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Solid ammonia technology for near-zero polluting diesel vehicles

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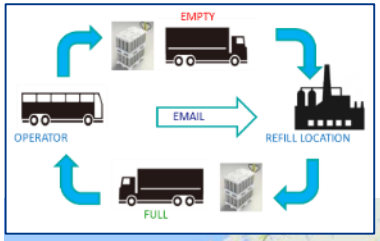
March 2018

VERT Forum - 2018

Amminex company intro

- **Amminex is a Danish clean-tech company; spin-off from university**
- **Since December 2016: Daughter company of Faurecia**
- **Core technology: ASDS Solid ammonia for optimal SCR function**
- **HQ, R&D and production in Denmark**
- **ASDS launched for emissions upgrade of trucks/buses; proven for LD/LCV**
- **Euro VI-equivalent retrofit fleets:**
  - >300 in Cph/Scandinavia
  - 120 → 900 in London
  - ~50 million km so far…
- **Cartridge refill and distribution in operation**
- **Ready for Germany**
- **Ready for OEMs for Ultra-Low NOx programs…**



Supply in Northern Europe from Denmark

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Amminex is daughter company of Faurecia: A global automotive industry leader

HIGHLIGHTS 2016

€15.6 Billion
Value-added Sales*
€18.7 Billion
Total Sales

35
Countries

30
R&D Centers

98 700
Employees

225
Sites worldwide

6 000
Engineers
& Technicians

** Value added sales : Total Sales w/o Monoliths*

FINANCE, TECHNOLOGY / 13/12/2016

Faurecia acquires Amminex to accelerate efficient nitrogen oxide reduction for passenger and commercial vehicles

Faurecia today announced that it has increased its participation in the Danish company Amminex to 91.5% through a share purchase. Amminex has developed an Ammonia Storage and Delivery System (ASDS™) which has demonstrated its efficiency to almost completely eliminate nitrogen oxide (NOx) pollutants from diesel engines.




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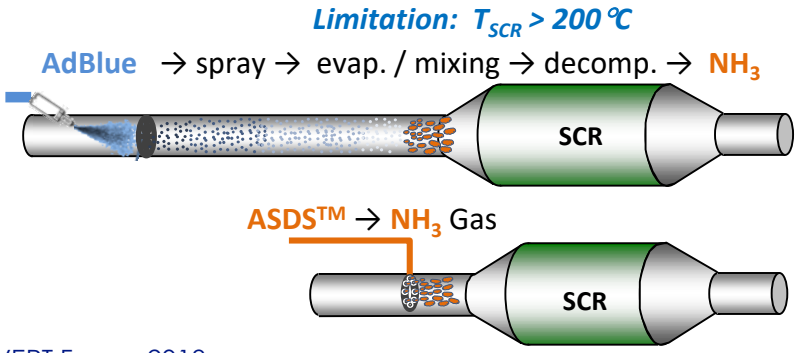
ASDS™ Technology

- **AdAmmine™ is the core material in all products**
  - Solid, safe ammonia storage ("ammonia in salt")
  - 2x volumetric capacity compared to lia. urea)
  - Cartridge not pressurized at room temperature
- **ASDS™ provides ammonia dosing on-demand**
  - Plug & play system replacing an AdBlue system
  - Controlled release:
    Pure NH_3 on-demand into exhaust line
- **Direct ammonia dosing: "Always-on SCR"**
  - Enables the full conversion of the SCR catalyst, also at temperatures below 200°C where DEF dosing is critical

ASDS™ for commercial vehicles



AdAmmine™
Releases ammonia via
Ammonia **S**torage and
Delivery **S**ystem

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

Always on: T_{SCR} > 120 °C

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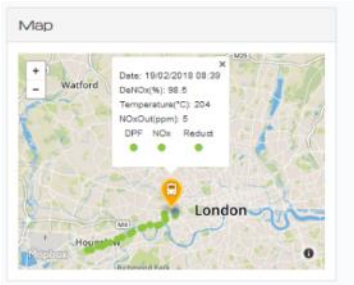
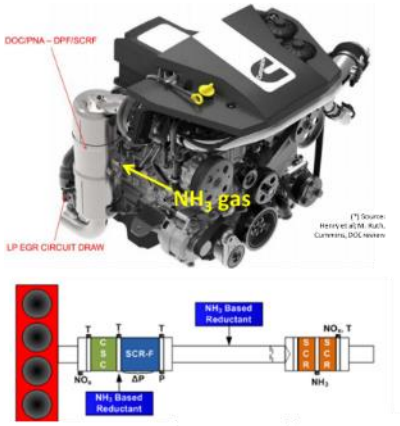
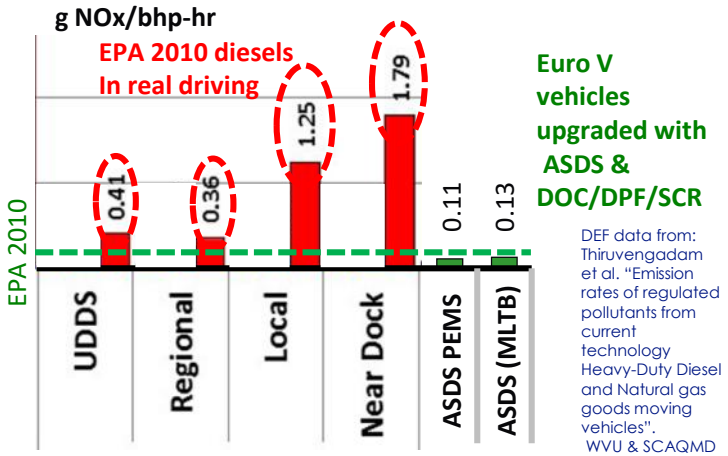
Performance examples: Light and heavy vehicles

- **OEM passenger cars / SUV / Pick-up truck segment**
  - Euro 6d: Below 40 mg/km proven on cycle and in PEMS testing
  - For China NS-6b, less than 50 mg/km proven
  - US Tier2-Bin2 proven with 50% margin w/o heat strategy (Pick-up truck; **10 mg NOx/mile**)
- **Commercial vehicle segment (incl. retrofit):**
  - Euro VI proven on WHTC and low load/speed cycles.
  - Real Driving Emissions below Euro VI NOx:
    - Europe: In-service conformity (with PEMS) proven at <20% engine load
    - US perspective: ASDS has proven high DeNOx performance well below current 250C Not-To-Exceed temperature threshold.
      Outperforms current EPA2010 systems
- **Emissions vs. fuel economy:**
  - DeNOx performance achieved without/ reduced engine thermal management.







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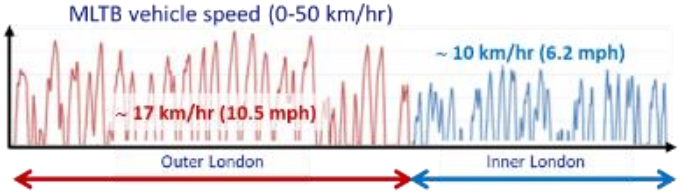
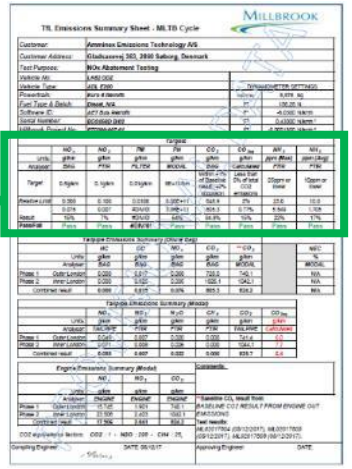
ASDS-upgrade to reach near-zero polluting diesel bus: From 17 g/km to 76 mg NOx/km in London

- **London city bus: ADL Enviro 200**
- **4.5 L Euro V Cummins engine, non-EGR**
  - Fitted with **ASDS** &
  - **DOC/DPF/SCR/ASC exhaust by *Eminox***
- **Emissions on London bus cycle (MLTB):**
  - Engine-out emissions: 17 g NOx/km
  - Tailpipe level: 76 mg NOx/km (< 0.1 g/kWh)
  - 99.6% NOx reduction
  - Ultra-low NO_2
  - N_2O (CO2-eq) less than 1%





Targets								
	NO_x	NO_2	PM	PN	CO_2	CO_{2eq}	NH_3	NH_3
Units:	g/km	g/km	g/km	g/km	g/km	g/km	ppm (Max)	ppm (Avg)
Analyser:	BAG	FTIR	FILTER	MODAL	BAG	Calculated	FTIR	FTIR
Target	0.5g/km	0.1g/km	0.01g/km	6E+11/km	Within +1% of Baseline result (+2% accuracy)	Less than 5% of total CO2 emissions	25ppm or lower	10ppm or lower
Relative Limit	0.500	0.100	0.0100	6.00E+11	848.9	5%	25.0	10.0
	0.076	0.007	#DIV/0!	3.86E+11	805.3	0.77%	5.549	1.705
Result	15%	7%	#DIV/0!	64%	94.9%	15%	22%	17%
Pass/Fail	Pass	Pass	#DIV/0!	Pass	Pass	Pass	Pass	Pass

Euro VI equivalent retrofit req. from Transport for London
- incl. limits on secondary emissions

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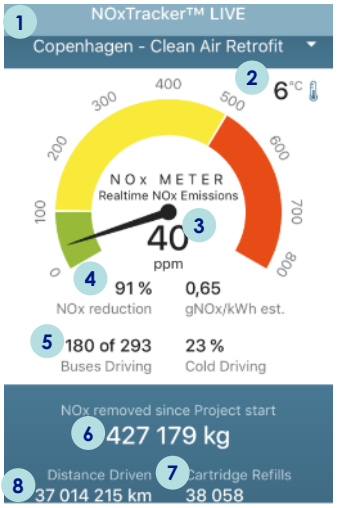
Retrofitting with transparency to customers and local communities in real-time

LIVE NOxTracker™ App

- Convincingly illustrates how ASDS™ is dealing with the NOx problem
- Free to download on the App Store and on Google Play.



Features:

1. City selection
2. Ambient temperature
3. Current NOx emissions (in real-time)
4. NOx reduction
5. Number of vehicles driving
6. Total NOx removal
7. Number of ASDS cartridge refills
8. Distance driven

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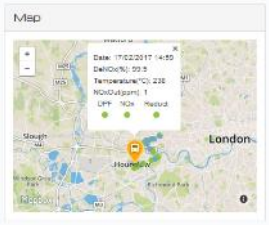
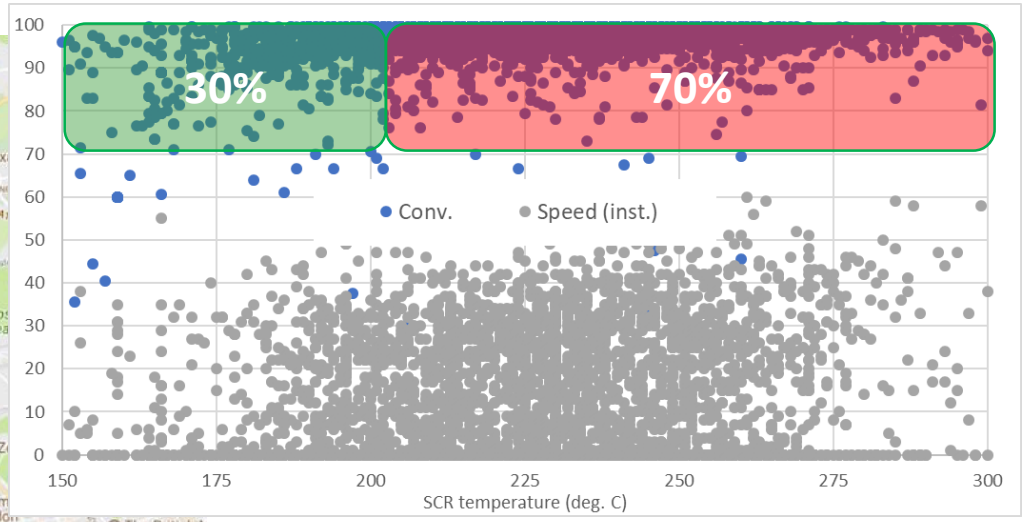
From MLTB to London winter conditions 2017/18

- **One-week data from multiple buses from current Metroline locations in London**
- **Observations:**
  - SCR temperature frequently below "MLTB level"
  - Average SCR-temperature: 225°C
  - 30% operation below 200C
- **Full dosing enabled below 150C: Average conversion above 96%**
- **All-included tailpipe ppm average: 20-25 ppm**

→ **ASDS enables full capture of retrofit investments for health damage cost benefits**





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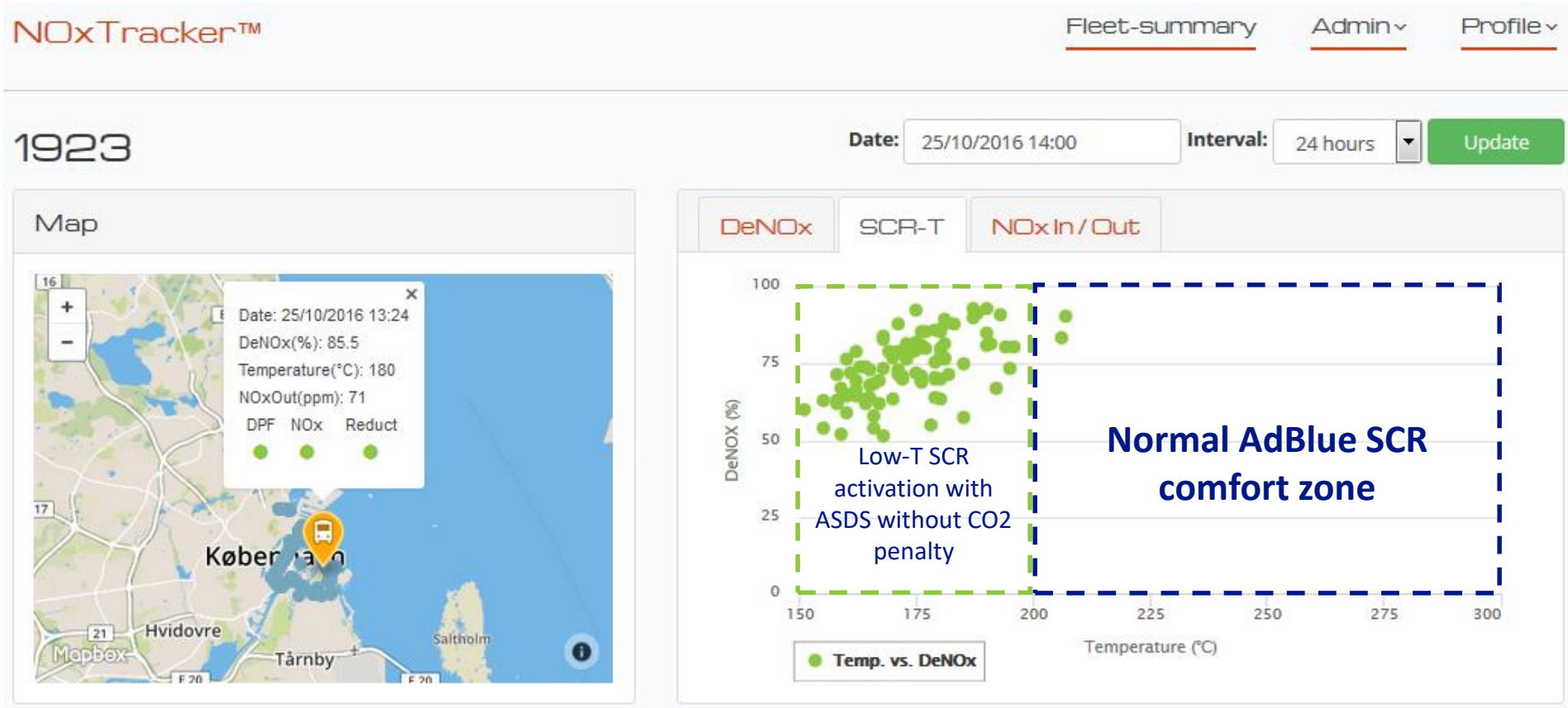
Performance example from Copenhagen: Urban driving with full dosing capability



Typical single-decker bus in Copenhagen/central Europe: Even more often below 200°C SCR temperature than in London; NOx reduction without excessive heat management

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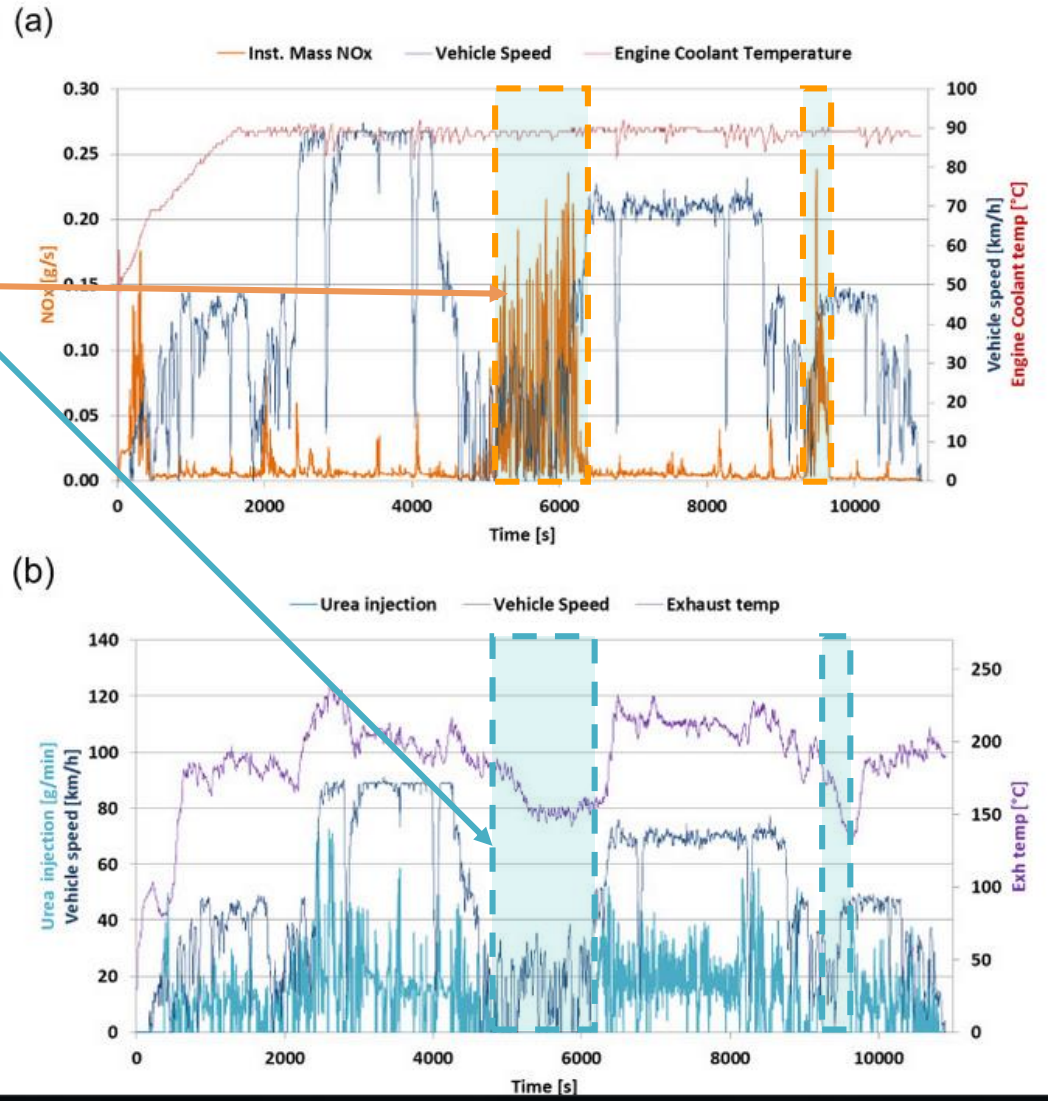
Comparison: New Euro VI vehicles still have dosing limitation during slow-speed city driving

- **Euro VI PEMS Study from JRC:**
  - No AdBlue dosing in slow urban driving
  - → High tailpipe NOx in urban driving



ELSEVIER

Science of The Total Environment

Volume 609, 31 December 2017, Pages 546-555

NO_x, NH_3, N_2O and PN real driving emissions from a Euro VI heavy-duty vehicle. Impact of regulatory on-road test conditions on emissions

Pablo Mendoza-Villafuerte, Ricardo Suarez-Bertoa, Barouch Giechaskiel, Francesco Riccobono, Claudia Bulgheroni, Covadonga Astorga, Adolfo Perujo

Show more

https://doi.org/10.1016/j.scitotenv.2017.07.168

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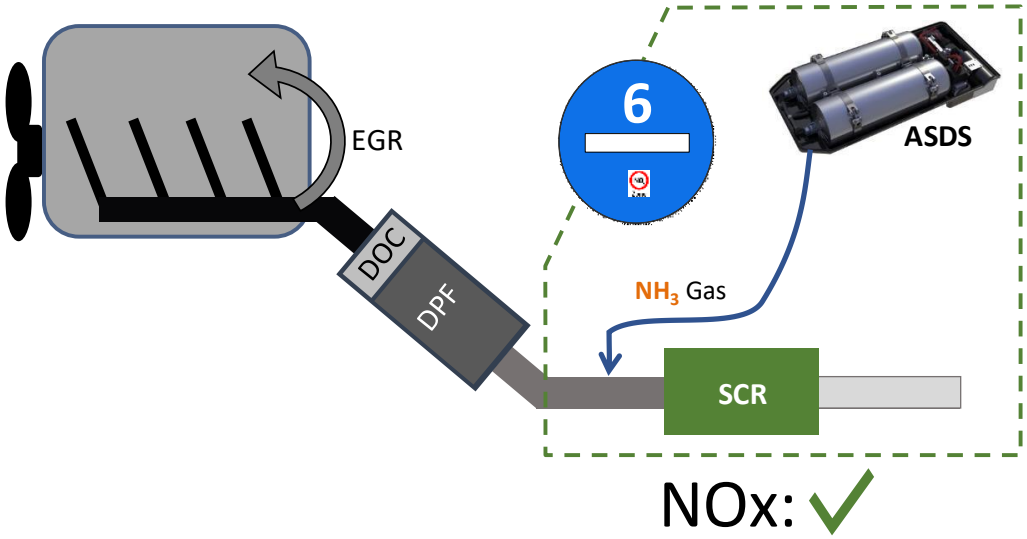
Highlights

- Current boundary conditions lead to underestimation of NO_x emissions.
- High NO_x emissions were observed in urban environments.



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Retrofit of Light-Duty Diesels

Demonstration of light-vehicle retrofit solution for low emission zones

- **Product strategy and main features of ASDS-based solution:**
  - Engine-independent upgrade with low impact on CO_2 (~1% CO_2 from SCR brick & ASDS)
  - Adding under-floor SCR with low back-pressure to the existing Euro 5 DOC/DPF.
  - SCR-reductant to activate the "cold" position of under-floor SCR: LD-ASDS with controller installed in spare-wheel well
  - Stand-alone integration:
    - Not engine recalibration or modification on the certified DOC/DPF or hot-end exhaust in engine compartment.
    - Use existing vehicle power/battery system
  - Customer-friendly solution with up to ~16,000km range
- **Option for smart-phone App for vehicle (existing smart-phone platform for retrofit of CV fleets)**

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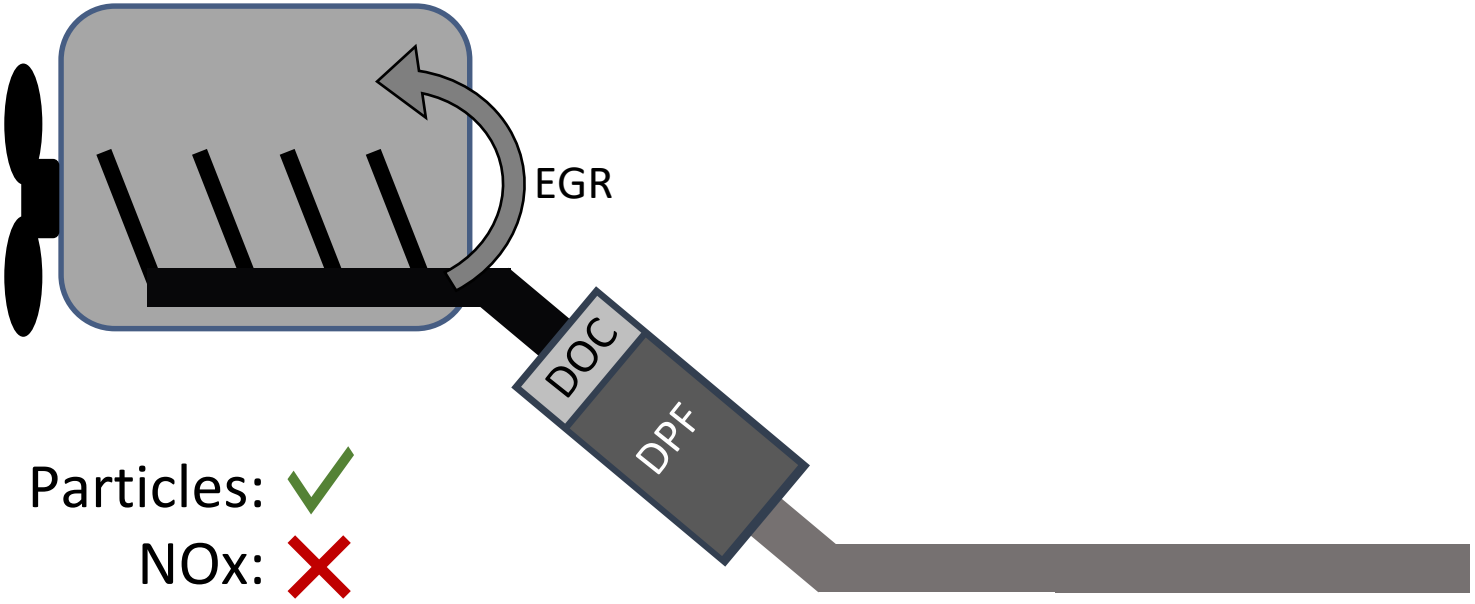
Euro 5: Initial configuration

Euro 5: EGR, DOC & DPF



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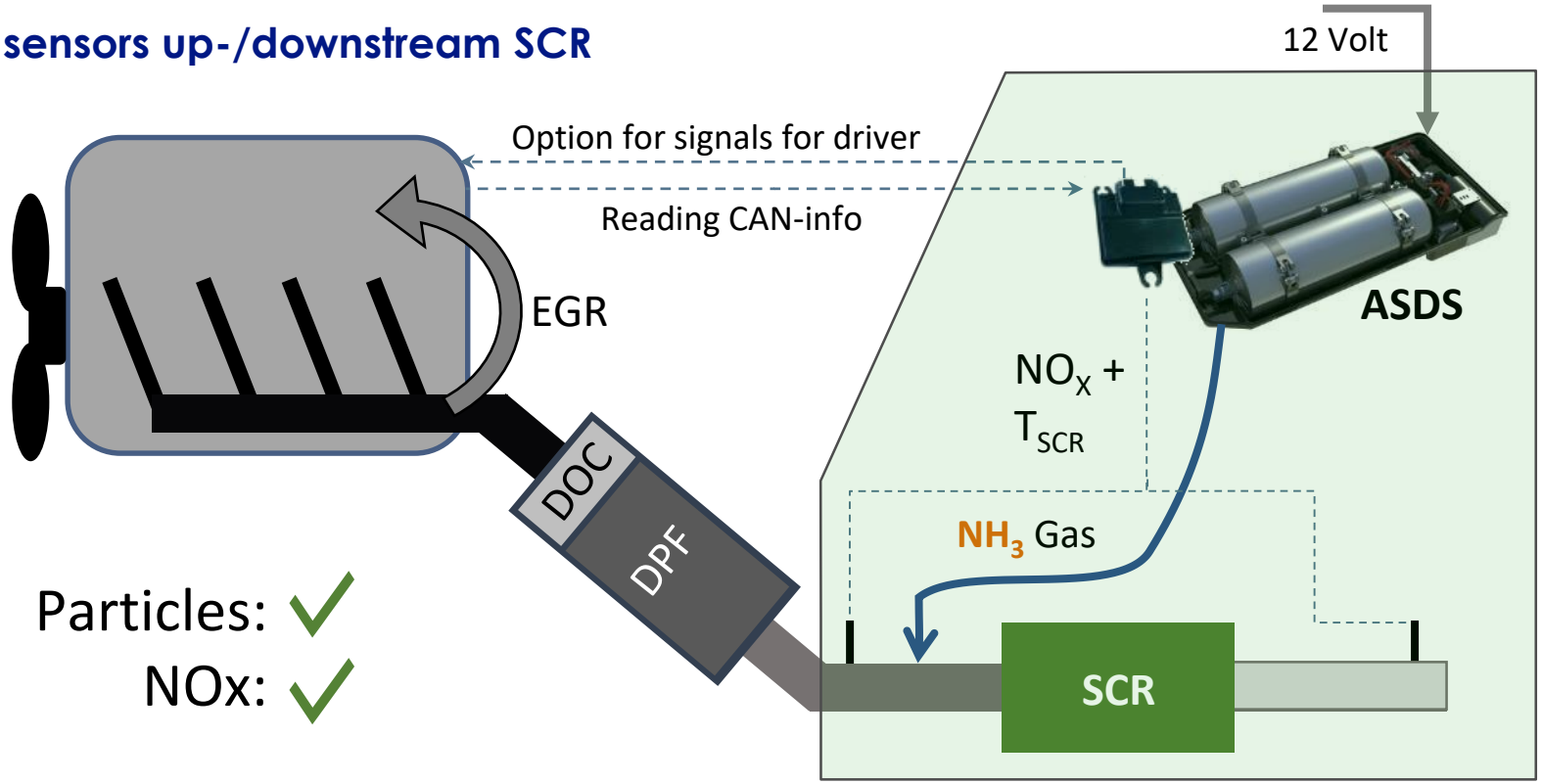
LD-Retrofit of Euro 5: Interfaces and main functions in stand-alone solution

- **System configuration: OEM DOC/DPF + ASDS & SCR**
- **Retrofit NH_3-dosing strategy based on:**
  - ECU input for exhaust mass flow
  - NOx and T_{SCR}-sensor
- **NO_X sensors up-/downstream SCR**



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Compact system:
LD prototype placed in spare-wheel compartment

Fits easily in spare-wheel compartment(*)
In specific vehicle, 12V power is located next to system.

SCR and NOx/T sensors installed in "tunnel" in under-floor position

Servicing: Exchanging cartridges at "refill" takes less than two minutes.
A simple procedure done at dealer or certified workshop

(*) Example in existing Euro 5 car. Not with system cover;
controller not shown. Not optimized/matured for specific vehicle

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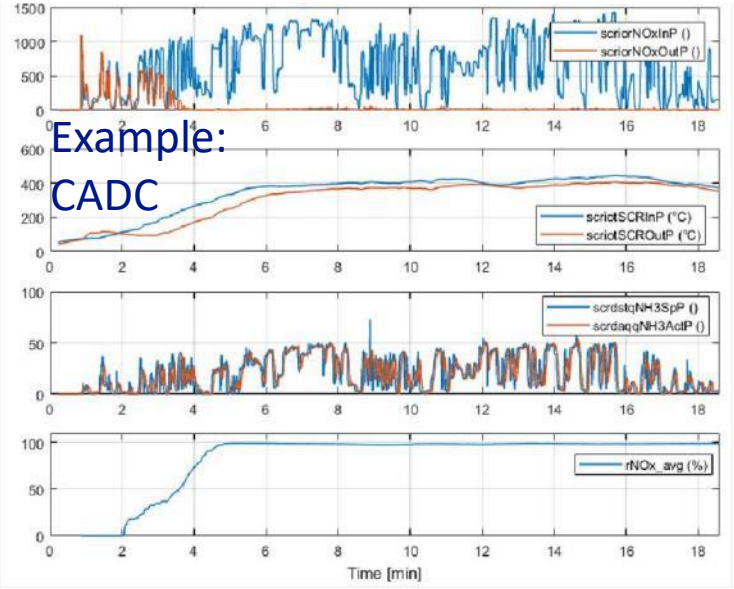
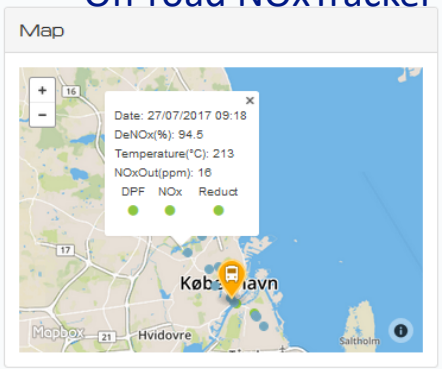
PEMS test results of retrofitted Euro 5 car: ~ 40 mg NOx/km

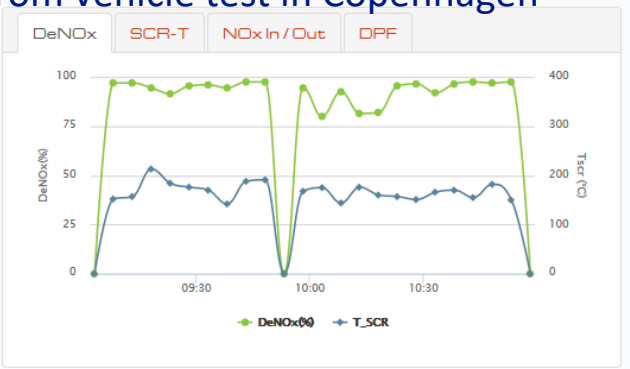
- **Independent RDE PEMS testing by TU Graz**
  - Before (OEM Euro 5):
    800-1300 mg NOx/km
  - With BlueFit™ : Multiple tests with
    ~40 mg NOx/km (95% reduction)
- **Emissions upgrade with low CO_2-impact (~ 1%).**



Test car:
C-segment Euro 5 (1.5 liter)
upgraded with ASDS and uf-SCR

On-road NOxTracker from vehicle test in Copenhagen





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Euro 5 Demonstrator vehicle: Retrofit impact relative to rating on EQUA index?

Ratings Explained

Rating	Lower bound[1]	Upper bound[2]	External reference point
A	0.00	0.08	Meets Euro 6 limit for diesels, meets Euro 4 limit for petrols
B	0.08	0.1	Meets 1.5 Conformity Factor under Euro 6 Real Driving Emissions regulation
C	0.12	0.18	Meets Euro 5 limit for diesels ...similar to 2.1 Conformity ...under Euro 6 Real ...issions regulation)
D	0.18	0.2	...Euro 4 limit for diesels
E	0.25	0.5	...Euro 3 limit for diesels
F	0.50	0.7	...mparable Euro standard: ...y equal to 6-8 times Euro
G	0.75	1.0	...mparable Euro standard: ...y equal to 8-12 times ... limit
H	1.00	None	No comparable Euro standard: ...equal to 12+ times Euro 6 limit

Units: g/km, [1] exclusive, [2] inclusive

After

Before

Download the data

View the top Euro 6 diesels currently on sale
EQUA Euro 6 Diesel

View the top Euro 6 petrol and hybrids currently on sale
EQUA Euro 6 Petrol and Hybrids

View all Euro 5 vehicles

Show 10 entries

Search:

Make	Model	Fuel Type	Model Year	...	Driven Wheels	Transmission	Euro Stage	EQUA Aq Rating
Make	mega	die	2014	Engine S...	Power Bhp	Drive Train	Driven ...	Transmis...	Euro Stage	EQUA Aq...
	Diesel	2014	1.5	108	FWD	2	Manual	Euro 5	H

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Overview:
Target of ASDS core components and system elements

- **ASDS (all-in-one box)**
  - **Two cartridges: 2 x ~4.5 Liter solid** with dosing control (18 liter AdBlue equivalent)
- **SCR**
  - **Use existing Euro 6 SCR catalyst** for uf-integration
  - NOx- and T-sensors
- **Vehicle interfaces**
  - **Power: 12V; 350W peak; 30-80W average**
  - Interface to CAN; key-on signal; exhaust mass flow input
- **Performance target:**
  - Targeting 80 mg NOx/km in typical PEMS testing.
  - Dosing strategy with emphasis on low-speed city driving.
- **Range vs. servicing:**
  - Cartridge exchange at dealer / workshop
  - No involvement of driver needed.

+

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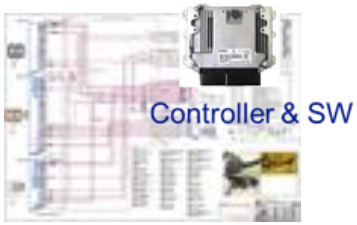

- **Add-on service:**
- NOxTracker (data subscription not included)
- BlueFit™ App for Customer

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Infrastructure

AdAmmine cartridge refill/distribution

- **Amminex ASDS system for CV:**
  - 50 million km driven
- **Supply of refilled ammonia cartridges**
  - > 50,000 refilled cartridges supplied (equivalent of 1000 ton AdBlue)
  - Equivalent to approx. 120,000 cartridges for LD-systems
- **Current solid ammonia supply corresponds to ~ 700 million km of passenger car SCR driving**

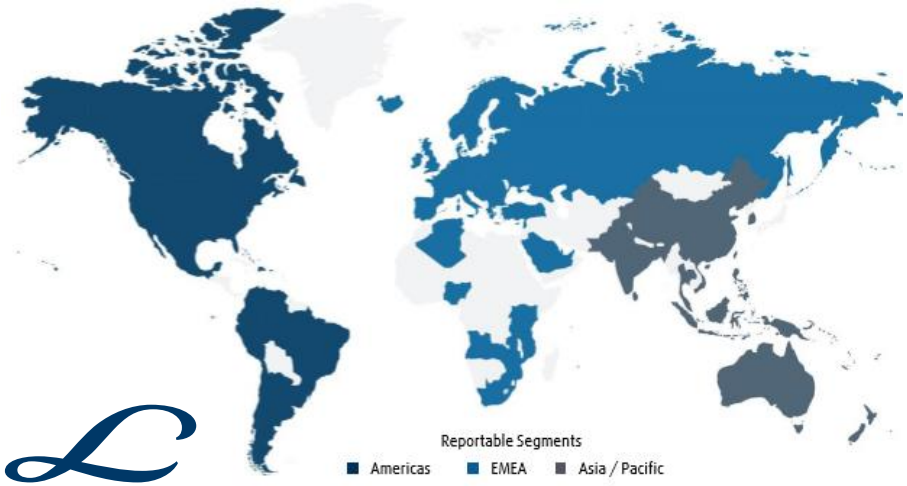
Global/regional expansion in cooperation with leading industrial gas company:
Refill & cartridge supply cooperation discussions with Linde AG ongoing.

The Linde Group & Amminex
Focus on sustainability and clean-tech solutions.

THE LINDE GROUP

The Linde Group & Amminex

The Linde Group worldwide - global presence in more than 100 countries*



THE LINDE GROUP

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Towards the future

Solid ammonia systems endorsed by authorities in China

China-MEP endorses use of Solid ammonia SCR (SSCR) for NS-VI/6 legislation having emphasis on RDE / conformity

中华人民共和国环境保护部
Ministry of Environmental Protection of the People's Republic of China

索 引 号：000014672/2017-02062　　分类：环境科技及其管理信息\环境科技管理
发布机关：环境保护部　　生成日期：2017年12月12日
名　　称：关于发布《机动车污染防治技术政策》的公告
文　　号：公告 2017年 第69号　　主 题 词：

环境保护部公告

公告 2017年 第69号

关于发布《机动车污染防治技术政策》的公告

为贯彻《中华人民共和国环境保护法》和《中华人民共和国大气污染防治法》等法律法规，改善环境质量，完善环境技术管理体系，促进机动车污染防治技术进步，环境保护部组织修订了《机动车污染防治技术政策》。现予公布，供参照执行。以上文件内容可登录环境保护部网站（http://www.mep.gov.cn/）查询。

自本公告发布之日起，《关于发布〈机动车排放污染防治技术政策〉的通知》（环发〔1999〕134号）废止。

附件：机动车污染防治技术政策

环境保护部
2017年12月11日

抄送：各省、自治区、直辖市环境保护厅（局），新疆生产建设兵团环境保护局。
环境保护部办公厅2017年12月12日印发

分享到：

"…
11. All new diesel vehicle should install qualified ATS device, such as DPF, SCR etc, **encourage to using solid ammonia SCR (SSCR).** Adopt SSCR or SCR technologies, ammonia slip must control due to avoid pollution again.
12. City bus, sanitation, mail vehicle, logistic etc. should priority select new energy vehicle, or replace energy clean energy vehicle; For those kind of diesel vehicle must install DPF, **SSCR** or SCR etc. after treatment device.
…" 附件

The Policy of Vehicle Emission Control Technologies 机动车污染防治技术政策

二、源头控制 Source Control

（一）新生产及进口汽车、摩托车及其发动机 New produced and imported vehicle, motorcycle and relevant engine

11. 新生产柴油车应安装符合产品技术标准要求的排气后处理装置，如柴油车颗粒过滤器（DPF）、选择性催化还原装置（SCR）等，鼓励使用固体氨选择性催化还原装置（SSCR）。采用 SSCR、SCR 控制技术时，应采取控制措施防止氨逃逸引起的污染。

12. 城市公交、环卫、邮政、物流等行业应优先选择新能源汽车、替代能源汽车等清洁能源汽车；用于这些用途的柴油车应安装 DPF、SSCR 或 SCR 等排气后处理装置。

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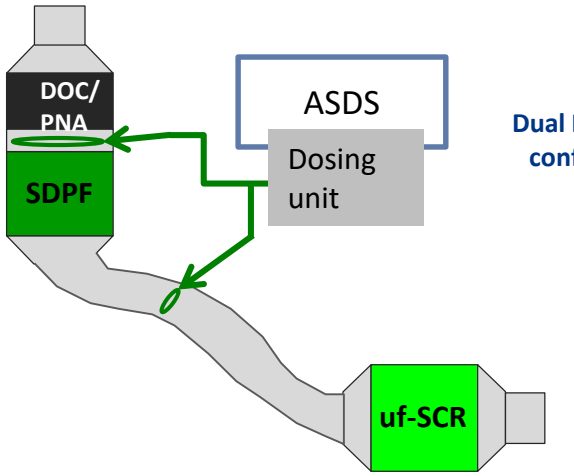
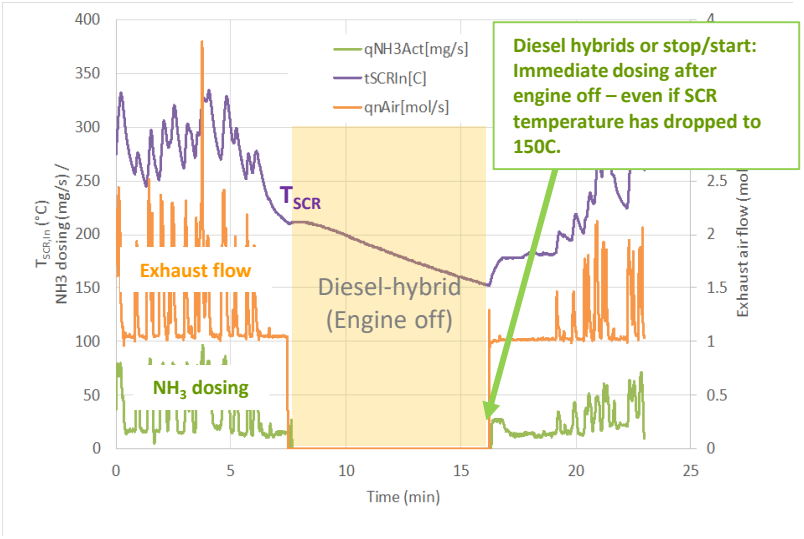
Future Ultra-Low NOx programs: Benefits from direct-NH_3 SCR

- Reduced need for thermal management at cold start / low load
- Earlier start-of-dosing in cold start
- Development & calibration:
  Simpler dosing map & stop/start
- Simpler mixer → Reduced back-pressure
  → improved peak Hp-rating of engine
- Dual dosing for SCRF+ uf-SCR → improved IRAF capabilities
- Elimination of deposit removal controls by "extra" active DPF regeneration
- Reduced need for EGR in urban driving:
  Improved soot-to-NOx balance
- Freezing issue eliminated
- OBD Impacts - examples:
  - Urea quality control eliminated
  - Improved pin-pointing expected



Dual NH_3-dosing configuration



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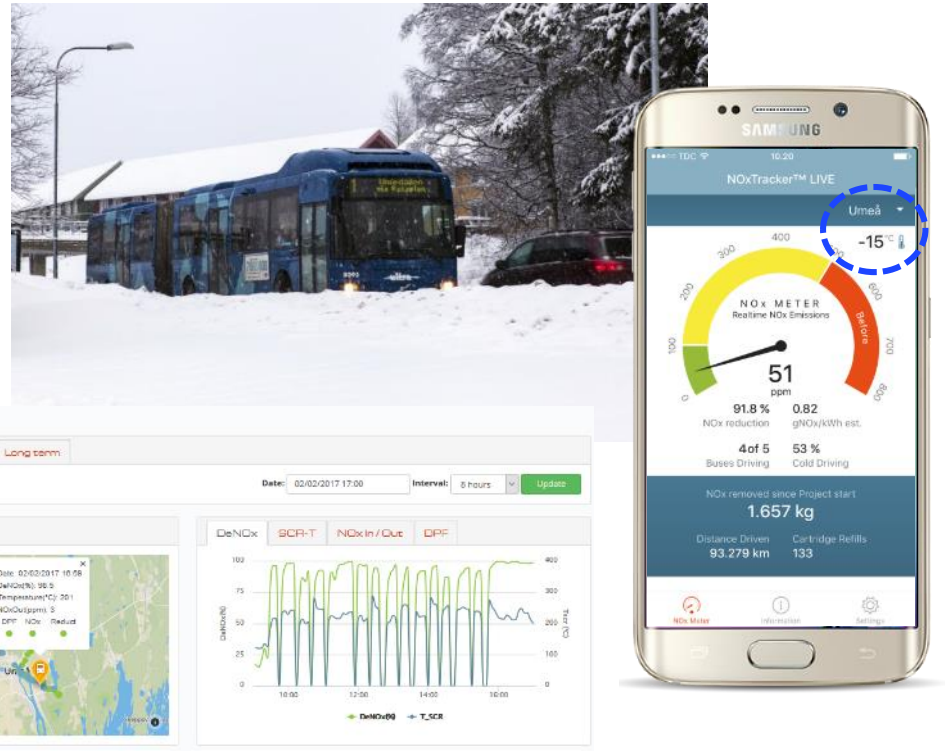
Cold climate: Freezing of AdBlue vs. NH_3-release from ASDS

- **Time to dose at freezing conditions: 70 minutes allowed for AdBlue under current EPA 2010 rules**
- **The ASDS is ready to function after few minutes (before SCR light-off)**
- **Winter operation in Sweden confirms good DeNOx performance in real driving**



Conventional technology (AdBlue)

Freeze Protection

- *Issue*: Whether SCR systems are designed to ensure that DEF does not freeze or refreeze during operation
- *EPA Thinking:*
  - Freeze protection systems will be evaluated as Auxiliary Emission Control Devices (AECDs)
  - Engine designs expected to incorporate DEF thawing and freeze prevention technology
  - For engines installed in equipment not intended to operate in cold temperatures, in lieu of a DEF thawing system, manufacturers may demonstrate engine is designed not to operate in freezing conditions
- *Examples:*
  - The following test procedure has been offered as an example of a test procedure that could be used for ensuring that the AECD is used appropriately
    - Prior to Procedure:
      - Temperature: DEF at 20° F (maximum)
    - Soak Conditions:
      - Temperature: 0° F (maximum)
      - Time: 72 hours or solid DEF (whichever occurs first)
    - Test Duty Cycle:
      - Temperature: 0° F (maximum)
      - Time: 70 minutes (maximum)
        - » Start engine and idle with no engine load for 20 minutes
        - » Operate engine at no more than 40% load at rated speed for up to 50 minutes
  - SCR systems that are capable of fully functional dosing at the conclusion of the test procedure may be considered acceptable

2011-07-26 U.S. Environmental Protection Agency 17

- Test Duty Cycle:
  - Temperature: 0° F (maximum)
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SCR systems that are capable of fully functional dosing at the conclusion of the test procedure may be considered acceptable

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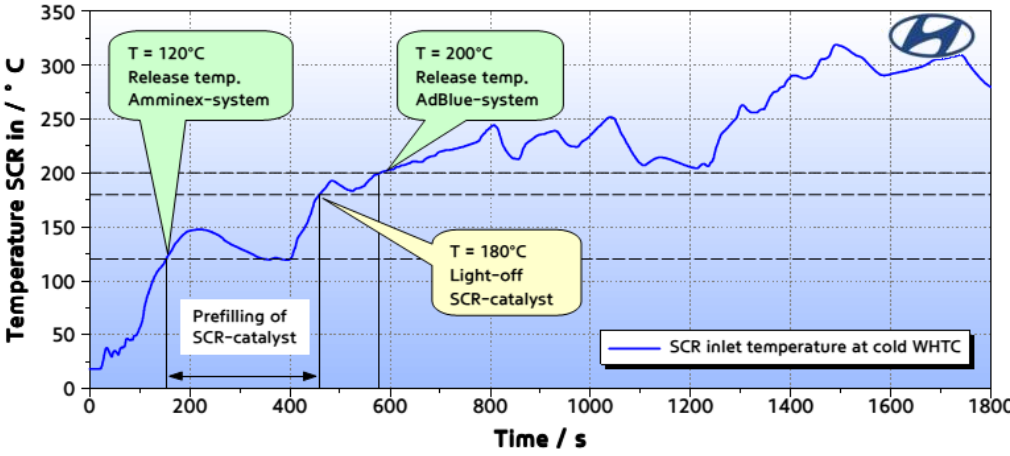
Example of NH_3-impact in cold-start cycle

- **Improved SCR calibration and high DeNOx performance proven by HME:**
  - ASDS-system with 28% lower NOx-emission at WHTC compared to AdBlue-system (same dosing)
  - NOx-emission can be reduced by 45% with advanced dosing release at 120°C (DEF/AdBlue: 200°C)
  - With dosing control optimization, overall ~75% reduction of NOx-emission with ASDS-system compared to DEF/AdBlue system could be realized with same catalyst!
- **Potentials identified:**
  - **Use improved DeNOx performance for recalibration of engine for better fuel economy (CO_2) and/or**
  - **Down-size of SCR catalyst.**

Dosing Release... @WHTC	Temp. @SCRin	after time @WHTC	Tailpipe NOx-emissions	NH3 dosed
Reference with AdBlue-system	200°C	~ 570 s	100%	-
... std. from AdBlue (with ASDS)	200°C	~ 570 s	-28%	27g
... at SCR-catalyst light-off	180°C	~ 450 s	-45%	28g
... at release temperature Amminex	120°C	~ 170 s	-60%	31g



Adaptation of NH3 Load Governor @WHTC	Tailpipe NOx-emissions	NH_3	Delta
Base with ASDS (Temp. release 120°C)	100%	31g	100%
Base with ASDS and Load Governor activated	-17%	35g	+13%
Final calibration of Load Governor	-41%	38g	+23%

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