CALIFORNIA
AIR RESOURCES BOARD

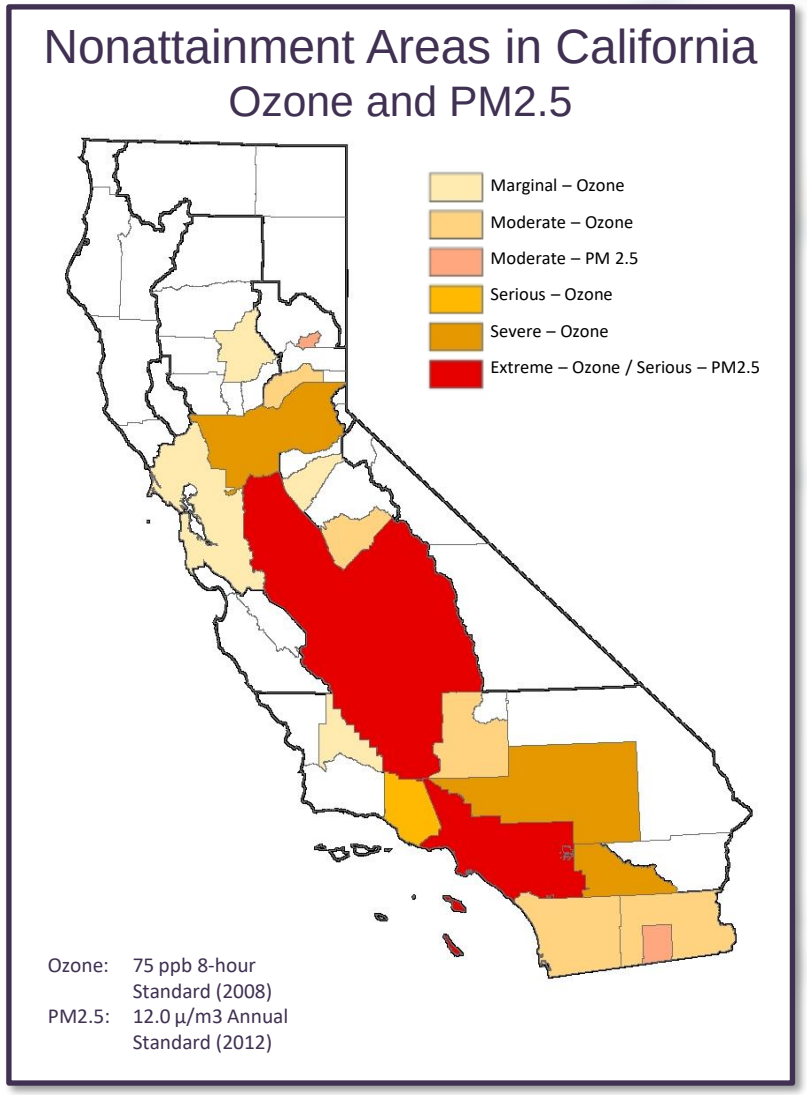
Heavy Duty Emissions Challenges and Scalable Opportunities: A California Perspective

Bill Robertson

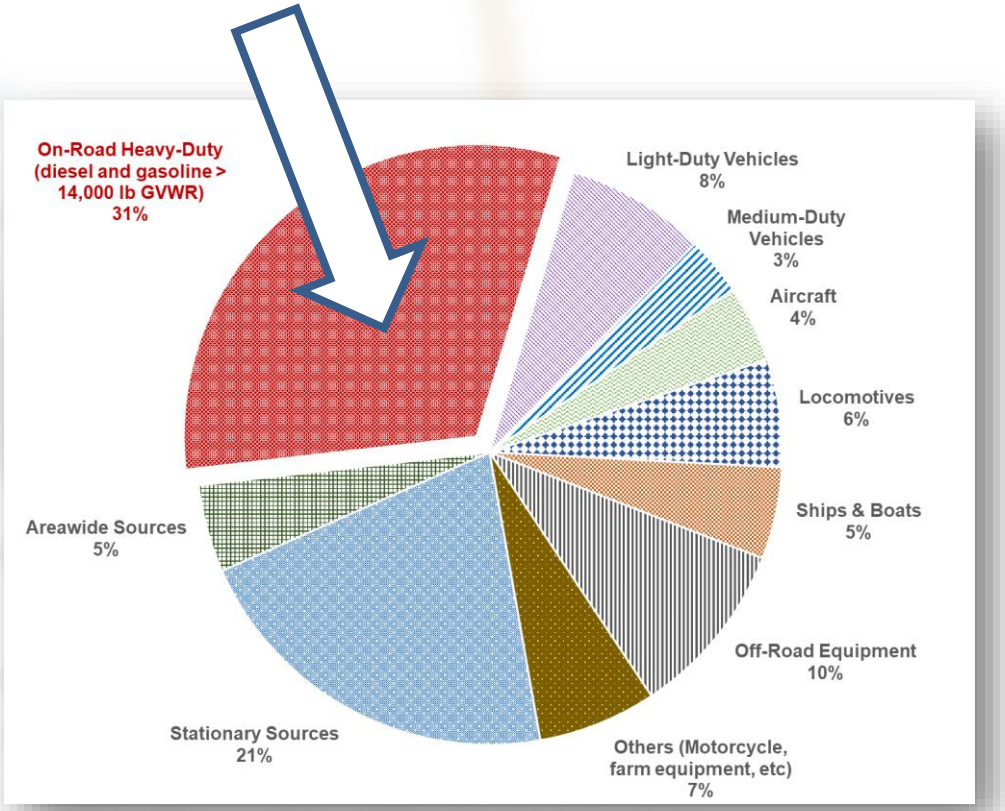
Vehicle Program Specialist
California Air Resources Board

NACAA Spring Membership Meeting, April 18, 2020

Ozone & PM Challenges



Heavy Duty largest category for
CA's Mobile Source-dominated NOx



Ozone and Health

EPA's CASAC during the 2015 Ozone NAAQS revision:

- "There is considerable discussion about the possible existence of threshold effects, with the EPA concluding that there is **no evidence for a sharp break point between exposures of 80 and 60 ppb**."

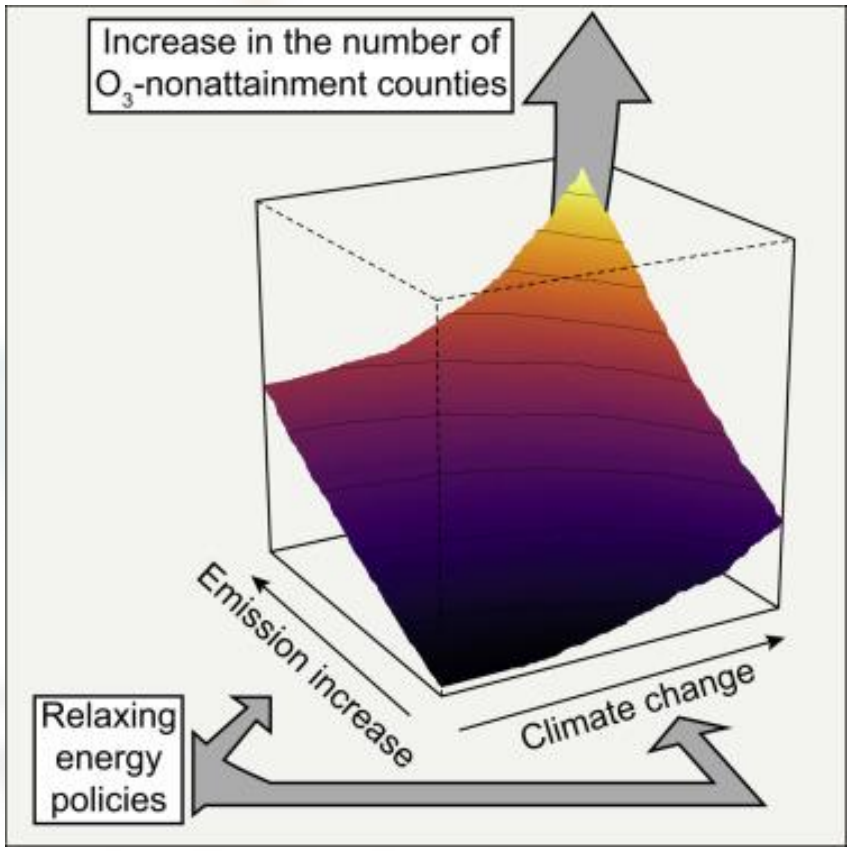
- "The CASAC further concludes that **there is adequate scientific evidence to recommend a range of levels for a revised primary ozone standard from 70 ppb to 60 ppb**. …based on the scientific evidence from clinical studies, epidemiologic studies, and animal toxicology studies…."

- "…**clinical studies do not address sensitive subgroups**, such as children with asthma, and that there is a scientific basis to anticipate that the **adverse effects for such subgroups are likely to be more significant at 60 ppb than for healthy adults**."

https://yosemite.epa.gov/sab/sabproduct.nsf/5EFA320CCAD326E885257D030071531C/$File/EPA-CASAC-14-004+unsigned.pdf

Looking at the future for Ozone

- Longterm Growth?
  - Economic
  - Population
  - Transportation/Mobility changes
- Policy shifts for other source categories?
- Climate shifting of modeling base case?



"Relaxing Energy Policies Coupled with Climate Change Will Significantly Undermine Efforts to Attain US Ozone Standards" Shen et al, https://doi.org/10.1016/j.oneear.2019.09.006

Heavy Duty On-Road NOx a Significant Ozone Contributor

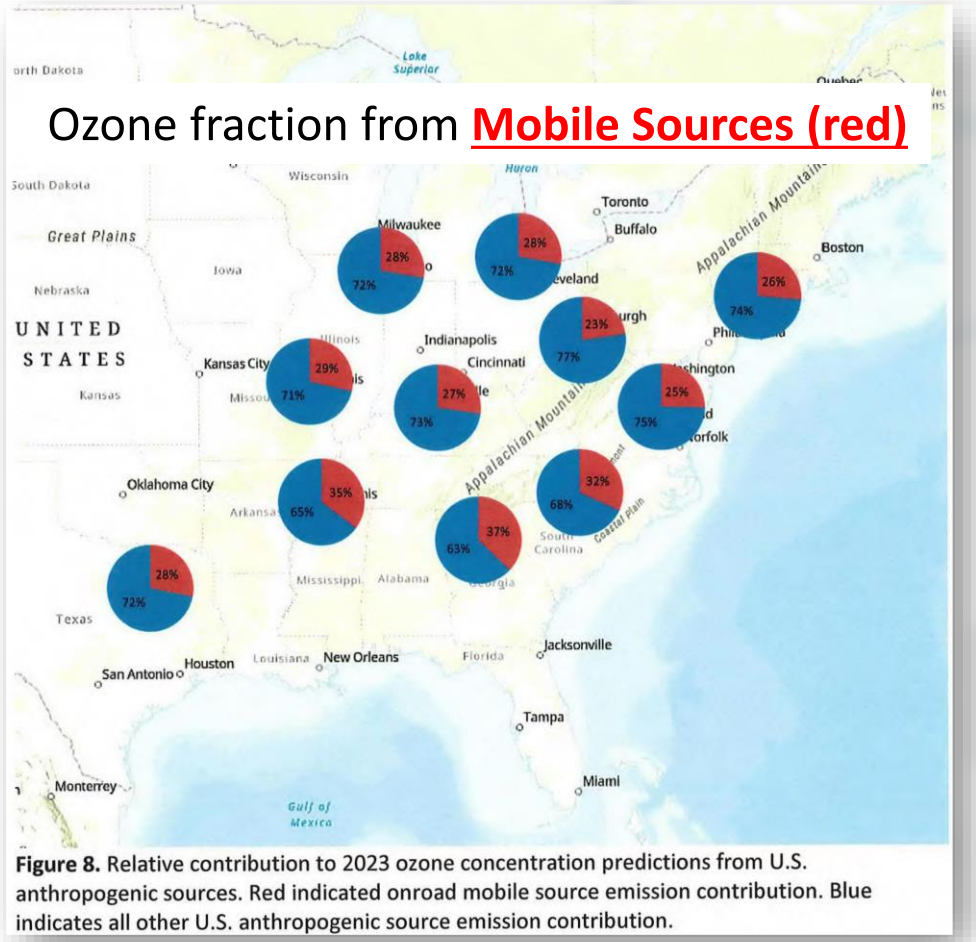
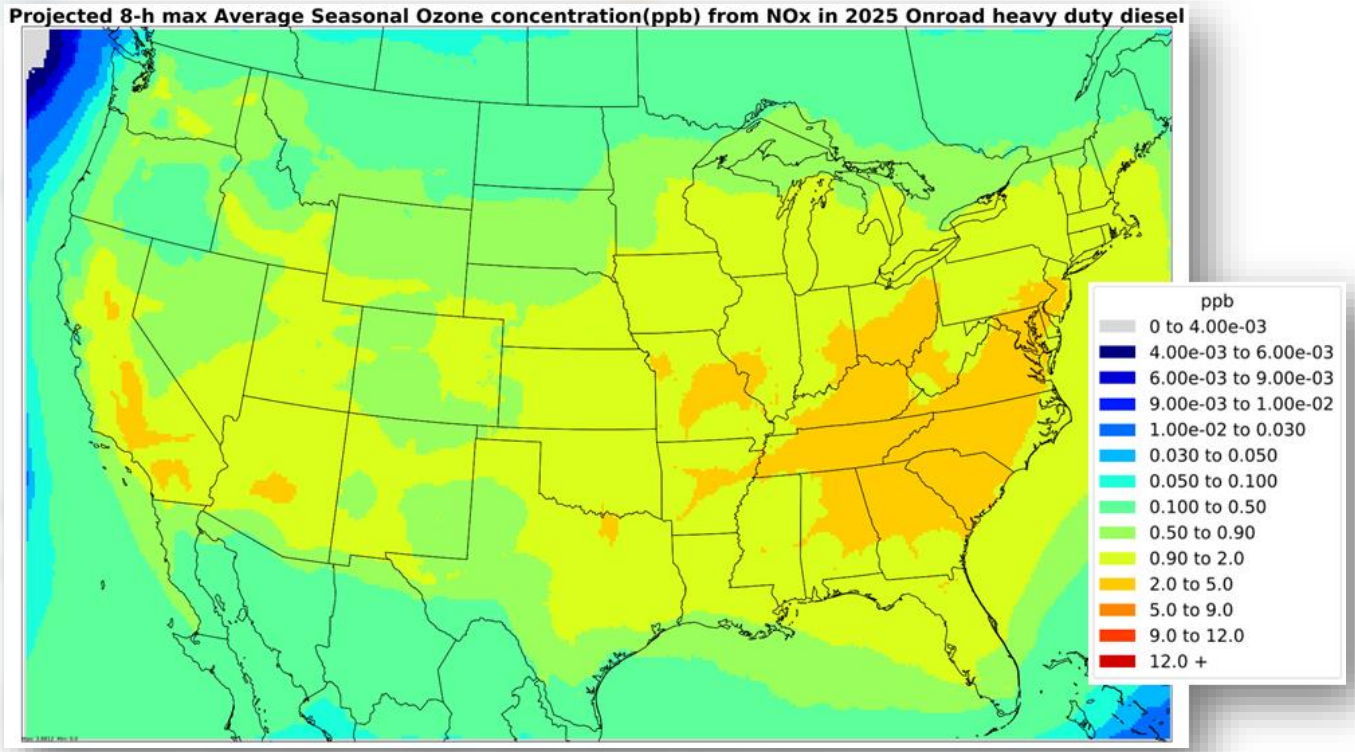


Figure 8. Relative contribution to 2023 ozone concentration predictions from U.S. anthropogenic sources. Red indicated onroad mobile source emission contribution. Blue indicates all other U.S. anthropogenic source emission contribution.

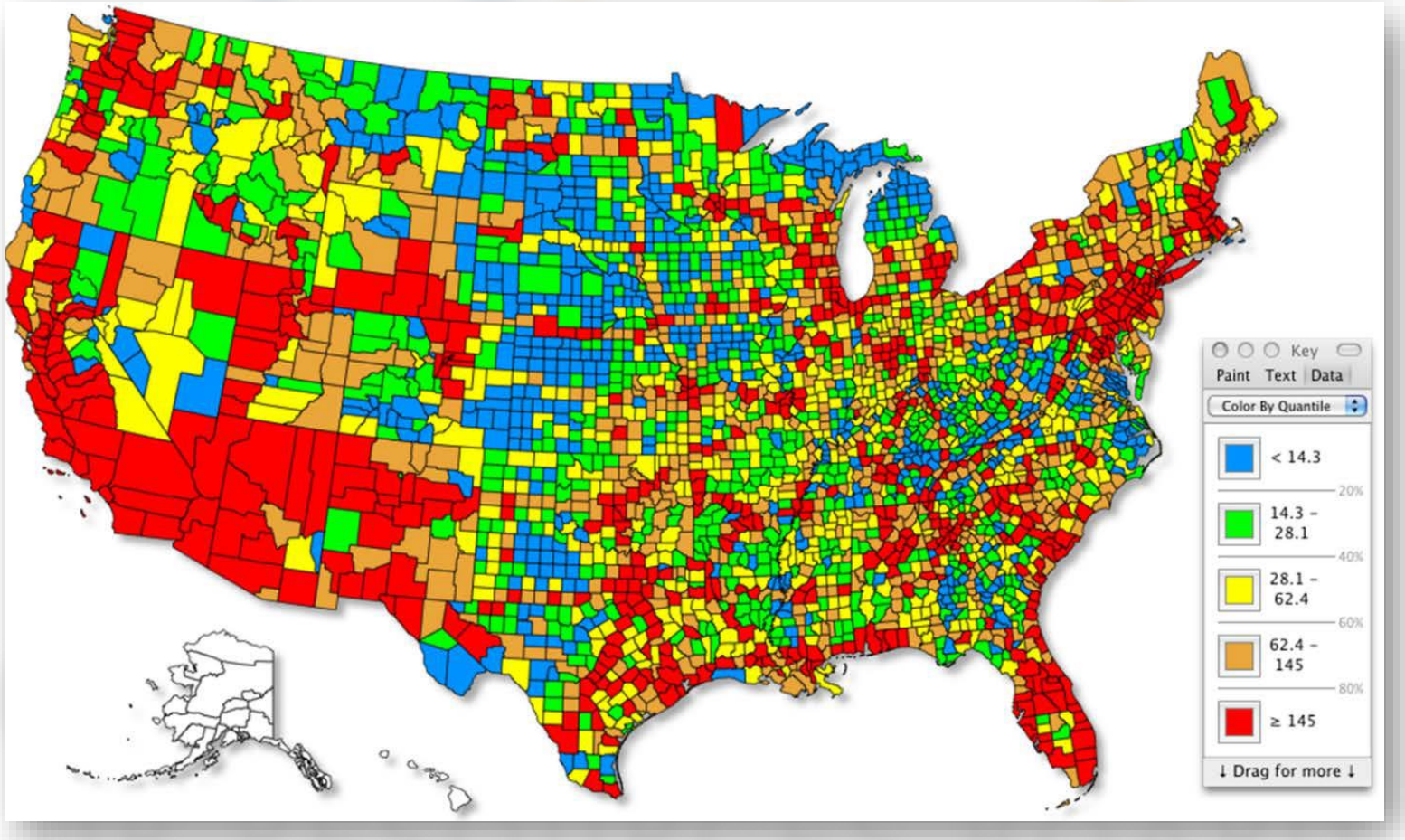
Midwest Ozone Group comments to EPA's Cleaner Trucks Initiative: https://www.regulations.gov/document?D=EPA-HQ-OAR-2019-0055-0279

EPA on Ozone: HD On Road is largest Mobile Source action available



EPA mobile source ozone study: https://doi.org/10.1016/j.atmosenv.2018.04.057

Heavy Duty NOx Reductions Possible



Modeled NOx Reductions by County from Cleaner Trucks Initiative in 2035 (tons).

Inventory modelling from MECA comments to EPA's Cleaner Trucks Initiative:
http://www.meca.org/attachments/3472/MECA_comments_on_EPA_CTI_02202020.pdf

Protecting our Vulnerable Communities

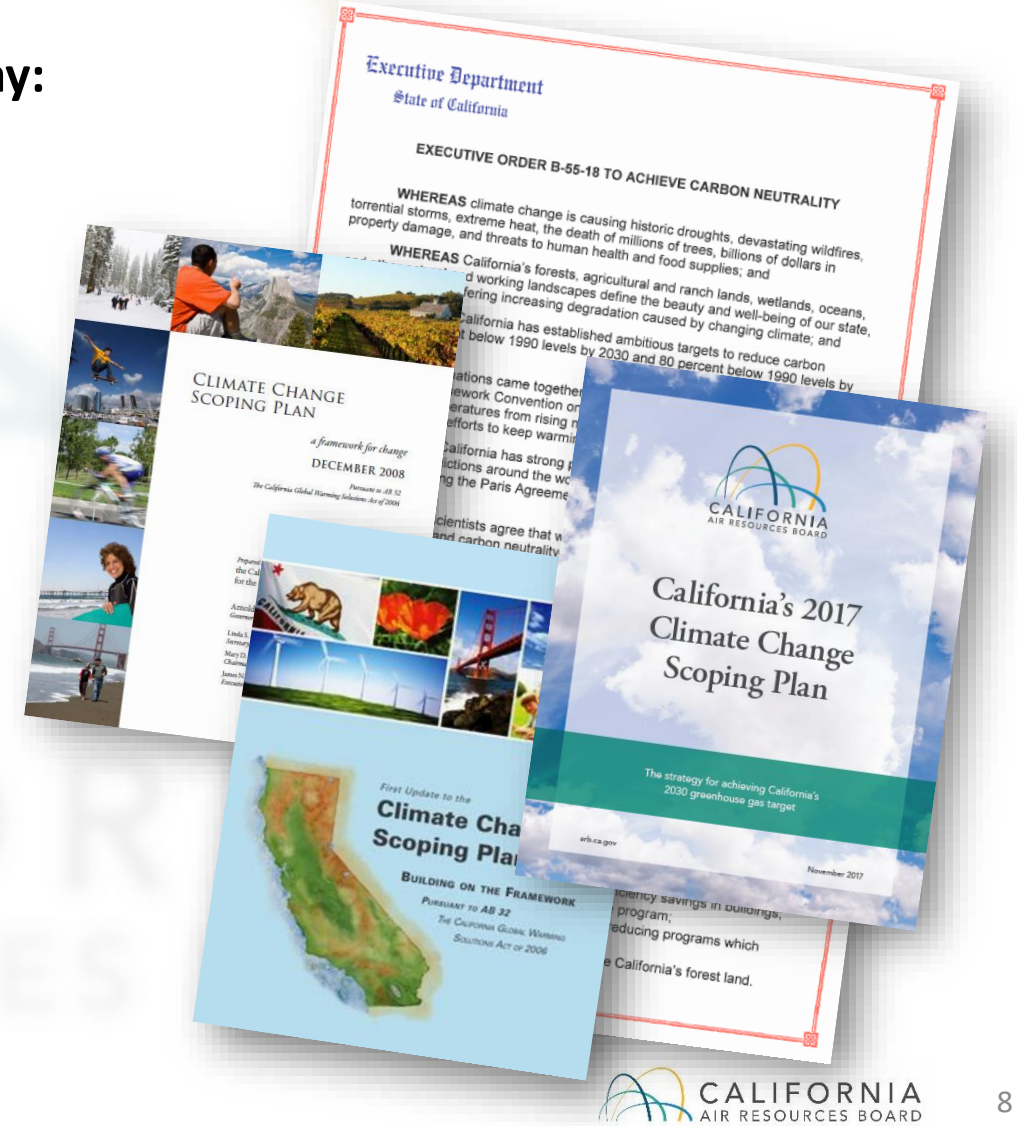
- **Goods Movement emissions disproportionately affect Environmental Justice Communities**
  - Populations least able to mitigate have the highest exposures
  - High activity concentrations of truck traffic and off road equipment
    - Freight Corridors/Near Roadway
    - Ports
    - Warehouses & Distribution Facilities
  - Higher local emission rates: Congestion/idling by deactivating current SCR NOx controls

Need Concurrent NOx & GHG Progress

- **California's AB32 & SB32 implementation underway:**
  - 2020: return CA to 1990 GHG levels (on target)
  - 2030: 40% below 1990 GHG levels
  - **CA-wide Carbon Neutrality Goal in 2045**

~~'Either/Or'~~: Need 'Both/And' solutions for NOx & GHG

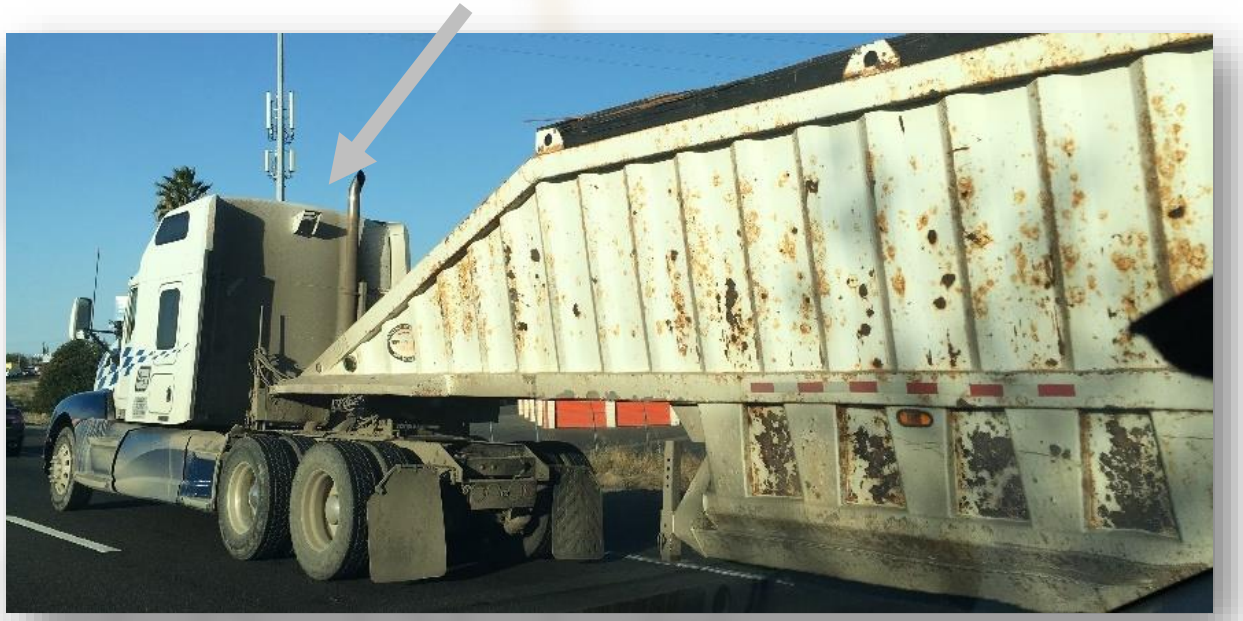
- **GHG efforts across other regions too**
  - Regional Greenhouse Gas Initiative
  - Oregon Clean Fuels program
  - Quebec Cap and Trade Auction
  - Many other state and local commitments



https://ww3.arb.ca.gov/cc/scopingplan/scopingplan.htm
https://www.ca.gov/archive/gov39/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf

National Scope of Heavy Duty Challenges, Need for Broadly Applicable Solutions

- **Widely spread impacts: for example, 2/3rds of CA VMT from out of state trucks:**
  - Trucks often operate far from where Purchased or Registered
  - Migration in the Secondary Market
  - Emissions felt Locally and from Upwind



- **Long Service Lives**
  - Slow Natural Turnover
  - Late life emissions performance

- **Dutycycle Dependence of Current SCF Designs**
  - Each truck experiences Low Load Operation challenging today's SCR NOx controls, often near people
  - 2nd, 3rd, 4th owner Vocation Changes tend to increase Low Load Operation
    (note: dirt hauler with sleeper & empty telematics bracket from previous life)

Heavy Duty On-Road Challenges

Guest presentation themes from CARB 9/26/2019 workshop:

- **CAPCOA, SCAQMD, NESCAUM, NACAA**
  regional NOx needs & urgency, need for widespread action
- **Connecticut & New York**
  95 Corridor through trucks & intent to study CA Low NOx Opt-In
- **Colorado**
  I/M program and recent "S177 State Opt-In" to LD LEV and to LD ZEV
- **Oregon**
  recent law creating In-Use Fleet Rule similar to CA's "Truck & Bus" Rule

- Tech availability/analysis from **MECA, Achates Power, SwRI, ICCT**

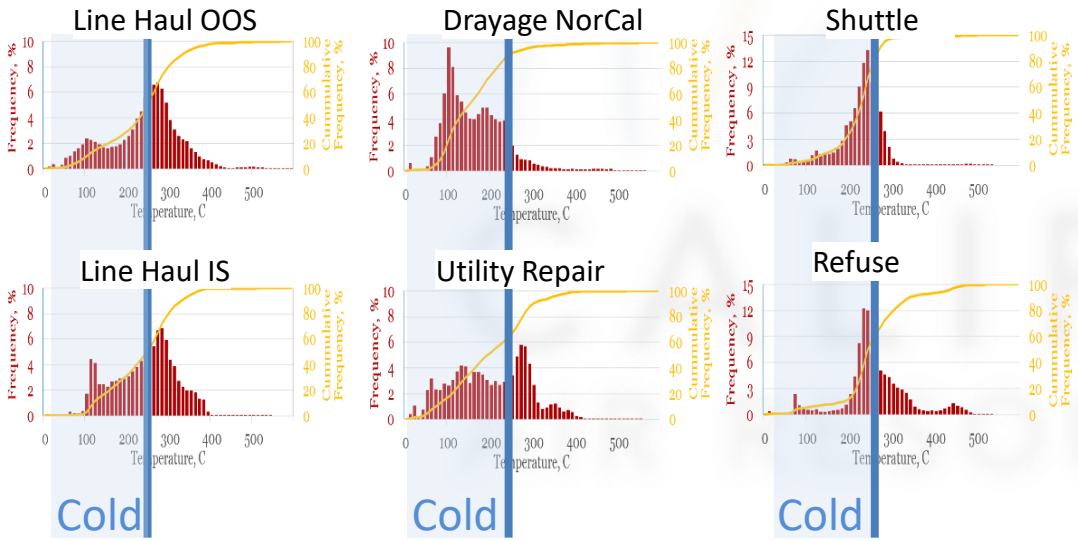
Similar themes in comments made to EPA Cleaner Trucks Initiative ANPRM

https://ww2.arb.ca.gov/our-work/programs/heavy-duty-low-nox/heavy-duty-low-nox-meetings-workshops
https://www.regulations.gov/docket?D=EPA-HQ-OAR-2019-0055

Improvement needed for In-use Performance

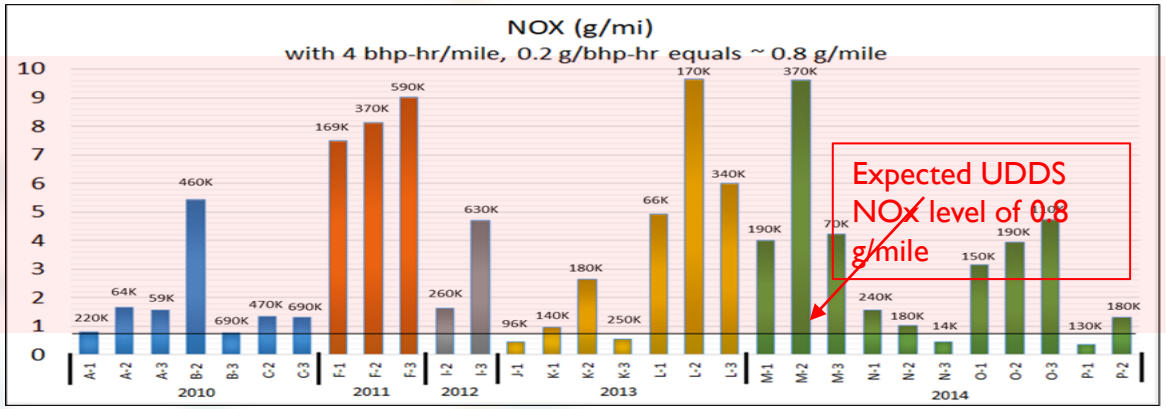
Broader Design Intent and Better Robustness needed for NOx controls

Calibration/Dutycycle Incompatibility:
SCR-Deactiving Cold Operation common in datalogs

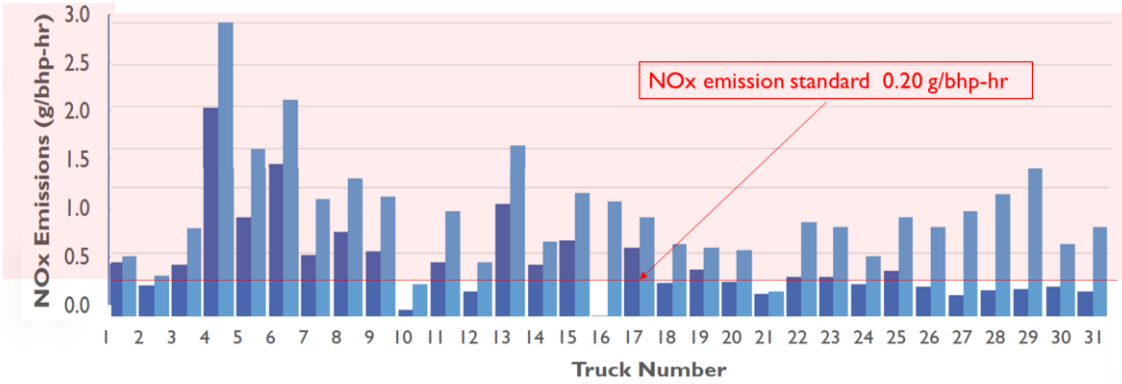


SCR should be active: In-Use Surveillance Chassis Dyno Urban Dynamometer Driving Schedule Tests (UDDS)

High NOx



"Hot" SCR Highway driving: PEMS NTE On-Road Tests



High NOx

Need for NOx control across Dutycycles

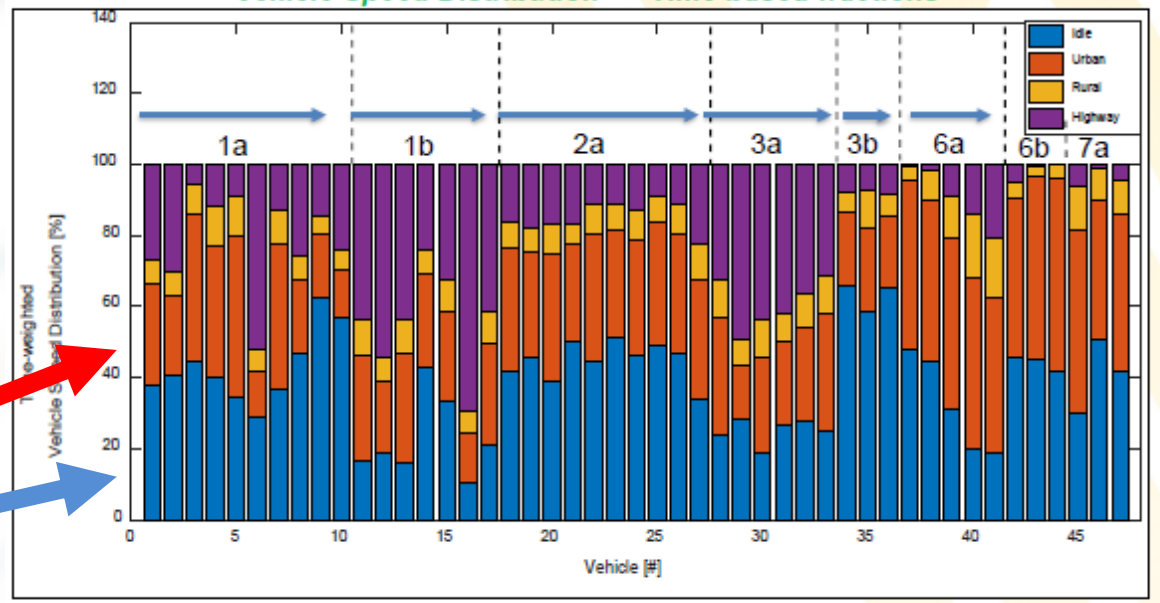
Distribution of speeds from EMA 100 truck datalogging study

RED: Low Speed

BLUE: Idle

Need to Design Engines for how they are actually being used

Vehicle Speed Distribution => Time-based fractions



Category	1a	1b	2a	3a	3b	6a	6b	7a
Avg Vehicle Speed [mph]	18	31	15	30	9.50	17	9	12
Avg Engine Power [bhp]	67	95	52	103	53	47	39	36
Total ECU Logging Duration [hr]	1457.6	1222.8	1885.3	1422	908.4	312	109.5	429

Vehicle Speed Bins

Mode	Low [mph]	High [mph]
Idle	0	0.93
Urban	0.93	31.06
Rural	31.06	46.6
Highway	46.6	

Per EU Regulations

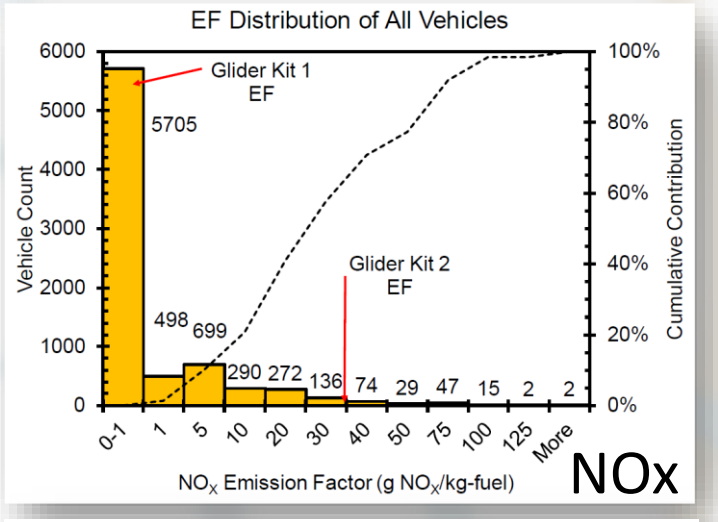
Category	Vocation
1a	Long haul
1b	Short haul
2a	Port Drayage
3a	Tractor construction
3b	Cement mixer
6a	Food/Beverage
6b	Food/Beverage
7a	Goods distribution

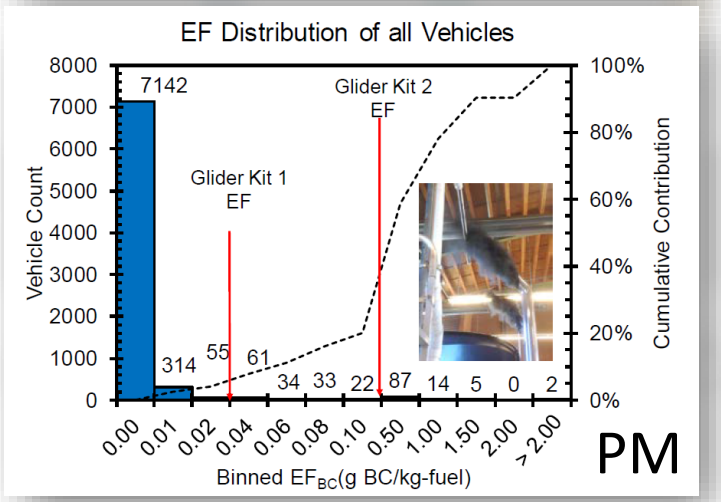
‘High-Emitter Tail’ Increasingly Important

Small fractions of **‘High-Emitters’ can double** overall emission **inventory:**

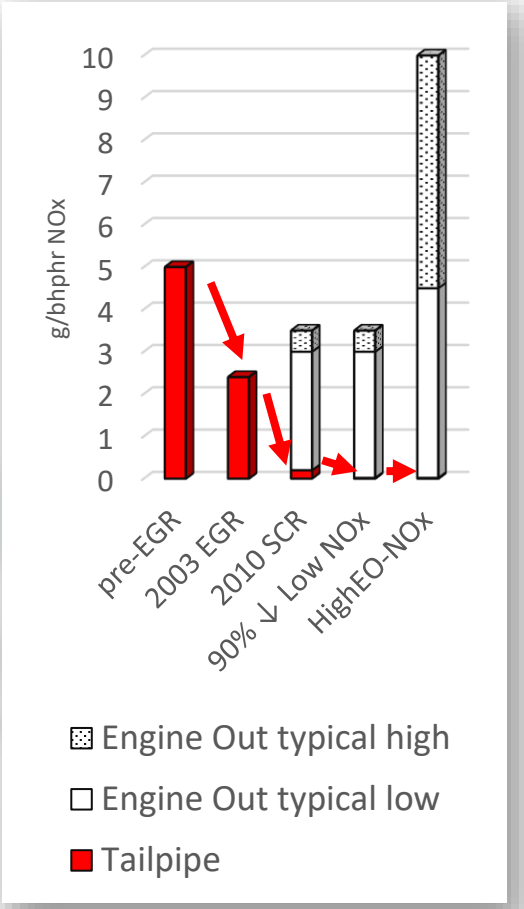
- **Engine out NOx orders of magnitude greater than tailpipe NOx**
- **Aftertreatment Durability is critical** to real world reductions from high conversion efficiency aftertreatment designs
- **Engine robustness needed** to support longterm aftertreatment durability
- Prompt addressing of field issues: Warranty & Maintenance

CA Roadside Observations





NOx vs Engine Tech



Roadside data from CARB Glider comments: https://www.regulations.gov/document?D=EPA-HQ-OAR-2014-0827-4831

How can we do better?

CARB strategy: **"Zero emissions everywhere feasible, and near-zero emissions with renewable fuels everywhere else."**

- **Zero Emission Technologies**
  - Eliminate Tailpipe emissions
  - Utilize increasingly green energy sources including: Renewable electricity and Renewable hydrogen
- **Make existing Internal Combustion Technology Cleaner**
  - CARB **Optional Low NOx engines** exist today at **90%↓NOx**
  - Bring remaining Diesel along: **Air handling** and **incremental SCR improvements** to **achieve** similar **90%↓ NOx**
  - Utilize cleaner renewable fuels: California's Low Carbon Fuels Standard

This Presentation's Focus

https://ww3.arb.ca.gov/gmp/sfti/sustainable-freight-pathways-to-zero-and-near-zero-emissions-discussion-document.pdf

Technical coordination with US-EPA Staff

- US-EPA to consider Heavy Duty On-Road Standards for MY2027+
- Last NOx standards developed 20 years ago
- In 10th year of SCR NOx controls

- CARB and EPA staff in regular technical coordination meetings
- Co-sponsorship of demonstration work

- EPA's ANPRM commented on, full NPRM expected later this year
  (Thank you NACAA/members for ANPRM comments! *Get ready for NPRM comment period*)

Docket ID #EPA-HQ-OAR-2019-0055
https://www.epa.gov/regulations-emissions-vehicles-and-engines/advance-notice-proposed-rule-control-air-pollution-new

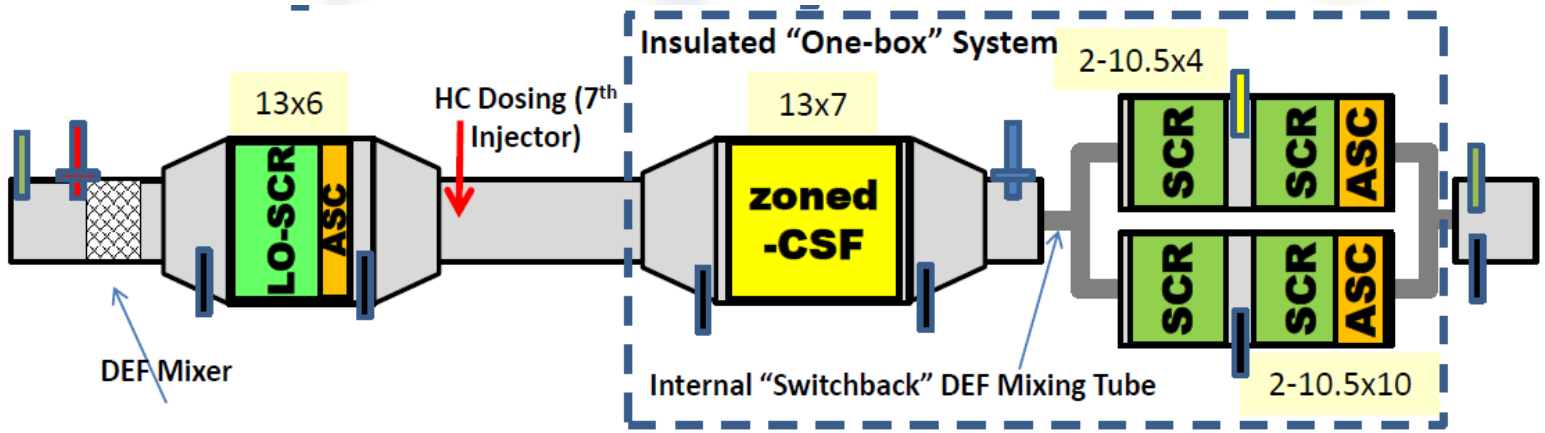
CA Demonstrating Low NOx Engines

- **10x cleaner "Optional Low NOx" engines** *already here*
  - 0.02g/bhphr FTP Commercialized since 2016 in NG and Propane

- **Low NOx Diesel** engine technology projects maturing
  - **Production engine + advanced SCR system & calibration**: 0.07g/bhphr Low Load Cycle performance *at baseline GHG*, <0.03g/bhphr FTP
  - **Production engine + air handling mods, Dual Dosing Split SCR & calibration**: Further NOx ↓ & GHG ↓, LLC 0.025g/bhphr, Full Useful Life Aging data pending
  - **Opposed Piston Engine with adv'd SCR, installing into semi tractor** 0.02g/bhphr NOx target with significant GHG reductions
  - **Diesel plug-in hybrid tractor with C-ITS & adv'd SCR**

https://ww3.arb.ca.gov/msprog/hdlownox/files/workgroup_20190926/guest/swri_hd_low_nox_demo_programs.pdf
https://www.arb.ca.gov/msprog/lct/pdfs/opposedpiston.pdf ; https://achatespower.com/wp-content/uploads/2020/03/Achates-Power-Cost-Study-White-Paper_March-2020.pdf
https://ww3.arb.ca.gov/msprog/lct/pdfs/drayagedemo.pdf

How are we doing Low NOx?



- **Warm up ECU strategies that limit engine out NOx and heating options**
- **Limit unnecessary airflow at lower loads and motoring (EGR rates, Cylinder Deactivation, Opposed Piston strategies)**
- **Position SCR catalyst early in system for fast lightoff**
- **Retain Passive PM regeneration GHG benefits with downstream SCR**

We're not the only demonstrations

- **'Stock HD engine + Dual Dosing twin SCR & calibration'**
  Bosch reporting **0.017** g/bhphr NOx data
  Navistar reporting **0.04** g/bhphr NOx using their current A26 engine

- **'Cylinder Deactivation + stock DPF/SCR'**
  Eaton and also ***Jacobs*** each reporting **86% NOx reductions** data in the CARB MY2024 NOx vicinity with GHG benefits (air handling strategies)
- ***Jacobs Vehicle Systems*** **Cylinder Deactivation included in** ***Navistar*** **Supertruck** Team with initial NOx/GHG performance data reported, fielding own demo truck
- ***Cummins*** & ***Tula*** showing **advanced controls for Cylinder Deactivation** for engine and demo vehicle

- ***MECA members*** providing enabling technology for **Urea (DEF) heated dosing** across wider SCR operating range

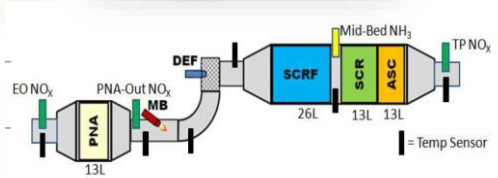
- ***VW*** and also ***BMW***: Light Duty **mass market launch of 'Dual Dosing close-coupled SCRF/underbody SCR'** configurations

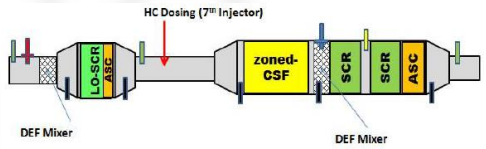
So what's California doing with this?

Heavy Duty Low NOx Omnibus Overview

Heavy Duty Low NOx Omnibus: Requiring Cleanest Possible Engines

- **Significantly Lowered NOx standard**
  0.05g/bhphr initial step for MY2024 then
  0.02 g/bhphr step for MY 2027 (beyond 435k mi tbd)
- **Low Load NOx control requirement**
  including Low Load Cycle & In-Use Metric
- **Adopting an In-Use Compliance Metric**
  Full workday emissions performance evaluation
- **Longer Warranty and Useful Life**
  reflect actual vehicle usage
- **Improving initial Durability Demonstrations**
  procedures for efficacy, efficiency, and practicality
- August 2020 Board Hearing





https://ww2.arb.ca.gov/our-work/programs/heavy-duty-low-nox

Omnibus: Lower NOx Standards

- **2024 0.05g/bhphr standard**
  - Intended to be achievable with ECU calibration and aftertreatment modifications.
  - Avoids necessity of major engine redesign or moving vehicle framerails or sheetmetal
  - OEMs may choose engine/powertrain-based alternatives for synergistic benefits (fuel economy benefits, meeting rising vehicle electricity demands, etc.)

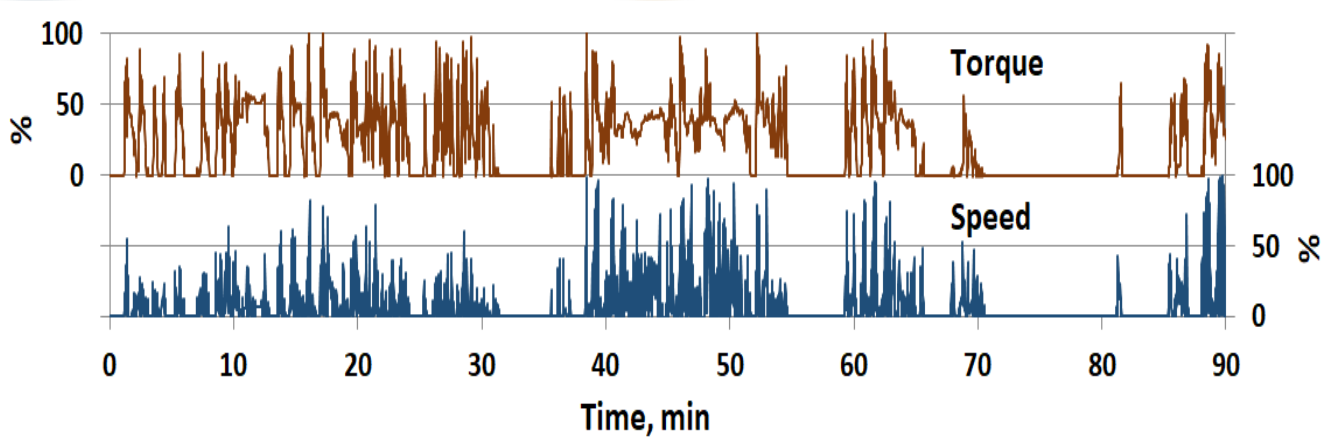
- **2027 0.02g/bhphr 435k mi standard**
  - Based on full engine-with-aftertreatment integration.
  - May include fitting of Close-Coupled underhood catalysts.
  - Assessing reasonable standards for ‘beyond 435k mi’ full 2027 & 2031 Useful Life

Omnibus: Low Load Cycle

Goal: LLC Cert Cycle driving Calibration and Hardware for typically encountered operation

Characteristic Challenges included:

- Low Load Transients
- Extended Idle
- Low Load-to-High Load Transitions
- Motoring (vehicle 'pushing' engine)



SwRI SOUTHWEST RESEARCH INSTITUTE

NREL National Renewable Energy Laboratory

Performance:

- **0.34-1.3 g/bhphr** from today's (0.2g/bhphr FTP certified) engines
- **~0.025g/bhphr** with GHG savings shown on Low NOx Demonstration engine

Omnibus: In-Use Metric
"3-bin Moving Average Windows"

Goals

- ***Preponderance of NOx examined*** in calculation for a workday
- ***Metric responsive on natural timescales*** of aftertreatment
- ***Stable Compliance Determination*** despite daily variation in vehicle activity
  (Idle, Low Load, Med/High Load)
- ***Avoid variability*** from arbitrarily splitting emission events across window boundaries

Concept

- ***Calculate 300sec averages*** each 1Hz timestep creating "windows"
- ***"Bin" each window*** according activity using window average fueling rate
- ***Assess "Bin" compliance*** to its own Standard on a Sum-over-Sum basis:
  (Total mass emissions)/(Total Fuel Used)

Omnibus: Warranty & Useful Life

Goals

- ***Useful Life meaningful for actual usage*** observed in fleet survival/rebuild data sources
- ***Warranty significant fraction of Useful Life*** to encourage good Design Decisions beyond user's control and Prompt Repair
- 2027 & 2031 MYs ***Phase-in to build experience*** with the technology

MY	LHDD	MHDD	HHDD	HDO
	Warranty (miles)			
June 2018 Step 1 Warranty 2022-2026	110,000 5 years	150,000 5 years	350,000 5 years	50,000* 5 years
2027-2030	150,000 7 years/ 7,000 hours	220,000 7 years/ 11,000 hours	450,000 7 years/ 22,000 hours	110,000 7 years/ 6,000 hours
2031 and Subsequent	**210,000** 10 years/ 10,000 hours	**280,000** 10 years/ 14,000 hours	**600,000** 10 years/ 30,000 hours	**160,000** 10 years/ 8,000 hours
	Useful Life (miles)			
Current-2026	110,000 10 years	185,000 10 years	435,000 10 years/ 22,000 hours	110,000 10 years
2027-2030	190,000 12 years	270,000 11 years	600,000 11 years/ 30,000 hours	155,000 12 years
2031 and Subsequent	**270,000** 15 years	**350,000** 12 years	**800,000** 12 years/ 40,000 hours	**200,000** 15 years

* Not included under Step 1 Warranty, but current periods are shown here for completeness.

https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks
https://www.nescaum.org/documents/nescaum-press-release_12-12-19.pdf/

Studies looking at cost

- **MECA** 2024-2026MY and 2027MY & beyond technology feasibility whitepapers: ***Technology ready. Hardware cost increment*** for 0.02g/bhphr NOx expected to be ***on the order of cost decline observed since 2010*** introduction.

- **ICCT** study of '2010 technology' cost; ***0.02 Low NOx update pending*** for anticipated release in next 2 weeks or so

- **NREL** study surveying OEMs and Suppliers: ***Bulk of estimates depend not on technology cost but on Warranty obligation assumptions***. A shift of significant existing user costs up to manufacturers, not necessarily an entirely new Total Cost of Ownership cost.

- **Achates Power/FEV** 'should cost' teardown study:
  Opposed Piston Engine with 0.02g/bhphr NOx aftertreatment ***has less unit production cost than today's equivalent conventional*** 0.2g/bhphr products

http://www.meca.org/resources/MECA_MY_2024_HD_Low_NOx_Report_061019.pdf ; http://www.meca.org/resources/MECA_2027_Low_NOx_White_Paper_FINAL.pdf
https://theicct.org/publications/costs-emission-reduction-technologies-heavy-duty-diesel-vehicles
https://achatespower.com/wp-content/uploads/2020/03/Achates-Power-Cost-Study-White-Paper_March-2020.pdf

Options for prior-to-EPA action

- EPA has reiterated their intention for 2027MY first applicability
- CARB will be implementing NOx standards starting 2024MY (S177 opportunity!)

- The agencies and EMA have discussed the merits and risks of a voluntary nation-wide industry agreement for 2024-2026MYs:
  Looser interim standard but apply to all engines nationally
  Target '1/3 of CA VMT at 100% of standard' or target '100% CA VMT at lesser standard' for similar results?

- CARB is evaluating Omnibus inclusion of a 50-state option at about twice the mandatory standard that individual OEMs could choose for their entire product line

Upcoming Process Engagement Opportunities

- **CARB Low NOx Omnibus**
  - Welcome individual interaction and feedback
  - Staff Proposal out in late June, 2020 with lengthened 60-day comment
  - Working towards the August 27, 2020 CARB Board Hearing

- **EPA Cleaner Trucks Initiative NPRM full proposal**
  - Expected ‘late summer’ 2020 with comment period

- **CARB Advanced Clean Trucks regulation (ZEV):**
  - Currently in official comment period
  - Returning for consideration at the June CARB Board Hearing: Expanded Sales Percentages and Phase-in Calendar Scope

Contact Info

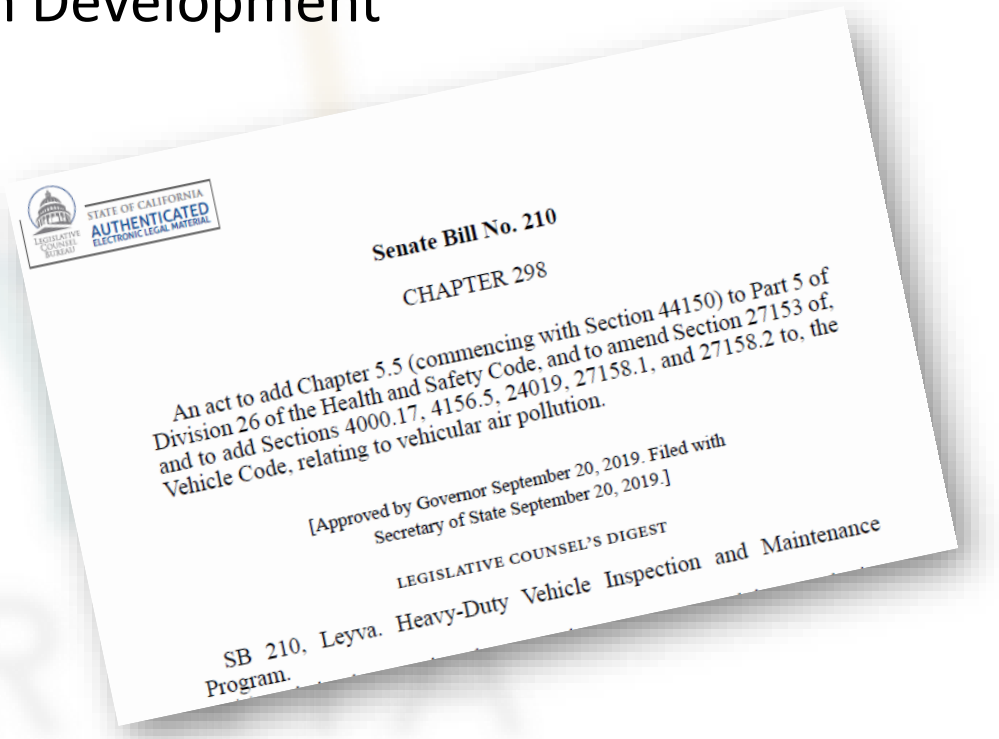
Bill Robertson, Vehicle Program Specialist
Heavy Duty Technology Advisor
email: william.robertson@arb.ca.gov

Assuring Late Life Emissions Control

CARB Heavy Duty Inspection/Maintenance Program Development

- **Recent legislation directs CARB to implement an HD I/M program**
  - SB210 signed September 20, 2019
  - 'SMOG Check' analog for trucks

- **Levels playing field for Commercial Vehicles**
  - Minimum emissions performance floor
  - Encourage prompt repair of failures
  - Discourage tampering
  - Promote accountability throughout service life


STATE OF CALIFORNIA
AUTHENTICATED
ELECTRONIC LEGAL MATERIAL

Senate Bill No. 210

CHAPTER 298

An act to add Chapter 5.5 (commencing with Section 44150) to Part 5 of Division 26 of the Health and Safety Code, and to amend Section 27153 of, and to add Sections 4000.17, 4156.5, 24019, 27158.1, and 27158.2 to, the Vehicle Code, relating to vehicular air pollution.

[Approved by Governor September 20, 2019. Filed with Secretary of State September 20, 2019.]

LEGISLATIVE COUNSEL'S DIGEST

SB 210, Leyva. Heavy-Duty Vehicle Inspection and Maintenance Program.

https://ww2.arb.ca.gov/our-work/programs/heavy-duty-inspection-and-maintenance-program