Opportunity for international harmonization of future emission standards: Post-Euro 6/VI perspective

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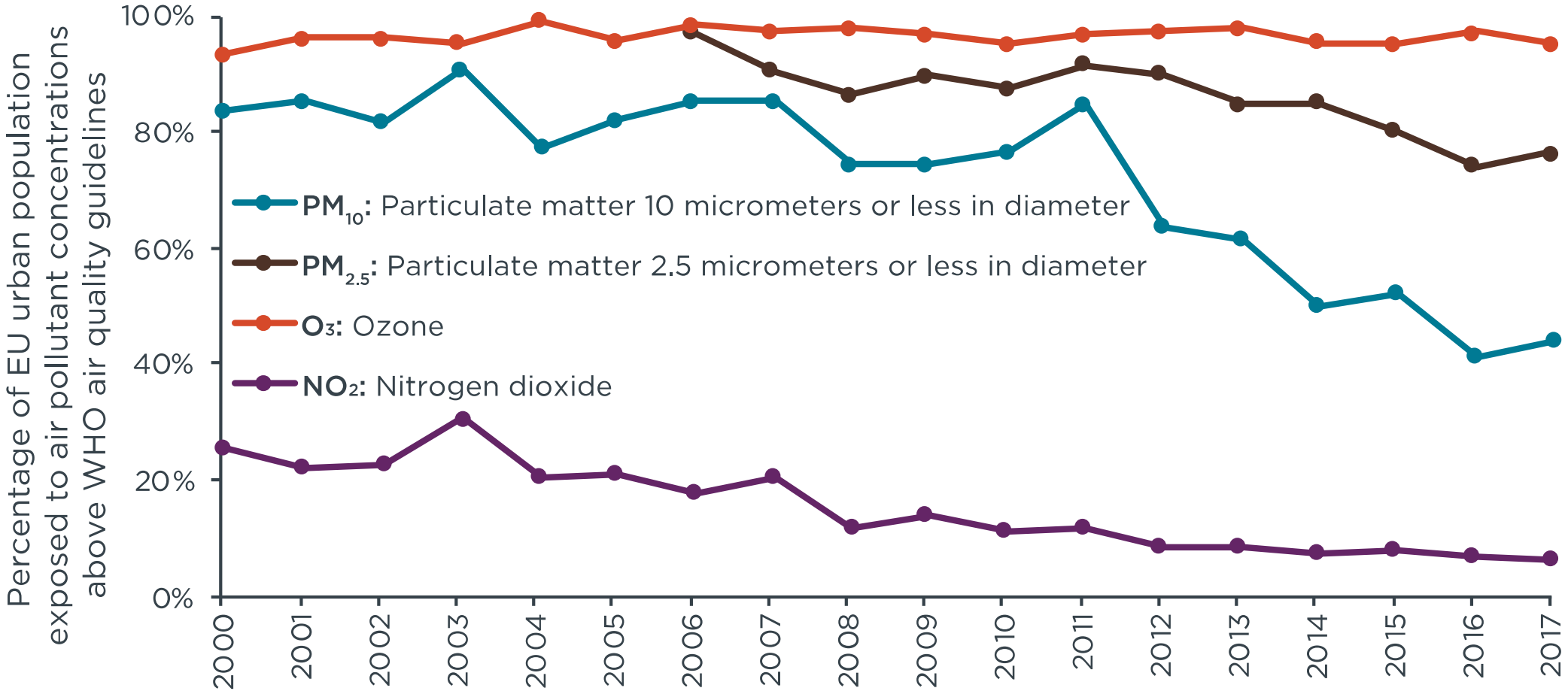
In 2017, 92% of the world's population lived in areas that exceeded the WHO Guideline for $PM_{2.5}$ (10 µg/m³).

Example: Share of EU urban population exposure above WHO's guidelines



G20 economies account for ~84% of global health burden from transportation tailpipe emissions.

Table 2. Air quality and health impacts of transportation tailpipe emissions in G20 economies in 2015. Estimates are rounded to two or three significant figures.

Region	Ambient $PM_{2.5}$ and ozone deaths			Transportation health damages		Share of transportation-attributable deaths by source/sector					
	Transportation-attributable deaths	All emissions sources	Transportation-attributable fraction (%)	Transportation health damages ($billion 2015 USD)	As a share of GNI, Atlas method (%)	On-road diesel vehicles	On-road non-diesel vehicles	Non-road mobile sources	International shipping
Argentina	970	16 000	6%	2.1	0.38%	38%	9%	38%	15%
Australia	620	4800	13%	6.4	0.45%	36%	9%	29%	25%
Brazil	5700	52 000	11%	9.9	0.47%	50%	7%	18%	25%
Canada	1 400	8700	16%	12	0.60%	37%	28%	30%	5%
China	114 000	1 020 000	11%	160	1.43%	34%	21%	27%	18%
France	6 400	20 000	32%	45	1.65%	66%	5%	12%	18%
Germany	13 000	43 000	31%	110	2.83%	66%	8%	13%	14%
Indonesia	7 100	54 000	13%	4.2	0.47%	34%	29%	10%	27%
Italy	7 800	32 000	25%	44	2.21%	66%	6%	11%	17%
India	74 000	800 000	9%	20	0.96%	66%	10%	19%	5%
Japan	9 900	52 000	19%	66	1.34%	32%	13%	15%	41%
Mexico	8 100	36 000	23%	14	1.11%	39%	31%	25%	6%
Russian Federation	13 000	104 000	13%	27	1.53%	27%	21%	40%	5%
Saudi Arabia	420	8800	5%	1.7	0.23%	55%	17%	10%	18%
South Africa	1 400	20 000	7%	1.5	0.44%	48%	24%	11%	16%
South Korea	2 900	18 000	16%	14	0.97%	45%	18%	13%	24%
Turkey	2 900	41 000	7%	6.0	0.64%	46%	11%	19%	25%
United Kingdom	8 400	25 000	33%	63	2.20%	46%	6%	10%	38%
United States	22 000	115 000	19%	210	1.16%	43%	20%	24%	6%
Other EU	22 000	119 000	18%	110	1.68%	53%	9%	15%	19%
G20 subtotal	323 000	2 530 000	12%	914	1.37%	47%	16%	22%	15%
Global	385 000	3 370 000	11%	976	0.72%	47%	17%	21%	16%
G20 share of global	84%	77%		94%					

Anenberg, S. C., Miller, J., Henze, D. K., Minjares, R., & Achakulwisut, P. (2019). The global burden of transportation tailpipe emissions on air pollution-related mortality in 2010 and 2015. *Environmental Research Letters*, *14*(9), 094012. https://doi.org/10.1088/1748-9326/ab35fc

Progress toward cleaner fuels and vehicles in G20 economies

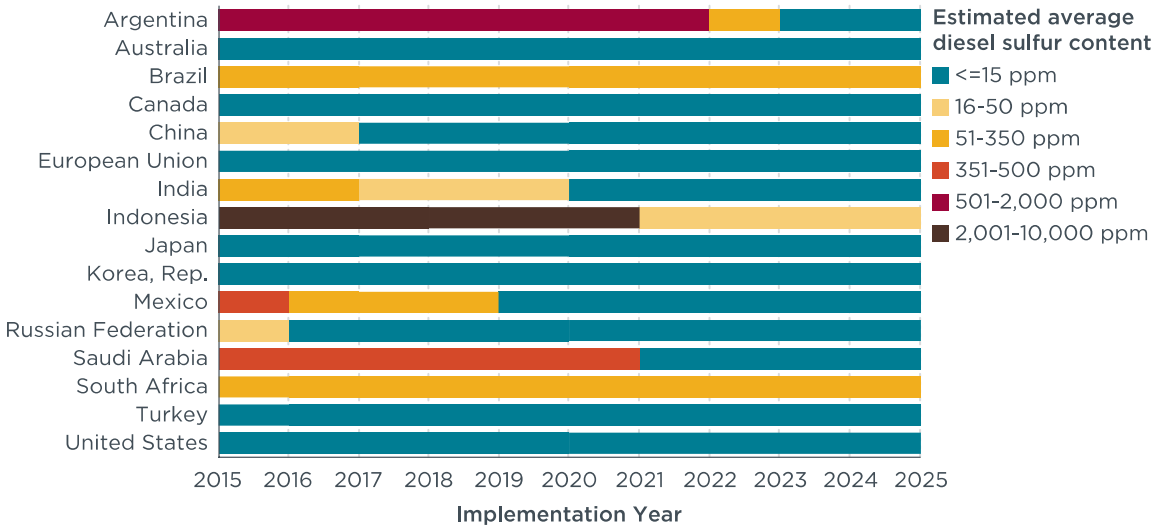


Figure 3. Timeline of average on-road diesel sulfur content in G20 economies

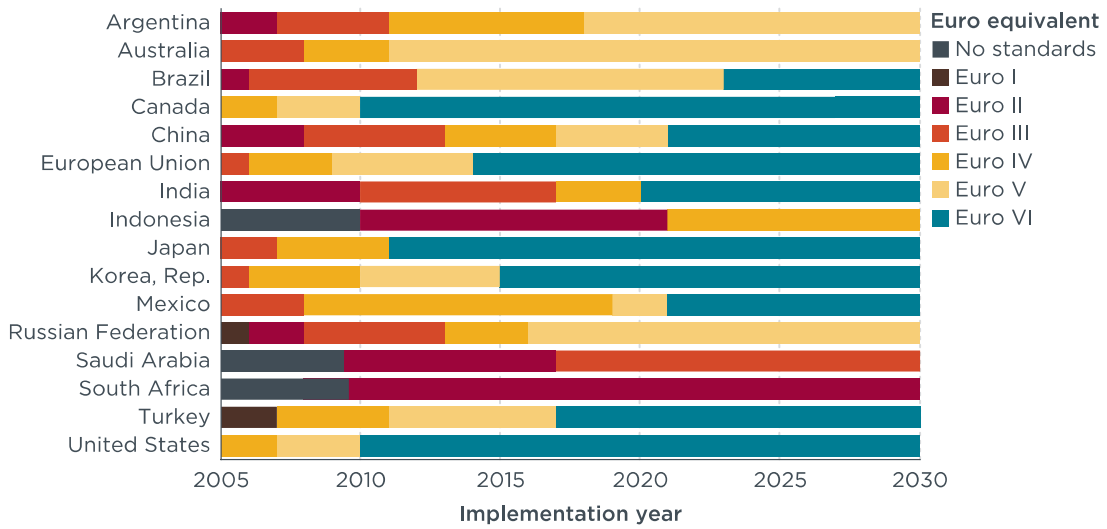
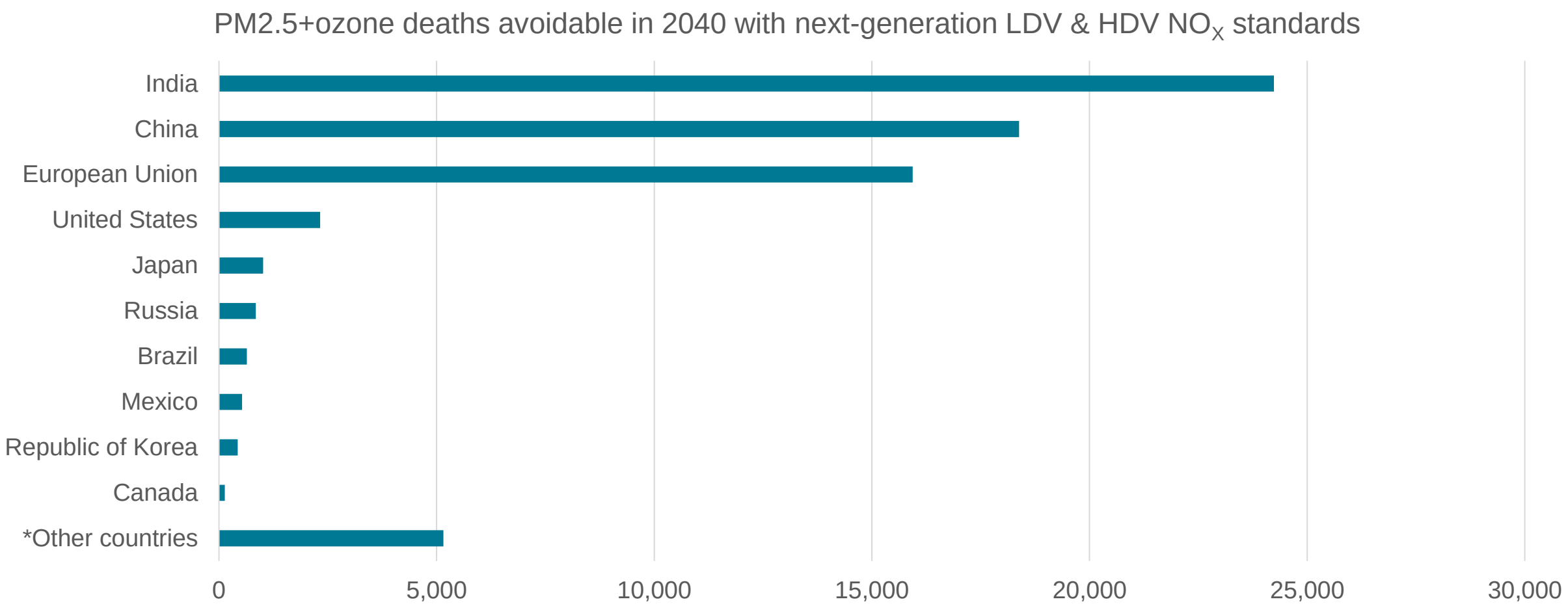


Figure 6. Implementation of heavy-duty diesel engine emission standards in G20 economies

https://theicct.org/publications/global-progress-toward-soot-free-diesel-vehicles-2019

Further standards to reduce on-road NO_X emissions in major markets could avoid ~70,000 premature deaths annually by 2040.

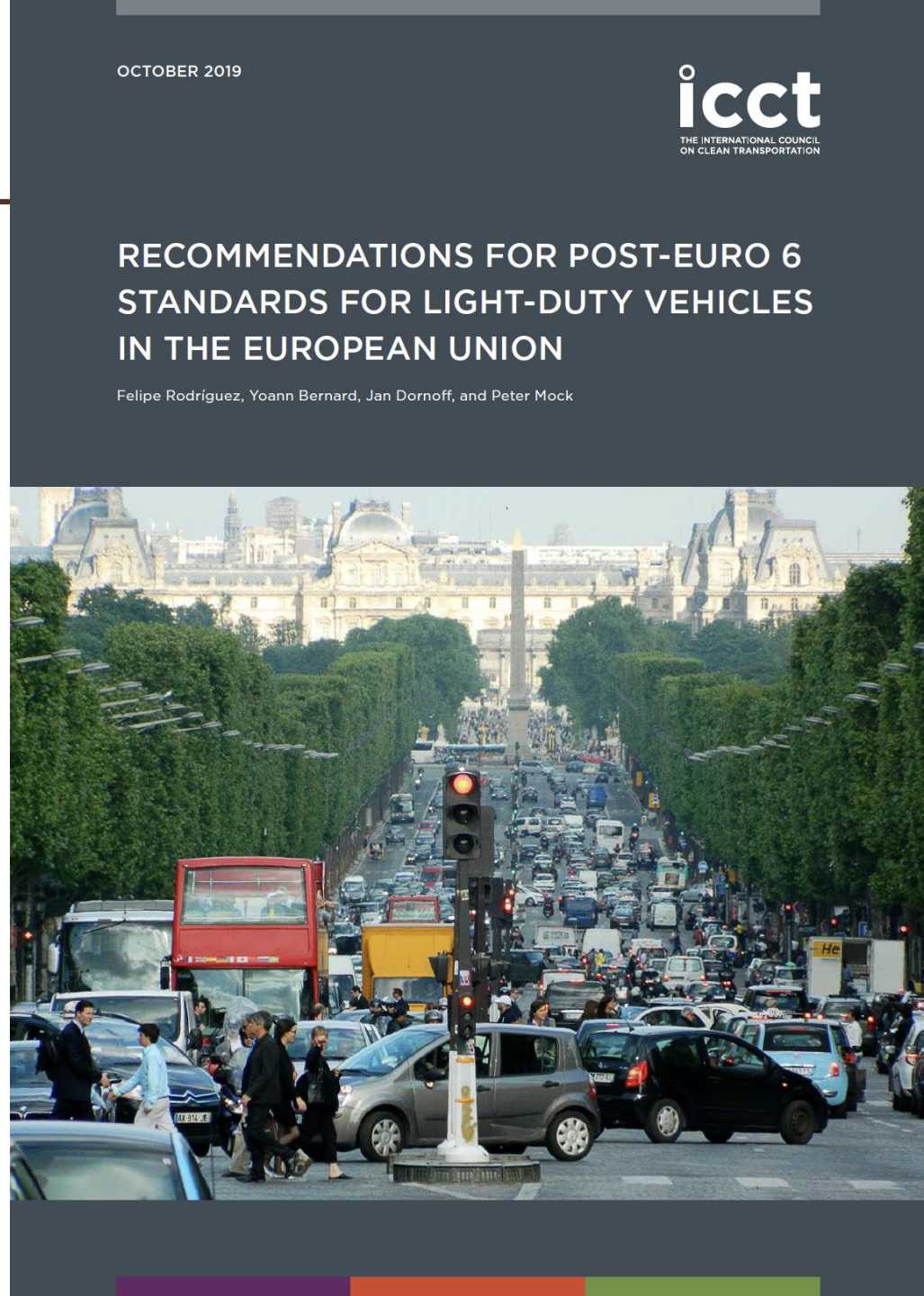


**Transboundary air pollution effects from major markets*

Data source: Anenberg, S. C., Miller, J., Minjares, R., Du, L., Henze, D. K., Lacey, F., … Heyes, C. (2017). Impacts and mitigation of excess diesel-related NOx emissions in 11 major vehicle markets. *Nature*, *545*(7655), 467–471. https://doi.org/10.1038/nature22086

Recent report

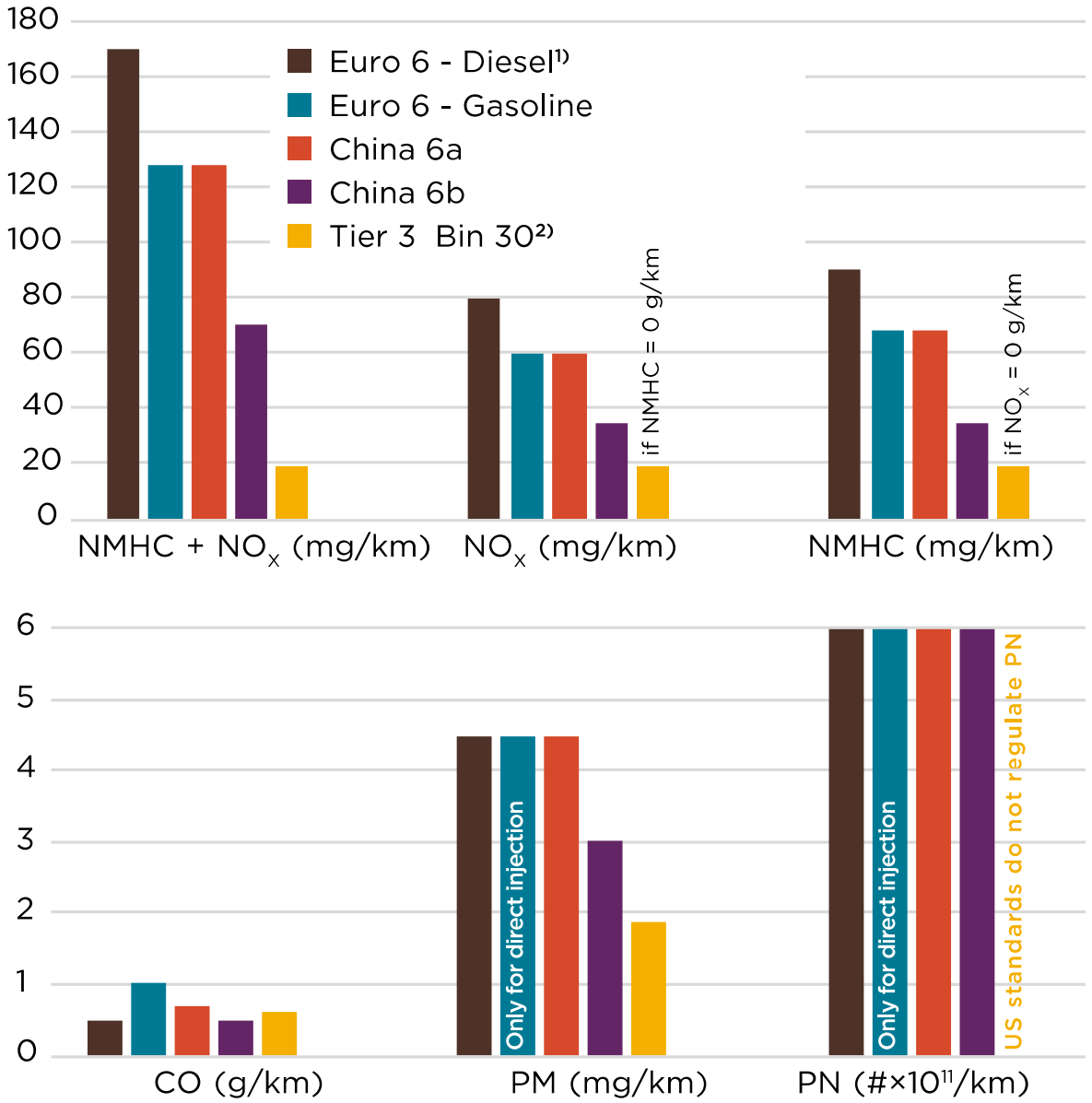
- This presentation is based on a recent ICCT report, providing ICCT's recommendations for the development of post-Euro 6 standards.
- Published paper covers only LDVs
- Similar HDV paper will be published in a couple of weeks.
- https://www.theicct.org/publications/recommendations-post-euro-6-eu



What to regulate?

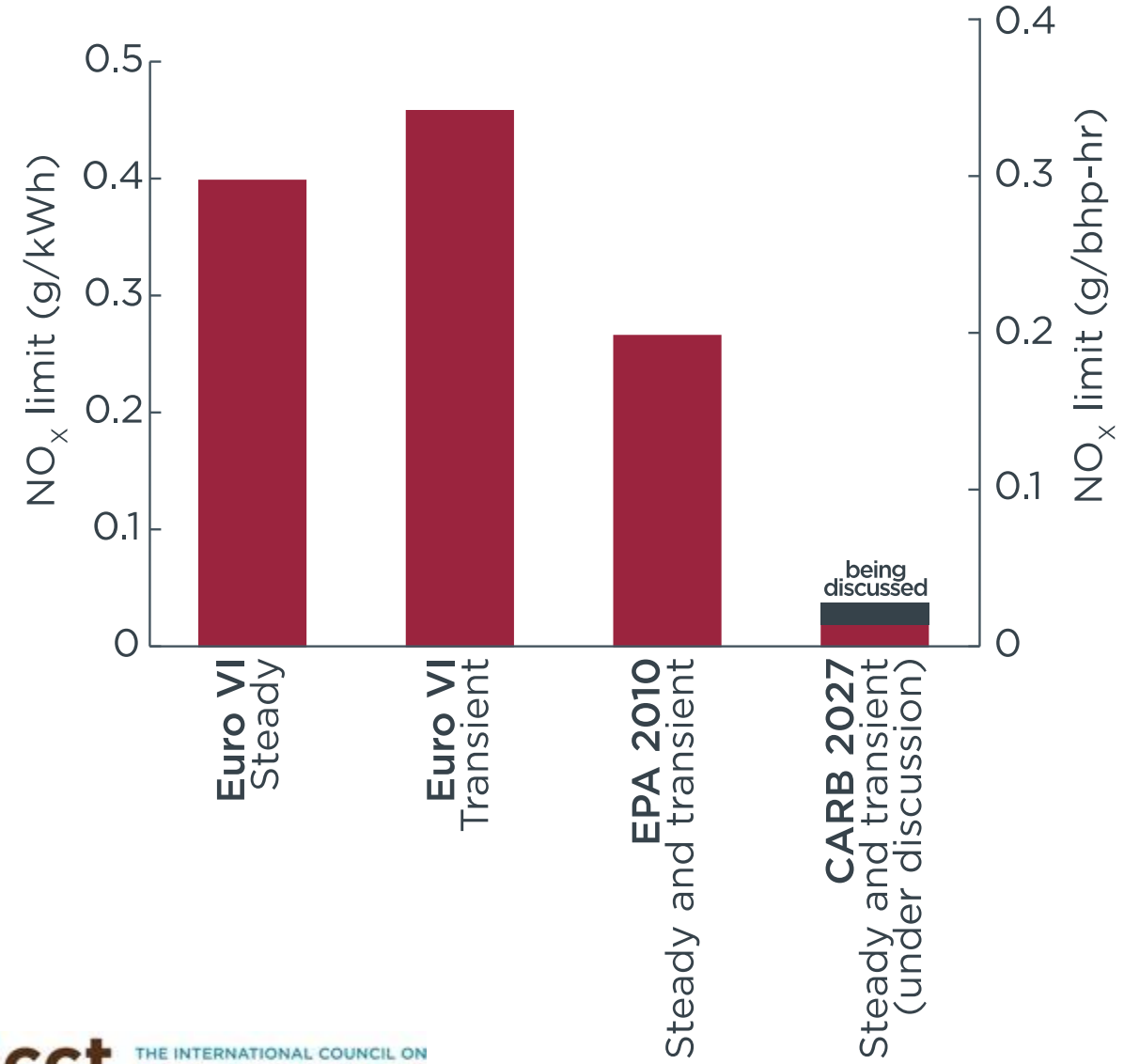
Pollutant emissions

LDV: US and China have fuel neutral and more stringent HC/NOx limits



- EU limits are not fuel neutral. Diesel engines get a less stringent limit.
- Euro 6 sets more lenient limits for CO (gasoline), NMHC and NOx compared to Tier 3 Bin 30, and China 6b.
- The US regulates NMOG. NMOG covers NMHC and also include other oxygenated hydrocarbons.
- China 6b will be implemented in 2023. Tier 3 fully phased-in by 2025.

HDV: EPA'10 is cycle neutral and has lower NOx limits. CARB's plans would more than halve limits.



- The US 2010 heavy-duty engine standard limits NOx emissions to 0.27 g/kWh, 30-40% lower than the Euro VI limit.
- CARB's limits are currently being discussed. Current proposal would set ~ 0.07 to 0.11 g/kWh (FTP/SET) for 2024.
- CARB's 2027 limit will depend on technical feasibility. Program initially aimed for ~0.03 g/kWh, which is the current optional low NOx limit.

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HDV: There are technologies addressing NOx and CO_2 simultaneously

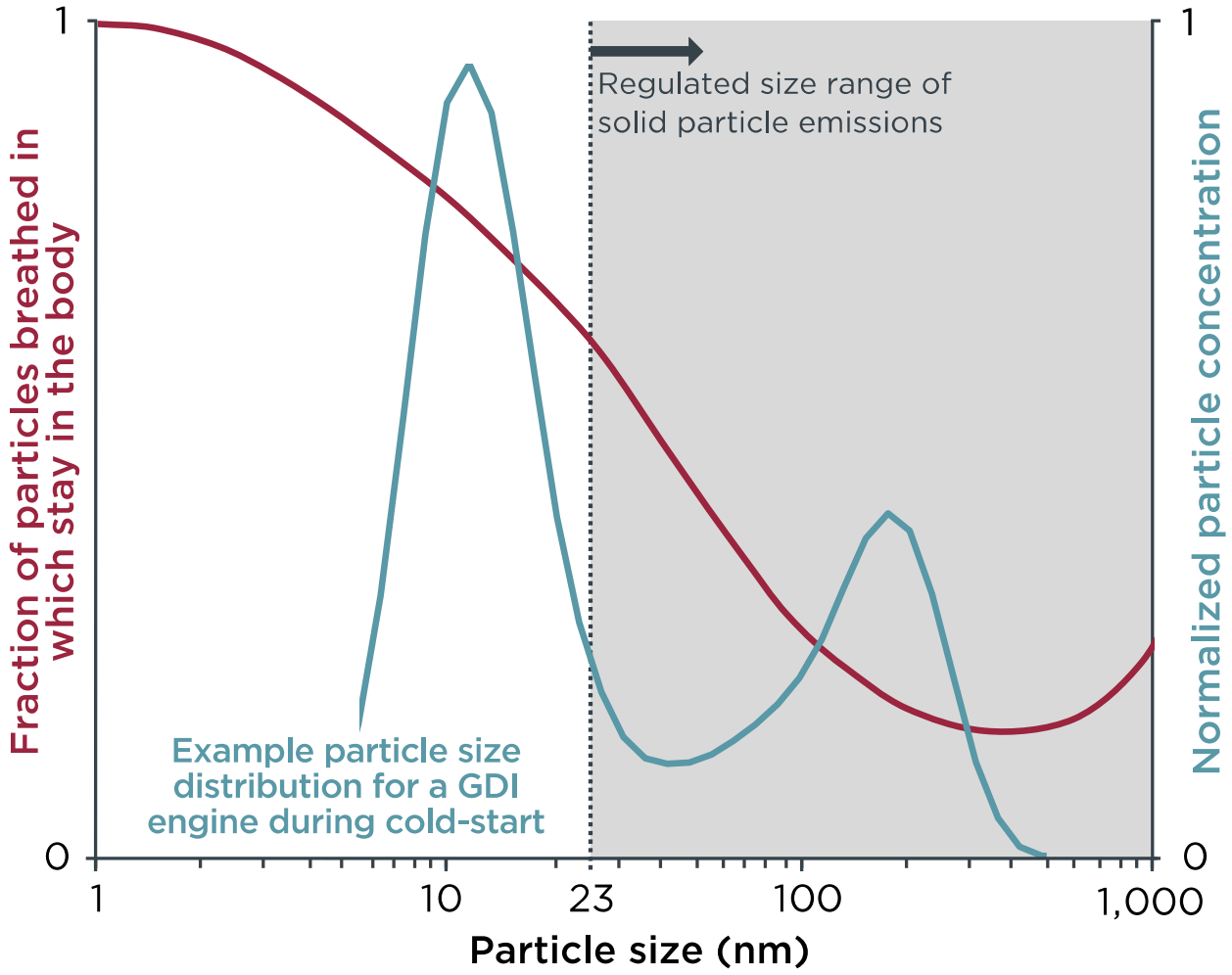
	Impact on CO_2 / GHG	Low NO_x into SCR	Fast warm-up	Stay warm	High conv. efficiency
Air gap insulated manifold	⇨		X		
Burner	⇧		X	X	
Closed-coupled SCR	⇨		X		
Cylinder deactivation	⇩		X	X	
Dual urea dosing	⇧				X
Ducted fuel injection	⇨	X			
EGR (backpressure)	⇧	X			
EGR pumps	⇩	X			
EGR cooler, turbo, charge-cooler bypass	⇨		X		
Electric boosting	⇩		X		
Electric catalyst heating	⇧		X	X	

	Impact on CO_2 / GHG	Low NO_x into SCR	Fast warm-up	Stay warm	High conv. efficiency
Fast idle	⇧		X		
Heated urea dosing	⇧		X		
Improved SCR chemistries	⇩		X	X	X
Larger SCR volume	⇨				X
Mild-hybrid (48 Volts)	⇩	X	X	X	
Passive NOx adsorbers	⇧	X			
Post / late injection	⇧	X	X	X	
SCR on DPF (SCRF)	⇨		X		
Seventh injector	⇧		X	X	
Stop/start	⇩			X	
Variable valve actuation	⇩		X	X	

"A variety of technology options can be deployed on heavy-duty engines and vehicles to reduce engine-out NOx while improving fuel economy… Once implemented, these technologies will help to pay for themselves by delivering fuel savings to truck owners."

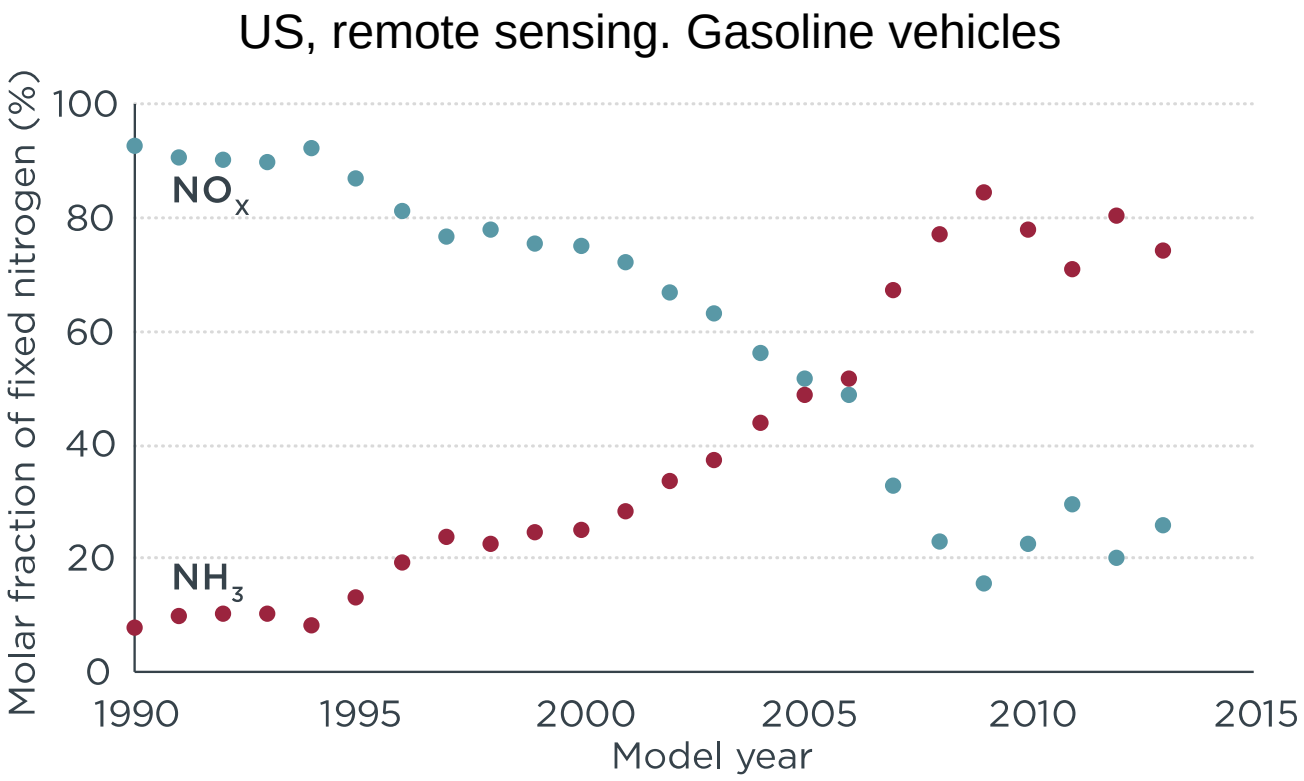
MECA. (2019). *Technology Feasibility For Model Year 2024 Heavy-Duty Diesel Vehicles In Meeting Lower Nox Standards*.

HDV/LDV: Regulation of ultrafine particles



- PN is measured as solid particles larger than 23 nm. SPN in the 10-23 nm range are abundant in DI engines, but also in PFI and gas engines.
- Lowering the size threshold for solid particle counting from 23 nm down to 10 nm is achievable without major measurement challenges.
- New emissions standards are an opportunity to set the framework for measuring total PN, including volatile and semi-volatile particles

HDV/LDV: Ammonia emissions



- 1 mg ammonia emissions leads to ~1 mg of ambient PM2.5
- Vehicles can surpass agriculture as the main source of NH_3 in cities.
- NH_3 limit exists for HDVs. The 10 ppm limit was intended to limit NH_3 slip from diesel SCR's.
- Brazil set NH_3 limits for LDVs (diesel, 10 ppm) PROCONVE L8.
- Gasoline's better NOx puts the light on NH_3 as source of fixed nitrogen

LDV/HDV: Other pollutants worthy of attention

- **Methane (CH_4) and nitrous oxide (N_2O)** are both powerful greenhouse gases (GHGs) that can be found in the exhaust of vehicles.
- **Going from NMHC to NMOG.** Organic compounds are underestimated by EU's measurement technique with *flame ionization detectors*. This underestimation has been shown to be as high as 74% when high ethanol blends are used (E85).
- **Aldehydes:** Probable carcinogens. Linked to high ethanol blends / flex fuel vehicles. Regulated in the US, South Korea and Brazil.
- **Primary NO_2** emission limits
- **PAHs:** Highly toxic. Linked to the use of biodiesel.
- **Isocyanic acid:** Highly toxic. Formed in the catalyst (both TWC and SCR).
- **Brake and tire wear** particulate emissions.

How to regulate it?

Tests and boundary conditions

LDV: US, China and Brazil have stricter EVAP emissions provisions

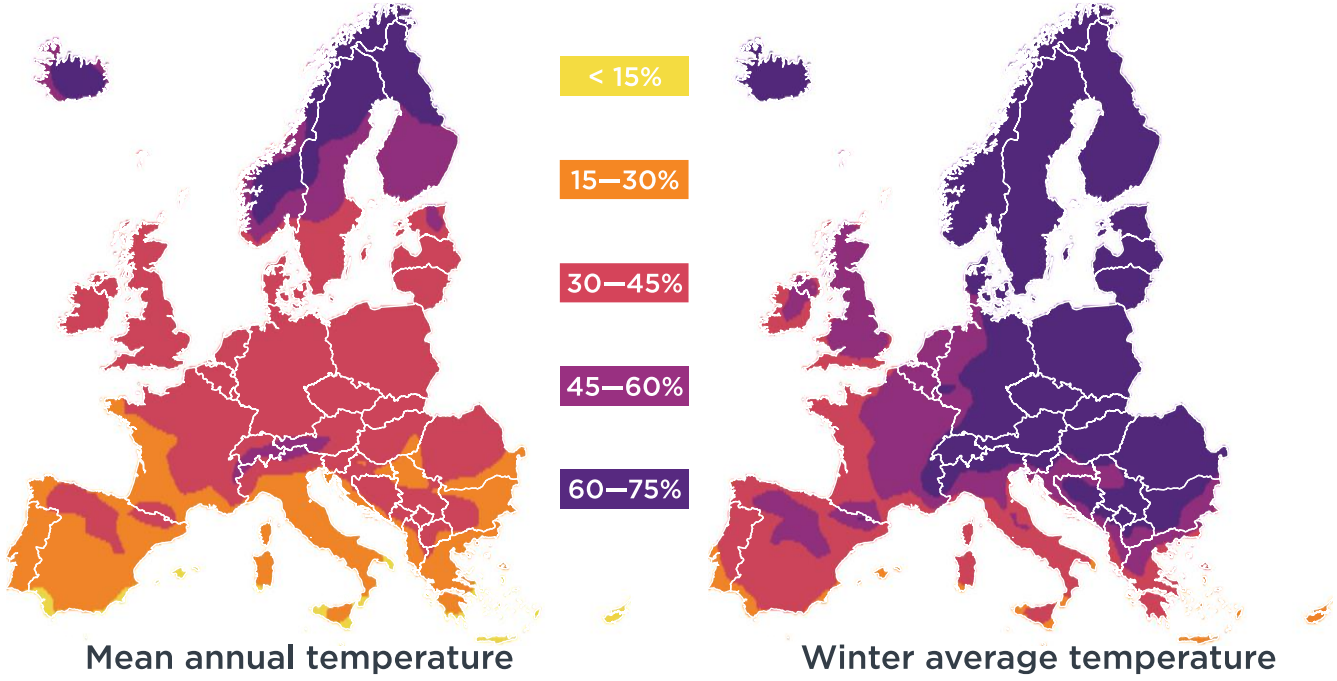
US tests / limits	
High temperature hot soak + 3-day diurnal test	0.3 g/test
Hot soak + 2-day diurnal test	0.3 g/test
Canister bleed test	0.020 g/test
Running losses test	0.031 g/km
Refueling test	0.053 g/liter
Spit back test	1 g/test
Leak test / OBD EVAP monitors	0.5 mm eq. diameter

- China 6 EVAP limit is **0.7 g/test** over the 2-day test and has a refueling emission limit of **0.05 g/L.** Brazil's PROCONVE L7 sets an EVAP limit of **0.5 g/test** over the 2-day test and introduces a refueling emission limit of **0.05 g/L.** US test procedures.

- **Post-Euro 6 is an opportunity to:**
  - Tighten the evaporative emissions limit. (75-85% lower in US, Brazil and China)
  - Introduce a refueling emissions standard, forcing the adoption of ORVR.
  - Increase the temperature during hot soak prior to the 2-day diurnal test.
  - Introduce requirements for the monitoring of leaks in the OBD provisions.

LDV: Low temperature test

Increase in diesel NO_x emissions due to deviations in ambient temperature from the temperature used for type-approval laboratory testing



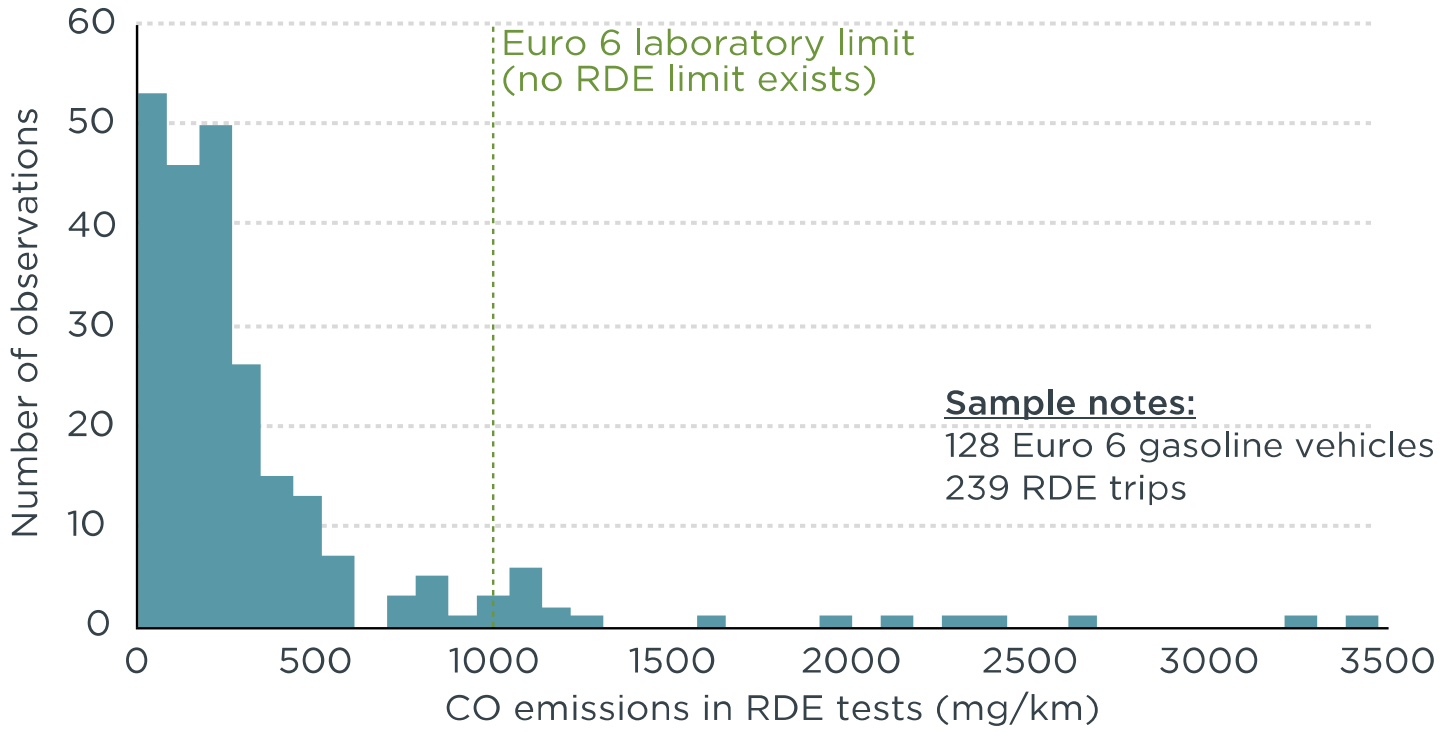
Mean annual temperature

Winter average temperature

- Cold ambient temperatures tend to increase emissions of all pollutants from spark ignition and diesel vehicles.
- Currently, low T (Temperature) test applies only to gasoline vehicles.
- The low T limits for CO and HC are 15 and 18 times the Euro 6 limit.

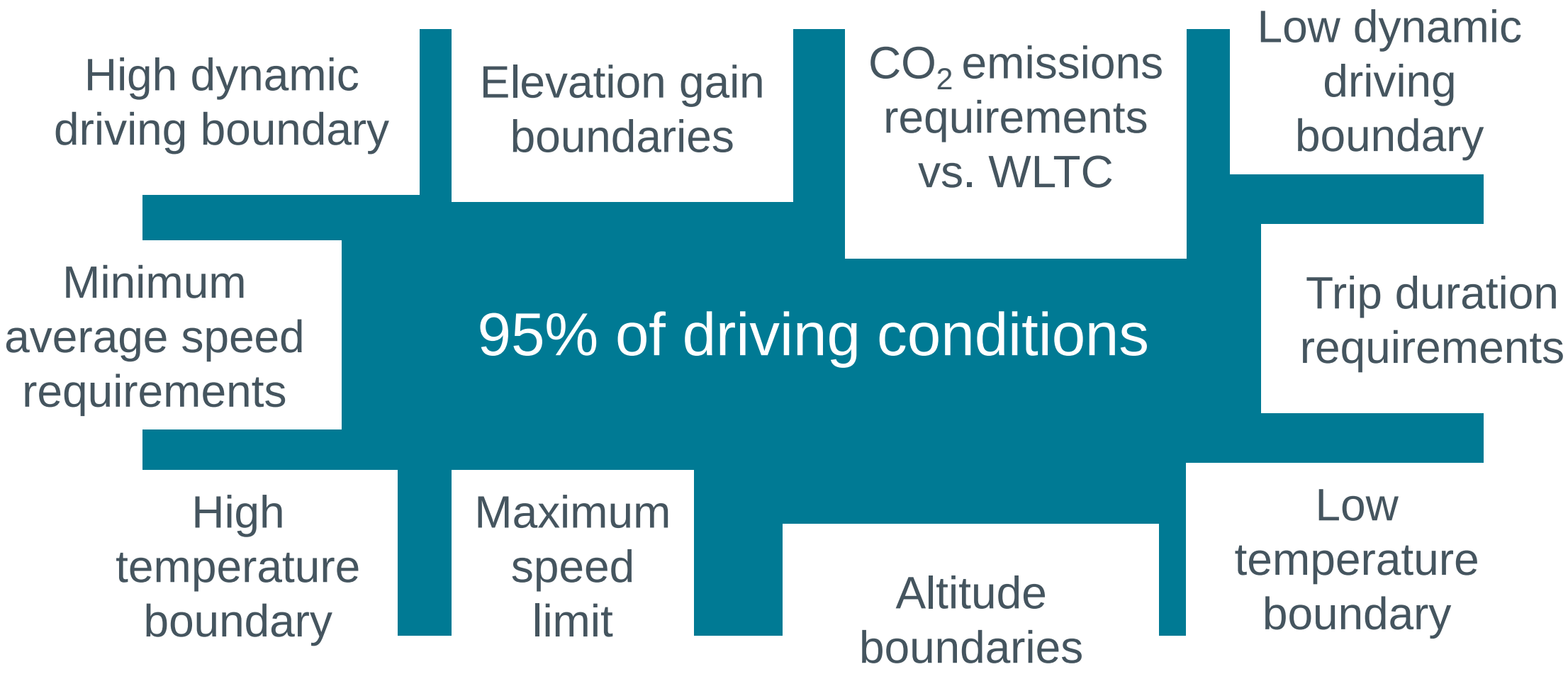
- **Post-Euro 6 is an opportunity to introduce low temperature limits for NOx and PN, for both gasoline and diesel.** RDE testing is not a replacement of low temperature chassis dyno testing for type approval.

LDV RDE: In-use CO emissions



- Post-Euro 6 is an opportunity to introduce not-to-exceed limits for CO during RDE testing
- The US Tier 3 standards* attempt to reduce emissions from AES that command over-fueling, by setting limits on enrichment.

LDV RDE: Aimed to cover 95% of driving, but…



HDV: CARB's thinking for implementation details. Official proposal to be presented in March 2020.

California Air Resources Board. (2019). California Air Resources Board Staff Current Assessment of the Technical Feasibility of Lower NOx Standards and Associated Test Procedures for 2022 and Subsequent Model Year Medium-Duty and Heavy-Duty Diesel Engines [Staff White Paper]. https://www.arb.ca.gov/msprog/hdlownox/white_paper_04182019a.pdf

California Air Resources Board. (2019, September 26). Public workshop to discuss potential changes to the heavy-duty engine and vehicle emission standards, test procedures, warranty, and other related heavy-duty programs. Retrieved from https://ww2.arb.ca.gov/our-work/programs/heavy-duty-low-nox/heavy-duty-low-nox-meetings-workshops

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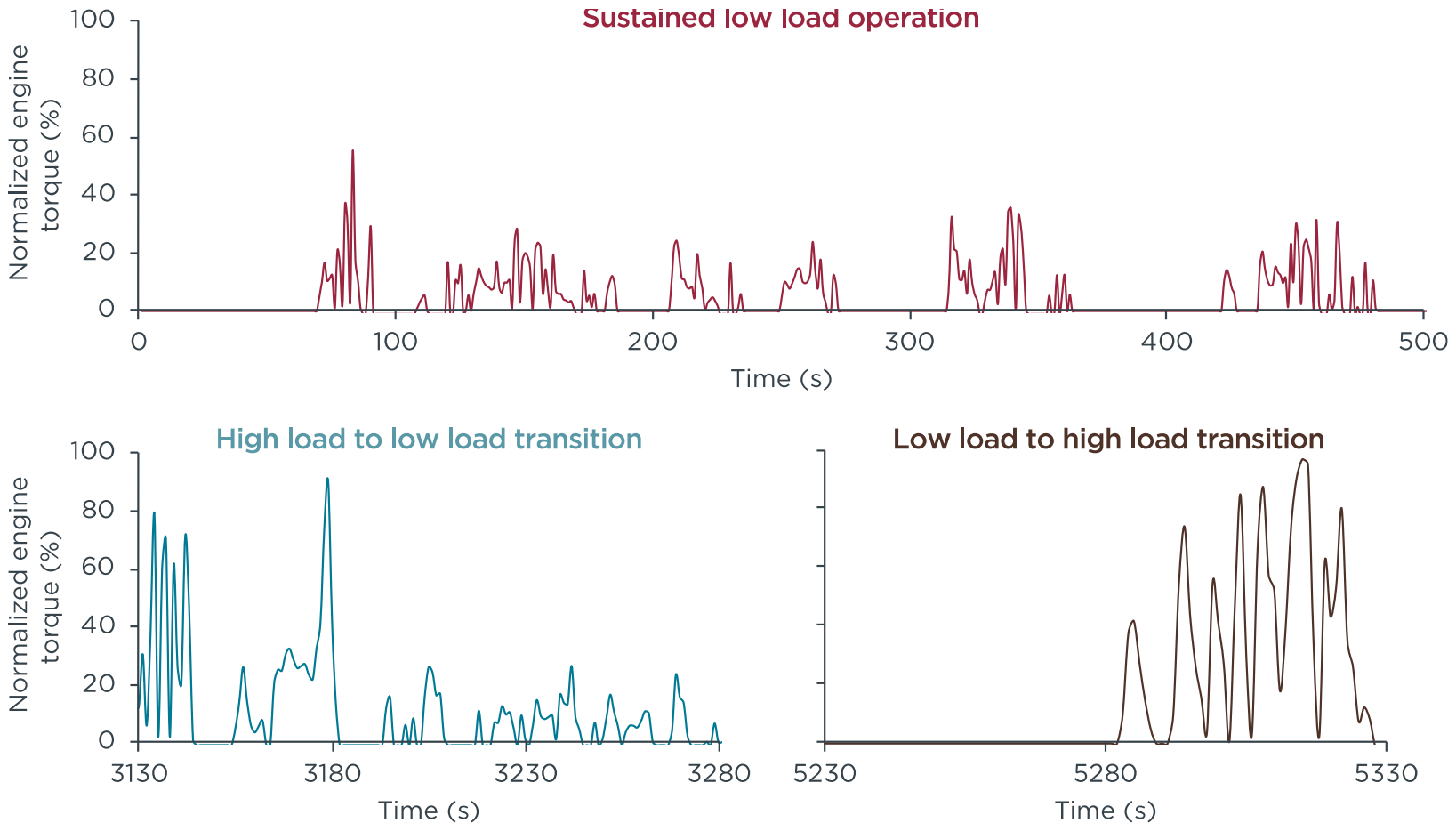
	MY 2022 - 2023	MY 2024 - 2026	MY 2027 - onwards
NOx limit	Existing limits	~ 0.07 g/kWh FTP/SET ~ 0.27 g/kWh on the LLC 10 g/h NOx idling standard	~ 0.02-0.04 g/kWh FTP/SET ~ 1-3 x FTP on the LLC ≤ 10 g/h NOx idling standard
PM limit	Existing limits	~ 7 mg/kWh on FTP/SET	~ 7 mg/kWh on FTP/SET
In-use compliance	Modified NTE with exclusion for T<200 C. Reporting of all data and Euro VI-D report	**Euro VI-D method** with a CF of 1.5 (vs. FTP). No trip requirements, usual route Pilot test of NOx On-Board Monitoring (REAL) as an alternative compliance option	**Euro VI-E method** with a CF of 1.5 (vs. FTP). **No trip requirements**, usual route. **No power threshold.** **Possible changes to percentile**
Durability	Case-by-case approach to verify product durability and deterioration factors	**Full useful life aging** of engine and aftertreatment systems for durability demonstration	Possible alternate durability demonstration based on On Board Monitoring **1.4 M km (useful life)** **1.28 M km (warranty)**

HDV: Setting NO_x limits over a low load cycle can be a useful tool



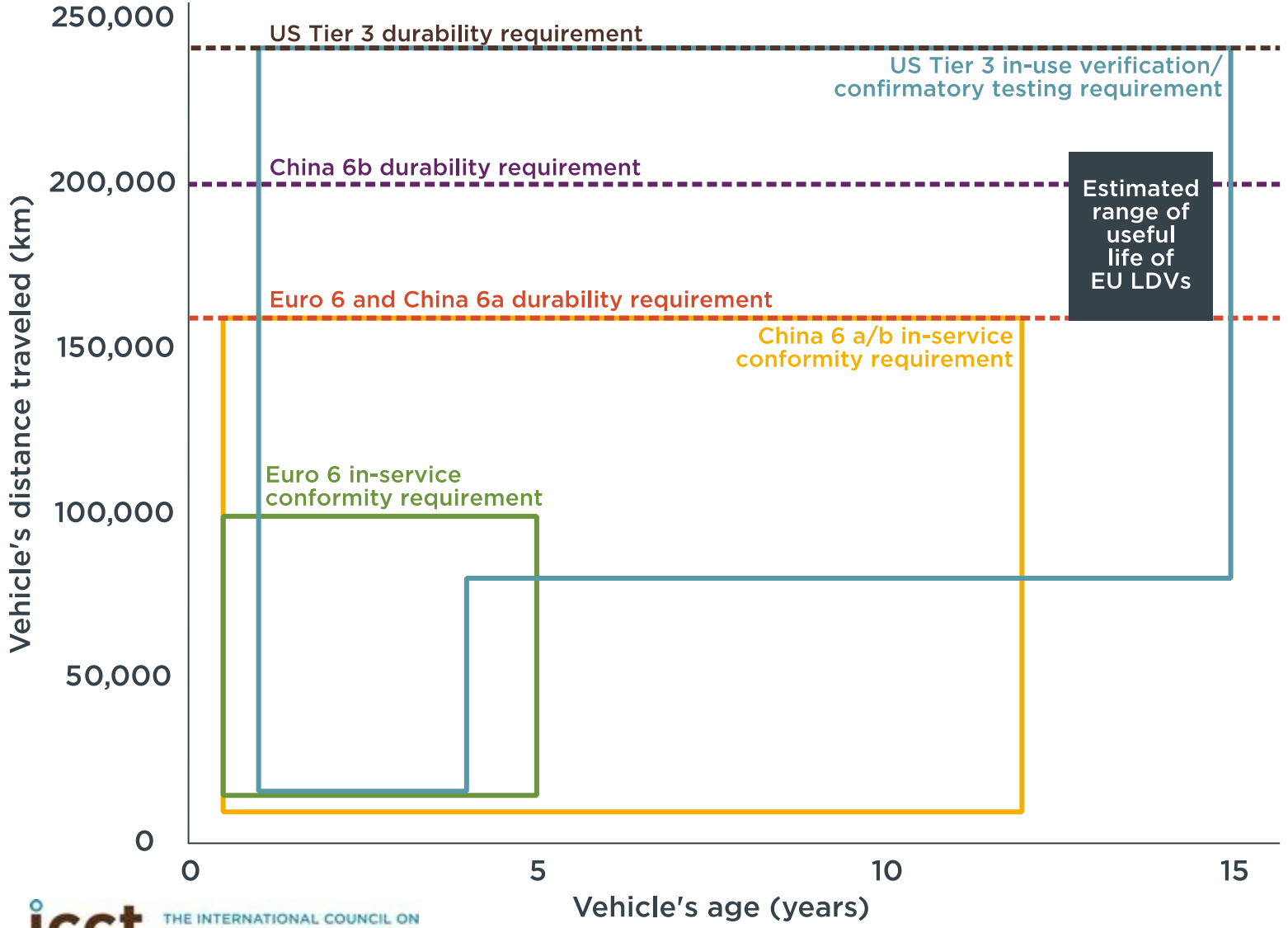
- Additional **low load certification test cycle** during type approval can address driving situations outside of on-road PEMS boundary conditions.
- **Idle NOx limits** can provide further benefits in urban operation.
- California has idle limits and plans to introduce a LLC (as shown). Lessons can be extended to the EU

California Air Resources Board. (2019, September 26). Public workshop to discuss potential changes to the heavy-duty engine and vehicle emission standards, test procedures, warranty, and other related heavy-duty programs. Retrieved from https://ww2.arb.ca.gov/our-work/programs/heavy-duty-low-nox/heavy-duty-low-nox-meetings-workshops

How to guarantee it?

Durability provisions and other measures

HDV/LDV: Durability and warranty requirements



- **Post Euro-6/VI is an opportunity to:**
- Extend the definition useful life for durability demonstration from the current 160k km for LDVs and 700k km for HDVs.
  - US useful life is 240k km for LDVs. California plans to extend useful life definition of HDVs to ~1.4M km.
- Align the **age** and **mileage** requirements for vehicle selection for ISC testing with the useful life.

HDV/LDV: On-board diagnostics (OBD) and monitoring (OBM)

OBD

- California's OBD II program is the most comprehensive program in the world, and now it is being largely followed by China, Korea, and Brazil. Understanding the limitations of Europe's OBD and importing the best elements of OBDII is necessary.

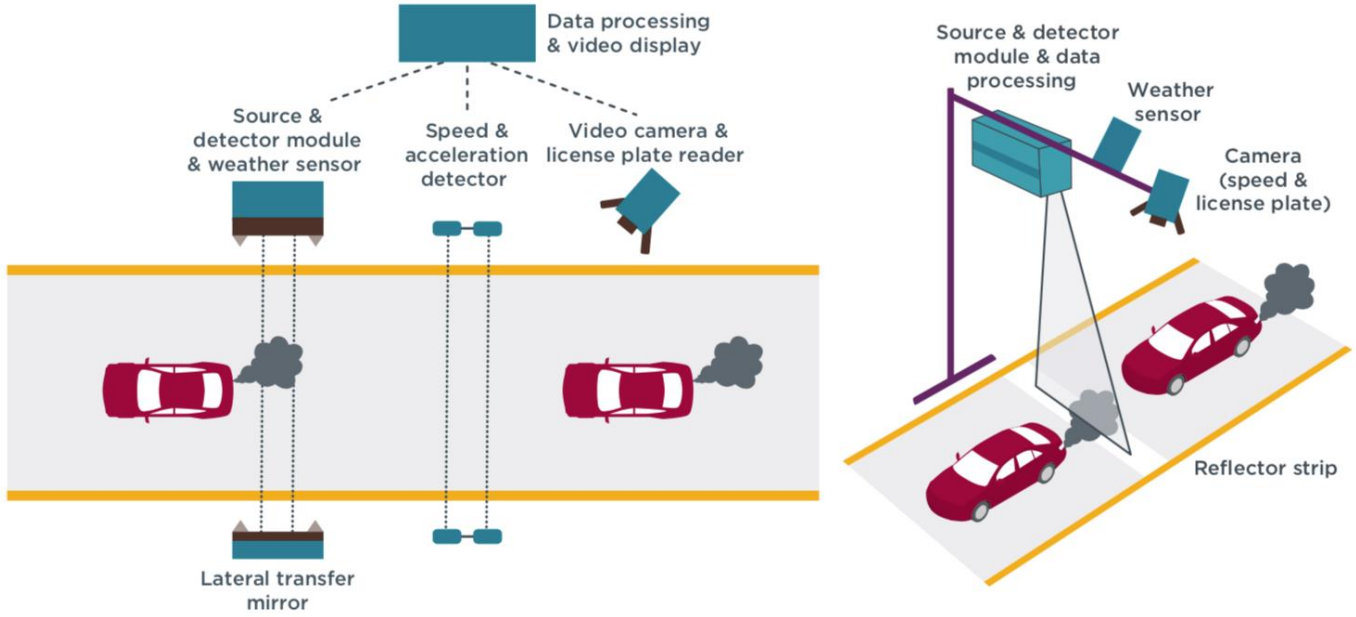
OBM

- EU has already precedent with the introduction of on-board fuel consumption monitors (OBFCM) in the CO_2 regulations. The data is to be transmitted to the Commission to be used among others in tracking CO_2 gap, ISC, and CO_2 standard compliance.
- OBM can be a valuable tool to identify durability issues, assess limitations of the NOx certification, address emissions tampering and possibly establishing compliance.
- China and California have introduced OBM for NOx (HDV)

HDV/LDV: Strengthen market surveillance and enforcement

- Establish a minimum emission warranty program
- Establish an emissions defect reporting program
- Develop a methodology for fleet screening to identify noncompliant vehicle models
- Clarify the criteria for failure of market surveillance tests
- Issue a defeat device guidance
- Extend the scope of market surveillance beyond pollutant emissions:
  - Road load parameters, CO_2 emissions, electric range, regenerating emission systems

LDV/HDV: Remote sensing is a powerful tool for market surveillance



- A remote sensing standard enables its consistent application
- China, Hong Kong, South Korea, and some states in the US are using remote sensing for identifying high emitters within the I/M activities
- A comprehensive and international database of remote sensing entries would enable robust and targeted market surveillance

Summary – Post Euro 6/VI is an opportunity to…

	LDV	HDV
Standard limits	Adopt technology-neutral limits	
	Tighten emission limits to harmonize with other regions and drive technology adoption	
	Address ultrafine (<23nm) particles	
	Introduce limits for unregulated pollutants and GHG: NH_3, N2O, sub 23-nm PN, Aldehydes, PAHs, etc.	
	Enhance the evaporative emissions standards	Introduce low load test and NO_x idle limits
ISC and compliance	Durability and warranty: Extend to 240,000 km and set emissions warranty programs	Durability and warranty: 1.4 million km and set emissions warranty programs
	Extend LDV RDE and HDV PEMS boundary conditions to be more realistic/comprehensive	
	Introduce OBD III	Enhance OBD
	Use remote sensing to support ISC	

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