Comparison of US and EU programs to control light-duty vehicle emissions

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THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Outline

- Overview on new vehicle standards
  - Weight classifications
  - Test cycles
- New vehicle emissions standards
  - Limit values
  - Durability
  - Evaporative emissions
  - OBD
- New vehicle greenhouse gas standards
- Compliance and enforcement of new vehicle standards
- Standards and programs for vehicles in circulation
  - Vehicle inspection
  - Remote sensing
  - Low emission zones

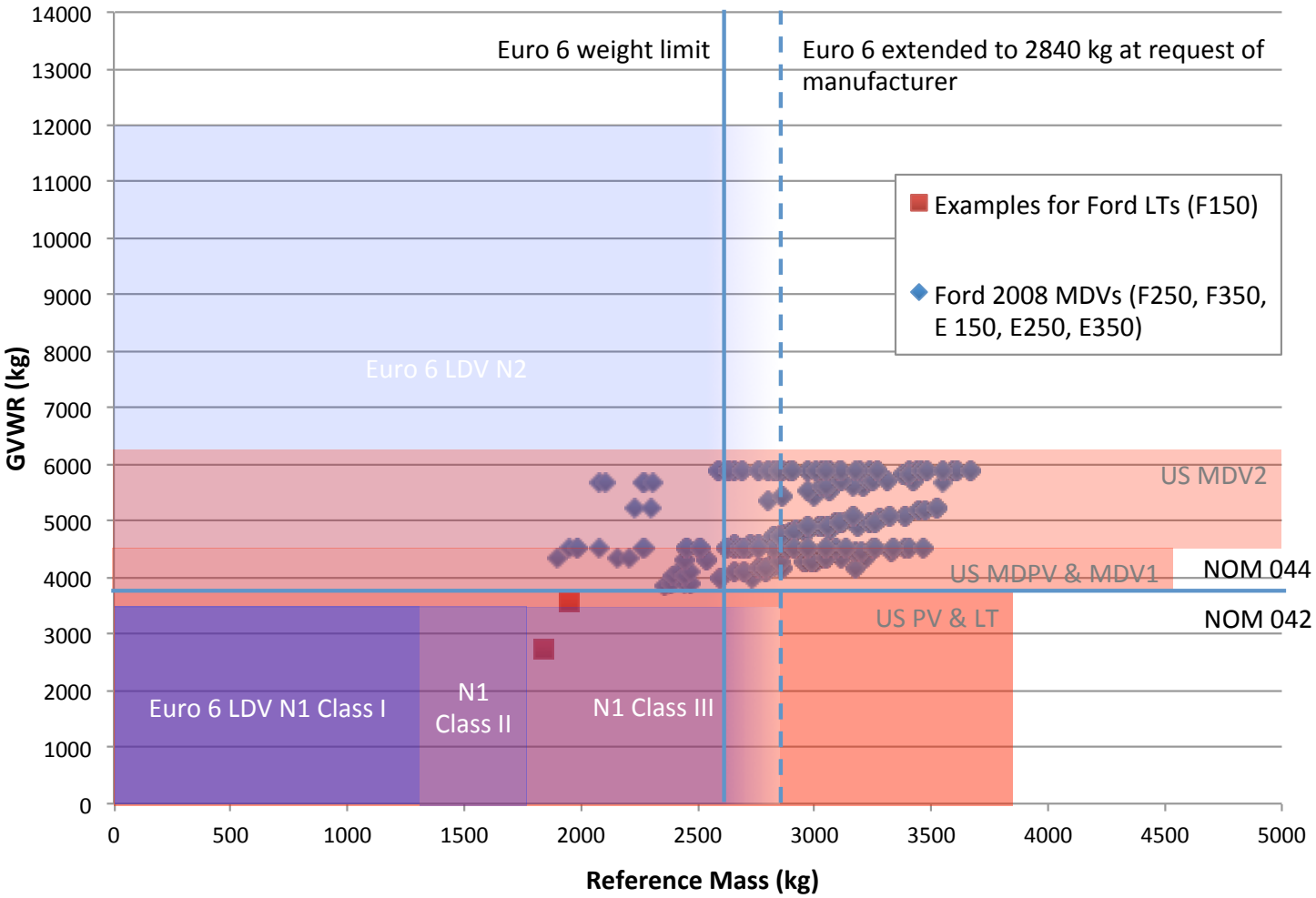
Overview

	US & California	European Union
Fuel quality	• Gasoline: 30 ppm sulfur average / 80 max (2006); 10 ppm average / 80 max (2017) • Diesel: 15 ppm sulfur max (2007)	• Gasoline & diesel: 50 ppm sulfur max (2005) • Gasoline & diesel: 10 ppm sulfur max (2009)
Test cycle	Federal Test Procedures + Supplemental Cycles: • FTP-75 (city cycle, includes cold start) • US06 (high speed) • SC03 (air conditioning) • HWFET (highway cycle, fuel economy only)	New European Drive Cycle: • NEDC (city and extra urban, includes cold start) World-Harmonized Light-Duty Vehicle Test Procedure: • WLTP (cold start, low, medium, high and aggressive driving in a single cycle) • Expected implementation in 2017
Coverage	Emissions: • Tier 2 standards cover all vehicles up to 3,855 kg GVWR and passenger vehicles up to 4,535 • LEV II and III and Tier 3 extend coverage to all complete vehicles up to 6,350 kg GVWR GHG: • Light-duty standards cover all LDVs (up to 3855 kg) and MDPVs (up to 4535kg) • Heavy-duty standards (all other on-road vehicles, including all trucks above 3855 kg)	Emissions: • Limit values set for passenger cars & light commercial vehicles by vehicle class/weight up to 2610 kg (RM) CO_2: • Passenger car standards apply to vehicles designed for the carriage of passengers (up to 3.5 tonnes GVWR) • Light commercial vehicle standards include all light trucks with RM up to 2610 kg in the N1 category (up to 3.5 tonnes GVWR)
Timeframe	Emissions: • US Tier 2 (phase in 2004-2009), Tier 3 (phase in 2017-2025) • California LEV II (phase in 2004-2010), LEV III (phase in 2015-2028) GHG: • Light-duty standards include 2012-2016 standards and 2017-2025 standards	Emissions: • Euro 4 (2005 for new vehicle type approval, 2006 all) • Euro 5a (2009 new, 2011 all); 5b (2011 new, 2013 all) • Euro 6 (2014 new, 2015 all); Euro 6c adds RDE (~2017) CO_2: • Current standards apply for the 2015 model year. 2020 standards are fully phased in for the 2021 model year and apply for all years beyond, until replaced.

Overview continued

	US & California	European Union
Pollutants	Emissions: • NO_x + NMOG and CO (bin certification, fleet averaging) • HCHO (limit value) • PM mass (limit values, phased in) GHG: • CO_2 (fleet average) • CH_4, N_2O (limit values) • F-gases (credits available)	Emissions: • NO_x, HC, NO_x+HC (diesels), PM and PN (limit values per vehicle category) CO_2: • CO_2 (fleet average)
Design	Emissions: • All passenger vehicles and vehicles under 3,856 kg GVWR certify to a single set of bins, with a fleet average requirements • Different bins for medium-duty cargo vehicles (3,856 – 6,350 kg GVWR) • Standards phase in over time, as fleets are required to meet lower average emissions and/or higher-emission bins are eliminated GHG: • Annual, footprint-based standards, increasing in stringency each year. • Banking of credits and debits for annual targets. • Credits for off-cycle emissions, hybrid trucks, F-gases and air conditioning, and electric vehicles.	Emissions: • Different maximum limit values set for diesel and gasoline • Values stay stable until for multiple years, until new standards are introduced CO_2: • Single year, mass-based standard, applying to an increasing percentage of the fleet in preceding years. • Super credits (for vehicles with 50 g/km or less CO2 emissions) and eco-innovation credits (up to 7 g/km).
Durability (emissions)	• 193,000 km or 10 years (Tier 2/LEV II) • 240,000 km or 15 years (Tier 3/LEV III)	• 160,000 km or 5 years, whichever comes first

Light and medium-duty weight classifications



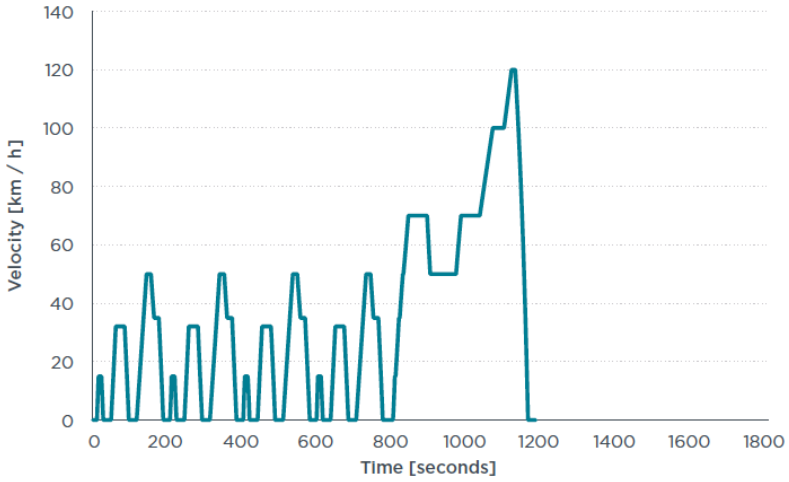
Weight classification mismatch between European and North American standards

Weight classifications

Standard	Classification			RM (EU) o LVW (US)	GVWR
EU, Euro 6	Euro 6			**Up to 2610 kg, up to 2840 kg at manufacturer request**	
	PV			All	
	LT	N1	Class II	0-1305 kg	0-3500 kg
			Class II	1306-1760 kg	
			Class II	More than 1760 kg	
		N2			3500-12,000 kg
US, Tier 3	Tier 3				**Up to 6350 kg**
	PV		PV		3856 kg
			MDPV		3856-4536 kg
	LDT		LDT1	0-1701 kg	
			LDT2	More than 1701 kg	Less than 3856 kg
	MDV		Class 2b		3856-4536 kg
			Class 3		4536-6350 kg
Mexico, NOM 042					**Up to 3856 kg**

Test cycles

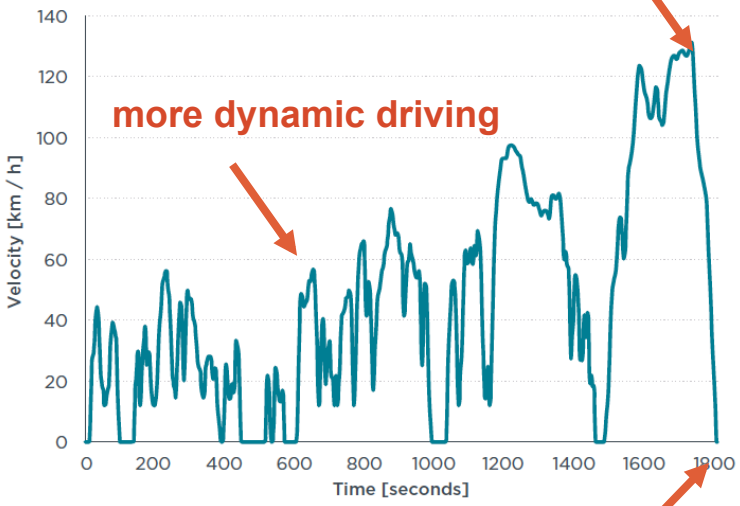
NEDC (1970s / 1990s)



WLTP (2014, replace NEDC in 2017)

130 km/h vs. 120 km/h

more dynamic driving

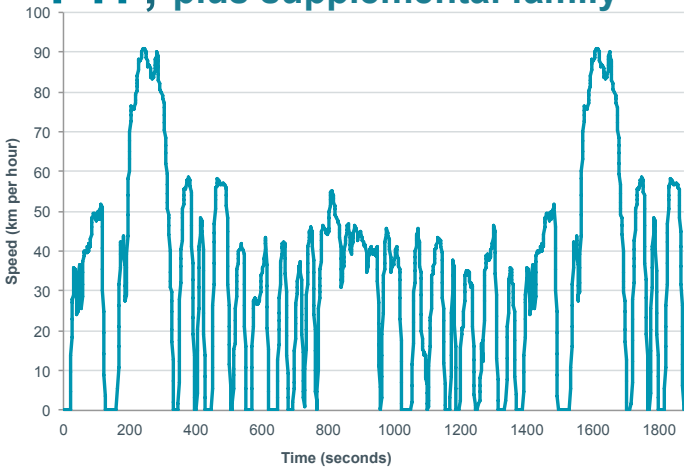


longer test cycle

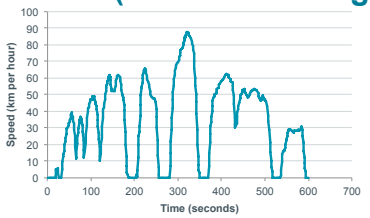
+ improved test procedure

http://www.theicct.org/wltp-november2013-update

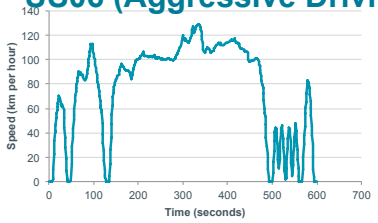
FTP, plus supplemental family



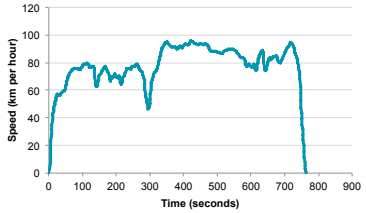
SC03 (Air conditioning)



US06 (Aggressive Driving)



HWFET (Highway, Fuel Economy only)



Emissions standards

Tier 2 Bins (FTP)	NMOG (mg/km)	NOx (mg/km)	PM[a] (mg/km)	CO (mg/km)	HCHO (mg/km)
Bin 8	78	124	12	2610	11
Bin 7	56	93	12	2610	11
Bin 6	56	62	6	2610	11
Bin 5	56	44	6	2610	11
Bin 4	44	25	6	1305	7
Bin 3	34	19	6	1305	7
Bin 2	6	12	6	1305	2
Bin 1	0	0	0	0	0

Tier 3 Bins (FTP)	NMOG+ NOX (mg/km)	PM[a] (mg/km)	CO (mg/km)	HCHO (mg/km)
Tier 2 Bin 5/	56+44=100	6	2610	11
Bin 160	100	2	2610	2
Bin 125	78	2	1305	2
Bin 70	44	2	1057	2
Bin 50	31	2	1057	2
Bin 30	19	2	622	2
Bin 20	12	2	622	2
Bin 0	0	0	0	0

Euro 6 standards by vehicle class	NMOG+ NOX (mg/km)	PM[a] (mg/km)	CO (mg/km)	PN (#/km)
Diesel				
LT, N2 & N1, III	215	5	740	6.0×10^{11}
LT N1, II	195	5	630	6.0×10^{11}
LT N1, I & PV	170	5	500	6.0×10^{11}
Gasoline (NMOG & NOx are set as separate limits)				
LT, N2 & N1, III	242	5	2270	6.0×10^{11}
LT N1, II	205	5	1810	6.0×10^{11}
LT N1, I & PV	160	5	1000	6.0×10^{11}

- Bin 5 (fleet average) becomes the highest (interim) bin in Tier 3
- Euro 6 standards are similar in stringency to Tier 2
- Realworld NOx emissions from Euro 6-certified diesels are ~600 mg/km.

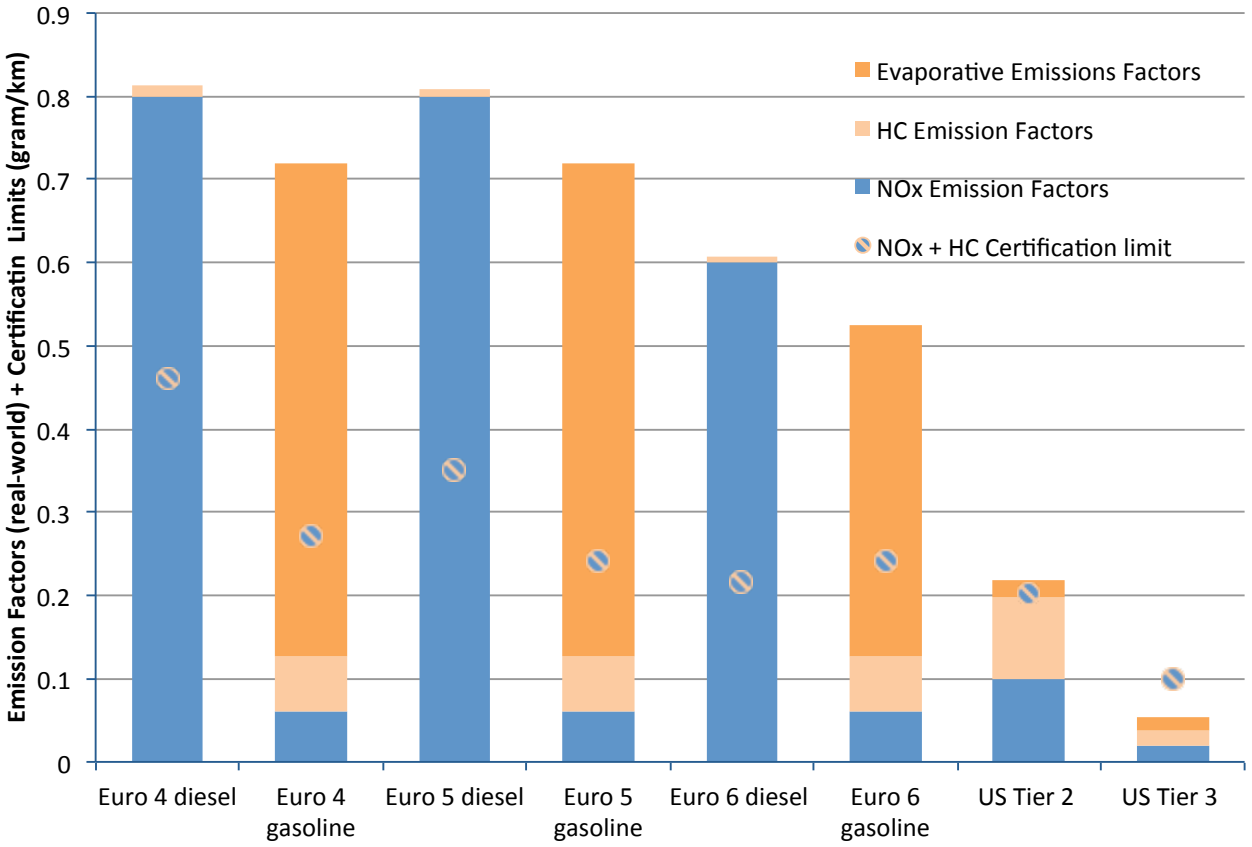
US EPA Tier 3 and CA LEV III Program

- Unlike Euro standards, US Tier 3 & CA LEV III standards:
  - Are fuel-neutral (same for gasoline and diesel).
  - Apply to all passenger vehicles and light trucks, phasing down to a single fleet average for all.
  - Cover medium-duty commercial trucks (separate bins provided), previously regulated with heavy-duty engine standards.
- Fleet average, bin standards:
  - NMOG+NOx are fleet average standards: each vehicle certified to a per-vehicle "bin" standard and values are sales weighted to calculate fleet-average emissions.
  - Bin structure allows manufacturers flexibility, provides motivation for marketing of significantly cleaner vehicles.
- PM is a per-vehicle limit:
  - Phased-in as a % of new vehicle sales.
  - Final Tier 3 limit is 3 mg/mi (1.9 mg/km) in 2022, LEV III includes additional phase-in period to 1 mg/mi (0.6 mg/km).

Tier 3 NMOG+NOx (mg/mi)	2017	2018	2019	2020	2021	2022	2023	2024	2025+
LDV & LDT1	86	79	72	65	58	51	44	37	30
LDT2, 3,4 & MDPV	101	92	83	74	65	56	47	38	

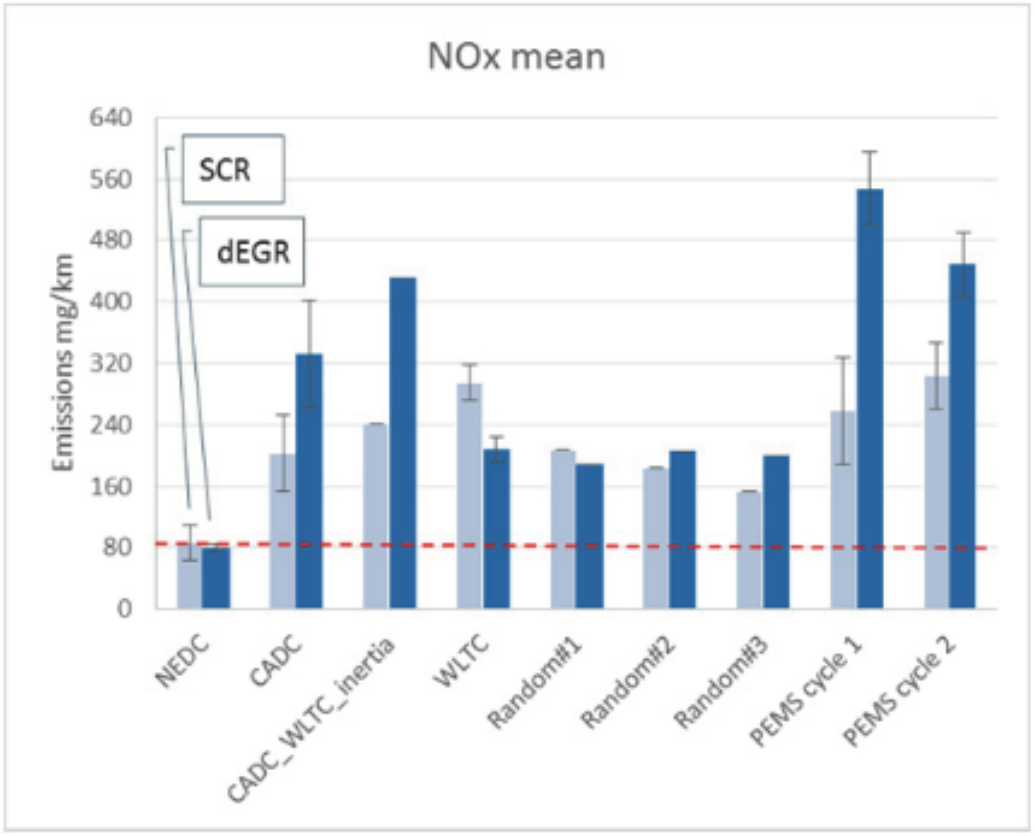
Tier 3 PM (mg/mi)	2017	2018	2019	2020	2021	2022
Phase-in (%)	20%	20%	40%	70%	100%	100%
FTP certification (mg/mi)	3	3	3	3	3	3
FTP In-use (mg/mi)	6	6	6	6	6	3

US and European standards are not equivalent



- Very little change from Euro 3 to 6 in exhaust emissions. Evaporative emissions go down for Euro 6 gasoline vehicles.
- Diesel emissions might decline as WLTC and Real Driving Emissions (RDE) are incorporated into Euro 6.
- Different test cycle complicate comparison: NEDC is a little stronger for gasoline vehicles (cold start is more important) but weaker for diesels (higher loads are more important). WLTP is more similar to FTP.
- US Tier 2 and 3 standards are fleet average standards, whereas Euro 6 is based on maximum limits. Current NOM 042 standards also set maximum value limits, which do not provide incentive to introduce cleaner models.

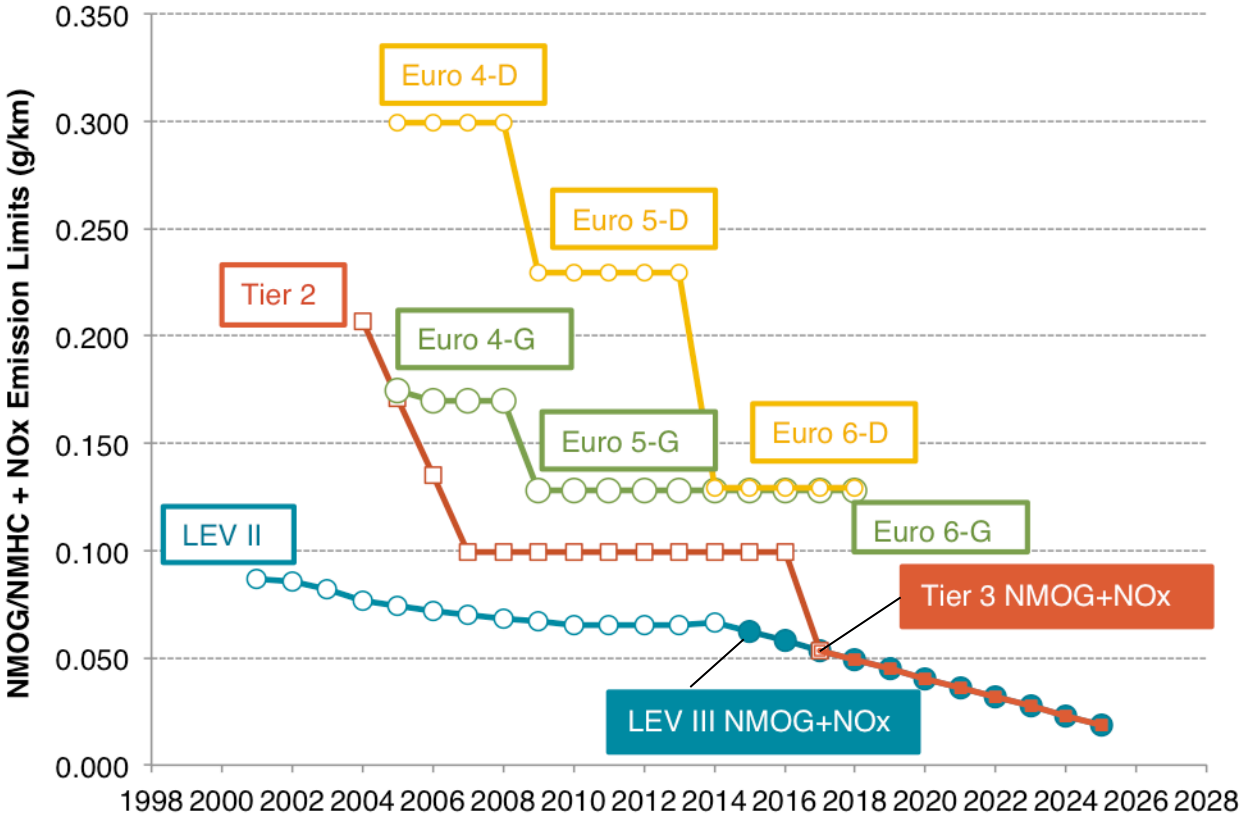
Test cycle makes a difference in stringency



On-Road Testing and PEMS Data Analysis for two Euro 6 Diesel Vehicles. J. May, C. Favre, D. Bosteels, J. Andersson, D. Clarke and M. Heaney, 20th International Transport and Air Pollution Conference 2014

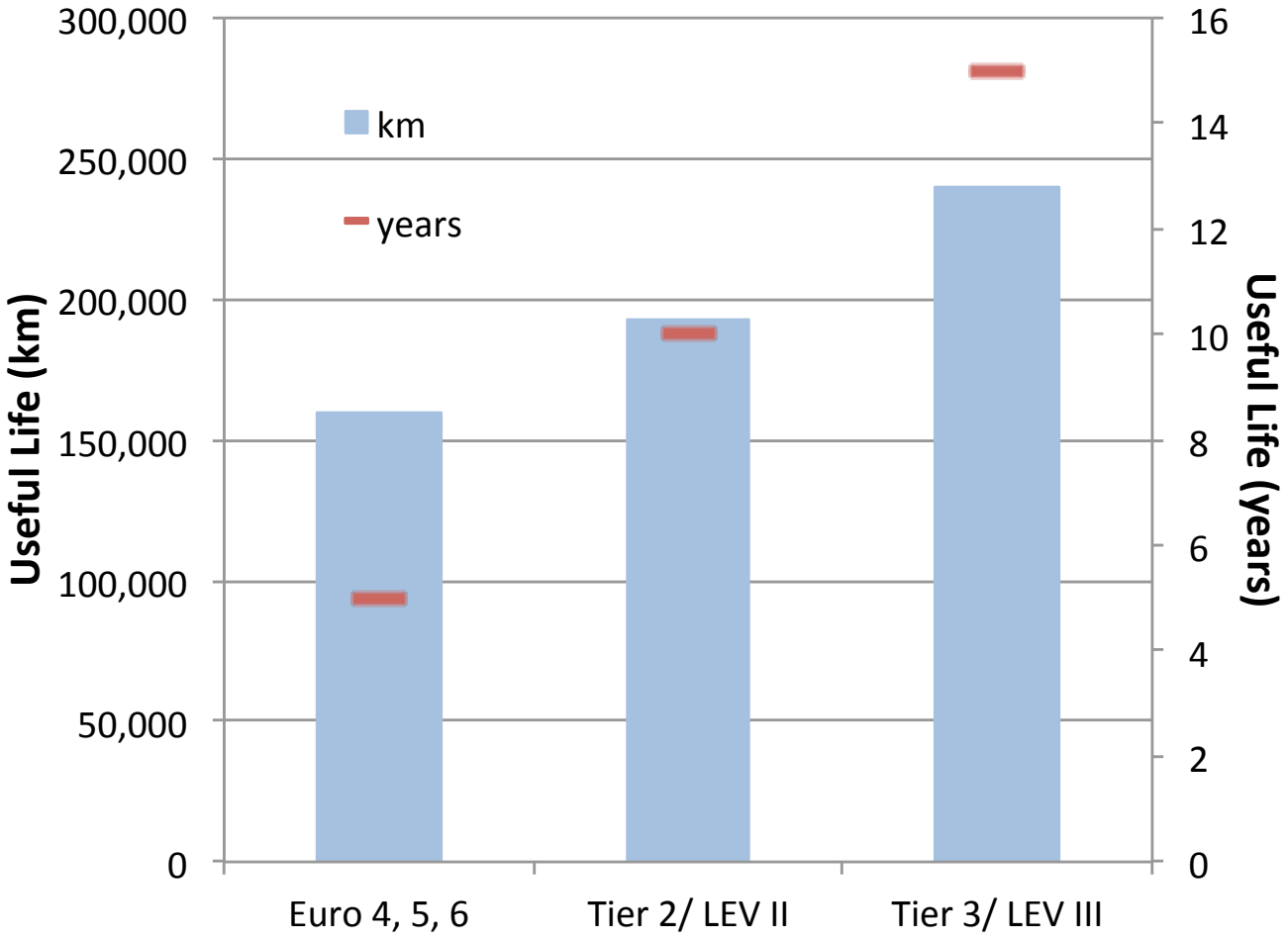
- Lack of aggressive driving and high load conditions make NEDC particularly weak for diesel vehicles.
- In contrast, the high apportionment of cold start makes it a more stringent cycle for gasoline vehicles.

Comparison of Standards – NOx and NMHC/NMOG

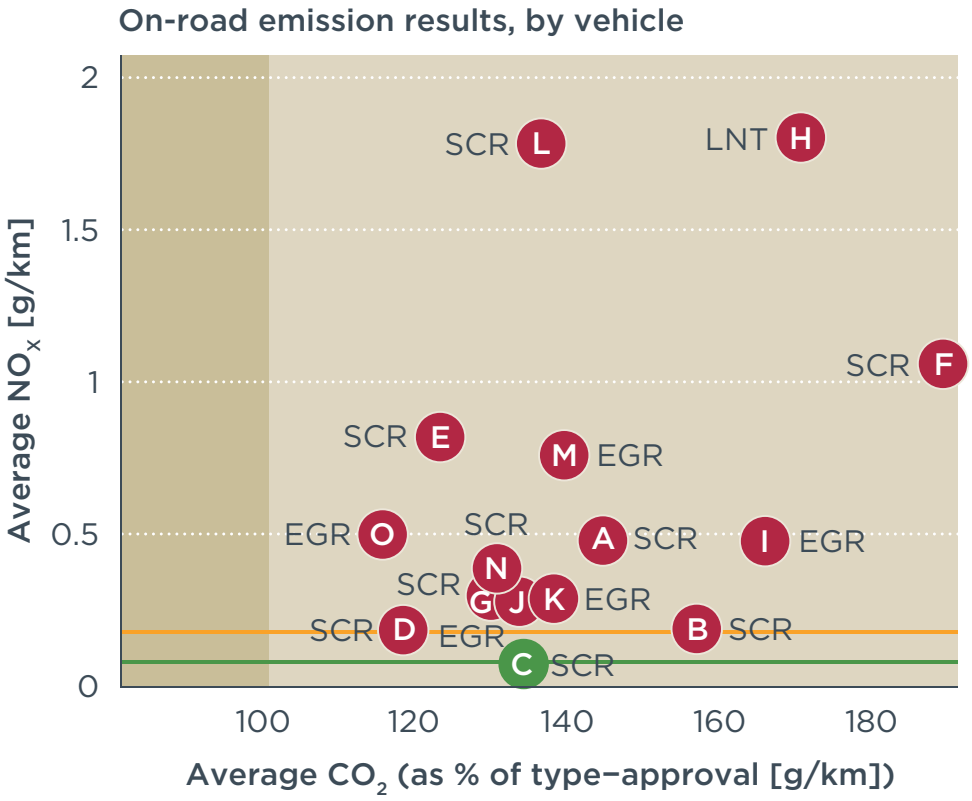


- Values for ARB LEV and EPA Tier programs are fleet average values; Euro program values are max-per-vehicle values
- Only LEV III and Tier 3 have set NMOG+NOx standards; all other "standards" presented here are the summation of independent NOx Standards and NMHC or NMOG

Useful Life of Emissions Control Systems



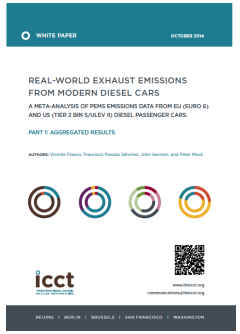
Real NO_x emissions of Euro 6 diesel cars are on average 7 times higher than allowed limit



Above type–approval
Below or equal to type–approval
Above Euro 5 limit
Above Euro 6, below Euro 5 limit
Below Euro 6 limit
Euro 5 limit
Euro 6 limit

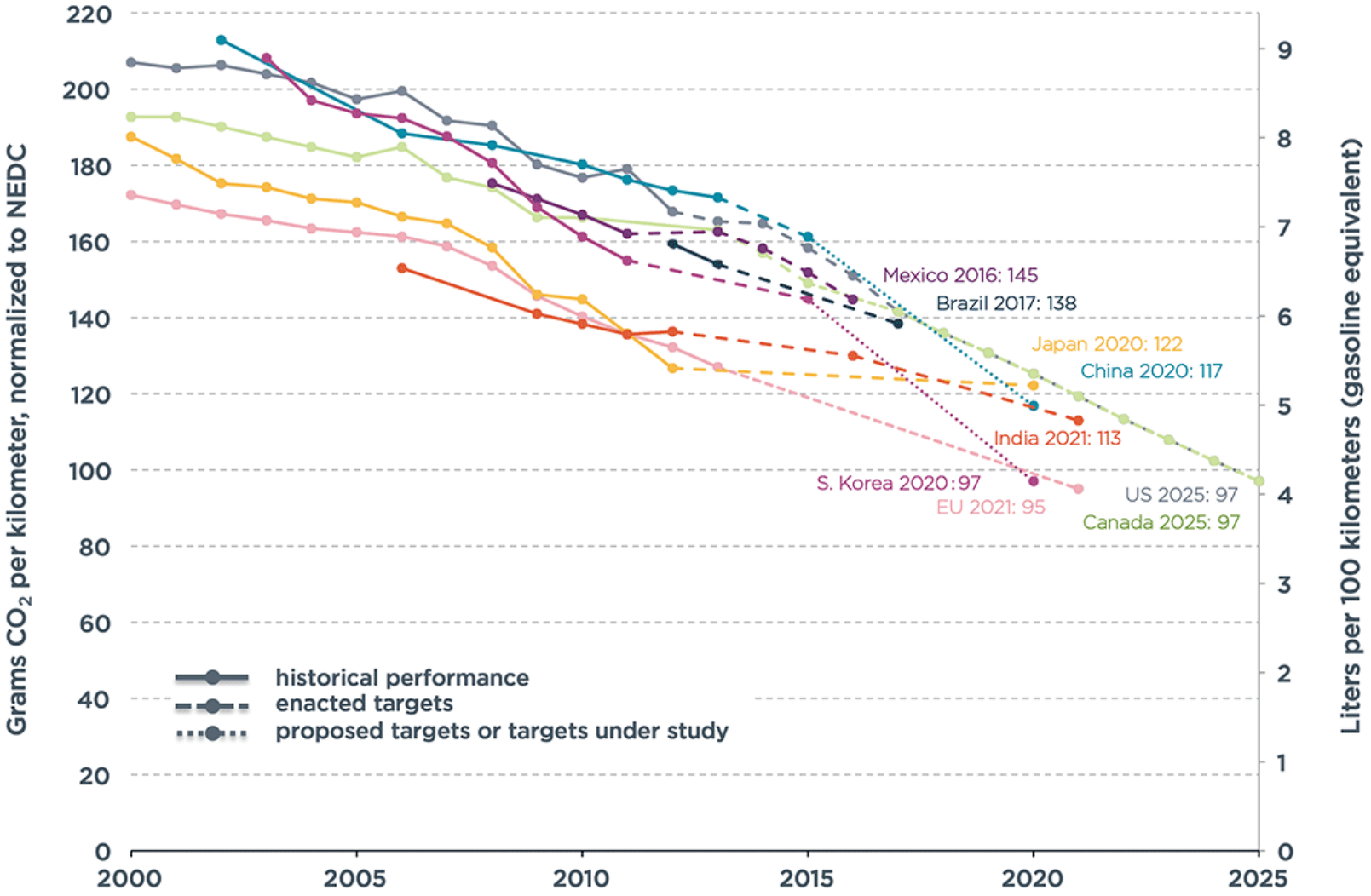
15 test vehicles in total (6 manufacturers), with different NO_x control technologies:
- 10 selective catalytic reduction (SCR)
- 4 exhaust gas recirculation (EGR)
- 1 lean NO_x trap (LNT)

Average Euro 6 NO_x conformity factors (ratio of on-road emissions to legal limits):
- all cars: 7.1
- best performer (Vehicle C, SCR): 1.0
- bad performer (Vehicle H, LNT): 24.3
- worst performer (Vehicle L, SCR): 25.4

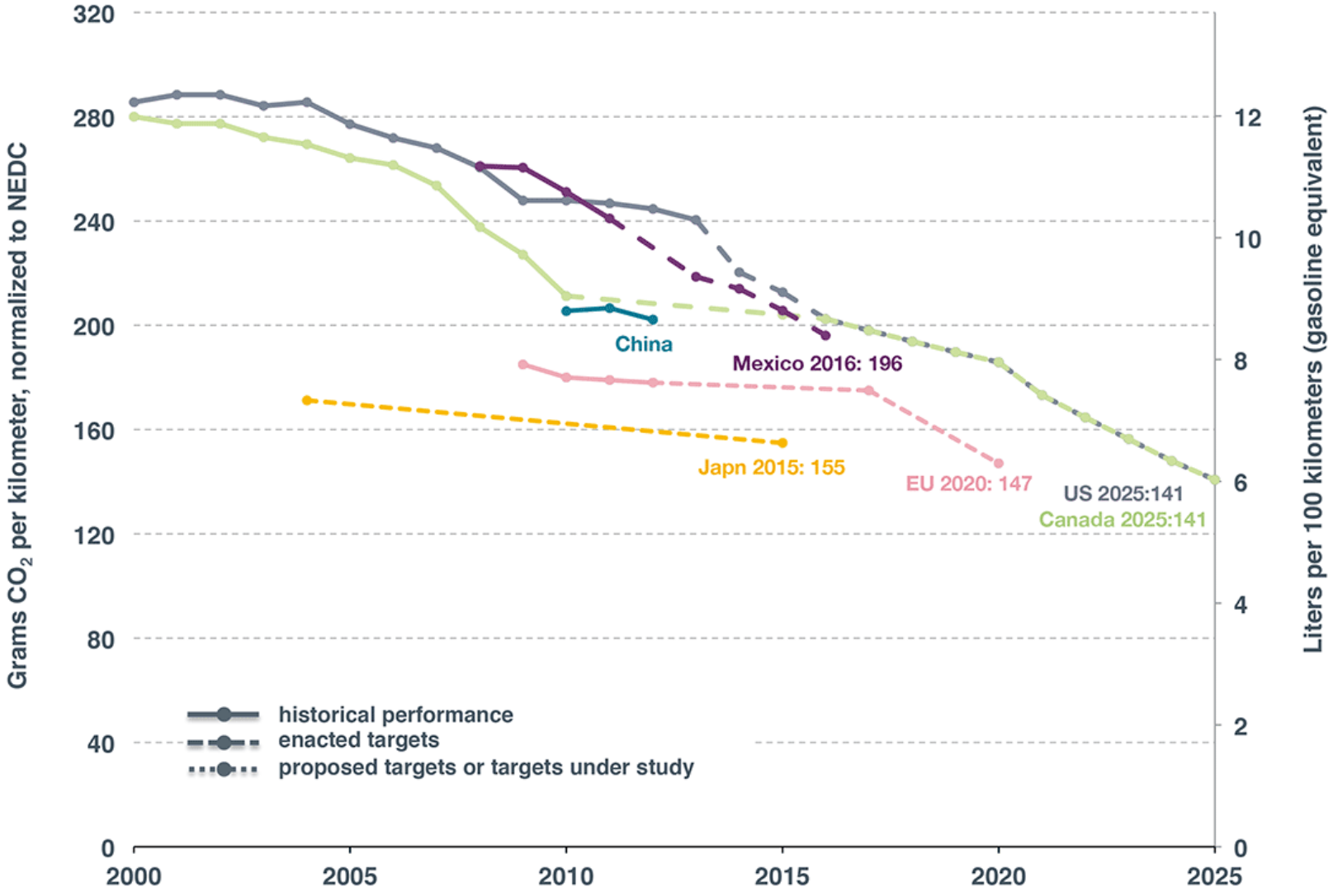


http://www.theicct.org/real-world-exhaust-emissions-modern-diesel-cars

Passenger vehicle GHG standards



Light truck GHG standards

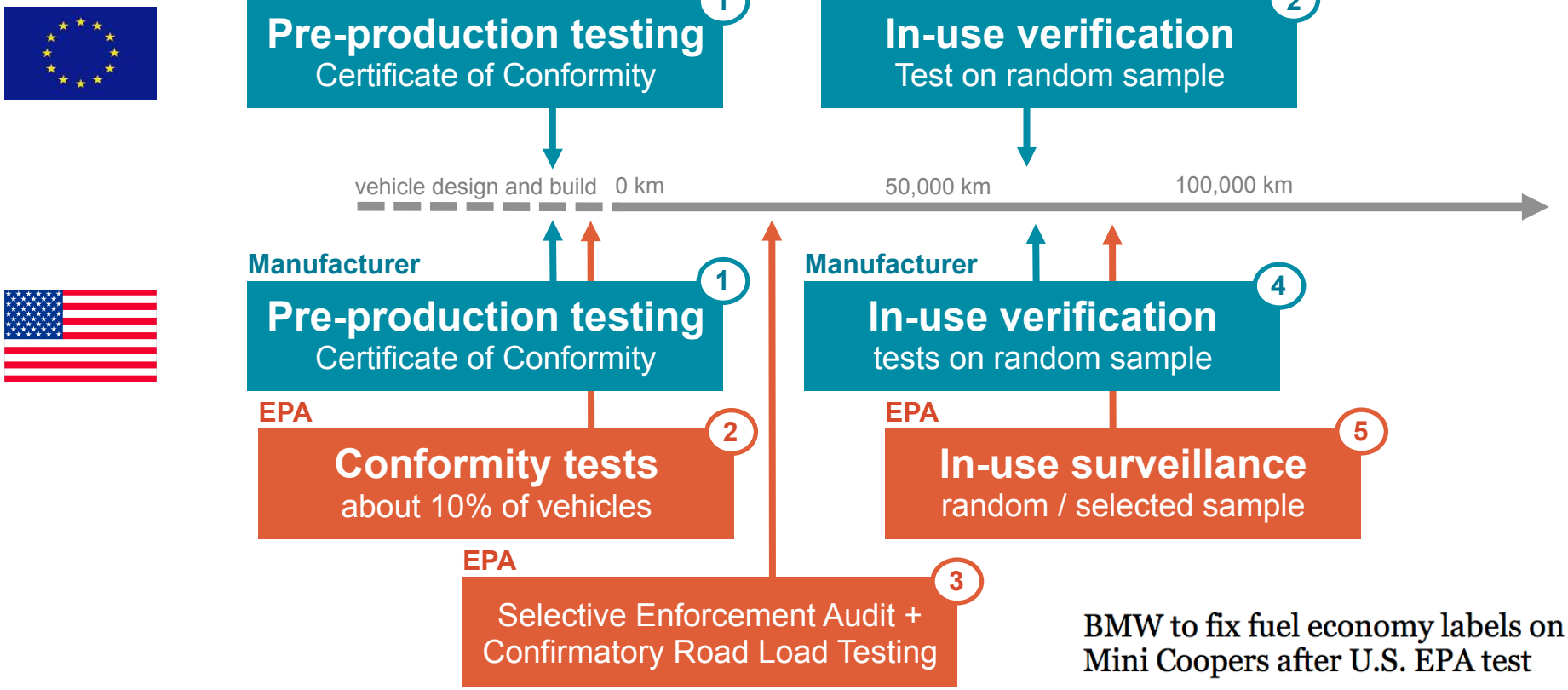


GHG standards

- Standard stringency
  - Similar stringency for both passenger cars and light trucks, standards are similarly split
- US standards
  - Annual fleet average standards with banking of credits and debits, ensure ongoing fleet improvement while allowing flexibility in compliance
  - Footprint-based standards allow for GHG reductions/efficiency improvement due to weight reductions
  - Rigorous testing requirements, more comprehensive test cycles, and real compliance enforcement
- European standards
  - Standards are 4 years ahead of US standards
  - Fewer light trucks result in better overall fleet average
  - Higher share of diesels further increase fuel economy

In-Use Emissions

Compliance and Enforcement



BMW to fix fuel economy labels on Mini Coopers after U.S. EPA test

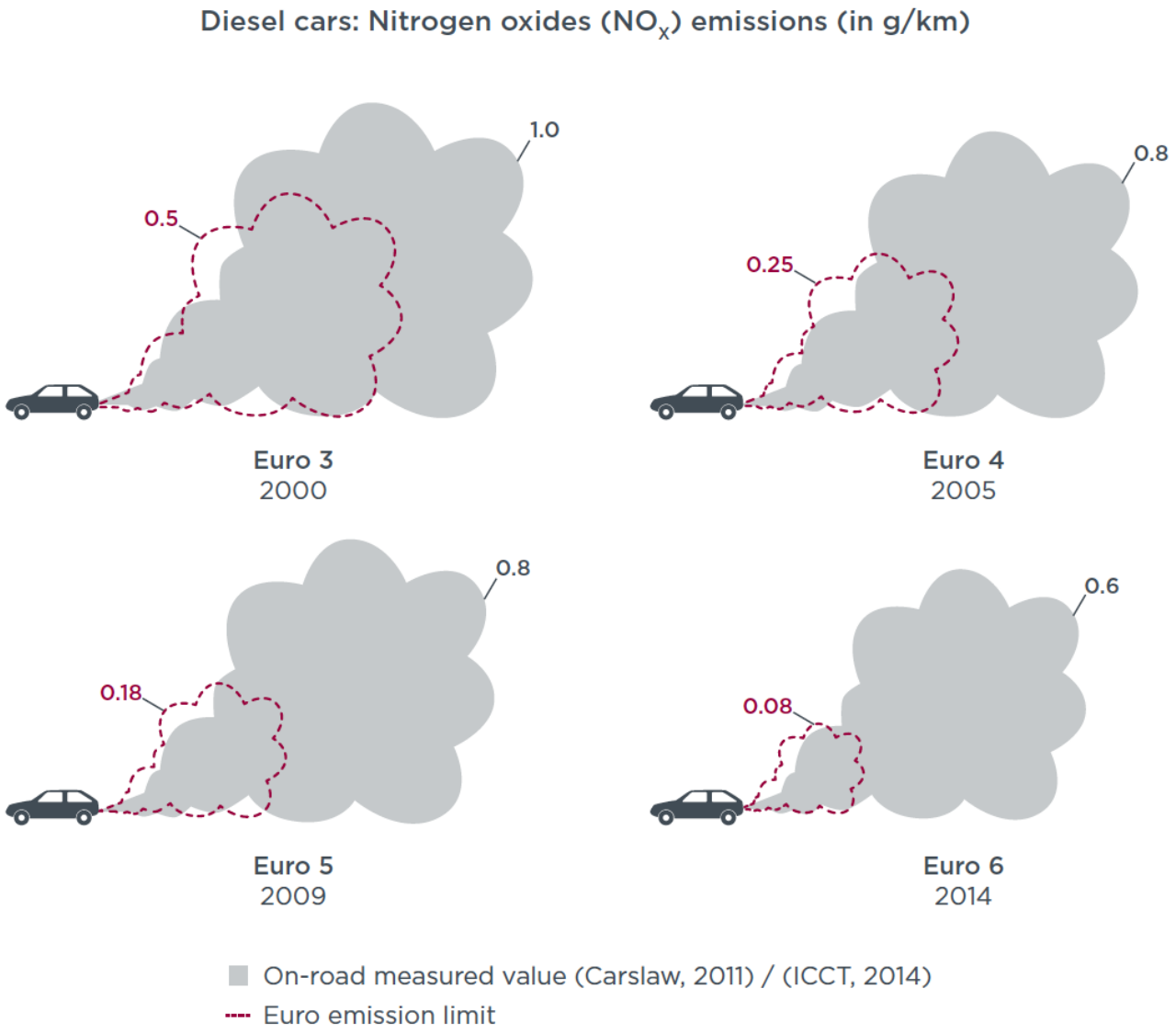
DETROIT | Wed Oct 22, 2014 11:08am EDT

U.S. Fines Hyundai, Kia for Fuel Claims

Penalty of $300 Million Is Largest Ever, Could Set Pricey Precedent for Other Auto Makers

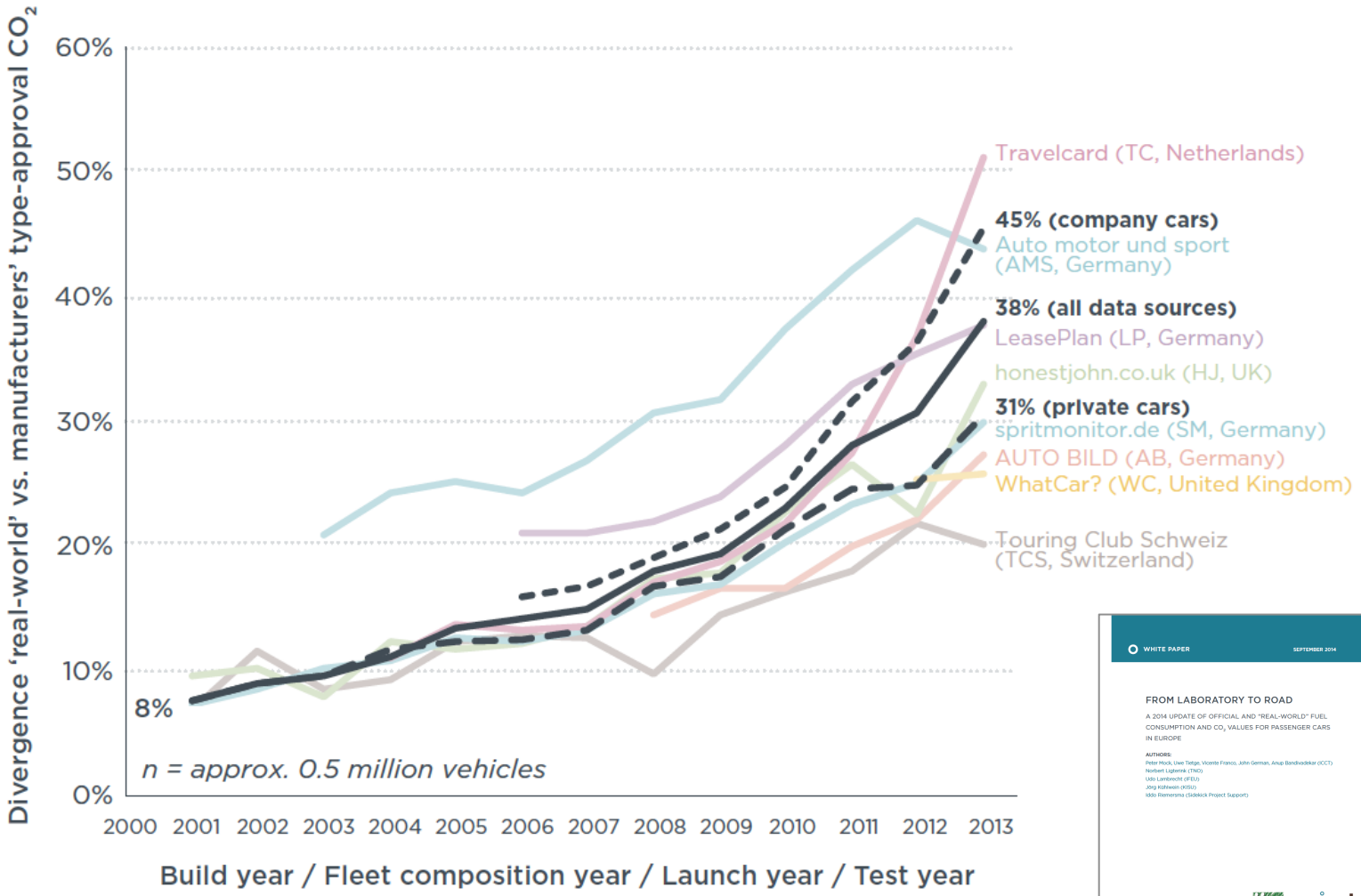
http://www.theicct.org/blogs/staff/bought-tiger-got-hello-kitty-how-fix-vehicle-fuel-economy-fraud-china

NO_x emissions of Euro 6 diesel cars higher than the Euro 3 limit value



http://www.theicct.org/real-world-exhaust-emissions-modern-diesel-cars

Real-world fuel consumption of new cars in EU is about 30+% higher than claimed by manufacturers



WHITE PAPER SEPTEMBER 2014

FROM LABORATORY TO ROAD

A 2014 UPDATE OF OFFICIAL AND "REAL-WORLD" FUEL CONSUMPTION AND CO_2 VALUES FOR PASSENGER CARS IN EUROPE

AUTHORS:
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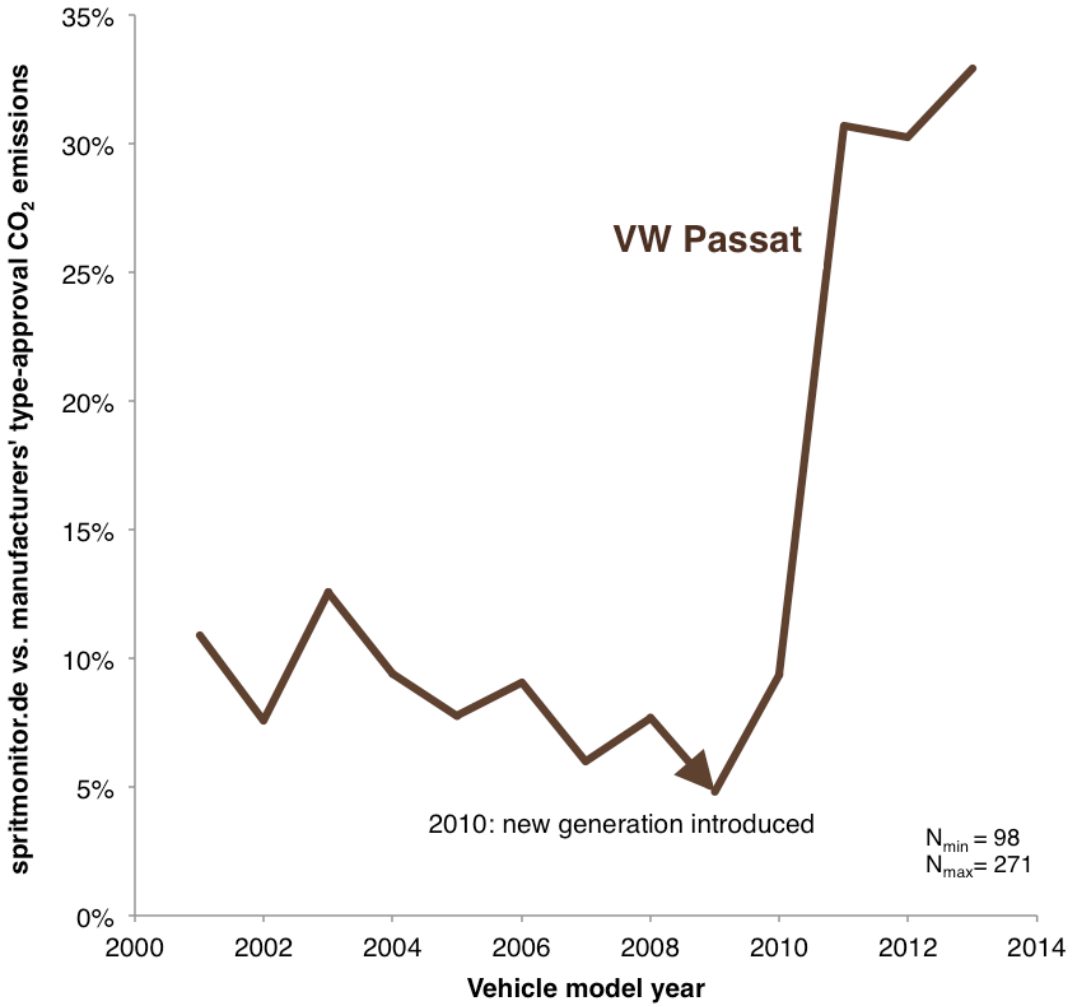
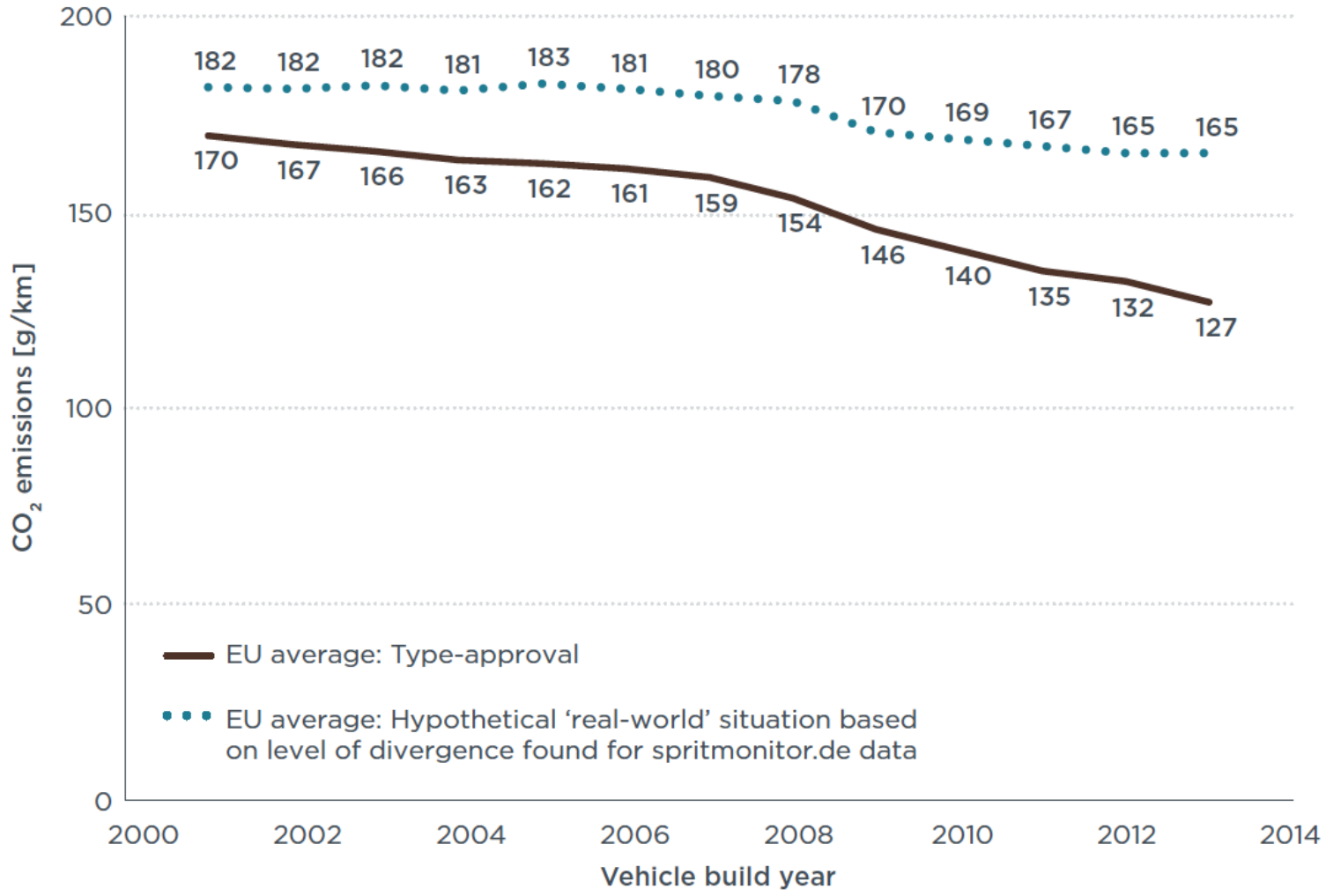
http://www.theicct.org/laboratory-road-2014-update

The growing gap appears to be largely attributable models being strongly optimized to the test cycle



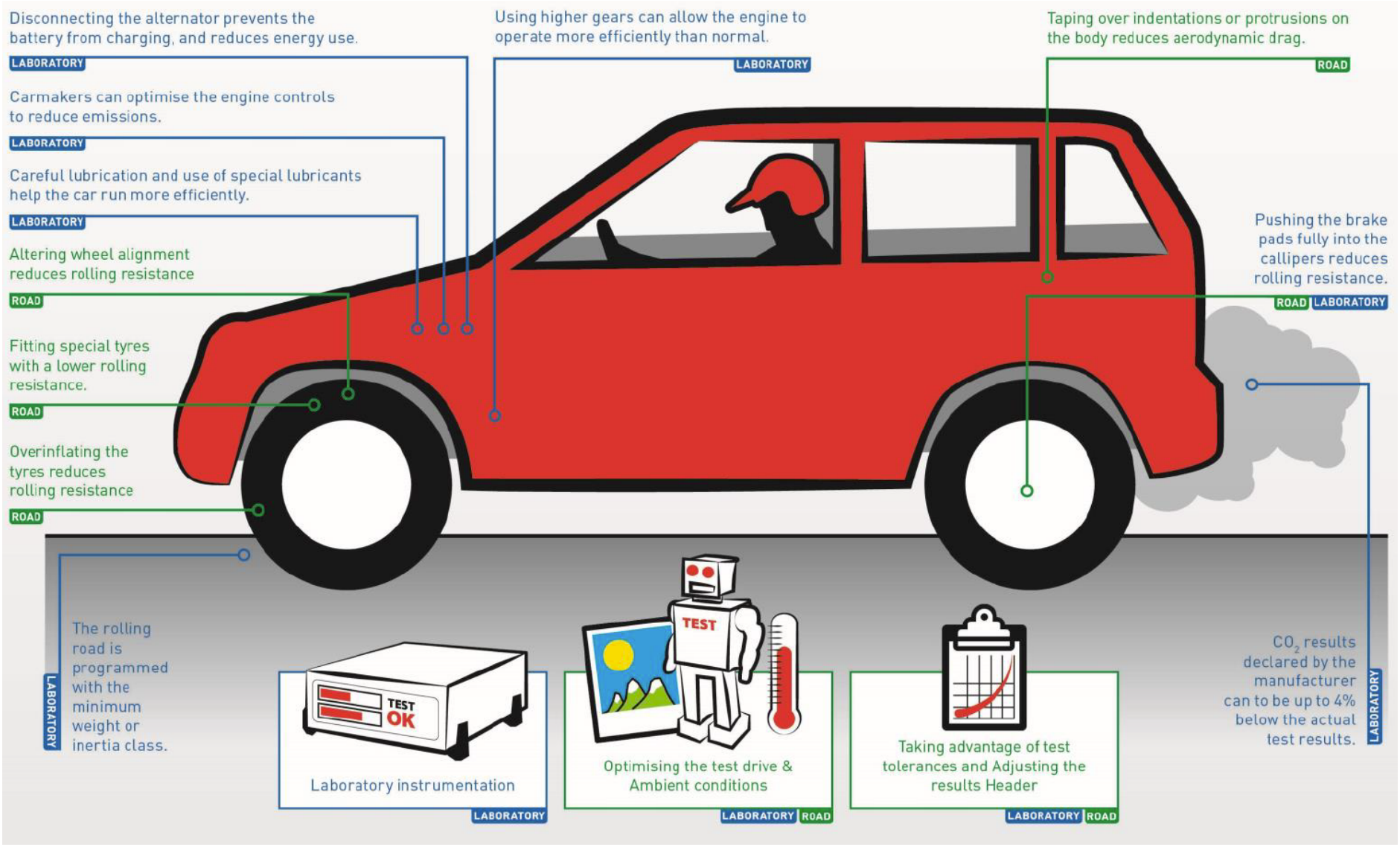
http://www.theicct.org/blogs/staff/trend-that-cant-continue-europes-car-co2-emissions-gap

A growing gap means that only part of the expected fuel consumption/CO_2 reduction may be real



http://www.theicct.org/laboratory-road-2014-update

There are many ways to optimize vehicles for the laboratory testing



Vehicle inspection

- European Union
  - Requires periodic inspection of all vehicles and trailers at regular intervals
  - Allows for unannounced roadside inspections of commercial vehicles in any EU country, regardless of place of registration
  - Sets standards for implementation
  - Member states are responsible for implementation
- United States
  - Clean Air Act requires I/M for certain regions, based on air quality, population and location
  - Sets standards for implementation and QA/QC
  - States are responsible for I/M implementation
  - State programs may include tailpipe emissions tests (idle, acceleration, etc) and/or OBD tests for MY1996+, along with visual checks, evaporative emissions tests (primarily gas cap)
  - Mostly focus on gasoline vehicles, set cutpoints, frequency, and MY requirements by state

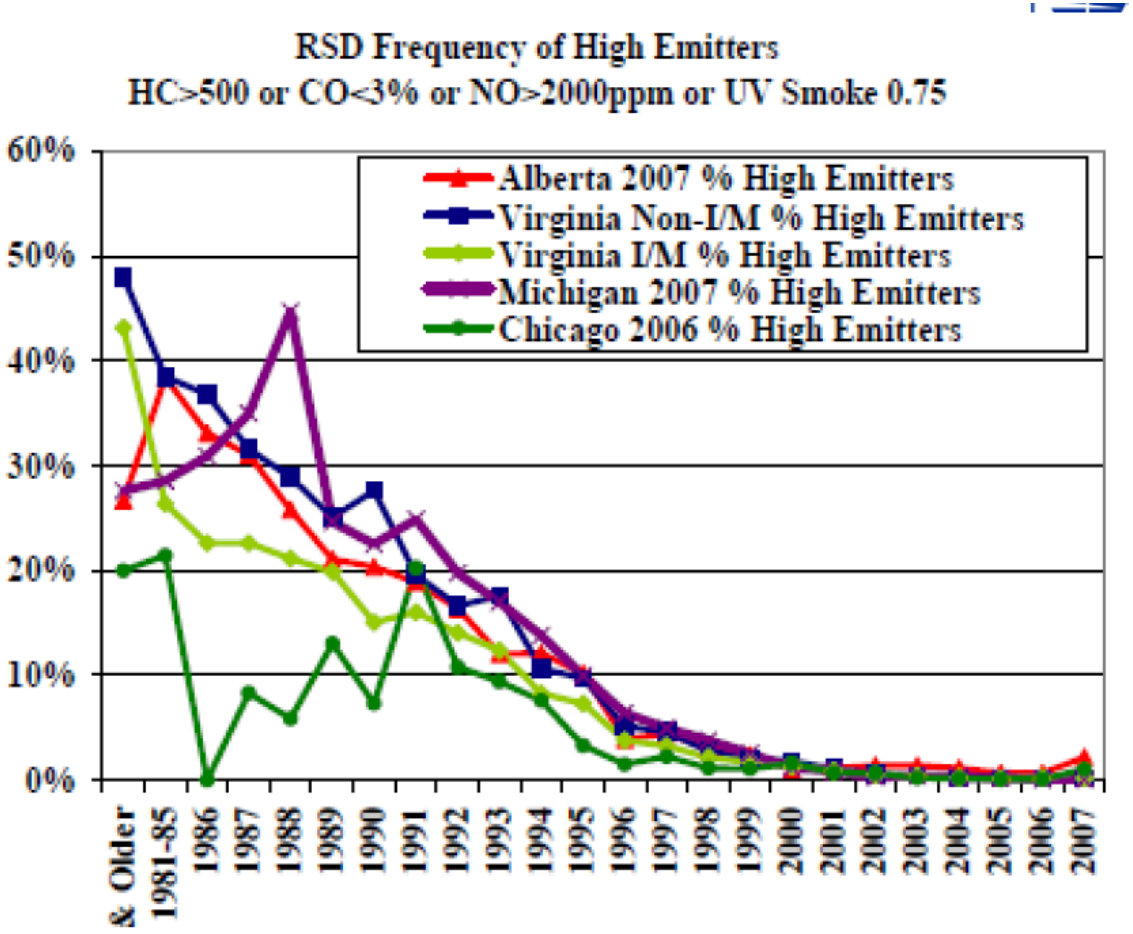
OBD in inspection

- Widely used in US and Europe
  - US OBDII and EU EOBD Systems are very different, with different software and hardware requirements
  - EOBD systems: Euro 5 communication compliant with ISO 15031-5
    Euro 6 communication complaint with ISO 15765-4
  - OBDII systems are complaint with ISO 15765-4
- Ensuring proper implementation
  - Provisions (like those to be discussed by ARB) are critical to guard against cheating are critical to ensure effectiveness of programs
  - Also need requirements in place for reporting of defects, doing field fixes and implementing running changes
- OBD appears to be a relatively robust tool for controlling emissions from vehicles in use, if proper safeguards and procedures are in place

Remote sensing

- Programs are widespread in Europe and U.S.
- Useful tool for monitoring mean on-road fleet emissions
  - Ensure that new vehicle standards are operating as intended
  - Ensuring the effectiveness of I/M programs, including guarding against corruption in test centers
  - Can be used to better calibrate emissions modeling
- Challenging to use results for enforcement or to replace I/M
  - Requires a mandate to repair/further inspect identified high emitters
  - Clean screen can reduce the burden of I/M programs

Remote sensing: OBD effective



Remote sensing: high diesel NOx emissions

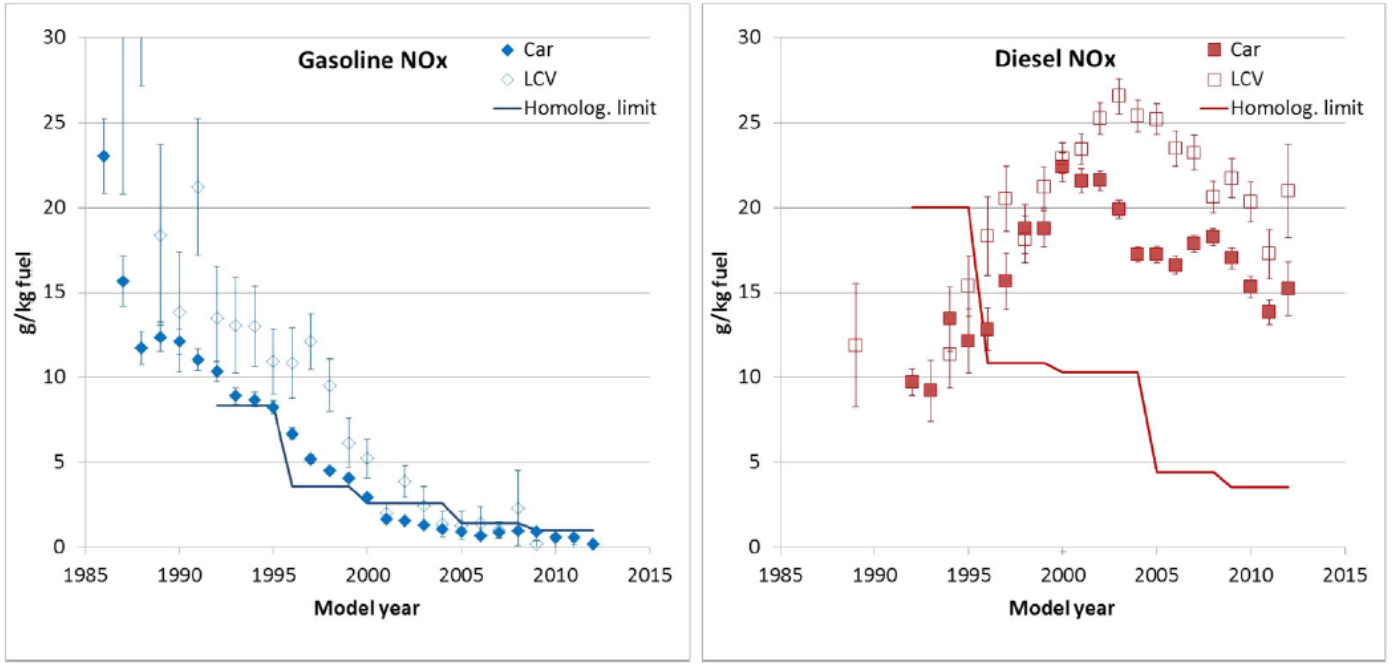


Fig. 4. Mean hot NO_x emission factors of gasoline (left) and diesel (right) passenger cars and light commercial vehicles as a function of model year. Whiskers represent the 95% confidence interval over the mean. Added are the type approval limit values for Euro 1 to Euro 5 passenger cars over the homologation test cycle in force in the respective year. For conversion from limit values in g per km see SI (using measured fuel consumption rates from Hausberger (2010)). For color plot consult online version.

Chen, Y., Borken-Kleefeld, J. (2014). Amospheric Environment 88 (2014) 157-164

Low Emission Zones

- Definition: designated geographic areas within which certain categories of vehicles – usually the highest-emitting vehicles in a fleet – are restricted from operating.
  - Outright ban of certain class of vehicles or emission standard
  - Ban during certain times of the day
- LEZs are very popular in Europe and China, not in the U.S.
- Labeling is a strong complementary policy to LEZ
  - Generally based on original certification level, with retrofit option if available

Emission groups	**1**	**2**	**3**	**4**
Stickers	no sticker			
Requierements for **diesel engines**	Euro 1 or worse	Euro 2 or Euro 1 + particulate filter	Euro 3 or Euro 2 + particulate filter	Euro 4 or Euro 3 + particulate filter
Requierements for **petrol engines**	Without a reg. cat according to Ann. XXIII StVZO			Without a reg. cat according to Ann. XXIII StVZO or. Euro 1 or better

- Clearly specified timelines for implementation with increasing stringency
- Effective enforcement with appropriate penalties to deter non-compliance
  - "Appropriate" varies by region. In Italy, equal to a parking ticket (70 Euros). In Denmark, equal to the cost of a DPF (10,000 Euros).

Low Emission Zones – selected results

City / Region	Year of LEZ Introduction / Measurement	Indicator
Berlin	**2008** / 2009	-24% diesel PM -8% overall PM_{10}
Munich	2006-7 / **2008** / 2009-10	-60% transport contribution from 1.1 to 0.5 µg/m³ elemental carbon[18]
Netherlands – 9 cities	**2007** / 2008	up to 2µg/m³ PM reduction
London	**2008** / 2008-2012	-5.8% PM_{10} -13% average annual PM_{10} concentration[19]
Cologne	**2008**	4µg/m³ PM_{10} reduction 1.2µg/m³ NO_2 reduction
Stockholm	**1996** / 2000	-60% PM_{10} -20% NO_x
Milan – emission-based congestion charge	**2011** / 2012	-19% PM10[20] -14% NOx -15% CO_2

Conclusions

- Compliance and enforcement is the most critical aspect of all regulations and the key to success of US and CA policies
- US/CA programs are both more complex and more rigorous while providing more flexibilities to manufacturers
  - Bin system encourages manufacturers to design and market increasingly clean vehicles
  - Footprint-based GHG standards reward weight reduction
  - Enforcement is a real threat, standards are very detailed to eliminate loopholes
  - OBD enforcement mechanisms both reduce ability to cheat and increase increase information to regulators (defect reporting requirements)
- European LEZs have been effective in reducing air pollution in key areas and accelerating fleet turnover

Autoline interview with Oliver Schmidt, Powertrain Development, VW