

Euro VII RDE Applied to US 2027 Heavy-Duty Emission Controls

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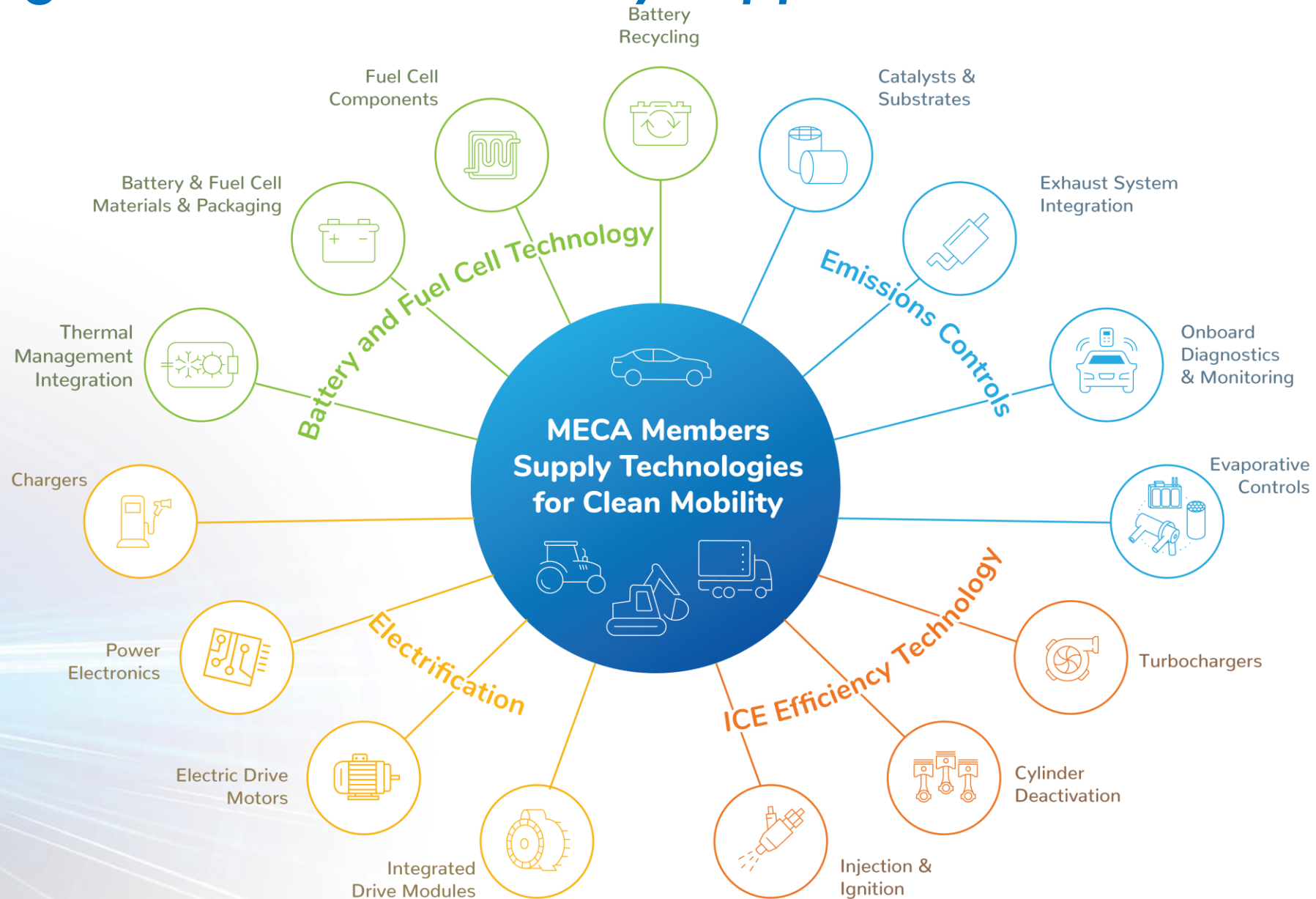
Emission Control Technologies 2025

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For 50 years, MECA has been the Credible Voice of Diverse Technologies from Clean Mobility Suppliers



Outline

- U.S. 2027 and Euro VII Heavy-Duty regulations
- Technology demonstration
- Performance over U.S. and European certification and real-world cycles
- Euro VII work-based window analysis results

U.S. 2027 Heavy-duty Regulation and Euro VII final

U.S. 2027		Euro VII	
FTP / RMC NO _x , mg/kw-hr	47	WHTC / WHSC NO _x , mg/kw-hr	200
Low Load Cycle NO _x , mg/kw-hr	67	n/a	
RDE NO _x Standard, mg/kw-hr	105 (Bin 2)	RDE NO _x Standard, mg/kw-hr	260
RDE NO _x Low Temp	up to 164 at 5°C, n/a below	RDE NO _x Low Temp	same to -7°C
RDE Type	2B-MAW, 300- sec window	RDE Type	Work-Based Window (WHTC), 90th percentile
n/a		OBM	2.5X standard
FUL(HHD), km	1,083 M	FUL(HHD), km	700k (875k with multiplier TBD)

- Proposed Euro VII was similar to U.S. 2027
- Euro VII final was considerably relaxed
- The two regulations drive different technology pathways

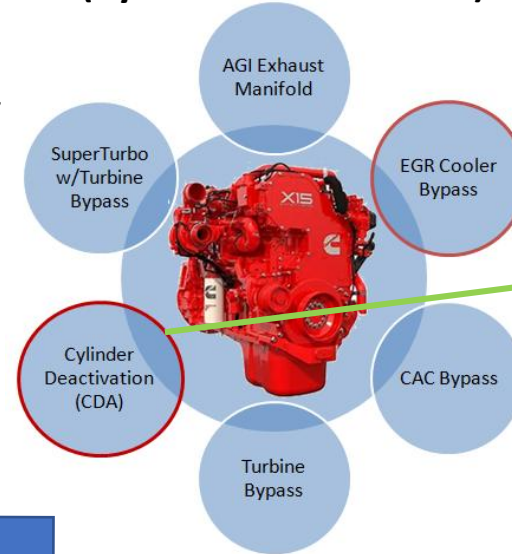
EPA, CARB, MECA Low NO_x Technology Demonstration Program

2017 Cummins X15 Engine

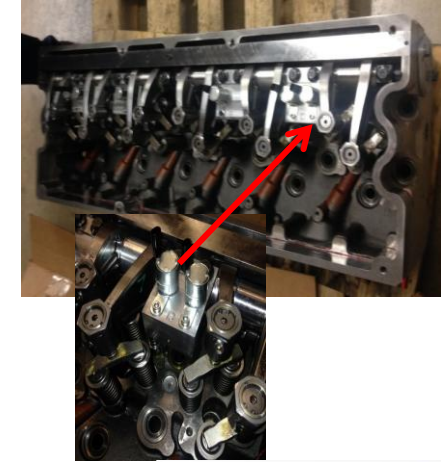


Full System Details
SAE Paper
2021-01-0589

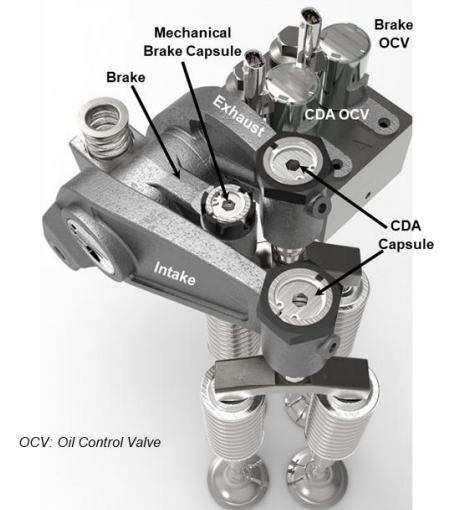
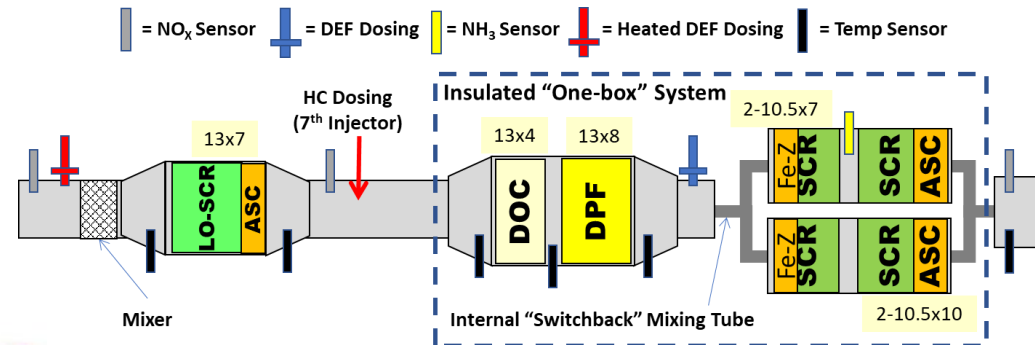
Additional Engine Hardware (Cylinder Deactivation)



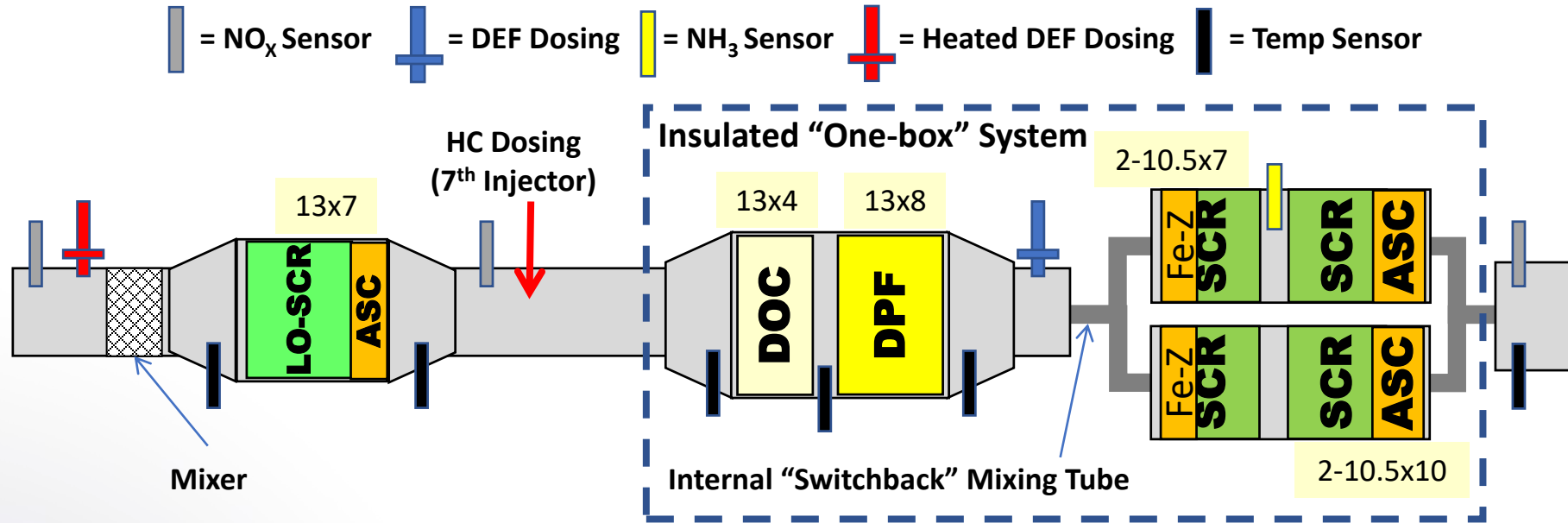
Eaton Cylinder Deactivation Hardware



Advanced Low NO_x Aftertreatment (Dual SCR-Dual Dosing)



2027 MY Aftertreatment System



Third generation system improvements...

Improved catalyst formulation including Fe-zeolite layer at front of downstream SCR

- Reduced N₂O formation with new system at below half EPA standard

Further improved low temperature durability by replacing CSF with DOC+DPF

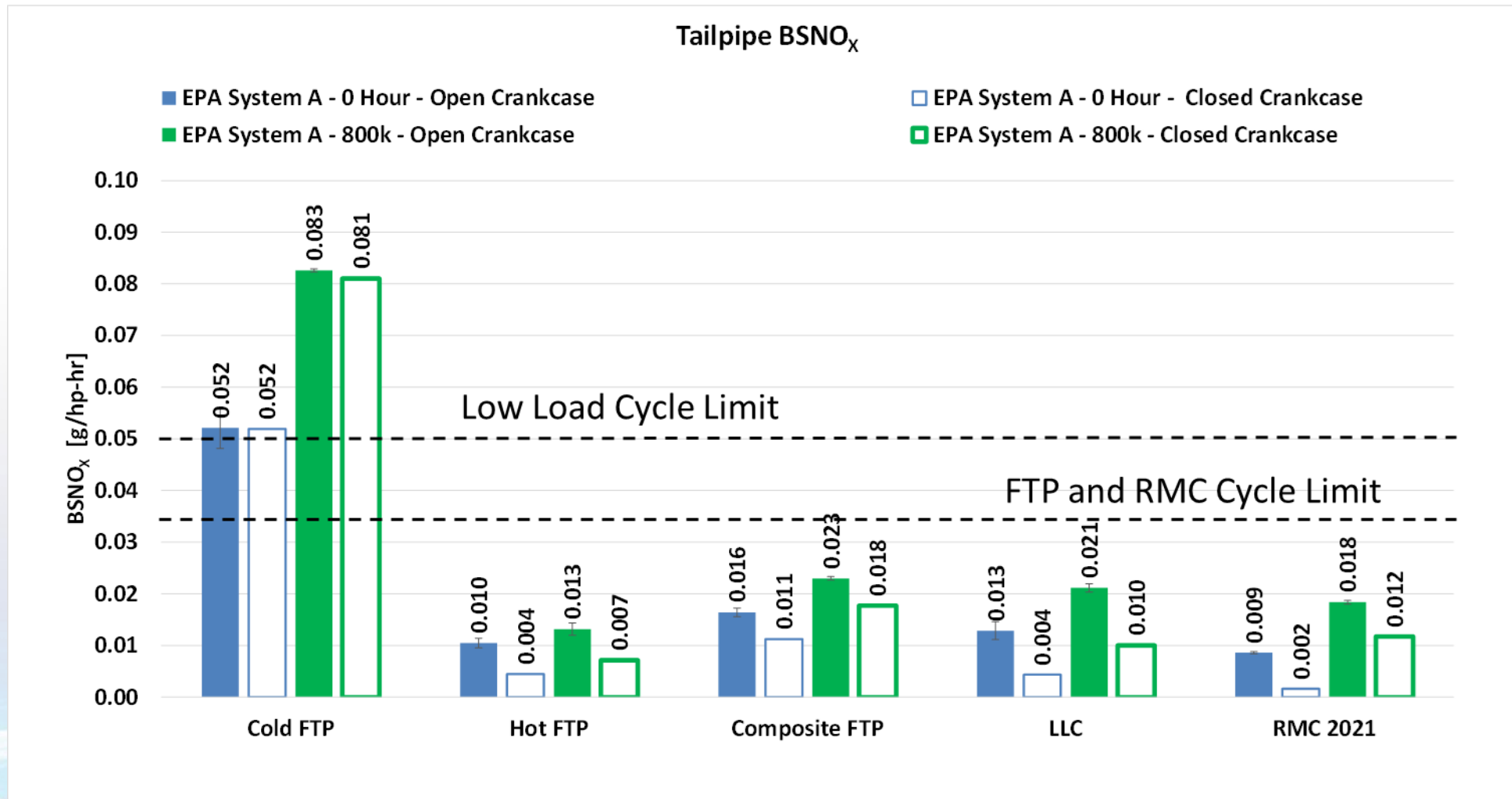
DAAAC engine aging accelerated both chemical and thermal deterioration

Heavy-Duty Pathways Towards 2027 Emissions

International S13 (2024/2027)	Volvo D13 2024	PACCAR MX13 2024 (CARB)	Cummins X15 2027
			
Uncooled EGR, (LO-SCR) Dual dosing, dual SCR, no DOC	DOC + DPF + 48V eHeater + SCR	48V eHeater + DOC + DPF + EH + longer SCR	CCV, cooled EGR, 48V eHeater + DOC + DPF + 48V eHeater + SCR

Source: SAE WCX2025 Year in Review Panel; C. Sharp, SwRI

U.S. Cycle Performance after 1,200,000 km engine aging



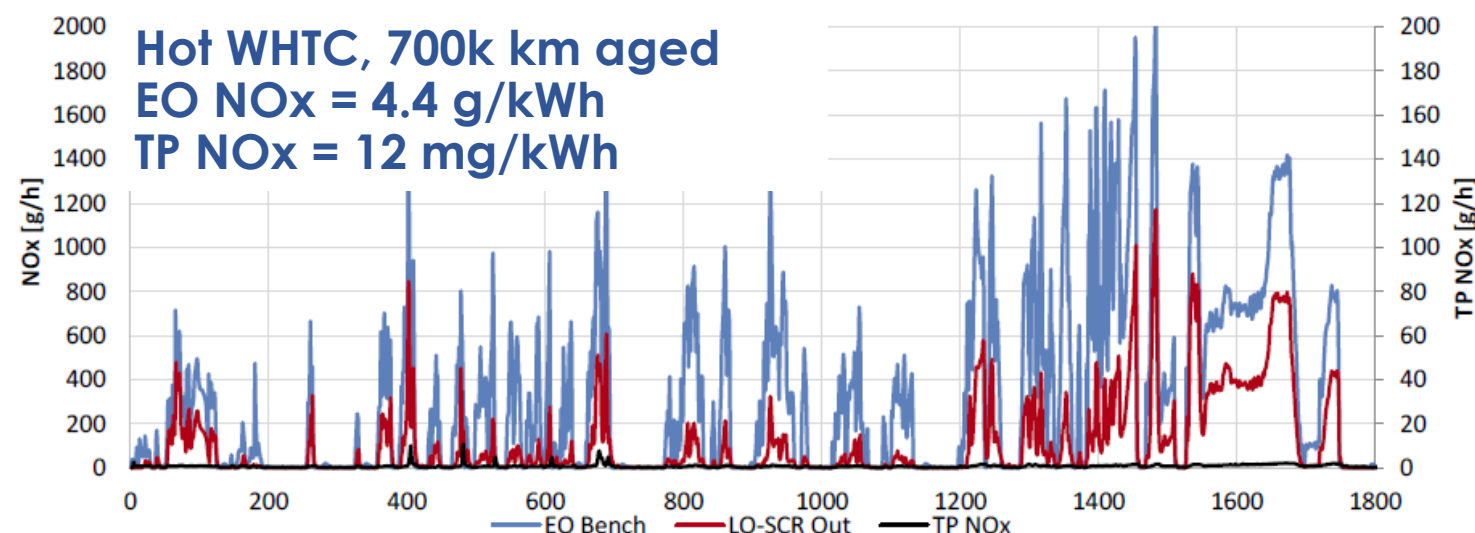
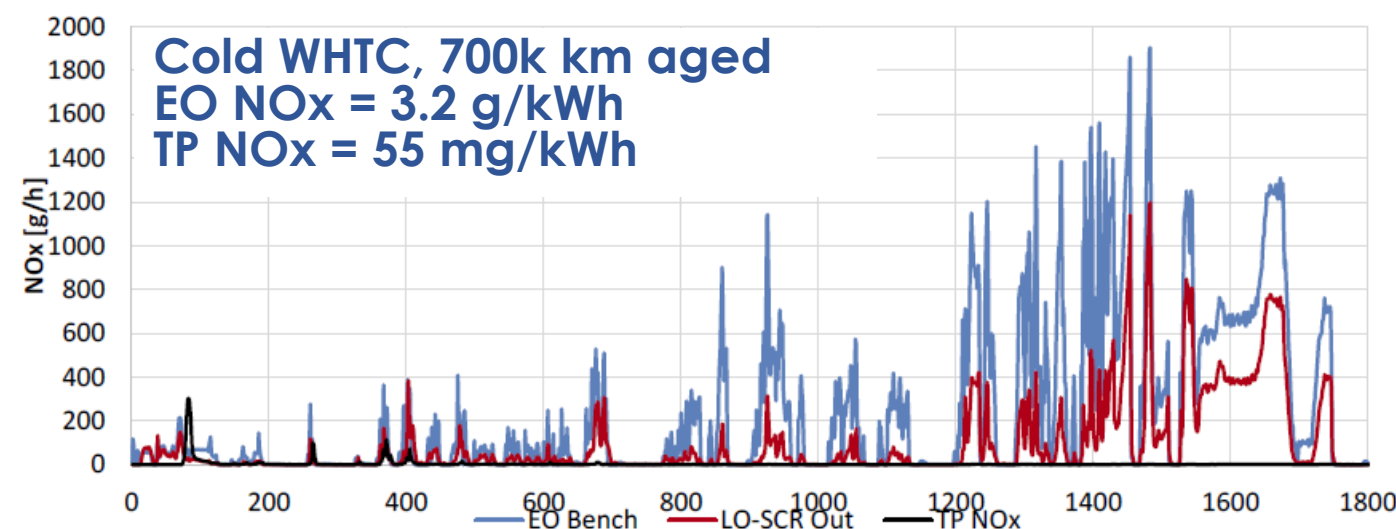
- Sufficient margin below the limits after accelerated aging
- Closing the crankcase provides additional NO_x reduction by up to 30%

WHTC Testing shows Low-NOx Engine Provides Margin Below Euro 7

**Euro VII WHSC/WHTC
standard = 200 mg/kWh**

**Euro VII MAW excludes all
emissions below 6% power**

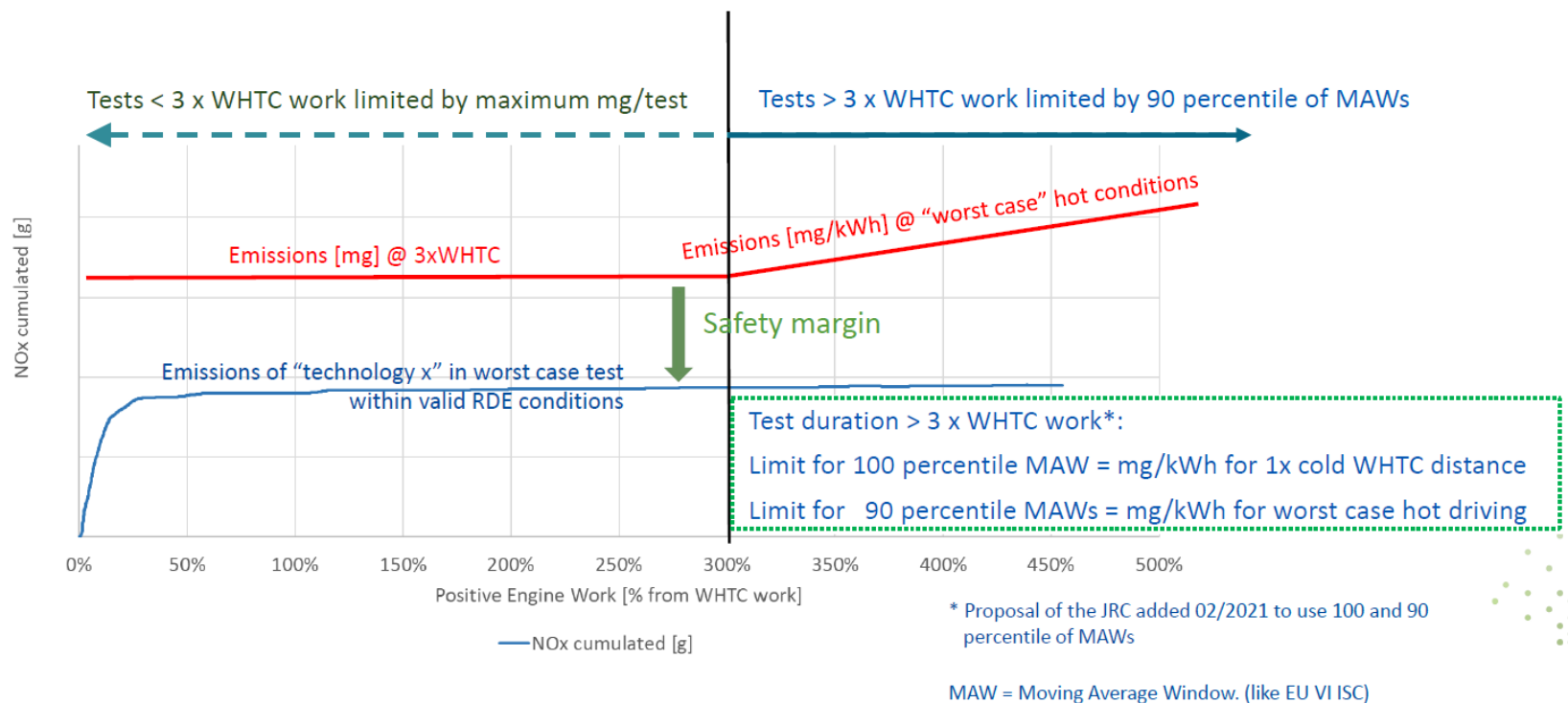
- Duty cycles such as drayage or delivery with stop and go (creep) operation will have high off-cycle emissions



Real-World Cycle Testing of Low NO_x Engine



Proposed Euro VII - Details



Limit for trips $\leq 3 \times$ WHTC work:

Budget [g/test] =

$$\left(\frac{\text{g}}{\text{kWh}} \right)_{3 \times \text{WHTC-work}} \times [\text{kWh}]_{3 \times \text{WHTC}}$$

For trips > 3 x WHTC work:

100 Percentile

Limit for MAWs =

$$\left(\frac{\text{mg}}{\text{kWh}} \right)_{1 \times \text{WHTC-work cold start}}$$

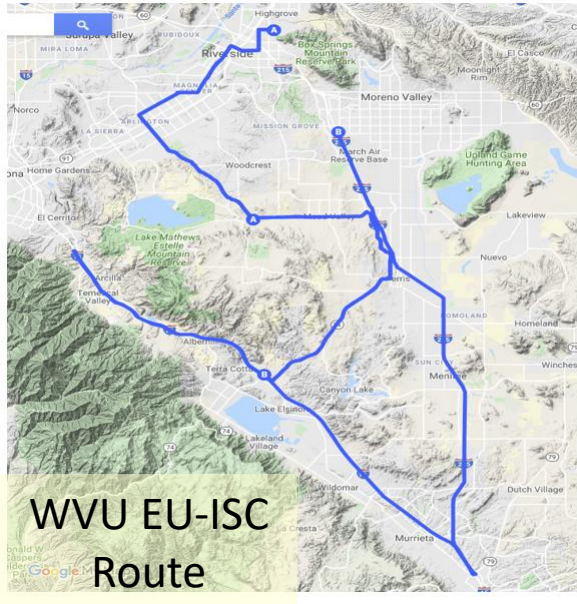
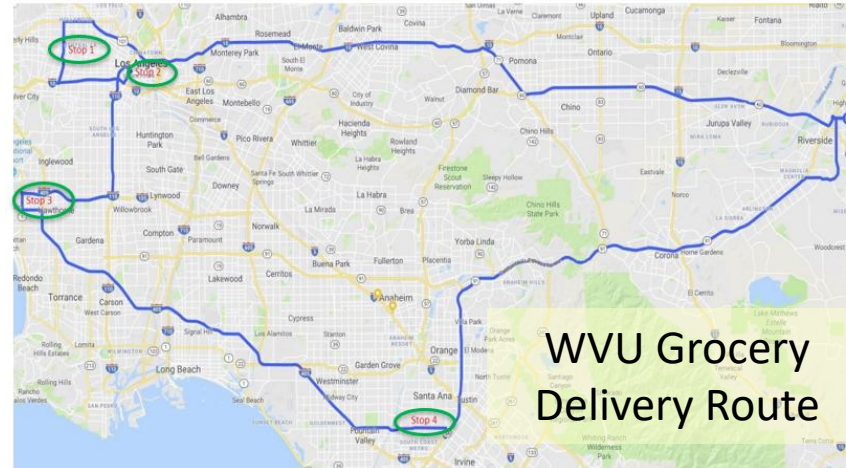
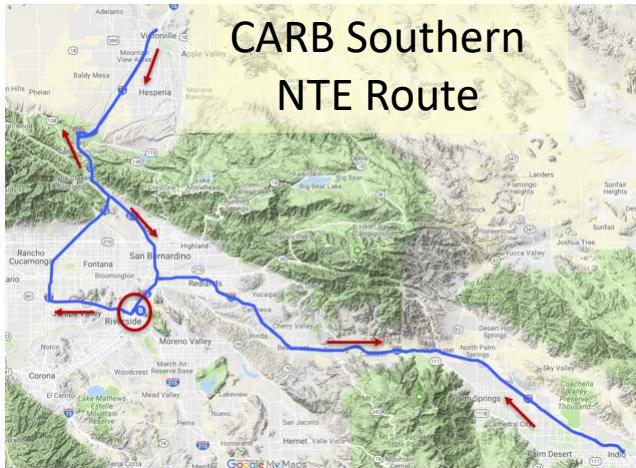
90 Percentile

Limit for MAWs =

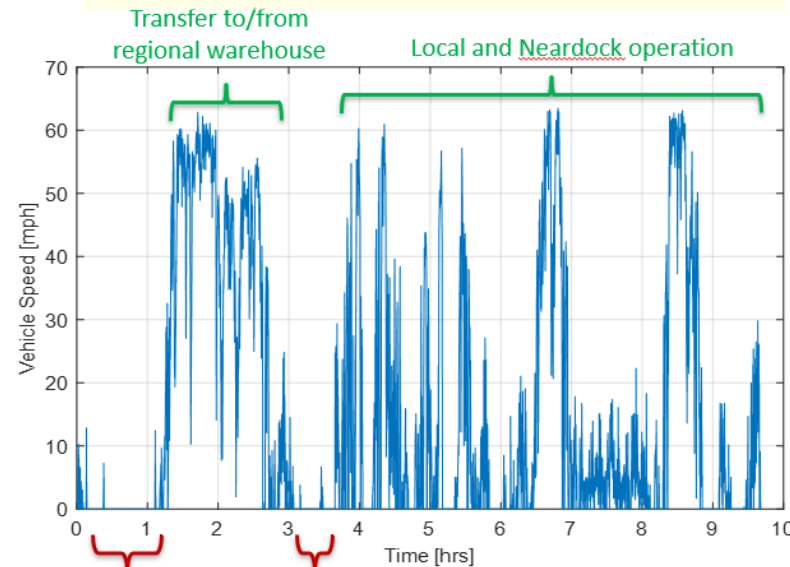
$$\left(\frac{\text{mg}}{\text{kWh}} \right)_{\text{Worst case hot}}$$

¹ Euro VII methodology proposed by AGVES April 2021, "CLOVE AGVES-HDV_Exhaust Pres 040821.pdf" and "AGVES-2021-04-27-HDV_Exhaust-v6b.pdf"

Real-World Duty Cycles



WVU Drayage Route



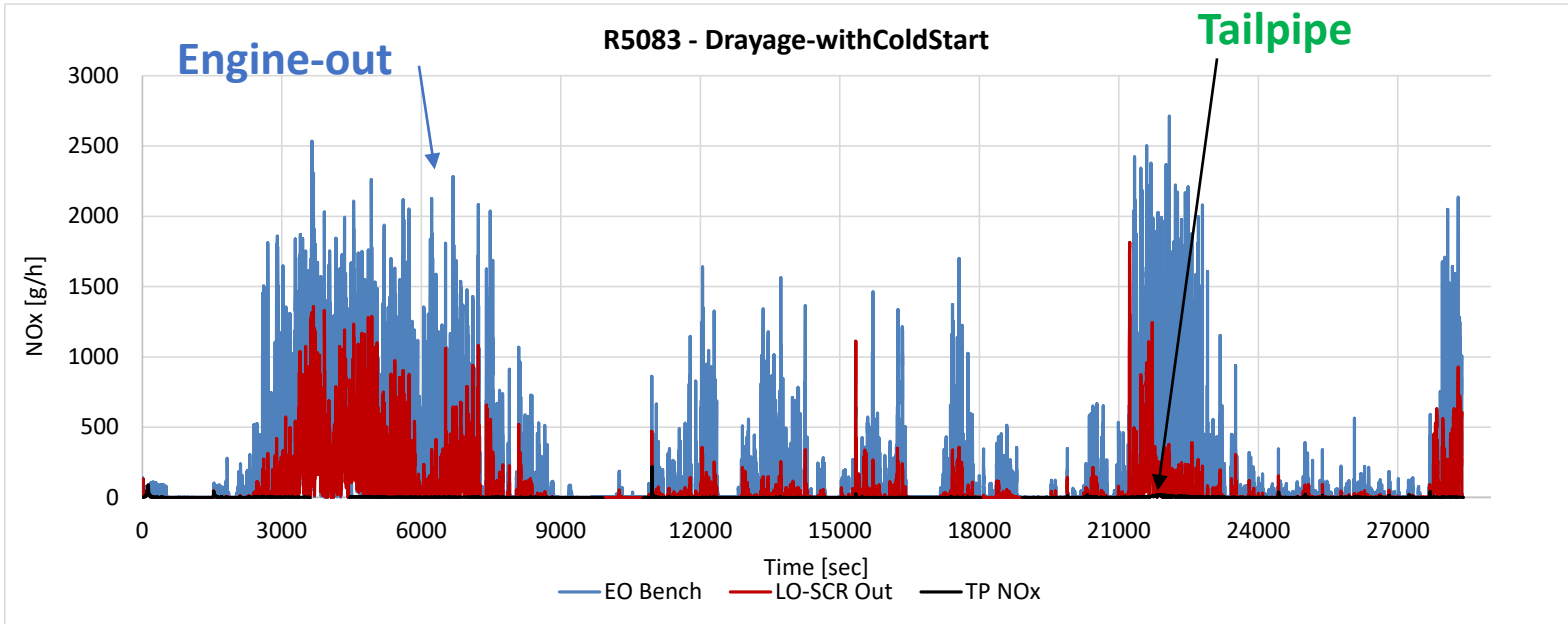
Inside port or drayage yard operation =>
extended idle operation

Each of these cycles is a real working route that was driven with multiple Class 7 and Class 8 trucks

Cycles represented a wide variety of different kinds of vehicle operations

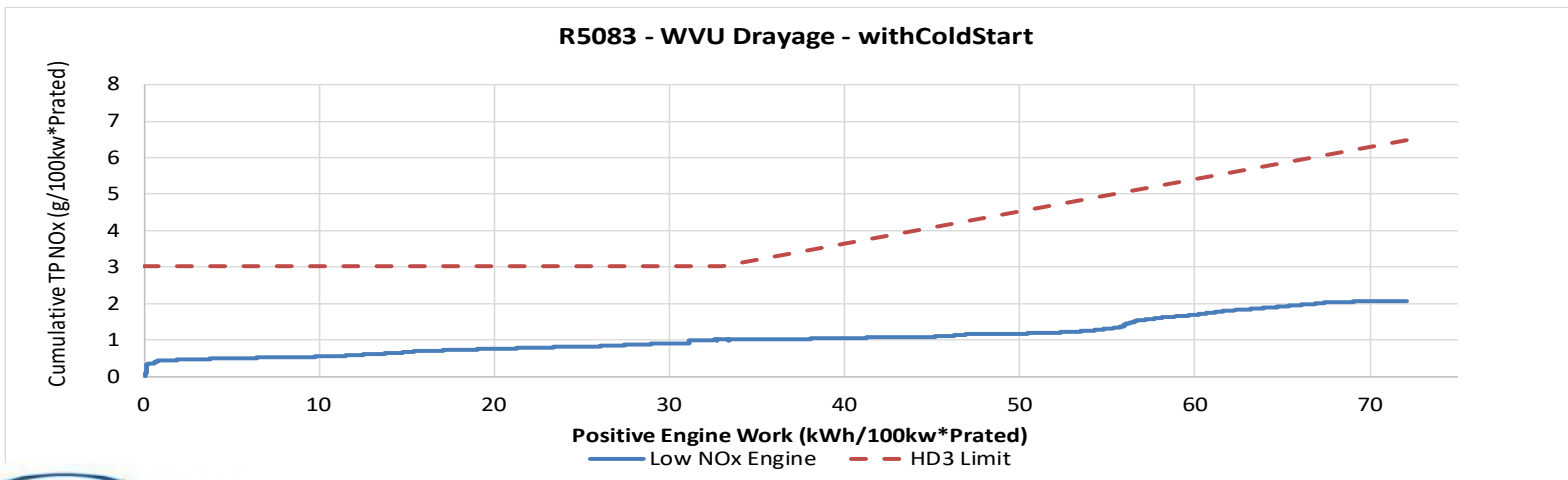
Recorded Vehicle Data was used to develop speed/load profiles that could be translated for Laboratory dyno testing

Port Drayage Route – About 10 hours of Operation



Cycle Characteristics

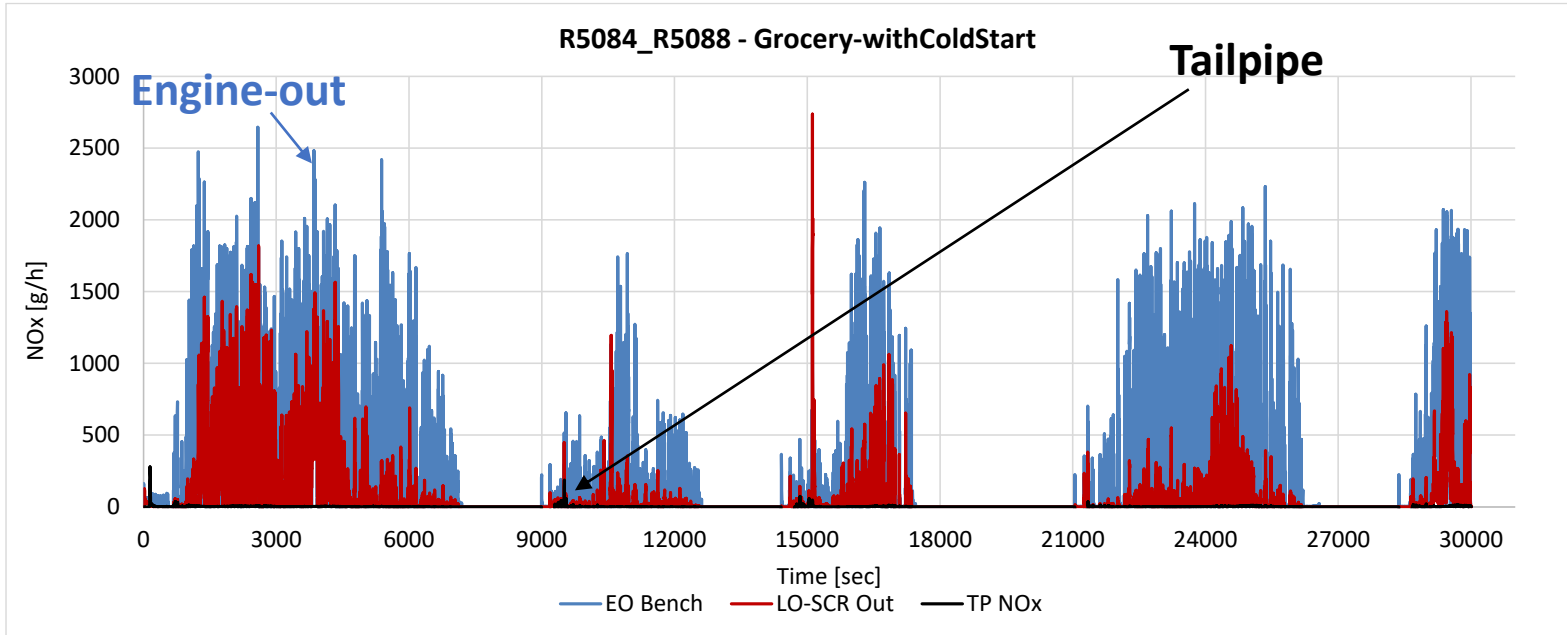
- 30-minute idle after cold-start
- Sustained low speed and low load
- Lowest load of the five cycles



Emission Results

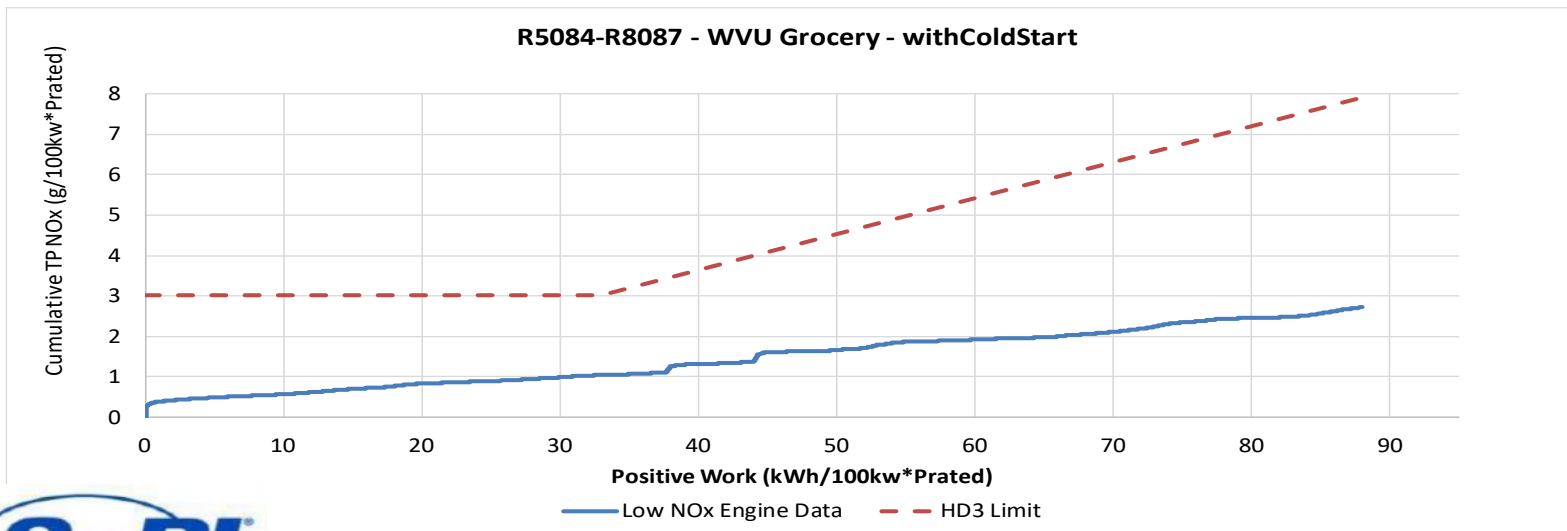
- 50th = 16 mg/kw-hr
- 90th = 36 mg/kw-hr
- 100th = 61 mg/kw-hr
- “Budget” = 31 mg/kw-hr

Grocery Delivery Route – 8.3 hours of Operation



Cycle Characteristics

- 30 to 60-min engine off
- Varying between low and mid loads
- Quick system recovery after warm starts



Emission Results

- 50th = 30 mg/kw-hr
- 90th = 56 mg/kw-hr
- 100th = 60 mg/kw-hr
- “Budget” = 33 mg/kw-hr

Euro VII Analysis Result – Using Proposed WBW Methodology¹

U.S. 2027 controls aged for 700k km on engine (Open Crankcase results)

	Duty Cycle					Euro VII HD3 Limit Values
	CARB Southern	Drayage	EU-ISC	5m-ACES	Grocery	
	BSNO _x Level, mg/kw-hr					
50 th percentile	25	16	26	24	30	n/a
90 th percentile	57	36	86	42	56	90
100 th percent	118	61	122	66	60	175
3xWHTC “budget”	60	31	68	33	33	100

- Results on all real-world duty cycles are below HD3 scenario proposed by AGVES for Euro-VII

¹ Euro VII methodology proposed by AGVES April 2021, “CLOVE AGVES-HDV_Exhaust Pres 040821.pdf” and “AGVES-2021-04-27-HDV_Exhaust-v6b.pdf”

Euro VII Analysis Result – Using Proposed WBW Methodology¹

U.S. 2027 controls aged for 700k km on engine (Closed Crankcase results)

	Duty Cycle					Euro VII HD3 Limit Values
	CARB Southern	Drayage	EU-ISC	5m-ACES	Grocery	
	BSNO _x Level, mg/kw-hr					
50 th percentile	18	9	19	17	23	n/a
90 th percentile	50	29	79	35	49	90
100 th percent	111	54	115	59	53	175
3xWHTC “budget”	53	24	61	26	26	100

- Results on all real-world duty cycles are below HD3 scenario proposed by AGVES for Euro-VII

¹ Euro VII methodology proposed by AGVES April 2021, “CLOVE AGVES-HDV_Exhaust Pres 040821.pdf” and “AGVES-2021-04-27-HDV_Exhaust-v6b.pdf”

Summary and Conclusions

- **U.S. 2027 ready Low NO_x demonstration hardware showed capability to meet original (more stringent) proposed Euro VII limits from the European Commission**
 - Technology is being put into production now in U.S. (LO-SCR, e-heaters, etc.)
- **Use of Low Load Cycle during calibration helped to guarantee low in-use emissions under all conditions without data exclusion**
 - Field cycle testing met all EU-WBW limits based on calibration over U.S. cycles
 - Low Load emission control was **as good or better than at average/high load**
- **Technology has been demonstrated to meet NO_x limits substantially below Euro VII final limits.**

Thank You!

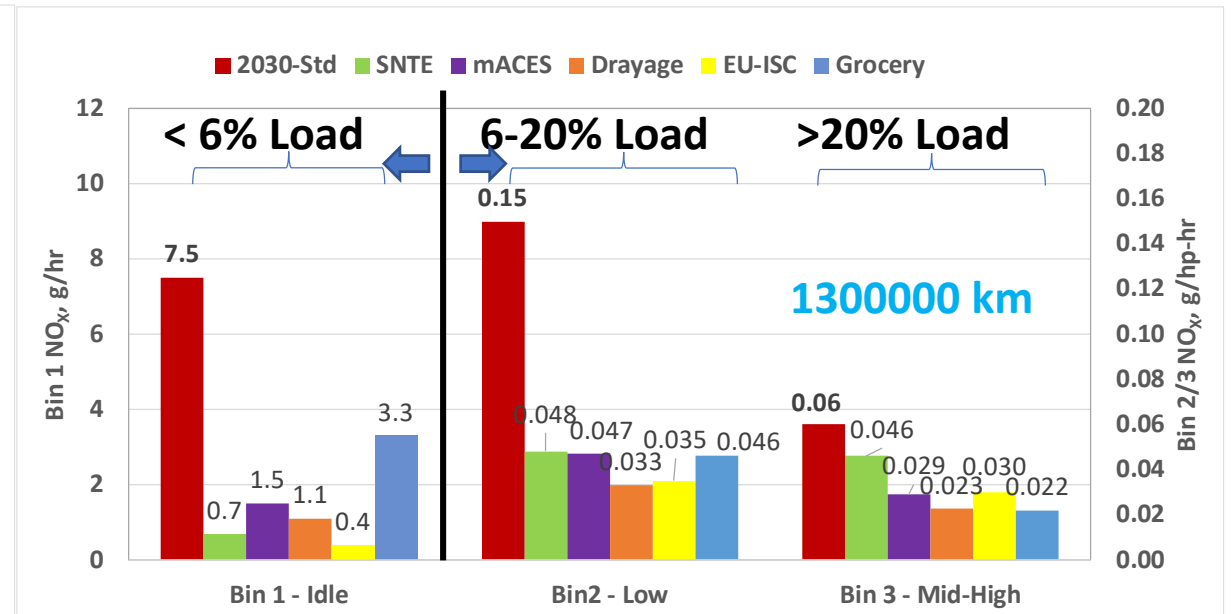
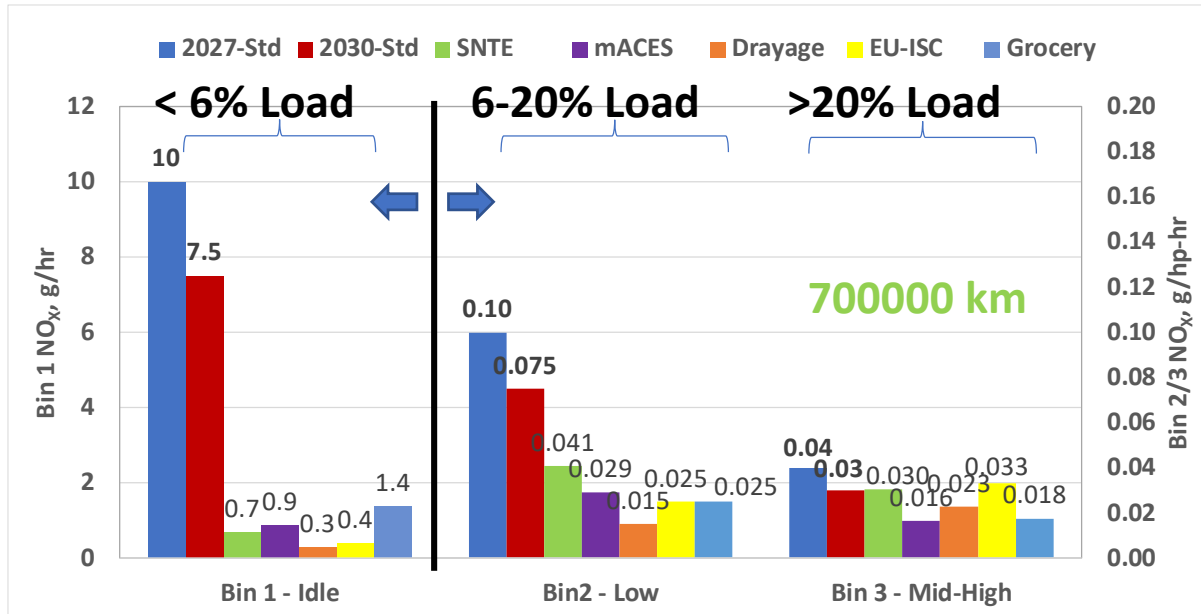
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Supplemental



Field Duty Cycle Results (3Bin-MAW) Full Engine Aged



- Low Load emission problem is no longer present with Low NO_x technology - controlled as well or better than high load
- Emission controls are durable – still below thresholds at 1.3M km
- Note that these results are for OCV, with CCV Bin 2 and Bin 3 results are lower by ~10%**

Euro VII Final Proposed Limits Emphasize In-Use Operation

Units mg/kWh (gas) #/kWh (PN)	Euro VI	Euro 7 HD proposal		
		Cold 100 th percentile	Hot 90 th percentile	Budget Trips < 3xWHTC
NOx	460	350	90	150
PM	10	12	8	10
PN (#/kWh) Euro VI : PN ₂₃ Euro VII : PN ₁₀	6x10 ¹¹	5x10 ¹¹	2x10 ¹¹	3x10 ¹¹
CO	4000	3500	200	2700
NMOG	160 _{THC}	200	50	75
NH ₃	10 ppm	65	65	70
CH ₄	500	500	350	500
N ₂ O	-	160	100	140
HCHO	-	30	30	-

Joshi, Mobility Notes – 12/2022

Test conditions	Normal	Extended Emissions / 2
Ambient T (°C)	-7 – 35	- 10 to +45
Max. Altitude (m)	< 1600	< 1,800
Max. Speed (km/h)	≤ 145	≤ 160
Payload	≥ 10%	< 10%
Trip composition	As per usual use	
Min. mileage (km)	5,000 for < 16t 10,000 for > 16t	> 3,000