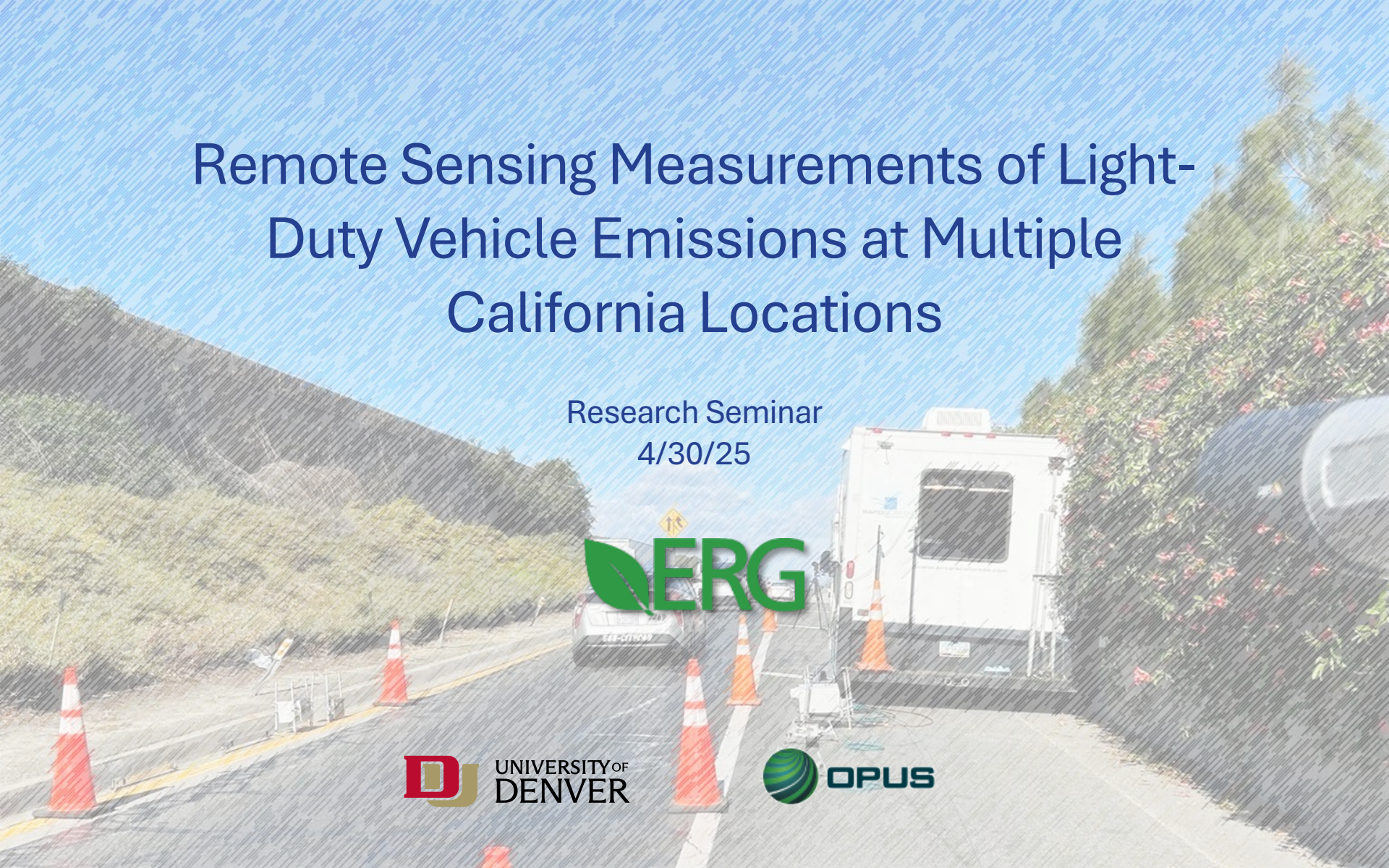
Remote Sensing Measurements of Light-Duty Vehicle Emissions at Multiple California Locations

Research Seminar
4/30/25



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OPUS

Acknowledgements

- Sponsors
  - CARB, under Project 20RD001
  - Bureau of Automotive Repair
- Support
  - CARB
    - Tao Zhan, Seungju Yoon, and Chris Ruehl
  - Denver University
    - Gary Bishop
  - Opus
    - Niranjan Vescio and RSD team
  - Coordinating Research Council (CRC)

Presentation Overview

- Project Background
  - Research Goals
  - Community Type Definitions
- RSD Measurement
  - Measurement principles
  - Data preparation/QA
  - Measurement Campaigns and Other Supporting Datasets
- Analysis Results
  - Campaign dates and statistics
  - Initial data review and observations
  - Project research topics

Research Goals

Continue CARB's long-term efforts to measure and analyze pollutant emissions by Remote Sensing Device (RSD) via 6 Analysis Topics:

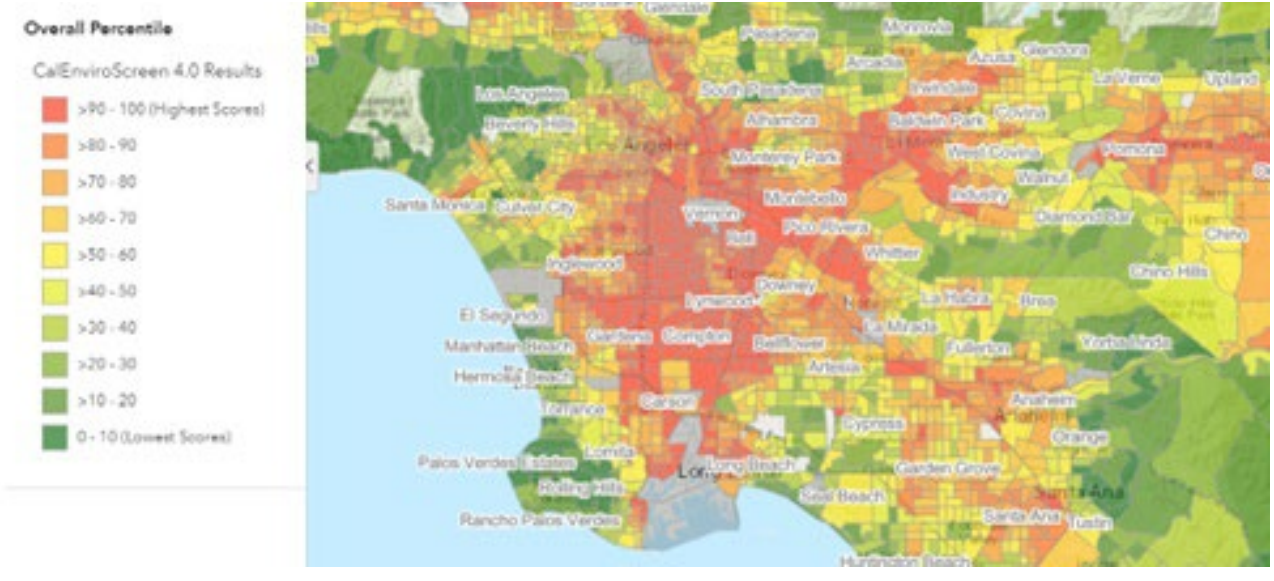
1. Investigate emissions disparities between light duty vehicles (LDVs) registered in disadvantaged and non-disadvantaged communities (DAC/non-DAC)
2. Continue historical West LA RSD measurements
3. Compare and contrast in-state and cross-border vehicles
4. Evaluate DAC/non-DAC electric vehicle (EV) fractions on-road
5. Analyze heavy duty vehicle (HDV) profiles and emissions trends
6. Compare RSD results to Smog Check records on vehicle-by-vehicle basis

CA Disadvantaged Communities

- SB 535 (2012): Includes funding for air-quality investment to improve public health, quality of life, and economic opportunity in DACs.
  - Development of CalEnviroscreen (CES), a tool to assign pollutant, health, and environmental vulnerability "score" by census tract
  - CalEPA designates DACs using the CES tool
- AB 617 (2017): Directs CARB Board to select specific communities for air quality improvements, with requirement for ongoing measurement of progress
  - In this project, vehicles registered in AB617 communities are analyzed as a separate group (data quantity permitting)

CalEnviroScreen

- The source of CES Scores indicating percentile of pollutant exposure/other health or economic vulnerability
  - ERG assigned top 25th CES percentiles as DAC based on data provided by CARB



RSD Subcontractors

DU has been conducting RSD measurement programs since the early ’90s using Fuel Efficiency Automobile Test (FEAT), developed and patented by Dr. Stedman and Dr. Bishop

Acquired the Envirotest team with decades of experience in RSD measurement, which uses a similar principle of operation to FEAT

RSD Measurement

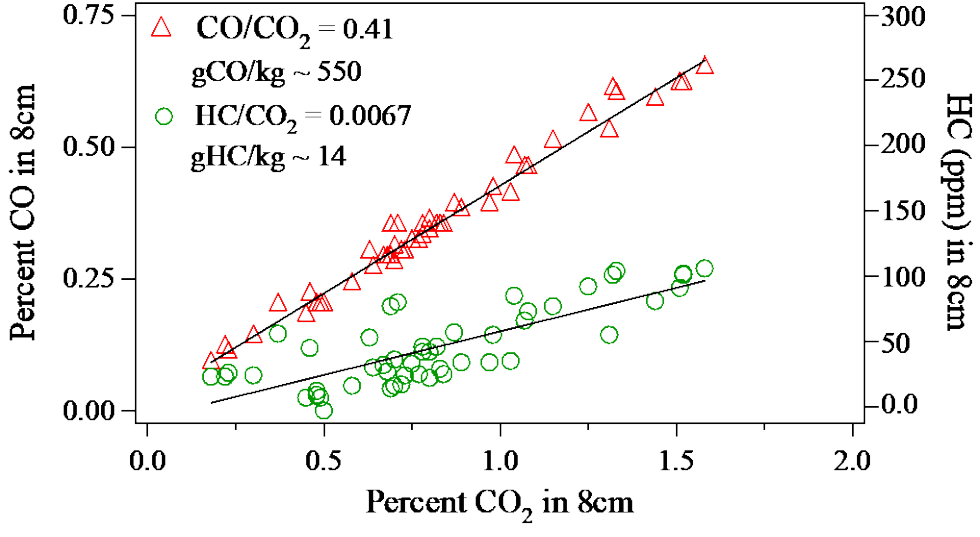
- Set up to optically measure across a single-lane of traffic
- Camera records license plate of each vehicle, laser records speed & acceleration

RSD Measurement (1/3)

- Operates by measuring light beam attenuation at different wavelengths corresponding to each pollutant
- Non-dispersive infrared (NDIR) – CO_2, CO, HC
  - HC measurements multiplied by 2 to account for long-documented "unseen" hydrocarbons as compared to flame ionization detector (FID) measurement)
- Ultraviolet (UV) Spectrometers – NO, NO_2, NH_3

RSD Measurement (2/3)

- Measurement is made over ½ second at 100 Hz (i.e. 50 points)
- Concentration results analyzed based on ratio to CO_2
  - Perform linear fit of each pollutant to CO_2 over the ½ second
  - Pollutant emission rates presented on basis of g/kg_{fuel}



Source: *Measuring Emissions from the On-Road Vehicle Fleet in West Los Angeles*. CARB Project 17RD015 Seminar, Denver University, February 13, 2020

RSD Measurement (3/3)

- Quality Assurance Process
  - Automated/Instantaneous validation of readings for the RSD (linearity, signal strength) and the vehicle speed/acceleration
  - RSD Contractor Tag-Edit (i.e. check license plate transcription) based on vehicle pictures
  - ERG manually reviewed data ranges for outliers and trends
- Analysis Process
  - Vehicles with invalid measurements were removed from emissions analysis but otherwise included for vehicle counts/numbered distributions (unless registered as EVs)
  - Emissions calculated relative to CO_2, presented on the basis of g/kgfuel
  - Matched license plates with CA registration for vehicle/community info

HDV Measurement

- Measurement setups were for downdraft exhaust only
- Front and rear license plate pictures to allow truck identification if towing a trailer
  - For DU, a 2nd camera was added to the existing RSD system
  - For Opus, a complete second RSD system was used in parallel
    - Triggered on CO2 instead of light beam block
    - ERG developed software code to isolate only one of each vehicle-pass' measurements for analysis

RSD Campaigns

- Each campaign approximately 1 week in duration
  - Daylight/business hours only (setup taken down each night)
  - Weekends and weekdays
- Goal of approximately 25,000 measurements per campaign
- Conducted on highway onramps or highway interchanges
- Most campaigns involved a single site, some campaigns split time at 2 different sites to maximize traffic counts
- 9 total campaigns analyzed in this work
  - 8 campaigns conducted in this work
  - Coordinating Research Council (CRC) cooperatively shared the Fresno campaign data from RW-117

Other Supporting Datasets

- CA Registration Extract
  - Vehicle information (make, model, MY, GVW class, etc)
  - Current registration currency and current expiration date
  - Smog check program area and next test due date
  - Registered geographic information (Census tract and lat/long of centroid)
  - CES score and percentile and whether registered in an AB 617 area
- Smog Check Data
  - By-inspection data such as date, vehicle information, test type and reason
  - Emissions test result values or OBD codes present
  - Specific and overall test results
- Mexican state/locality vehicle registration information
  - Limited vehicle information (vehicle type, model year, fuel type)

AB 617 Communities and RSD Campaign Locations

RSD Campaign Locations:

- Oakland
- Stockton
- Fresno (CRC RW-117)
- Bakersfield
- West Los Angeles
- City of Industry
- Riverside
- San Ysidro
- El Centro

RSD Campaign Measurements

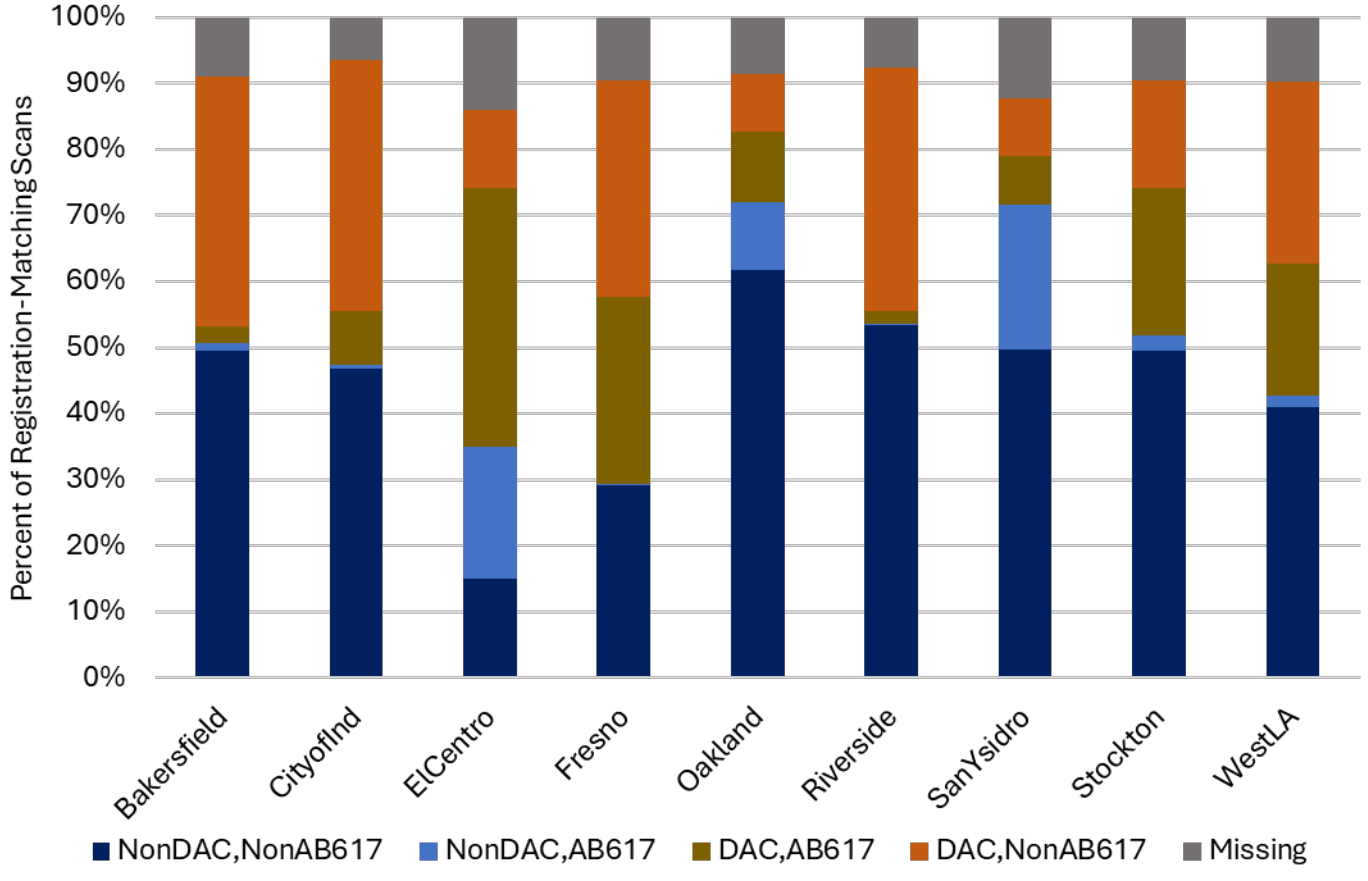
Campaign	Subcontractor	Date Range	# Test Days	# Readable Passes
Bakersfield	Opus	10/18/21 - 10/29/21	10	35,509
City of Industry	Opus	2/19/23 – 3/4/23	7	56,166
El Centro	Opus	10/7/22 – 10/14/22	8	21,929
Fresno[a]	DU	6/7/21 - 6/12/21	6	8,763
Oakland	DU	3/31/22 - 4/6/22	7	27,616
Riverside	Opus	11/13/22 – 11/19/22	7	34,259
San Ysidro	Opus	4/2/23 – 4/8/23	7	33,358
Stockton	DU	6/13/21 - 6/19/21	7	30,055
West LA	DU	10/26/21 - 11/1/21	7	19,842

[a] – Testing funded by CRC Project RW-117, conducted by DU

RSD to Registration/CES Matching

Campaign	Scans with Read Plates	Registration Matched (% of read)	CES Score Match (% of read)
Bakersfield	35,509	31,866 (90%)	28,963 (82%)
City of Industry	56,166	49,234 (88%)	45,895 (82%)
El Centro	21,929	16,631 (76%)	14,283 (65%)
Fresno	8,763	8,558 (98%)	7,729 (88%)
Oakland	27,616	27,026 (98%)	24,668 (89%)
Riverside	34,259	30,487 (89%)	28,132 (82%)
San Ysidro	33,358	25,750 (77%)	22,573 (68%)
Stockton	30,055	29,271 (97%)	26,344 (88%)
West LA	19,842	19,309 (97%)	17,358 (87%)

DAC Status by Campaign

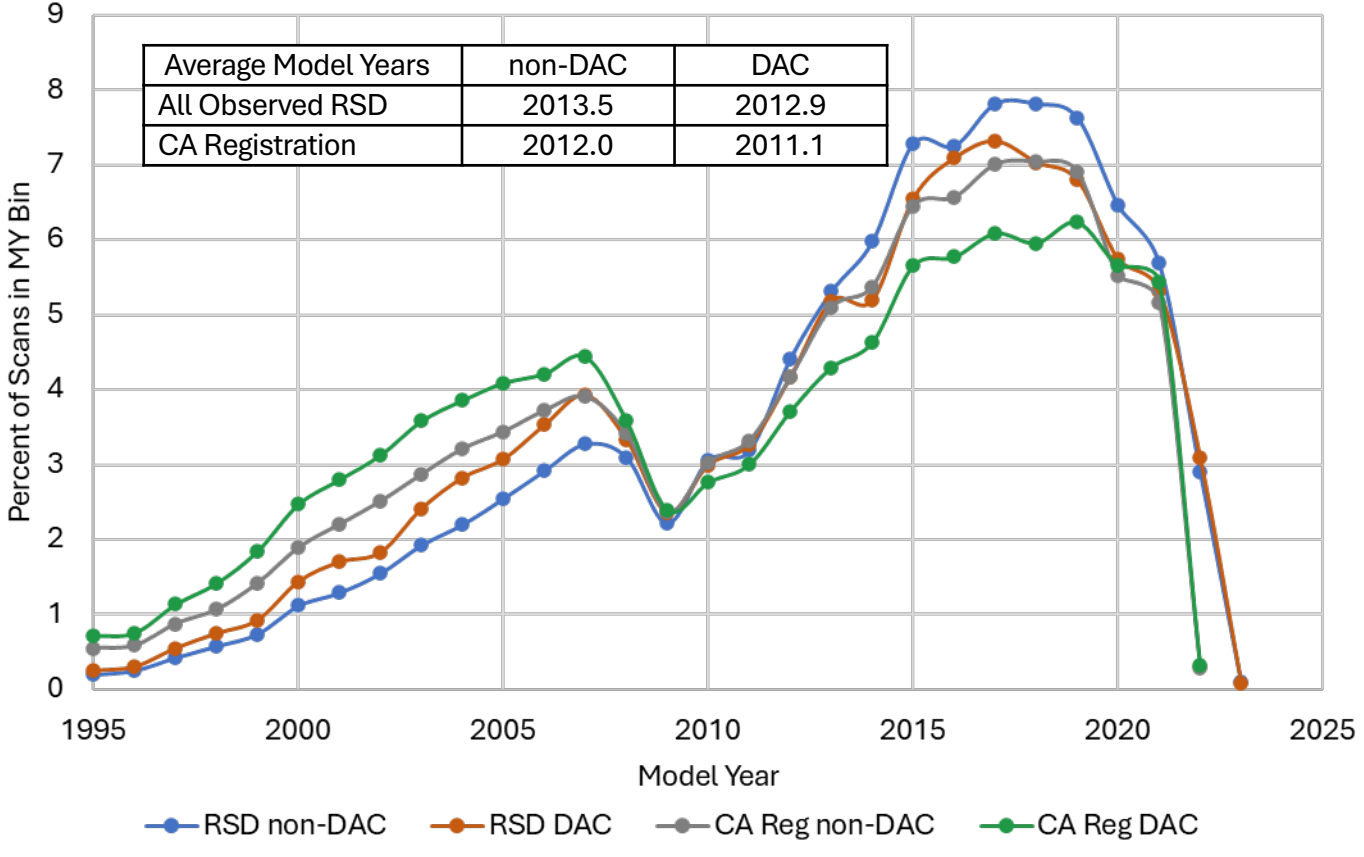


- Campaign locations resulted in good coverage of all combinations (note that NonDAC, AB617 is relatively rare)

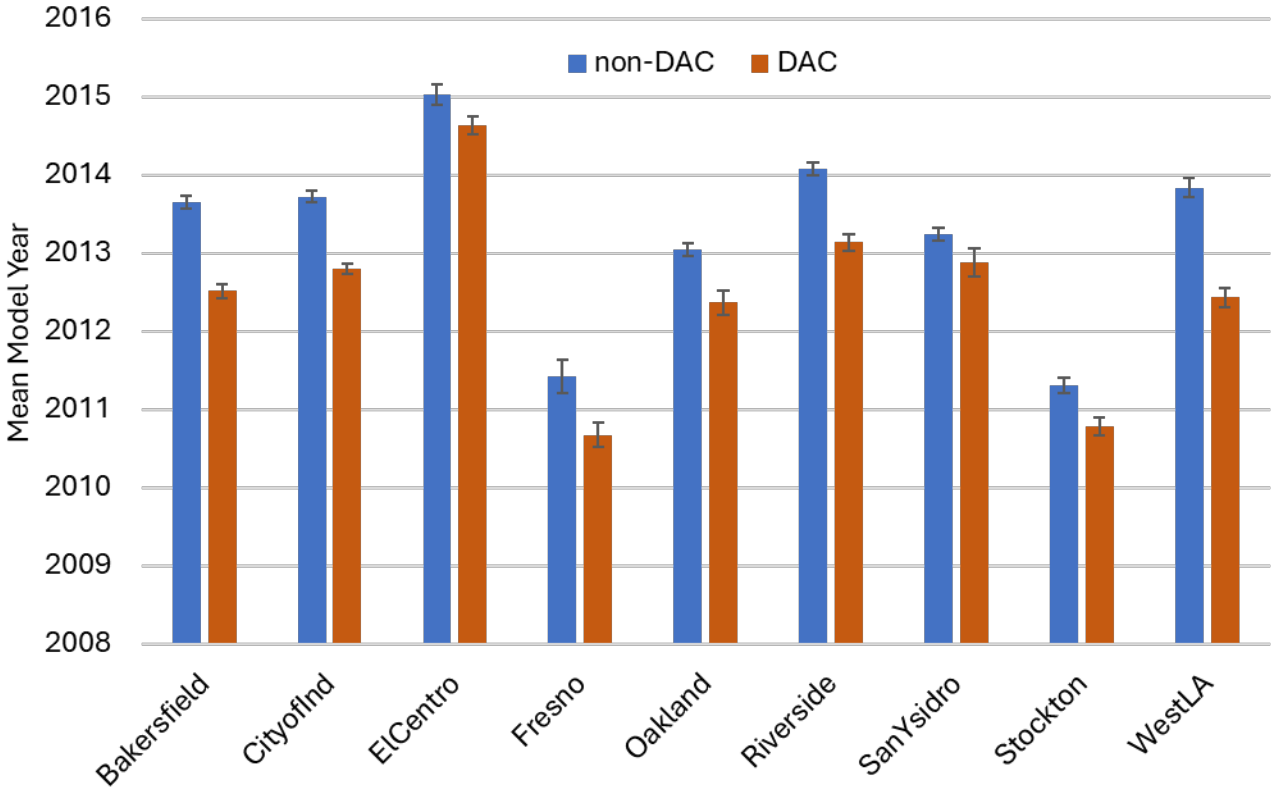
- All community assignments are based on the vehicle's registered address

Model Year Distributions

Average Model Years	non-DAC	DAC
All Observed RSD	2013.5	2012.9
CA Registration	2012.0	2011.1

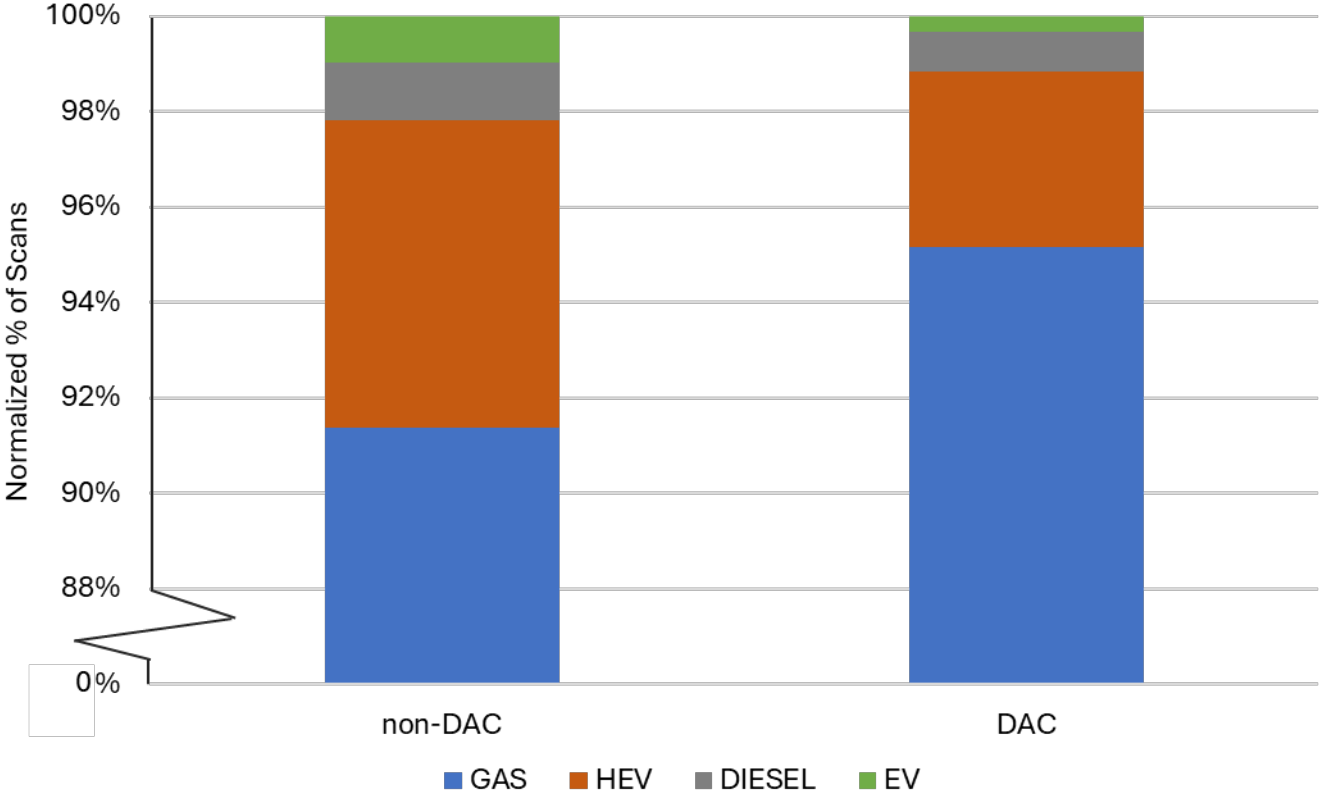


Average Model Years

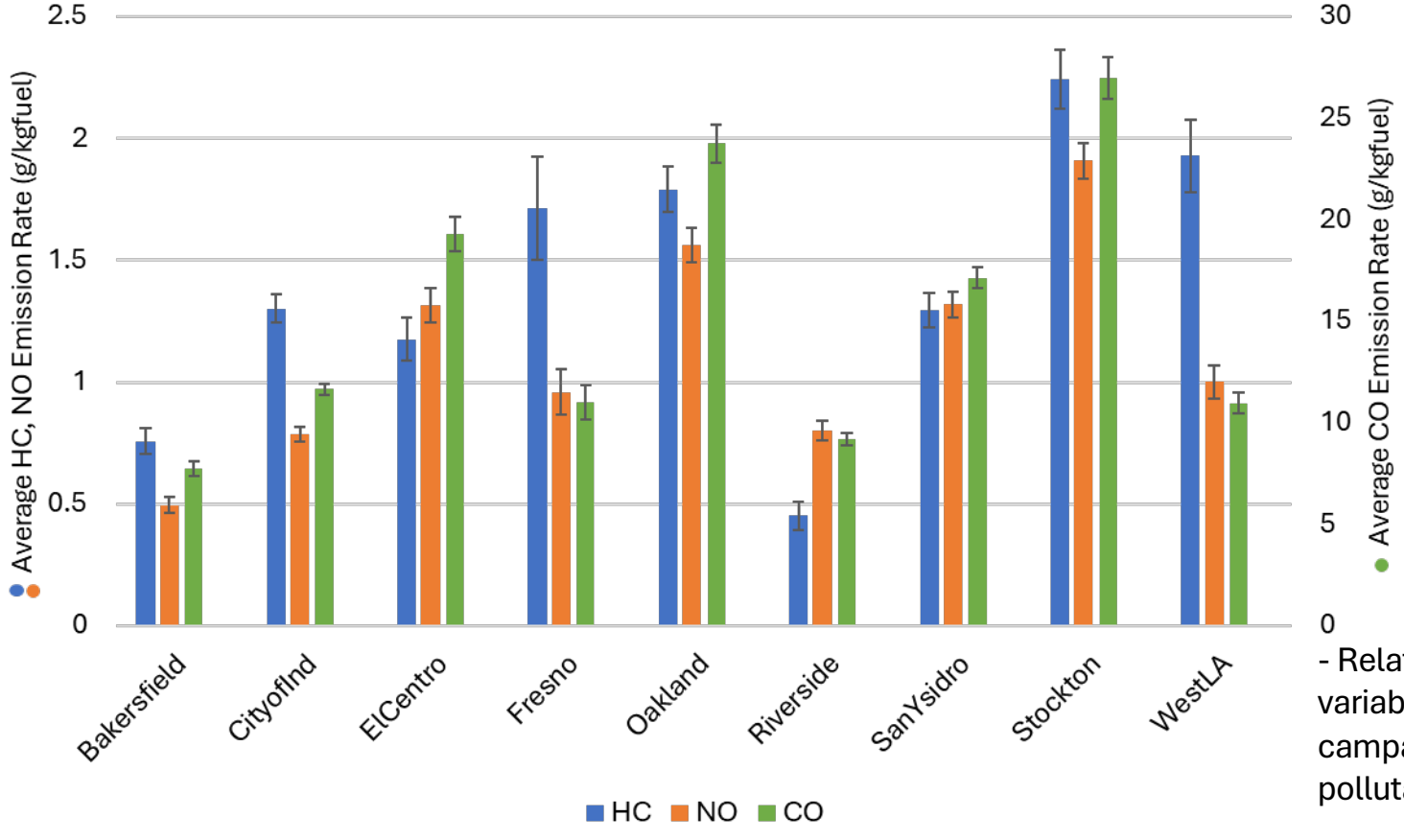


- DAC vehicles significantly older at all campaigns

LDV Fuel Types



Average Emission Rates

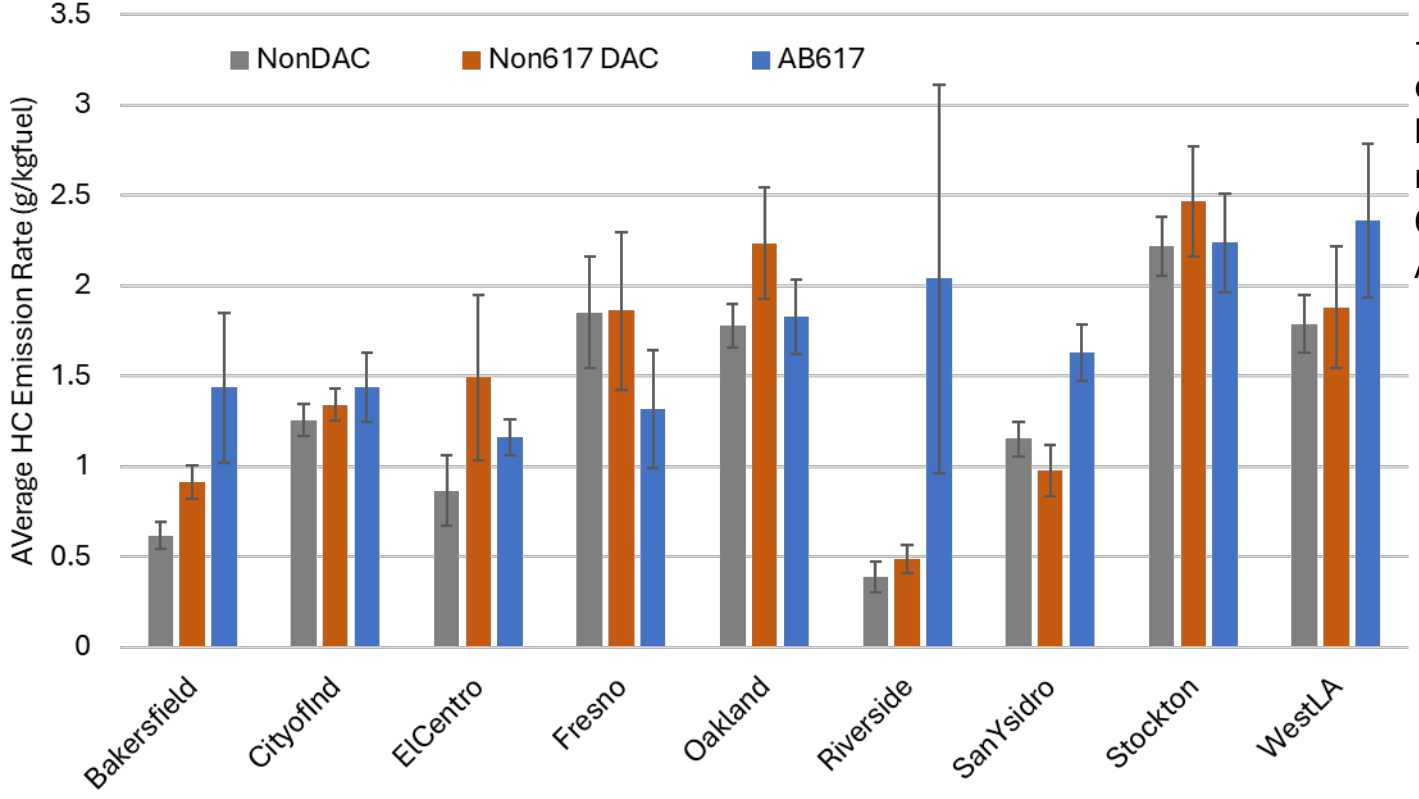


- Relatively high level of variability across campaigns for all 3 pollutants

Cross-Campaign Variability

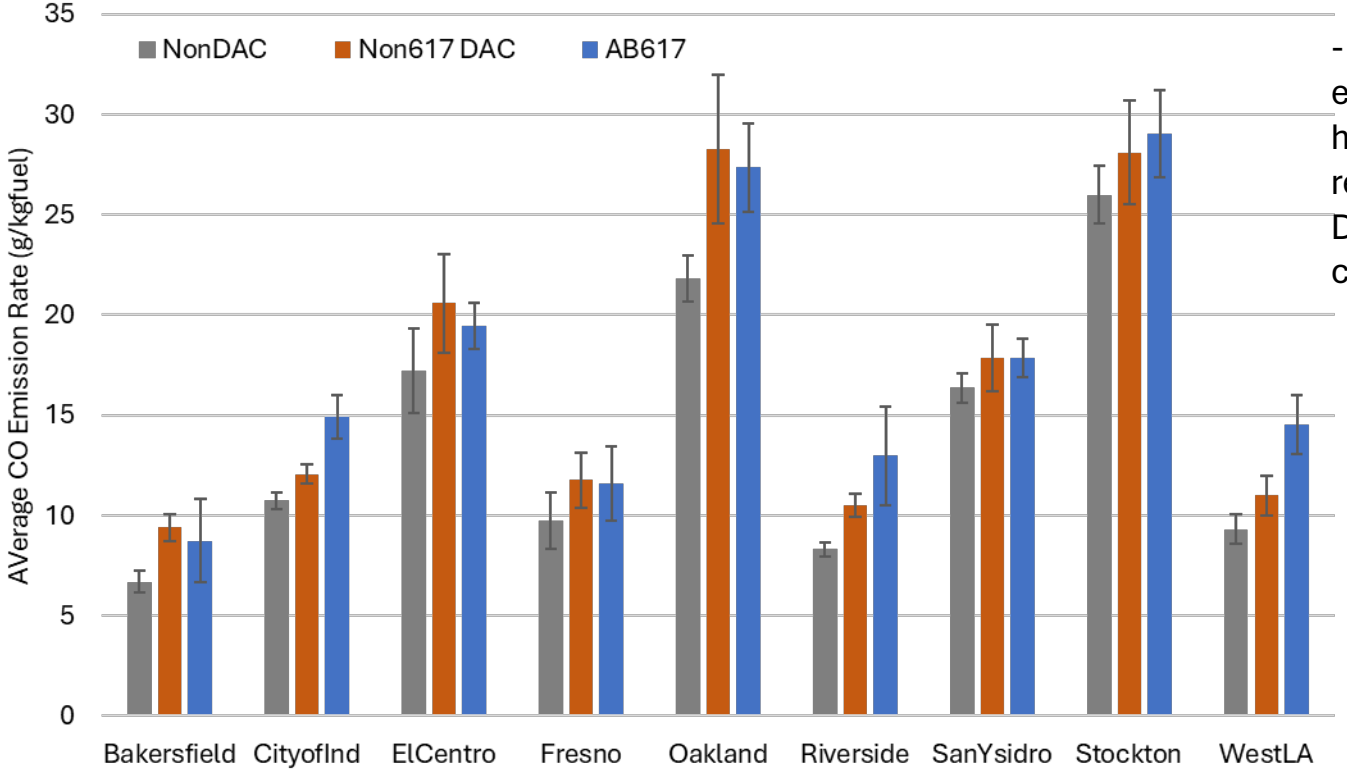
- Emission rates showed large variability across campaigns
- ERG conducted numerous analyses to understand the variability in emission rates across campaigns
  - Day to day variability at a site was much lower than cross-campaign
  - Different avg VSP levels at each site have a minor but measurable effect
  - Weather did not appear to affect measured emission rates
  - "Narrow Spectrum Analysis": Isolating to narrow groups of all available data indicated that it is likely that the main causes of differences are not explainable within the data available from RSD measurement
  - Site-to-site variation was consistent with other multi-site RSD projects

DAC vs. Non-DAC Emissions: HC



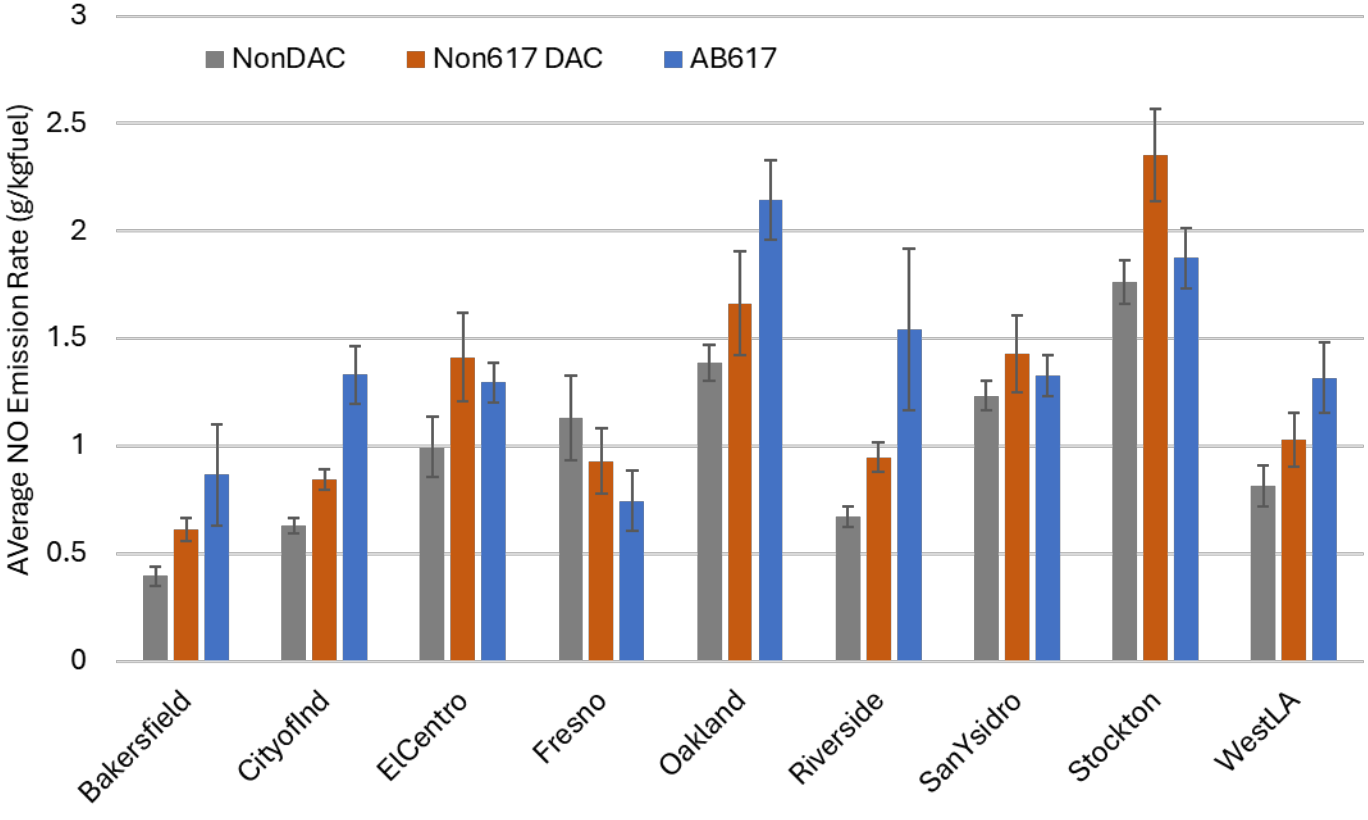
- In most cases, emission rates are higher for vehicles registered in Non-617 DAC and/or AB617 communities

DAC vs. Non-DAC Emissions: CO



- In most cases, emission rates are higher for vehicles registered in Non-617 DAC and/or AB617 communities

DAC vs. Non-DAC Emissions: NO



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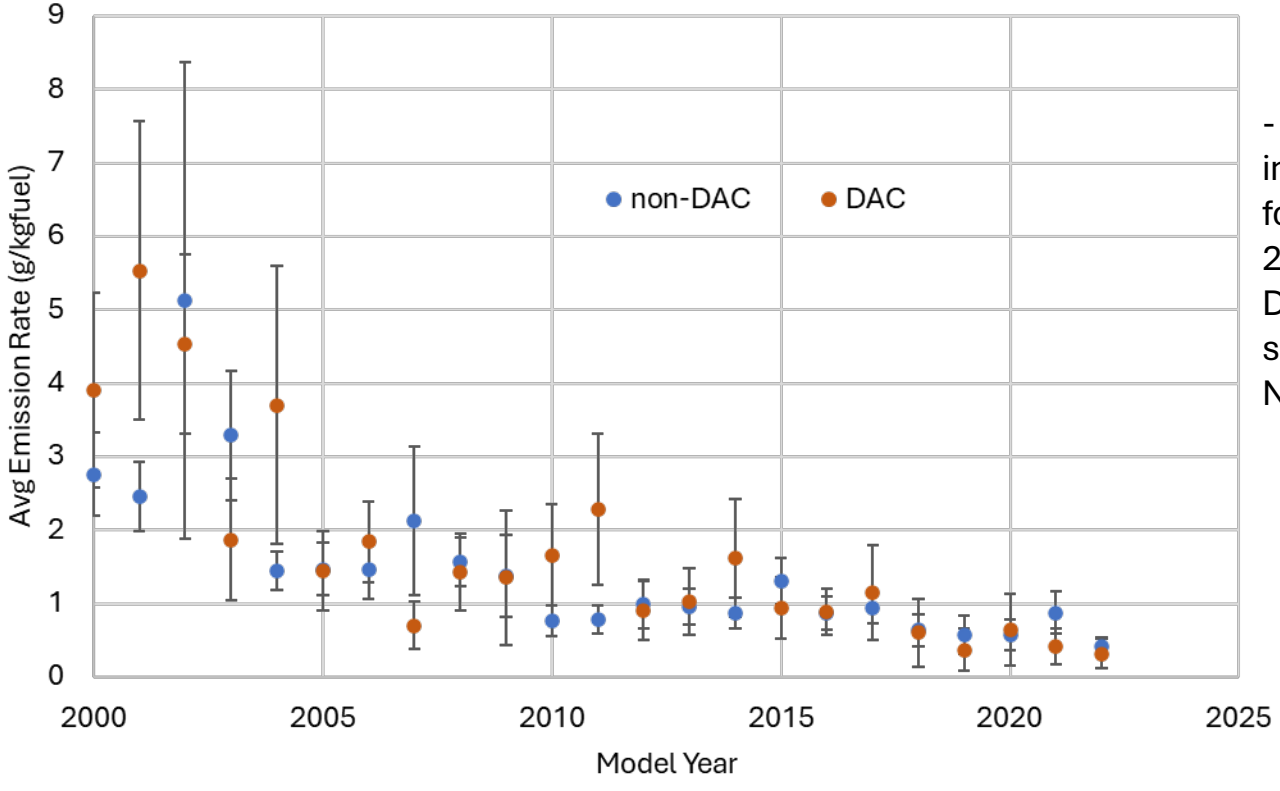
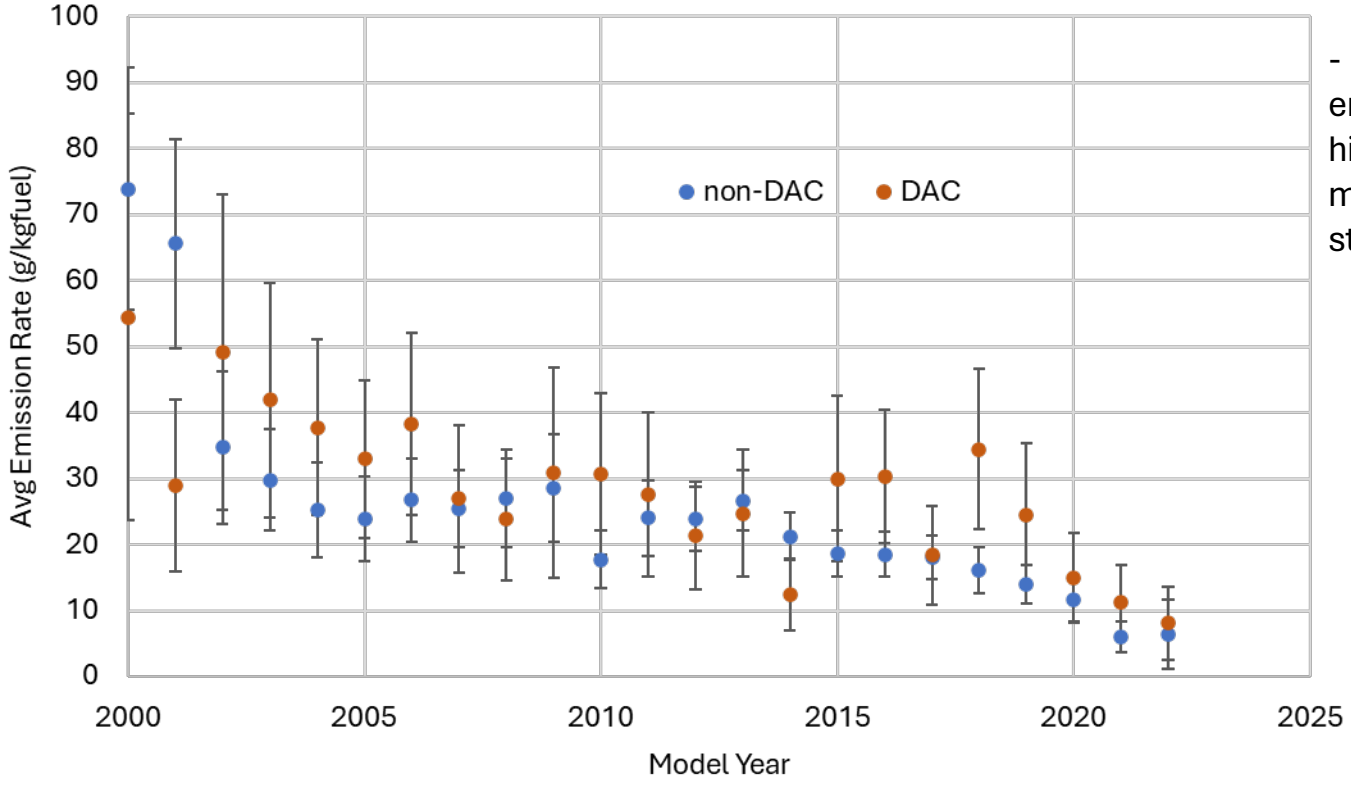
Emissions by Model Year: HC



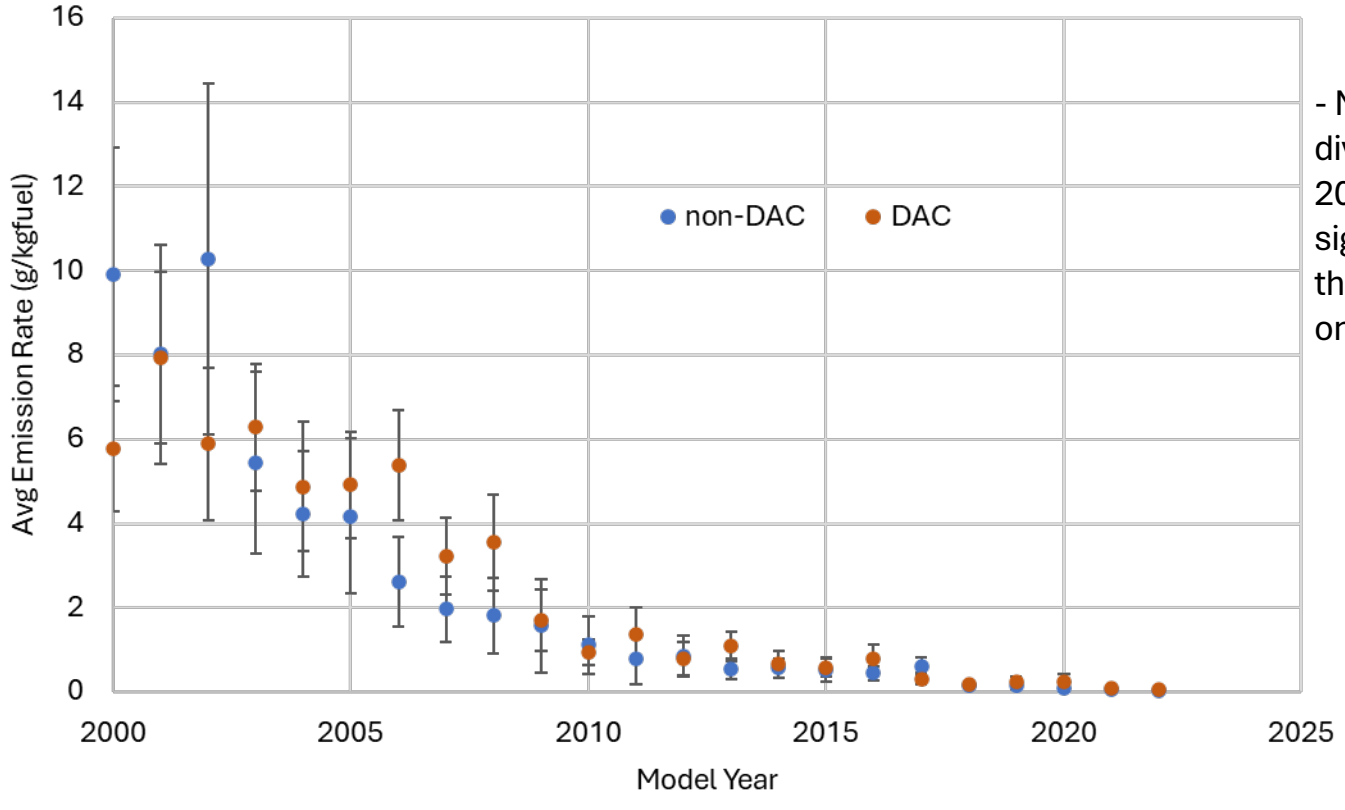
- Emission rates diverge in the older model years; for some MYs older than 2012, emission rates of DAC vehicles are significantly higher than Non-DAC

Emissions by Model Year: CO



- For most MYs, emission rates are higher for DAC, but most are not statistically significant

Emissions by Model Year: NO



- Mean emission rates diverge around MY 2008; DAC vehicles significantly higher than Non-DAC in only one MY, however

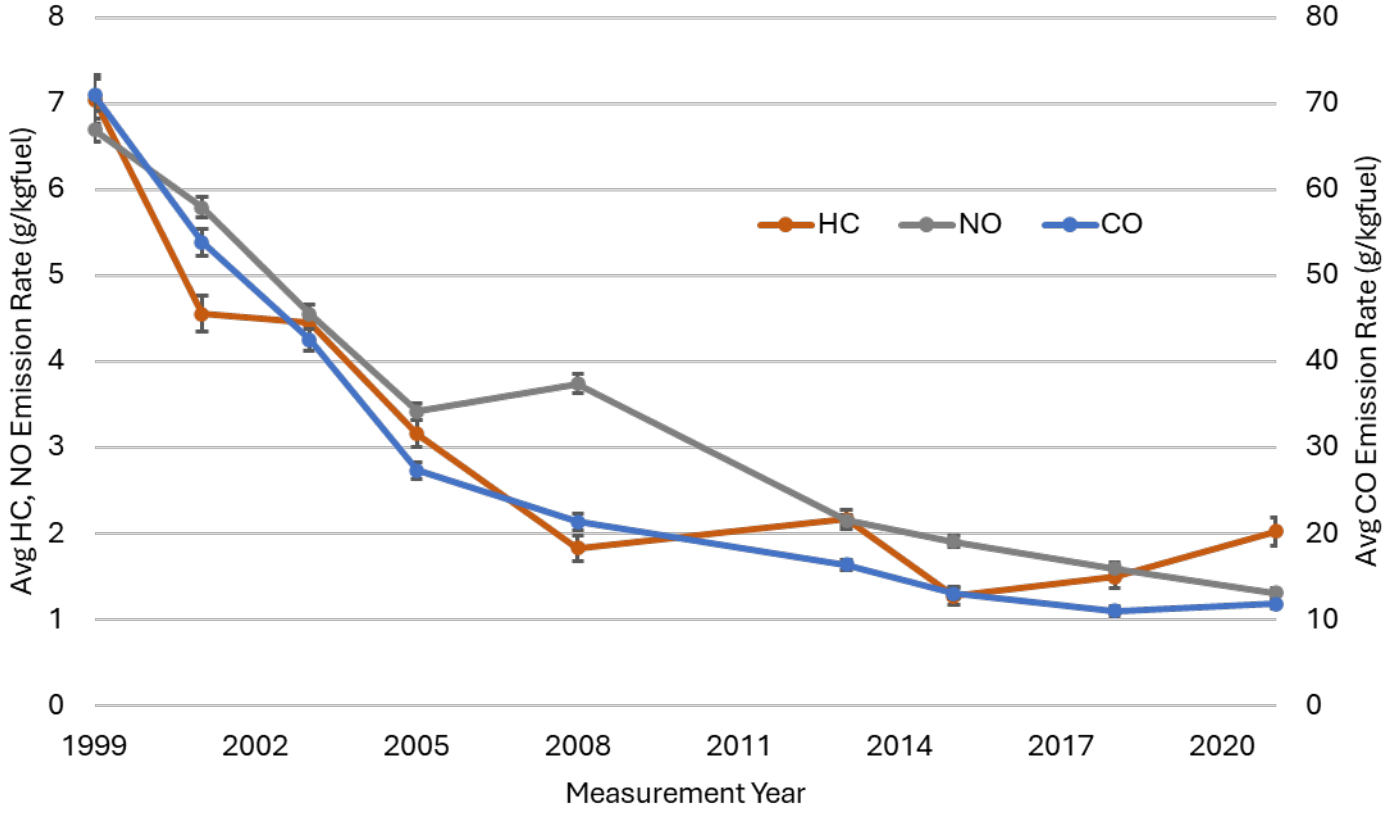
Model Year & Emissions Differences

- DAC vehicles tend to be older
  - This partly explains the exhaust emission rate differences
  - Differences persist even within model years
- We can estimate the fraction of the elevated emissions that are ***not*** caused by the model year difference
  - Calculate the overall average emissions if the non-DAC emission rates were re-weighted to the DAC model year distribution
  - **How much higher are the DAC emission rates than the model-year re-weighted non-DAC emissions:**

HC	CO	NO
48%	30%	45%

Historical West LA Data

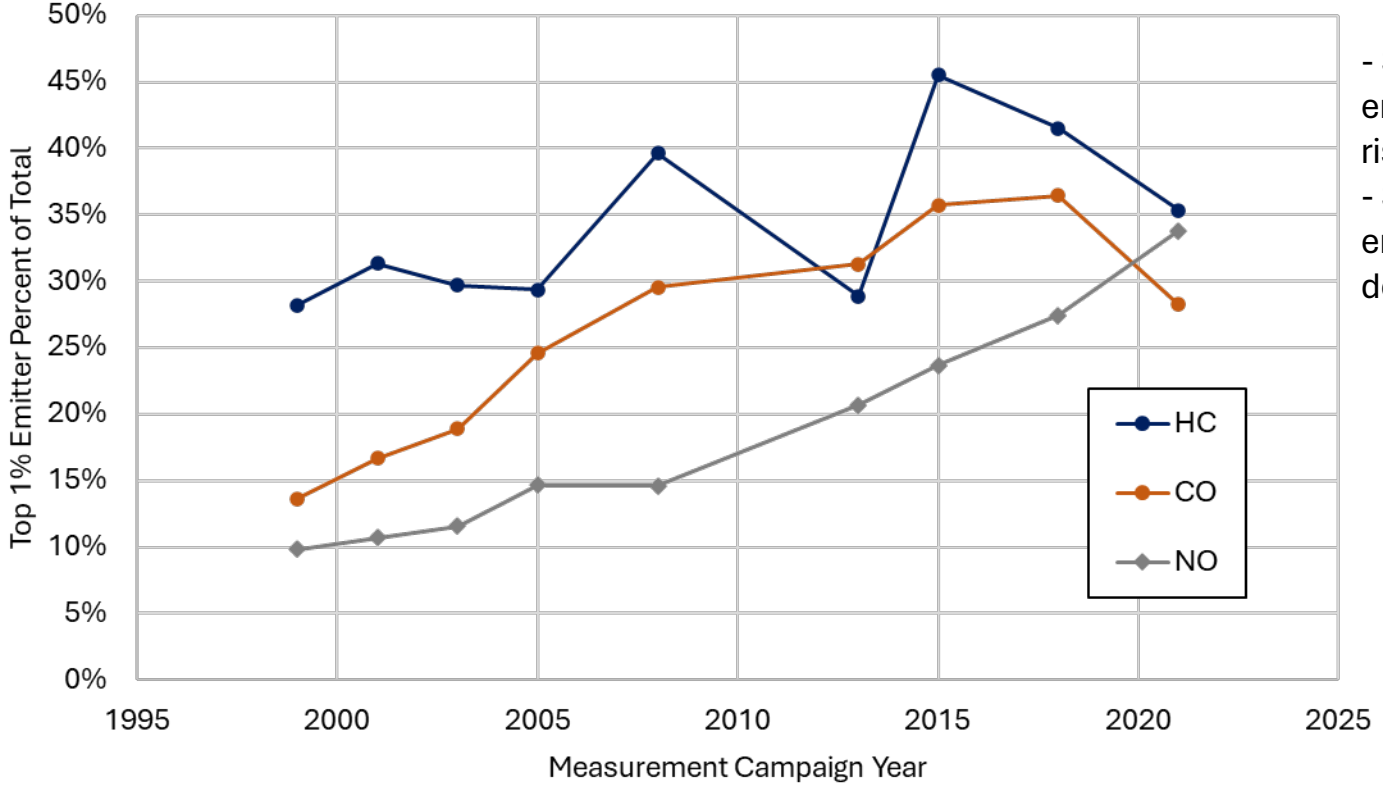
La Brea Ave Site: Avg Emissions by Campaign Year



- Emission rates have been declining over time, but have leveled off for CO and slightly increased for HC

Emissions from Top 1% of Emitters

by Measurement Year: West LA - La Brea Ave Site



- Share of high-emitter emissions continues rising for NO.
- Share of high-emitter emissions has been declining for HC, CO.

Cross-Border Campaigns:

El Centro & San Ysidro

- El Centro
  - Both sites approximately ~8 miles from border
  - Approximately 6% of readable plates were ID'd as from Mexico
- San Ysidro
  - Sites were approximately 1 and 3 miles from border
  - Approximately 9% of readable plates were from Mexico

- Approximately 77% of readable Mexican plates matched with the available registration data: all LD

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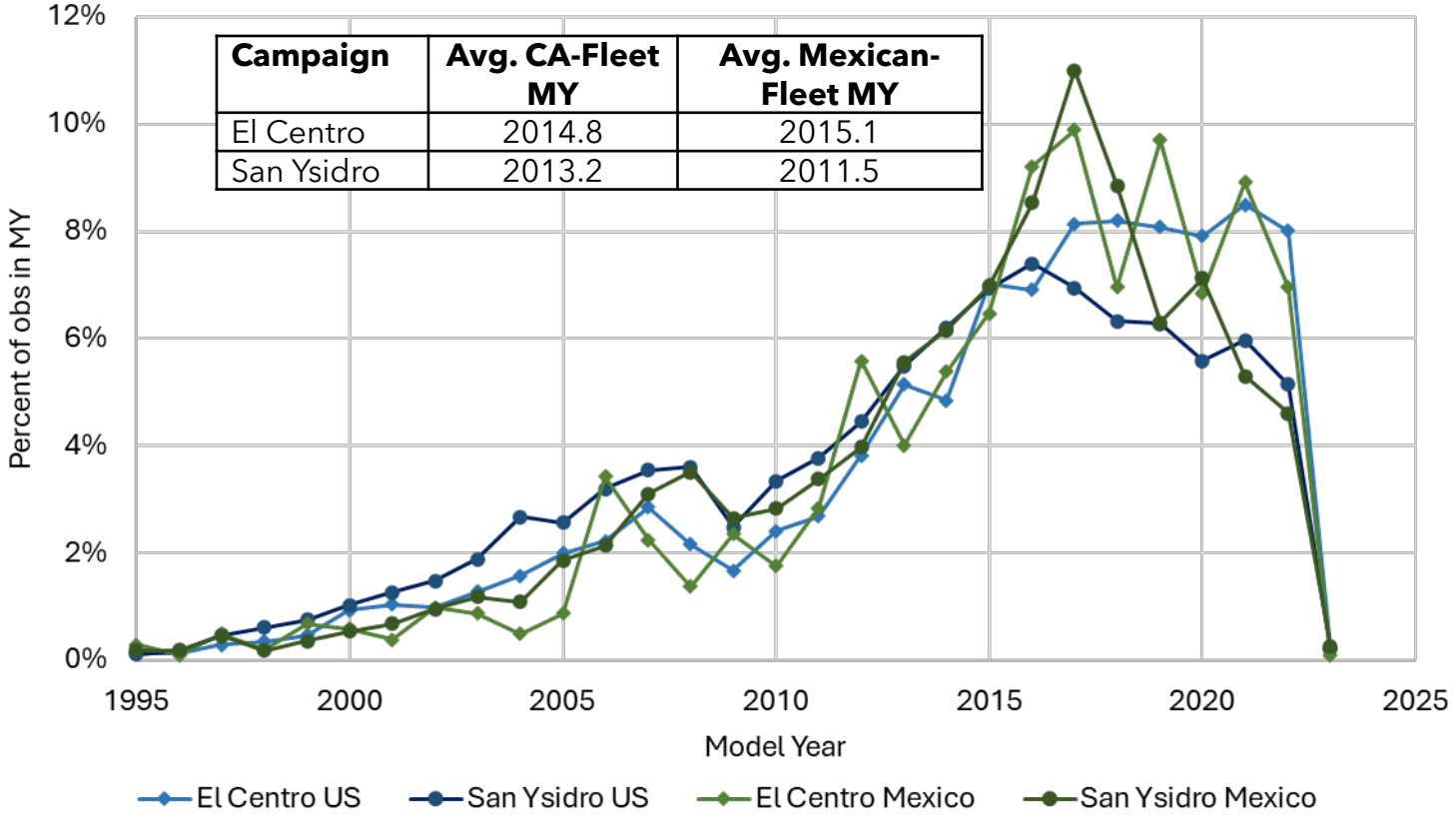
Cross-Border Campaigns:

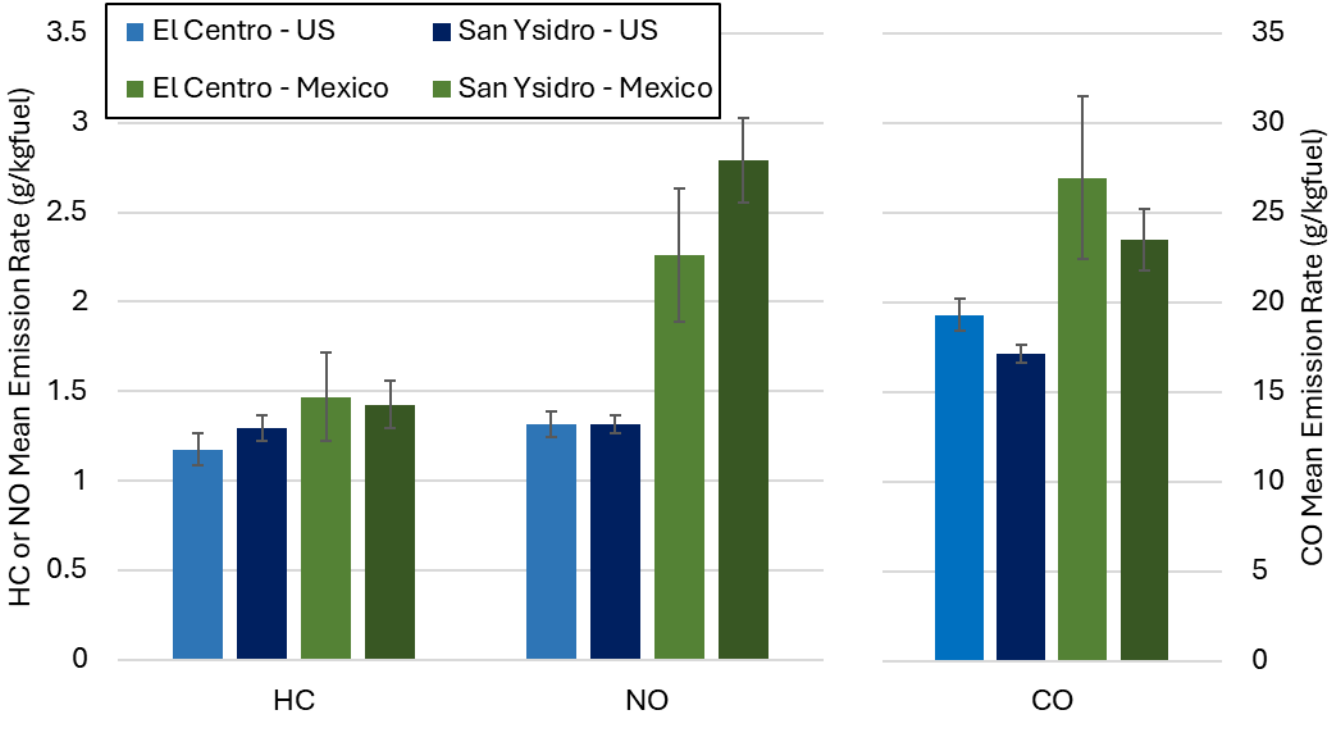
Model Years

Campaign	Avg. CA-Fleet MY	Avg. Mexican-Fleet MY
El Centro	2014.8	2015.1
San Ysidro	2013.2	2011.5



Cross-Border Campaigns:

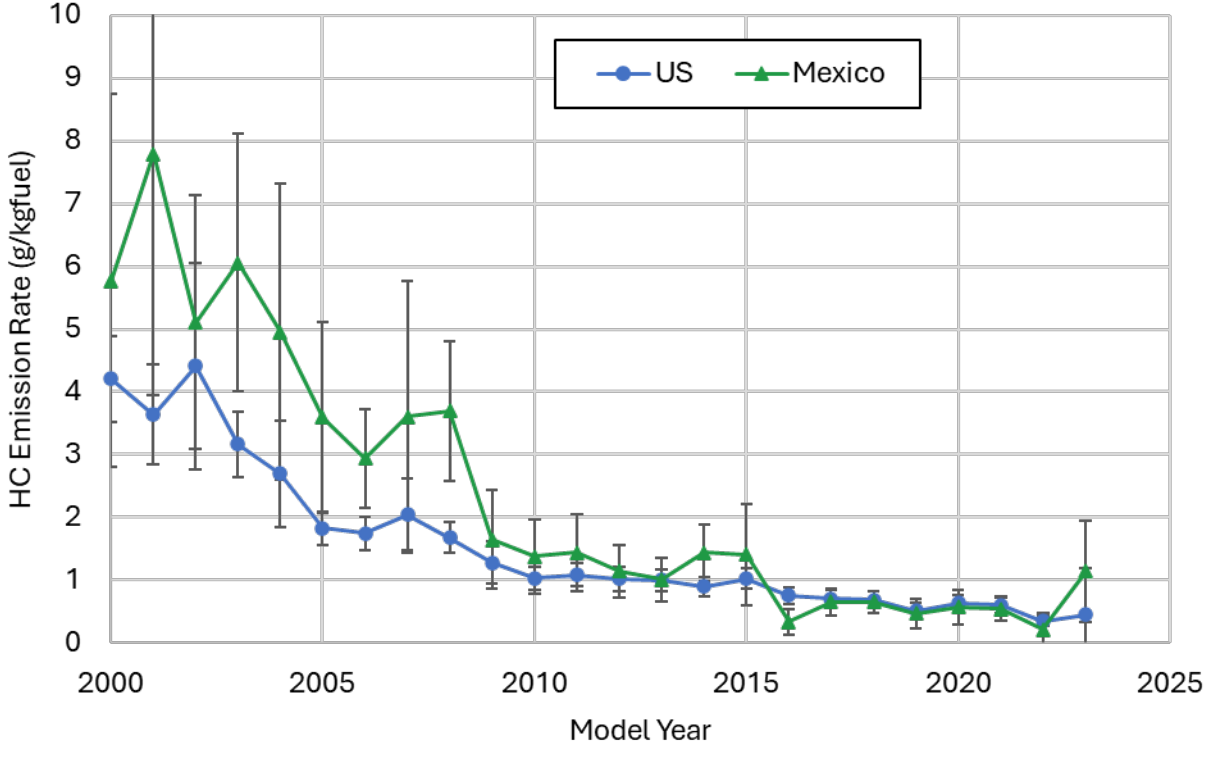
Average Emission Rates



- Emissions of vehicles from Mexico significantly higher in NO, CO despite similar model years

Cross-Border Campaigns:

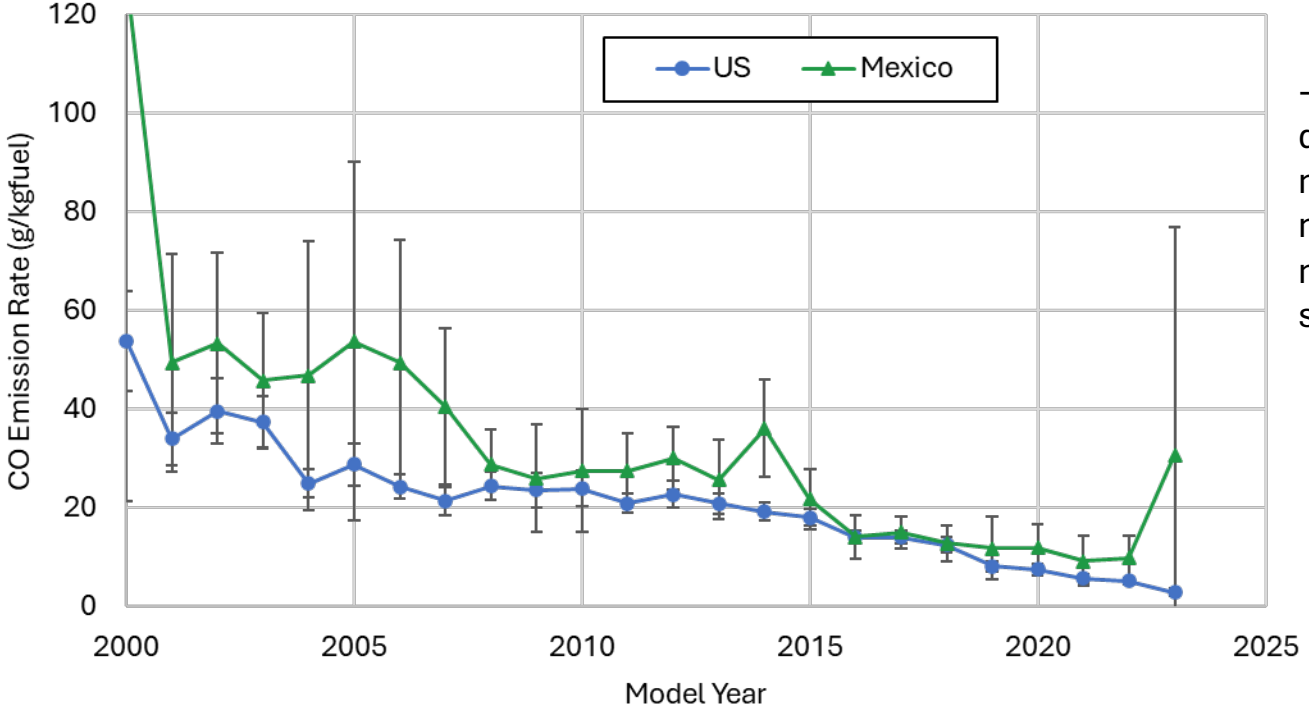
Emission Rates by Model Year - HC



- Emission rates diverge especially for older model years, in which many differences are statistically significant

Cross-Border Campaigns:

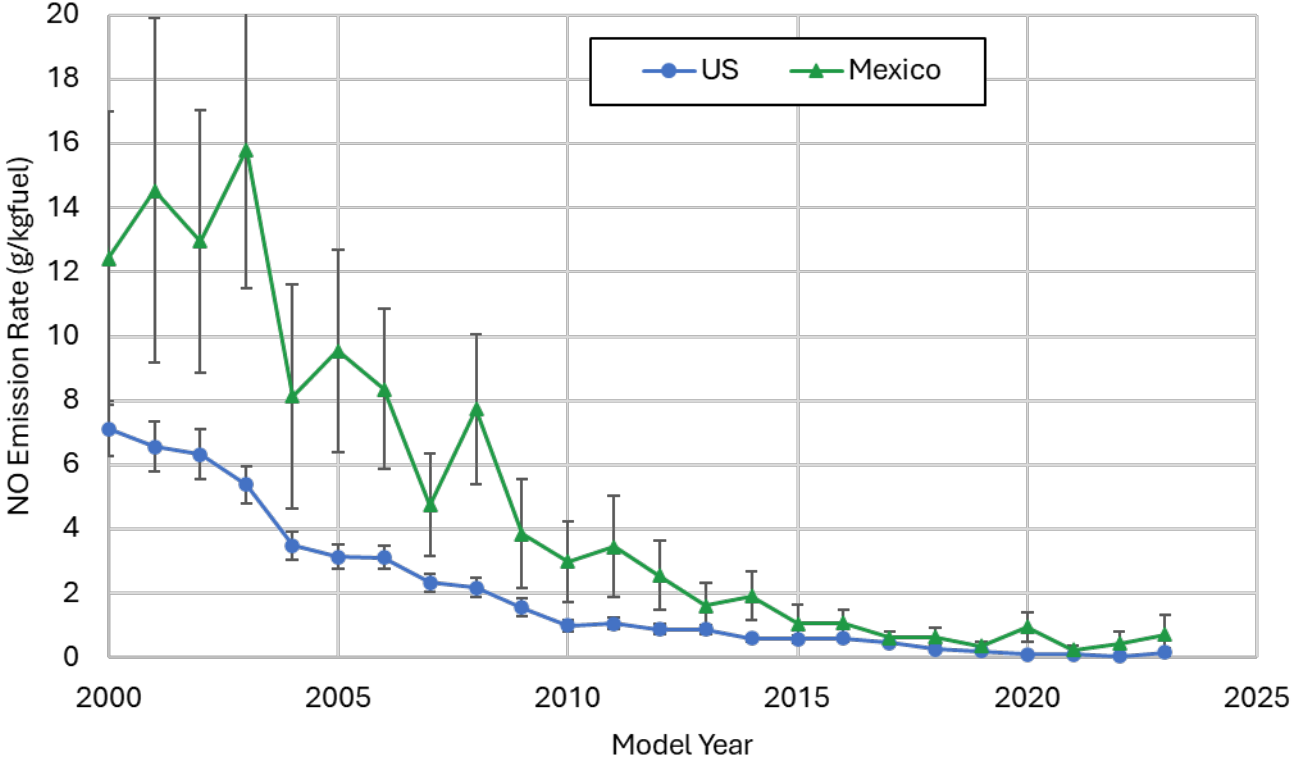
Emission Rates by Model Year - CO



- Emission rates diverge in older model years, but most differences are not statistically significant

Cross-Border Campaigns:

Emission Rates by Model Year - NO



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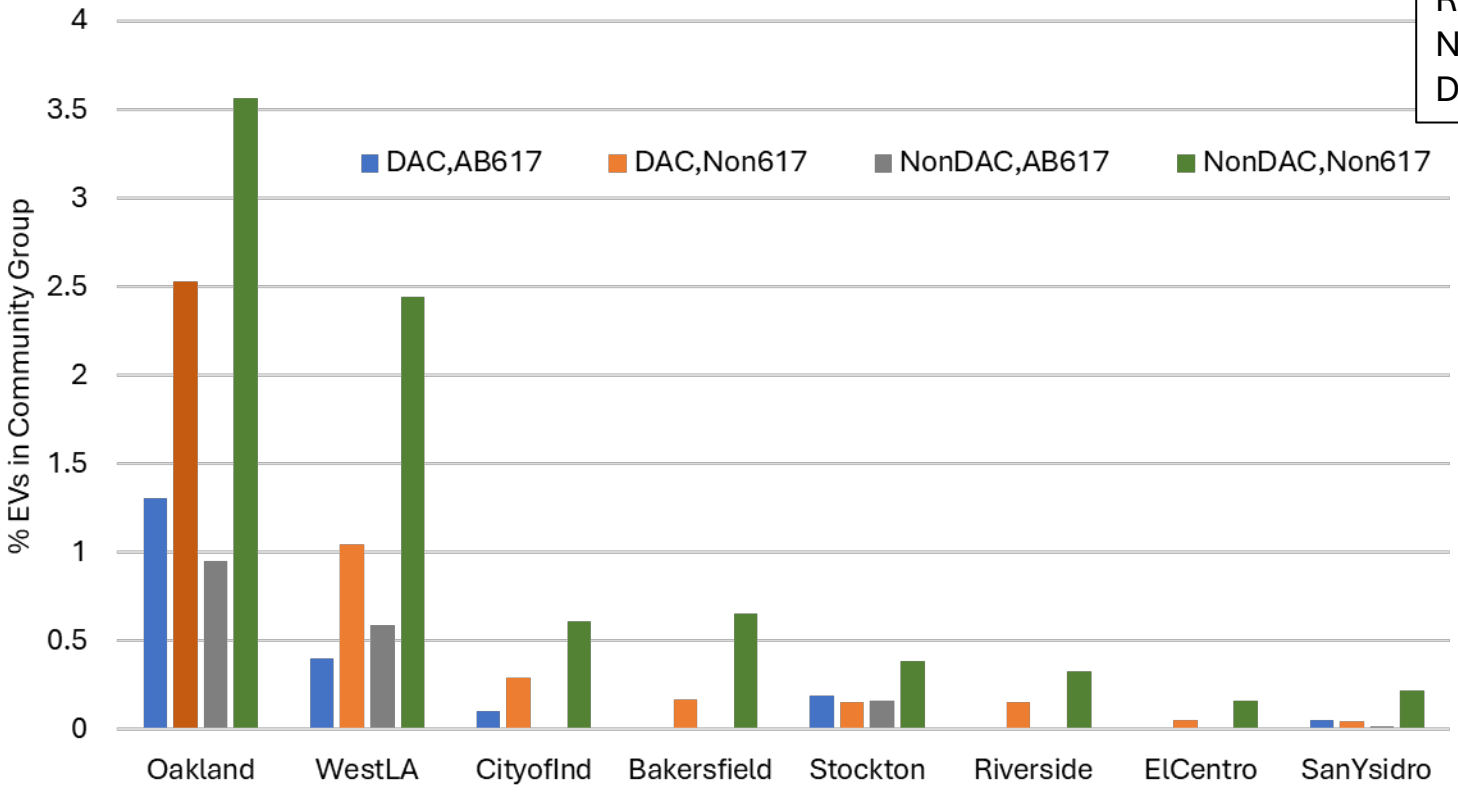
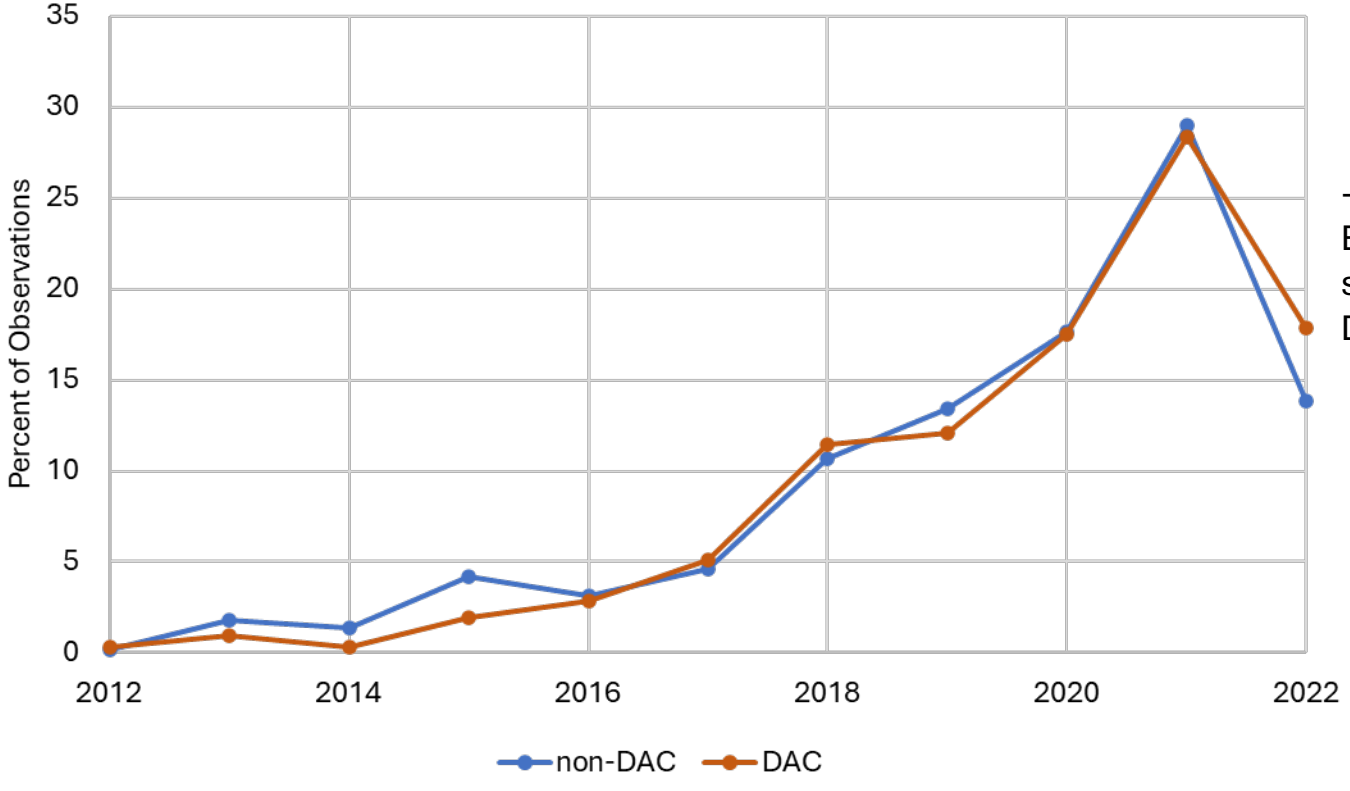
Electric Vehicle Fraction



Recall Slide 19:
Non-DAC Fleet: 1% EV
DAC Fleet: 0.3% EV

- EV prevalence varies widely by geographic area and community type

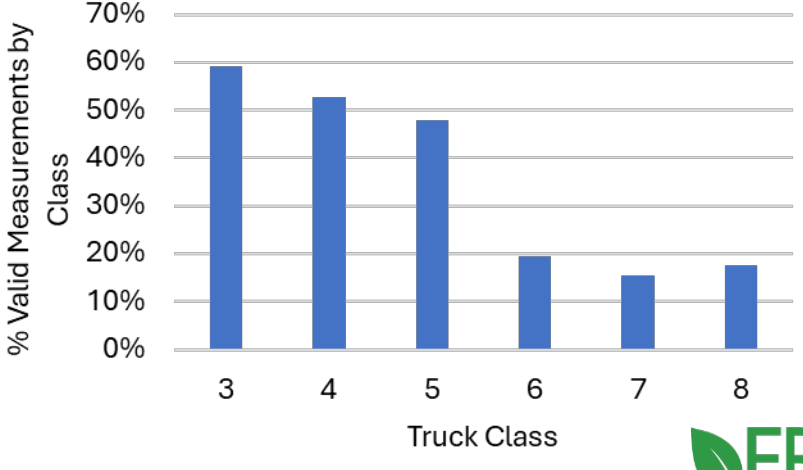
EV Model Year Distributions



- Model years of EVs are very similar across DAC/NonDAC

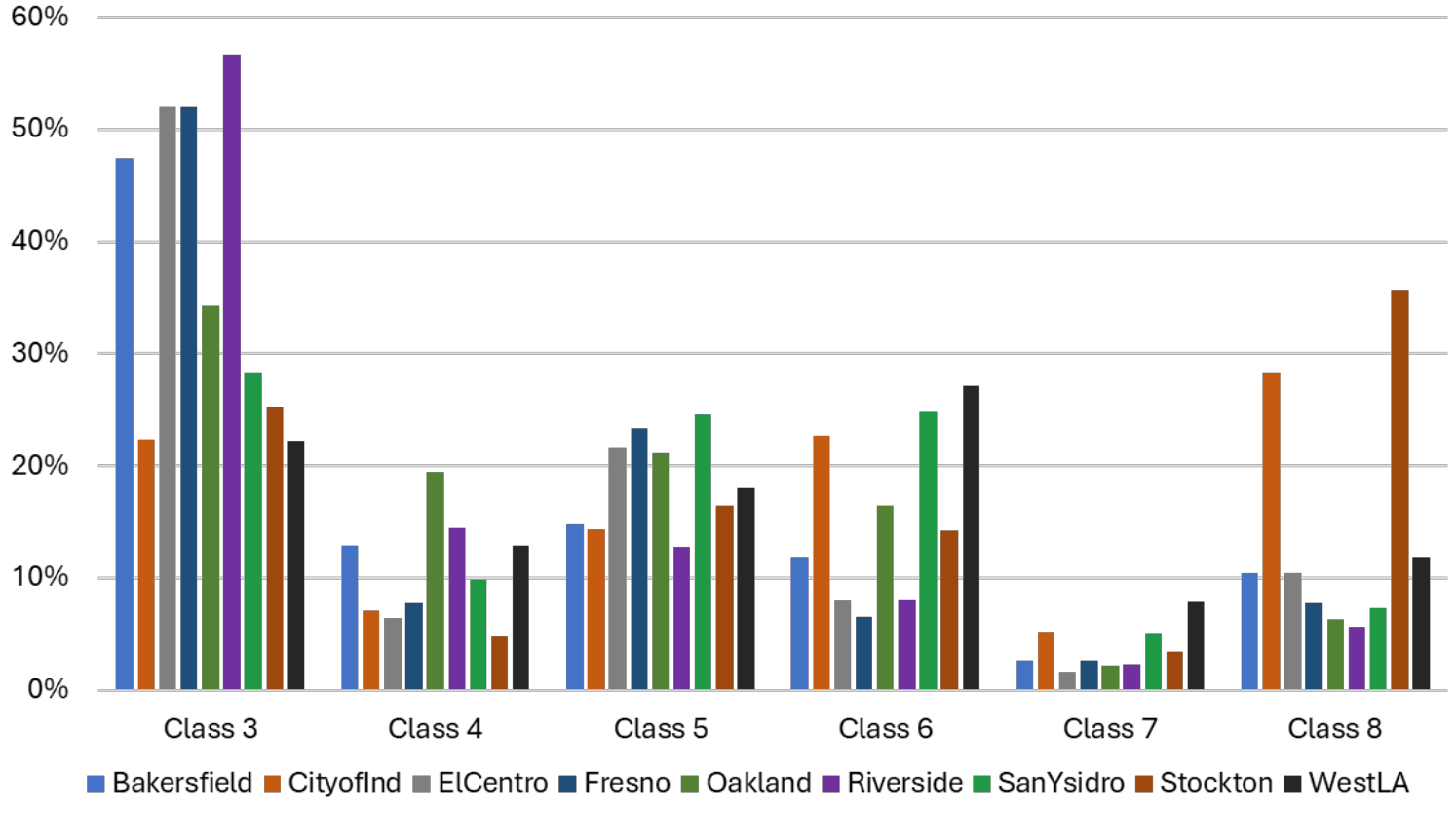
HDV Measurement & Analysis

- HDV measurement by RSD is more challenging with fewer valid measurements
  - Measurement setup could detect downdraft exhaust only
  - Presence of trailers, chains, mudflaps, vocational equipment, etc. interrupts light beam and reduces likelihood of successful measurement
  - Valid measurement % by class:
    - Avg's up to 30% pts less than LDVs



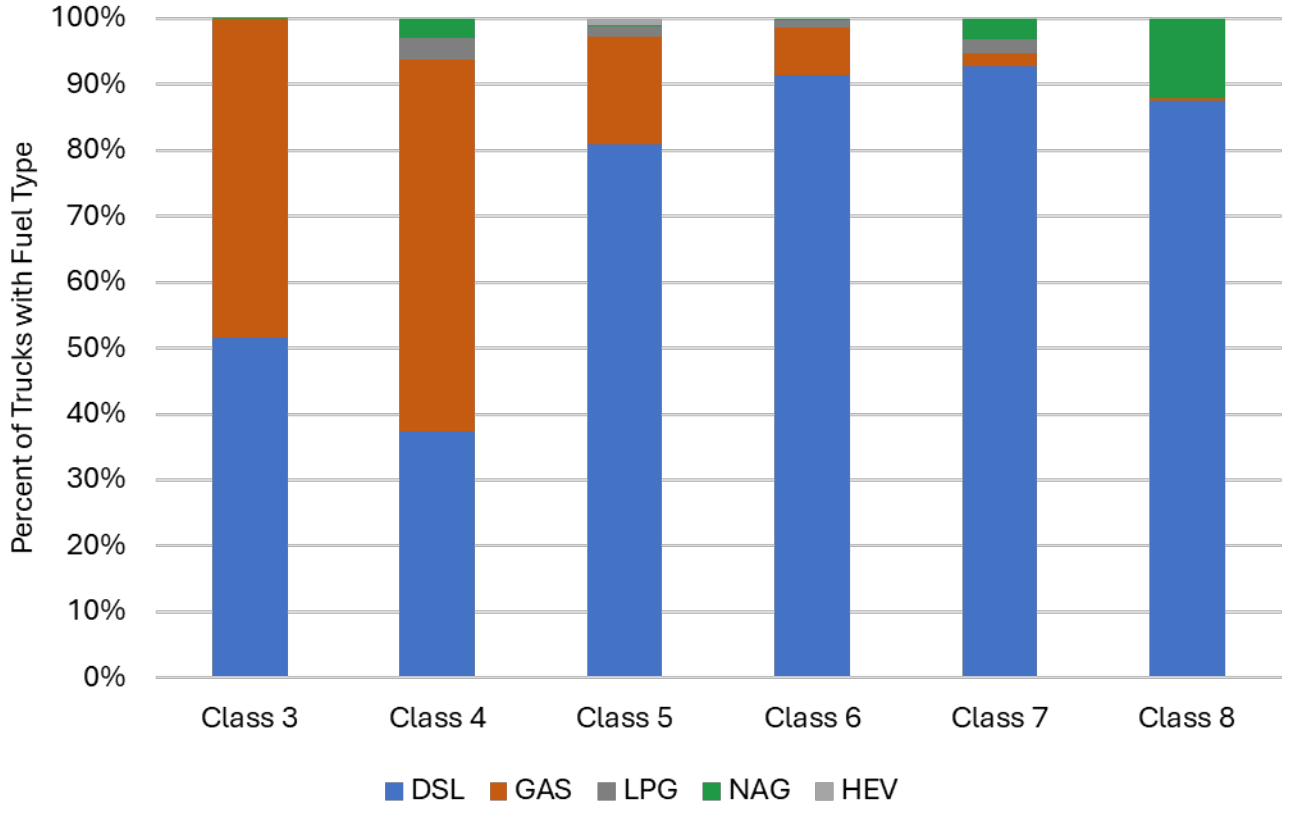
HDV Measurement & Analysis

Percentage of Observed HDVs in Each Class



HDV Measurement & Analysis

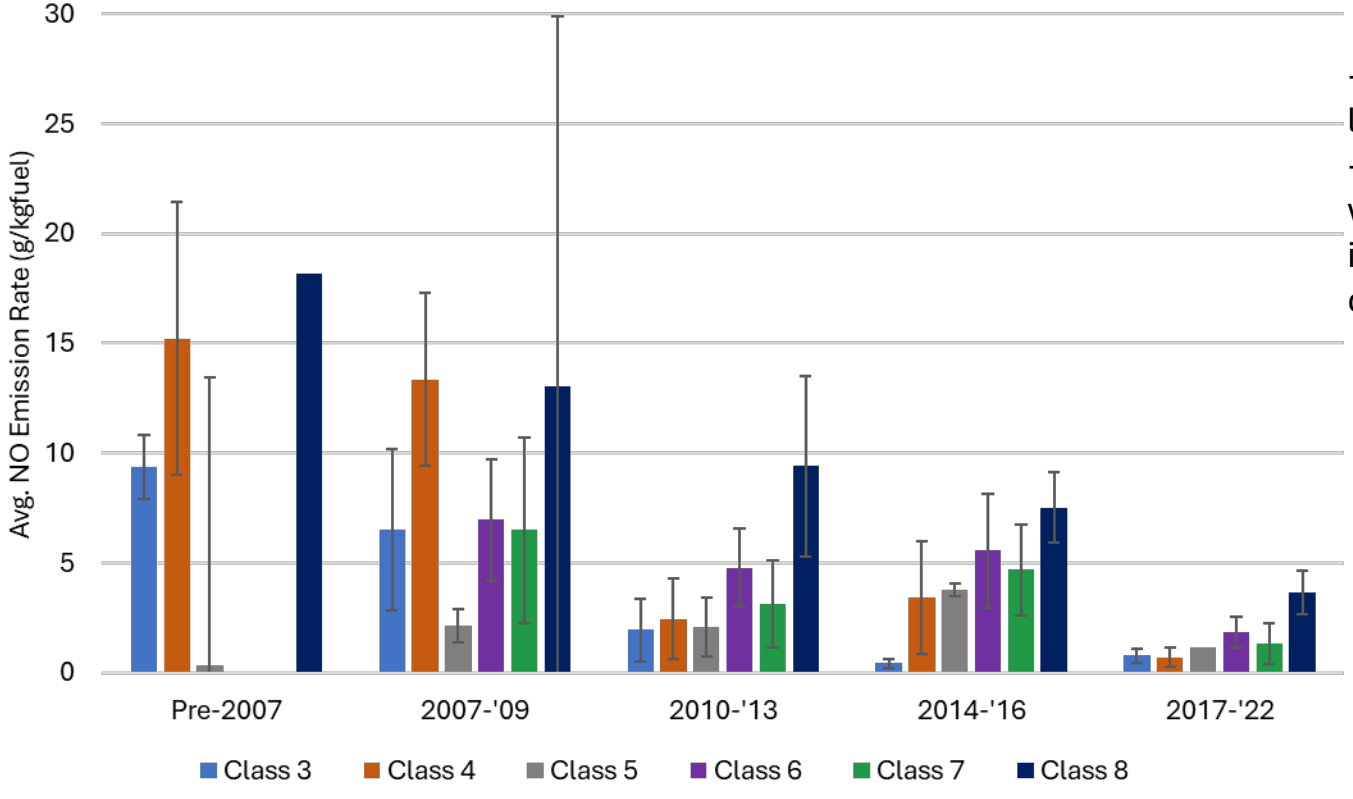
HDV Fuel Types (Valid Measurements Only)



- The lighter truck classes are nearly 50/50 gas vs diesel; increasing weight correlates with higher diesel prevalence

HDV Measurement & Analysis

Average Emission Rates by Class and Model Year



- Error bars larger than for light-duty
- Emissions trend down with MY and up with increasing vehicle weight class

Smog Check Analysis

1. Evaluate the emissions of Change-of-Ownership (COO) area vehicles compared to Enhanced and Basic (i.e. biennial test) area vehicles
2. Compare unregistered and out-of-state (US) vehicle emission rates to in-state
3. Evaluate RSD emission rates vs. station pass rates to determine if any stations have significant numbers of passing vehicles that later have elevated emissions
4. Determine if any trends exist in how emission rates vary throughout vehicles' biennial inspection period
5. Determine if the RSD data indicates an observable effect of the 8-model-year exemption

Smog Check Program Areas

Program area requirements relevant to this work:

Enhanced and Basic Areas

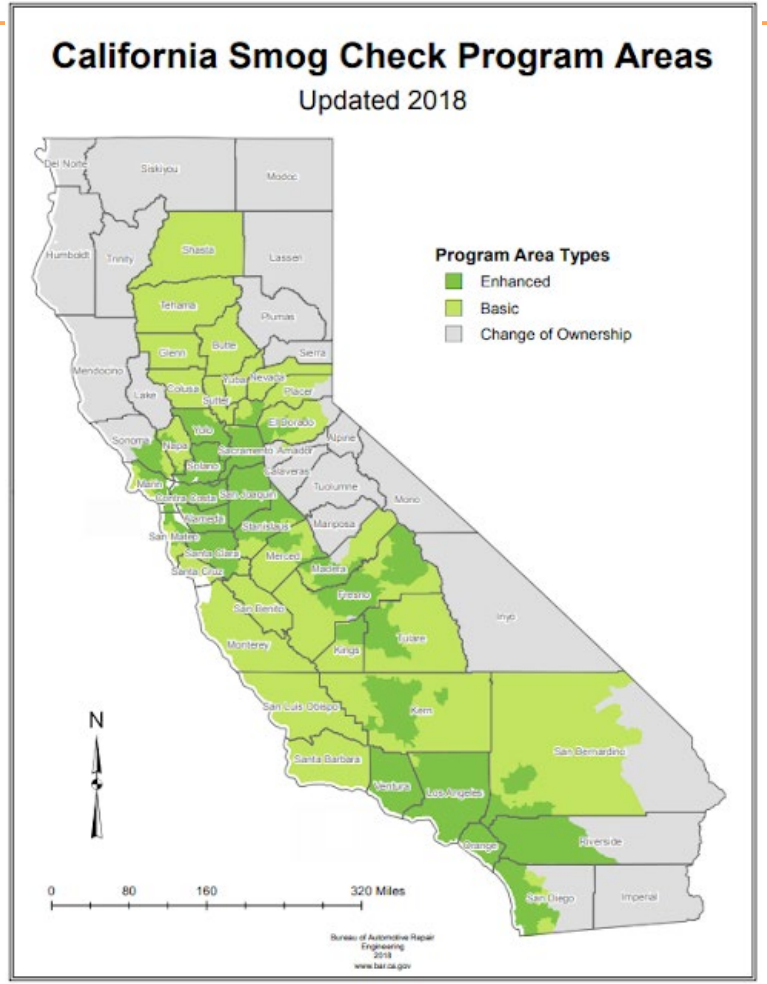
- Require inspection every 2 years
- Require inspection on change of ownership
- Exempt gasoline vehicles less than 8 yrs old

COO Area

- Require inspection on change of ownership only

Confounding Factors include:

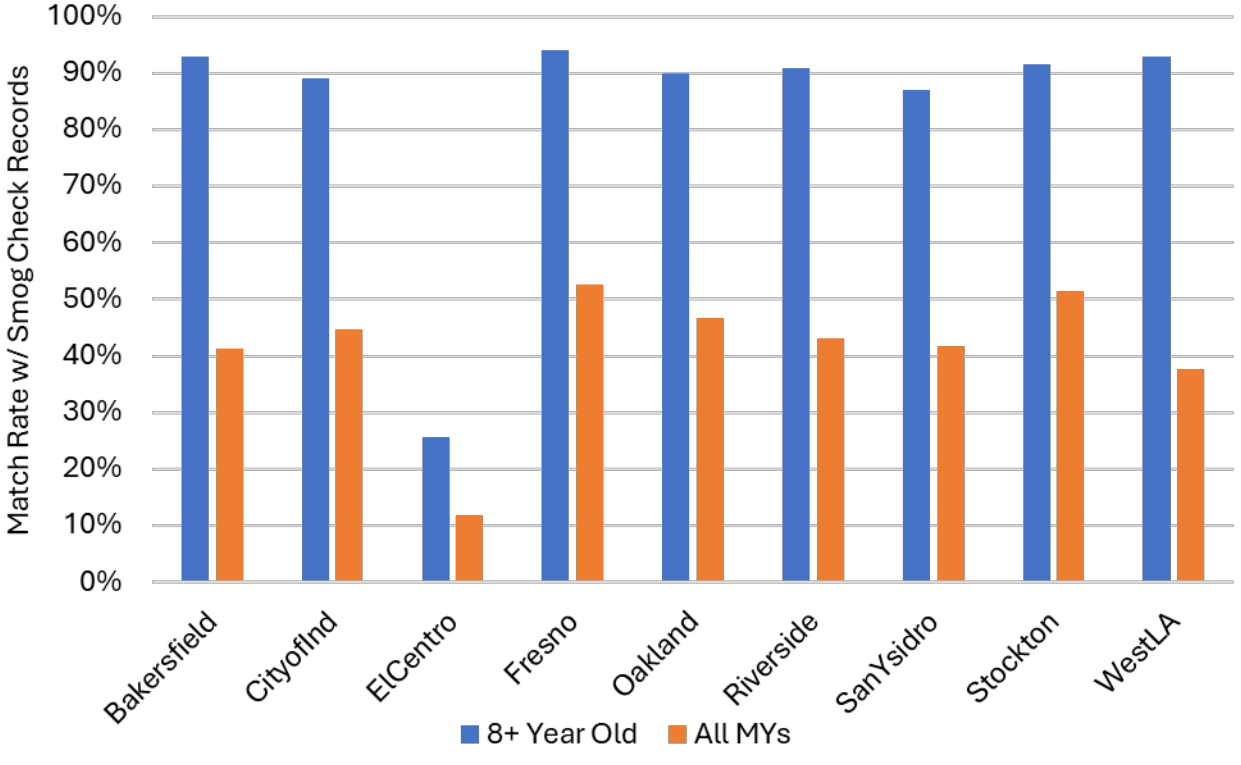
- No MY exemption for diesels
- Geographic overlap of DAC and COO area
- El Centro was only campaign in COO area



https://www.importavehicle.info

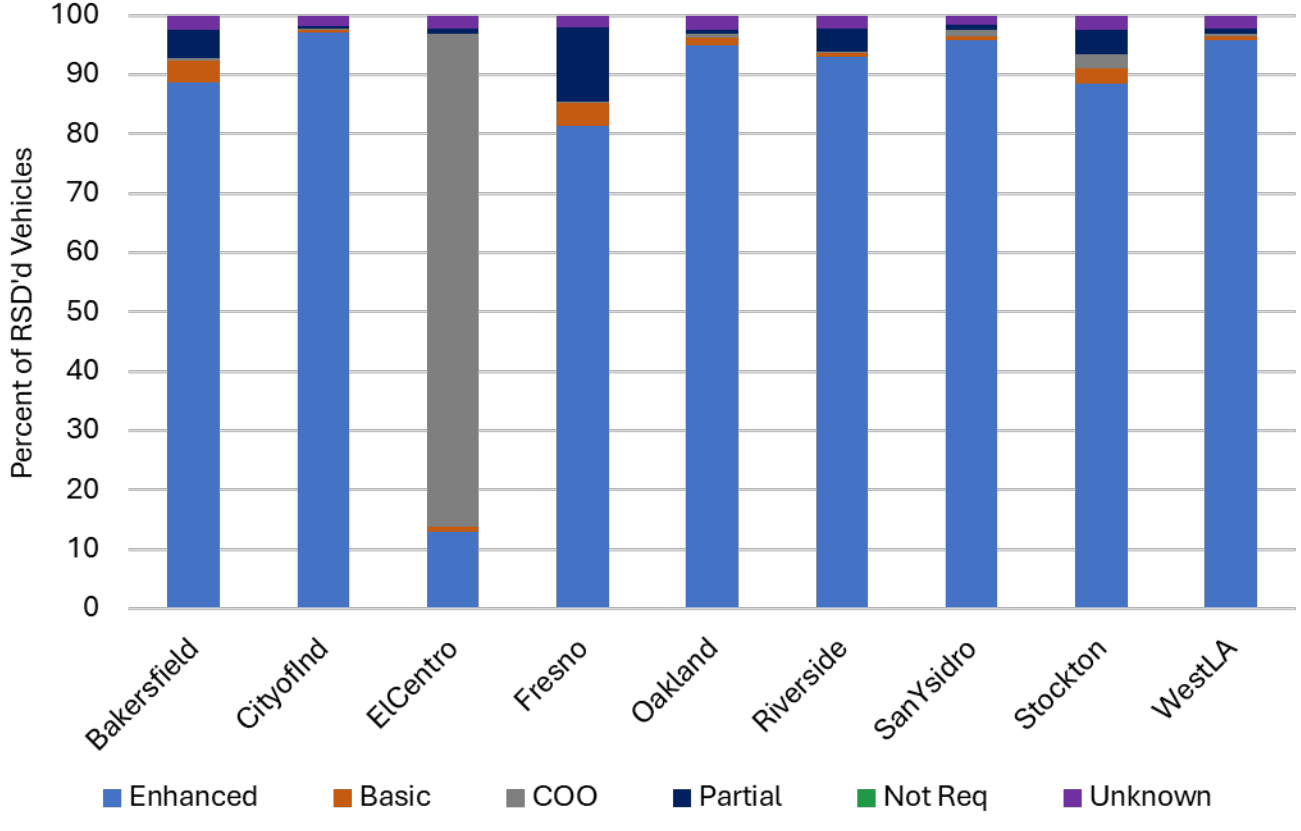
Matching with Smog Check Data

Of vehicles that matched with CA registration, how many appear in Smog Check records?



- Approximately half of the vehicles do not appear in Smog Check records, likely due to 8 MY exemption

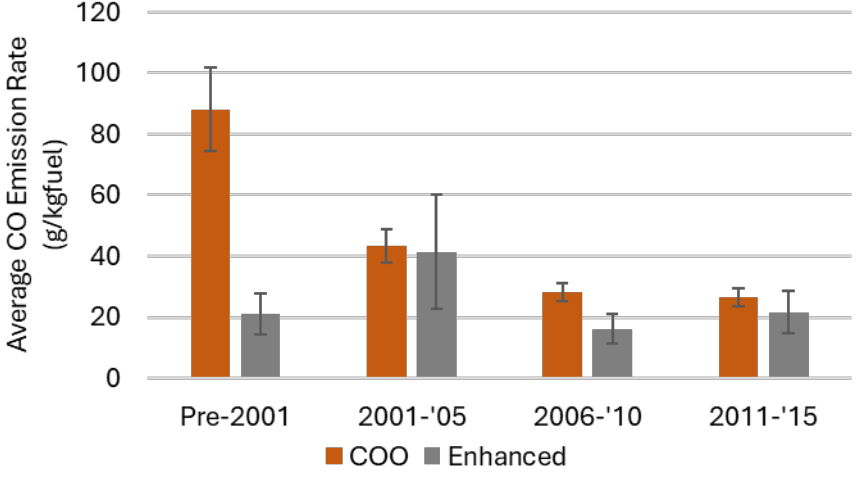
Smog Check Areas of RSD'd Vehicles



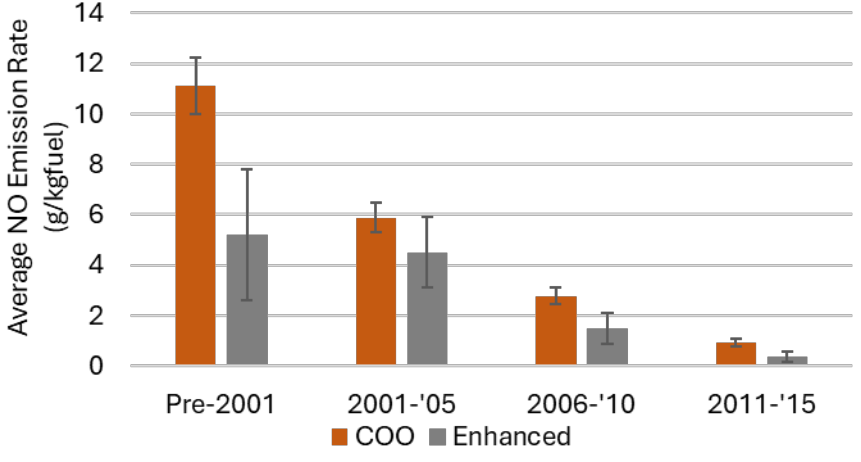
- Only the El Centro campaign had significant COO-vehicle prevalence, so some Smog Check analyses isolated to that campaign only

Emissions Across Program Areas

- Average emission rates by model year groups shown
- El Centro campaign only
- HC showed no significant differences; COO vehicles have significantly higher CO and NO emissions than Enhanced vehicles in some MY groups



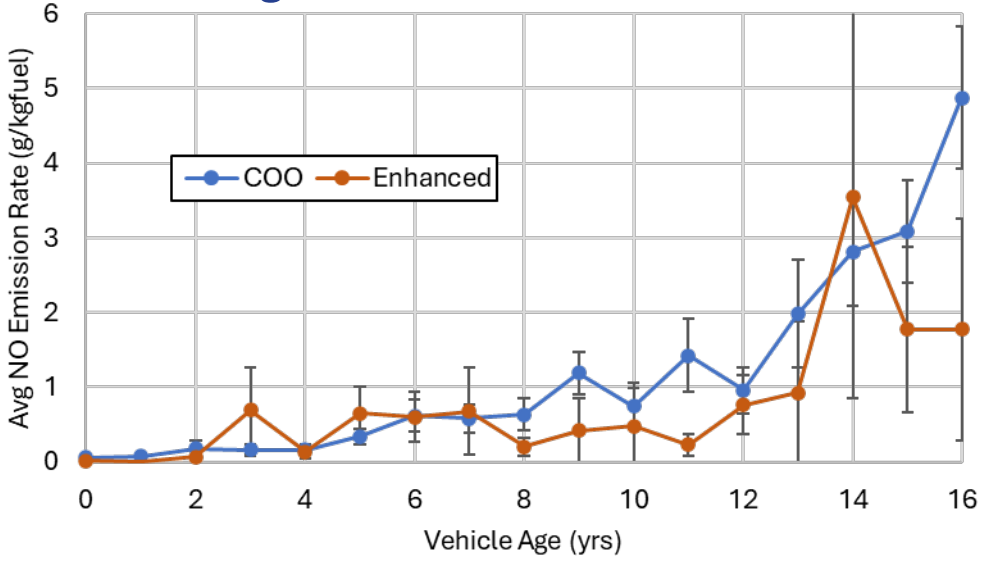
CO



NO

8 Model Year Exemption

- Compare emission rates by age for gasoline vehicles in El Centro campaign. NO shown, similar findings for HC and CO



- Divergence after ~8 yrs does not prove effect of 8 yr exemption
- Does indicate that emissions tend to rise faster after 8 yrs for COO vehicles

Smog Check Analyses 2,3,&4 Inconclusive

2 - Emissions of out of state vehicles to in-state vehicles

- Did not have out of state registrations so could not conduct meaningful comparisons

3 - Smog check stations with high passing rates that are associated with vehicles with elevated emissions

- ERG's search for outliers did not successfully isolate any stations
- Over 6,000 stations were visited by the population of RSD'd vehicles; there was no way to make statistically significant observations at the individual station level

4 - Emissions over the inspection cycle

- Various analyses conducted, all inconclusive

Project Summary

- 9 weeklong RSD campaigns were conducted across California
- Observed differences for DAC vehicle fleets
  - More vehicles tended to be non-EV or non-HEV gasoline; Older MYs
  - DAC vehicles had higher emissions, even when adjusted for MY
- Continue historical West LA measurements
  - NO rates continue to decline, observed CO and HC steady or increasing slightly
- Cross border findings
  - Cross-border vehicle emission rates tended to be higher; MYs similar
- HDV Trends
  - Error bars much larger than for LDV; older, larger vehicles are highest emitters
- Smog check
  - COO and Enhanced vehicles have similar emission rates during their first 8 model years, but older COO vehicles tend to have elevated CO/NO emissions
  - Smog Check findings statistically limited due to correlation with DAC status and campaign location

Recommendations for Future Work

- Consider potential confounding factors in campaign locations selection, especially for Smog Check evaluations (i.e. COO vs DAC areas)
- Continue historical West Los Angeles data
- Continue to utilize RSD in evaluation of AB617 programs
- Considerations for HD vehicle sampling (high-stack, useful "A to B" comparisons)
- How to prepare for variability across different measurement sites (consider RSD in series at same site-how much do emission rates vary over short distance for the same fleet)

Thank You

Portions of this work were also presented in the 33rd CRC Real World Emissions Workshop, 2023 "Remote Sensing Measurements of Light-Duty Vehicle Emissions at Multiple California Locations"

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