



# SCR Retrofits: a potential for reducing NO<sub>2</sub> emissions in salt mines

MDEC 2005

Thierry Leprince – Extengine Transport Systems




## Agenda

- Introduction
- Principles of urea-SCR systems
- SCR systems for mobile applications




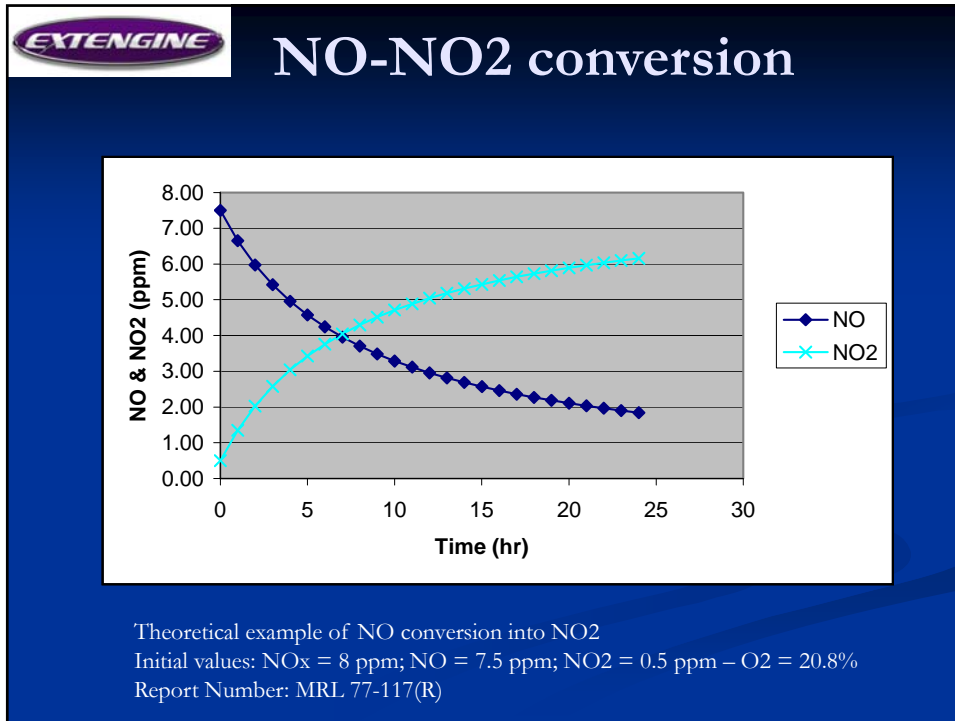
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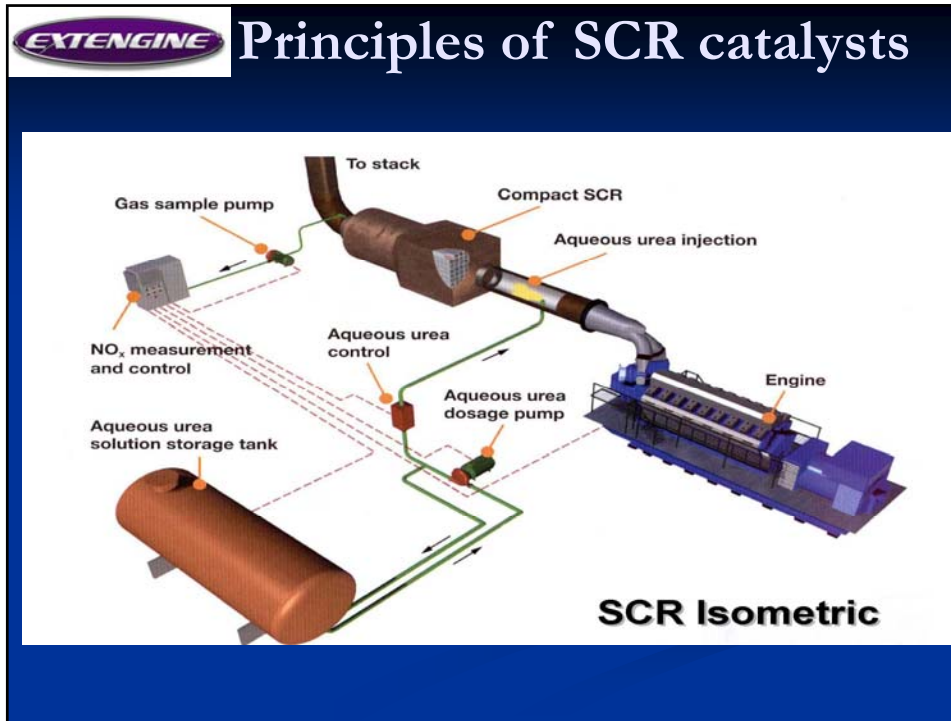
## Introduction


- Salt mines may have an ambient NO<sub>2</sub> problem because of:
  - Long residence time of ventilation air specific to salt mining architecture [large openings, front face is often located at the furthest point from the ventilation inlet]
  - Diesel engines emit NO<sub>x</sub>, which is 90% NO & 10% NO<sub>2</sub>. Long residence time leads to NO being oxidized into NO<sub>2</sub>; which contribute to higher ambient NO<sub>2</sub> levels
  - Proportion of NO<sub>2</sub> coming from the engine in ambient NO<sub>2</sub> levels is not well known
- One potential method for reducing the amount of ambient NO<sub>2</sub> is to reduce to reduce NO<sub>x</sub> emissions coming out of the tailpipe of diesel engines with SCR technology
- SCR is a mature technology that can reduce NO<sub>x</sub> emissions from diesel engines. It has been used in stationary applications for many years and can also be used on mobile non-road applications



**EXTENGINE** Introduction

- SCR is a mature technology which has been used in stationary applications for many years





## Introduction

- SCR is a mature technology which has been used in stationary applications for many years
- SCR is now being used in Europe for mobile applications




 **SCR in Europe**

  
<http://www.purem.de>

  
<http://www.adbloom.co.uk/>

  
<http://www2.mercedes-benz.co.uk>

  
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 **Introduction**

- SCR is a mature technology which has been used in stationary applications for many years
- SCR is now being used in Europe for mobile applications
- **SCR is verified as a retrofit device for non-road applications by CARB**



**EXTENGINE** **First SCR verified in Jan 05**

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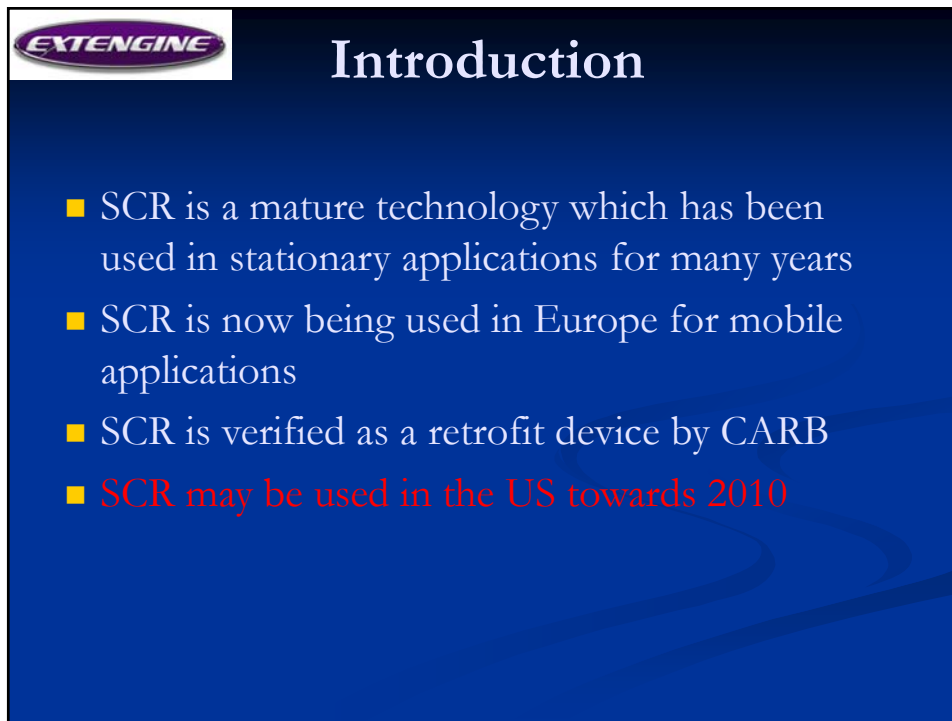
*This page updated January 20, 2004.*

For information on how to submit an application for verification of a diesel emission control technology, please see the regulation at [Go there](#)

**What's New...**

◆ **1/20/05:** The ARB has verified the Extengine Transport Systems Advanced Diesel Emission Control (ADEC) system for 1991 to 1995 model year off-road Cummins 5.9-liter diesel engines from 150 to 200 horsepower, which are used in excavators, dozers, and loaders, all with rubber tires, and utility tractor rigs operating on standard CARB or ultra low sulfur diesel fuel. The ADEC system employs a diesel oxidation catalyst, selective catalytic reduction catalyst, and ammonia slip catalyst to achieve a 25 percent reduction in particulate matter emissions, qualifying it for a Level 1 verification. The system also achieves an 80 percent reduction in NO<sub>x</sub> emissions. Specific conditions for which the ADEC system has been approved may be found in the Executive Order which will be posted within 10 days.

**Background**  
**Contact Information**  
**Formal Regulatory Documents**  
**Level 1 - Verified Technologies**  
**Level 2 - Verified Technologies**  
**Level 3 - Verified Technologies**  
**Verification Procedures**  
**Alternative Diesel Fuels**




**EXTENGINE** **Introduction**

- SCR is a mature technology which has been used in stationary applications for many years
- SCR is now being used in Europe for mobile applications
- SCR is verified as a retrofit device by CARB
- **SCR may be used in the US towards 2010**




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## Principles of urea-SCR catalysts

Urea  $(\text{NH}_2)_2\text{CO}$  or  $\text{NH}_3$



Exhaust gas →

SCR

$$4\text{NH}_3 + 4\text{NO} + \text{O}_2 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O}$$

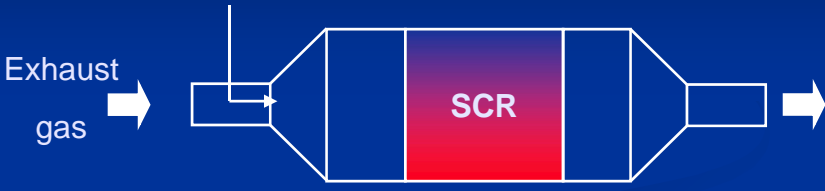
$$8\text{NH}_3 + 6\text{NO}_2 \rightarrow 7\text{N}_2 + 12\text{H}_2\text{O}$$

$$2\text{NH}_3 + \text{NO} + \text{NO}_2 \rightarrow 2\text{N}_2 + 3\text{H}_2\text{O}$$



**EXTENGINE** Principles of urea-SCR catalysts

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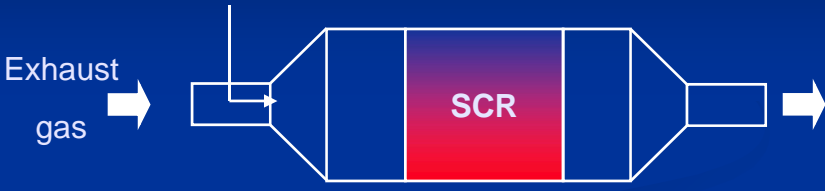
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Fastest reaction  $\rightarrow 2\text{NH}_3 + \text{NO} + \text{NO}_2 \rightarrow 2\text{N}_2 + 3\text{H}_2\text{O}$

**EXTENGINE** Principles of urea-SCR catalysts

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Fastest reaction  $\rightarrow 2\text{NH}_3 + \text{NO} + \text{NO}_2 \rightarrow 2\text{N}_2 + 3\text{H}_2\text{O}$

Optimum:  $\text{NO}/\text{NO}_2 = 1$   
 Engine out:  $\text{NO}/\text{NO}_2 \approx 10$

**EXTENGINE** Principles of urea-SCR catalysts

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Exhaust gas

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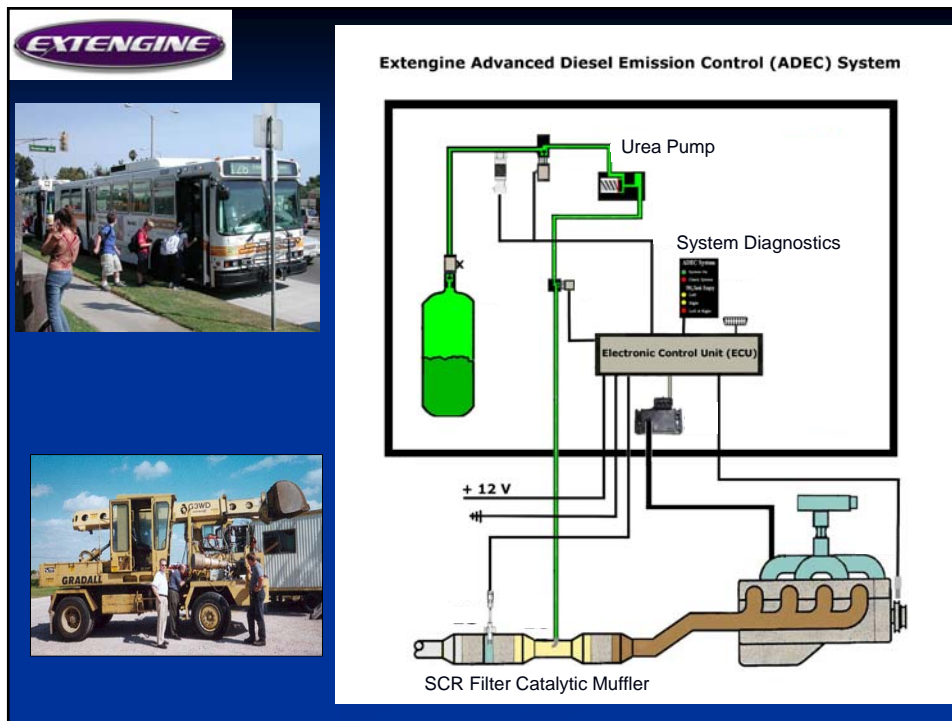
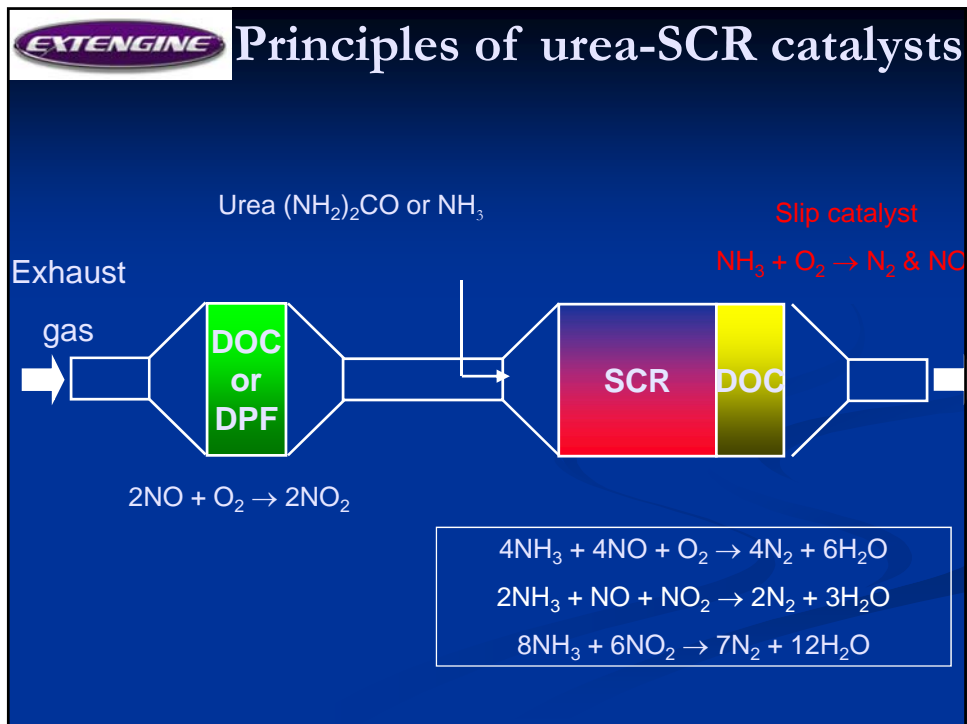
Exhaust gas

$2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2$

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**EXTENGINE** **SCR system: ADEC Gen I**

- Verified by CARB verification for non-road applications

Not to scale

Exhaust gases → Pre-catalyst → NH<sub>3</sub> injection → SCR catalyst → Slip catalyst →

RPM, Load, Temp → ADEC ECU → Solenoid valve signal → NH<sub>3</sub> spray

Anhydrous ammonia tank → Metered NH<sub>3</sub> → NH<sub>3</sub> spray

- Can also be used with urea

**EXTENGINE** **ADEC Generation II**

Catalyzed DPF → Urea injection → Static Mixer → SCR catalyst → Slip catalyst →

RPM, Load, Temp → ADEC ECU → Solenoid valve → Urea spray

Urea tank → Urea pump → Air/urea mixer → Urea → Urea spray

Compressed air → Urea spray



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## Objective

- Demonstrate the possibility of bringing a diesel engine to emission levels lower or similar to 2007 standards or CNG levels in terms of NO<sub>x</sub>+NHC and PM



## Test engine

- 2003 Detroit Diesel 50 – 8.5 L displacement
- Direct injection
- Engine certified @ PM = 0.01 g/bhp.hr  
(equipped with catalyzed diesel particulate filter)
- Turbocharged, charge air cooling, water-cooled EGR
- Rated 275 HP @ 2100 RPM



## Catalysts description

- Diesel particulate filter
  - Cordierite DPF catalyzed by Engelhard
  - Supplied by Detroit Diesel as certified system
- SCR catalyst
  - Metallic substrate catalyzed by Umicore
  - Vanadia based SCR catalyst
  - Diam 11.25" x 10"
- Slip catalyst
  - Metallic substrate catalyzed by Umicore
  - Diam 11.25" x 3"
- SCR & slip catalysts have been aged by 1000 hours
- Complete systems has run 25 hours prior to emission measurements



**EXTENGINE**

## Results: baseline

Engine Certification Data (engine family)						
Emissions (g/bhp.hr)	NMHC+NOx	PM	CO	NOx	NO2	CO2
Diesel (3DDXH08.5FJB)	2.13	0.012	0.35	----	----	----
CNG (3DDXH08.5FJG)	0.94	0.008	0.03	----	----	----

Baseline Emission Tests (Engine is equipped with DPF)						
Emissions (g/bhp.hr)	NMHC+NOx	PM	CO	NOx	NO2	CO2
Hot start 1	2.95	0.01	0.26	2.95	0.69	755
Hot start 2	3.01	0.01	0.15	2.97	0.79	765
Hot start 3	2.81	0.01	0.17	2.77	0.73	743
<i>Average Hot</i>	2.92	0.01	0.19	2.90	0.74	754
Cold start	3.56	0.01	0.27	3.56	0.90	795
<i>Composite Baseline</i>	3.01	0.01	0.20	2.99	0.76	760

Engine data is higher than certification data



## Results: NH<sub>3</sub> SCR


DPF with Anhydrous Ammonia SCR						
Emissions (g/bhp.hr)	NMHC+NO <sub>x</sub>	PM	CO	NO <sub>x</sub>	NO <sub>2</sub>	CO <sub>2</sub>
Hot start 1	0.77	0.005	0.25	0.75	0.15	741
Hot start 2	0.83	0.001	0.14	0.81	0.24	738
Hot start 3	0.90	0.002	0.24	0.90	0.23	735
<i>Average Hot</i>	0.83	0.003	0.21	0.82	0.21	738
Cold start	1.60	0.007	0.35	1.58	0.34	787
<i>Composite Baseline</i>	0.94	0.003	0.23	0.93	0.23	745
<i>Conversion</i>	69%	NC	-12%	69%	70%	2%



## Results: urea-SCR

DPF with Urea SCR						
Emissions (g/bhp.hr)	NMHC+NO <sub>x</sub>	PM	CO	NO <sub>x</sub>	NO <sub>2</sub>	CO <sub>2</sub>
Hot start 1	1.06	0.01	0.43	1.06	0.25	746
Hot start 2	0.96	0.01	0.24	0.95	0.16	738
Hot start 3	0.99	0.01	0.27	0.99	0.24	740
<i>Average Hot</i>	1.00	0.01	0.31	1.00	0.22	741
Cold start	1.96	0.01	0.17	1.96	0.34	799
<i>Composite Baseline</i>	1.14	0.01	0.29	1.14	0.24	749
<i>Conversion</i>	62%	NC	-43%	62%	69%	1%






## Results: summary


Results summary						
Emissions (g/bhp.hr)	NMHC+NOx	PM	CO	NOx	NO2	CO2
Certification data diesel	2.13	0.012	0.35	-----	-----	-----
Certification data CNG	0.94	0.008	0.03	-----	-----	-----
Baseline emissions	3.01	0.01	0.20	2.99	0.76	760
Retrofit NH3 SCR	0.94	0.00	0.23	0.93	0.23	745
Retrofit urea SCR	1.14	0.01	0.29	1.14	0.24	749

- NMHC + NOX engine emissions are higher than 2004 heavy-duty diesel standard
- Engine equipped with anhydrous NH<sub>3</sub>-SCR shows similar NMHC+NO<sub>x</sub> and PM emissions when compared to CNG
- Engine equipped with urea-SCR is at 2007 NO<sub>x</sub> levels. It shows slightly higher emissions in terms of NO<sub>x</sub>+NMHC when compared to CNG engine. Emissions could be improved with larger catalyst




## Summary

- Diesel engines can meet same levels as CNG engines in terms of NO+NMHC and PM emissions when retrofitted with SCR & DPF system
- Additional benefit with diesel is lower THC emissions when compared to CNG
- Overall reduction in greenhouse gases





## Conclusion

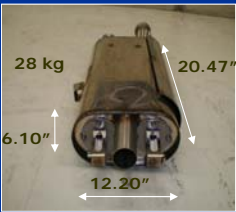
- SCR could be used in salt mines for reducing NO<sub>x</sub> emissions form diesel engines
- It should reduce ambient NO<sub>2</sub> levels.
- Magnitude of reduction on ambient NO<sub>2</sub> levels is not known. It could be estimated with some modeling of air quality
- Extengine is interested in participating in a demonstration in a salt mine
- Active DPF could also be integrated into package in order to reduce PM emissions



## MaxTRAP™ Active Diesel Particulate Filter

**Mercedes-Benz Sprinter Active DPF**



28 kg  
6.10"  
12.20"  
20.47"

Temperature (°C)	Time %	Pressure (mbar)	Time %
< 200	97.25	< 100	95.76
200 - 250	1.64	100 - 148	3.56
250 - 340	0.90	148 - 300	0.68
340 - 400	0.17	300 - 400	0.00
400 - 450	0.04	400 - 500	0.00
> 450	0.01	> 500	0.00

**Dimension and weight of ExoClean™ design for Mercedes-Benz Sprinter application.**

**Data from ExoClean™ field application on Mercedes-Benz Sprinter with commercial standard fuel (350ppm of Sulfur) for 1900 to 2000 hour field operation (fleet) with average speed 9.2 km/h.**



Questions ?