Diesel Exhaust Fluid (DEF) and SCR

TDIMeister

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- Diesel Emissions Basics
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- What is DEF?
- Are there other options to reduce NOx?
- Summary

Diesel Emissions Basics

- What causes engine exhaust emissions?
  - $C_xH_y + [O_2 + 3.77N_2] \rightarrow$

$CO_2 + H_2O + N_2$

Diesel Emissions Basics

- What causes engine exhaust emissions?
  - $C_xH_y + [O_2 + 3.77N_2] \rightarrow$

$CO_2 + H_2O + N_2 + O_2 +$

$CO + HC + PM + NO + NO_2 + \ldots$

DOC DPF NSC/SCR

DOC = Diesel oxidation catalyst
DPF = Diesel particulate filter
NSC = NOx storage catalyst
SCR = Selective catalytic reduction

Diesel Emissions Basics

- What causes emissions?
  - CO + HC are caused by incomplete combustion
    - (rich mixtures, crevice volumes, flame quenching, etc.)

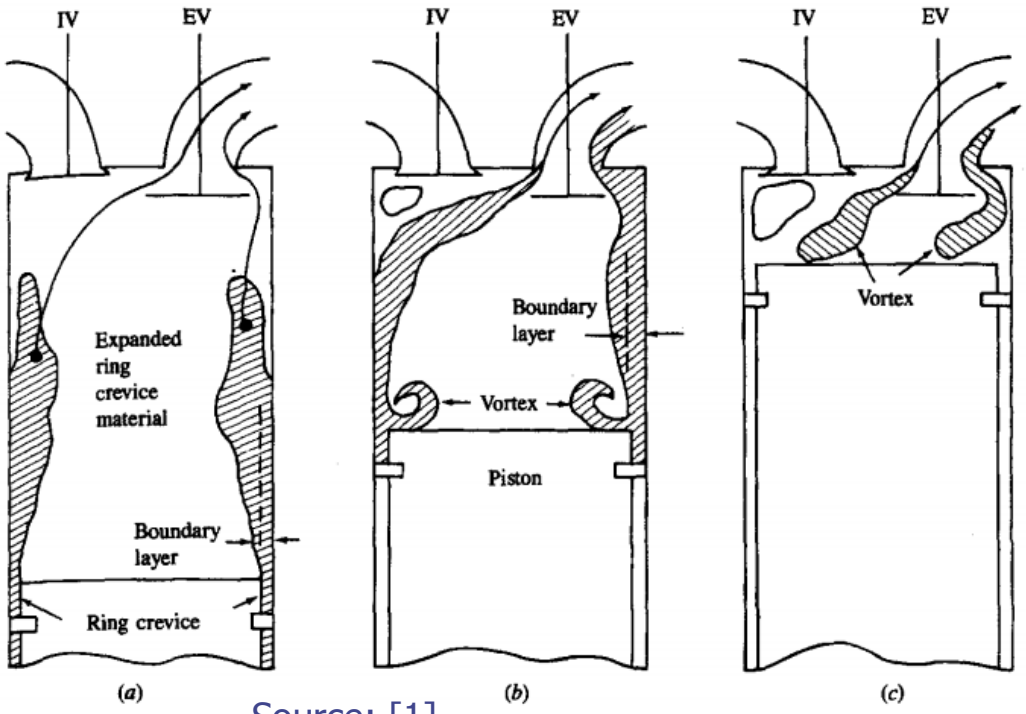
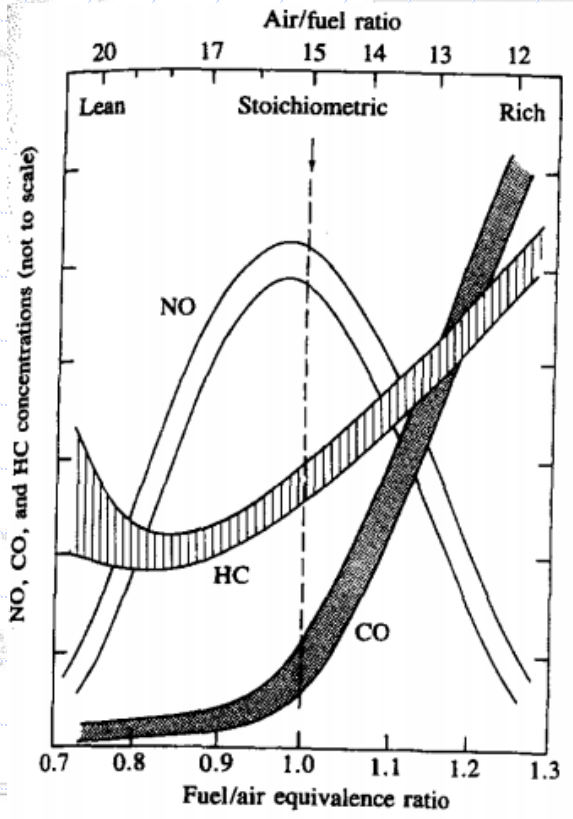


FIGURE 11-30
Schematic of flow processes by which ring crevice HC and HC desorbed from cylinder wall oil film exit the cylinder: (*a*) exhaust blowdown process; (*b*) during exhaust stroke; (*c*) end of exhaust stroke.[60]

Source: [1]



Diesel Emissions Basics

- What causes emissions?
  - PM (soot) are formed due to liquid fuel evaporating and undergoing thermal and chemical transformations

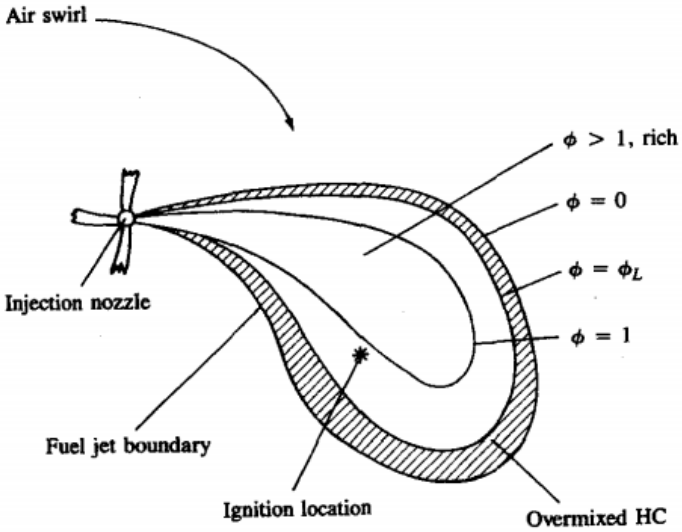


FIGURE 11-34
Schematic of diesel engine fuel spray showing equivalence ratio (ϕ) contours at time of ignition. ϕ_L = equivalence ratio at lean combustion limit ($\approx$0.3). Shaded region contains fuel mixed leaner than ϕ_L.[67]

Source: [1]

Diesel Emissions Basics

- What causes emissions?
  - NOx are primarily formed due to high temperatures
    - Only dependent on local temperature and local species concentrations
    - (Extended) Zeldovich Mechanism

      $O_2 + N_2 \rightarrow NO + N$

      $N + O_2 \rightarrow NO + O$

      $N + OH \rightarrow NO + H$
    - Generally independent of fuel used
    - Gasoline engines deal readily with NO_X (and HC and CO) because of the 3-way catalyst

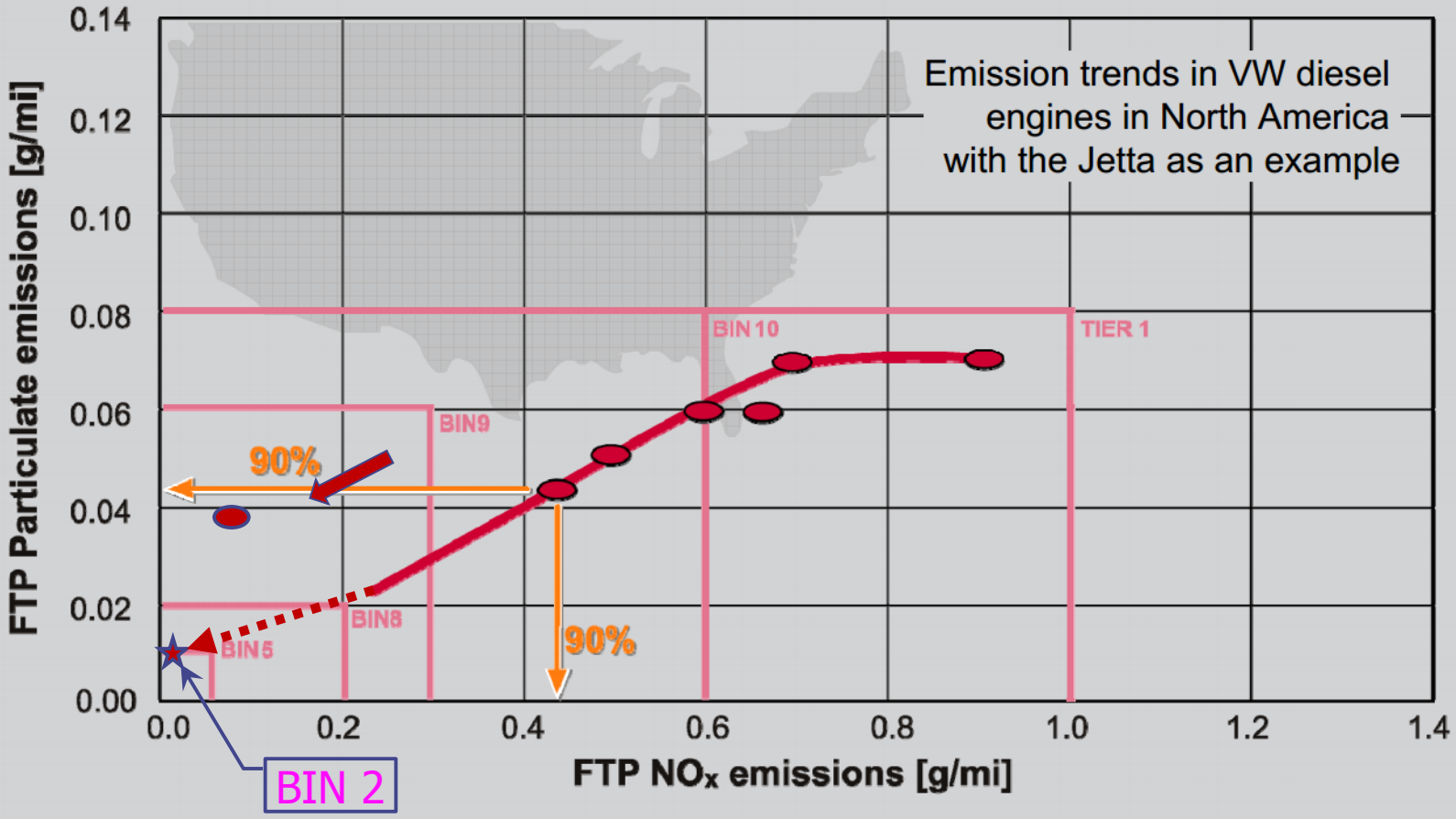
Diesel Emissions Basics

- Who the heck cares about NOx?
  - Causes smog (remember smog days?)

  - Causes respiratory problems
- Who should care about NOx? YOU!

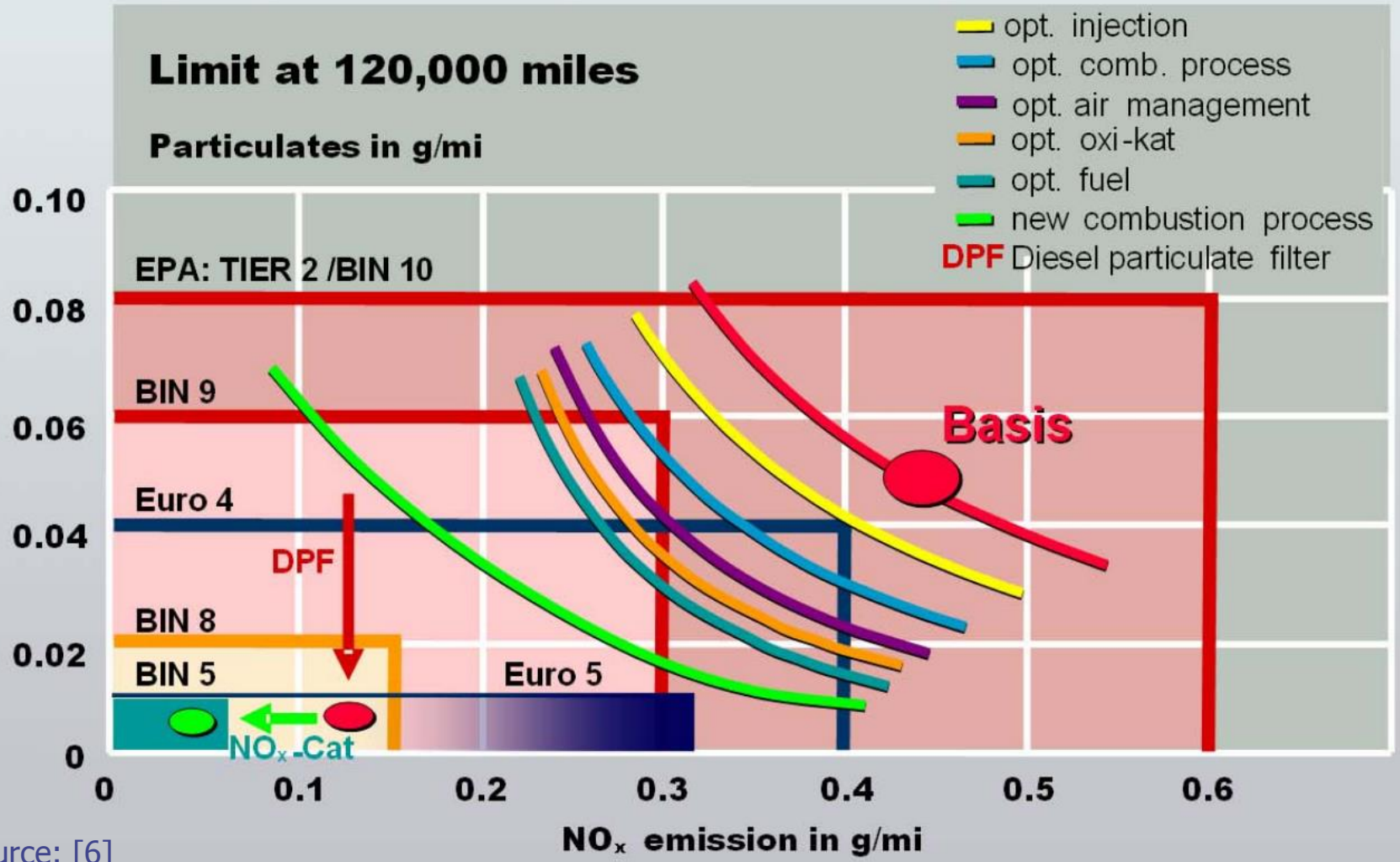
Source: [2]

Diesel Emissions Basics



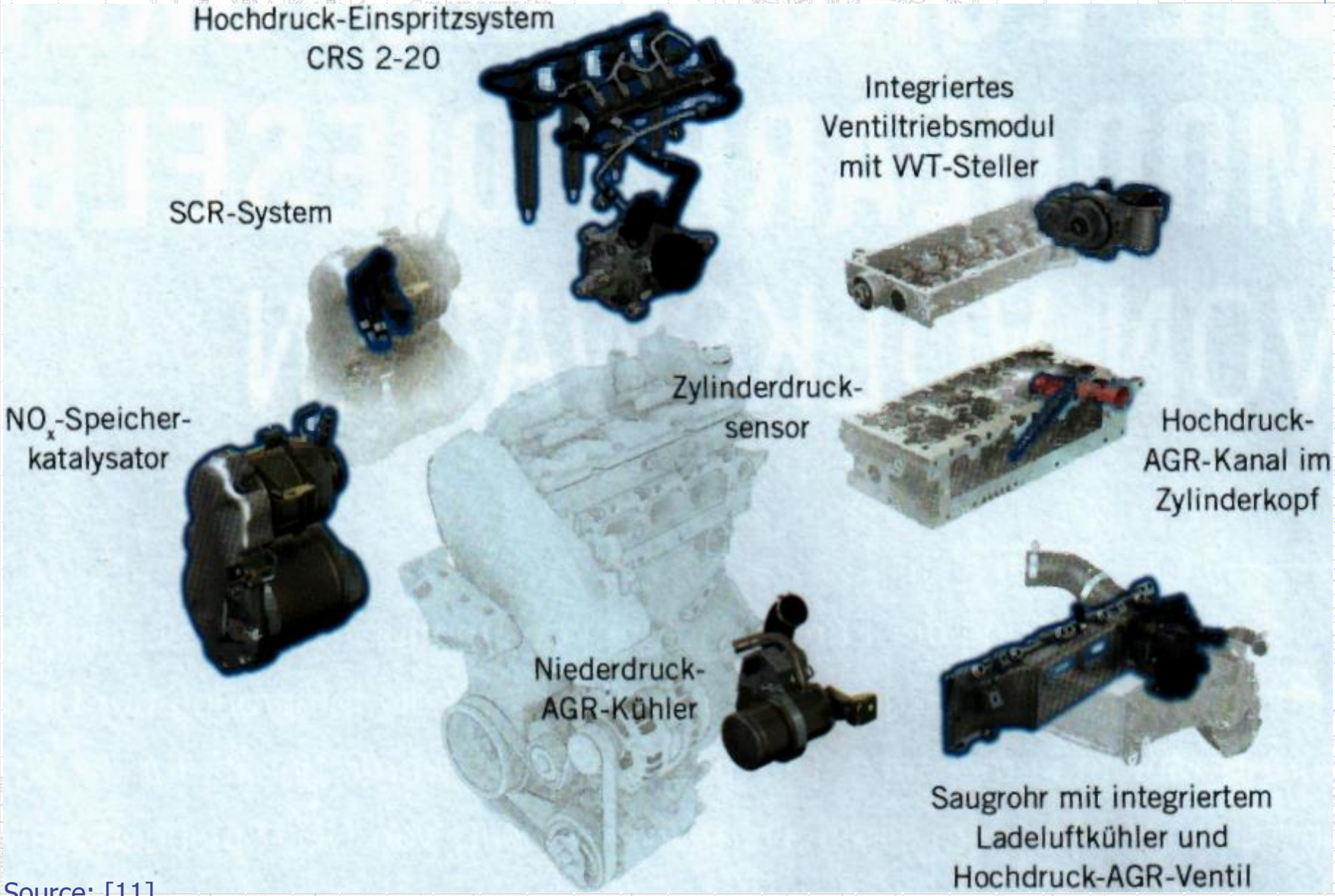
Adapted from [3]

Diesel Aftertreatment



Source: [6]

Diesel Aftertreatment



Source: [11]

NSC vs SCR

- Both NSC (NOx storage catalyst) and SCR (selective catalytic reduction) are equally effective in dealing with NOx.
  - Both require a chemical reductant
  - Both have pros and cons

General Conditions for NO_x Catalytic Converter Systems

1. **NO_x-storage catalytic converter (discontinuous)**

   $\lambda > 1$: NO_x storage (formation of Nitrates)

   $\lambda < 1$: NO_x release and reduction

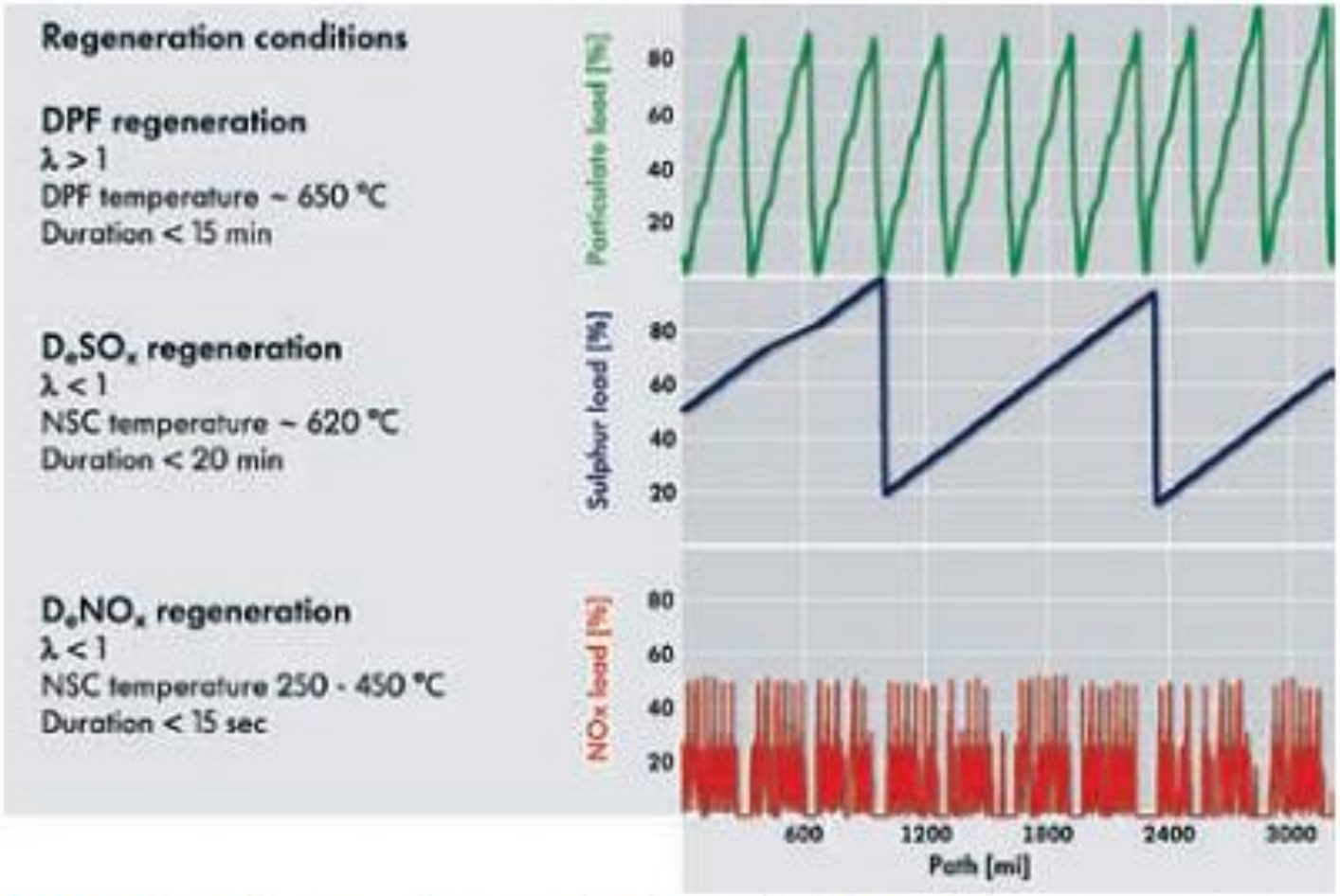
   - Low sulfur fuel (S < 10 ppm) necessary
   - Additional fuel consumption as a result of catalytic converter regeneration

2. **Urea SCR catalytic converter (continuous)**

   - Hydrolysis and thermolysis of urea → formation of NH_3
   - Reduction of NO_x in the SCR catalyst using NH_3
   - Logistics necessary for the reduction agent, urea
   - Customer-friendly topping up of urea at filling stations

Source: [3]

NSC vs SCR



Source: [5]

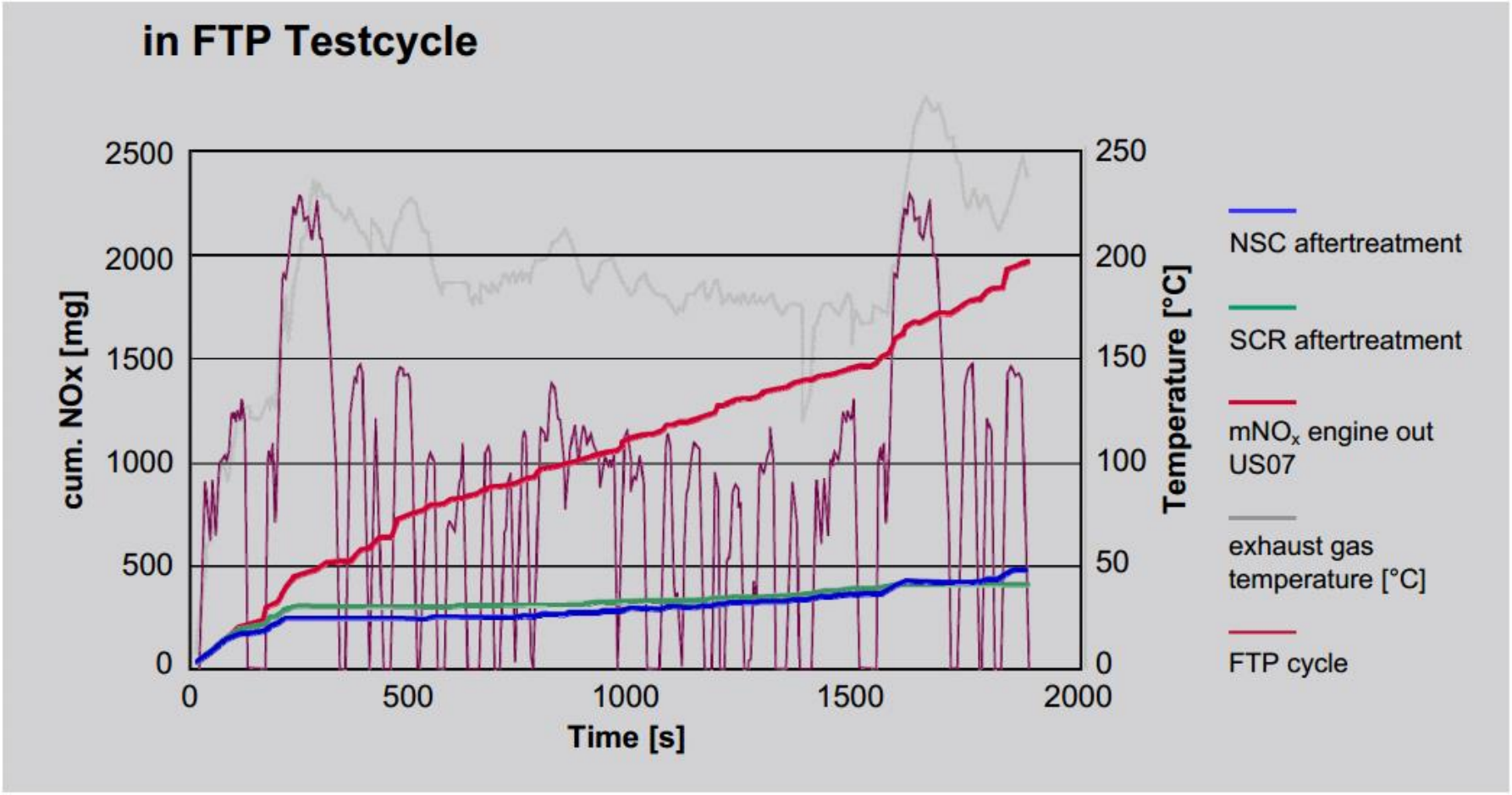
Figure 12: Graph of regeneration modes in the dynamic driving cycle (standard road cycle)

System Benchmark Test

	NO_x Storage Cat	SCR System
NO_x Red. Potential (Golf)		
FTP	+	+
US06	+	++
NEDC	+	+
NO_2 Emissions	+	+
HC	-	0
Fuel Consumption	-	0
Required Infrastructure	0	--
Servicing	0	-
Packaging Space	-	--
Error Rate / Complexity	0	-
Costs	-	--

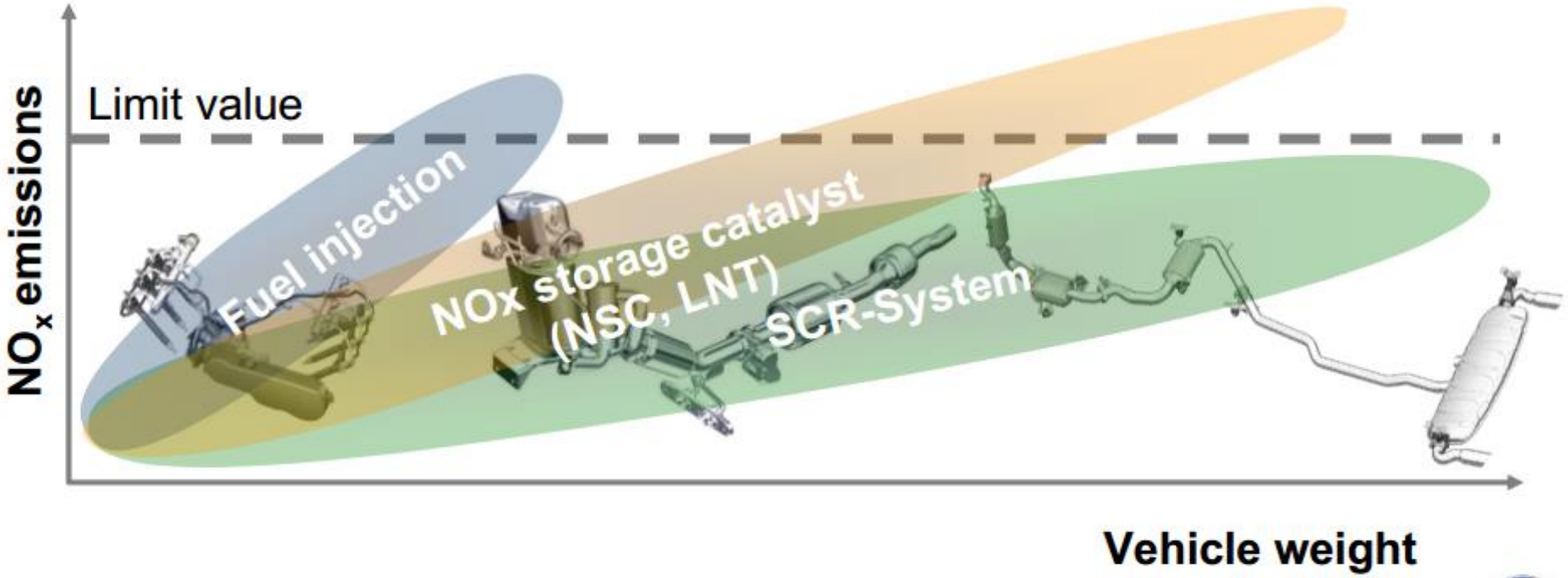
Source: [3]

NO_x Emission Results of SCR and NSC



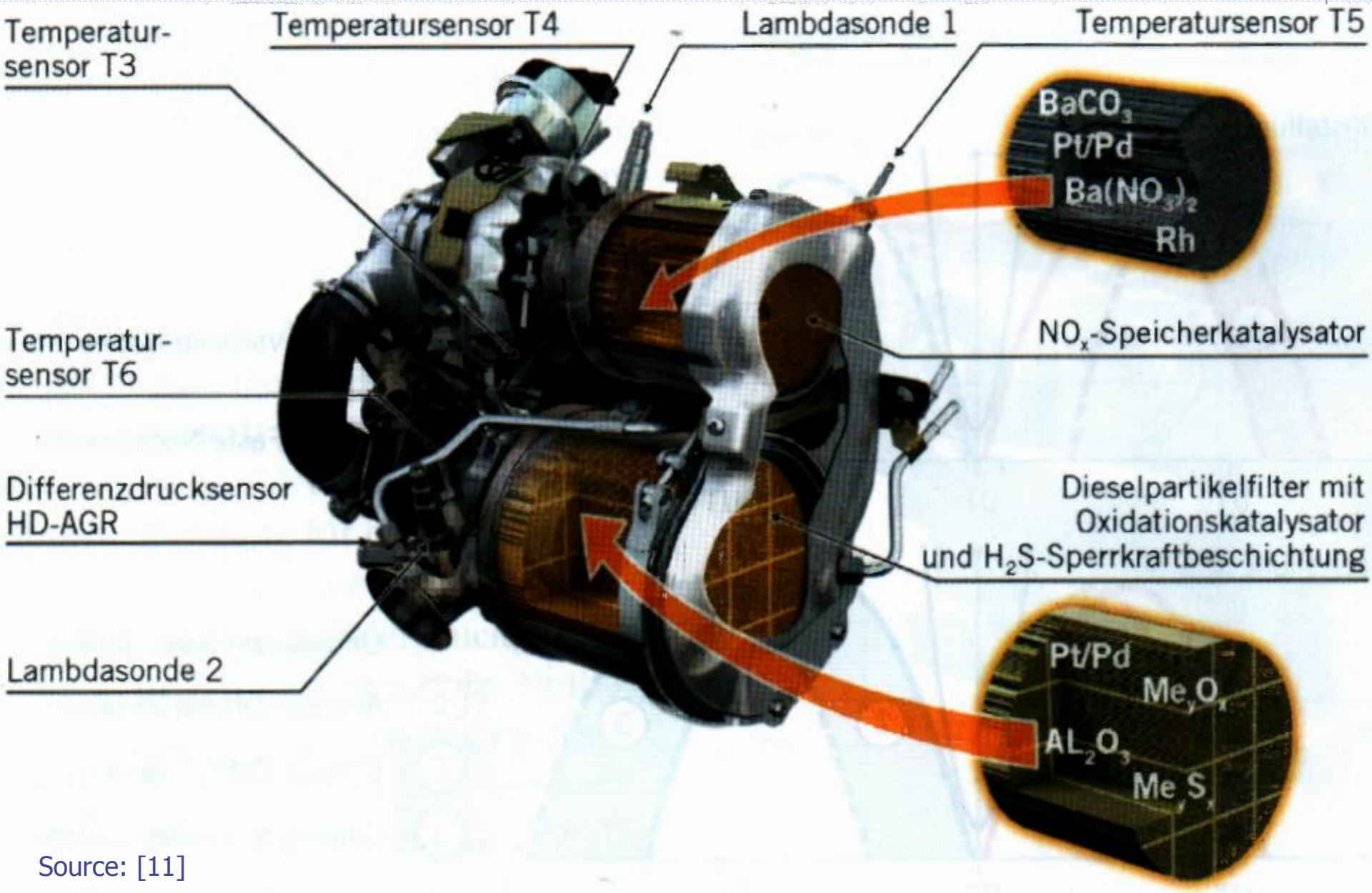
Source: [3]

Measures to meet ultra low emission limits



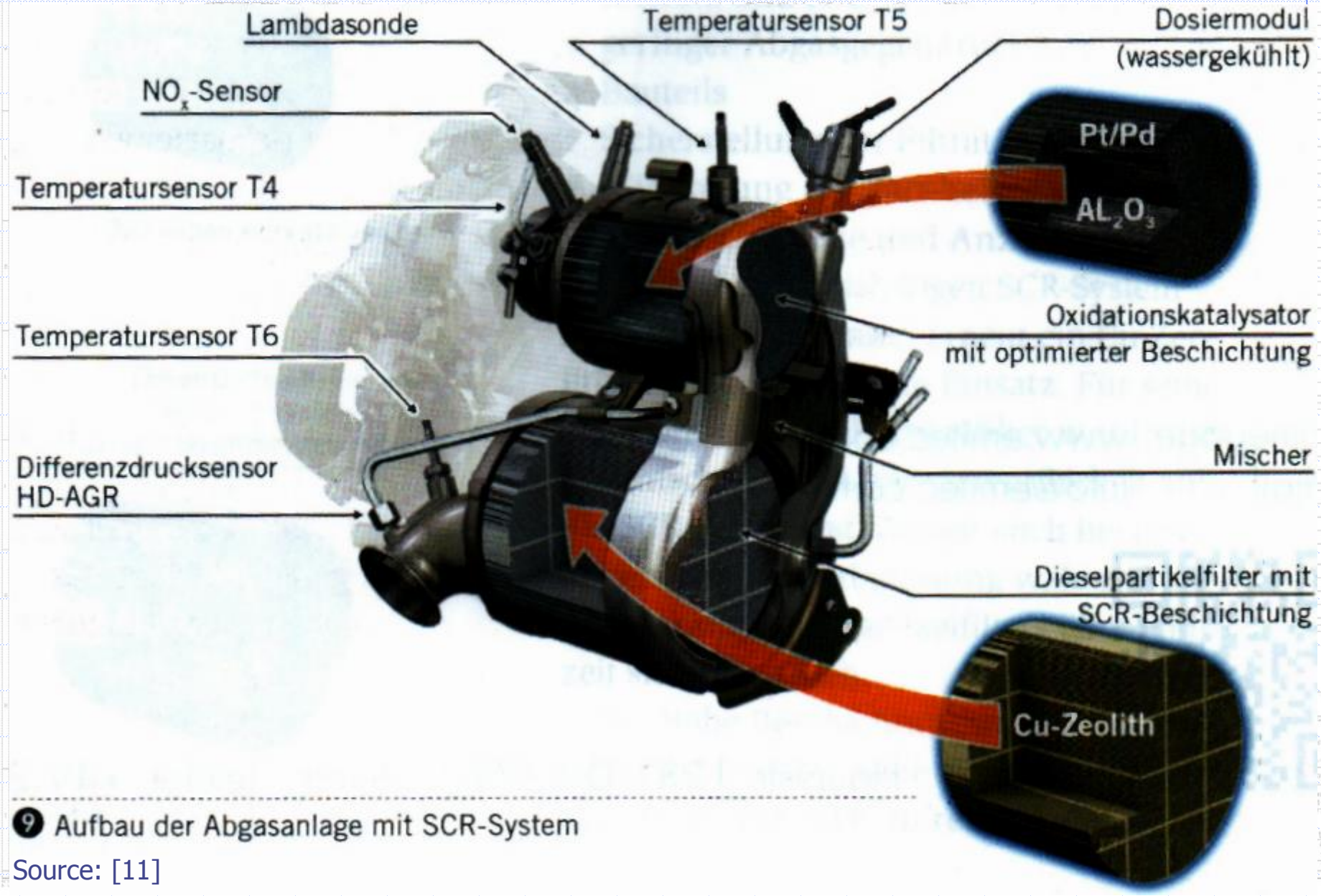
Source: [4]

NSC vs SCR



Source: [11]

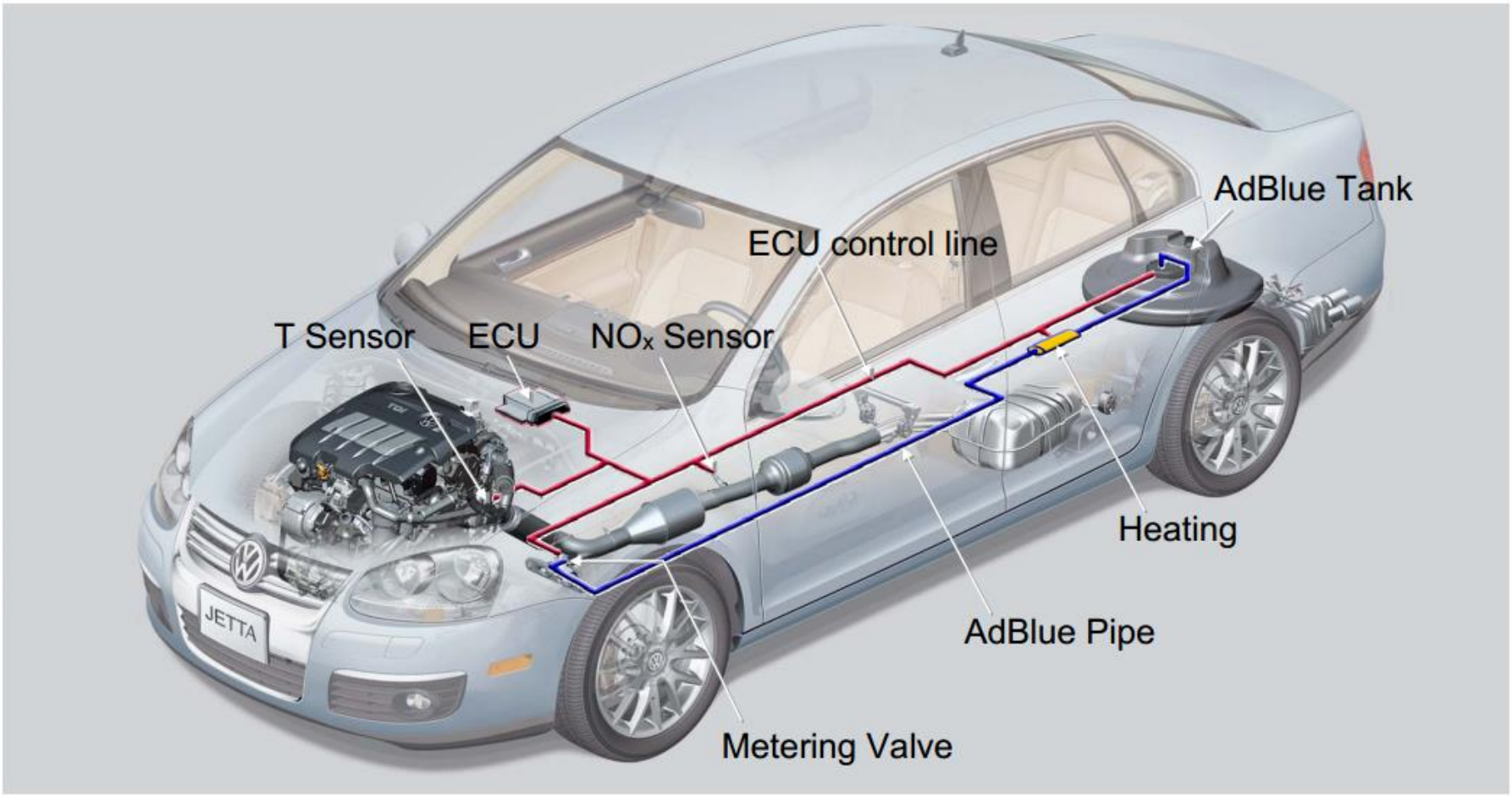
NSC vs SCR



❾ Aufbau der Abgasanlage mit SCR-System

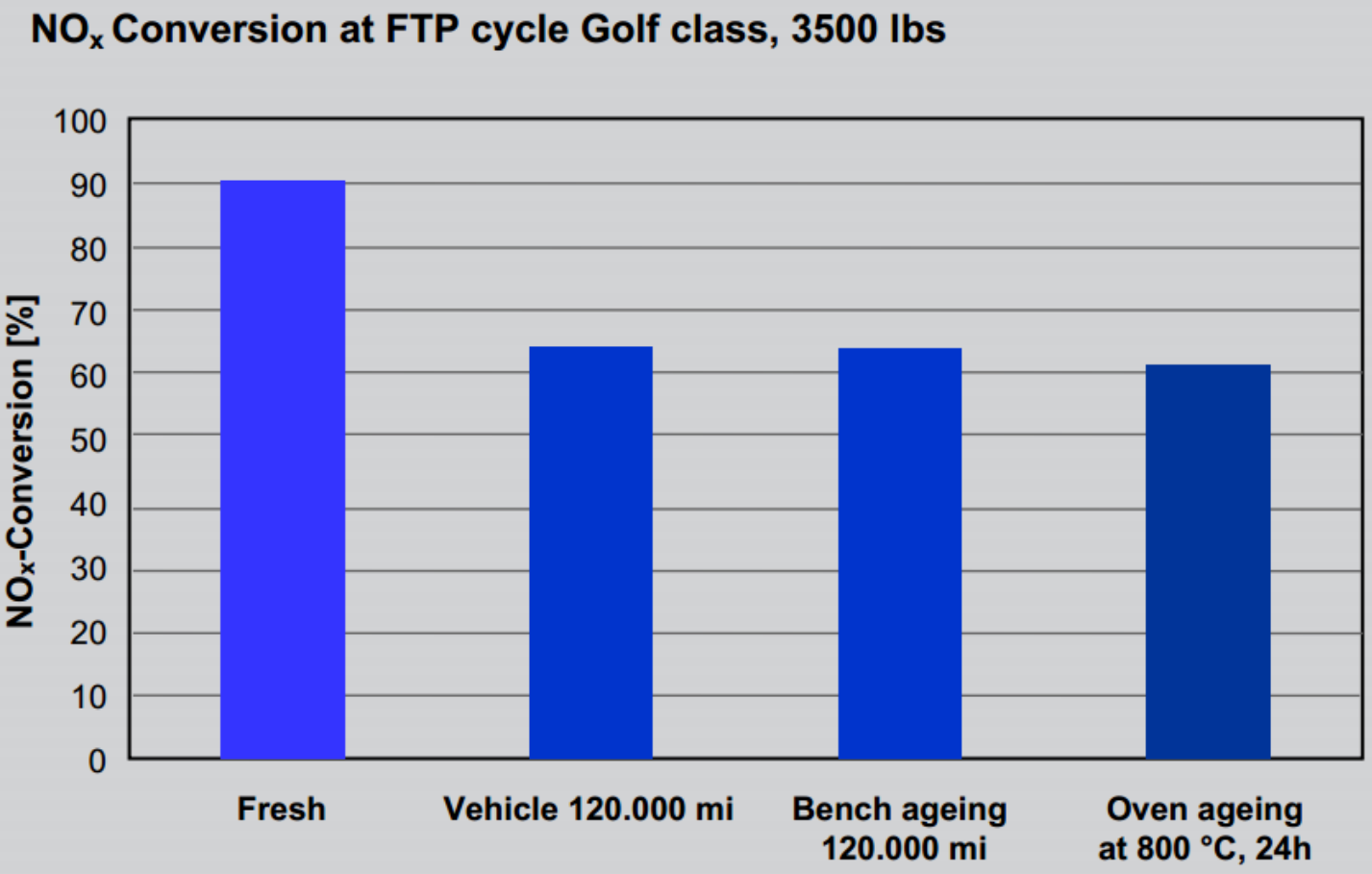
Source: [11]

SCR-System Structure



Source: [3]

Correlation between Bench and Vehicle Ageing



Source: [3]

What is DEF?

- Diesel Emission (Exhaust) Fluid (AdBlue™)
  - Internationally standardized solution containing 32.5% high-purity urea and rest deionized water
  - Pure urea is a clear, colourless solid crystal
  - SCR does not use urea directly!

$$(NH_2)_2CO \rightarrow NH_3 + HNCO$$

$$HNCO + H_2O \rightarrow CO_2 + NH_3$$

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$

$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$$

$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

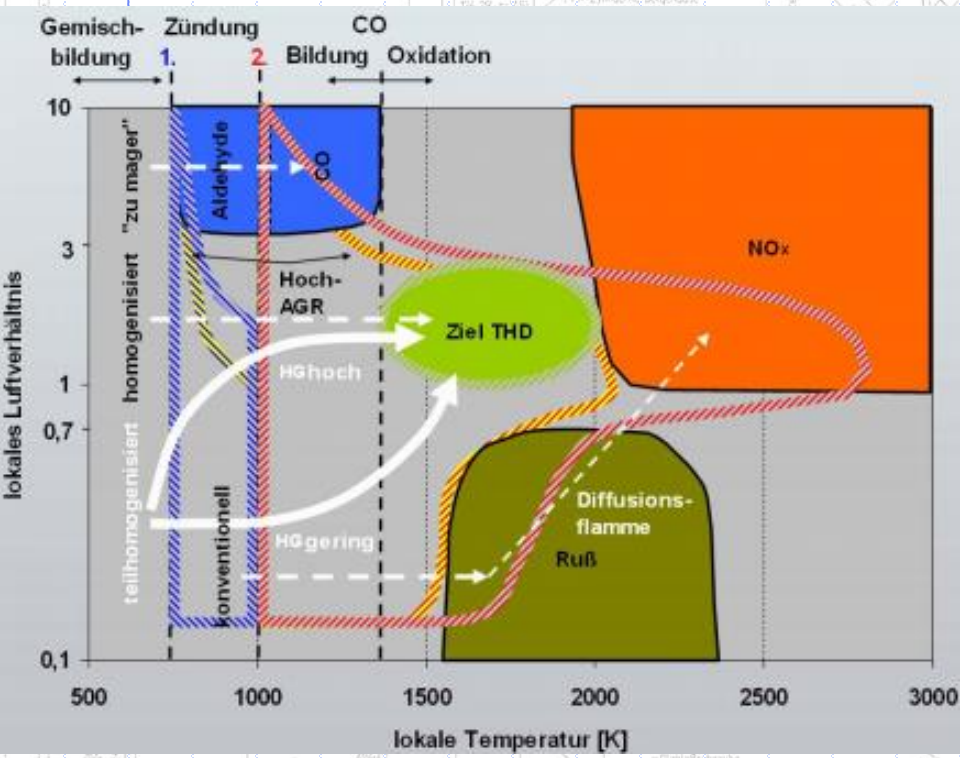
  - DEF freezes at 12°F (-11°C)

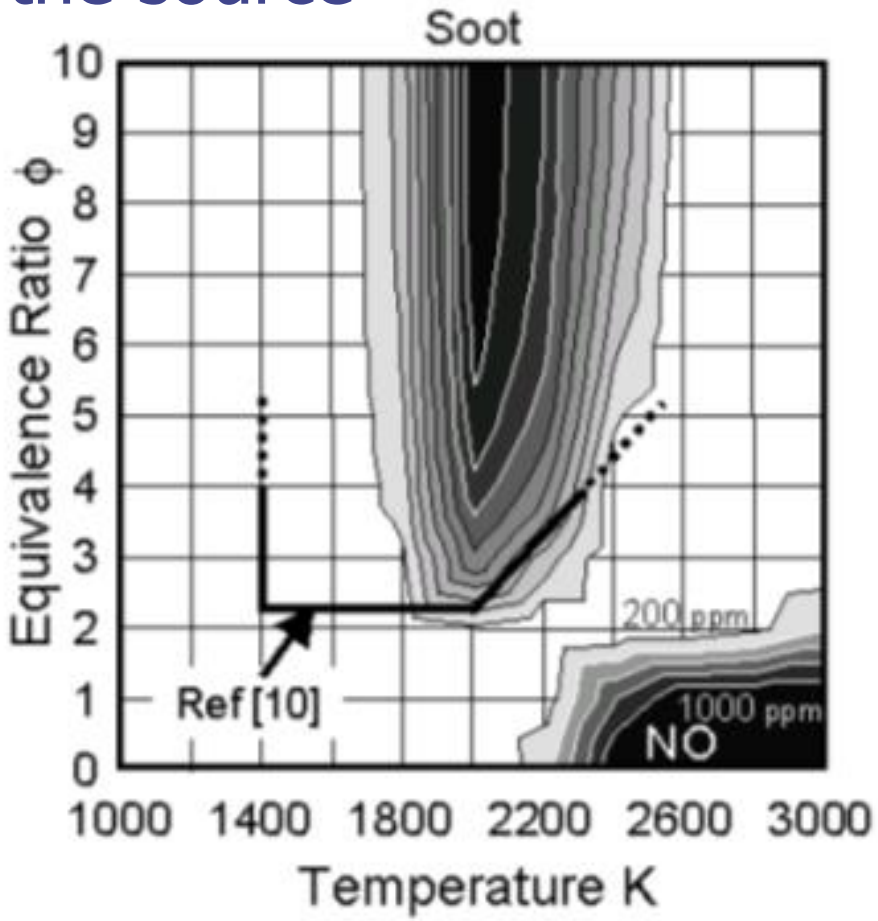
Other Ways to Reduce NOx

- Emissions reduction from the source combustion process
  - Involves lots of EGR (60-80%) and highly sophisticated control over air flow and injection events
  - Many names used in industry: PCCI (premixed charge compression ignition), HCCI (homogenous charge compression ignition), CAI (controlled auto-ignition), LTC (low temperature combustion, flameless combustion, "smokeless Diesel"

Other Ways to Reduce NOx

- We have the know-how to reduce emissions drastically from right at the source

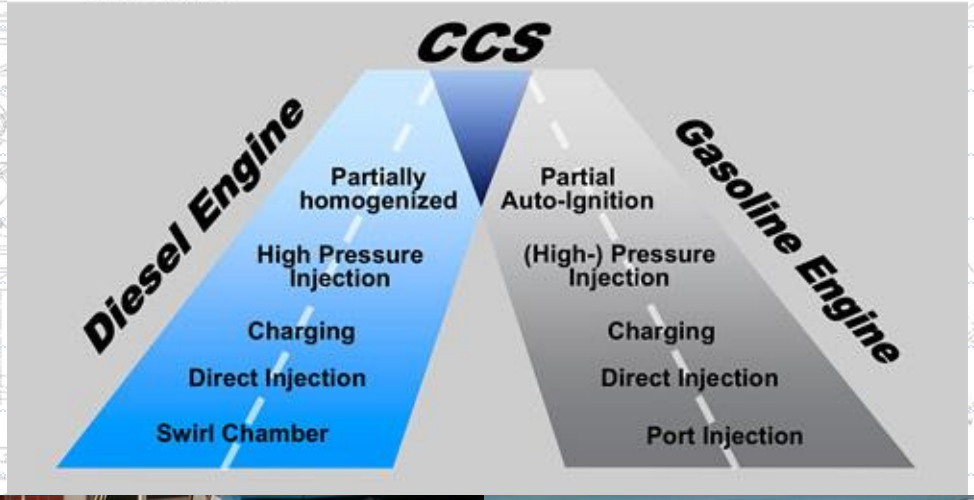


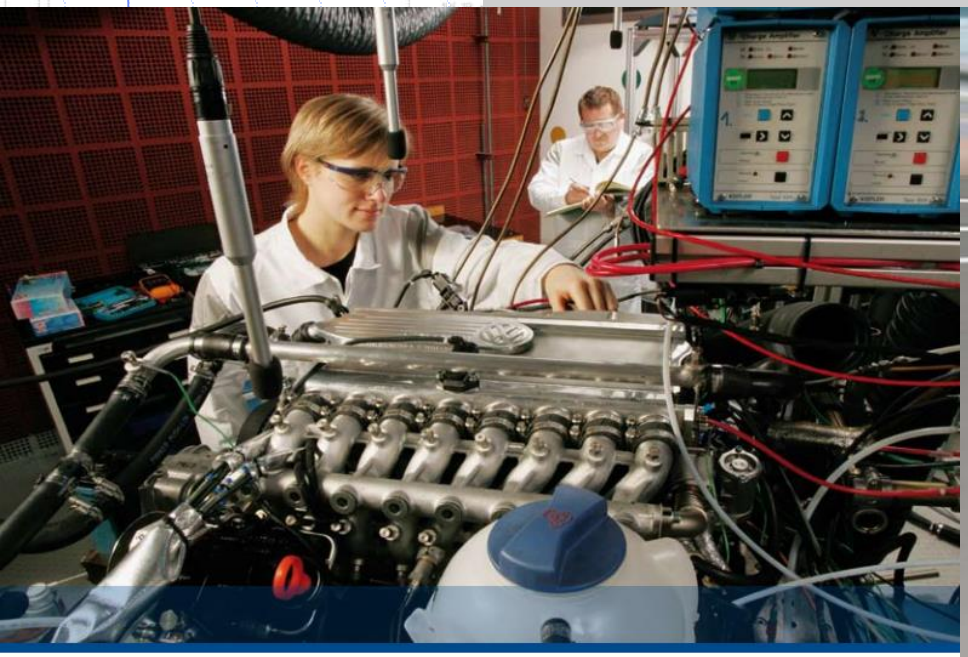


Source: [6], [7]

Combined Combustion System
Synergies

Sources: [9], [10]





The CCS Combustion System from Volkswagen

Summary

- SCR allows meeting emissions standards without the fuel economy penalty of NSC
- Minimal increase in running costs
  - DEF much cheaper than Diesel fuel
  - Amount of DEF consumed much less
- Increased complexity of SCR system
  - Failure modes – heating system, level sensors
  - Topping up, maintenance issues
- Amount of DEF consumed depends on driving
  - Don’t worry about running the DEF dry and getting stranded

Summary

- Biggest enemies of SCR system:
  - HEAT (Excessive EGT) – tuning beware
  - COLD (Freezing DEF, defective heating system)
  - Fuel quality (sulfur, contamination)
  - Engine oil (SAPS level)
  - Disabling or removal
- SCR and DEF ARE NOT MYSTERIOUS!!!

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