Aiming at the increase of California's ethanol 'blend wall': gaseous and particulate emissions evaluation from a fleet of GDI and PFI vehicles operated on E10 and E15 fuels

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Presenter Background

- After graduating with an M.S. in Environmental Engineering at USC, I joined the Emissions and Fuels Research group at CE-CERT, UCR in 2019 as a Ph.D student

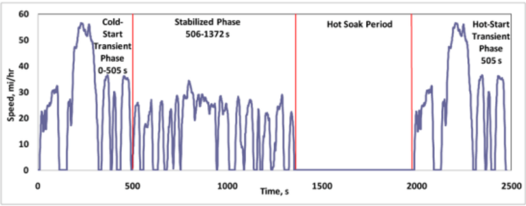
- Over the past three years I have worked on various projects to understand emissions from various alternative and renewable fuels to help legislative parties to determine future regulations

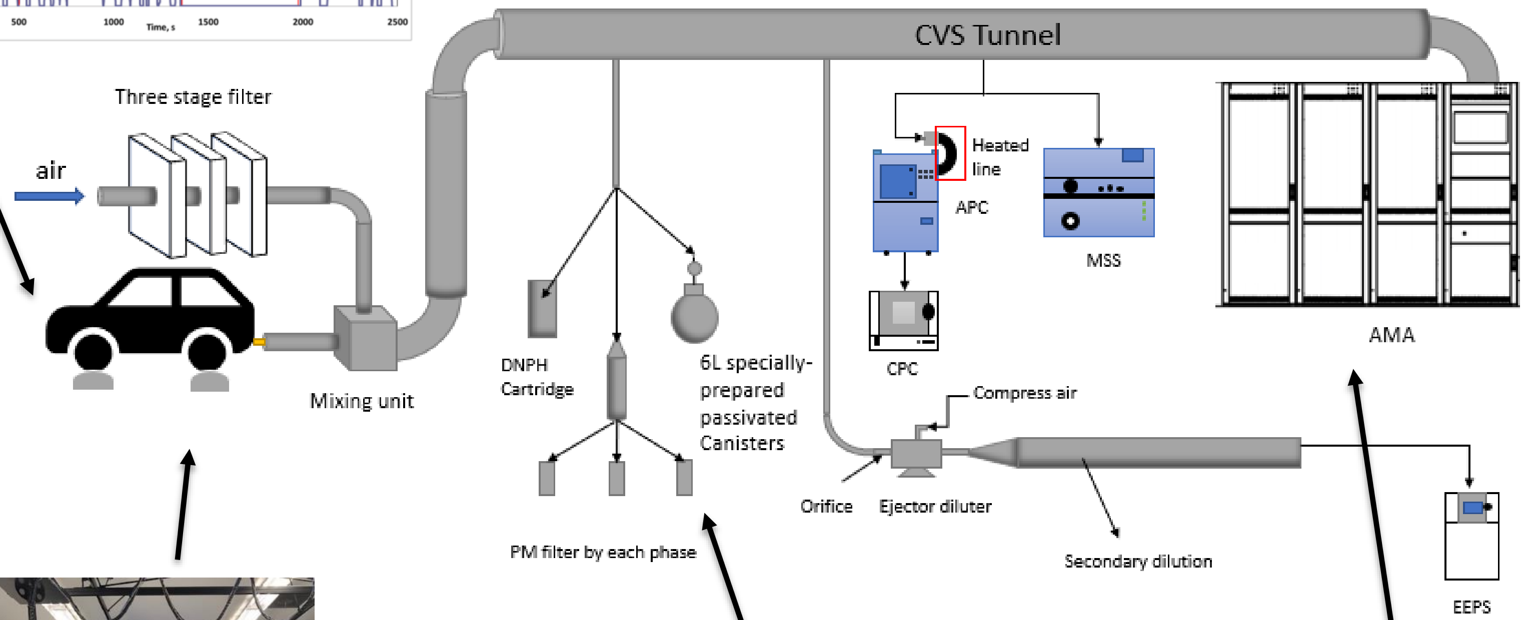
Motivation

- Ethanol has been promoted in the US as the biofuel of choice through several mandates (i.e., RFS, EISA)
- The US EPA allows E15 fuel to be sold year-round across the US
- CARB considers to increase the ethanol blend limit from E10 to E15 in California
  - Ethanol is produced from renewable sources, which will result in more low-carbon fuel in the transportation sector and less petroleum gasoline consumption
  - Reduction of harmful pollutants and GHGs
- There is limited data on the emission impacts of E15 from current PFI and GDI vehicles

Test Setup

FTP test cycle





Vehicle Specifications

Vehicle descriptions (20)	11 GDI vehicles, 6 PFI vehicles, 2 PFI+GDI vehicles and 1 PFI plug-in Hybrid vehicle
Year	2016-2021
Vehicle class (EPA)	LDV and LDT
Engine size (L)	1.4 L to 5.7 L
AIR system	3 Turbocharged vehicles + 17 Naturally aspirated vehicles
Number of cylinders	4 to 8
Engine compression ratio	9.3:1 to 13:1
Technology group (CA)	5 SULEV30 + 5 ULEV50 + 5 ULEV70 + 5 ULEV125
Aftertreatment systems	All vehicles equipped with TWC + 3 vehicles equipped with EGR

Test Fuels

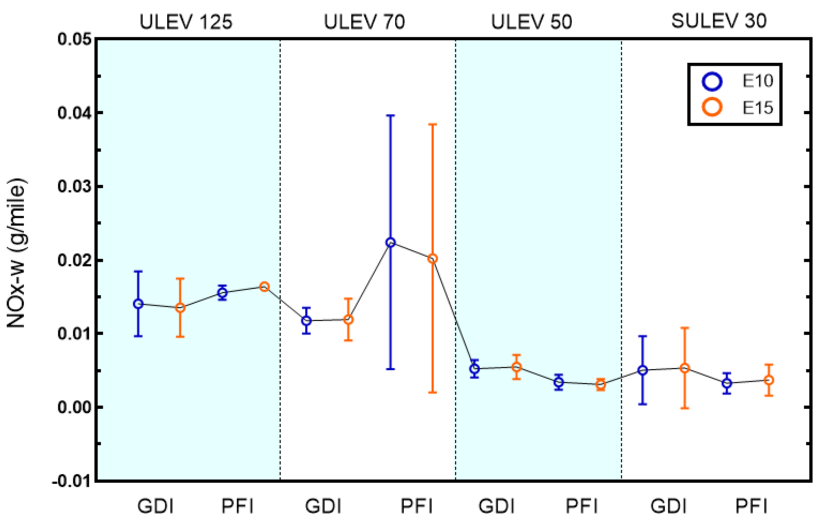
Property	Test Method	Unit	E10-avg	E15-avg
RVP (EPA Equation)	D5191	psi	7.43	7.35
Research Octane Number	D2699Mdp	ON	91.13	93.63
Motor Octane Number	D2700Mdp	ON	83.53	85.07
API Gravity	D4052		59.15	58.48
Heat of Combustion, Gross	D4809	BTU/lb.	19264	18877
		MJ/kg	44.81	43.91
		cal/g	10702	10487
Heat of Combustion, Net		BTU/lb.	17982	17605
		MJ/kg	41.83	40.95
		cal/g	9990	9780
Ethanol		Vol%	9.66	14.45
Total Oxygen		wt.%	3.59	5.35
Carbon	D5291 CH	wt.%	82.80	80.91
Hydrogen		wt.%	14.05	13.94
Sulfur	D5453	ppm	6.25	4.47
Benzene	D5580	Vol%	0.60	0.56
Toluene		Vol%	4.04	3.81
Ethylbenzene		Vol%	0.94	0.89
p,m-Xylene		Vol%	3.85	3.65
o-Xylene		Vol%	1.36	1.29
C9 plus Aromatics		Vol%	8.74	8.26
Total Aromatics		Vol%	19.53	18.46
Olefin	D6550	Mass %	5.03	4.63
Distillation	D86			
IBP		deg F	101.63	102.27
10%		degF	135.33	136.00
50%		degF	204.50	161.13
70%		degF	248.70	244.00
90%		degF	313.63	310.50
Final Boiling Point		degF	394.07	393.93
Particulate Matter Index (Aikawa *et al.*)			1.15	1.10

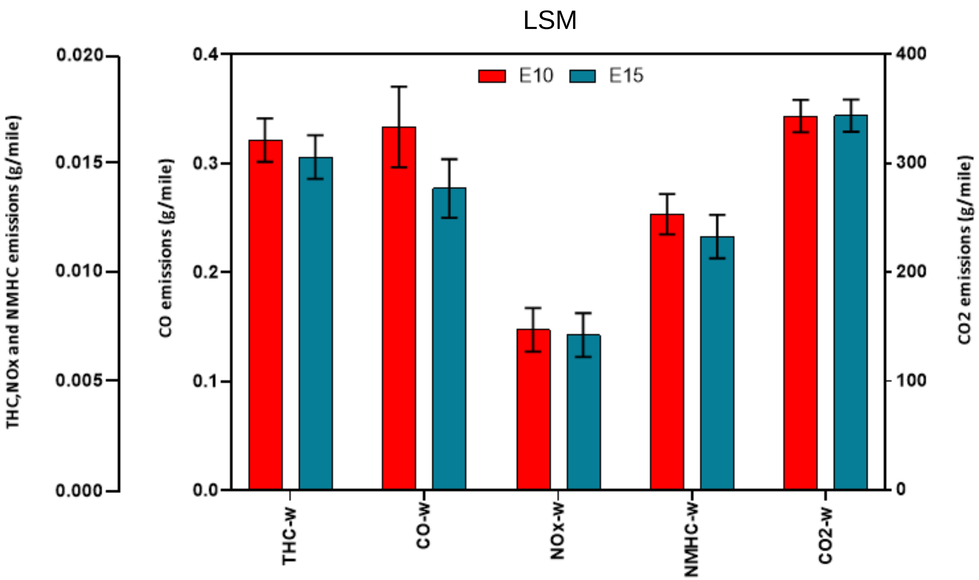
Driving Cycle, Test Protocol and Statistical Analysis

- Emissions and fuel economy measurements were conducted over triplicate FTP cycles.
- The fuel testing sequence was randomized for every vehicle.
- The test vehicles were preconditioned with a procedure including:
  - Fuel drain and fill (40%)
  - HWFET
  - Fuel drain and fill (40%)
  - HWFET
  - 2 LA4s

- Statistical analyses for each pollutant were run using the mixed procedure in PC/SAS from SAS Institute, Inc. The fuel type was treated in the model as a fixed factor and the vehicles as a random factor
  - The results from the natural logarithms (ln) or inverse models were "back transformed" to provide least square means (LSMs) for all pollutants on each fuel
  - This provides an arithmetic value to evaluate the magnitude of statistically significant effects
  - We define when $p \leq 0.05$, it is at statistically significant level. When $0.05 < p \leq 0.1$, it is at marginally statistically significant level

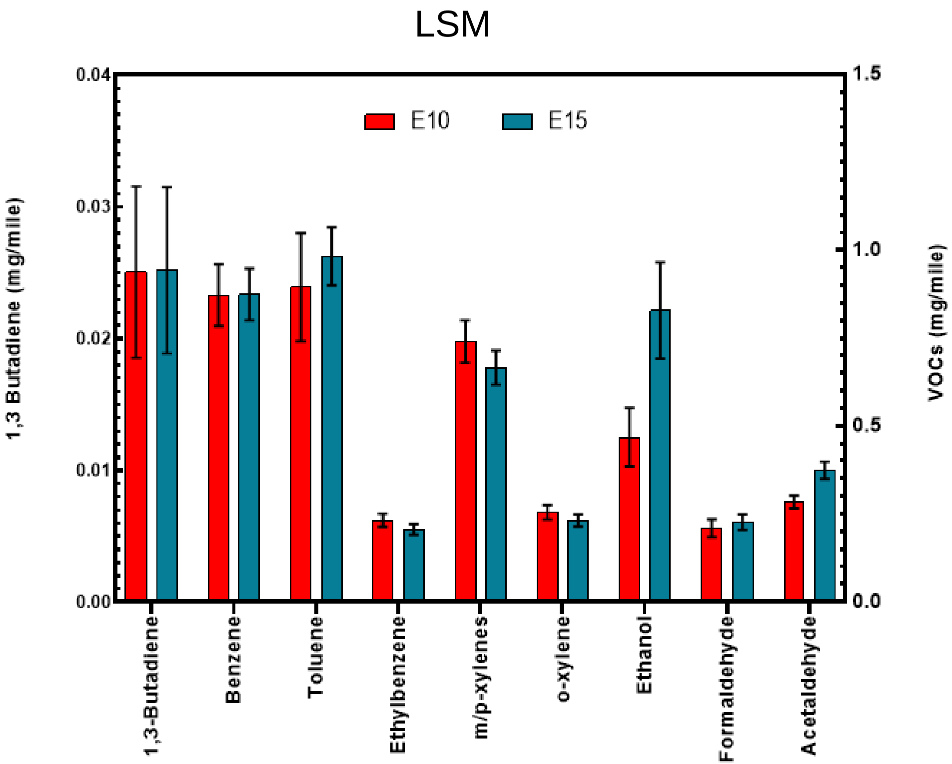
Gaseous emissions





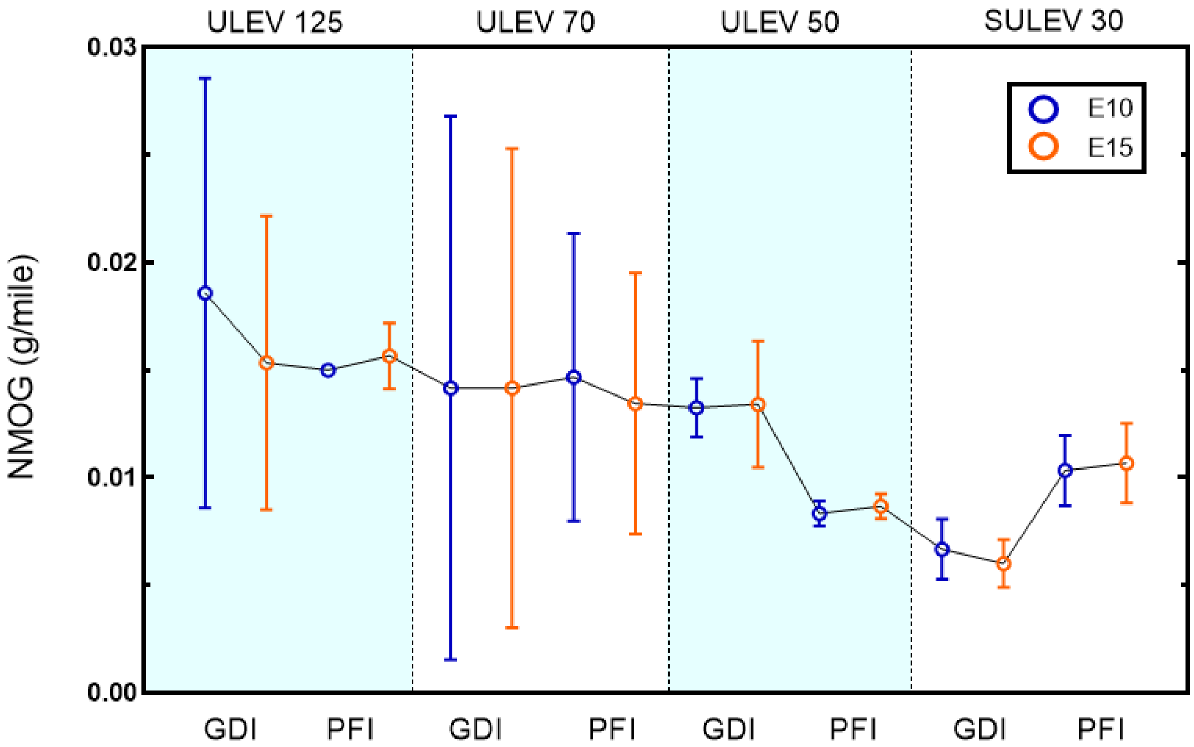
- For NOx emissions, a decreasing trend for more stringent regulations was observed
- For THC weighted emissions, E15 was 5% lower than E10 at statistically significant level
- For CO weighted emissions, E15 was 17% lower than E10 at statistically significant level
- For NMHC weighted emissions, E15 was 8% lower than E10 at marginally statistically significant level
- NOx and CO2 did not show statistically significant difference between E10 and E15

MSAT



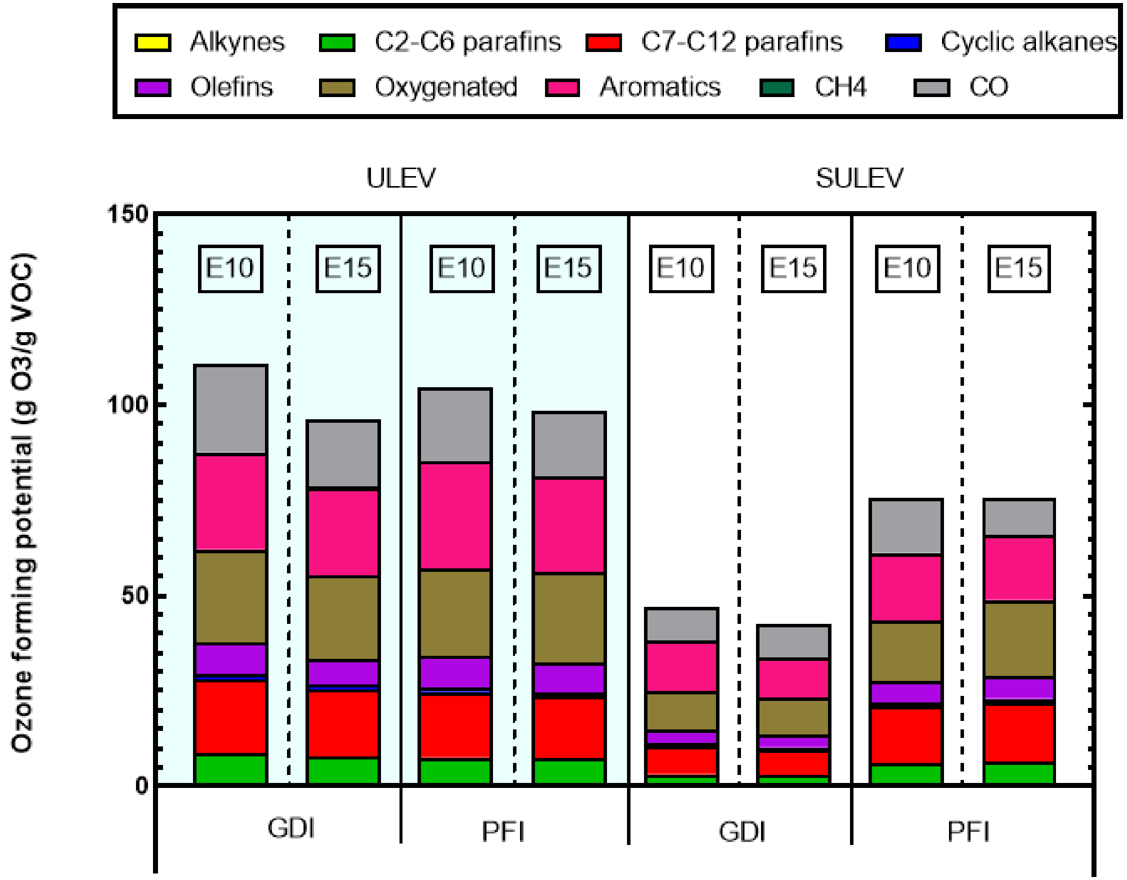
- For ethylbenzene emissions, E15 showed 11% decrease compared to E10 at statistically significant level
- For m/p-xylenes emissions, E15 showed 10% reduction compared to E10 at marginally statistically significant level
- For o-xylene emissions, E15 showed 9% reduction compared to E10 at marginally statistically significant level
- For ethanol emissions, E15 showed 77% increase compared to E10 at statistically significant level
- For acetaldehyde emissions, E15 showed 32% increase compared to E10 at statistically significant level

NMOG



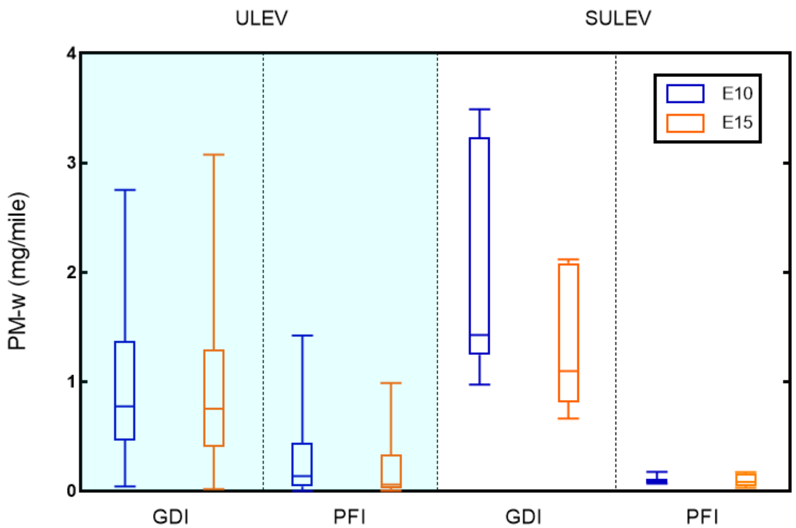
- Similar trend compared to NOx emissions. A decreasing trend for more stringent regulations

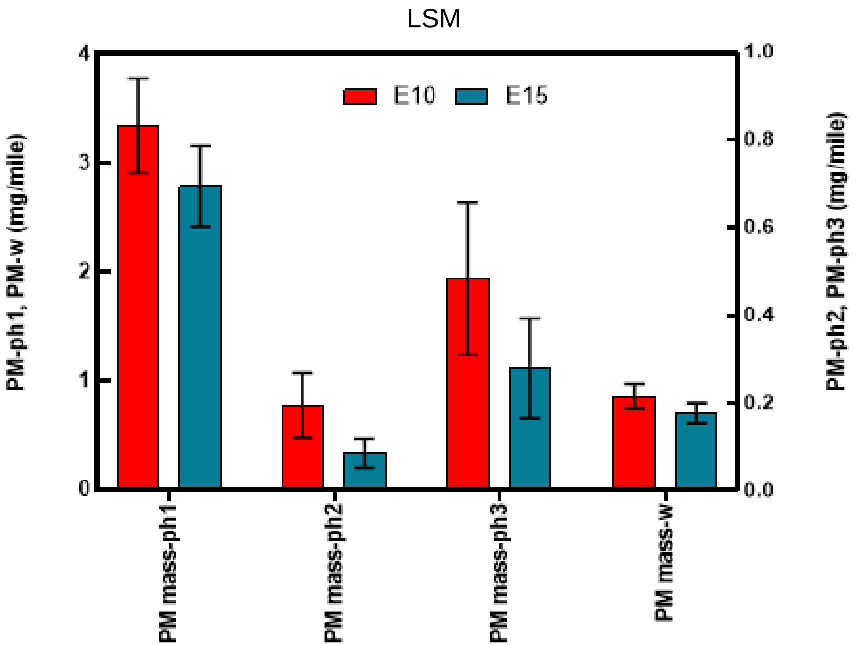
Ozone Forming Potential



- E15 trends lower for OFP
- Newer vehicles led to lower OFP, with the more efficient GDIs showing lower OFP than PFIs

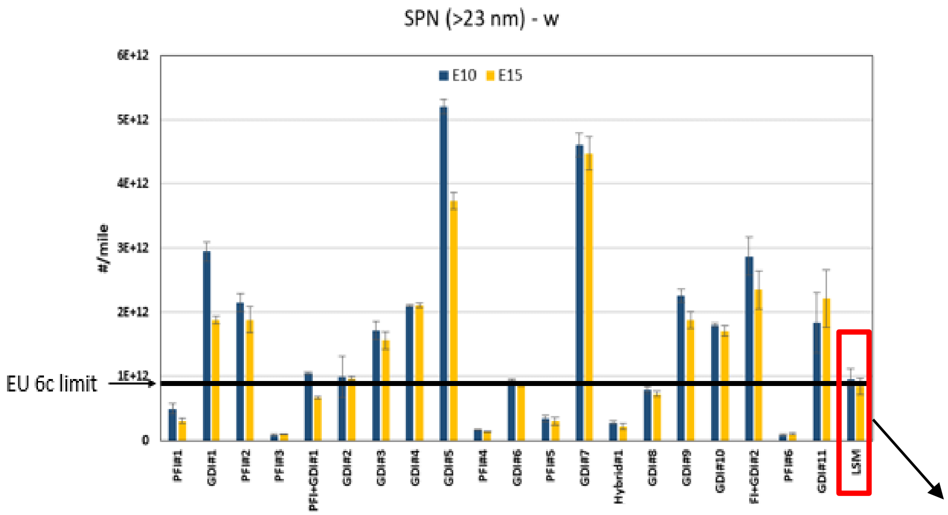
PM mass emissions

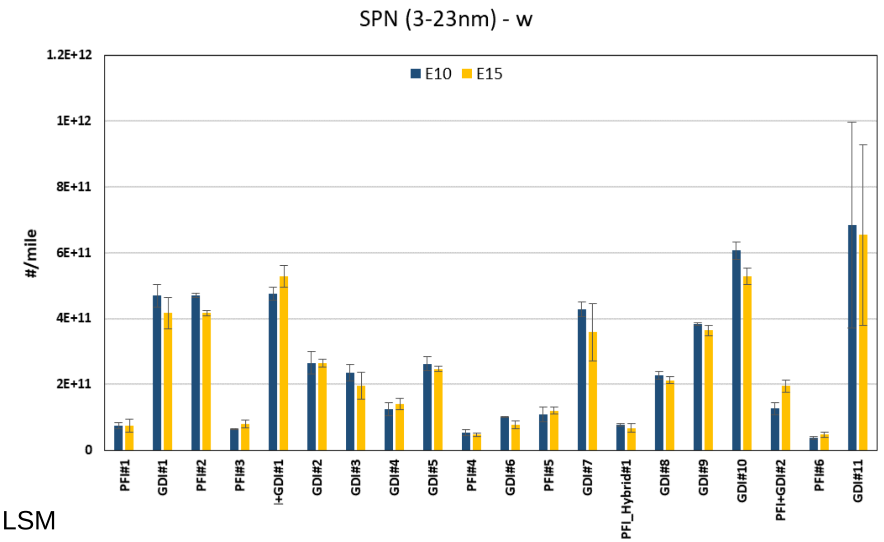


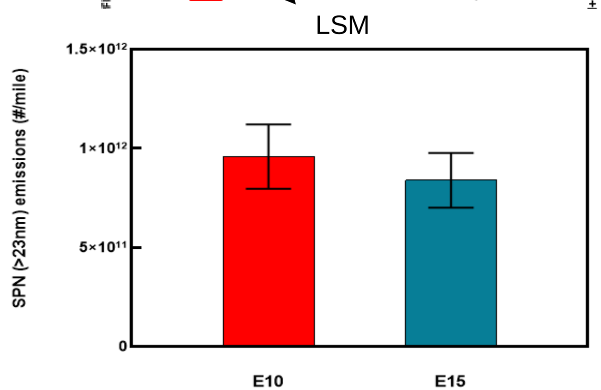


- Lower emissions for PFI vehicles compared to GDI vehicles
- Lower trend for E15 compared to E10
  - For weighted emissions, E15 showed 18% reduction compared to E10 at statistically significant level
  - For cold start (ph1) emissions, E15 showed 17% reduction compared to E10 at statistically significant level
  - For hot running (ph2) emissions, E15 showed 54% reduction compared to E10 at statistically significant level
  - For hot start (ph3) emissions, E15 showed 43% reduction compared to E10 at marginally statistically significant level

Solid Particle Number Emissions



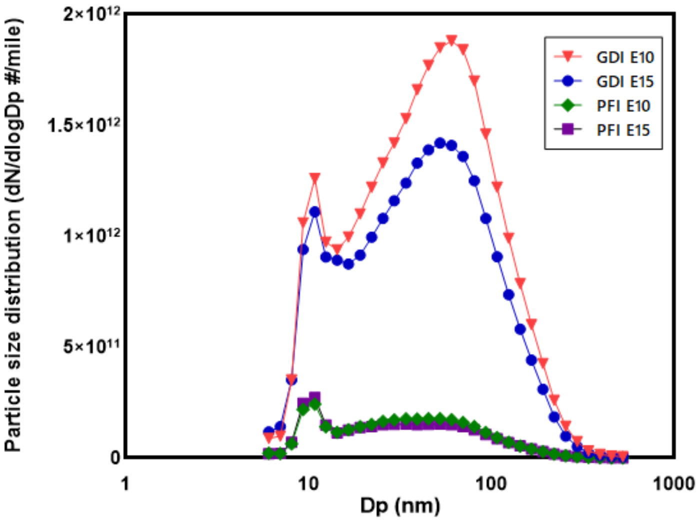




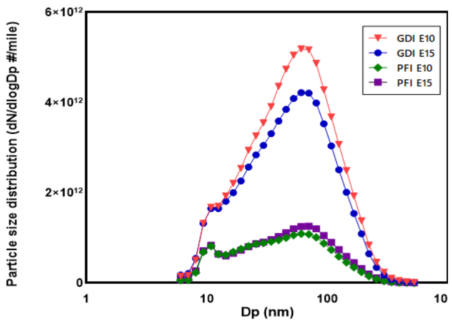
- Weighted SPN (>23nm) emissions showed a statistically significant reduction of 12% for E15 compared to E10.
- Overall, high concentrations of sub-23nm SPN emissions were observed for all vehicles

Particle Size Distributions

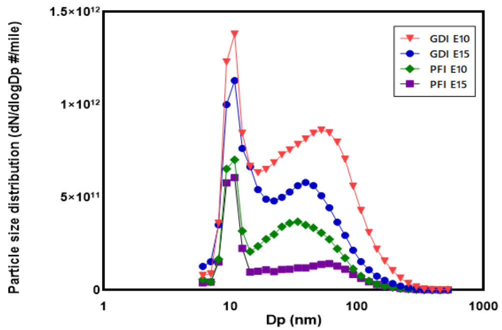
Weighted

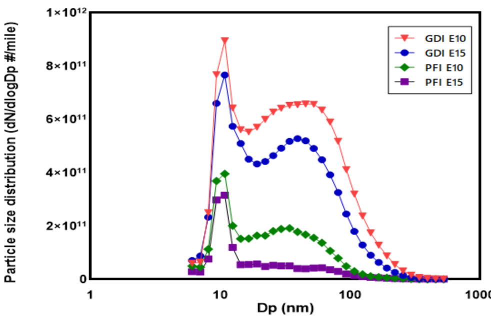


Cold-start



Hot-running





Hot-start

- For weighted PSD, significantly higher particle populations in the accumulation (soot) mode for the GDI vehicles compared to PFI vehicles
  - Accumulation mode particles were centered at about 52-60nm and 52nm for the GDI and PFI vehicles, respectively
  - E15 resulted to lower particle diameters
- E15 showed decreasing trend for different phases of FTP for both GDI and PFI vehicles

Summary

- Overall, E15 showed statistically significant reductions on THC, CO, and NMHC emissions compared to E10
- PM mass emissions showed strong statistically significant reductions for E15 across the 20 vehicle fleet
- No strong statistically significant fuel effects were observed for NOx
- The introduction of E15 will likely reduce air toxics from current technology vehicles and will not lead to air quality degradation in California
- Particle number emissions showed statistically significant reductions for E15 compared to E10
- Ozone forming potential trended lower for E15 compared to E10

Acknowledgments

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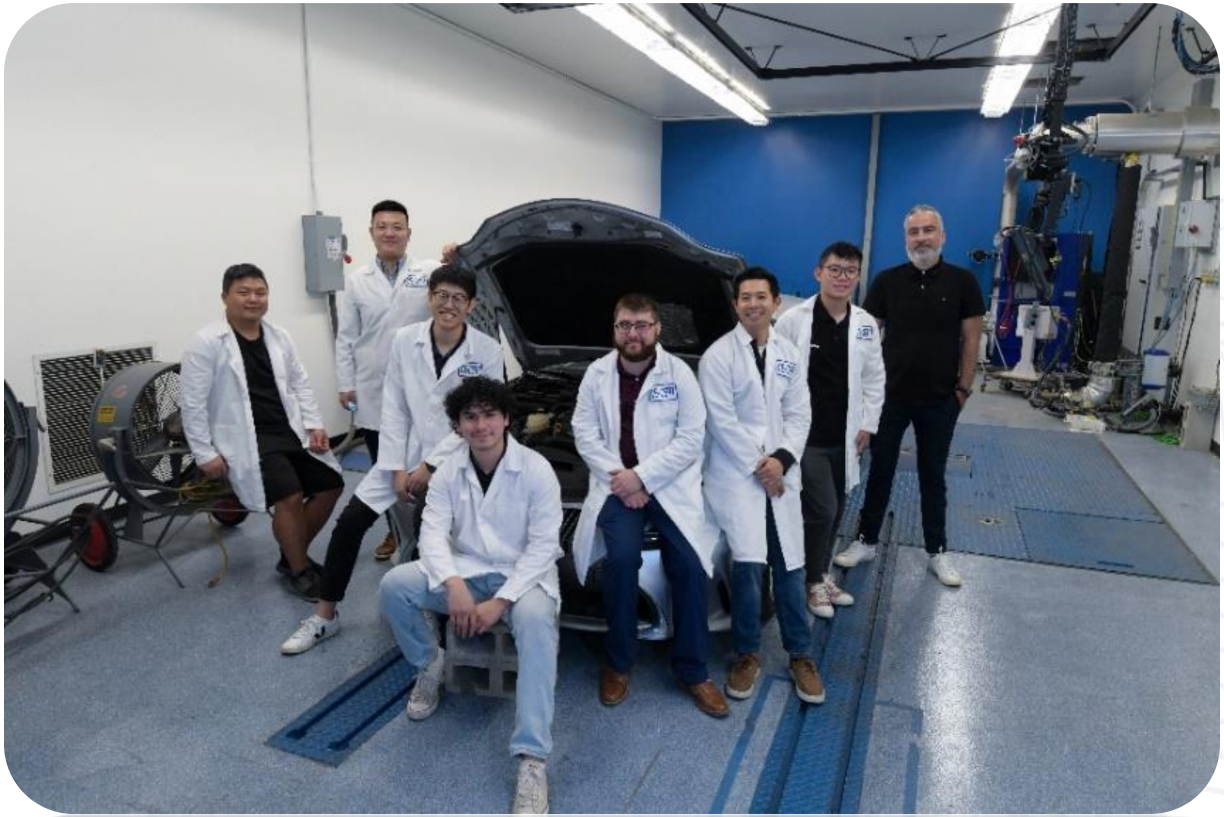
THANK YOU!



Test Vehicles

	PFI#1	GDI#1	PFI#2	PFI#3	PFI+GDI#1	GDI#2	GDI#3	GDI#4	GDI#5	PFI#4	GDI#6	PFI#5	GDI#7	PFI_Hybrid#1	GDI#8	GDI#9	GDI#10	PFI+GDI#2	PFI#6	GDI#11
Year	2019	2018	2020	2016	2019	2018	2016	2020	2019	2021	2020	2020	2020	2020	2020	2020	2021	2017	2021	2018
Make	Dodge	Honda	Jeep	Nissan	Toyota	Honda	Mazda	Ford	Chevrolet	Chevrolet	KIA	Jeep	Nissan	Toyota	GMC	Buick	Chevrolet	Ford	Hyundai	Chevrolet
Model	Ram1500	Fit	Compass	Rogue	Rav4	Civic	Mazda3	Fusion	Impala	Spark	Optima	Cherokee	Armada	Prius	Acadia	Enclave	Colorado	F-150	Accent	Suburban
Miles at start (mi)	32234	35547	29174	63491	37329	35776	74339	33029	25728	4073	29377	23272	32731	10015	34942	32621	17603	7352	12226	34477
Engine size (L)	5.7	1.5	2.4	2.5	2.5	1.5	2.5	2	3.6	1.4	2.4	3.6	5.6	1.8	3.6	3.6	3.6	3.5	1.6	5.3
Fuel injection type	PFI	GDI	PFI	PFI	GDI+ PFI	GDI	GDI	GDI	GDI	PFI	GDI	PFI	GDI	PFI	GDI	GDI	GDI	GDI+ PFI	PFI	GDI
AIR system	NA	NA	NA	NA	NA	Turbo	NA	Turbo	NA	NA	NA	NA	NA	NA	NA	NA	NA	Turbo	NA	NA
Emission standard	USEPA: T3B70 CA: ULEV70	USEPA: T3B30 CA: SULEV30 PC	USEPA: T3B50 CA: ULEV50	USEPA: For sale only in states with California emission standards CA: LEV3-ULEV70	USEPA: T3B50 CA: ULEV50	USEPA: IT3B125 CA: ULEV125 PC	USEPA: N/A CA: SULEV30/PZEV	USEPA: T3B70 CA: ULEV70 PC	USEPA: TIER3 CA: PC/SULEV30	USEPA: TIER3 CA: PC/ULEV70	USEPA: T3B70 CA: ULEV70 PC	USEPA: T3B30 CA: SULEV30	USEPA: T3B125 CA: LEV3-ULEV125	USEPA: T3B30 CA: SULEV30 PC	USEPA: TIER3 CA: ULEV50	USEPA: TIER3 CA: ULEV50	USEPA: TIER3 CA: ULEV50	USEPA: T2B5 CA: ULEV125	USEPA: T3B125 CA: ULEV125 PC	USEPA: TIER3 CA: ULEV125