Smart NOx Sensor
Diagnosis functions

- The Smart NOx sensor has the self diagnosis capability to detect shorts or open wires for the 8-wire connection of sensor ECU to sensor probe
  - 40 out of 44 error conditions (36 shorts incl. battery + 8 open wires) can be detected directly
  - 4 error conditions can be detected by plausibility checks
  - Self diagnosis is done during normal operation
  - Self diagnosis result is provided on the CAN-link
- Under voltage and overvoltage detection is implemented
- A self-diagnosis function in the sensor-software for detection of a deteriorated NOx-output has been developed for gasoline applications
- Development of self-diagnosis function for diesel applications has been started

Smart NOx Sensor
Diesel durability experience

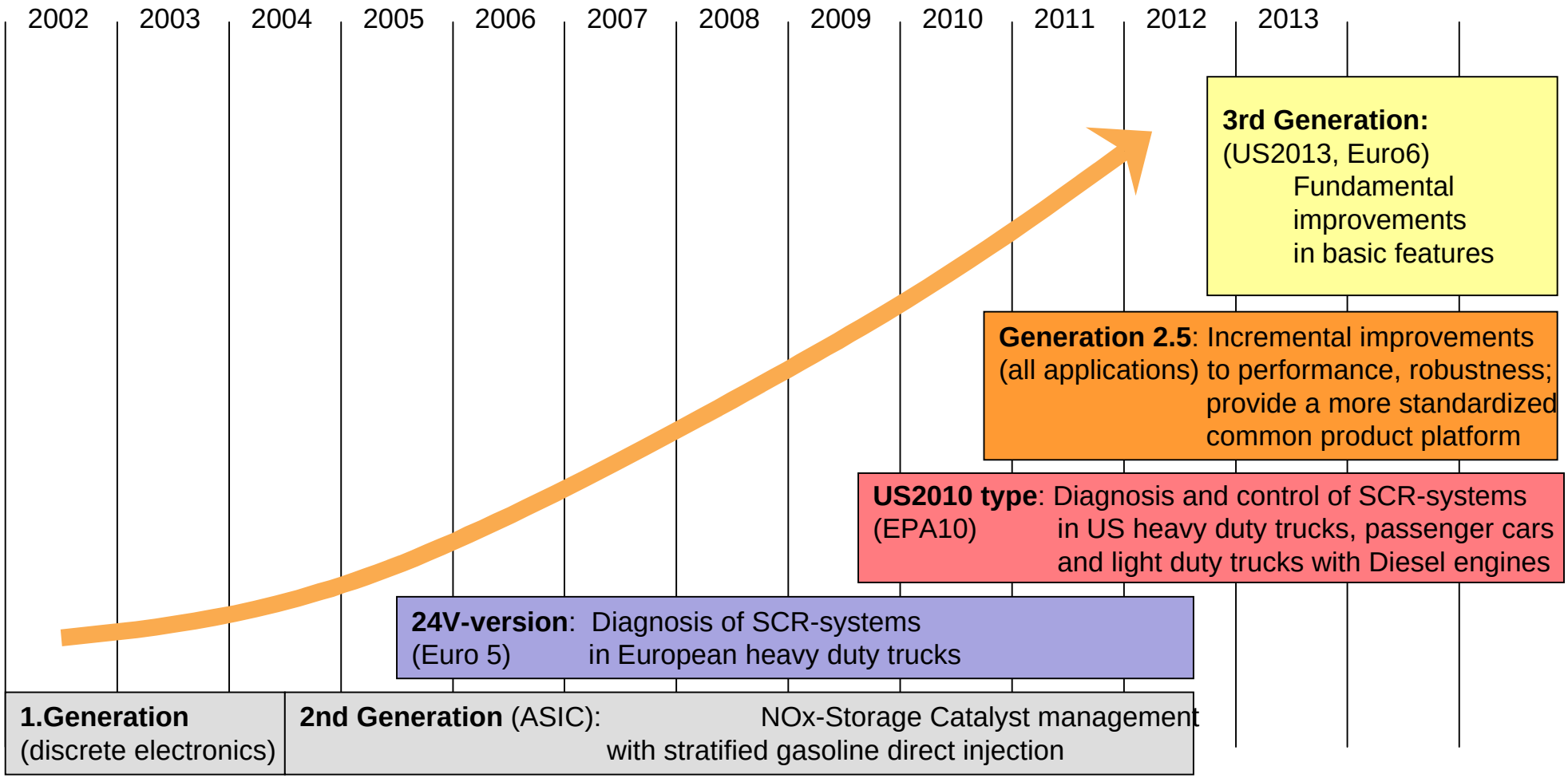
- **Successful engine dyno tests up to 8500h**

Test	Sensor Install Position	Equivalent Mileage	Result
3.400h AMA cycle test (2,5l Diesel engine)	Exhaust out (no after treatment)	100.000km	No failure
6.000h engine dyno (12l Diesel engine)	Downstream SCR catalyst	700.000km	No failure
8.500h engine dyno (6l Diesel engine)	Downstream DPF	700.000km	No failure

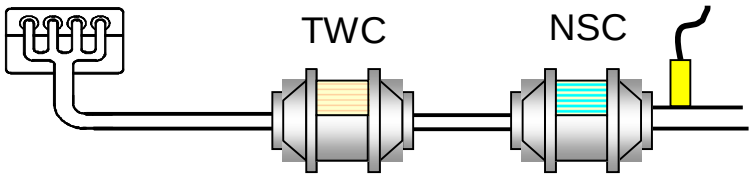
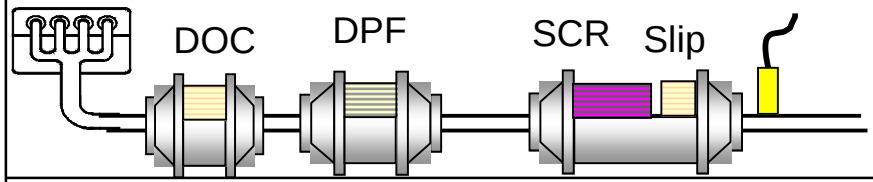
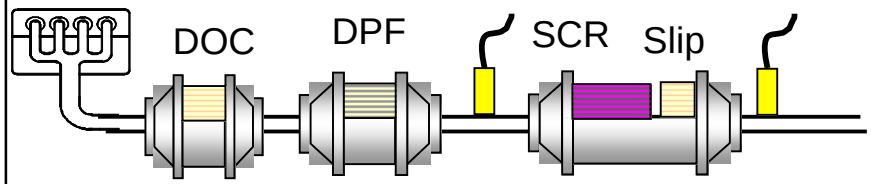
- **Successful vehicle tests up to 600.000km**

Application	Sensor Install Position	Mileage	Results
Heavy duty Truck (9-16l Diesel engines)	Downstream SCR catalyst	> 40 parts with more than 200.000km 20 parts with more than 300.000km	Sensor characteristic within specification

Smart NOx Sensor
Historical Evolution of Generations & Applications



Smart NOx Sensor
Sensor applications

System Layout: typical example	**Application**	**Explanation**
NSC system 	**NSC:** **- Passenger /Lean burn**	**1) Catalyst regeneration control** **2) Model adjustment** **3) OBD**
SCR System (DOC + DPF) 	**SCR:** **- Heavy Duty Truck (EU5)**	**1) OBD of SCR system**
SCR System (DOC + DPF) 	**SCR:** **Heavy Duty Truck** **(EU6; US2010)** **Passenger Diesel** **(EU6; T2bin5)**	**1) OBD for the system (downstream)** **2) Urea Control (2 sensors)** **Modeling adjustment** **Feedback for Urea injection**

Smart NOx Sensor
Summary

- **Calibrated High Accuracy Smart NOx Sensor**
  - NGK Insulators and Continental, bringing together their expertise in ceramics and electronics
  - More than 20 years experience in planar Zirconium Sensor Technology
  - Advanced know-how regarding sensor calibration and control strategy of NOx Sensor

- **Series experience**
  - Series applications for gasoline engines since 2002
  - Series applications for heavy duty diesel engines starting 2005
  - More than 1.500.000 NOx sensors in the field

- **Common development to meet future emission standards**
  - Improved accuracy
  - Additional functionality
  - Improved durability and reliability

Thank you for your attention