Diesel – a Clean and Efficient Fuel with BSVI Emission

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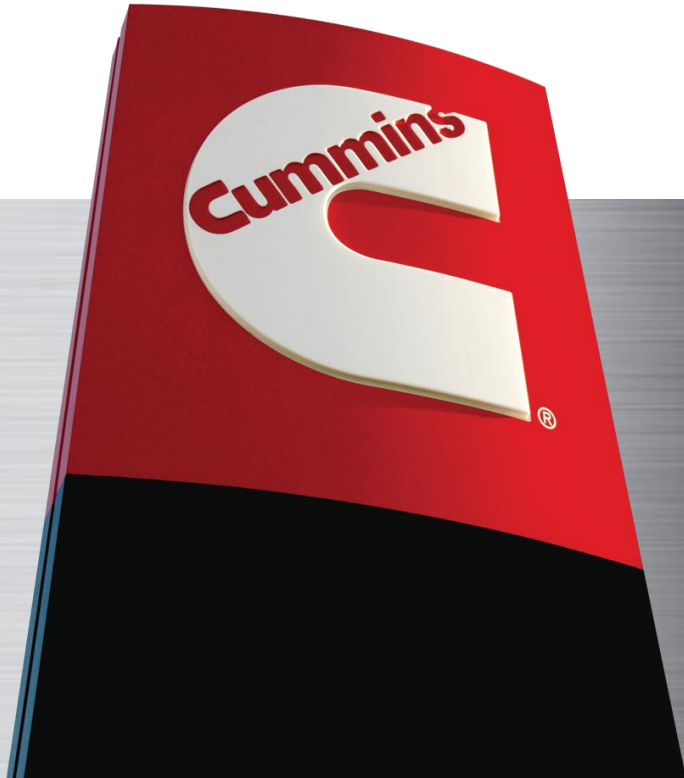
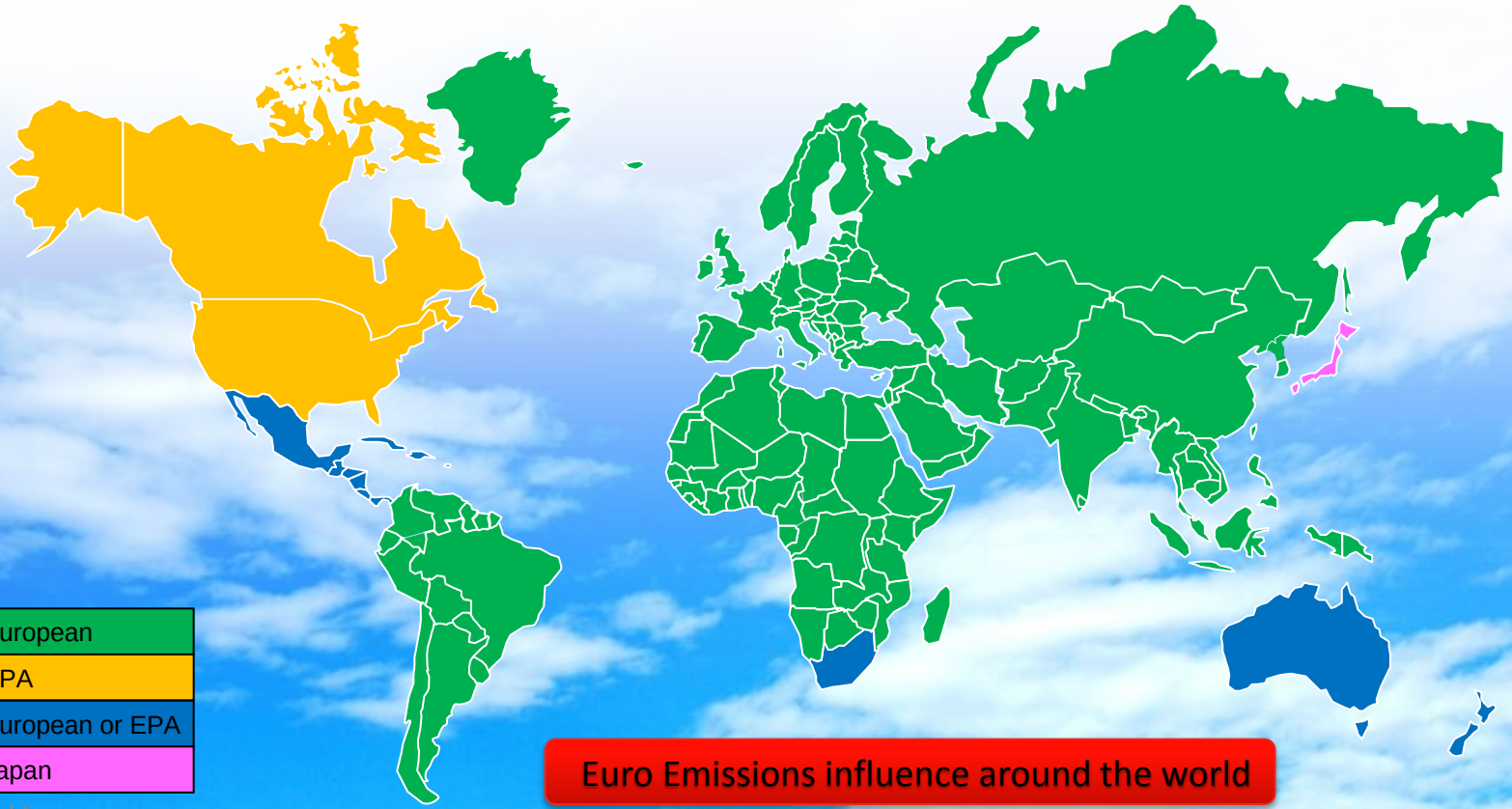


Content:

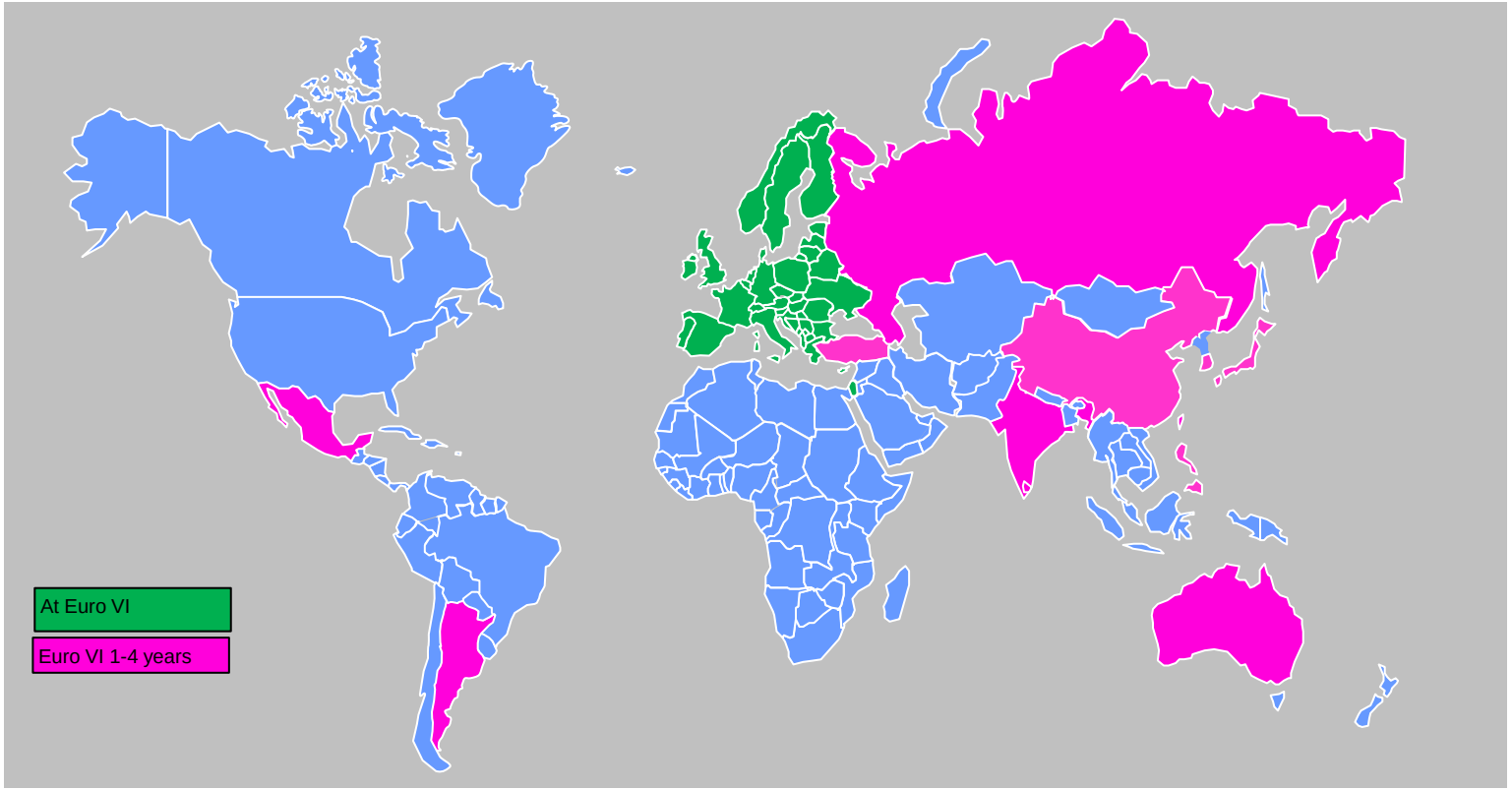
- Emissions Norms Worldwide
- Emission Norm Evolution
- BSVI Emission norms
- Importance of Diesel Engines in HD Commercial vehicle segment
- Real World Driving Emissions and Comparison
- Diesel Engine and Aftertreatment Technologies Integration
- Continued Evolution for Fuel Economy / GHG
- Conclusion

Global Emissions Map (On & Off HWY)



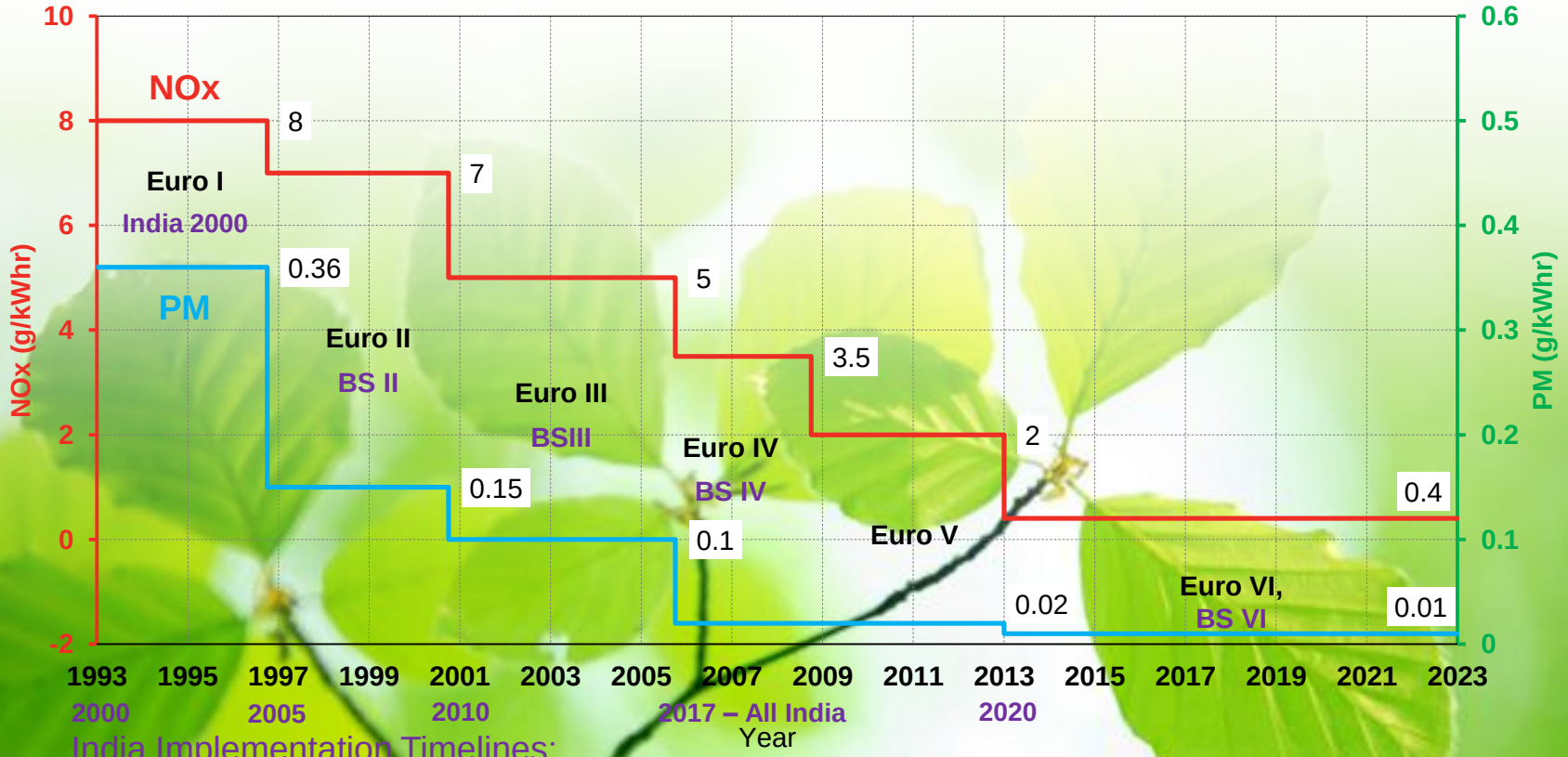
Euro Emissions influence around the world

Global Rollout of Euro VI (or Euro VI adopted) Norms:



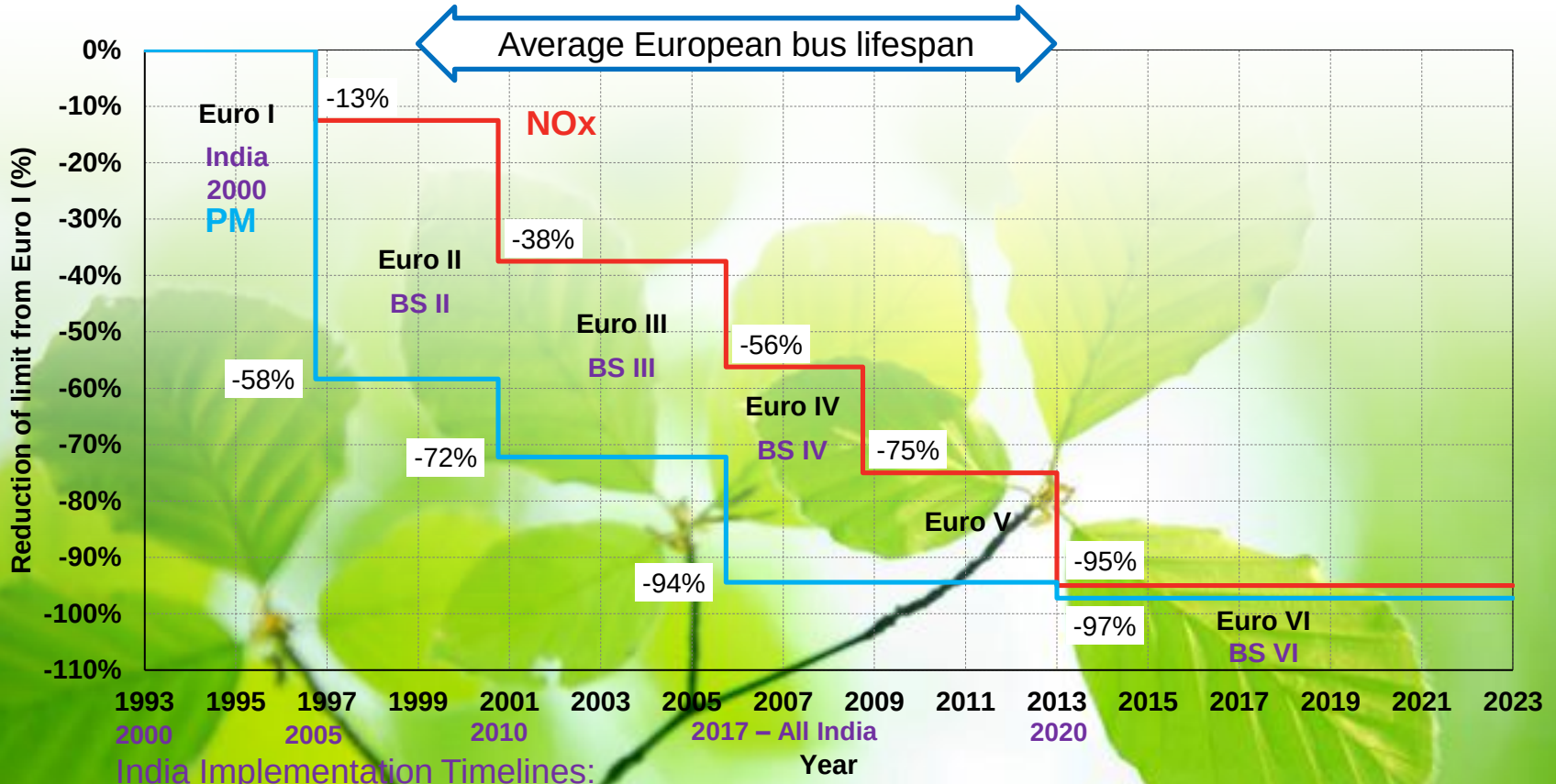
Challenging Emissions Limits

Euro Emissions Levels



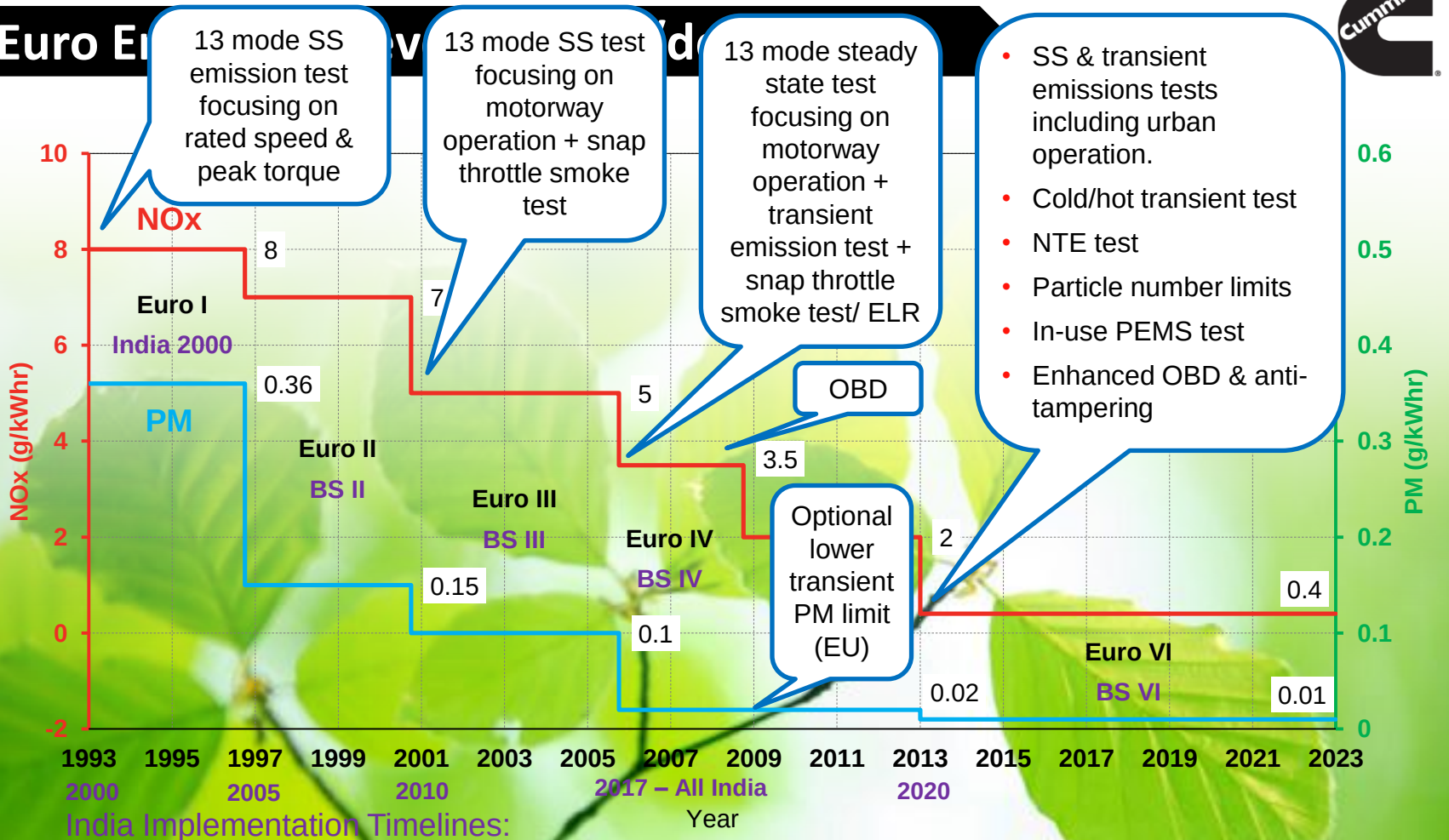
Challenging Emissions Limits

Euro Emissions Levels



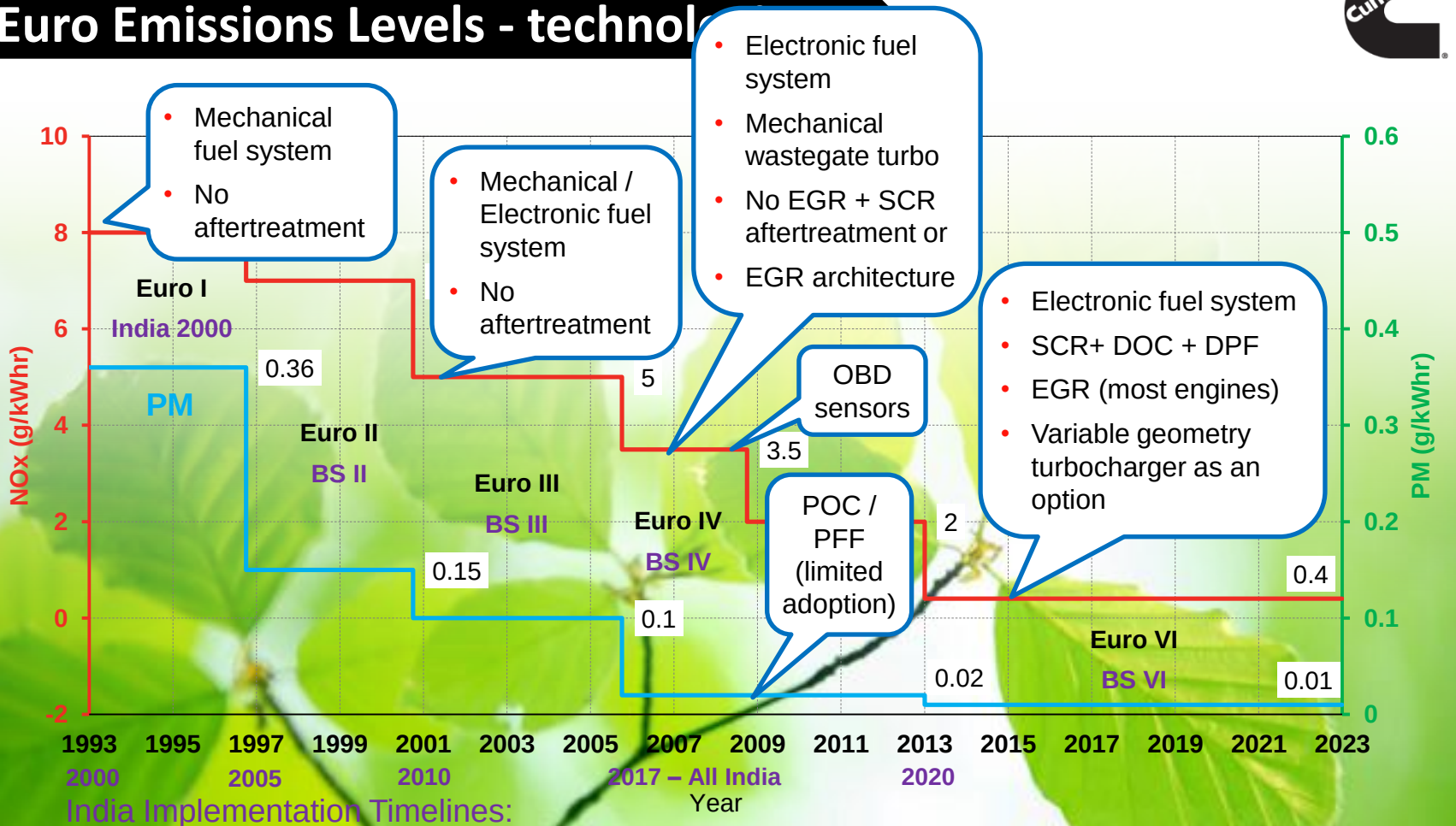
Challenging Emissions Limits

Euro E… …v… …d…



Challenging Emissions Limits

Euro Emissions Levels - technol



BSVI Emission Norms:

BSVI Norms Dictate Equally Stringent Limits for Diesel Engines:

- For > 3500 kg GVW category, CI engines have equal or stringent emission limits compared to PI engines.
- CI engines have to additionally certify over WHSC cycle with stringent NOx and THC limits.
- Off Cycle Emissions (WNTE) applies to CI and Duel Fuel engines only.
- For M and N category vehicles with <=3500 kg reference mass, NOx limits are relatively relaxed for CI engines however NOx+THC limits are stringent compared to PI engines.
- Real Driving Emissions needs including compliance ratio post OBD II will ensure NOx and PM emissions in check – Both criteria pollutants predominant with Diesel engines.

All emission and fixed DF tables referenced from GSR 889(E) regulation

Diesel Engines in HD Commercial Space:

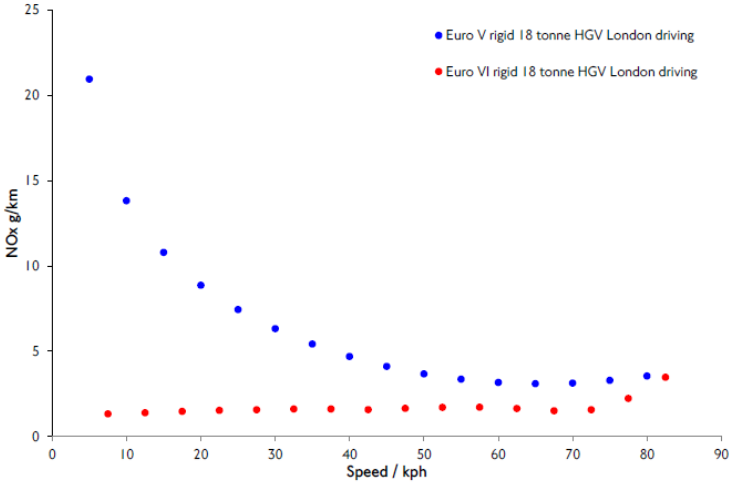
Why?

- Fuel Economy Offered
- Long range per filling – suitable for long distance travel
- Ultra Low Emissions at BS VI level & In use compliance
- Choice of prime mover even for Hybrids
- Technology available for deployment and now
- Improvement potential for GHG reduction
- Established ULSD network

Euro VI Norms and Impact on Real Life Emissions

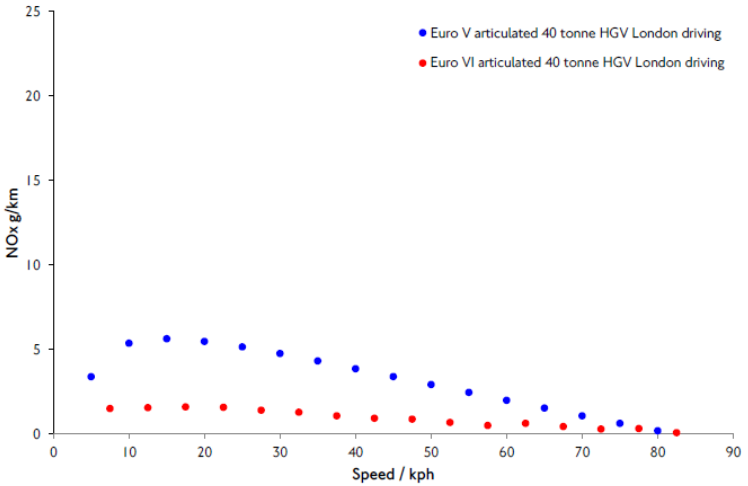
Transport for London data:

Figure 5 Comparison of Euro V versus Euro VI NO_x emissions over a range of road speeds: 18 tonne rigid HGV 100% payload



18 tonne Rigid Truck

Figure 6 Comparison of Euro V versus Euro VI NOx emissions over a range of road speeds: 40 tonne articulated HGV 100% payload.

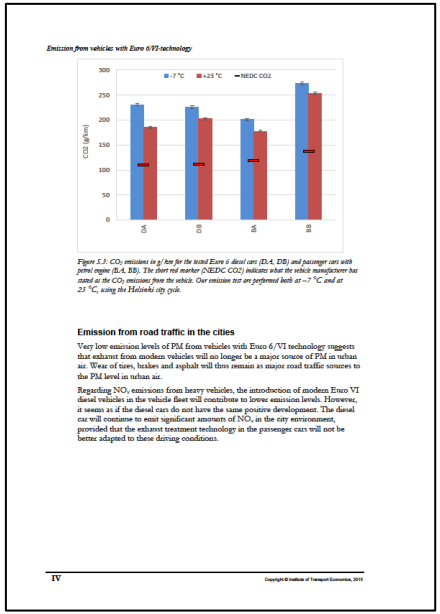


40 tonne Articulated Truck

- **Significant NOx reduction in real driving cycle compared to Euro V vehicle**
- **NOx emissions lower with loaded vehicle – High exhaust temperatures**
- **DPF guards against wide variety of loads and duty cycles on PM emissions**

https://tfl.gov.uk/cdn/static/cms/documents/in-service-emissions-performance-of-euro-6vi-vehicles.pdf

Norwegian data – city bus



Emission from vehicles with Euro 6/VI-technology

Figure 5.3: CO_2 emissions in g/km for the tested Euro 6 diesel cars (DA, DB) and passenger cars with petrol engine (BA, BB). The short red marker (NEDC CO_2) indicates what the vehicle manufacturer has stated as the CO_2 emissions from the vehicle. Our emission test are performed both at --7 °C and at 23 °C, using the Helsinki city cycle.

Emission from road traffic in the cities

Very low emission levels of PM from vehicles with Euro 6/VI technology suggests that exhaust from modern vehicles will no longer be a major source of PM in urban air. Wear of tires, brakes and asphalt will thus remain as major road traffic sources to the PM level in urban air.

Regarding NO_x emissions from heavy vehicles, the introduction of modern Euro VI diesel vehicles in the vehicle fleet will contribute to lower emission levels. However, it seems as if the diesel cars do not have the same positive development. The diesel car will continue to emit significant amounts of NO_x in the city environment, provided that the exhaust treatment technology in the passenger cars will not be better adapted to these driving conditions.

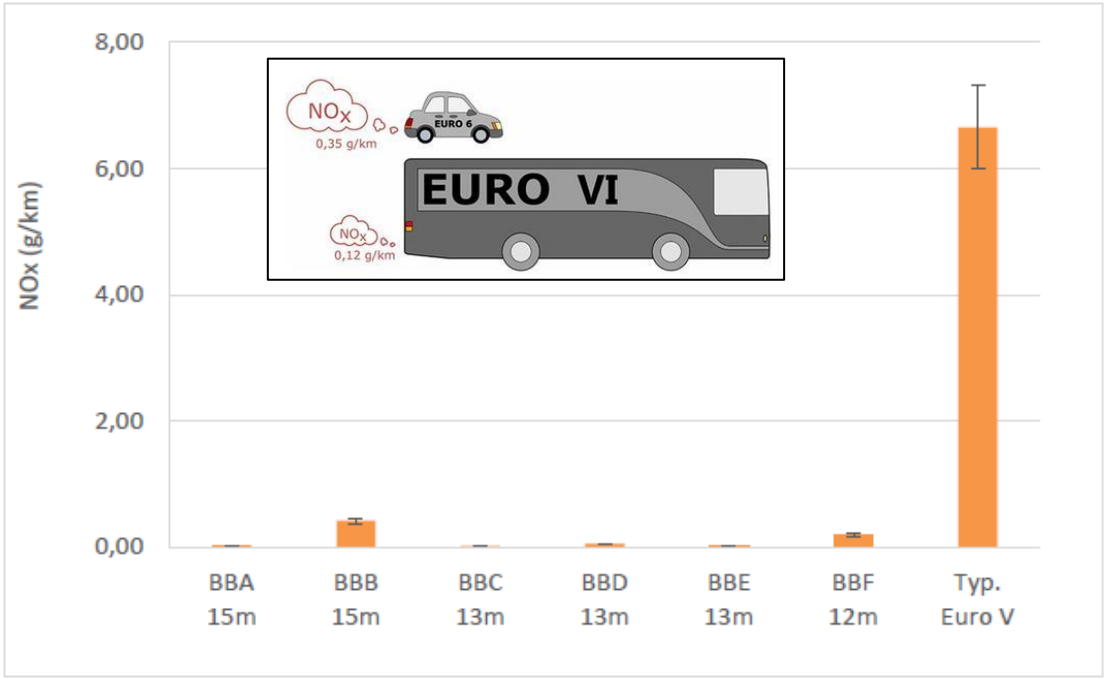


Figure S.1: NO_x emissions in g/km for six city buses (BBA-BBF) with Euro VI engine. Emission values are very low compared to the emissions from a typical 12 meter bus with Euro V engine.

https://www.toi.no/environment-and-climate/diesel-cars-have-high-emissions-in-real-traffic-article33388-1314.html

Euro VI / 6 In Use Emissions Comparisons:

Table 6. Comparison of Euro VI and Euro 6 on road testing procedures

	Euro VI	Euro 6 (future)
PEMS testing program	In-service conformity (ISC)	Real-driving emissions (RDE)[24]
Implementation year	2014	2017 (first step, conformity factor of 2.1)
Analytical equipment	PEMS	PEMS
Vehicles tested	In-use	Pre-production[25]
Applicable vehicles	M1/M2/M3; N1/N2/N3 over 2,610kg	M1, N1, N2[26]
Mandated test frequency	18 months with minimum of 25,0000km and then every two years	Once at type-approval
Driving shares (% of distance)	Urban (0–50 km/h; 20%–45%) Rural (50–75 km/h; 25%–30%) Motorway (75 km/h+; 30%–55%)	Urban (0–60 km/h; 29%–44%) Rural (60–90km/h; 23%–43%) Motorway (90km/h+; 23%–43%)
Sample size	3 engines per engine family	1 representative vehicle of the "PEMS test family"
Cold start included	No[27] (analysis starts when coolant temp >70°C, when engine coolant is stabilized within +/-2K, or 20 minutes whichever is first)	Current regulation states analysis starts when coolant temp >70 °C or 5 minutes, whichever is first. Currently proposed regulation includes analysis of cold-start data
NO_x Conformity factor	1.5	2.1 (between 2017 and 2020), 1.5 (after 2020)
Test length	Defined by WHTC work (5x work of WHTC)	90 to 120 minutes
Payload	50%–60%	2 test operators plus the test equipment, Up to 90% of maximum permissible payload
Vehicle Preparation	OBD check, replace oil, fuel, reagent	General technical and operational check
Vehicle Driver	Usual professional driver of the vehicle	Driver supplied by manufacturer or technical service
Ambient conditions	Atmospheric pressure ≥ 82.5 kPa (altitude of approximately 1700 m), Temperature ≥ -7°C, Temperature ≤ 37.85 °C (at atmospheric pressure of 101.3 kPa)[28]	Altitude ≤ 700m. Temperature ≥ 3 °C, Temperature ≤ 30 °C. For "extended" ambient conditions of altitude between 700–1300m and temperatures between -7°C to 3°C and 30 to 35 °C emission during this time interval are divided by 1.6

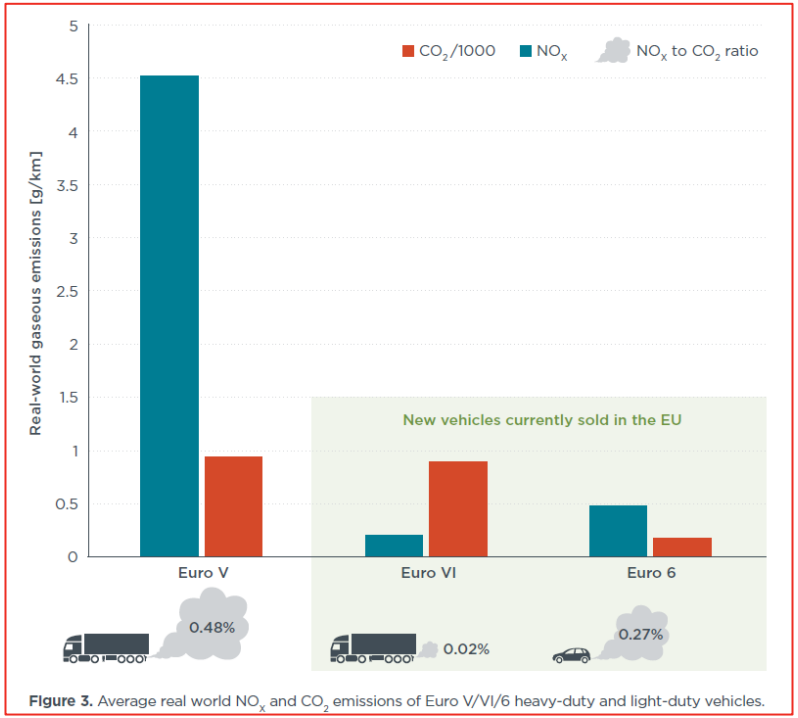


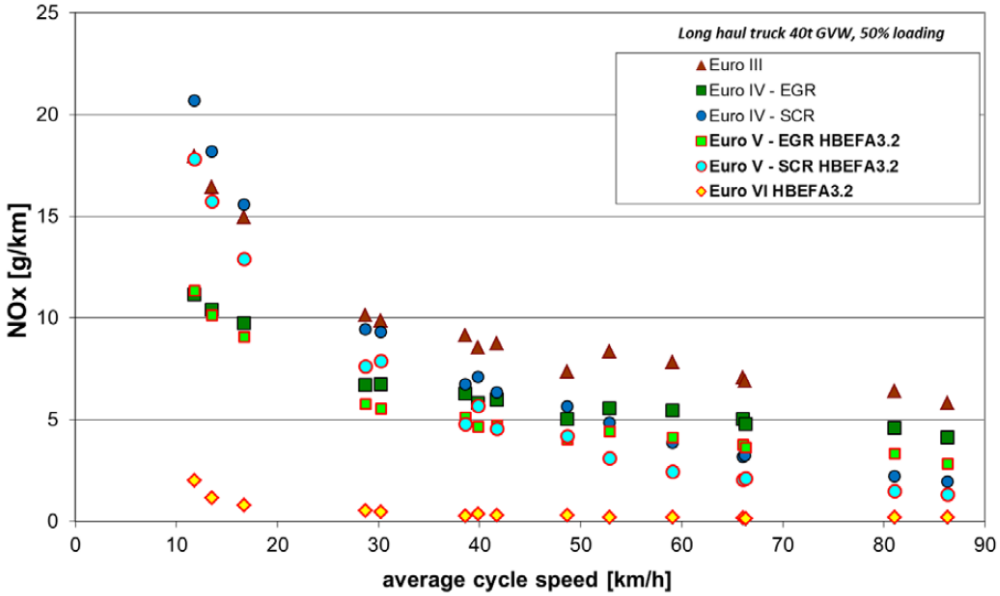
Figure 3. Average real world NO_x and CO_2 emissions of Euro V/VI/6 heavy-duty and light-duty vehicles.

Currently Diesel Passcars emit significantly higher NOx in real driving conditions whereas HDVs exhibit strong in-use compliance. This is something to do with RDE process implied.

http://www.theicct.org/sites/default/files/publications/Euro-VI-versus-6_ICCT_briefing_06012017.pdf

Understanding real vehicle operation

- Euro VI In Use Emissions are very, very low
- Need to ensure compliant emissions on all duty cycles
  - Need to keep this curve ‘flat’
- Drives architecture choice

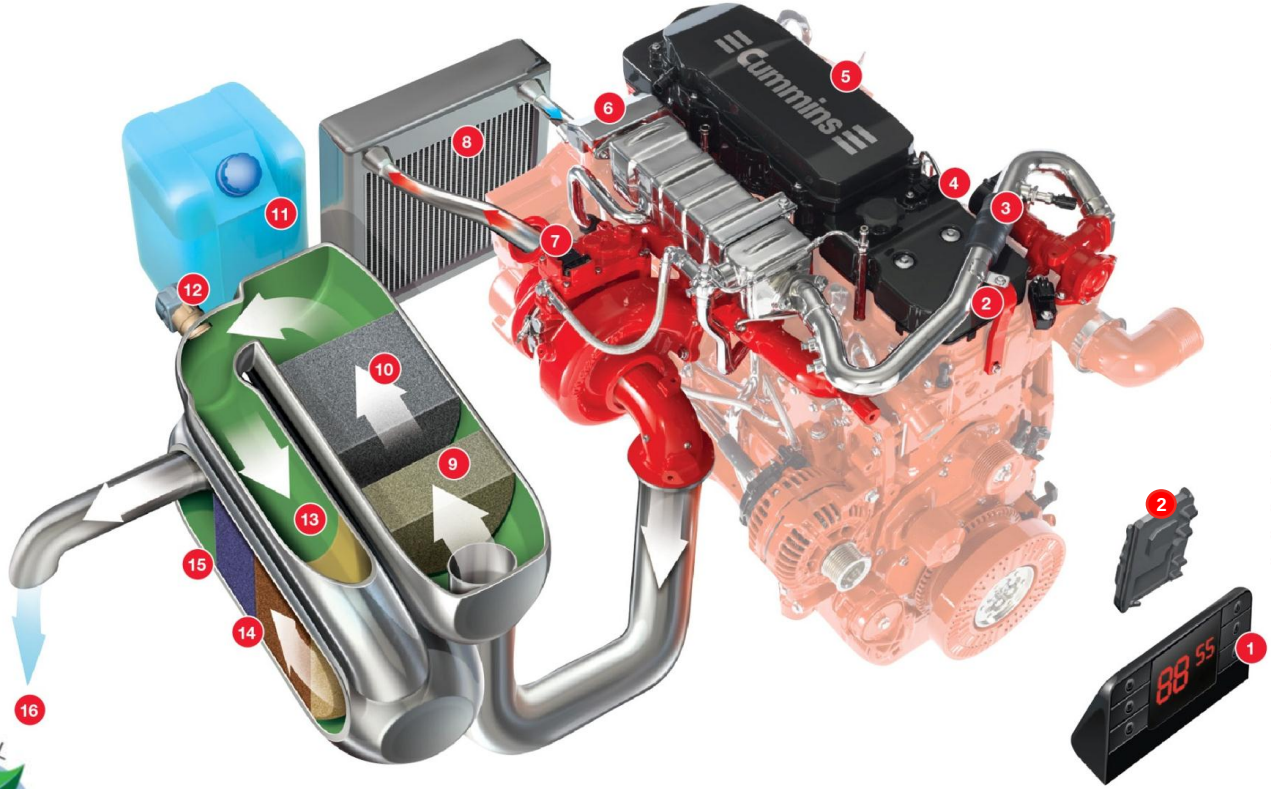


Source: TU Graz

http://www.hbefa.net/e/documents/HBEFA32_EF_Euro_5_6_TUG.pdf

Architectural Choices and Future Scope

Euro VI System Typical Architecture:



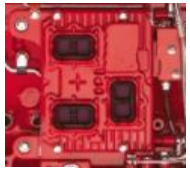
1. On-Board Diagnostic (OBD) in-cab display
2. Electronic Control Module – can be remote or engine mounted
3. Cummins Designed EGR Mixing Device
4. High Pressure Common Rail Fuel System
5. Closed Crankcase Breather (CCV)
6. Exhaust Gas Re-circulation (EGR) Cooler
7. Cummins Variable Geometry Turbocharger (VGT)
8. Charge Air Cooler
9. Diesel Oxidation Catalyst (DOC)
10. Diesel Particulate Filter (DPF)
11. AdBlue Tank
12. AdBlue Doser
13. Decompostion Reactor Tube
14. Selective Catalytic Reduction (SCR) Catalyst
15. Ammonia Slip Catalyst
16. Ultra-clean exhaust outlet

THE NATURAL Cummins EURO6 CHOICE

Representative architecture only

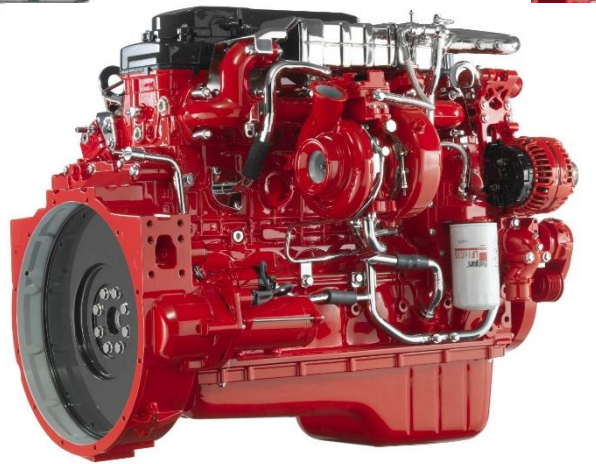
Integrating Critical Subsystems:

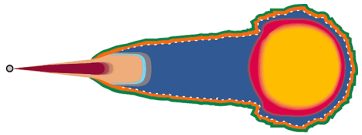
Valvoline
Cummins



Electronic Controls

Cummins Emission Solutions





Combustion Technology

Cummins Turbo Technologies

Cummins Fuel Systems

Technology Selection:

The broadest technology portfolio of any engine company

Application		Date	In-Cylinder Only	Cooled EGR / VGT	NOx Absorber	SCR	Diesel Particulate Filter	Compact Catalyst
Tier 3 / EU Stage IIIA		2005	●					
EPA Tier 2 > 751 hp		2006	●					
Euro IV On-Highway		2006				●		
EPA 07 On-Highway		2007		●			●	
EPA 07/10 Pickup Truck		2007		●	●		●	
Euro V On-Highway		2009				●		
EPA 10 On-Highway		2010		●		●	●	
Tier 4 Interim/ Stage IIIB	174-751 hp	2011		●			●	
	75-173 hp	2012		●				●
Euro VI On-Highway		2014		●		●	●	
Euro VI / BS VI / NS VI Alternate Architecture		2020				●	●	

Looking Beyond Euro 6

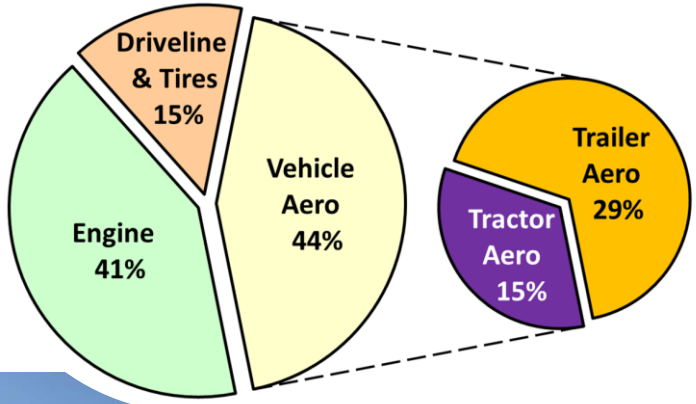
Reducing Fuel Consumption / Green House Gases (CO_2)

SuperTruck Technology Contributions:

6 mpg /
39 l/100km

75%
improvement

10.7 mpg /
22 l/100km



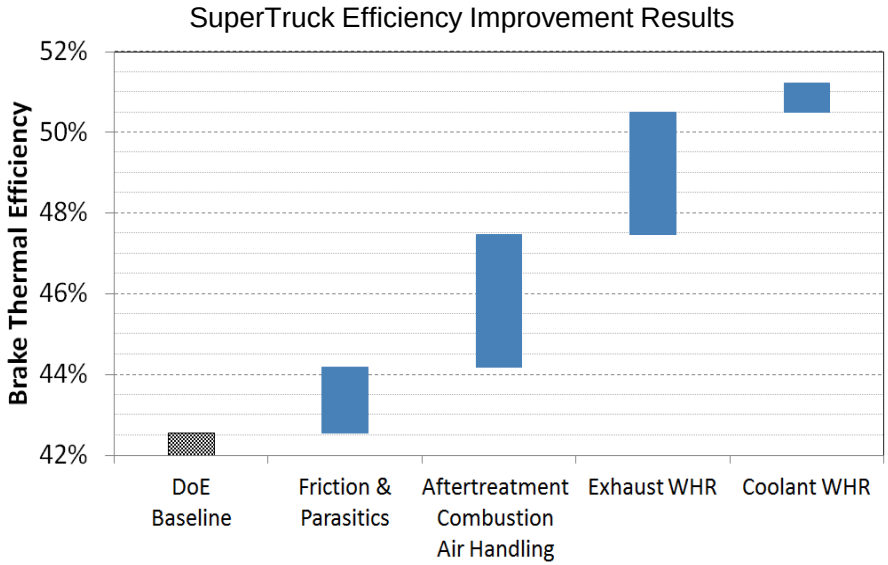
Technologies for 50% Engine Thermal Efficiency:

Combustion & Air Handling

- Piston bowl size and shape
- Injector specification
- Calibration optimization
- Turbocharger efficiency
- Aftertreatment optimization

Parasitic reductions

- Shaft seal
- Variable flow lube pump and viscosity
- Geartrain
- Cylinder kit friction
- Cooling and fuel pump power



WHR system

- EGR, exhaust, recuperator
- Turbine expander
- Low GWP refrigerant

Conclusion:

- Diesel engines has potential to remain choice of powertrain in long run for heavy duty applications owing to it's in use compliance, ultra low emissions and higher thermal efficiencies.
- Diesel engines will improve further with advent of technology in aftertreatment systems, waste heat recovery etc.
- Passcars with Diesel Engines has strong potential to be inline with HD Diesel application from in-use emissions perspective. On- road RDE cycles need to be defined in order to achieve this.

Questions