



SCR SYSTEMS FOR HEAVY DUTY TRUCKS: PROGRESS TOWARDS MEETING EURO 4 EMISSION STANDARDS IN 2005

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ABSTRACT

Emissions of diesel engines contain some components, which support the generation of smog and which are classified hazardous. Exhaust gas aftertreatment is a powerful tool to reduce the NOx and Particulate emissions.

The NOx-emission can be reduced by the SCR technology. SCR stands for Selective Catalytic Reduction. A reduction agent has to be injected into the exhaust upstream of a catalyst. On the catalyst the NOx is reduced to N₂ (Nitrogen) and H₂O (Water). This catalytic process was developed in Japan about 30 years ago to reduce the NOx emission of coal-fired power plants. The first reduction agent used was anhydrous ammonia (NH₃).

SCR technology was used with diesel engines starting mid of the 80s. First applications were stationary operating generator-sets. In 1991 a joint development between DaimlerChrysler, MAN, IVECO and Siemens was started to use SCR technology for the reduction of heavy duty trucks. Several fleet tests demonstrated the durability of the systems. Today, SCR technology is the most promising technology to fulfil the new European Regulations EURO 4 and EURO 5 being effective Oct. 2005 and Oct. 2008. The efficient NOx reduction of the catalyst allows an engine calibration for low fuel consumption. DaimlerChrysler decided to use the SCR technology on every heavy duty truck and bus in Europe and many other truck manufacturers will introduce SCR technology to fulfil the 2005 emission regulation.

The truck manufacturers in Europe agreed to use aqueous solution of Urea as reducing agent. The product is called AdBlue. AdBlue is a non toxic, non smelling liquid. The consumption is about 5% of the diesel fuel consumption to reduce the NOx emissions. A small AdBlue tank has to be installed to the vehicle. With an electronically controlled dosing system the AdBlue is injected into the exhaust. The dosing system is simple and durable. It has proven its durability during winter and summer testing as well as in fleet tests.

The infrastructure for AdBlue is under evaluation in Europe by Urea Producers and Mineral Oil companies to be readily available in time. Urea is one of the most common chemical products in the world and the production and the distribution very much experienced. However, a pure grade is needed for automotive application and requires special attention.



This paper shall give an overview of the progress towards meeting Euro 4 emission standards using SCR denoxation technology with diesel engines. An insight is given to some of the extreme testing procedures which the systems and components are exposed to. Furthermore the progress in urea distribution in Europe to date will be shown. The outline of the paper is as follows:

I. Introduction

II. SCR Technology

- »Operation: Principles and Advantages
- »Aqueous Urea Solution (AdBlue) as the Reducing Agent

III. SCR System Components

- »Overview
- »Requirements

IV. Methodology for meeting Required Standards

- »Component Testing
- »Vehicle Testing

V. AdBlue (Urea Solution) Distribution Approach

VI. Summary and Outlook

I. INTRODUCTION

By using SCR exhaust aftertreatment technology for diesel engines, the future European Emission Targets can be met by heavy duty engines, like shown in **Figure 1**.

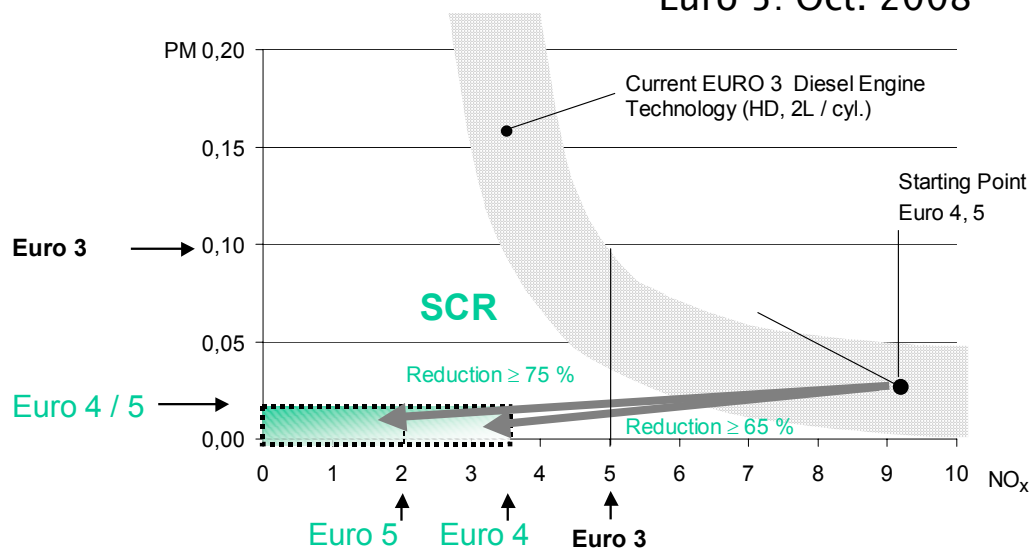
EURO 4 will start from 1st October 2005 for all new homologated engines and from 1st October 2006 for all engines sold.

EURO 5 will start from 1st October 2008 and from 1st October 2009 respectively.

Figure 1: Engine and Aftertreatment Strategy using SCR-Denoxation for Euro 4/5 Emission Targets

(Emissions: g/kWh, Test cycle ESC)

Euro 4: Oct. 2005
Euro 5: Oct. 2008





Using SCR technology for aftertreatment of NO_x gives the potential to adjust the engine combustion in a way for minimum fuel consumption and particulate matter. By applying selective catalytic reduction the emission targets of 3.5 g/kWh NO_x for 2005 and 2 g/kWh NO_x for 2008 can be reached with overall catalytic efficiency rates of more than 65% and 75 %.

II. SCR TECHNOLOGY

Because SCR technology requires a reducing agent it was essential to jointly agree on one product for Europe. In September 2001 the European Truck Manufacturers CEOs decided to use aqueous urea solution for SCR technology. The following principle reasons were stated:

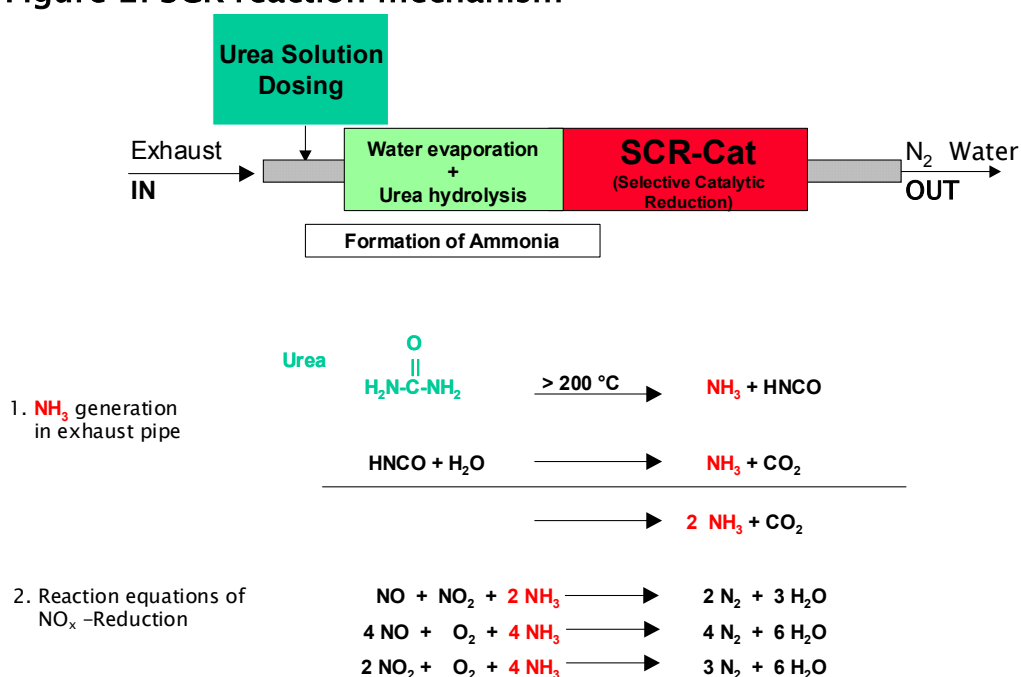
- Availability of urea
- Urea non hazardous product
- Experience with urea SCR
- SCR catalyst production very likely to be extended to CV OEM demand
- Commitment of European Urea Producers to provide high quality grade
- Potential that urea SCR might also be implemented for light duty or passenger car application

It was stated, that the focus of the European engine manufacturers is a joint infrastructure for Urea which has the potential to be extended to light duty vehicles and passenger car applications for meeting future legislation. Furthermore the CV industry will coordinate their view with the mineral oil industry, logistic companies and other stakeholders in developing an efficient Urea infrastructure.

The European trade name of aqueous urea solution for automotive application is “AdBlue”. AdBlue is specified in the German standard DIN 70070. It will be submitted to ISO standardisation shortly.

Some basics of the SCR Selective Catalytic Reduction Process are shown in **Figure 2**.

Figure 2: SCR reaction mechanism



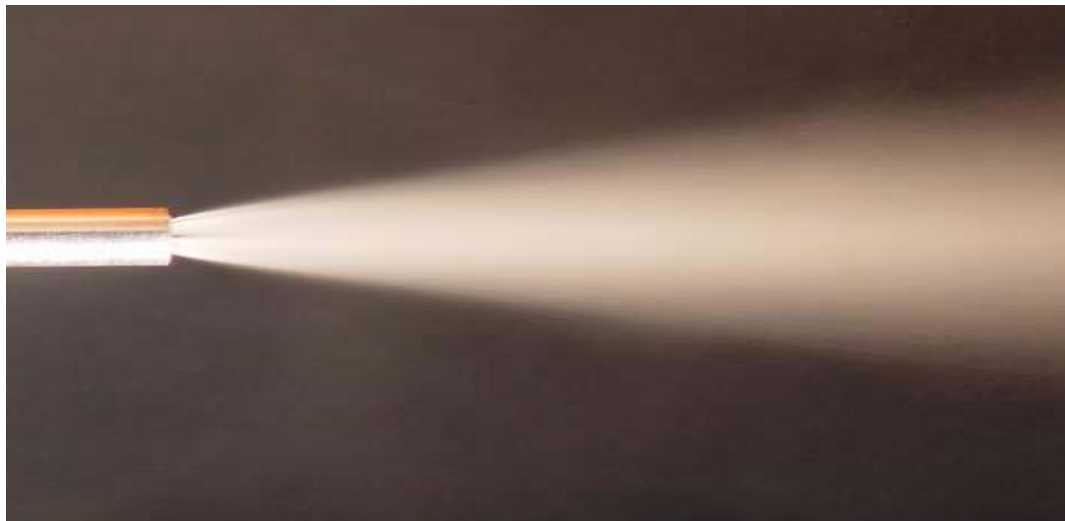


NO_x is reduced to nitrogen, N₂, and water on the SCR catalyst with presence of ammonia, NH₃.

NH₃ is formed from urea at elevated temperatures and by hydrolysis, shown green in the middle part of the diagram. The schematic shows that urea (green) is mixed with the exhaust upstream of the SCR catalyst. So upstream of the catalyst urea decomposes to ammonia and on the catalyst the ammonia NH₃ makes chemical reactions together with the exhaust gases to form nitrogen N₂ and water, H₂O.

A key aspect for the SCR operation is a defined spray of urea which can be metered reproducibly at all typical operation conditions. **Figure 3** shows a spray of urea aerosol as is sprayed into the exhaust.

Figure 3: Key for SCR operation:
 the Spray of Urea aerosol in the exhaust
 →definedly and reproducibly metered for less
 than 0.1 seconds dwell time



III. SCR SYSTEM COMPONENTS

Figure 4 shows an SCR system consisting of the following parts:

- Urea Aerosol Injection:

- »Urea Supply Unit, Compressed Air Controller, Dosing Unit
- »Sensors
- »Nozzle
- »Electronic Control Unit

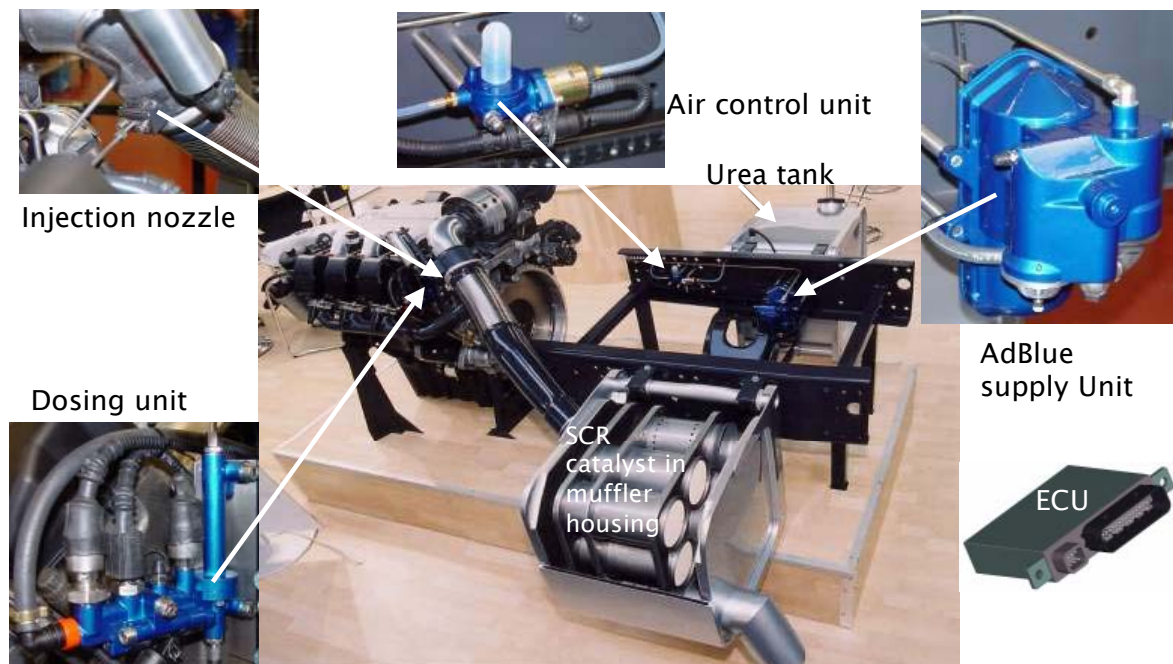
- Muffler Unit:

- »Catalytic Converter, Temperature Sensors
- »Housing optimized for
 - Mechanics, fixation to the vehicle frame
 - Flow Distribution



- Acoustics
- Material--Production technology
- Urea on board storage, preparation and flow
 - »Urea tank
 - »Urea pipes
 - »Heating of tank and pipes
 - »Level Sensor, Temperature Sensors

Figure 4: PUREM SCR System



All these components are mounted at their best individual position to the vehicle frame or to the engine. Very much attention is paid to the dosing unit which is mounted at the engine to be very close to the injection nozzle which is typically downstream of the turbocharger.

The urea supply unit is mounted at the vehicle frame close to urea tank. The SCR catalysts in muffler housing contains as well the catalysts as well it is optimised for the noise attenuation issue.

SCR SYSTEM COMPONENTS' REQUIREMENTS

Looking at the requirements which a SCR system has to meet, as shown in **Figure 5**, there is the key OEM restrictions given by durability which is 1 Mio. km tested also under bad road testing conditions and component shaking conditions. The temperature range is -40°C to $+80^{\circ}\text{C}$ for parts fixed to the frame and up to $+140^{\circ}\text{C}$ for components fixed to the engine. The dosing precision of urea needs to be in the range of $\pm 5\%$ under both static and dynamic operation conditions. The catalytic efficiency for EURO 4 has to be more than 65 % for 10.000 h which is equivalent to 500.000 km.

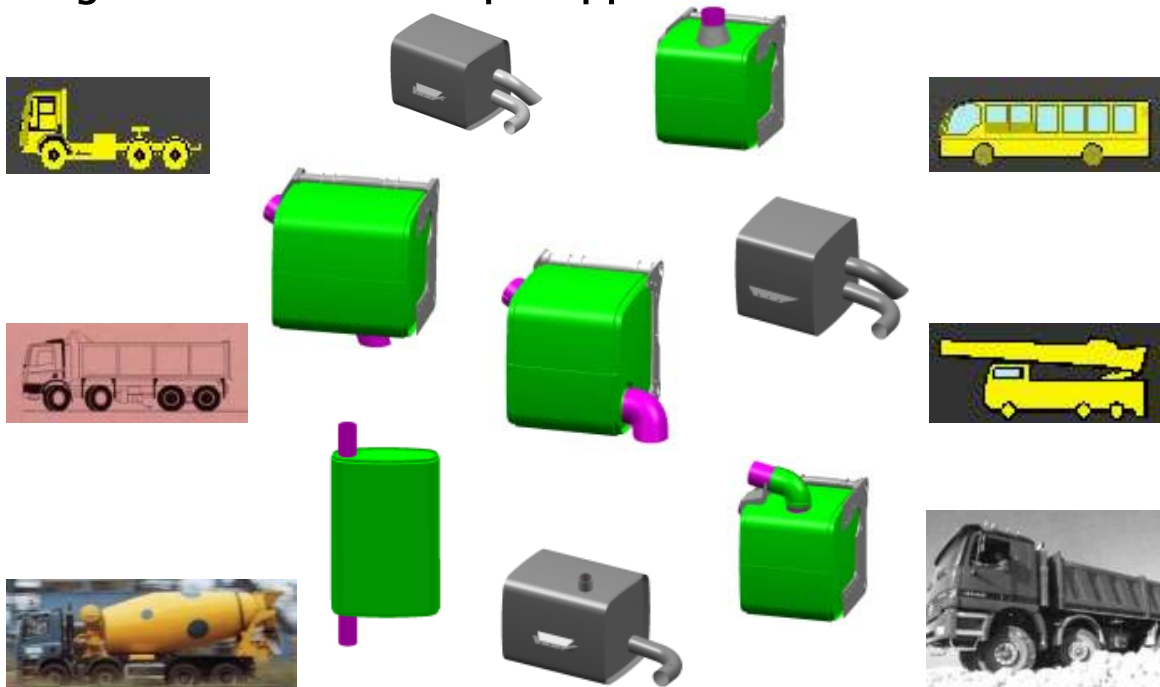


Figure 5: Key OEM Requirements to be met by the SCR System

- » Durability:
 - 1,000,000 km (620,000 mi)
 - Truck setup Bad Road testing
 - Component Shaker Testing
- » Temperature:
 - Components fixed to frame - 40 °C (-40 F) ... + 80 °C (+176 F)
 - Components fixed to engine max. 140 °C (285 F)
- » Dosing precision:
 - + / - 5 weight %
 - Static and dynamic operation
- » Catalytic efficiency for Euro 4:
 - >65% for 10,000 hr, equivalent 500,000 km (310,000 mi)

Another very important aspect which has to be considered is the device variability. The designs must be applicable for multiple application which is shown in **Figure 6**.

Figure 6: Key Requirement: Device Variability Design suitable for multiple application



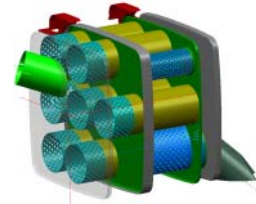
The communality parts consideration is shown in **Figure 7**. Under different exhaust gas flow directions, like straight through, vertically out or side out the parts need to be as “common” as possible in order to have as little design variation as possible.



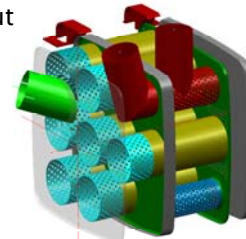
Figure 7: Key Requirement: Common Catalysts and Housing



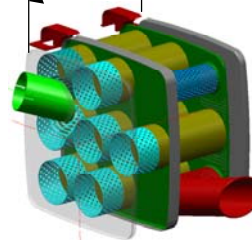
Straight through



Vertically out



Length1 /
Length2



Side out

Of course the necessary size of the exhaust aftertreatment system needs much of the vehicle designers consideration too. As consequence, a redesign may be necessary to find the required space for the aftertreatment system, like shown in **Figure 8**. Battery tray, air tanks and auxiliaries are removed from their standard position which is typically between cabine and rear axle to a new place. Shown here is 2003 Mercedes Benz Actros model with rearrangement of these vehicle components at the middle part of the chassis frame between the rear axle. Hence, the modification of Battery tray- and Air tank placement provides the necessary space for the aftertreatment unit including Urea tank for Euro 4 and Euro 5 systems .

Figure 8: Key Requirement – Meet Design Constraints of Exhaust System

←Driving direction, left side view





IV. METHODOLOGY FRO MEETING REQUIRED STANDARDS

Looking on the testing methodology of components there is component testing on different test benches on the one side and vehicle testing on the other side. In **Figure 9** the component testing of a SCR catalyst housing on a 3 axis hydropulse test banch is shown. With this test a simulation using a bad road test course acceleration pattern is carried out.

**Figure 9: Testing Methodology –
SCR System on 3-axis Hydro Pulse test bench (cold)**

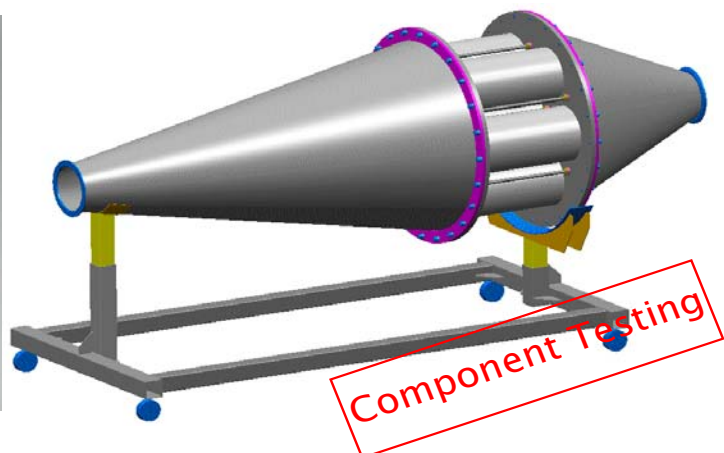
Simulation by Bad Road Test Course Acceleration pattern



In **Figure 10** a device for catalyst testing is shown. Here sleeve catalysts are mounted in a test

**Figure 10: Catalyst Testing
(reference and aging test)**

- Aging with 1,000, 6,000 and 10,000 hours



Argillon based test bench design



rig which is designed in such way that the exhaust gases are distributed equally over the several sleeve catalysts. By this arrangement aging with 1.000 h, 6.000 h and 10.000 h is possible insuring the equal flow conditions through the catalysts.

The component testings are accompanied by full size vehicle testings under extreme climatic conditions. **Figure 11** shows winter testing at -34°C in north of Finland. The components are covered with ice and snow as shown in **Figure 12 and 13**.

Figure 11: Winter Testing – JAN. 2003, Rovaniemi Finland, -34°C (-29°F)



Figure 12: AdBlue Supply Unit mounted next to AdBlue Tank





Figure 13: Air Regulator and AdBlue Tank



Winter Testing

Also the aqueous urea solution filling stations need to be tested under the arctic climate conditions like shown in **Figure 14**.

Figure 14: AdBlue filling stations' arctic experience



Winter Testing



The other temperature extreme was tested during summer testing. **Figures 15-17** show photographs taken from summer testing 2003 in the south of Spain in an altitude range from sea level to 2.100 m and temperature ranges from 32 °C up to 42 °C. The trucks are operated under extreme conditions when driving up the mountains to these altitudes. The urea solution filling station, **Figure 17**, is also tested and needs to prove its reliability in summer climate.

Figure 15: Summer Testing – July 2003, Sierra Nevada, Spain



Altitude range: From Sea level to 2,100 m (6,890 ft)

Temperature: 42 °C (108 F) Sea Level, 32 °C (90 F) Mountainside

Figure 16: Dosing Unit, Urea Solution Injection Nozzle



Dosing Unit



Urea Solution (AdBlue) Nozzle

Summer Testing



**Figure 17:
Urea Solution
(AdBlue)
Filling Station**



The testings rationale and outcome are:

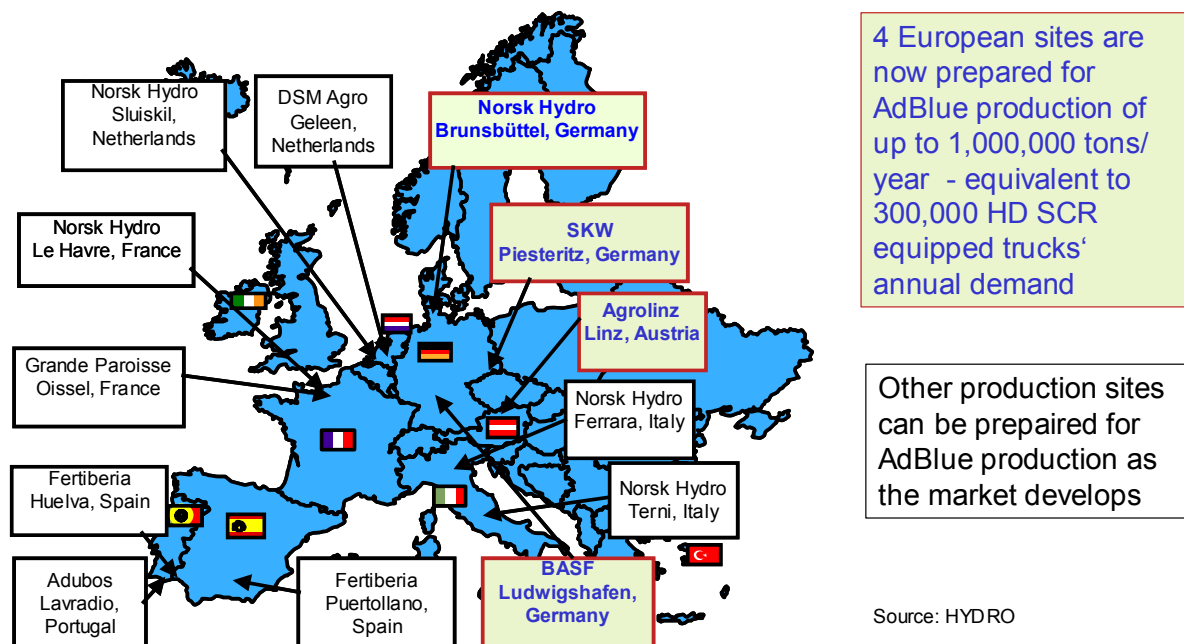
- Winter and Summer Tests provide Real-life Data as to the interaction of the SCR System and the vehicle: Climate, Air Flow turbulence, Dynamic/ Vibrational effects
- Basis for realistic, application specific test procedures
- Test bench provides weak spot detection and traceability in an accelerated timeframe
- SCR system design can be observed in detail and optimized as part of vehicle testing process
- This contributes to real life development and testing and thus to an accelerated time frame



V. AdBlue (UREA SOLUTION) DISTRIBUTION APPROACH

The Western European Urea Production Locations are shown in **Figure 18**. They are widely spread over the region. Already to date there are the 4 companies and production plants, shown in blue color, which can be prepared for an AdBlue production of up to 1 Mio. ton/year. This is equivalent to the annual demand of 300.000 heavy duty trucks equipped with SCR. Other production sites can be prepared for the AdBlue production as the market develops.

Figure 18:
2003 Western European Urea production locations



The AdBlue distribution in Europe is based on a 3 step concept as shown in **Figure 19**.

- In the first step the truck fleet depots where about 70 % of the diesel fuel is filled will be equipped with AdBlue dispensers in kind of totes.
- In the second step the truck stops will be equipped with totes, followed later by rigid tanks.
- In the third step major public gas stations will be equipped with rigid tanks.

The distribution concepts are announced by different organisations, like large chemical distributor companies, Raiffeisen cooperatives and Mineral Oil Industry.

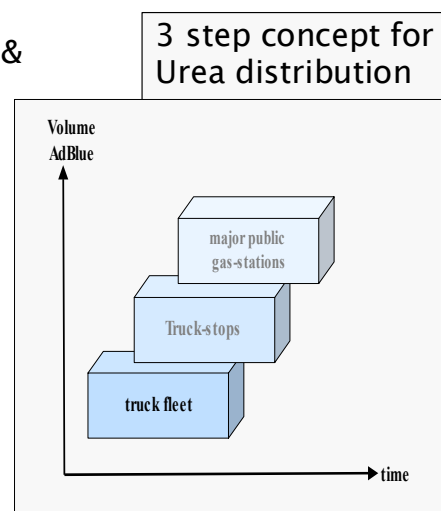


Figure 19: AdBlue Distribution in Europe

Univar, a large Chemical Distributor, has announced their proposed Distribution Plans. Univar provides Storage & Dispensing Units, European Wide Distribution Network, rational & Technical Support

Raiffeisen Cooperative, large distributor of Urea containing fertilizer liquids announced their proposed Distribution Concept. Agriculture Cooperatives provide Diesel fuel Filling stations with distribution to rural areas

German Mineral Oil Industry commissioned Scientific Association DGMK study (to be published in 09/03, Report #616-1). Decisions will be based on the findings of the report



Already to date some public AdBlue (Urea solution) filling stations are operating in Germany, like shown in the following table. These stations are installed for gaining handling and operation practise early enough.

Public AdBlue Filling Stations 2003 in Germany

<u>Operator</u>	<u>Location</u>
OMV	Dingolfing/ Munich
Raiffeisen Cooperative	Münster
TotalFinaElf	Berlin (Oct. 2003)



VI. SUMMARY AND OUTLOOK

This paper was to give an update on the work on SCR technology development to be ready for series application for 2005 emission legislation for heavy duty vehicles in Europe.

Summarizing it can be stated, that

- Euro 4 SCR requires Leading Edge Solution
- SCR is on schedule to be launched for 2005 Series
- Euro 4 SCR Technology provides the basis for achieving stringent future emission targets
- The introduction of additional sensors allows for further optimization
- Sensors to detect NH₃, NO_x, Urea are currently under development
- Major International Producers are committed to supplying Quality Grade Urea (AdBlue)
- AdBlue Distribution is a Reality in Europe today