AMMINEX
Emissions Technology

Direct NH_3-SCR: High DeNOx efficiency at low exhaust temperature

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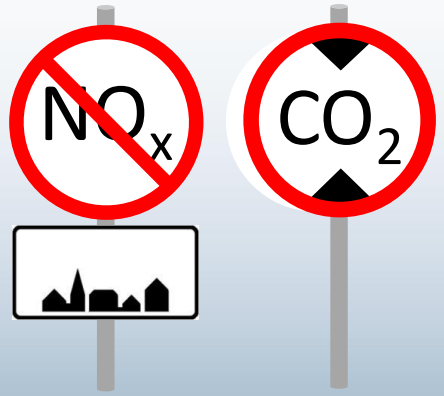

7th VERT Forum: Motivation

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MOTIVATION

The NOx problem, or more specific, the consistently high NO and NO_2 emissions of diesel vehicles, is not yet solved. The gap between real world NOx emissions and those achieved under ideal conditions during vehicle homologation is unacceptably large.

While particle filters made substantial progress in the last years, the achievements in diesel deNOx-tech-

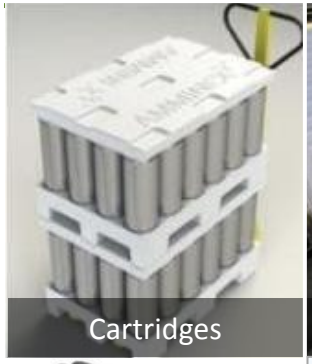
Amminex has the solution ready on the shelf!

While particle filters made sub[illegible]antial progress in the last years, the achievements in diesel deNOx-technolgies are moderate only. The performance at low engine loads e.g. in urban traffic, where low exhaust temperatures prevail or at cold-start conditions, is low as well and has to be improved.

Company Introduction

AMMINEX
Emissions Technology

- Danish cleantech company; spin-out from the Technical University of Denmark (DTU)
- Core technology: ASDS™
  Ammonia Storage and Delivery System
  - AdAmmine™; solid ammonia onboard vehicles
  - Enabling clean diesel emissions (NO_X and CO_2)
  - Strong IP with ~ 50 granted patents globally
- Headquarter and R&D in Copenhagen
- Production site in Nyborg
  - Capacity for ~200.000 vehicles/year
  - State-of-the art, highly automated manufacturing
  - Refilling of AdAmmine™ cartridges
- Shareholders: faurecia NORDEA FONDEN SEED CAPITAL


Cartridges


Automated production line


AdAmmine™


ASDS: City-SCRT


Refill

Amminex core technology intro

- Ammonia (NH_3) is required for NO_X reduction via SCR catalysts

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

- AdBlue® ("NH_3" as urea) is the conventional reductant technology
  - Works well at high SCR-temperature; often delivered far from target in cities

- ASDS™(NH_3 stored in solid salt):
  - Major DeNOx advantage in urban driving ('cold' engines)
  - Expands SCR-window for low engine load; no thermal management
  - Improved DeNOx at medium/high load => down-size potential

AdAmmine™

Cartridges, heater & relay, controller, and dosing unit

Controlled release of NH_3 gas to catalyst

Installed City-SCR™

Product Overview

- ASDS™ provides ammonia dosing on-demand
  - Plug & play system replacing a complete AdBlue® system
  - Configured for Commercial Vehicles
  - Passenger car applications are being developed

- AdAmmine™ cartridges
  - Replaces AdBlue® liquid - refillable
  - Scalable & modular for different applications

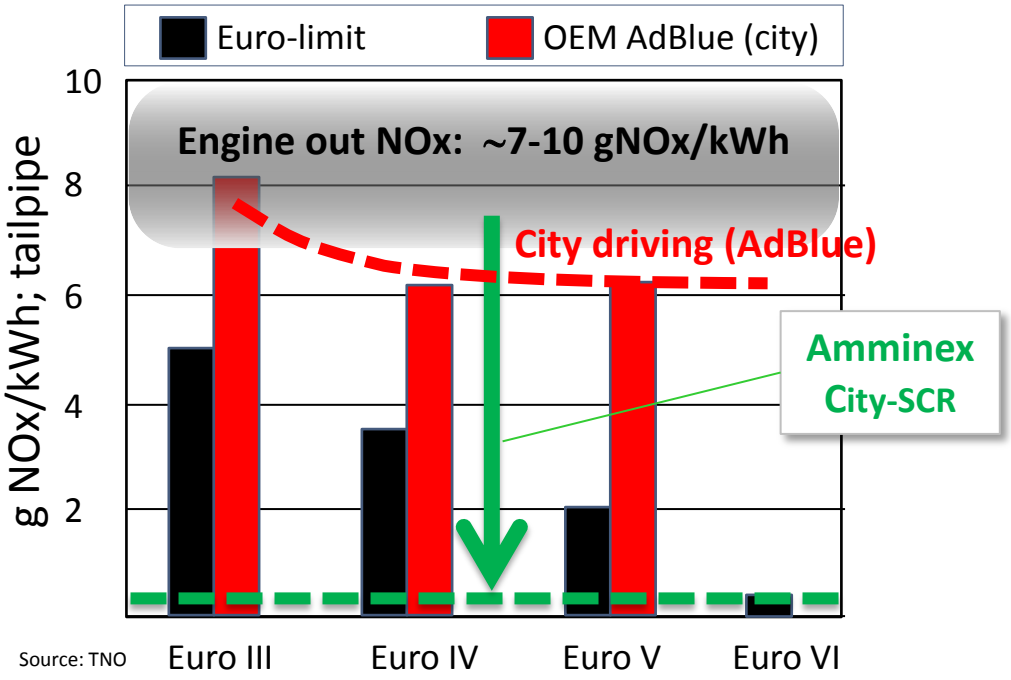
- Controller with system SW including
  - Easy-to-calibrate control/dosing software for ASDS system
  - OBD

- Dosing Unit (DU)
  - Replaces AdBlue® pump and injector
  - Provides robust and accurate dosing of NH_3-gas to the catalyst

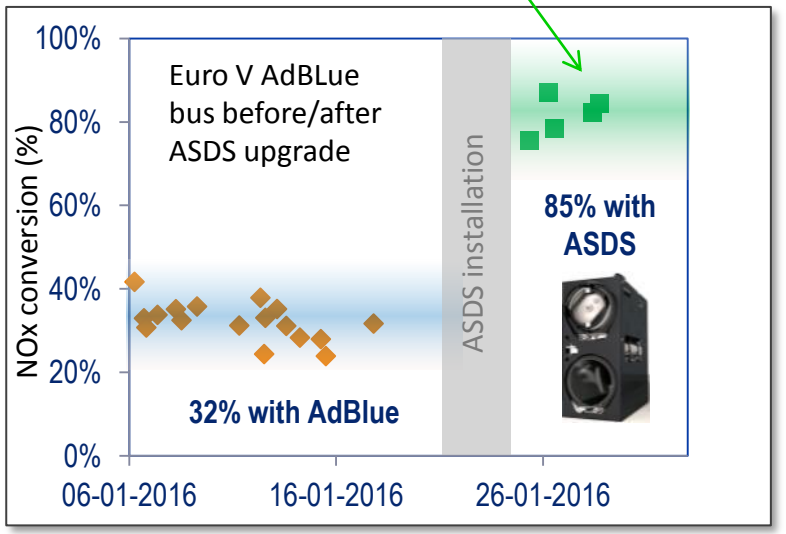
- FleetLogger for transparent emissions
  - On-board measuring and logging of RDE Emissions
  - Continuous monitoring over web interface

The essence: ASDS works all the time and solves known field issues

AMMINEX Emissions Technology



OEM EuroV catalyst with direct-NH_3



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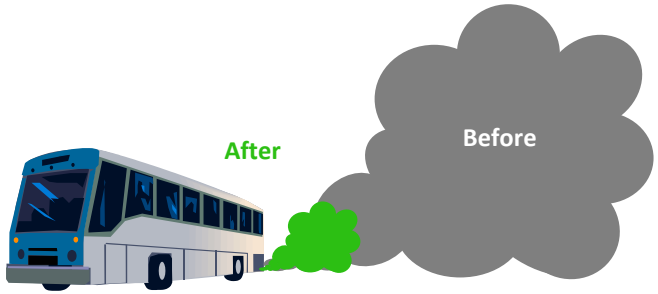
Amminex ASDS™ is now on the market for emissions upgrade of captive fleets

World's first retrofit program targeting Euro VI level: ~ 300 busses in CPH

AMMINEX Emissions Technology

- Major EU-tender won by Amminex in partnership with Eminox: Upgrade of ~ 300 Euro III/IV/V/EEV busses in Copenhagen
- Emissions kit:
  - Amminex ASDS™ for optimal NOx reduction
  - Controller with diagnostics (OBD) and monitoring of performance
  - On-line FleetLogger with real-time emissions data on web-portal
  - Eminox SCRT®-unit with state-of-the-art SCR catalyst and DPF with CRT-effect
- Combined solution:
  Optimal **City-SCRT** solution – "always on"

Euro VI conformity



+

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Eminox

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A few photos from Copenhagen

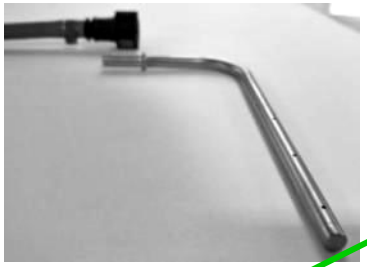
- ASDS installation

Volvo

Scania

Eminox SCRT-unit

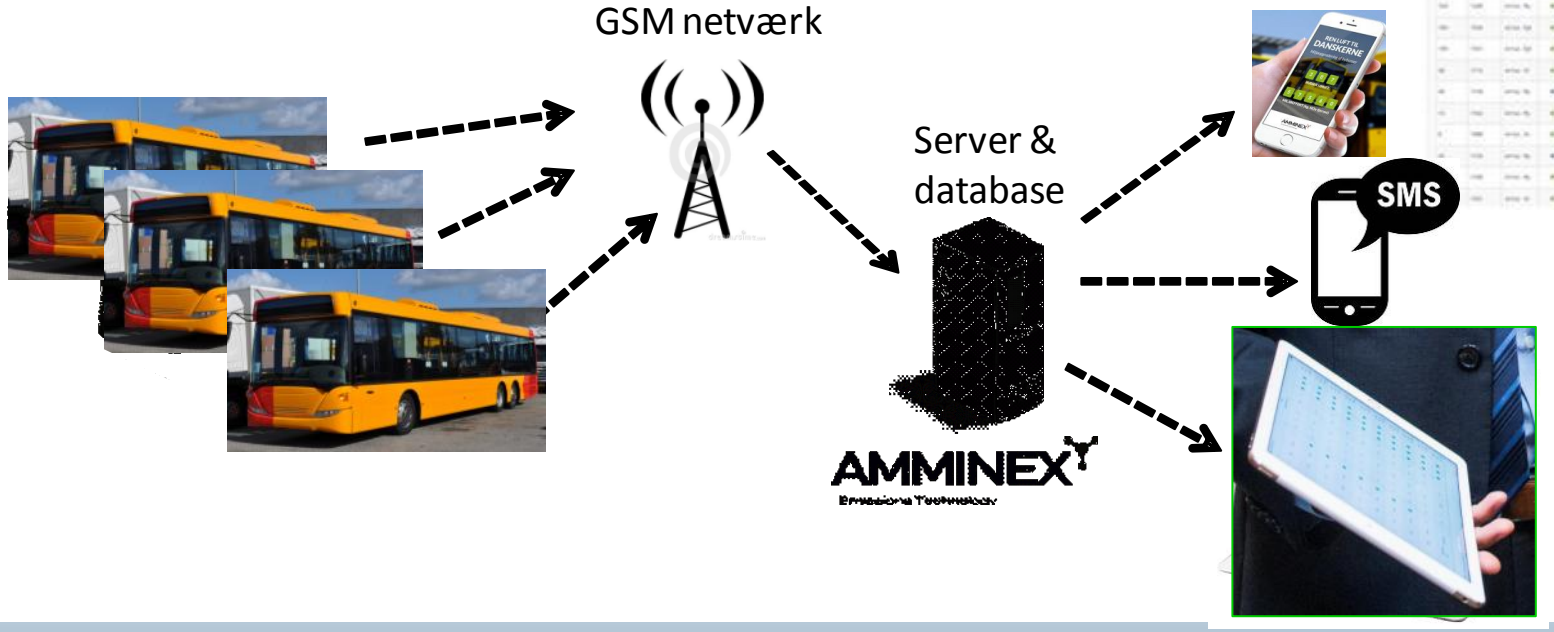
SCRT-unit (after months of op.)



NH_3-line from ASDS entering SCRT via ¼'' steel pipe

NOxTracker™
On-line emissions monitoring

- On-line surveillance provides full transparency
  - Real-time emissions performance
  - Measured on-board and transmitted in real-time
  - Monitor & error warning: SMS/email
  - GPS position & tracking
- Fleet operation on the road today in Copenhagen.
  - 30-85% of driving below 220°C SCR temperature
  - Reduces 80-95% NOx **also** in this temperature range



Status: Implementation on time; 95% completed

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- We have passed the first 4.5 million kilometers in CPH
- 280 out of 299 vehicles installed
- >50 ton NOx removed since mid- August
- > 5800 cartridges refilled and supplied to three operators:
  Arriva, Nobina and Anchersen
  Equivalent to 116 ton AdBlue
- Engines/brands:
  - Volvo: 7, 12 liter engines
  - Scania 9.3 liter engines
  - DAF (VDL/Solaris): 9 liter engines
- **NOxTracker™ LIVE app available for (free) download for iOS and Android**

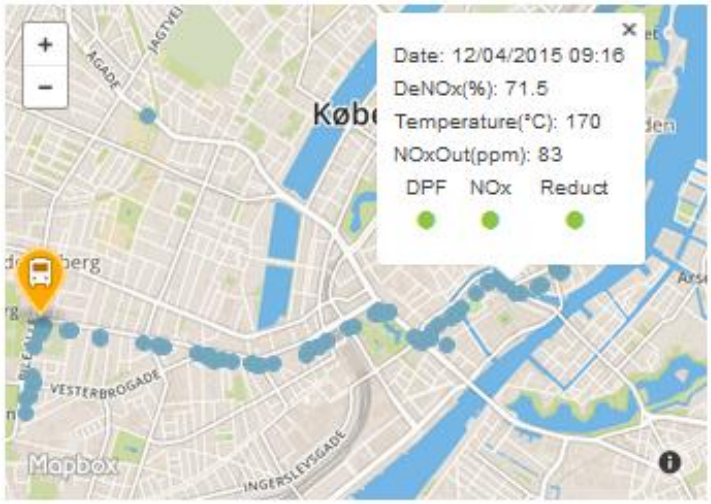
1118 passing the parliament with 72% DeNOx at 170°C SCR

AMMINEX Emissions Technology

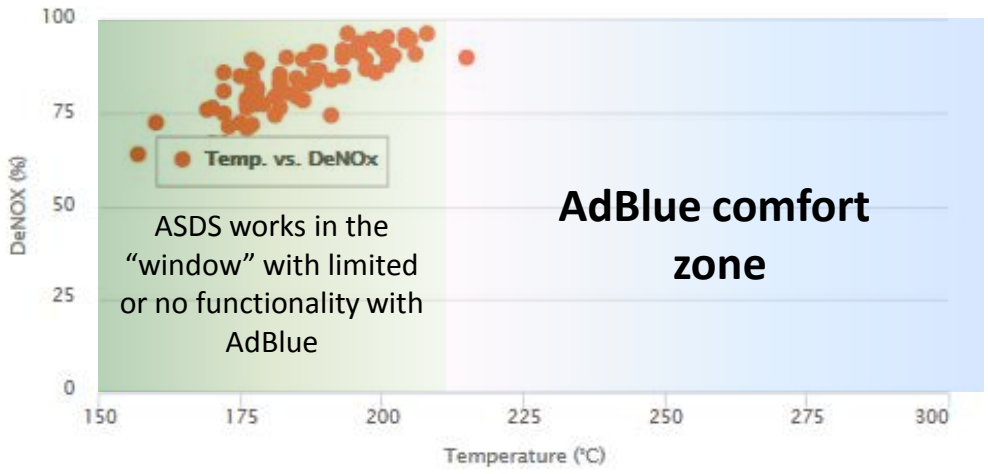
1118

Date: 12/03/2015 23:00 Interval: 24 hours Update

Map



In use | SCR-T | Nox In / Out



Winter time in Cph: 80% of fleet operation with SCR-temperature below 220°C

ASDS also works extremely well at medium/high SCR temperature…

AMMINEX Emissions Technology

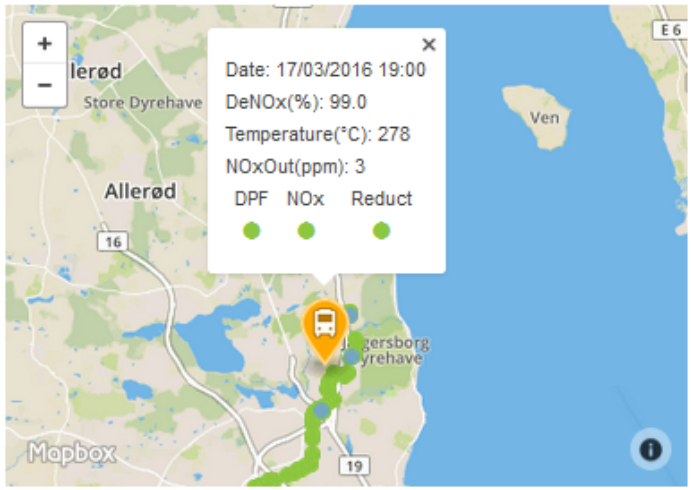
NOxTracker™

Fleet-summary Admin Profile

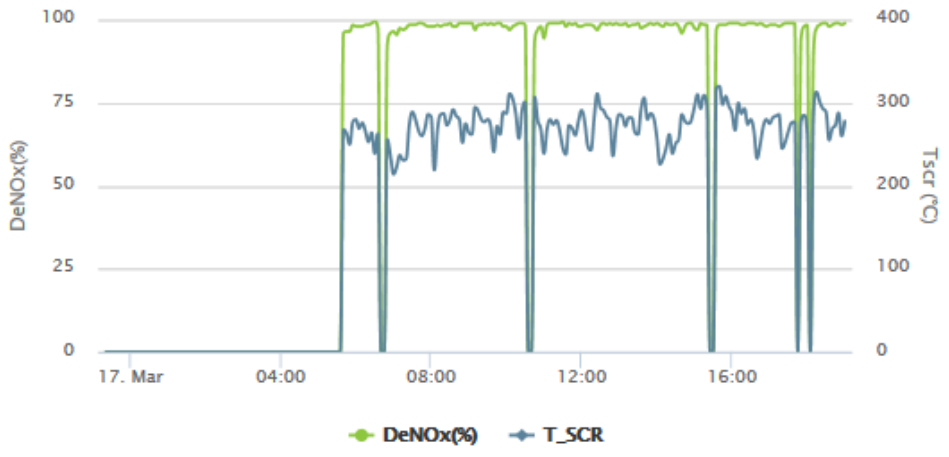
6034

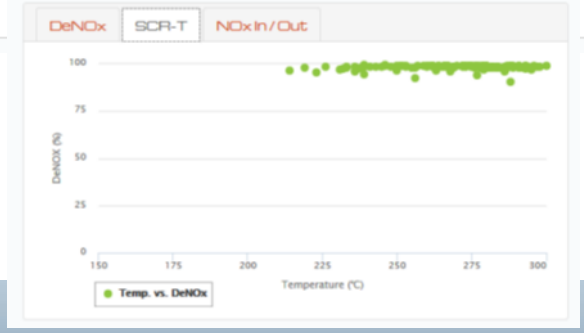
Date: 17/03/2016 20:00 Interval: 24 hours Update

Map

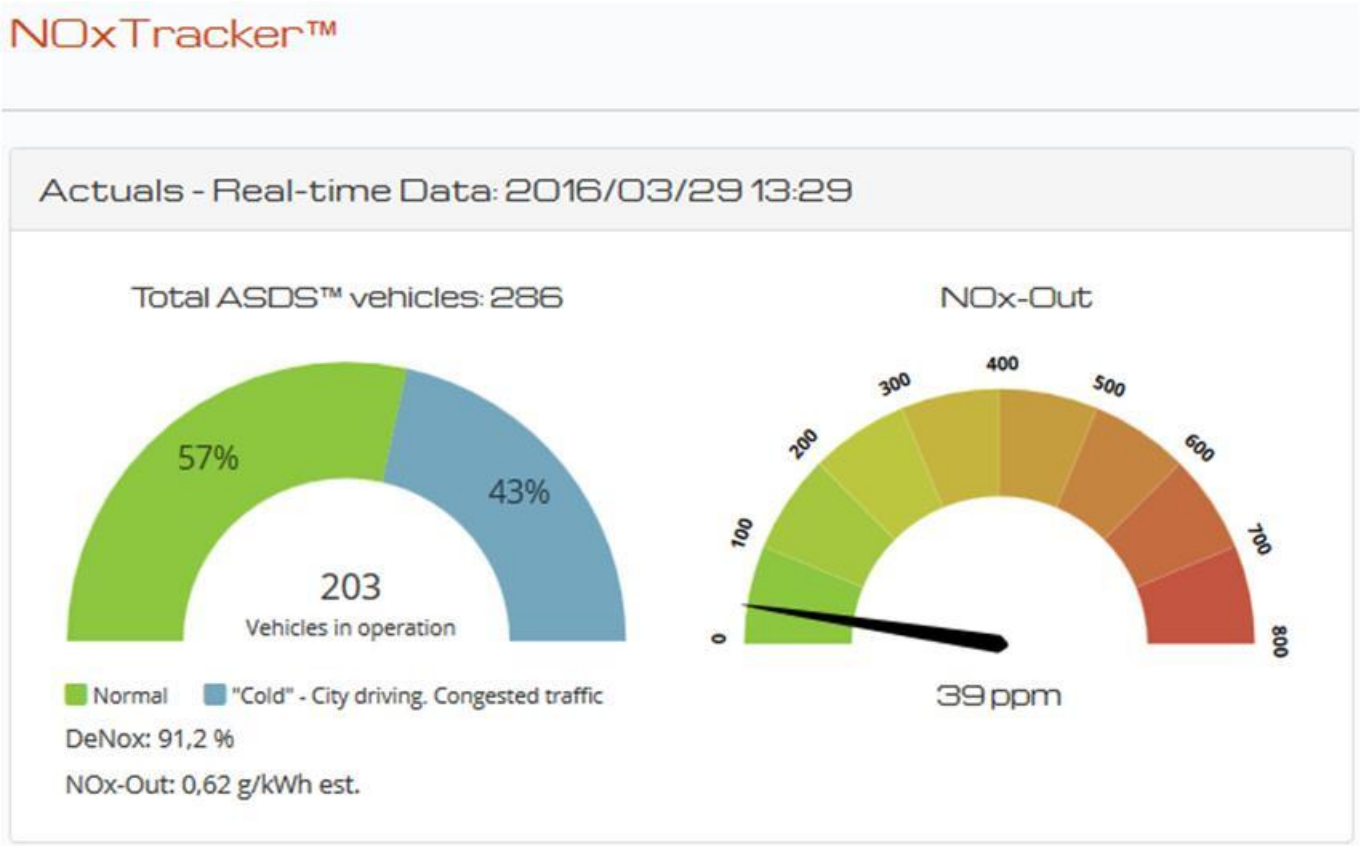


DeNOx SCR-T NOx In / Out





“Live”


NOxTracker™
Actuals - Real-time Data: 2016/03/29 13:29
Total ASDS™ vehicles: 286
57%
43%
203
Vehicles in operation
Normal
"Cold" - City driving. Congested traffic
DeNox: 91,2 %
NOx-Out: 0,62 g/kWh est.
NOx-Out
0
100
200
300
400
500
600
700
800
39 ppm

Field experience: Fuel economy / CO_2

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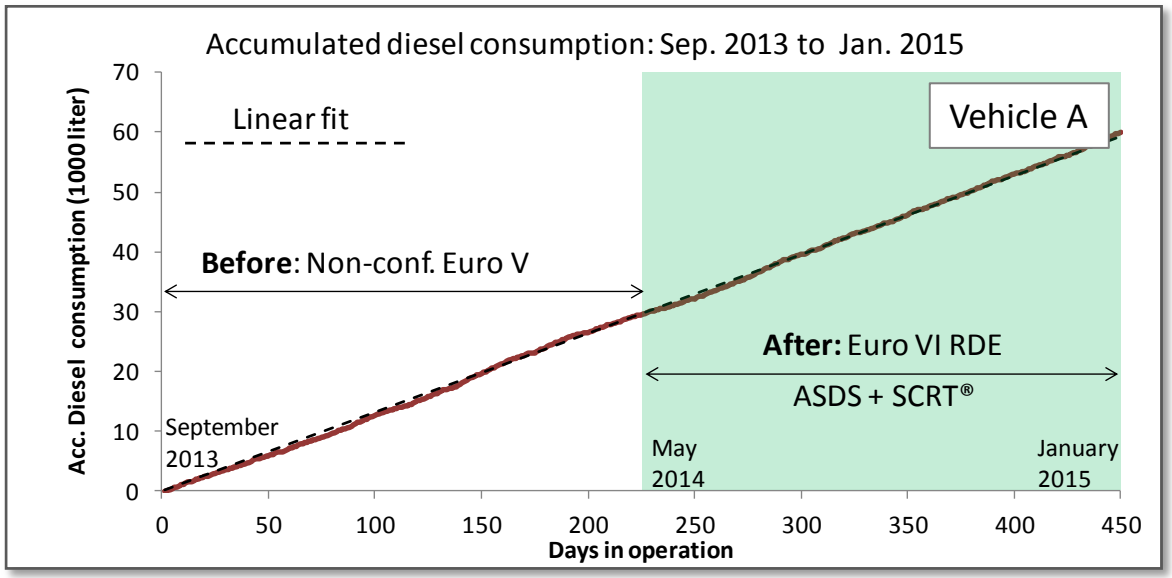
- Vehicle fuel consumption monitored before/after emissions upgrade
- Euro V engine achieves real-world Euro VI at <u>zero CO_2-penalty</u>
- ASDS & direct ammonia dosing:
  - No extra fuel needed to raise SCR-temperature
  - Low 'parasitic' losses from ASDS (no compressed air)
- AdAmmine™ reductant: Does not "carry" CO_2 ⇒ Saves 0.5% CO_2 compared with standard Euro VI vehicle

CO_2-neutral emissions upgrade



"Refill" is very simple: Easy to Make a Change

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AdAmmine™ cartridge exchange:
"*It only takes a minute…*"

10kg NOx removed for each cartridge depleted

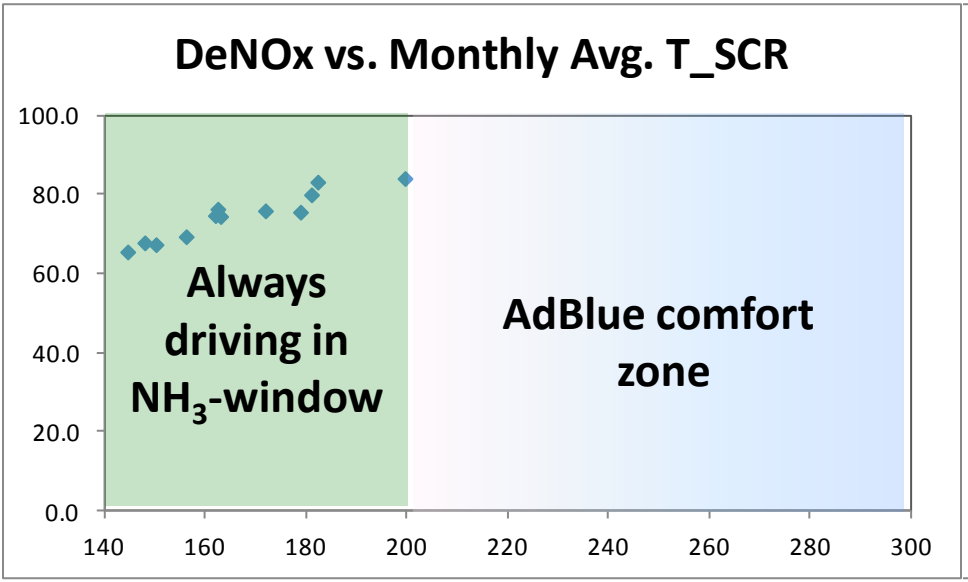
- One cartridge ≈ 20 liter AdBlue® refill
- Fast and simple procedure: 1 minute
- No Health & Safety issues
- No risk of spilling or contamination
- No risk of misfuelling liquids

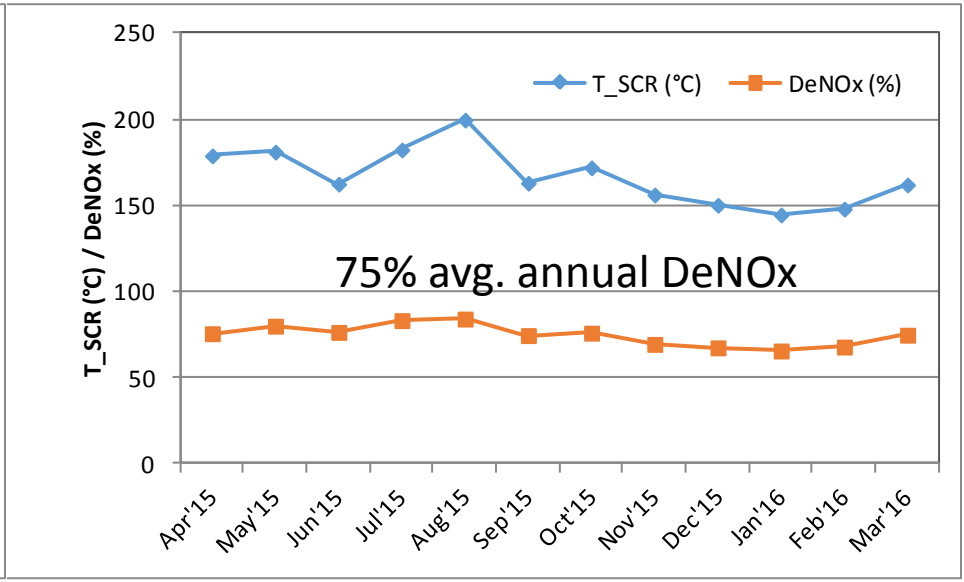
Video:
https://www.youtube.com/watch?v=7pFKs8fkwAM

US ambassador making a change – and making a difference – in Copenhagen

Latest summary of monthly data from project in Asia

- Euro V target: High DeNOx proven in ~ 1 year period.
- Average SCR temperature never exceeds 200°C
- Even in very cold winter conditions with avg. SCR temperature below 150C, the performance is above 60%





Feedback from the operators

Poul Anchersen /CEO, Anchersen Busses Aps

"After upgrading the Euro V bus with Amminex City-SCR solution, the reoccurring maintenance issues with the AdBlue system are gone. Months of stable operation and the NOx reduction proven in real city traffic is impressive. Instead of refilling with AdBlue liquid, there is now a weekly exchange of an Amminex cartridge. Simple operation – takes only a minute."

Ian Foster, Engineering Director, Metroline

"Using ASDS, we have more than doubled the NOx reduction on a relatively old Euro 4 bus bringing it below Euro 5 level without doing any changes to the catalytic system fitted in manufacture. This technology has proven extremely stable in terms of daily operation over the course of 18 months regardless of outside temperature and driving conditions. This recorded reduction in NOx emissions is quite impressive, and furthermore the use of ASDS™ has eliminated the typical reoccurring AdBlue® issues, such as solid deposits and crystallizations in the exhaust system and on our buses during refill"

John Kristensen, Adm. Dir. Nyborg-Rejser

"Nyborg Travel A/S has had an Amminex system in operation on a city bus for over half a year. The ASDS-unit, which replaced the traditional AdBlue system, has operated without problems and has resulted in an emissions improvement. The service team in the workshop have carried out the simple procedure of exchanging a cartridge whenever the system indicated that it was nearly empty. All the normal maintenance routines for the AdBlue system are now eliminated"

Production & supply: ASDS™, AdAmmine™ cartridges, system & NH_3-recharge (refill)

Launch of ASDS retrofit product & ready for OEMs

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- Amminex production plant in Nyborg (DK)
- Assembly of retrofit systems
- Cartridge production:
  Current capacity for OEMs is 200,000 cartridges per year
- Cartridge NH_3-recharge facility in place
  Currently supporting retrofit volume in Scandinavia.
- Expansion according to demand

AdAmmine™ cartridge refill & distribution

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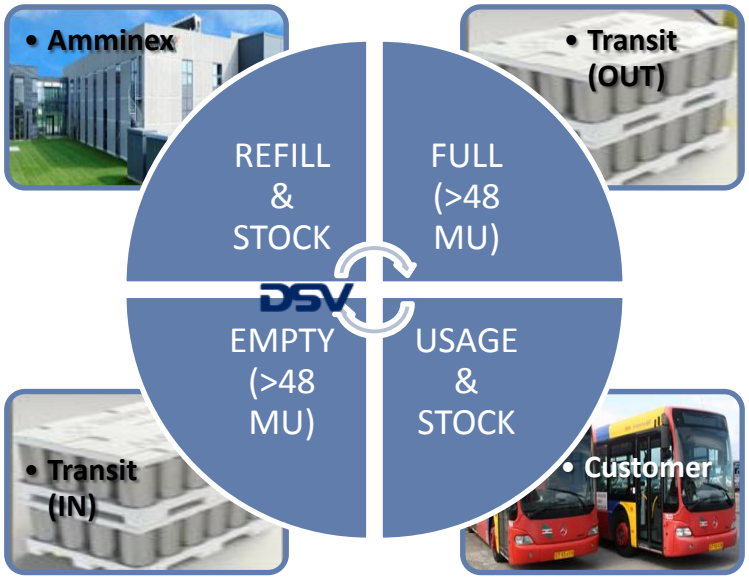
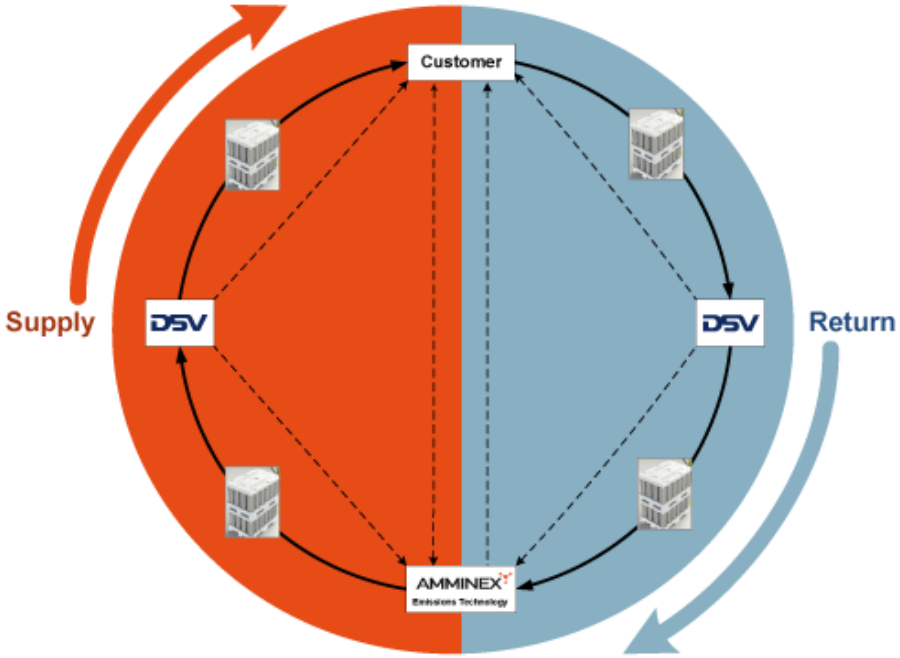
Refill capacity and logistics for retrofit in place

- EU: >40k refills/yr capacity installed (expansion ongoing)
- Asia and US: Supply chain partnerships in place (e.g. Airgas)





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Wrap-up…

"Lego" modularity for a variety of challenging applications

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- Robust, compact, modular and easy-to-calibrate $DeNO_x$ solution
- Efficient NO_2-clean-up on engines fitted with DOC/DPF
- NRMM applications without compressed air support: No problem

AdAmmine™ cartridges:
✓United Nations approval for global transportation (not hazardous goods)

Retrofitting with ASDS™ Solidair ™ (I)

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- Improved NOx and NO_2 reduction – no CO_2 impact
- Reduced complexity of exhaust system = reduced cost
  - No deposit risk; hydrolysis catalyst not needed.
  - Simplified mixing zone
  - Reduced grade of steel
- Fast installation = reduced cost: Plug 'n' play
  - No interaction with vehicles compressed air system.
  - ASDS + 24V + wireharness = ready to go
  - Potential to down-size SCR catalyst
- Without AdBlue deposits or crystallization risk:
  - Reduced warranty claims - in particular for low-T applications
  - Reduced service & maintenance costs: Virtually maintenance-free

  => Positive impact on total cost of ownership

Retrofitting with ASDS™ Solidair ™ (II)

- We are ready to work with retrofit/OEM partners who are supplying complete solutions that would benefit using ASDS for robust and optimal DeNOx

- Amminex can supply ASDS as a sub-system for system integrators

Thank you for your attention

Contact details:
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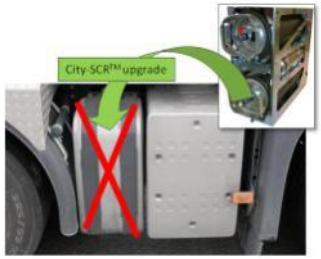
Back-up

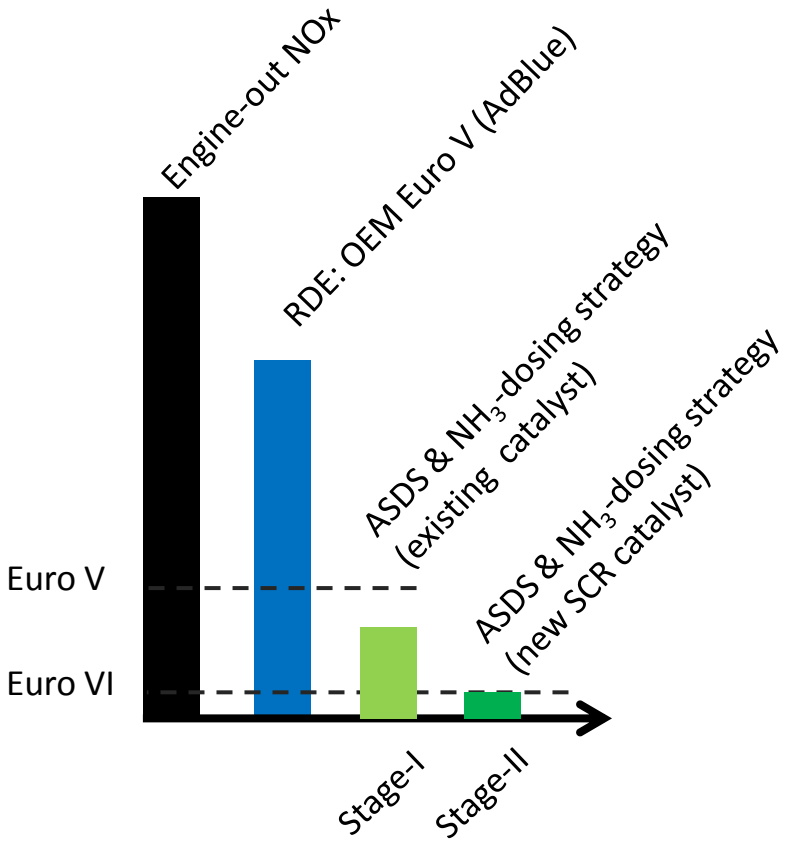
Two retrofit options with ASDS™

- Stage-1
  - Upgrade from AdBlue to ASDS™
  - ASDS™ will boost performance of "old" OEM catalyst



- Stage-2
  - Also upgrade SCR catalyst (and if wanted DPF)
  - ASDS™ will further boost the low temperature range (slow/cold driving)

Euro V SCR vehicles: Before/after
Real-driving performance before/after City-SCR upgrade



AdAmmine™ enables direct ammonia gas dosing: Safe and compact

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- **AdAmmine™:** Solid ammonia storage, safe, 2x volumetric capacity compared to AdBlue
- Room temperature: **Not pressurized** (0.4 bar)
- **Controlled release**: Pure NH_3 can be released on-demand from the cartridges into the exhaust line.
- **'Refill'**: Depleted AdAmmine cartridges are recharged with NH_3. Salt 'matrix' remains inside the cartridge at all times.

Production: $SrCl_2$ + **NH_3** + special formulation = AdAmmine™

Ammonia release: Controlled thermal desorption

$$Sr(NH_3)_XCl_2 \rightarrow Sr(NH_3)_{X-1}Cl_2 + \mathbf{NH_3}$$

Resaturation (refill):

Depleted cartridge + **NH_3** (& cooling) → 'refilled' cartridge

How to mitigate the gap: CO_2–penalty?

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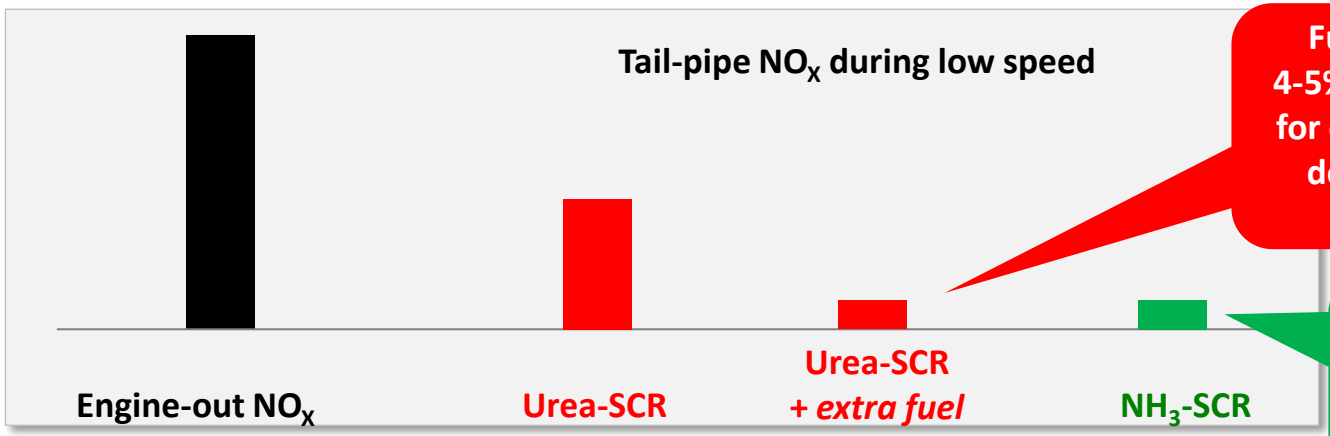
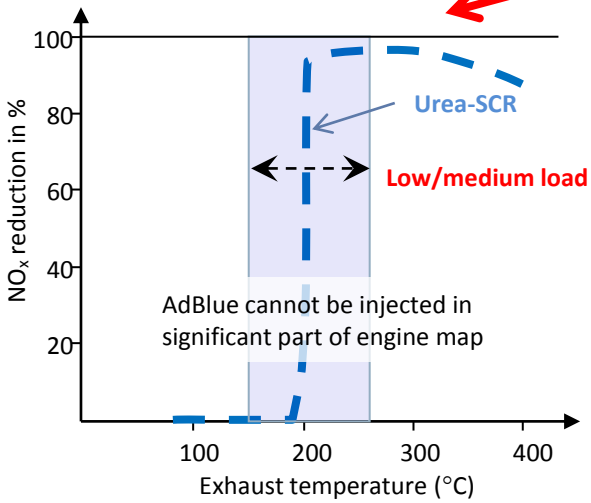
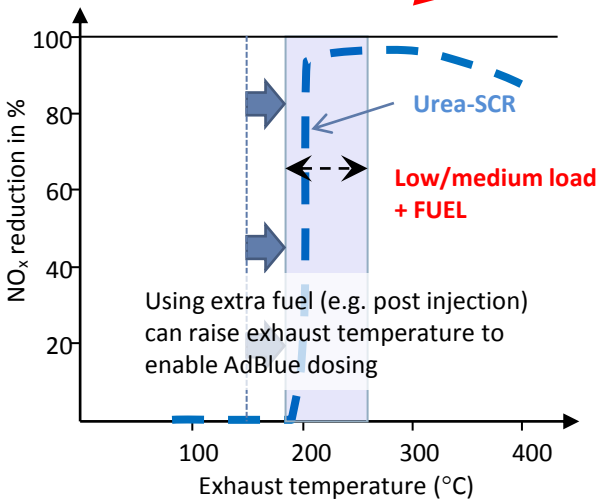
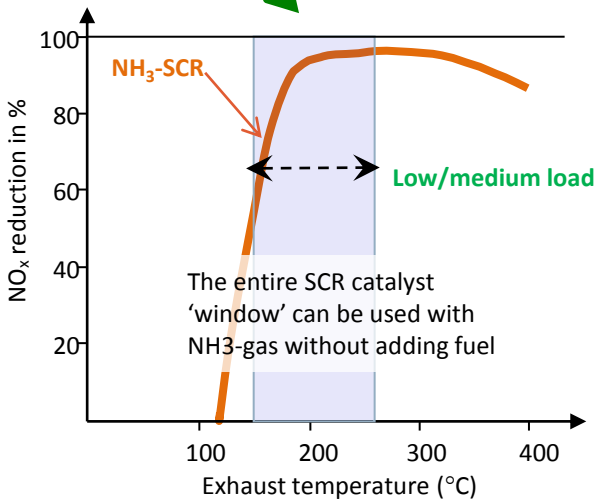


Fuel penalty: 4-5% fuel penalty for enabling urea dosing in city driving

No additional fuel penalty for active SCR temperature management







"Future proof": ATLAS project completed

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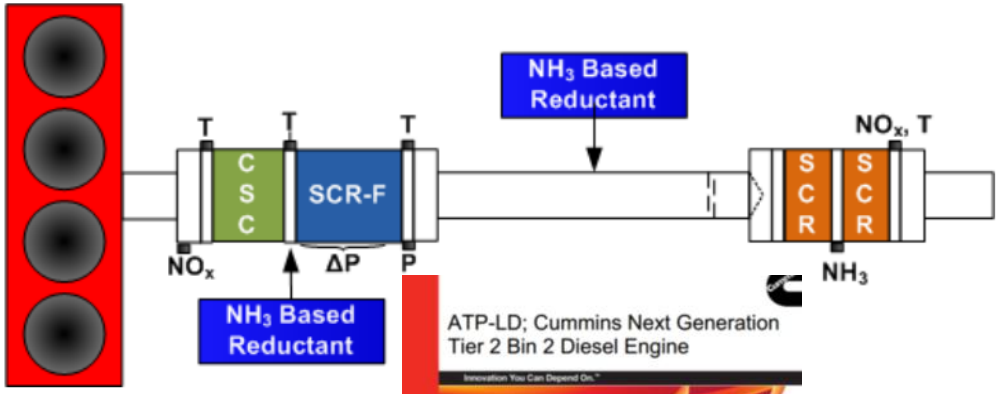
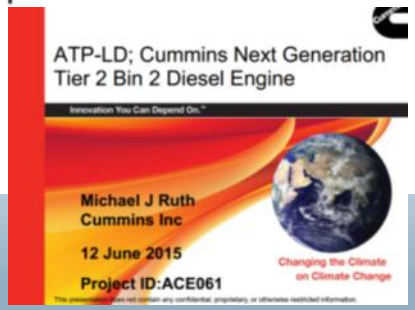
- DOE-funded project at Cummins is now completed(*):
- Dual-EGR engine for ½-ton pickup
- Catalyst partner: JM
- Direct ammonia gas dosing
- Low pressure drop mixing
- Compact "on-engine" aftertreatment system
- No active thermal management
- Tier2-Bin2 performance validated



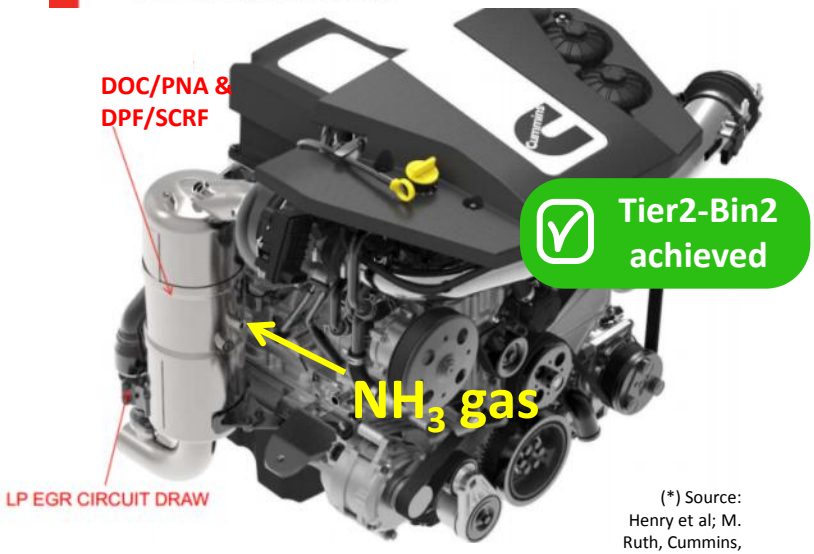


(*)http://energy.gov/sites/prod/files/2014/07/f17/ace061_ruth_2014_o.pdf

Relevance:
Next Generation T2B2 Diesel Engine Objectives

Innovation You Can Depend On™

- Engine design and development program to achieve:
  - 40% Fuel Economy improvement over current gasoline V8 powered half-ton pickup truck
  - Tailpipe requirements: US T2B2 new vehicle standards
- FE increase in light trucks and SUVs of 40% would reduce US oil consumption by 1.5M bbl/day
  - Lower oil imports and trade deficits
  - GHG emissions reduction of 0.5 MMT/day
  - Enable OEM ability to continue to offer products as capable as those in commerce today.



(*) Source: Henry et al; M. Ruth, Cummins, DEER 2012