# *Vehicle Standards and Technology Solutions in the US for 2027 and Beyond*


## Dr. Rasto Brezny


**Emission Control Technologies 2023**

**New Delhi, India**

MECA

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# MECA – Technologies for Clean Mobility

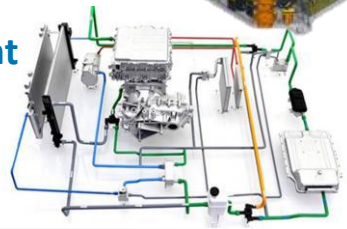
Battery & Fuel Cell Materials & Packaging

Evaporative Controls

Emission Controls

Catalysts & Substrates

Thermal Management Integration



Exhaust System Integration

ICE Efficiency Technologies

Electrification

Power Electrodes

Integrated Drive Modules

Electric Drive Motors

Turbochargers


Cylinder Deactivation

Injection & Ignition

Sensors

Onboard Diagnostics and Monitoring

ADVANCED ENGINE SYSTEMS

48V MILD & FULL HYBRID SYSTEMS

PLUG-IN HYBRID TECHNOLOGIES

BATTERY & FUEL CELL ELECTRIC COMPONENTS



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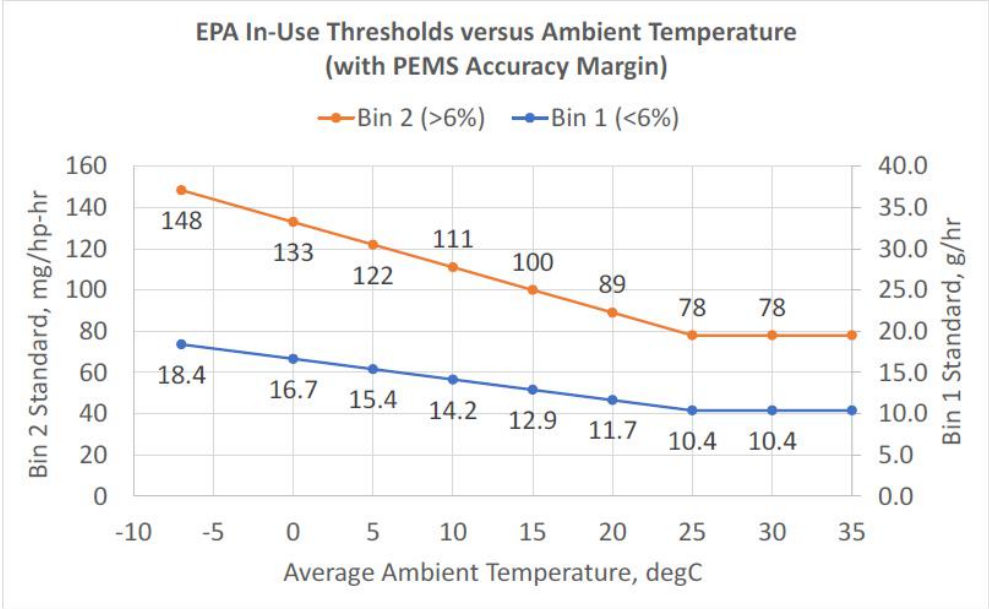
# Outline

- Heavy-duty GHG and Pollution Regulations Adopted and Proposed
- Light-duty GHG and Pollution Regulations Adopted and Proposed
- CARB Nonroad Tier 5 regulation under consideration
- Role of technology demonstrations to support regulations

# CARB and EPA Clean Truck Regulation for Criteria Pollutants

| Duty Cycle | CARB - HHD | | | EPA - HHD |
|---|---|---|---|---|
| | MY 2027-2030 | | MY 2031+ | MY 2027+ |
| | Intermediate Useful Life 435,000 miles | Full Useful Life 600,000 miles | Full Useful Life 800,000 miles | Full Useful Life 650,000 miles (750,000 miles cert tested) |
| FTP (mg/hp-hr) RMC (mg/hp-hr) | 20 | 35 | 40 | 35 |
| LLC (mg/hp-hr) | 50 | 90 | 100 | 50 |
| Idle (g/hr) | 5 | 5 | 5 | 10 |




Chris Sharp (SwRI) presentation to MECA January 4, 2023

Two-Bin Moving Average Window – Bin 1 is <6% engine power and Bin 2 is >6% engine power

Interim compliance margin of 15 mg/hp-hr for in-use field or lab compliance testing

PEMS accuracy margin of 5 mg/hp-hr for in-use testing with PEMS

PM standard = 5 mg/hp-hr for FTP/RMC/LLC cycles

NMHC standard = 60 mg/hp-hr for FTP/RMC/LLC cycles

***Ambient temperature correction (above figure)**

# EPA Proposed HD GHG Phase 3 Standards

- Vehicle $CO_2$ standards are "performance based" to be met by mix of EVs, hybrids, hydrogen, engine technology or advanced ICE in GEM
- EPA anticipates that a compliant fleet will include a diverse range of ICE and ZEV vehicle technologies.
- BEVs, FCEVs and H2-ICE considered as zero $CO_2$ emissions
- An all electric pathway would require in 2032:
  - 50% EV in Vocational
  - 35% EV in Short Haul
  - 25% EV in Long Haul

2027 Ph 2 & Proposed Tractor Standards (grams/ton-mile)

| Model Year | Roof Height | Class 7 All Cab Styles | Class 8 Day Cab | Class 8 Sleeper Cab |
|---|---|---|---|---|
| Phase 2 2027 | Low Roof | 104 | 80 | 66 |
| | Mid Roof | 115 | 86 | 73 |
| | High Roof | 120 | 89 | 72 |
| Phase 3 2027 | Low Roof | 86.6 | 66.1 | 64.1 |
| | Mid Roof | 93.1 | 70.2 | 69.6 |
| | High Roof | 90.0 | 68.1 | 64.3 |
| Phase 3 2032+ | Low Roof | 63.5 | 48.4 | 48.1 |
| | Mid Roof | 68.2 | 51.5 | 52.2 |
| | High Roof | 66.0 | 50.0 | 48.2 |

-20% -6%

2027 Ph 2 & Proposed Vocational Standards (grams/ton-mile)

| Model Year | Subcategory | CI Light Heavy | CI Medium Heavy | CI Heavy Heavy | SI Light Heavy | SI Medium Heavy |
|---|---|---|---|---|---|---|
| Phase 2 2027 | Urban | 367 | 258 | 269 | 413 | 297 |
| | Multi-Purpose | 330 | 235 | 230 | 372 | 268 |
| | Regional | 291 | 218 | 189 | 319 | 247 |
| Phase 3 2027 | Urban | 294 | 213 | 232 | 340 | 252 |
| | Multi-Purpose | 257 | 190 | 193 | 299 | 223 |
| | Regional | 218 | 173 | 152 | 246 | 202 |
| Phase 3 2032+ | Urban | 179 | 176 | 177 | 225 | 215 |
| | Multi-Purpose | 142 | 153 | 138 | 184 | 186 |
| | Regional | 103 | 136 | 97 | 131 | 165 |

-22% -19% -16% -20% -17%

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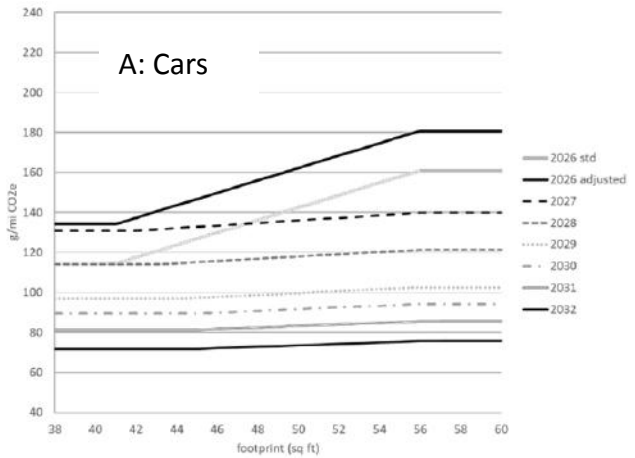
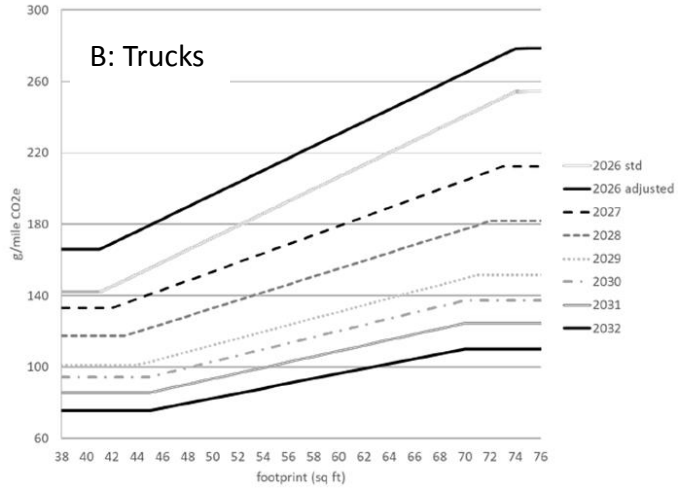
# EPA's Multipollutant LD standards include GHG limits

## EPA's Performance Based CO2 Fleet Average standards remain footprint based

| | Light-Duty Vehicles ($CO_2$, g/mile) | | |
|---|---|---|---|
| **Model Year** | Cars | Trucks | Fleet |
| **2026 adjusted** | 152 | 207 | 186 |
| **2027** | 134 | 163 | 152 |
| **2028** | 116 | 142 | 131 |
| **2029** | 99 | 120 | 111 |
| **2030** | 91 | 110 | 102 |
| **2031** | 82 | 100 | 93 |
| **2032+** | 73 | 89 | 82 |

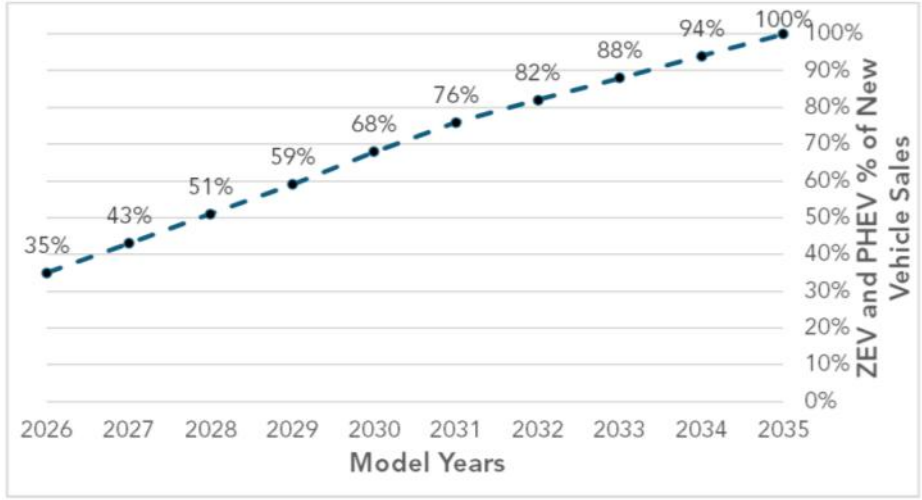



## U.S. EPA EV Compliance Scenario

| | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 |
|---|---|---|---|---|---|---|
| **Sedans** | 45% | 53% | 61% | 69% | 73% | 78% |
| **SUVs** | 38% | 46% | 56% | 59% | 61% | 62% |
| **Pickups** | 11% | 23% | 37% | 45% | 55% | 68% |
| **Total** | 36% | 45% | 55% | 60% | 63% | 67% |

## Mandated ZEV Sales in California States

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# Two approaches to criteria standards from Passenger Cars in U.S.

### EPA Set Performance Standards and allow EVs in Fleet Average at 0 g/mile

| Model Year | LDV, LDT1, LDT2 NMOG+NOx (mg/mi) | | LDT3, LDT4, MDPV NMOG+NOx (mg/mi) | |
|---|---|---|---|---|
| | Default | Early | Default | Early |
| Tier 3 | 30* | | 30* | 30* |
| 2027 | 22 | | 30* | 22 |
| 2028 | 20 | | 30* | 20 |
| 2029 | 18 | | 30* | 18 |
| 2030 | 16 | | 12 | 16 |
| 2031 | 14 | | 12 | 14 |
| 2032+ | 12 | | 12 | 12 |

### U.S. Bin Structure for Fleet Average

| Bin | NMOG+NOx (mg/mile) |
|---|---|
| Bin 160* | 160 |
| Bin 125* | 125 |
| Bin 70 | 70 |
| Bin 60 | 60 |
| Bin 50 | 50 |
| Bin 40 | 40 |
| Bin 30 | 30 |
| Bin 20 | 20 |
| Bin 10 | 10 |
| Bin 0 | 0 |

### CARB Phasing out ZEVs from Criteria Standards

| Model Year | NMOG + NOx Fleet Average | % of ZEVs Allowed in average |
|---|---|---|
| Pre-2025 | 0.030 g/mile | 100 |
| 2026 | 0.030 g/mile | 60 |
| 2027 | 0.030 g/mile | 30 |
| 2028 | 0.030 g/mile | 15 |
| 2029 | 0.030 g/mile | 0 |

### EPA Proposed Stringent PM standards with Phase In

| Test Cycle | Proposed PM Standard (mg/mi) |
|---|---|
| 25°C FTP | 0.5 |
| US06 | 0.5 |
| -7°C FTP | 0.5 |

| Model Year | Phase In |
|---|---|
| 2027 | 40% |
| 2028 | 80% |
| 2029 | 100% |
| 2030+ | 100% |

### CARB and EPA aligned on eliminating emissions from off cycle operation

- Same numerical standards on all cycles: 25°C FTP, HFET, US06 and SC03.
- Single NMOG+NOx fleet average -7C FTP standard of 300 mg/mi
- Set limit for high power cold starts over US06 for PHEVs
- Limits for 8 sec and current 20 sec. on FTP
- Partial soak warm engine starts (10 min., 40 min, >180 min)
- Tighter evaporative limits on running loss, sealed tanks and incomplete chassis to cover all gasoline vehicles.
- Battery minimum performance standards based on UNECE

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# CARB and EPA Multi-Year Technology Demonstration Program Supported by MECA

# CARB/EPA HD Low NOx Test Program Objectives
## Contract with Southwest Research Institute

- Started in 2014 with CARB and transitioned to EPA in 2020
- Program goal was to demonstrate 90% reduction below current HD $NO_X$ standards
  - 0.02 g/bhp-hr (0.03 g/kWh)
  - Aged parts (Full useful life engine-based accelerated aging)
- Solution must be production ready
- Solution not adversely impact GHG standards ($CO_2$ , $N_2O$)
- Engine calibration in parallel with thermal management and exhaust control development



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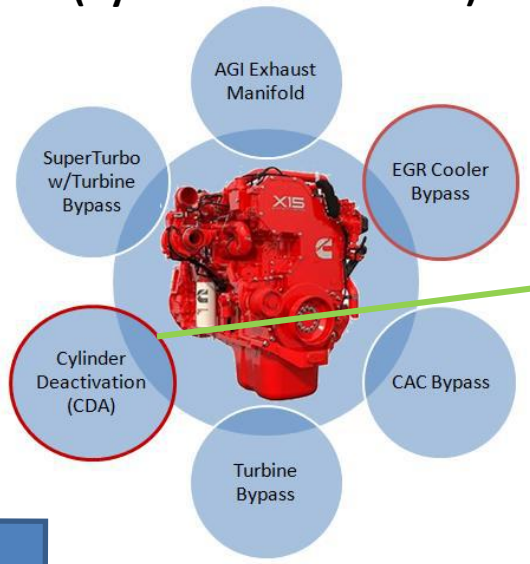
# EPA Low $NO_X$ Demonstration Engine

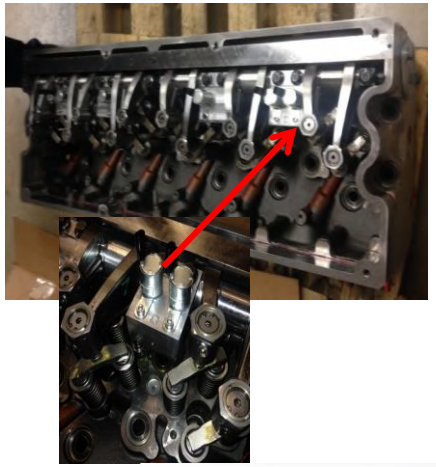
## 2017 Cummins X15 Engine

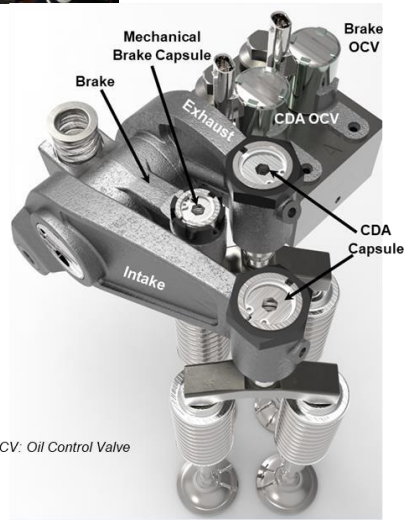
*Full System Details*
*SAE Paper*
*2021-01-0589*

## Additional Engine Hardware (Cylinder Deactivation)

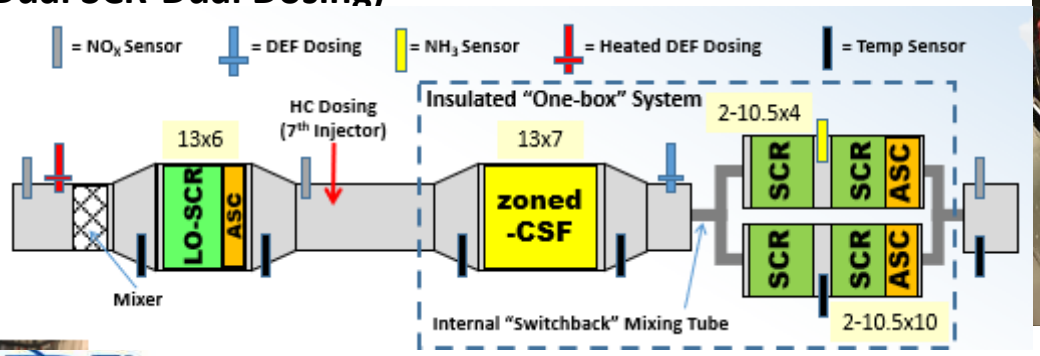



Eaton Cylinder Deactivation Hardware






## Advanced Low $NO_X$ Aftertreatment (Dual SCR-Dual Dosing)



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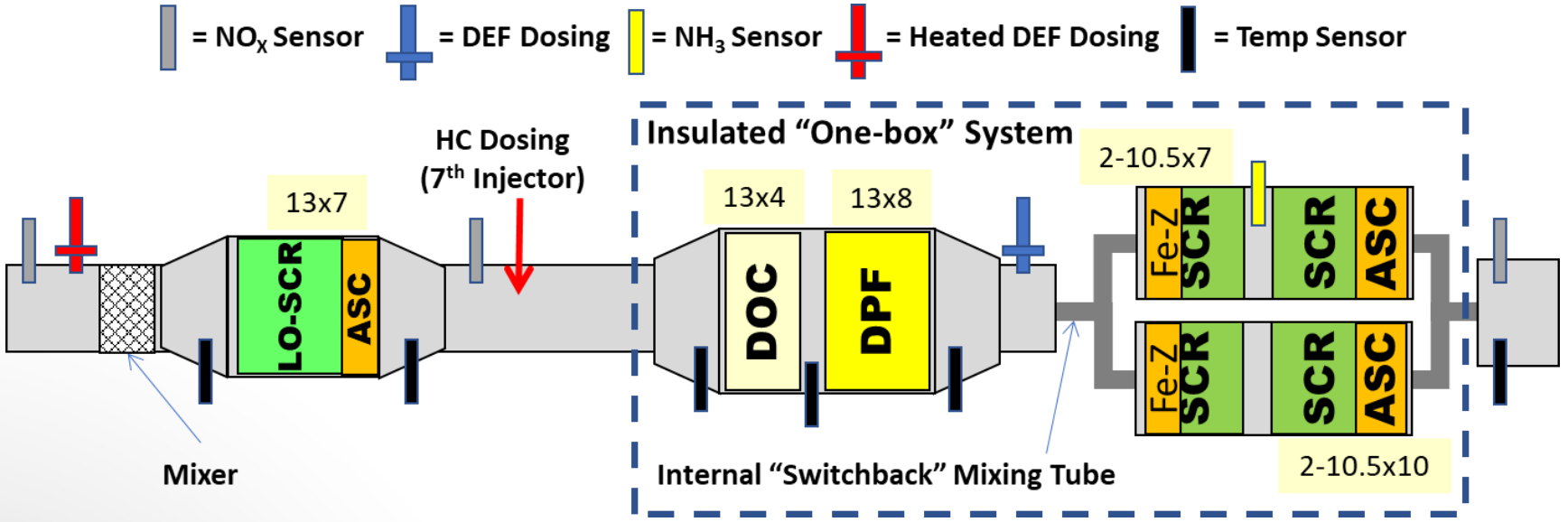
# EPA Improved Aftertreatment System for low $N_2O$




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

- Reduced $N_2O$ formation with new system at below half of EPA standard (0.13 g/kWh)

## Replaced zoned-CSF with DOC+DPF

## Improved downstream DEF mixing

## Further improved low temperature durability



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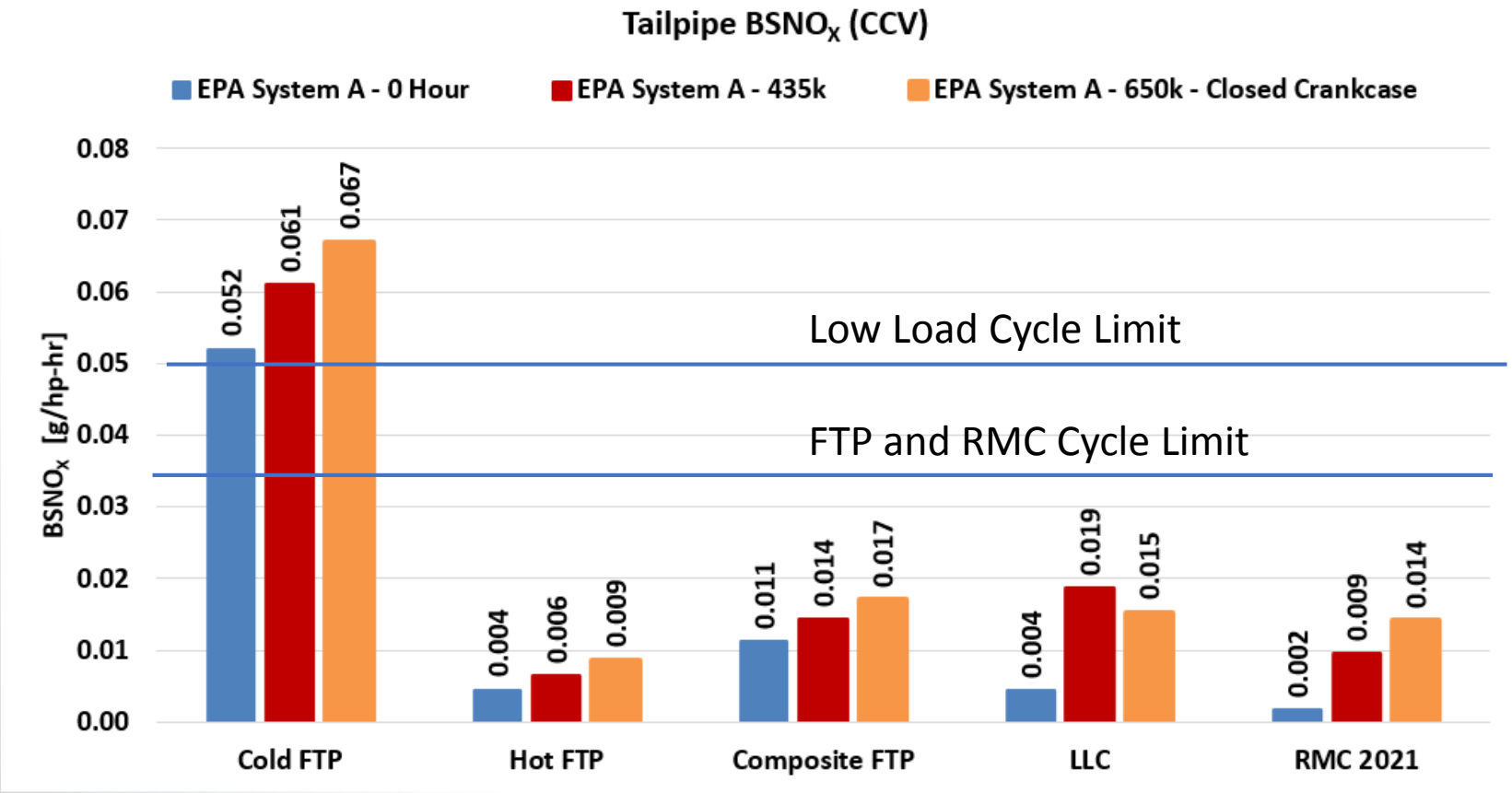
# Aftertreatment Testing after 1 million km




- Little degradation in NOx emissions after 700,000 km of engine aging
- Slight $CO_2$ increase caused by elevated backpressure due to ash load
- Open crankcase increases NOx by 0.01 g/kWh

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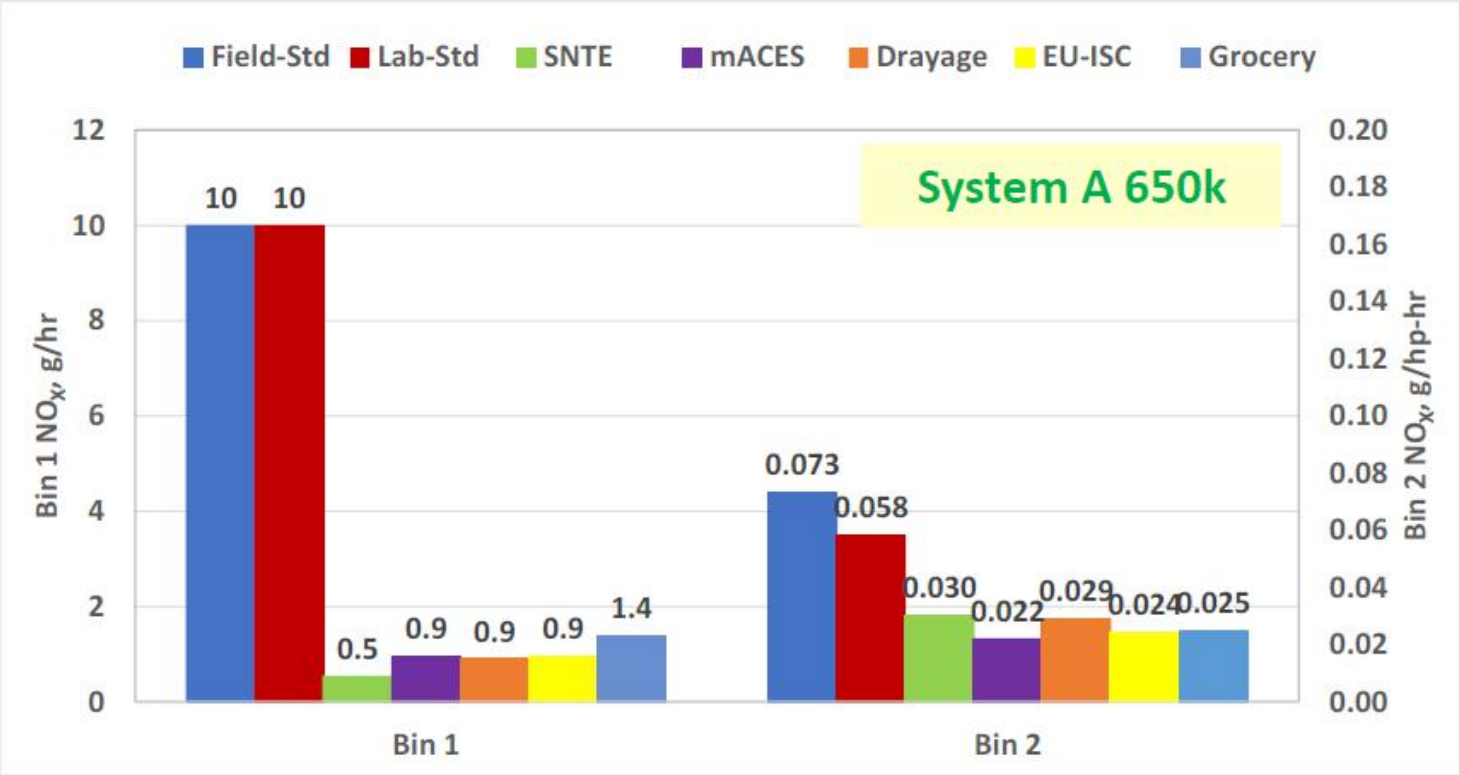
# Field Duty Cycle Results after 1,000,000 km




- Emissions evaluated using new EPA 2-bin Moving Average Windows method (no Exclusions)
- Low Load emission problem is <u>eliminated</u> with Low $NO_X$ technology
- Emission controls are durable to 1 million km
- **<u>For closed-crankcase, Bin 2 results would be lower by ~ 0.01 g/kWh</u>**



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# CARB Non-Road Low NOx Test Program

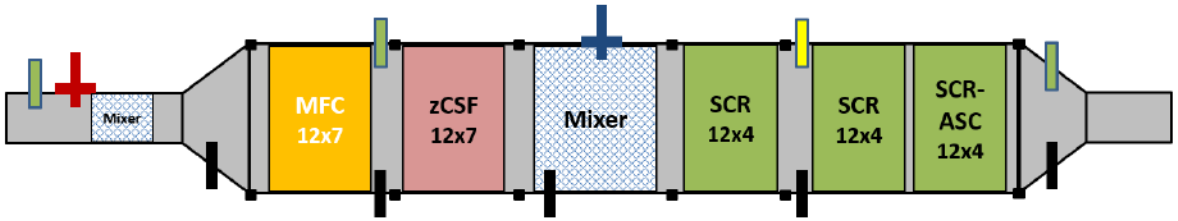
# Nonroad Low $NO_X$ Demonstration Program

## Overall goal of Nonroad Low $NO_X$ effort is to demonstrate production feasible technologies to reduce emissions:

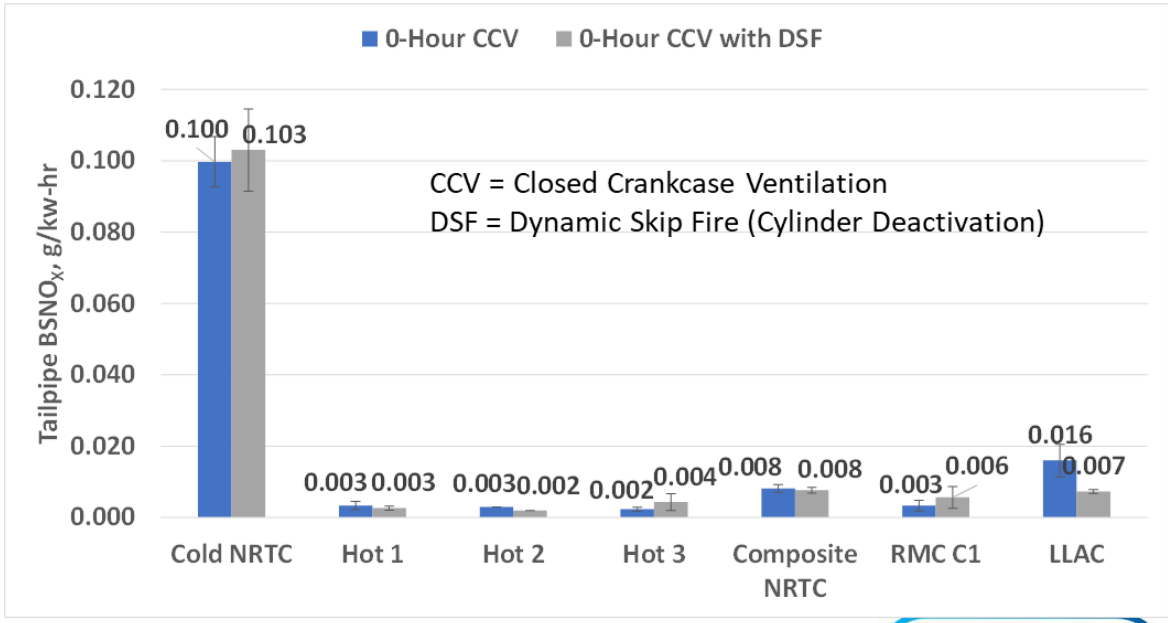
- $NO_X$ by 90% (nominal target of 0.04 g/kw-hr)
- PM by 75% (nominal target of 0.005 g/kw-hr)
- Useful Life target at 8,000 hours
- Test cycles include: NRTC and RMC 8-mode
- Adding NR-Low Load Cycle at 15% avg. load vs 35% for NRTC
- GHG reduction target 5-8.6%
- OBD and REAL periodic reporting of NOx and CO2

Cylinder Deactivation

John Deere 6068 (6.8L) Tier 4f Engine




| Cycle | Improvement in CO2, % | |
|---|---|---|
| | Pkg 2 without CDA | Pkg 2 with CDA |
| Cold NRTC | 4.7% | 5.7% |
| Hot NRTC | 5.6% | 6.3% |
| **Composite NRTC** | **5.6%** | **6.3%** |
| RMC C1 | 3.3% | 4.4% |
| LLAC | 5.5% | 10.9% |



# *Conclusions*

- Control of emissions to near zero levels from all powertrains will be needed as we transition transportation to achieve air quality goals
- Technology is evolving at a rapid pace creating new opportunities for system solutions including engines, aftertreatment and fuels to ensure real world reductions.
- Nonroad equipment can benefit from on-road experience: technology demonstration is ongoing at Southwest Research Institute with funding from CARB and MECA.

# *Thank You*

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# CARB Tier 5 Discussion Concept

- Tier 5 Targets:

| Power | Tier 5 Targets |
|---|---|
| ≤ 19 kW | Zero Emission |
| >19 kW to ≤56 kW | Up to 75% reduction in PM and NOx |
| >56 kW to 560 kW | 90% lower NOx and 75% lower PM |
| >560 kW | 50% lower NOx and PM |
| All | 5 to 8.6% lower $CO_2$ |

  - LLC and idle limits tbd after SwRI testing complete in Fall 2023

- CA-only Tier 5 standards will have limited scope, Federal EPA standards needed
  - CARB is pre-empted from regulating new farm and construction engines under 175 hp—category represents ~50% of off-road engine emissions in the state.



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