California's Program for Controlling Diesel Particulate Matter Emissions

An Update on Evaluation of DPFs on HDV In-use Applications, Related Policies, and Future Changes

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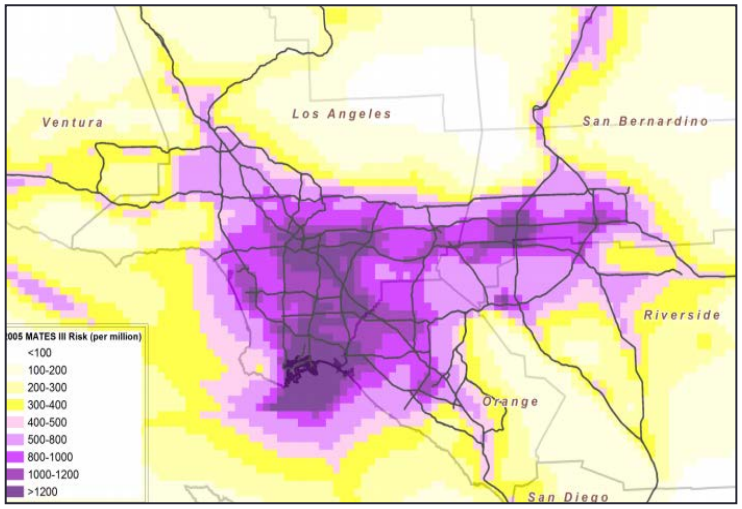
DPF graphic from Cummins brochure

California – the nation-state and its unique authority

- Largest U.S. State, ~36 million Californians
- ~27 million cars, ~1.3 million diesel engines
- 7th or 8th largest economy in world
- ~1.7 million annual new car sales
- Making tremendous progress on clean air (20 million Californians already breathing air that meets ambient air quality standards)
- But still have most polluted air in U.S., impacting health of 16 millions Californians
- Cars, trucks, and transport in general are largest source of conventional pollution and GHG emissions
- U.S. Law for clean air gives California unique authority to set own vehicle and engine emission standards
- Other U.S. States can follow California's regulations

Public Health Drives Policy for Control of Diesel PM and Other Emissions

- Diesel particulate matter (DPM) identified as carcinogen in 1998
- 14 years later in 2012 WHO/IARC did same
- Classified as Toxic Air Contaminant – sets legal requirement for development of exposure risk mitigation plan
- Mobile source emissions are 90% of total toxics risk where diesel emissions represent 68% of total toxic risk alone[3]
- Mobile source PM is ~ 20% of ambient $PM_{2.5}$ in California, ~24% in Southern California/Los Angeles Region[1]
- On-road and Off-road vehicles and equipment accounted for ~58% of mobile source anthropogenic BC emissions in 2013[2]
- Emissions of precursor gases (hydrocarbons, sulfate, ammonia, NOx) lead to formation of secondary PM



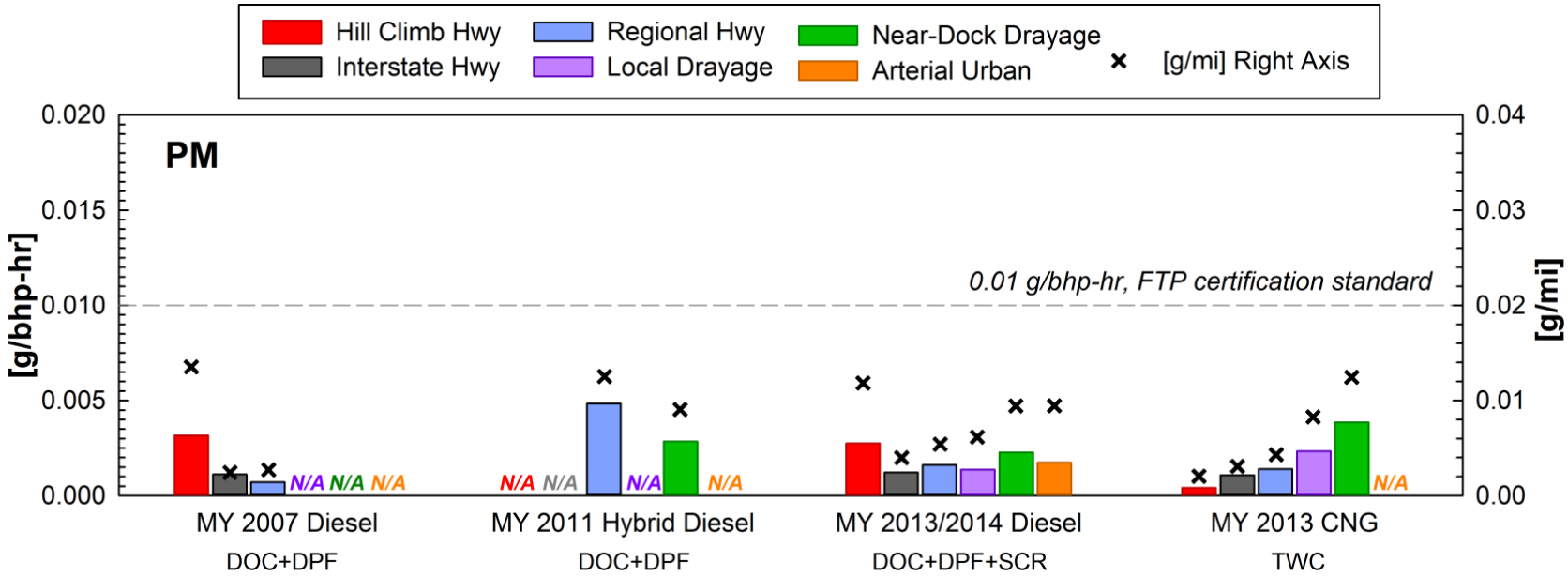
1. CARB Emission Factor (EMFAC) model, 2011
2. Short Lived Climate Pollutant Reduction Strategy: http://www.arb.ca.gov/cc/shortlived/meetings/04112016/proposedstrategy.pdf
3. MATES IV Study: http://www.aqmd.gov/home/library/air-quality-data-studies/health-studies/mates-iv

Comprehensive Approach for Controlling HD Diesel Emissions

- Increasingly stringent NOx and PM emission standards for HD engines since 1987
- For HDEs, NOx is biggest issue, PM problem solved with DPF ✓
- Standards driving use of original DPFs for PM compliance
- Regulations and public investment to accelerate cleanup and modernization of existing, in-use HD fleet
- DPF retrofit requirements for many applications
- Under CARB regulation, formal DPF verification program in place for all DPF retrofit applications
- Allows for wide assessment of reductions of any and all pollutants of interest (e.g., PM, PN, toxics, secondary emissions, etc.)
- Margin for study and testing under ample public process
- Covering both on-road and off-road applications
- Truck and Bus Regulation working towards all HD vehicles in California being 2010 or newer by 2023

DPF effectiveness is well documented -

HD Diesel Vehicles with DPFs Emit Below Standards During Off-Cycle Real-World Use

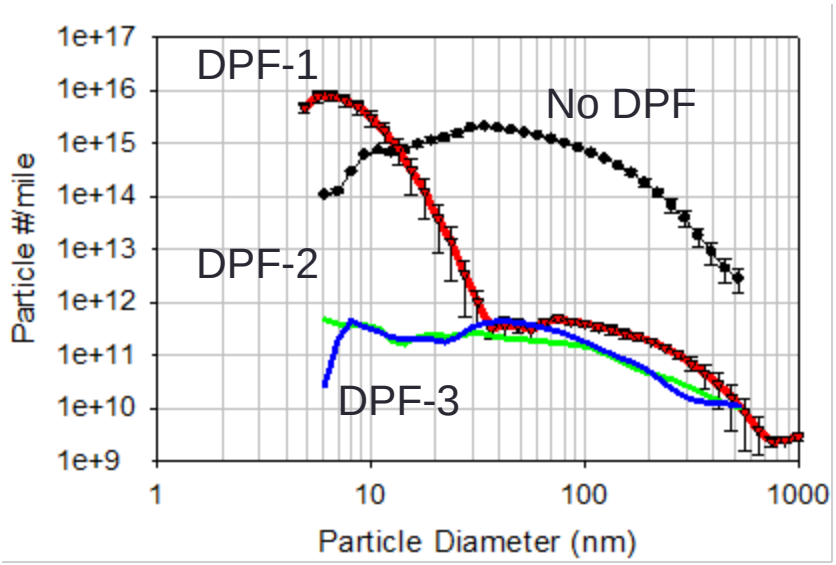


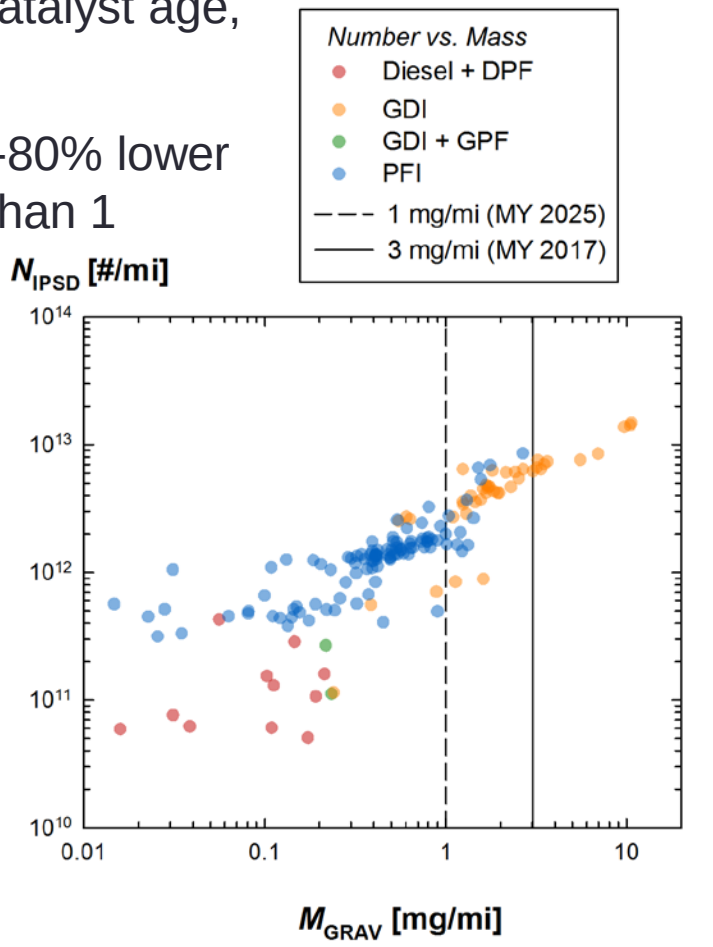
- Six HD diesel vehicles tested on road for over 1,500 miles each, throughout various California routes typically used for freight transport
- All new HD on-road diesel engines in the US equipped with DPF to meet 0.01 g/bhp-hr PM standard
- Vehicles emitted at least 50% lower than FTP certification standard, and diesels (three left groups) had similar emissions to a CNG engine (far right)

Quiros, et al. - Submitted to Emission Control Science & Technology for publication in April 2016.

DPF has demonstrated PM and total PN (volatile and solid) control

- **[LEFT]** In HD applications, DPFs can lead to or suppress nanoparticle formation depending on fill state, catalyst age, and operating conditions
- **[RIGHT]** Light-duty (LD) diesel vehicles have 70-80% lower PM mass, and 90-95% lower total PM number than 1 mg/mi compliant gasoline vehicles





Herner, et al. (2011). ES&T. DOI: 10.1021/es102792y

Quiros, et al. (2015). ES&T. DOI: 10.1021/acs.est.5b00666

Evaluation of DPFs in on-road HD vehicle applications

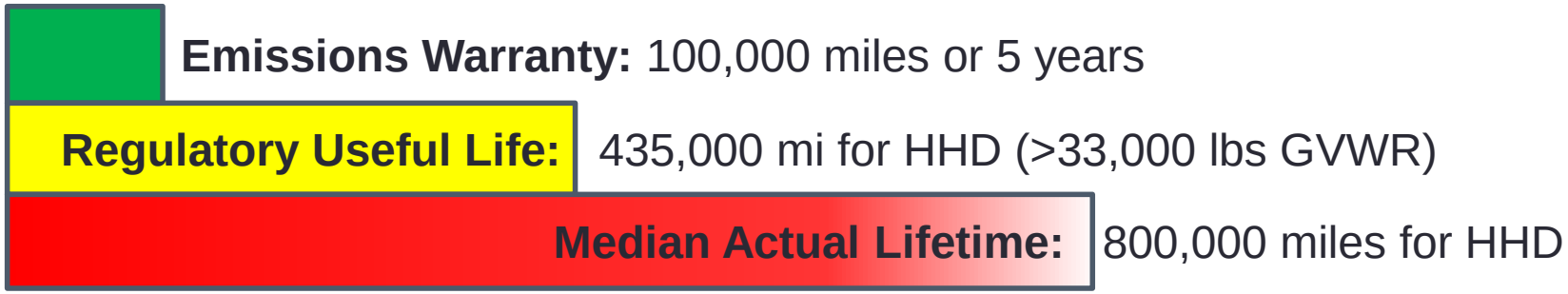
- Public interest in *on-the-ground*, field experience and performance of DPFs
- In response, CARB conducted extensive field investigation
- Inspected over 1000 trucks, interviewed fleet owners, surveyed truck drivers, worked with DPF retrofit installers, and evaluated certification data
- Considered costs, reliability, safety, and user-reported impacts of filters on performance
- Reviewed relevant vehicle testing and compliance reporting data
- Full report: http://www.arb.ca.gov/msprog/onrdiesel/documents/DPFEval.pdf

Key field evaluations findings

- Most DPFs are working properly; they are effective and safe
- Most trucking fleets are not having problems
- Some engine durability issues and inadequate maintenance practices are the primary reasons for occasional problems
- Fleets experiencing vehicle downtime due to mechanical problems caused by component failures (e.g., turbochargers or EGR)
- Component failures are generally caused by underlying issues that have occurred over time in the past

What about those underlying issues?

- Warranty claims must be reported to CARB by engine manufacturers for components (e.g., turbochargers and EGR systems)
- Up to 40 percent of these components require repair or replacement during warranty period
- Inadequate warranty period and limited recall ability



- Some fleets continue to experience component problems throughout life of truck
- Many of these failures are incorrectly diagnosed as DPF filter issues
- Findings bring into sharp focus lack of overall quality/robustness of some heavy-duty products on market

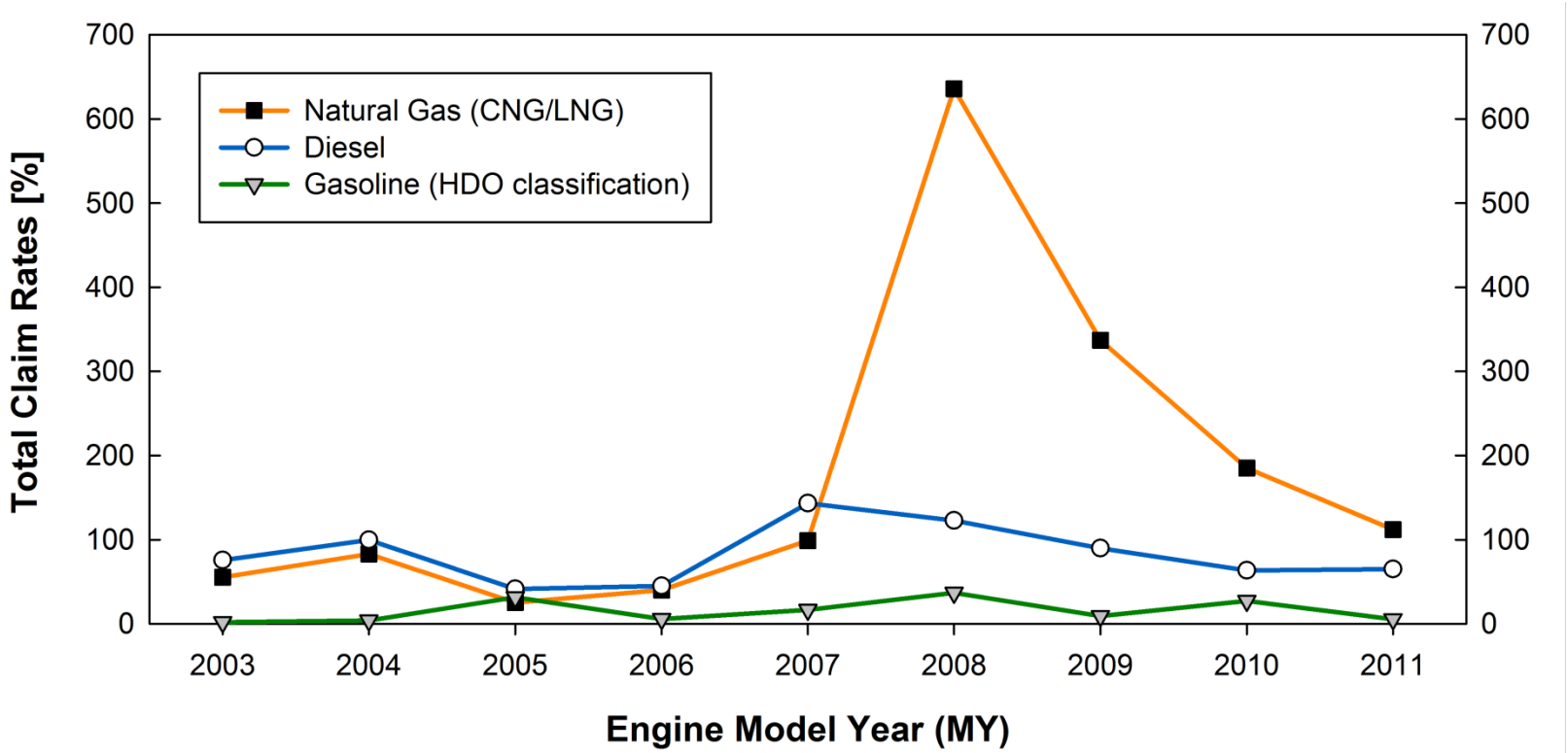
HD Warranty Claim Rates Are Relatively High For Some Components

	Percent Claims per Engines Sold: Heavy-HD Diesel								
	2003	2004	2005	2006	2007	2008	2009	2010	2011
Fuel Injectors	6%	67%	8%	3%	8%	12%	40%	22%	14%
Engine	16%	30%	22%	22%	90 %	59%	32%	17%	11%
Turbocharger	15%	38%	22%	25%	18%	12%	17%	3%	3%
EGR	26%	42%	35%	33%	41%	44%	31%	12%	10%
EGR Cooler	30%	12%	5%	6%	15%	14%	21%	20%	14%
Exhaust Manifold	10%	9%	7%	1%	0%	1%	4%	4%	4%
DOC	0%	0%	0%	0%	0%	2%	1%	1%	0%
DPF Related	--	--	--	--	35%	18%	7%	8%	4%
SCR Related	--	--	--	--	--	--	--	20%	10%

Warranty claim rates increase after new standards take effect (e.g. MY 2004, 2007, and 2010), but rates still too high during first 100K miles

Quiros, et al. Presentation at Coordinating Research Council (CRC) 25th Annual Real-World Emissions Workshop. Long Beach, CA (2015).

Warranty Claims are High for Diesel Engines, but Higher for Some Natural Gas Engines



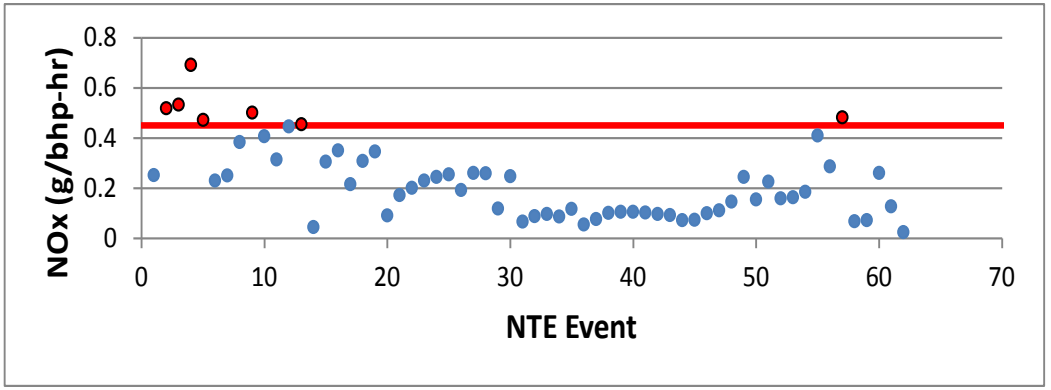
Total claim rates = sum of all parts reported in a fuel-MY across all engine families and weights divided by total number of sales reported for the fuel-MY

High warranty claim extend beyond diesel engines: MY 2008-2011 natural gas engines had highest total warranty claim rates

Quiros, et al. Presentation at Coordinating Research Council (CRC) 25th Annual Real-World Emissions Workshop. Long Beach, CA (2015).

What comes next?

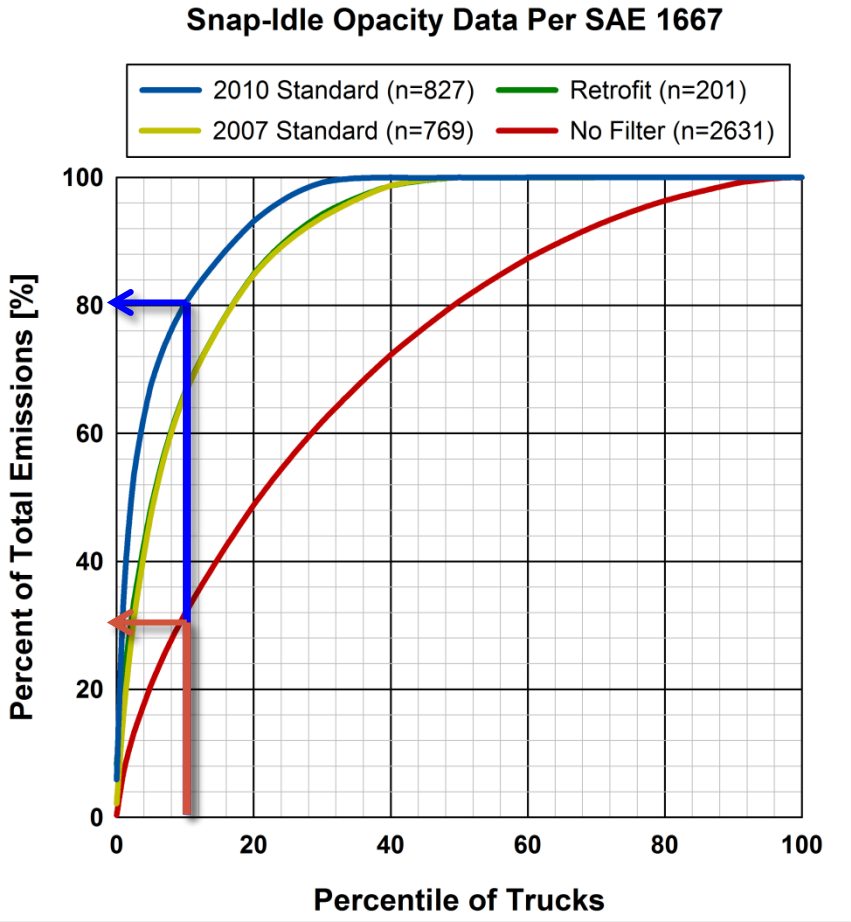
- CARB to work through regulatory process to hold manufacturers accountable and educate owners and operators
- **Development of new HD on-road emission standards**: for NOx (e.g. ~90% reduction or 0.02 g NOx/bhp-hr), for GHGs (e.g. HD GHG Phase II in California and U.S.)
- **Re-examining Not-to-Exceed (NTE)** - CARB began in-use compliance testing in 2015 using PEMS to enforce NTE limits
- Some vehicles exceeded NTE limits and additional testing is currently underway
- Considering broadening of NTE criteria and/or development of new general approach including engine dynamometer test cycles



O'Cain, et al. Poster presentation at Coordinating Research Council (CRC) 26th Annual Real-World Emissions Workshop. Newport Beach, CA (2016).

Improving HD Inspection and Maintenance

- Two existing programs no longer adequate
- **Heavy-Duty Vehicle Inspection Program (HDVIP) -** roadside inspection of engine labels, emissions control systems, and SAE J1667 opacity
- **Periodic Smoke Inspection Program (PSIP) –** audit and investigation of self-administered annual opacity testing requirements by fleets
- High-Emitting Vehicles Dominate the Fleet-wide Emissions Inventory
- 10% of MY 2010 and newer engines account for about 80% of their total opacity emissions
- New program to harness OBD capabilities for MY 2013 and newer vehicles HDV
- Considering all options, e.g., roadside plume-measurements and other approaches



Plenty motivation to improve emission certification, compliance, and enforcement – *life after diesel scandal and defeat devices*

- High expectations and tremendous public pressure to embrace lessons learned for LD and HD
- CARB discovered cheating thanks to existing robust program of certification, compliance testing, and enforcement
- PEMS alone was not the answer – only tells you "*what*"
- We needed "*why*" and "*how*" of excess emissions

- We applied new tools, methods, and approaches for challenging vehicle emission control system
- OBD program expertise plays a huge role
- Will apply many lessons learned and fully put to use new knowledge gained into regulation – new tools, new test methods, new "*views and understanding of the issues*"
- Improve and expand what is already our superior certification, compliance, testing, and legal enforcement
- New screening and selection of test vehicles. New approaches in dynamometer laboratory and outside on the road
- Enhance requirements for warranties, durability, in-use testing, certification, and public disclosure

Picture taken from caranddriver.com, A.Koerner/Getty images

danke schön!