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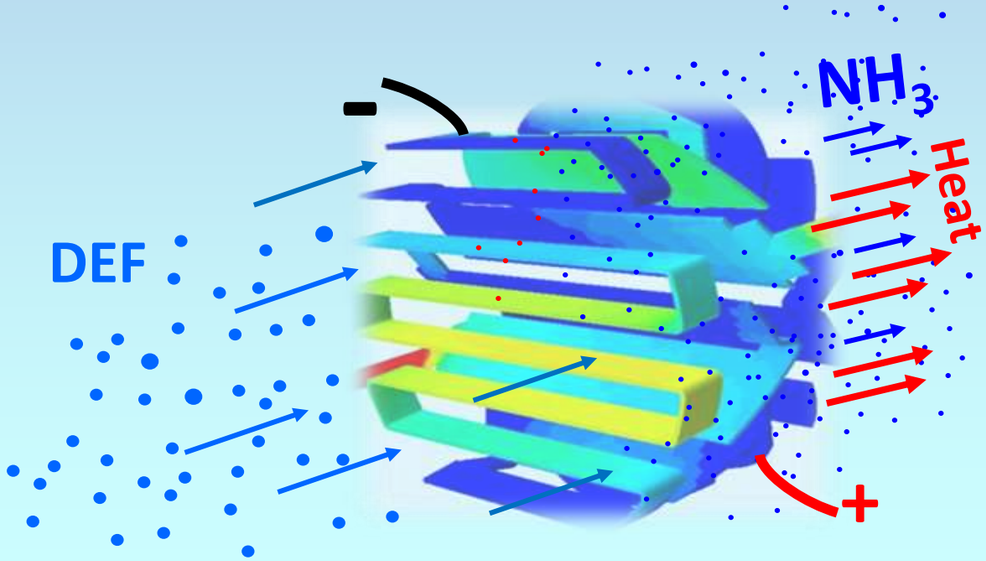
Electrically Heated Mixer (EHM™) for Peak SCR Efficiency, Maximum NOx Reduction

MDEC Conference

Emissol LLC

21-23 October 2024



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Why is Meeting Ultra-Low NOx Difficult?

Motivation

- **Achieving Extremely-Low, Near-Zero NOx Emission**
- **Severe Health Concerns in Closed Spaces, e.g., in Mines**

Challenges

- **Higher NOx Reduction Often Needs More Urea, Yielding:**
  - **Financial Concerns due to:** Deposit ↗; Damage to AFTS, Warranty Risks ↗
  - **Health Risks due to:** NH_3 Slip ↗
  - **Environmental Concerns due to:** N_2O ↗
- **Operational Challenges:** Rapid-Heat up in Cold Start
- **Total Cost of Ownership:** More Urea Injection Means More Cost
- **In-Use Compliance Challenges:** Due to Catalyst Aging, Injector Fouling, …

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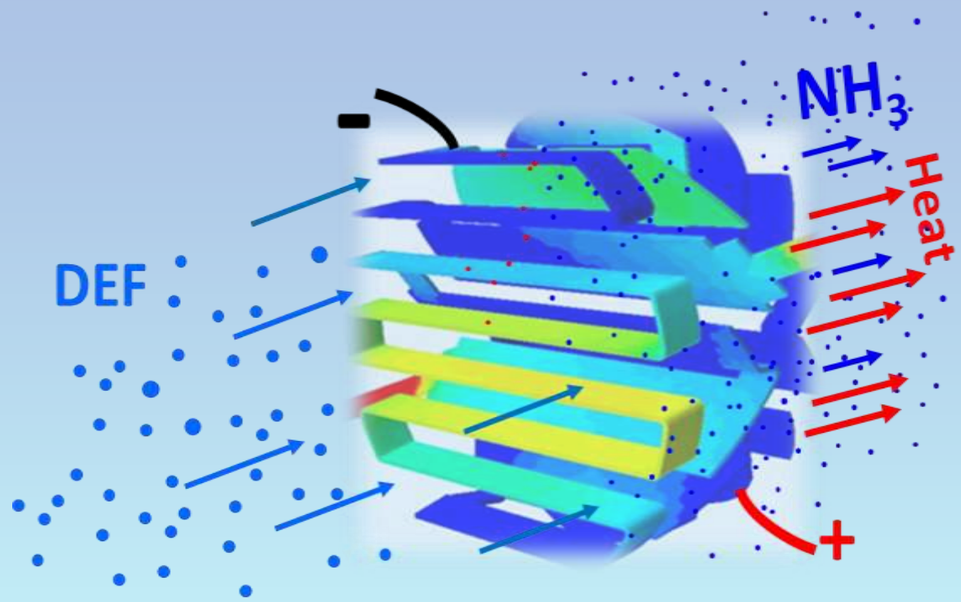
A New Solution: Electrically Heated Mixer (EHM™)

- **Peak SCR Efficiency Needs**
  - **Heat & NH_3**

- **<u>EHM is Two Units in One:</u> Heater & Mixer**
- **I. Rapidly Heats Up SCR** (e.g., in Cold-Start, …)
- **II. Its Heated Surface**
  - **Accelerates Thermolysis, Hydrolysis Reactions**
  - **Produces More NH_3 ↗, Important in**
    - Low Load Engine Operations
    - Cold Ambient
    - Ideal for Urea Injection below, or about, 100 °C (for stronger NH_3 storage in SCR)
- **EHM Forms Ammonia Nearly Independent of Exhaust Temperature**



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EHM For Ultra-Low Tailpipe NOx

Joint Demonstration
Emissol, Eaton & SwRI

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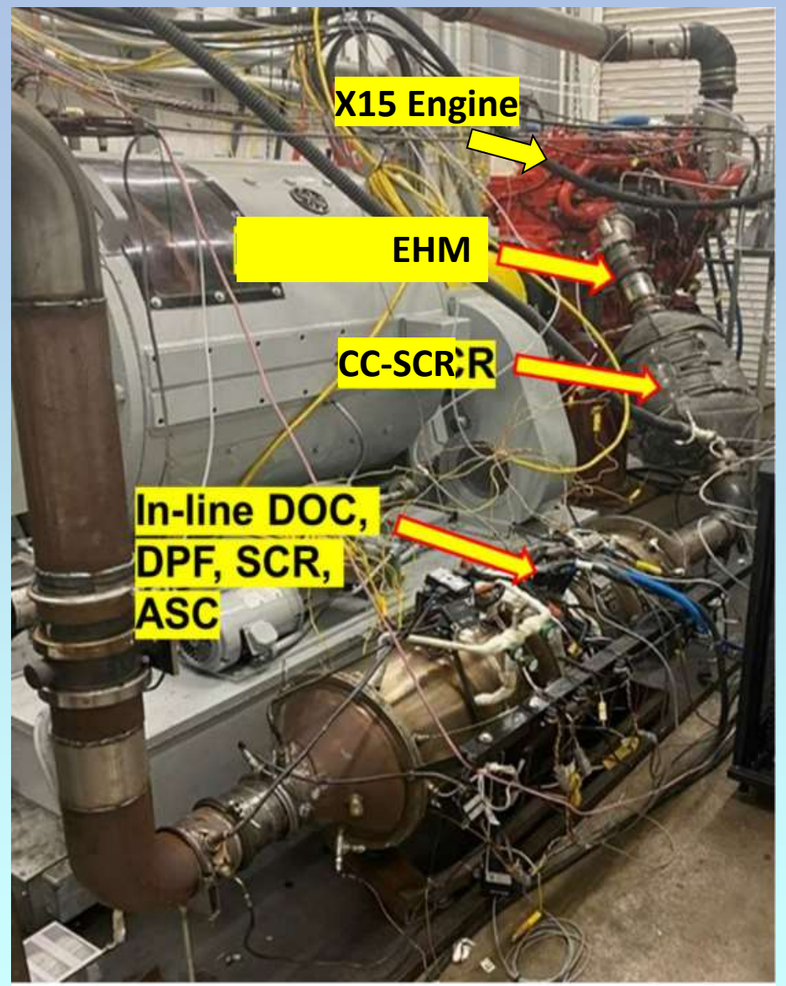
EATON
Powering Business Worldwide

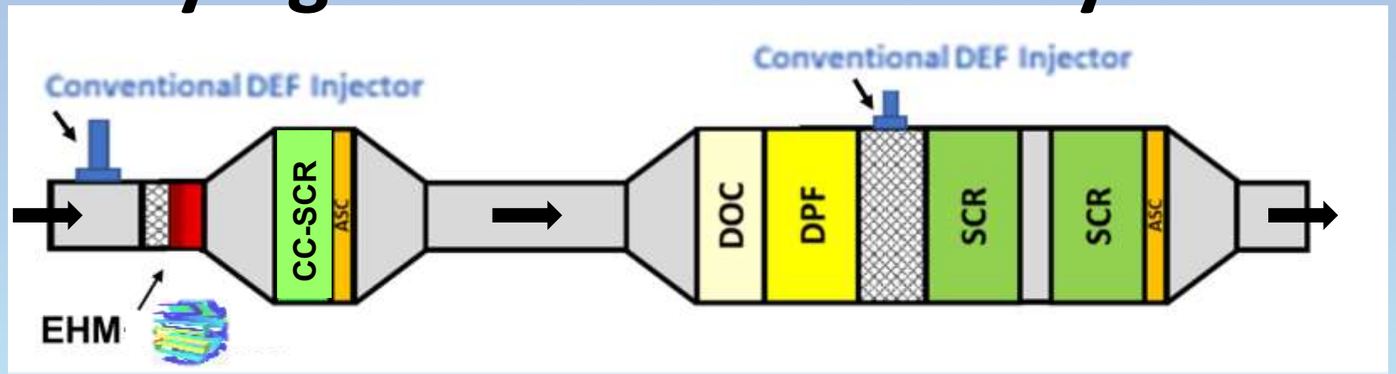
SwRI
SOUTHWEST RESEARCH INSTITUTE

- On Cummins X15 engine
- Using Fully-Aged Aftertreatment System

Set-up



- **Fully Aged Aftertreatment System**



- **Tested Various Cycles**
  - ***Cold & Hot FTP***
  - ***Low-Load Cycle (LLC)***
  - ***Cold, Hot WHTC***
  - ***Other Cycles***

Published in:
"Meeting Future NOx Emission Regulations by Adding an Electrically Heated Mixer".
Frontiers in Mechanical Engineering. Vol. 8. 2022

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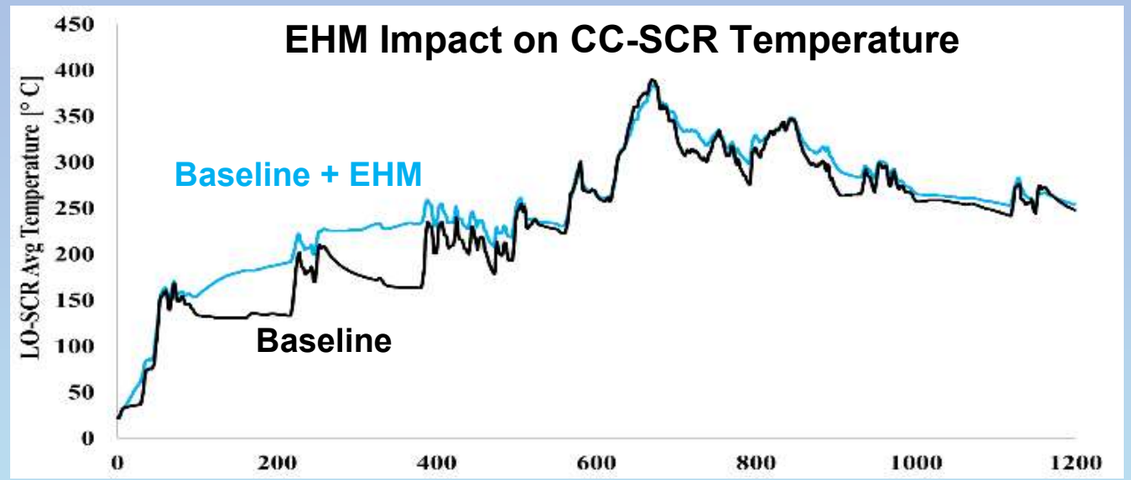
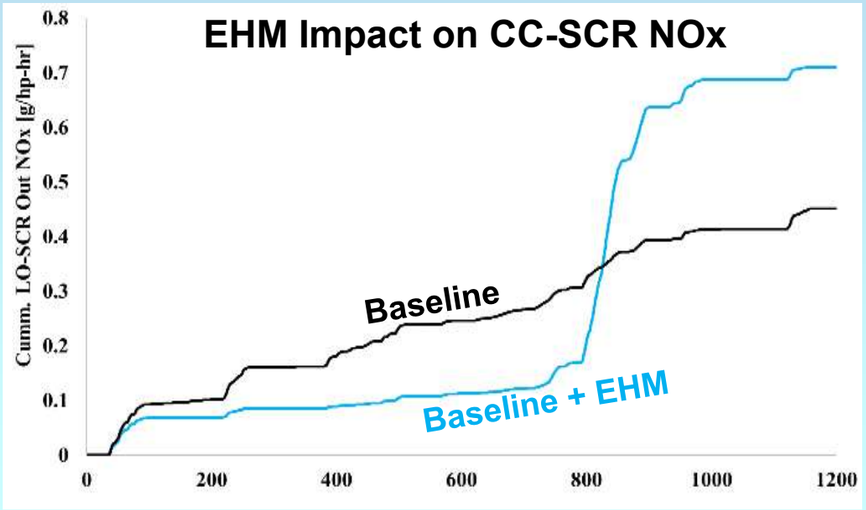
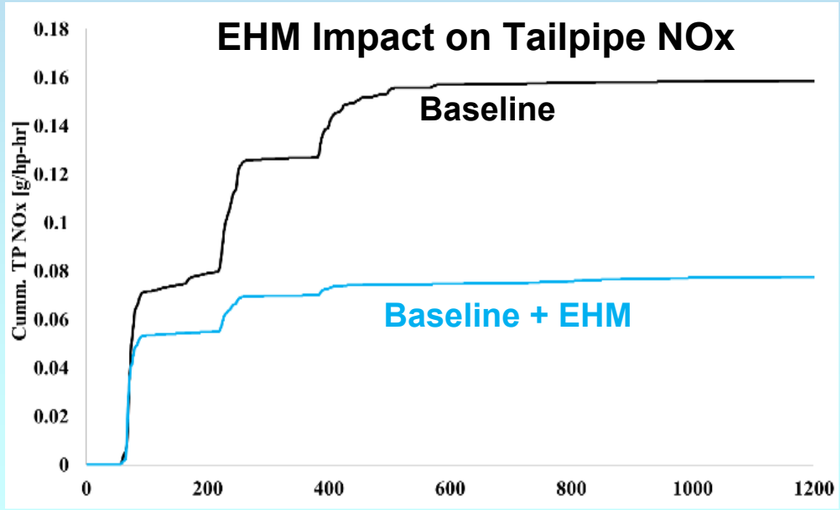
Cold FTP Cycle: EHM Impact on CC-SCR, Tailpipe NOx







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Cold FTP Cycle

Configuration	Tailpipe NOx (g/hp-hr)
Baseline AFTS	0.159
Baseline AFTS with EHM	0.078 ↓ NOx Emission Cut in Half

Hot FTP Cycle

Configuration	Tailpipe NOx (g/hp-hr)
Baseline AFTS	0.043
Baseline AFTS with EHM	0.008 ↓ 5.5X Lower NOx Emission

Full FTP Cycle

Configuration	Tailpipe NOx (g/hp-hr)
Baseline AFTS	0.060
Baseline AFTS with EHM	0.018 ↓ 3.3X Lower NOx Emission

Below World's Lowest NOx Targets:
-- 2027 EPA/ California HD On-Road
-- 2029 California HD Off-Road (Tier5)

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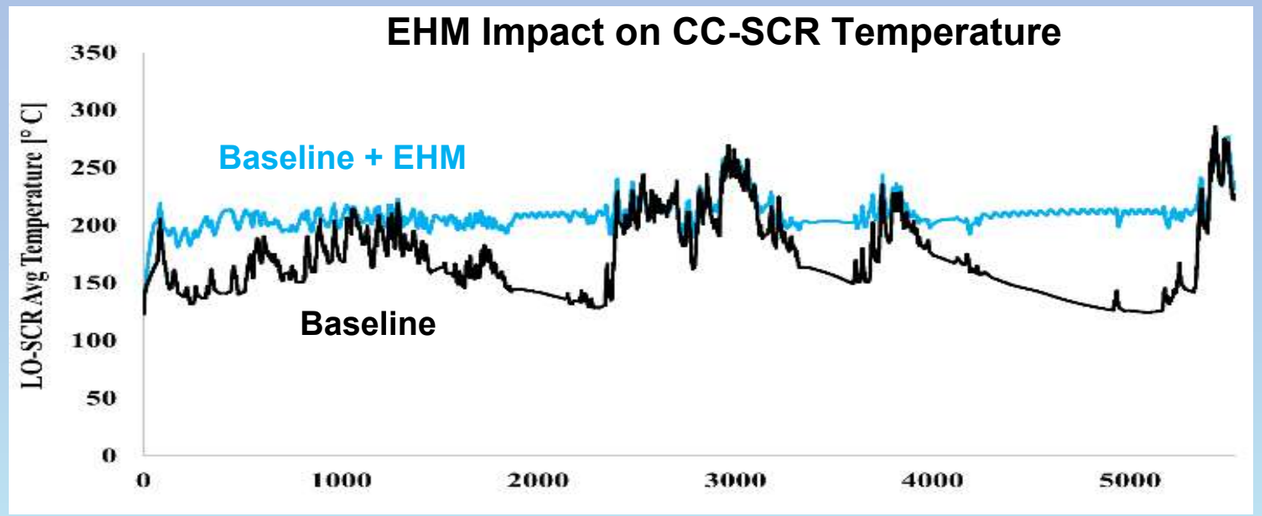
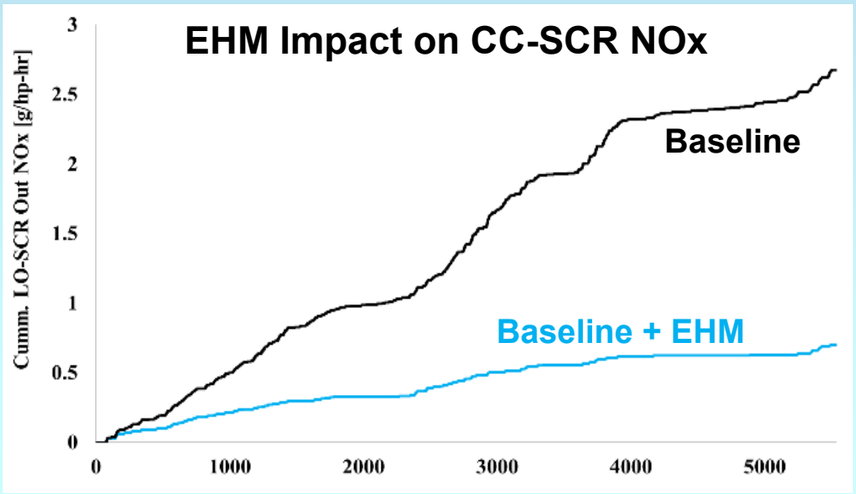
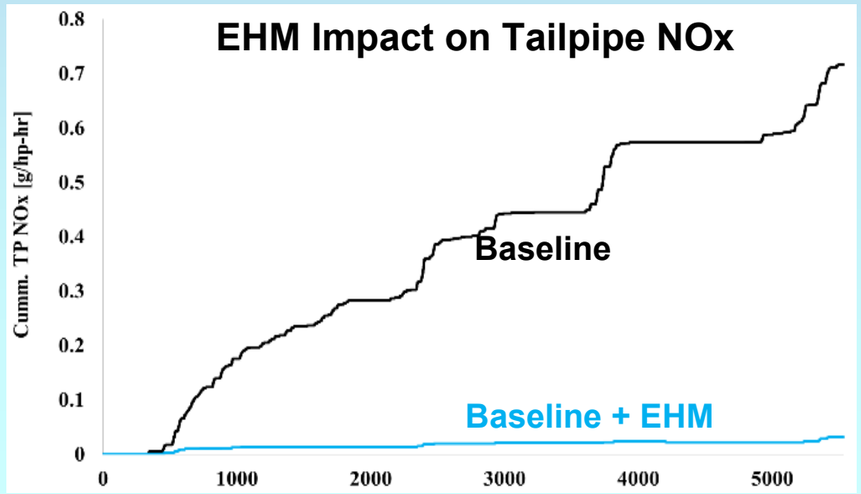
Low-Load Cycle: EHM Impact on CC-SCR, Tailpipe NOx







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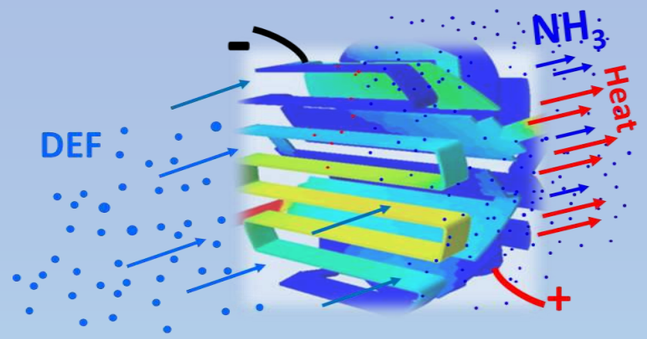
Low-Load Cycle



Configuration	Tailpipe NOx (g/hp-hr)
Baseline AFTS	0.716
Baseline AFTS with EHM	0.032 ↓ 22X Lower NOx Emission

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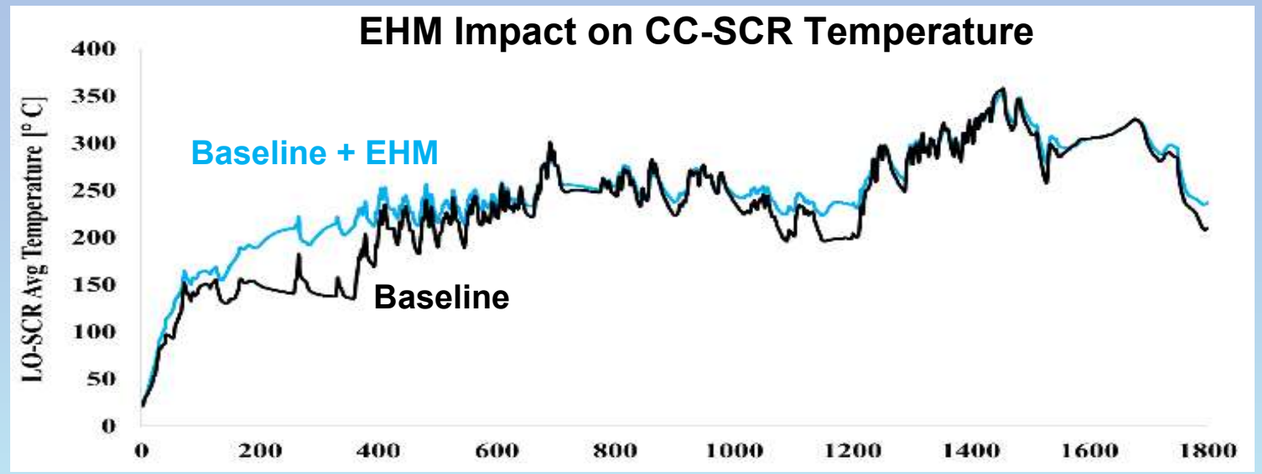
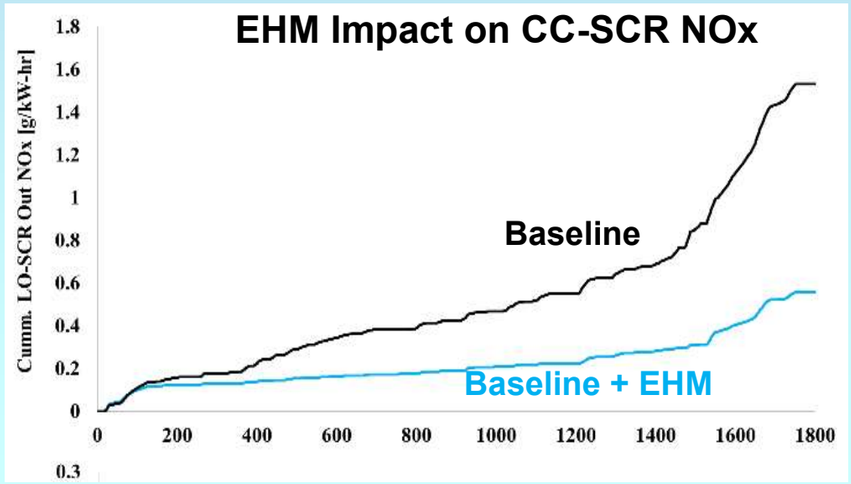
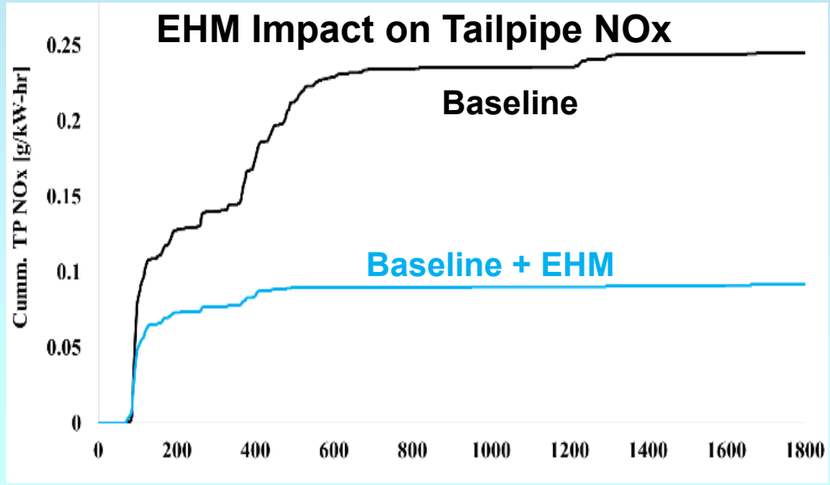
World Harmonized Transient Cycle/ WHTC: EHM Impact on NOx

Cold WHTC







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Cold WHTC (World Harmonized Transient Cycle)

Configuration	Tailpipe NOx (g/hp-hr)
Baseline AFTS	0.245
Baseline AFTS with EHM	0.091 ↓

2.5 X Lower NOx Emission

Hot WHTC

Configuration	Tailpipe NOx (g/hp-hr)
Baseline AFTS	0.125
Baseline AFTS with EHM	0.001↓

125X Lower NOx Emission

Full WHTC

Configuration	Tailpipe NOx (g/hp-hr)
Baseline AFTS	0.142
Baseline AFTS with EHM	0.014↓

10X Lower NOx Emission

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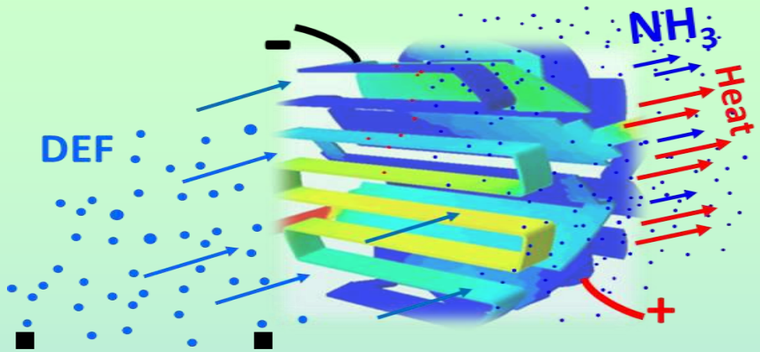

EHM

for Higher NOx Reduction in Challenging Cycles: Low-Temperature & Highly Transient

(Exhaust Temp. < 200℃)

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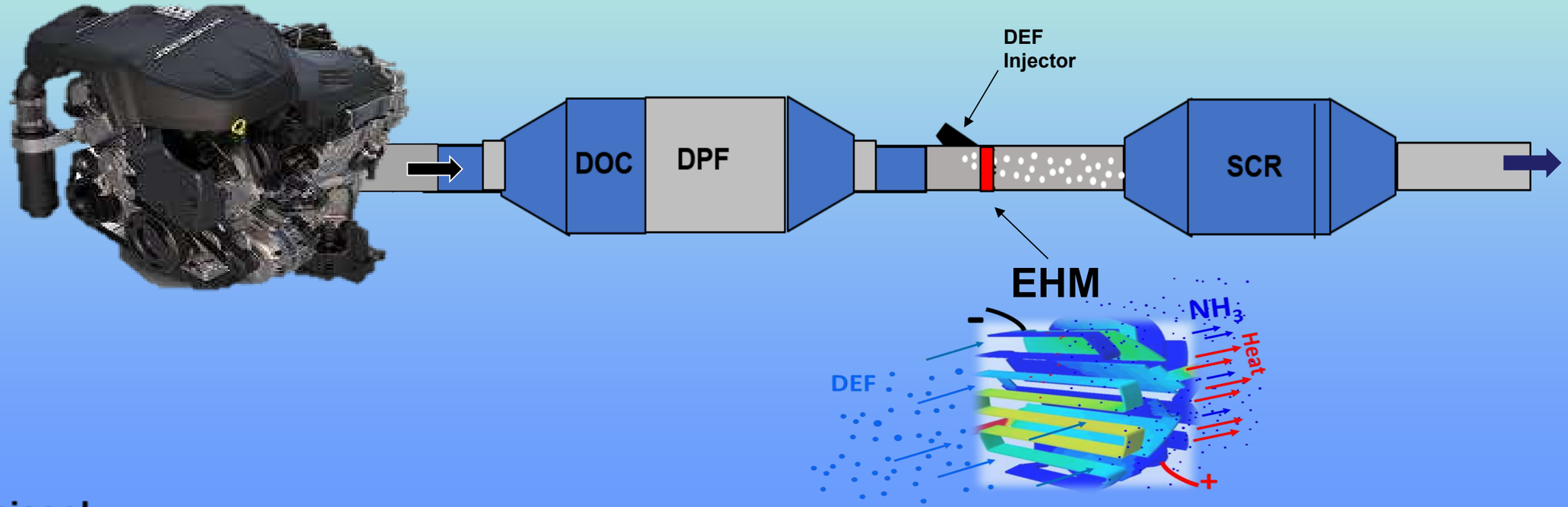
EHM for Peak SCR Performance: Low Temp., Highly Transient Cycles

- 3 Lit. Diesel Engine
- AFTS: DOC-DPF-SCR
- EHM positioned pre-main SCR



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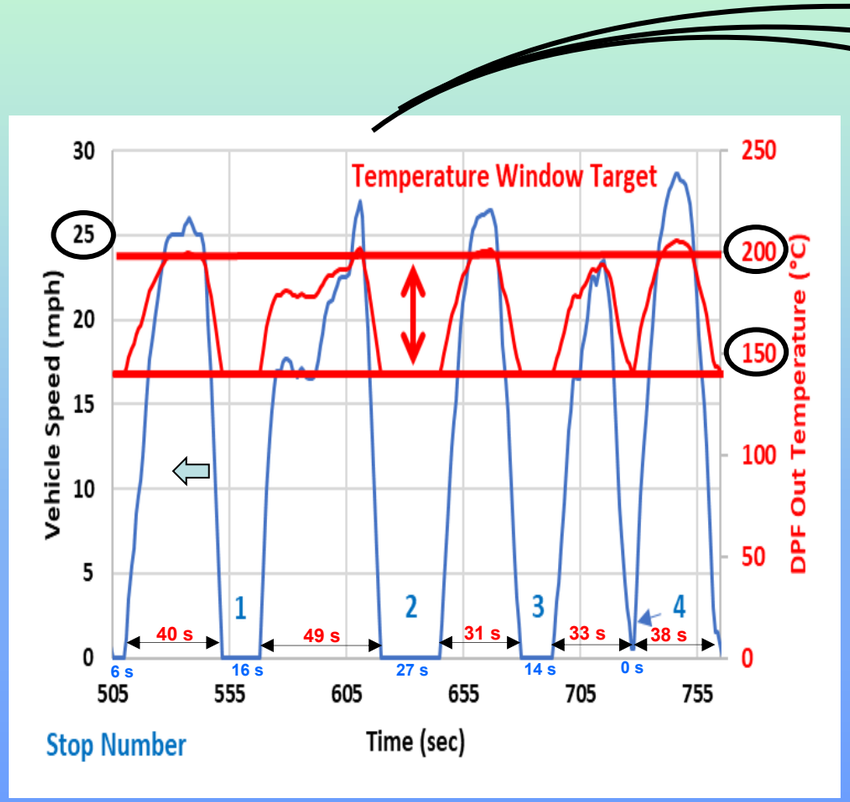
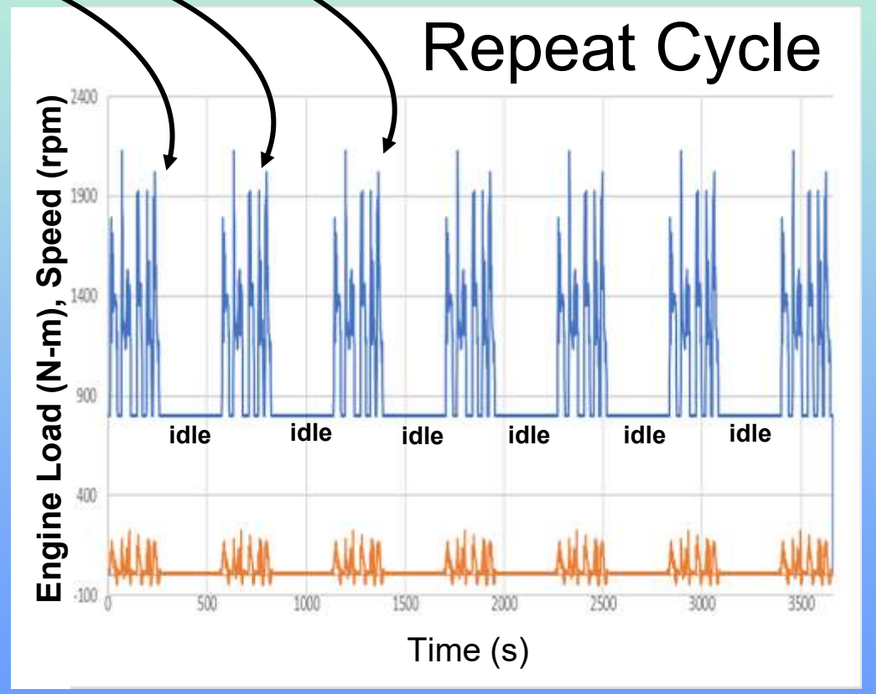
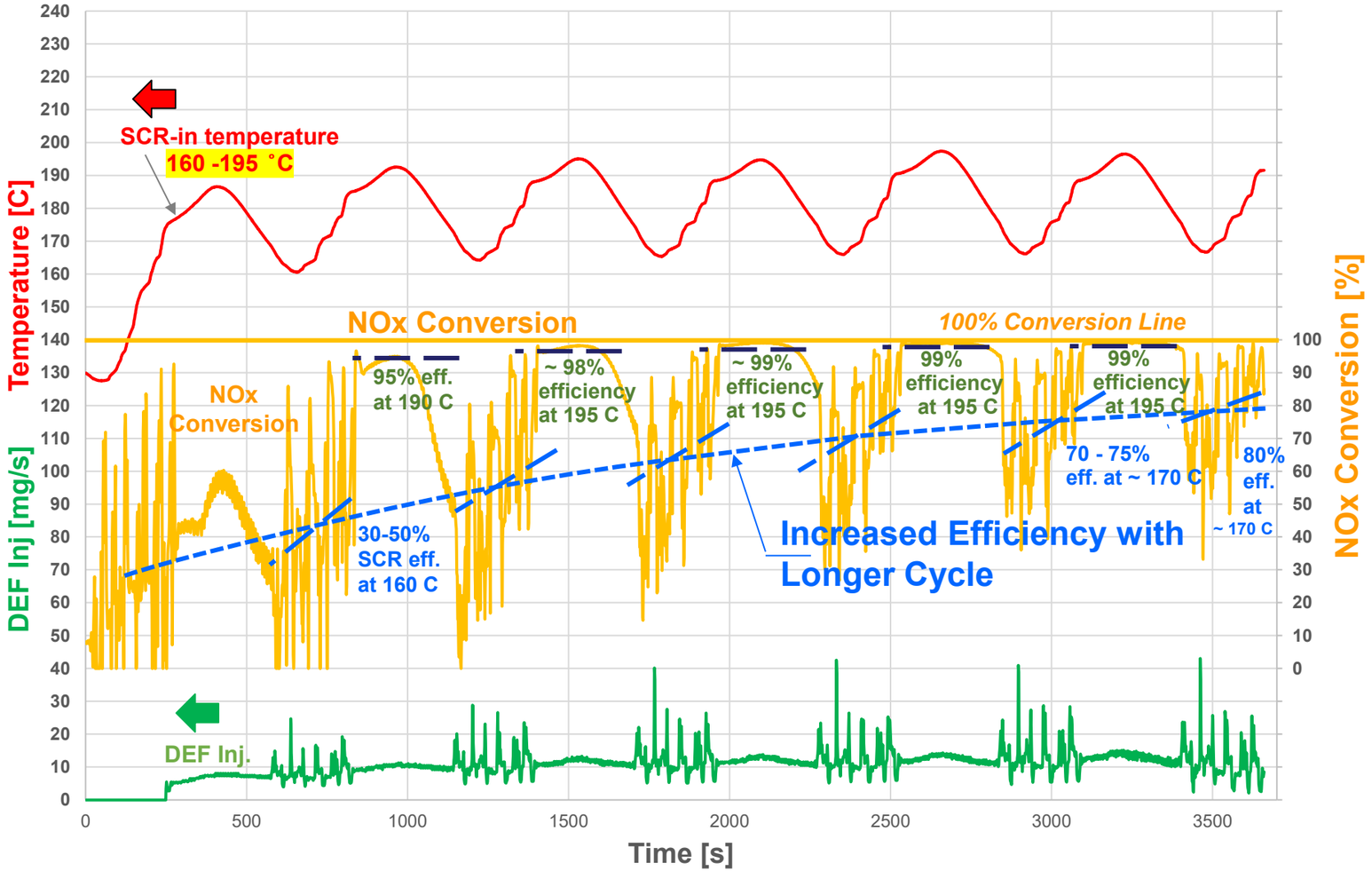
Highly Transient Cycle & is Low Temperature

- Pre-SCR Temperature Constantly Maintained Below 200˚C





Highly Transient Cycle: SCR Has Stored Ammonia



EHM Enables:

- **95 – 99%** NOx Conversion at Stops (**190 °C**)
- **Up to 80%** NOx conversion in Transients (**160 °C**)
- **Higher Efficiency as Cycles Continues**

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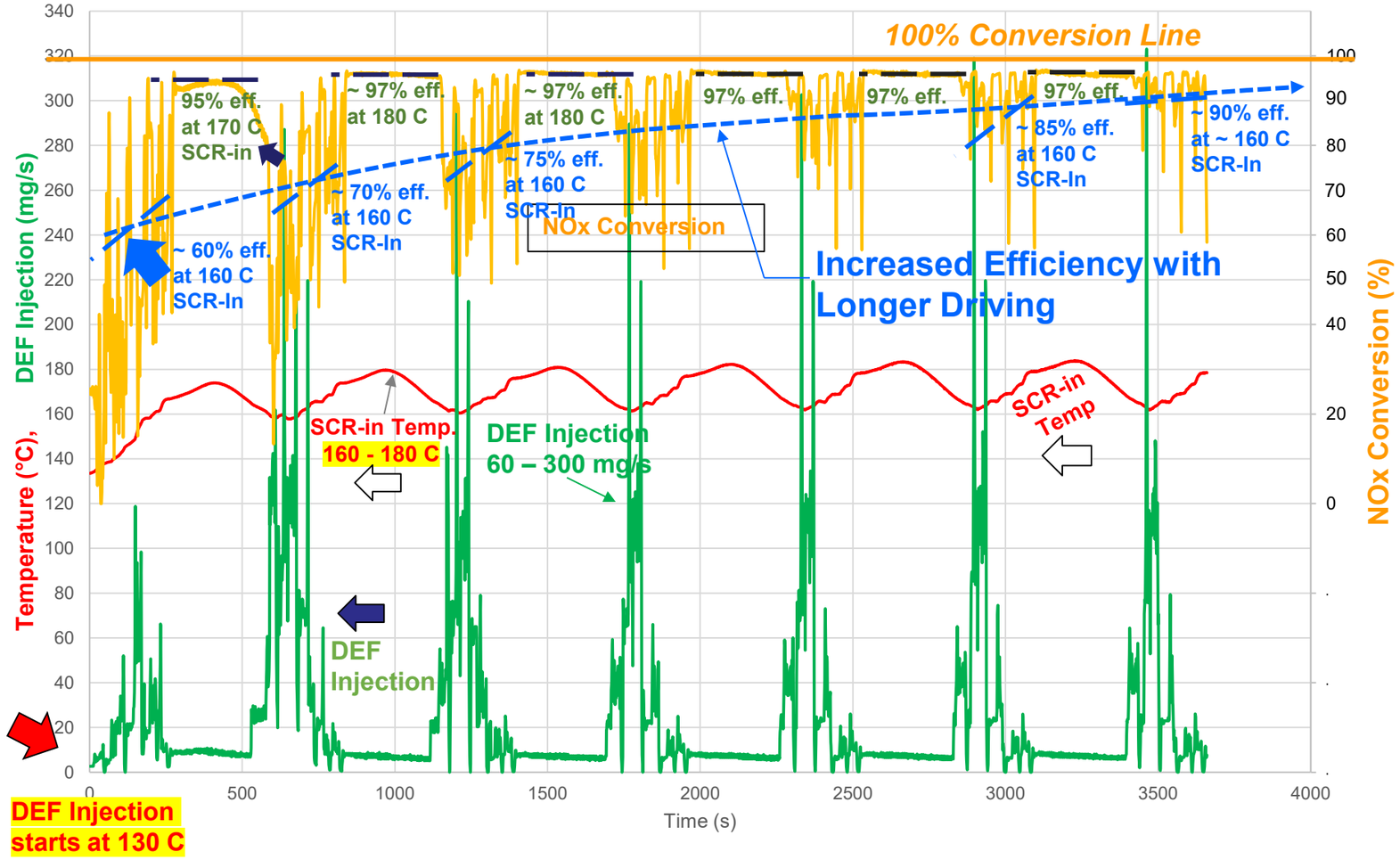
High Transient Cycle - SCR Has Without Stored Ammonia



EHM Enables:

- **95 – 9%** NOx Conversion at Stops (**180 °C**)
- **~ 90%** NOx conversion in Transients (**160 °C**)
- **Higher Efficiency as Cycles Continues**

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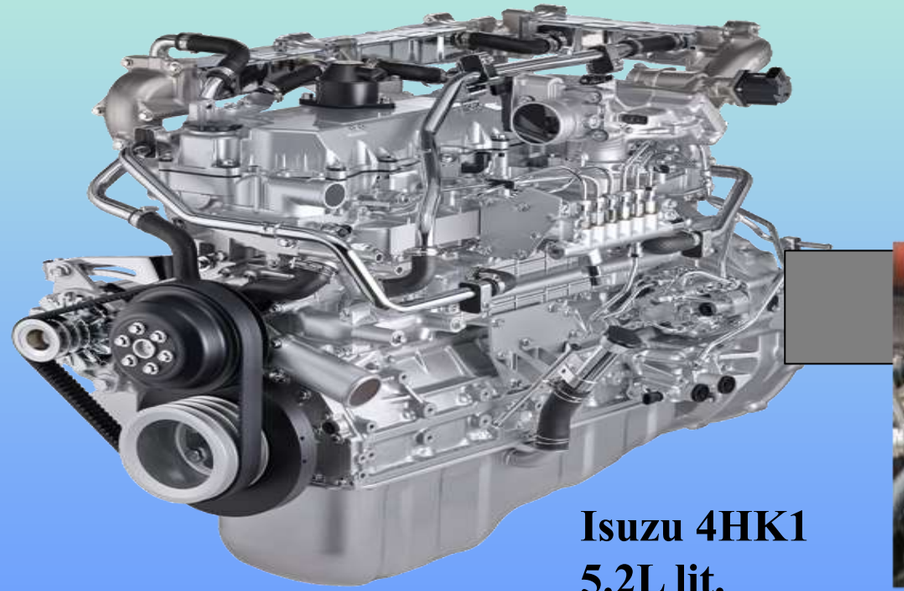
EHM for Deposit Mitigation

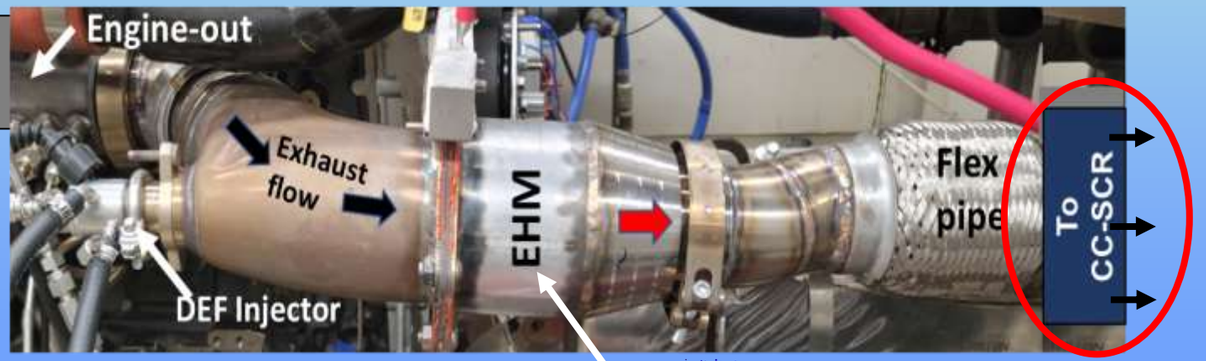
Join Emissol - Isuzu Demonstration

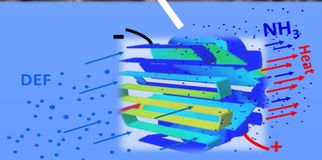
GOAL: Use EHM to Avoid Deposit



Isuzu 4HK1
5.2L lit.

CC-SCR positioned near engine





~ 100 Hours of Urea Injection

SAE 2024-01-2377

- **Deposits only ~ 0 - 1% of Injected DEF**

Operation Point / OP	Run Time	Exh Flow	Exh Temp	DEF Inj. Rate	Total DEF Injected	Deposit Cumulative	Deposit (% of Injected DEF)
OP#	hours	Kg/hr	degC	gr/hr	gram	gram	%
OP1	20	140	204	93	1860	7	0.4%
OP2	20	170	235	120	2400	13	0.5%
OP3	10	143	239	306	3060	45	1.5%
OP4	10	245	300	300	3000	0	0.0%
OP5	15	235	300	600	9000	3.5	0.0%
OP6	10	200	197	400	4000	33	0.8%

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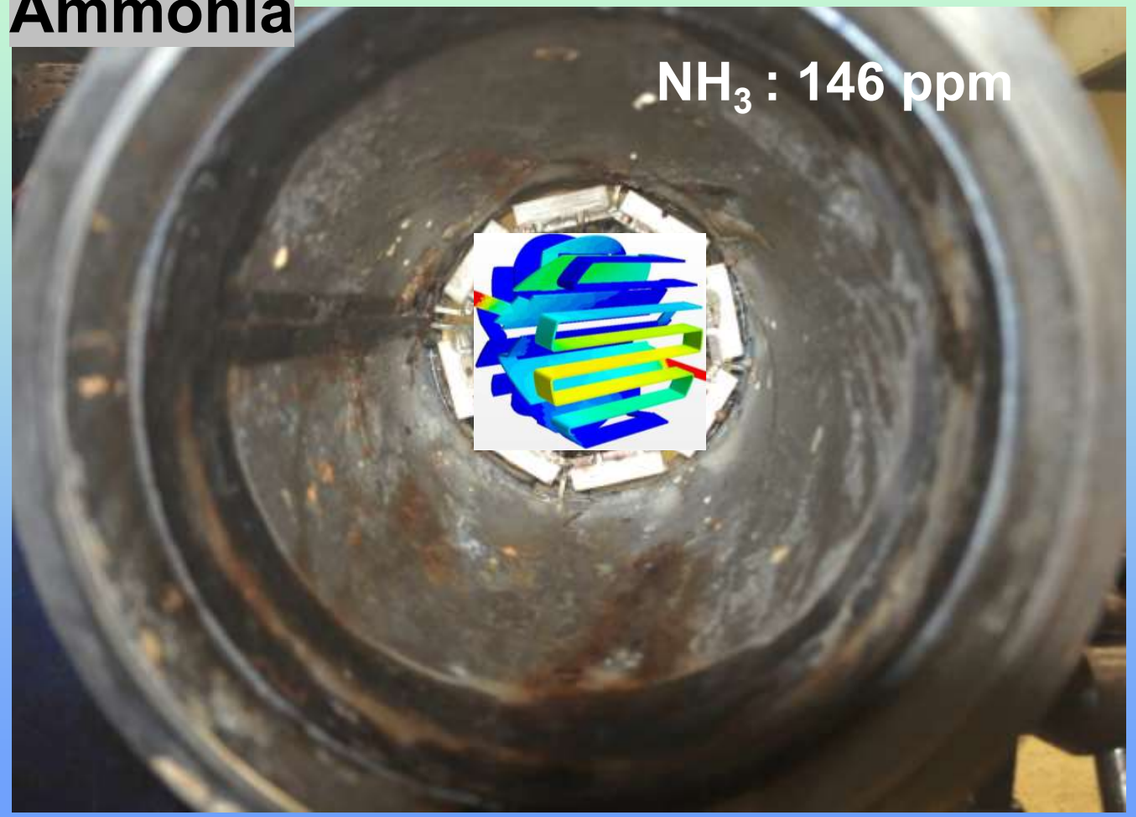
ISUZU

Urea Injection in 150 °C Exhaust: Without, & With EHM

Flow rate: 100 kg/hr.
Flow Temp.: 150 C
Urea Inj.: 75 mg/s
Duration: 1.5 hr.

Without EHM: Deposit

With EHM: No Deposit, More Ammonia



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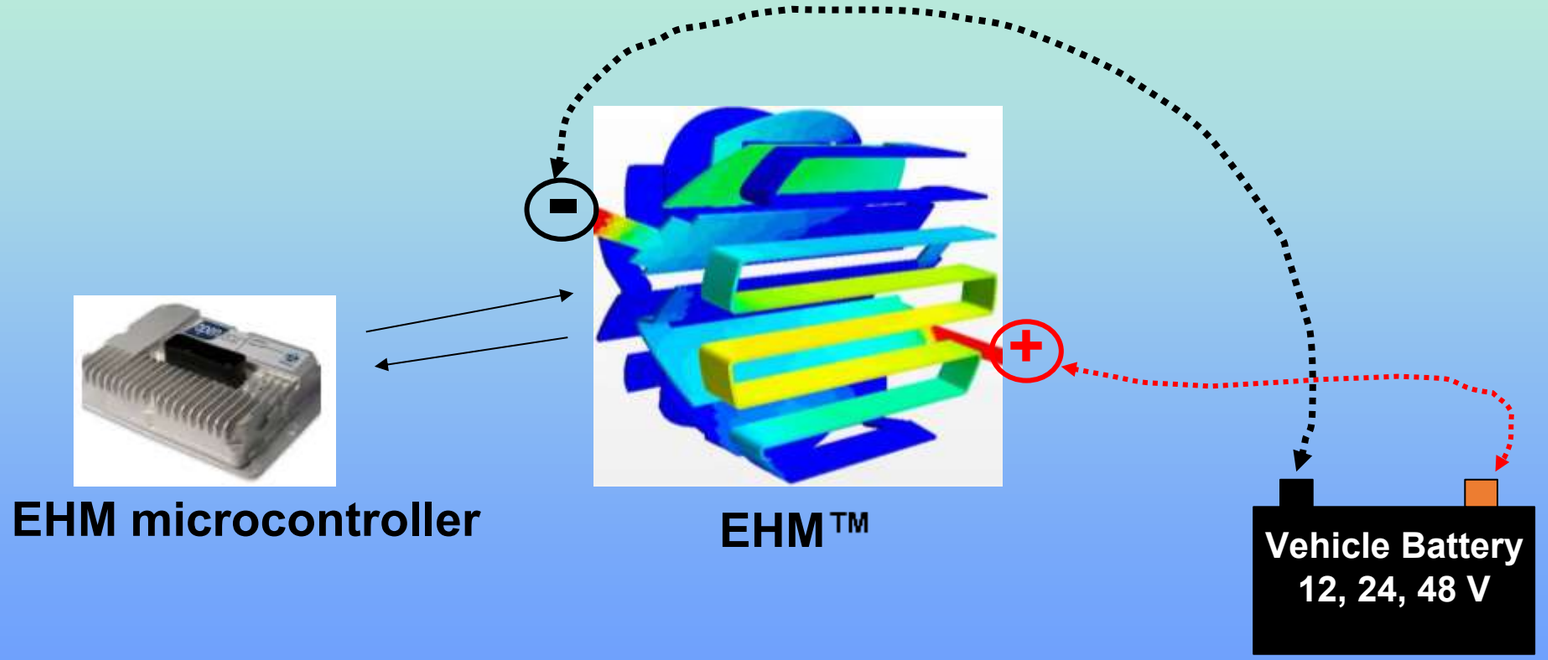
EHM Controller

- Prototype Controller Governs EHM Functions
- Control Algorithm is Integrated into Aftertreatment Control Module (ACM), or into ECU



EHM™ Awards, Recognitions

- SAE John Johnson Award (2024)
- German Innovation Award (2023)
- R&D-100 Award Finalist (2022)

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Summary

- **Electrically Heated Mixer/EHM™**
- **Enables Peak SCR Performance, Meeting Ultra-Low NOx Targets**
- **Provides SCR Both Heat & Ammonia in Any Operating Conditions**
- **Reduces NOx-Related Health Concerns in Closed Spaces, such as in Mines**
- **Low-Cost**
- **Easy Fit. Simply Swap Old Mixer with EHM. Needs No AFTS Re-Design**
- **Good also for Managing**
  - Cold-Start
  - Deposit Mitigation
  - Forming Ammonia Independent of Exhaust Temperature

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For Clean Air!

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Contact:
emissol@emissol.com

Questions asked at MDEC:

A) What is the electric power draw?
Directional numbers:
In LDD, ~ 0.2%.
MDD/ HDD: ~ 0.5%.
When EHM is used also for SCR heating in cold-start: ~ 0.5% (in WHTC, HDD demo), ~ 2% (FTP, HDD demo) or higher pending each specific application (how “cold” the cycle is).

B) Is it commercially available?
Short answer: Discussions for series manufacturing are starting.
There certainly is industry interest, as seen in our join publications with OEM and tier-1 suppliers. Interests include LDD, MDD, HDD, including off-road and marine.

C) You said it could be easily switched from the regular mixer. Wouldn’t this be a violation of engine certification rules and/or engine warranty?
- if EHM is integrated in a new (OEM) system, it would be a part of the certification process.
- if used in retrofit (there are indeed SCR retrofit activities, esp. outside of the US), this should not be an issue.
- if used in a system that is still under warranty, this may impact the warranty. Any such ‘retrofit’ should be coordinated with the OEM/ engine manufacturer (certifying party).

D) Impact on NO to NO2 toxicity?
If I understand the question right: What EHM does is to heat the SCR catalyst & to accelerate thermolysis-hydrolysis reactions (making more ammonia for peak SCR efficiency).
NO / NO2 toxicity is predominantly a question of catalyst formulation (is it Cu/Fe-zeolite? Vanadia? Or …? DEF dosing/ANR strategy? …?) Though we are happy to discuss this further.

Back-up Slide

CO_2 Impact due to EHM

- **Strongly Depends on Strategy (i.e., heating, DEF Injection Rate, etc.)**
- **Generally**
  - **EHM function to form more ammonia in low-temp. exhaust: ~ 0.2 to ~ 0.5%**
  - **EHM function as heater (e.g., in cold-start): Depending on strategy: ~ 0.5% and up**

EHM Lowering NOx and its CO_2 (fuel penalty) impact *

Cycle Type (examples)	NOx Reduction ↑by	CO_2 Impact
Full FTP Cycle	3 X	2%
WHTC	10X	0.6%
Low-Load Cycle (LLC)	22X	5.3%

* *Details in: :*
"Meeting Future NOx Emission Regulations by Adding an Electrically Heated Mixer".
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