Technology Solutions for Cleaning-Up Heavy-Duty Vehicles

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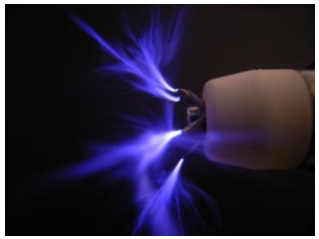
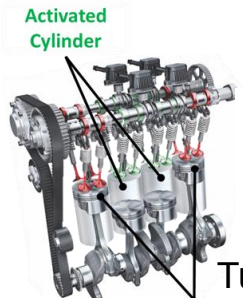
Summary

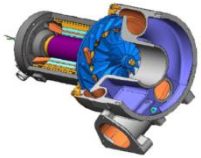
- Before the heavy-duty fleet is fully electrified, millions of truck engines will be sold and can last for decades
- States need NOx reductions as soon as possible to meet NAAQS attainment goals
- A 0.05 g NOx limit in 2024 and 0.02 g in 2027 will get early cost effective NOx reductions while also meeting GHG standards
- A fully implemented 0.02 g/bhp-hr national HD truck rule can deliver NOx reduction of nearly 730 tons per day in the continental U.S. (excluding California)

MECA Members Bring Technology Solutions for all Mobility Challenges

Engine Efficiency



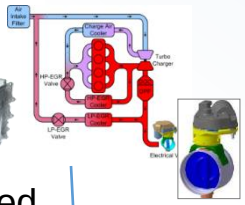




Turbo compounding

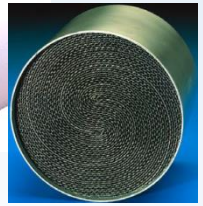
Cylinder Deactivation

Air Handling



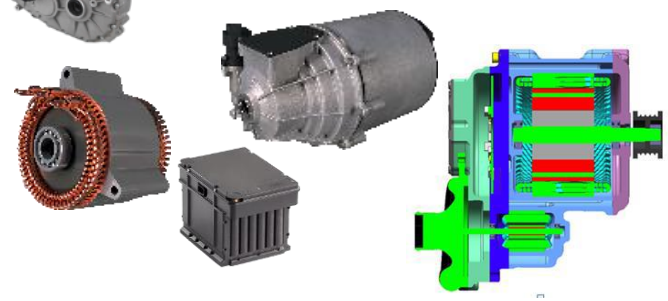
Cooled
EGR

Filters &
Substrates

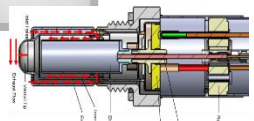


Exhaust System
Integration

Powertrain
Electrification



Evaporative Controls



OBD Sensors

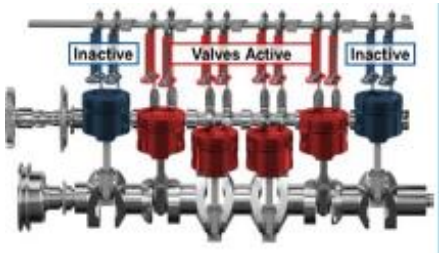
A 90% NOx Reduction from Heavy-Duty Trucks will Deliver Significant NOx reductions across the U.S.

Year	NOx Emission Reductions (tons per day)				
	Continental U.S. (excluding CA)	OTC	SESARM	LADCO	CenSARA
2025	139	22	33	25	38
2030	355	57	99	68	90
2040	604	98	162	110	159
2050	728	119	195	134	195

* Projected reductions based on modeled assumption of a 90% tighter heavy-duty NOx standard starting in MY 2021

Source: MECA, NOx Emission Reduction Benefits of Future Potential U.S. Mobile Source Regulations, June 2018

Ensuring the Cleanest and most Efficient Heavy-Duty Engines Requires a Systems Approach



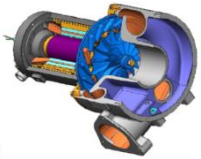
Cylinder Deactivation

Advanced Fuel Injection and Ignition

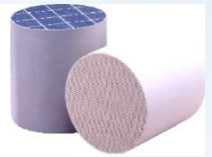
EGR

Turbo chargers

Electric components



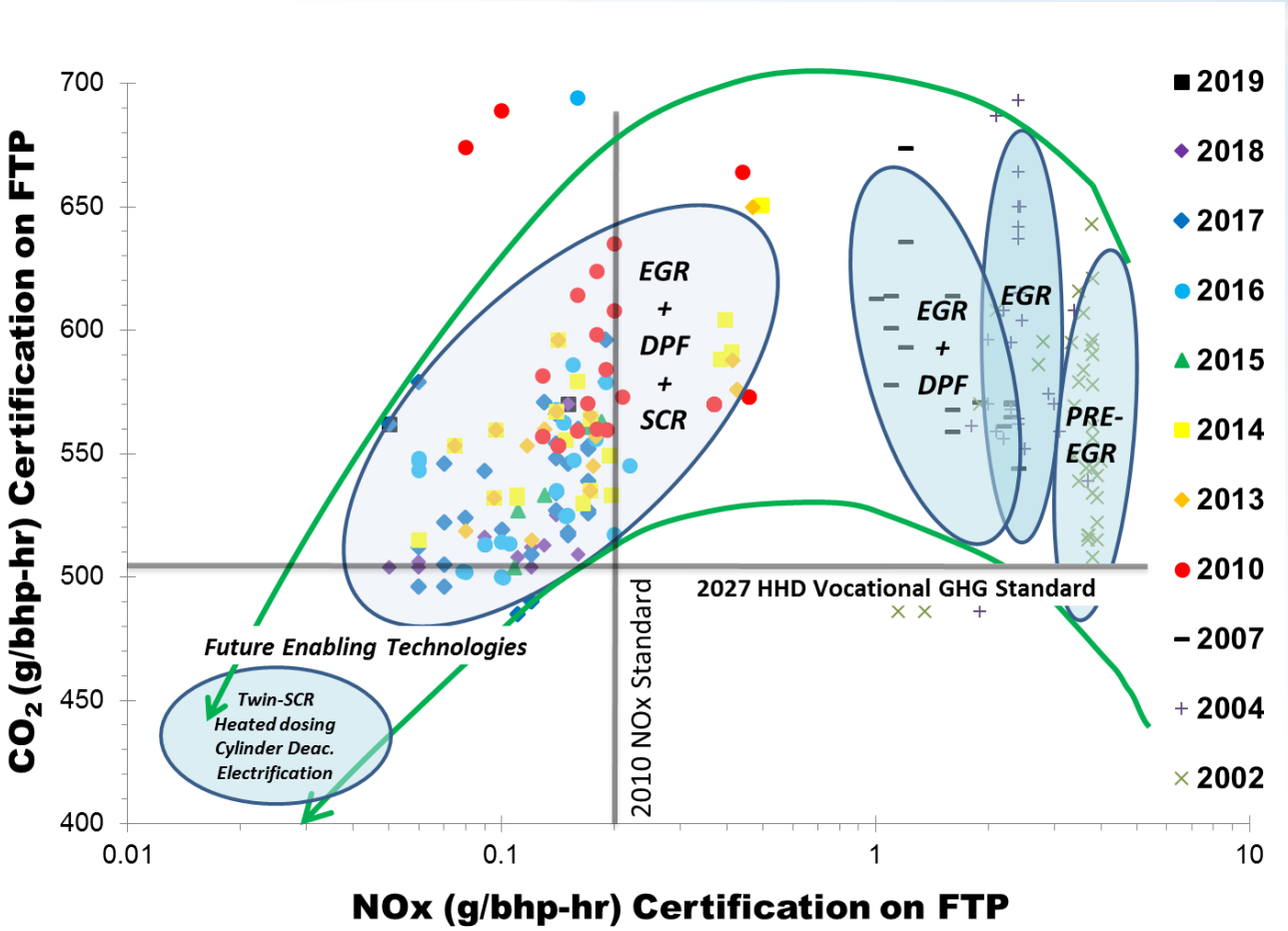
OBD Sensors



Filters & Catalysts

Getting to ultra low NOx and GHG levels requires clean fuels, efficient engines, advanced aftertreatment solutions and electrified powertrains

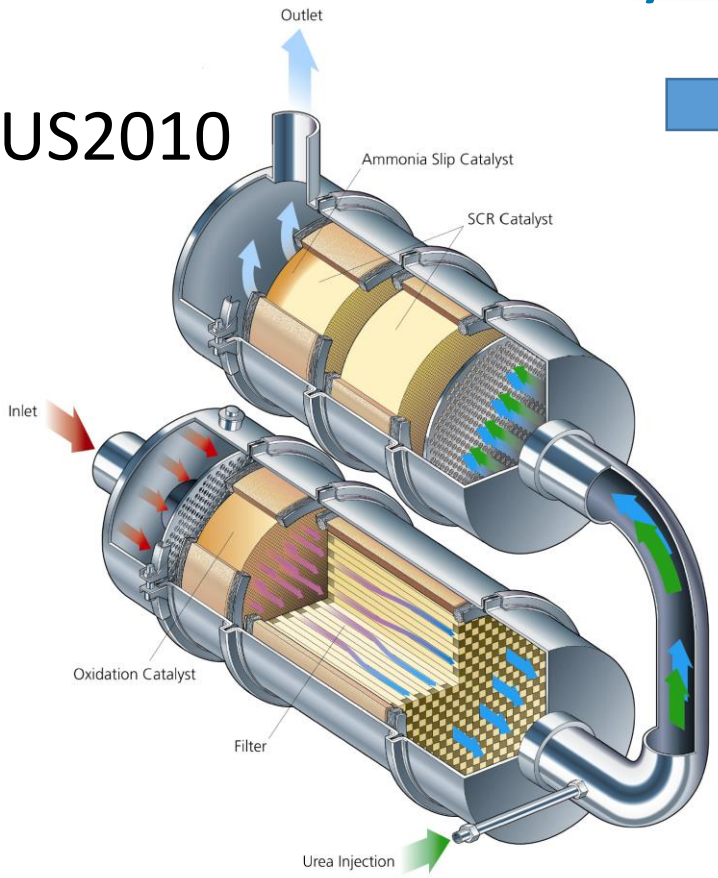
We don't have to give up CO_2 to have clean, low NOx Engines



Simultaneously optimizing engines to meet NOx and CO_2 standards is the most cost effective path to reducing pollution and GHGs

Evolution of Heavy-Duty Exhaust Control Technology

US2010

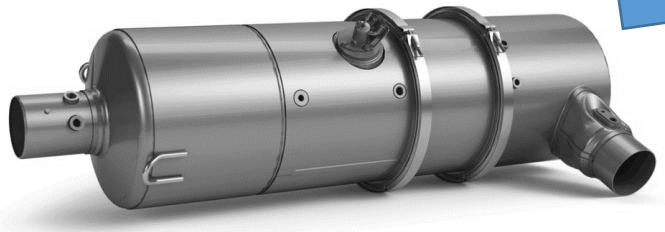


Repackaged

US2013

A natural optimization has resulted in 2019 systems being 60% smaller, 40% lighter, and cheaper than 5 years ago.

Downsized



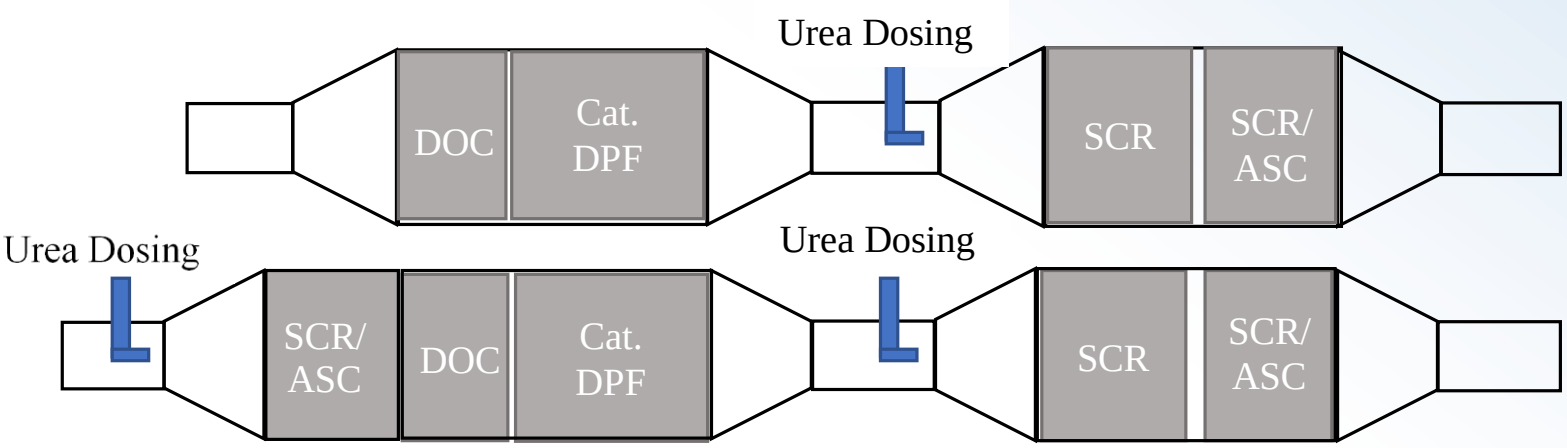
US2019

What NOx Emissions are Achievable

- MECA believes that by 2024 a 0.05 g/bhp-hr limit is feasible without major changes to aftertreatment designs
- By 2027, 0.02 g/bhp-hr is achievable at a cost of about $1,000 to $5,000 per ton of NOx reduced
- Trucks cannot be allowed to emit at high levels in the real world
  - Addition of a low load certification cycle and new in-use compliance requirements will ensure low NOx emissions all the time
- MECA's white paper highlights technology solutions that deliver both low CO_2 and low NOx in 2024 and 2027

2024 Exhaust Systems will be Similar to Today

2019 System

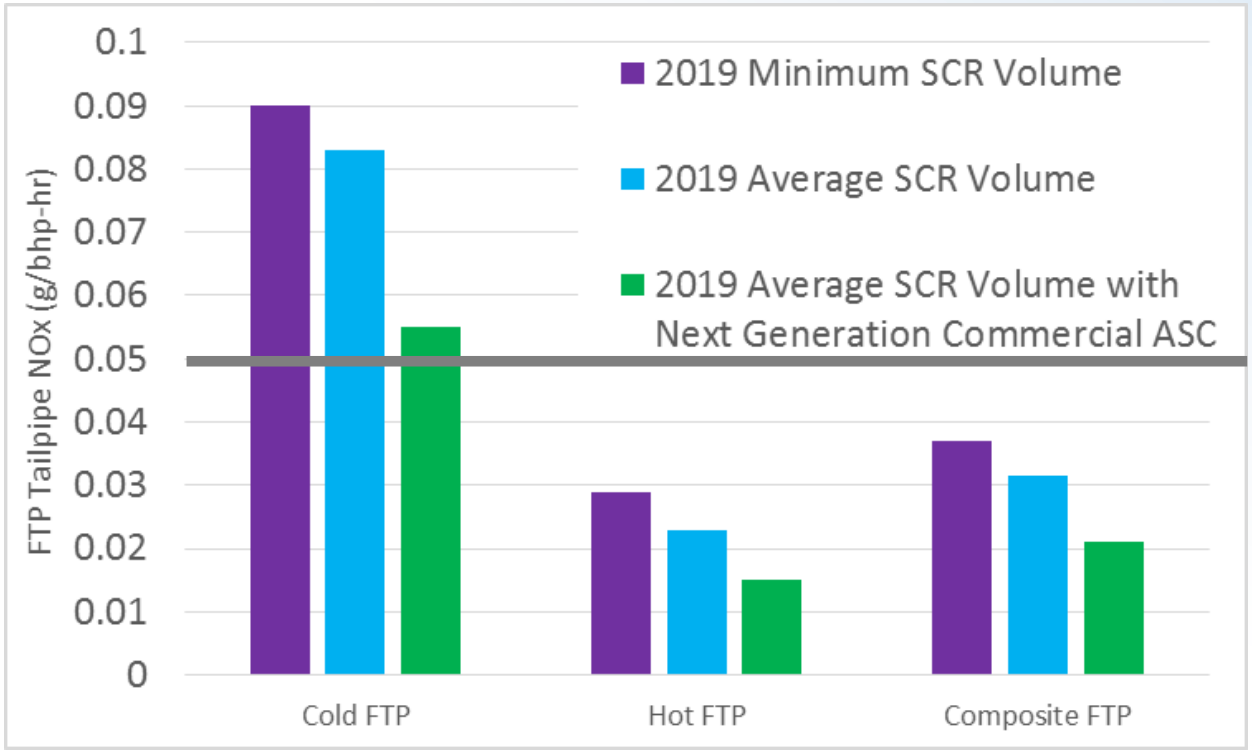


Potential 2024 Twin SCR System

How do you achieve a 75% reduction in NOx with the same exhaust system design?

- Better thermal management and low temperature catalysts
- Optimizing urea dosing to deliver ammonia at lower temperatures
- Adjusting catalyst volume for performance and durability

Emission Controls and Engine Thermal Management Can Achieve 0.05 g/bhp-hr by 2024

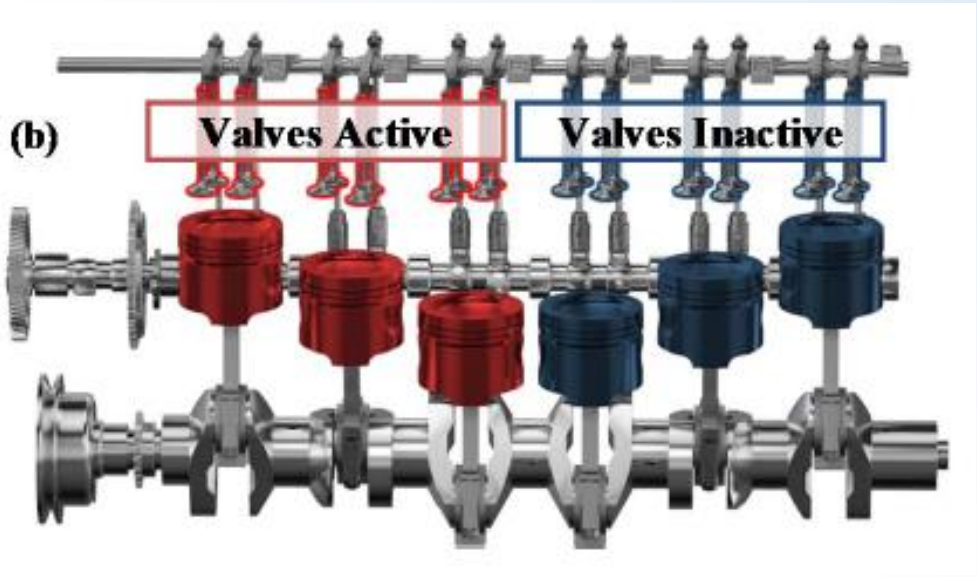


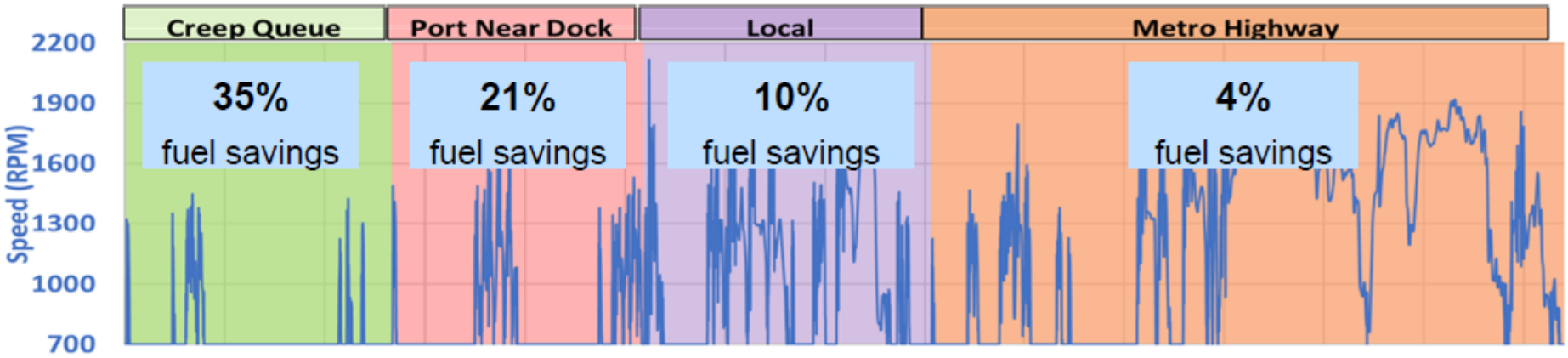
- Tailpipe emissions were modeled with improved engine calibration and fully aged commercial catalysts
- A 2019 exhaust control system with better engine calibration can meet a 0.05 g FTP standard
- Latest catalysts with improved urea dosing can significantly exceed a 0.05 g/bhp-hr FTP standard by 2024

Cylinder Deactivation Enables Low NOx and Low CO_2 in Low Load Operation

Deactivating 2-6 cylinders makes the remaining cylinders work harder and more efficiently
Shutting off all cylinders during idle or coasting keeps aftertreatment hot

- Fast heat-up of exhaust
- Keep exhaust hot at low loads
- Lower Engine out NOx
- Reduce fuel consumption





Heated Dosing Allows NOx Reduction at Lower Temperatures

- Heated dosing can deliver ammonia in exhaust temperatures as low as 130°C versus typical 200°C
- Can initiate dosing and NOx conversion 5 - 10 minutes sooner during heat-up from cold start

Heated Urea Injector

Injector for Electric Catalyst

Source: 2018 Vienna Motor Symposium

Low NOx at Low Load Can be Achieved with Today's Aftertreatment Designs

Model Run on Low Load Cycle	DPF Precious Metal Loading	SCR Pre-storage with NH3	Urea Dosing Temp (°C)	Tailpipe NOx (g/bhp-hr)
Baseline	X	20%	170	0.40
Scenario 1	2X	20%	170	0.38
Scenario 2	2X	50%	170	0.23
Scenario 3	2X	50%	150	0.18

- A 2019 system was optimized over CARB's low load cycle at 7% average engine load to simulate challenging real world operation
- Heated dosing for low temperature ammonia delivery can get below 0.2 g/bhp-hr under low loads; CARB white paper target (0.05-0.24 g/bhp-hr)
- Testing shows that adding cylinder deactivation can deliver CO_2 reductions while reducing engine out NOx at low loads and low speeds

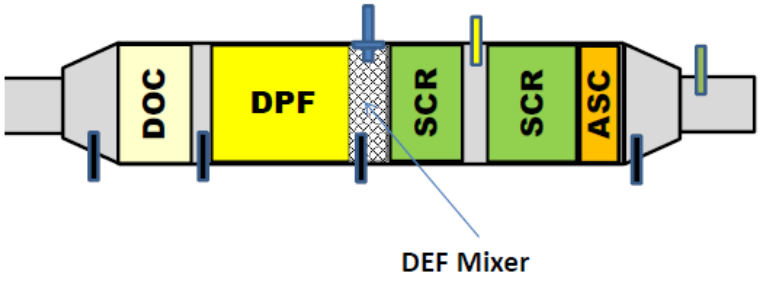
Achieving 0.02 g/bhp-hr NOx in 2027

= NO_X Sensor

= NH_3 Sensor

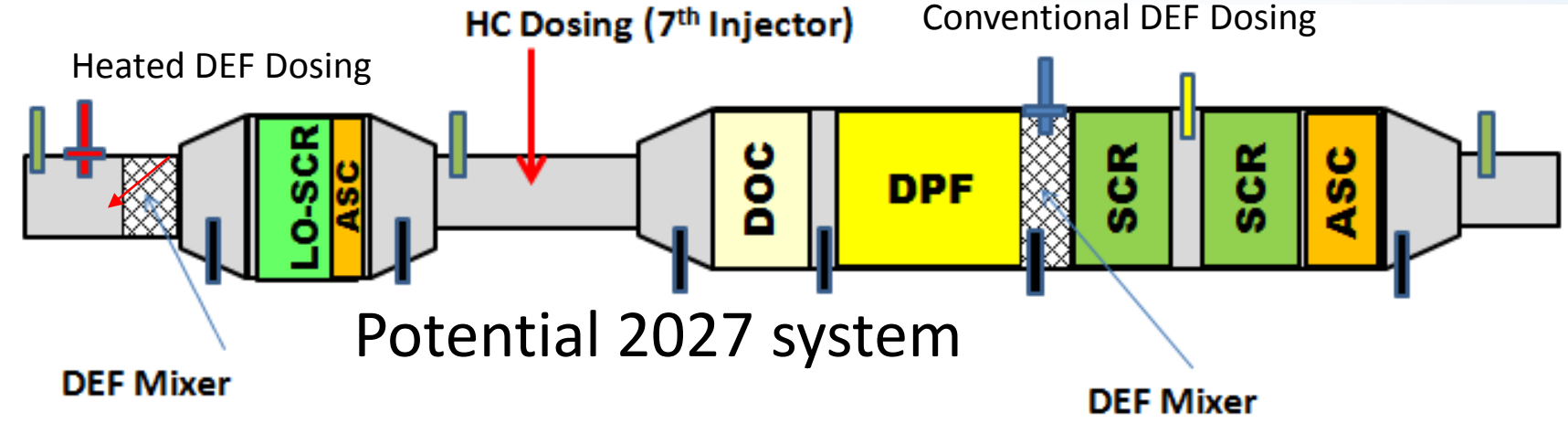
= Temp Sensor

= DEF Dosing



2019 system

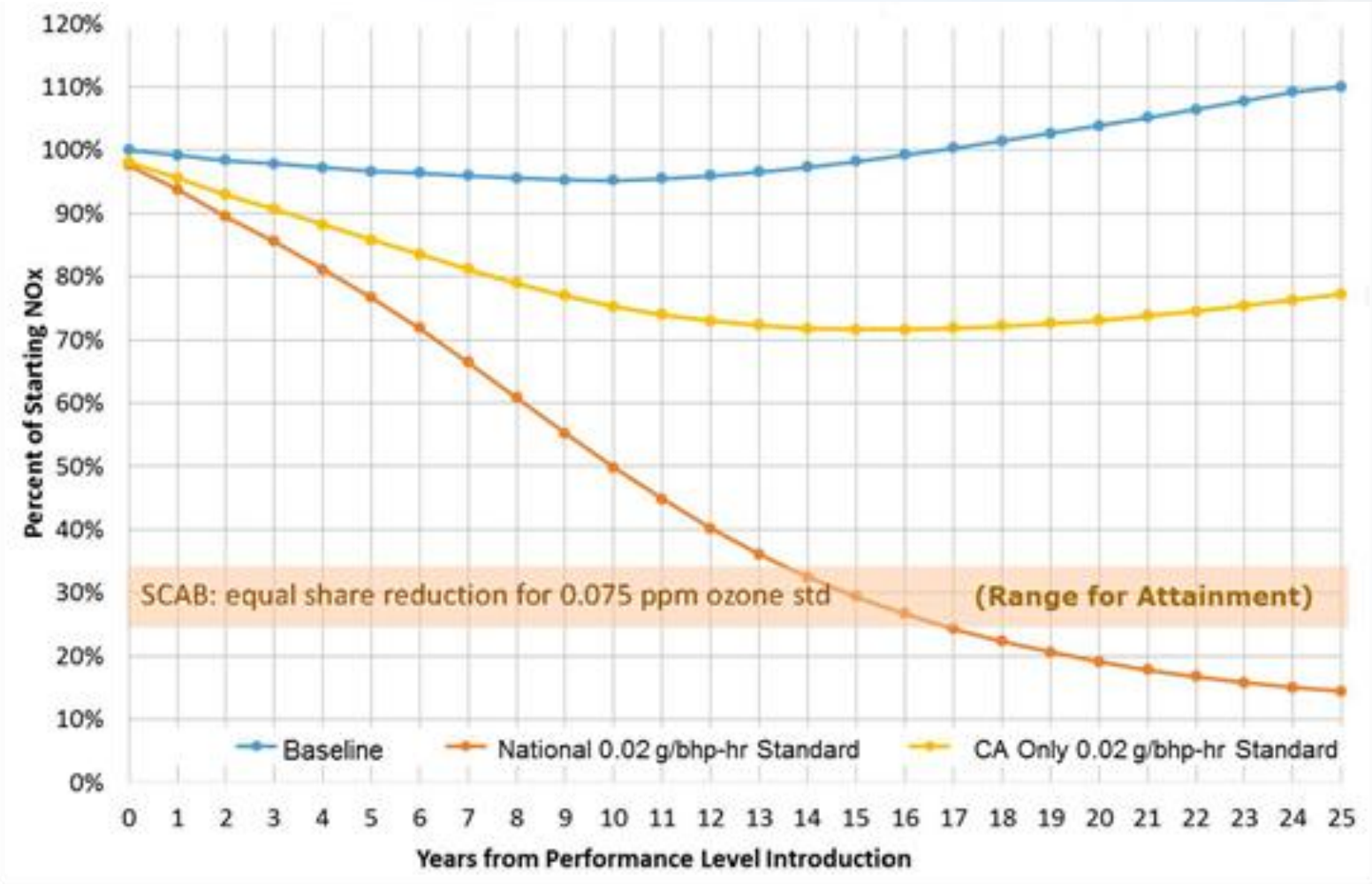
Exhaust Direction



Potential 2027 system

Engine and powertrain technologies like cylinder deactivation and mild hybridization will be important for thermal management and CO_2 reduction in 2027

National Standards Multiply Reduction Benefits



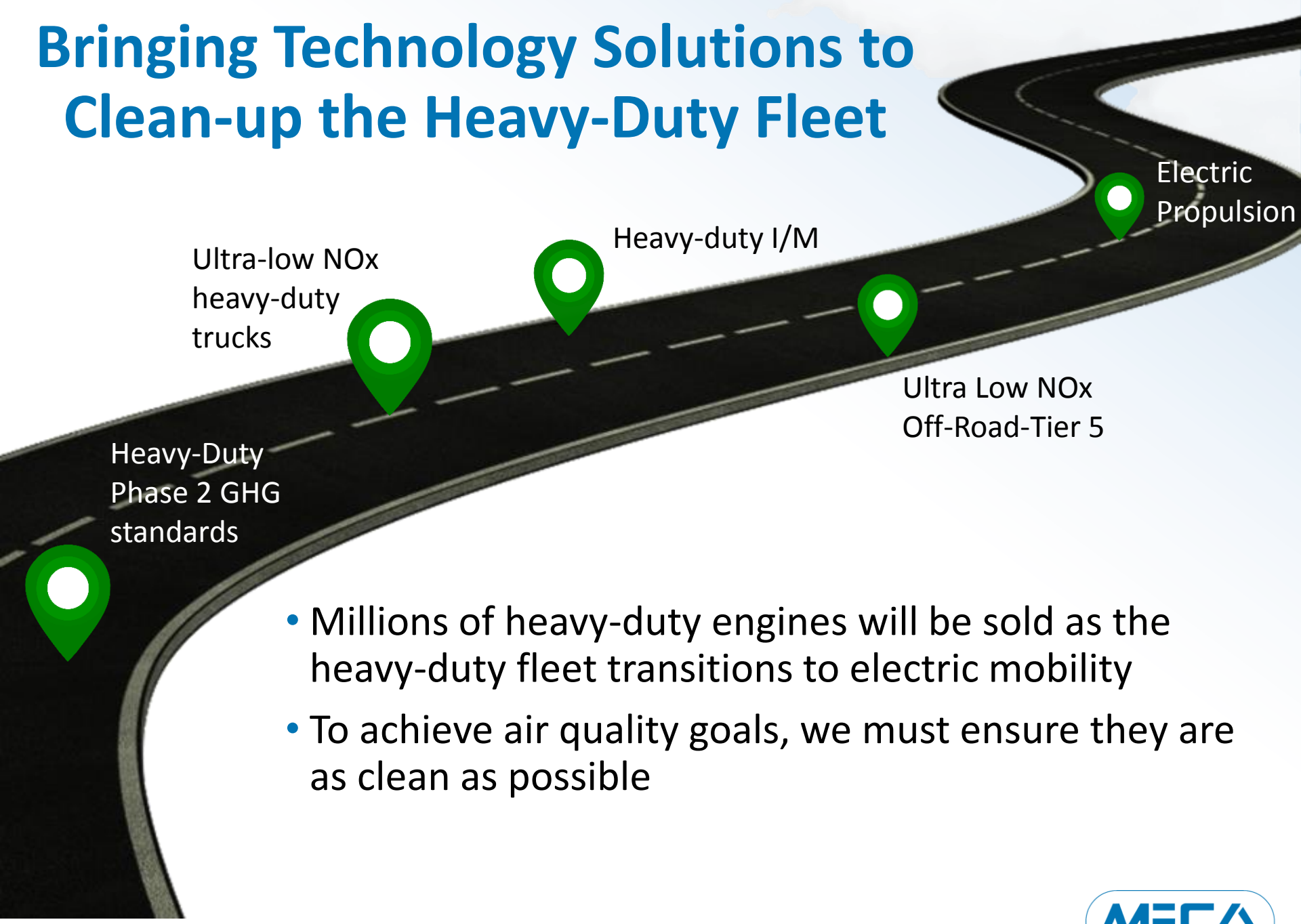
Source: Presentation by Mr. Cory Palmer, ARB at the Symposium on California's Development of its Phase 2 Greenhouse Gas Emission Standards for On-Road Heavy-Duty Vehicles (April 22, 2015)

Conclusions

- Before the heavy-duty fleet is fully electrified, millions of truck engines will be sold and can last for decades
- States need NOx reductions as soon as possible to meet NAAQS attainment goals
- A 0.05 g NOx limit in 2024 and 0.02 g in 2027 will get early cost effective NOx reductions while also meeting GHG standards
- MECA looks forward to working with NACAA and state air quality agencies to achieve a stringent heavy-duty truck standard in California starting in 2024 and nationally in 2027

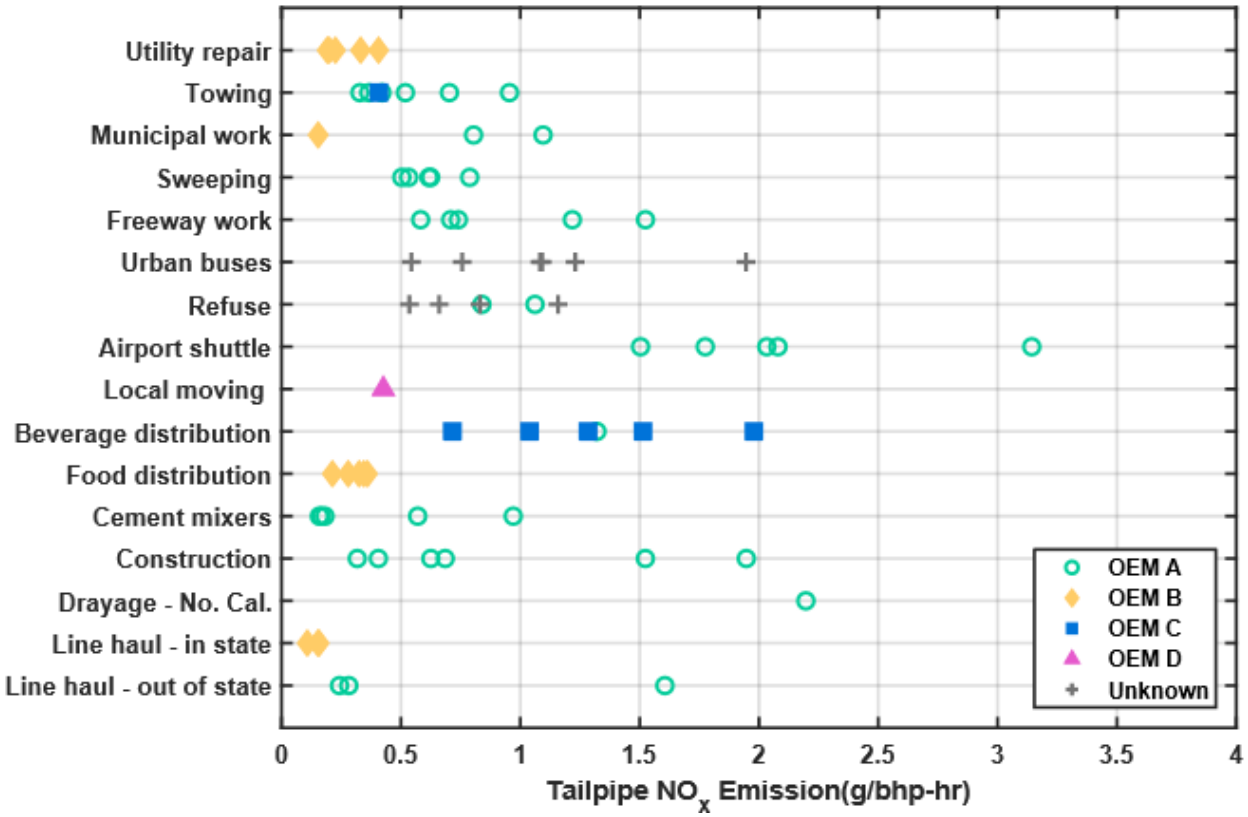
Supplemental Slides

Bringing Technology Solutions to Clean-up the Heavy-Duty Fleet



- Millions of heavy-duty engines will be sold as the heavy-duty fleet transitions to electric mobility
- To achieve air quality goals, we must ensure they are as clean as possible

CARB In-Use Testing Data suggests that real world reductions will be much greater



81% of engine operating time was in low load operation

- Stop and go
- Idling
- other

Source: Environmental Science and Technology "On-Board Sensor Based NO Emissions from Heavy-Duty Diesel Vehicles" 2019