Future Emission Norms

Implications for FIE, Controls and Software

B Viswanath
Chief Technology Officer

Date: 03rd November 2023

Contents

- About Delphi-TVS
- EU Proposals
- Updates to Euro 7 norms
- On Board Monitoring (OBM)
- Emission Norms Challenges
- Summary

About Delphi-TVS

- Joint venture between Phinia (Erstwhile BorgWarner / Delphi), USA and TVS Group to make fuel injection systems for diesel engines.
- 1st Plant set up in 1990.
- Technical Centres, with Engineers capable of supporting software, application and calibration developments to meet beyond BS6 and Tractors TREM V norms.
- High level of localization through a network of supplier partners developed in India
- Over 8 million (3 million CR and 5 million Rotary) Delphi-TVS systems in the field to-date. Products cover entire market range.
- Extensive aftermarket network with over 300 service centres dedicated to diesel in India and Delphi network worldwide.

Delphi - TVS Technologies

Delphi-TVS
Manufacturing & Technical Center

Delphi-TVS produces Diesel FI systems across 2 manufacturing facilities (near Chennai)

CR Manufacturing - Oragadam

- Common Rail FI Systems manufacturing site (Pumps, Injectors, Rails and Filters)

Technical Center - Mannur

- Application and Calibration Development / Product Development / Validation

Mechanical FI Manufacturing - Mannur

- Mechanical FI systems manufacturing site (Pumps, Injectors and Filters)

DTVS - Technical Centre

Snapshot

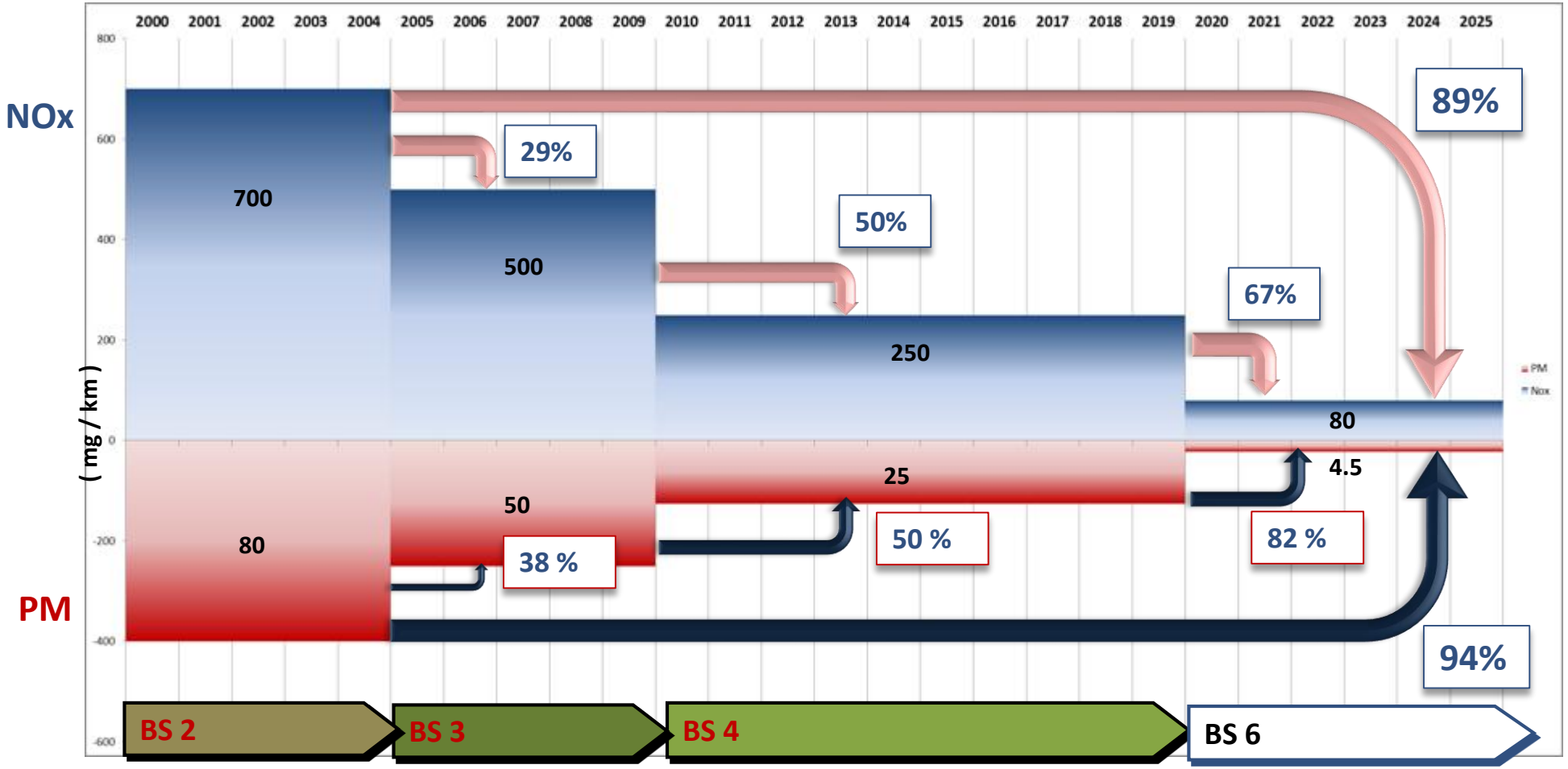
- Tech Centre was established in 2007.
- Over 200 Engineers involved in development work.
- Group of Electronics engineers to work with customers for initial contact.
- End to end facility for turnkey development available at the Tech Centre.
- All application developments for India market done from here, thereby providing speedy response.

End to End facility for turnkey development.

DTVS has the ability to absorb, adapt and applicate new technologies

Delphi - TVS Technologies

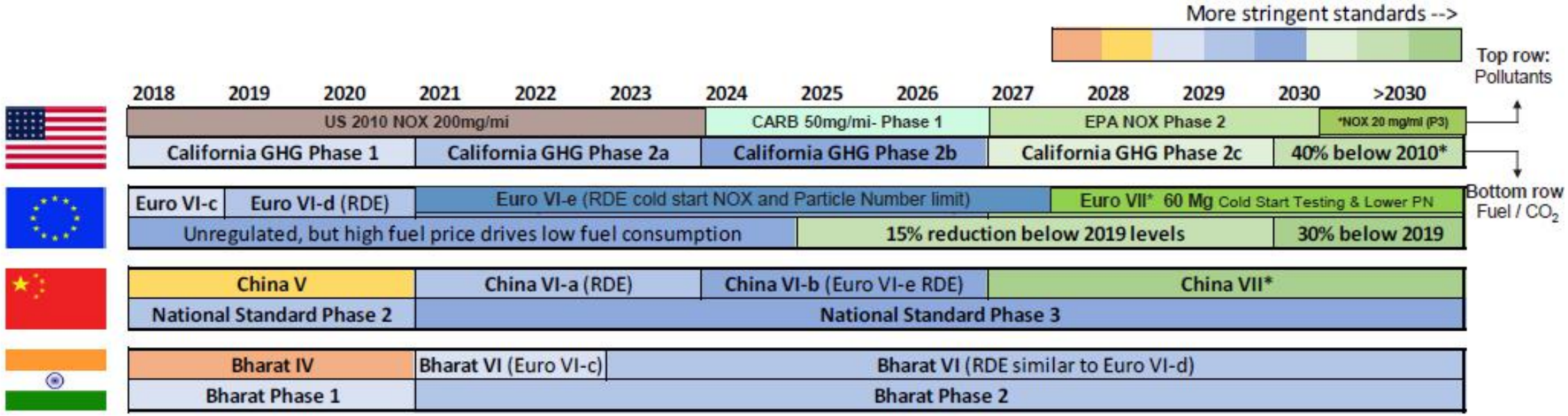
Progression of Indian emission norms



According to some recent studies in Europe, a modern diesel engine consumes up to 25% less fuel and emits up to 15% less CO_2 than a comparable gasoline engine.

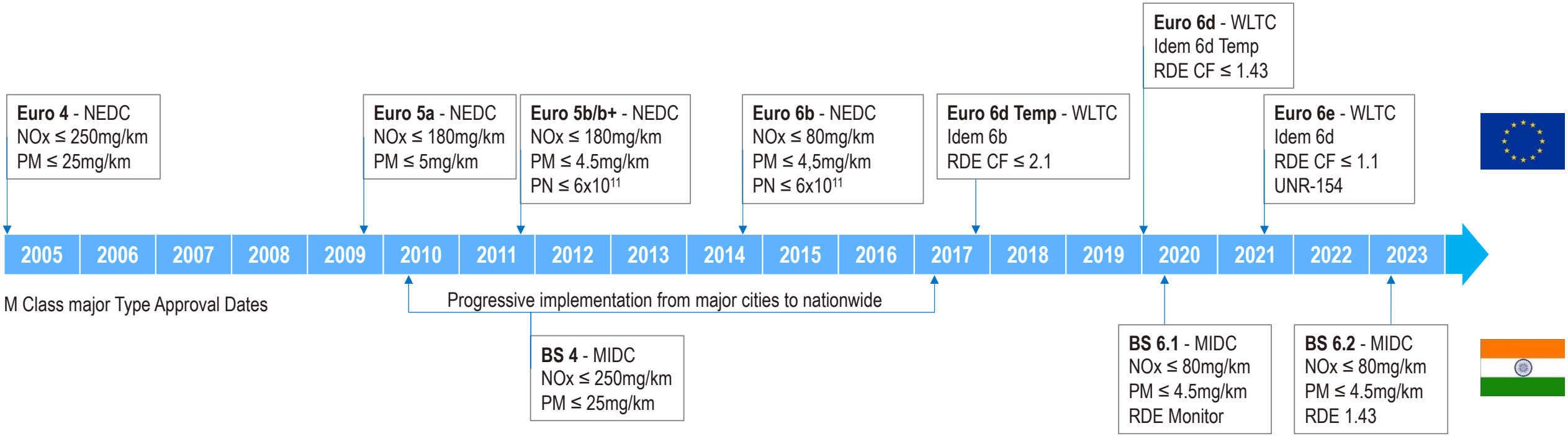
Delphi – TVS Technologies

Commercial Vehicles Emission & Fuel Economy Standards



- Implementation date for Euro 7 is unclear

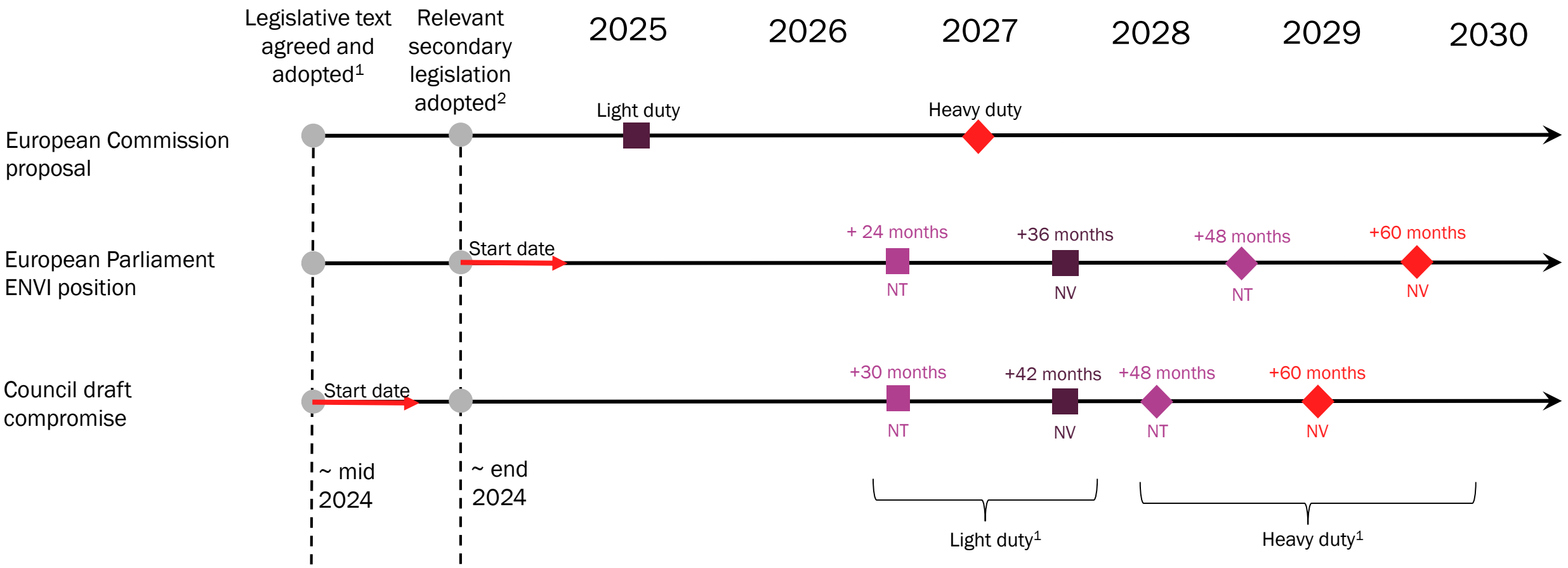
Background


Euro 4 - NEDC
NOx ≤ 250mg/km
PM ≤ 25mg/km
Euro 5a - NEDC
NOx ≤ 180mg/km
PM ≤ 5mg/km
Euro 5b/b+ - NEDC
NOx ≤ 180mg/km
PM ≤ 4.5mg/km
PN ≤ 6x10^11
Euro 6b - NEDC
NOx ≤ 80mg/km
PM ≤ 4,5mg/km
PN ≤ 6x10^11
Euro 6d Temp - WLTC
Idem 6b
RDE CF ≤ 2.1
Euro 6d - WLTC
Idem 6d Temp
RDE CF ≤ 1.43
Euro 6e - WLTC
Idem 6d
RDE CF ≤ 1.1
UNR-154
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
M Class major Type Approval Dates
Progressive implementation from major cities to nationwide
BS 4 - MIDC
NOx ≤ 250mg/km
PM ≤ 25mg/km
BS 6.1 - MIDC
NOx ≤ 80mg/km
PM ≤ 4.5mg/km
RDE Monitor
BS 6.2 - MIDC
NOx ≤ 80mg/km
PM ≤ 4.5mg/km
RDE 1.43

EU Proposals – from May 2023

- EU Council Compromise Proposal
  - Additional one year for all types
  - Fixed duration once it comes into force
- EU Parliament Compromise Proposal
  - Additional two years for all types
  - Fixed duration
  - Additional text to cover use of CO_2 neutral fuels
- Eu 7 LDV Implementation
  - New Types - Q2, 2027 to Q1, 2028
  - All Types - Q2, 2028 to Q1, 2029
- Eu 7 HDV Implementation
  - New Types - Q2, 2028 to Q1, 2029
  - All Types - Q2, 2029 to Q1, 2030

Institutional positions on implementation dates



NT: New Types (Entirely new model)

NV: All New Vehicles

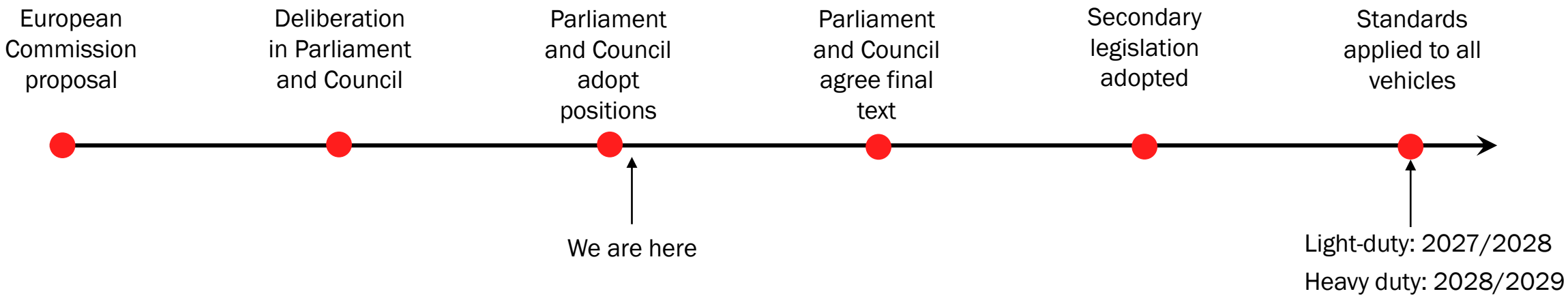
[1] estimated

[2] estimated, definition to be clarified

10

Delphi – TVS Technologies

Euro 7 process (simplified) & expected implementation dates



Euro 7 emission norms – explanation

- No technological distinction
  - Euro 7 standard will no longer make a technological distinction between “conventional” gasoline engines, gasoline direct injection (GDI) engines, and diesel engines.
  - Lowest emissions among the engines has been chosen for the future.
- Tighter rules for fine particulate matter
  - Euro 6 norm set limits for particles larger than 23 nanometers (Particulate Number, or PN23)
  - With the Euro 7 norm, limits are set for particles larger than 10 nanometers (PN10).
  - Smaller pollutants need to be considered, but also that more different types of pollutants
- Extension of emission standards
  - The period in which emission requirements must be met has doubled.
  - Euro 6 regulations - 100,000 kilometers or 5 years,
  - Euro 7 (light-duty) - 200,000 km or 10 years.

Euro 7 emission norms – explanation

- Limit for Short and Long Trips
  - Engines are most polluting during the first few minutes.
  - Cold, combustion is inefficient, and the exhaust aftertreatment systems do not work as effectively.
  - Euro 7 standard includes a test specifically for short trips of less than 10 kilometers.

	NOx	PM	PN10	CO	THC	NMHC	NH3
RDE (mg/km)	60	4,5	4×10^{11}	500	100	68	20
Trips <10km (mg/trip)	600	45	6×10^{12}	5000	1000	680	200

- Self-registration – used for ISC and Surveillance
  - Euro 7 vehicles must monitor themselves,
  - Existing OBD will change to OBM
  - Many additional sensors and a computer where the data can be stored and read.
- Maximum emission limits on brakes and tyres
  - Limit on the emissions from brakes and tyres, which will restrict the amount of brake dust and tyre particulates from all types of cars.

Proposed standards & potential outcome – heavy duty

Proposed limits

Euro 7 Exhaust emission limits for M_2,M_3,N_2 and N_3 vehicles

Pollutant Emissions	Cold emission[2]	Hot emissions[3]	Emission budget for all trips less than 3*WHTC long	Optional idle emission limits[4]
	per kWh	*per kWh*	*per kWh*	*per hour*
NO_x in mg	350	90	150	5000
PM in mg	12	8	10	
PN_{10} in #	5×10^{11}	2×10^{11}	3×10^{11}	
CO in mg	3500	200	2700	
NMOG in mg	200	50	75	
NH_3 in mg	65	65	70	
CH_4 in mg	500	350	500	
N_2O in mg	160	100	140	

[2] Cold emissions refers to 100th percentile of moving windows (MW) of 1 WHTC for vehicles, or WHTC $_{cold}$ for engines
[3] Hot emissions refers to the 90th percentile of moving windows of 1 WHTC for vehicles or WHTC $_{hot}$ for engines
[4] Applicable only if a system is not present that automatically shuts down the engine after 300 seconds of continuous idling operation(once the vehicle is stopped and brakes applied)

Potential outcome

- Limits maintained (except potentially higher limits for PN, N_2O)
- Possibly simplified limit and testing structure (replacing 90th percentile with average)
- Greater freedom to type approve with engine-only testing (with on-road testing for in-service conformity)

Proposed On-Road Test Conditions – heavy duty

Parameter	Normal driving conditions	Extended driving conditions*
Extended driving divider	-	2 (applies to measured emissions only during the time when one of the conditions set out in this column applies)
Ambient temperature	-7°C to 35°C	-10°C to -7°C or 35°C to 45°C
Maximum altitude	1600 m	From 1600 to 1800 m
Towing/aerodynamic modifications	Not allowed	Allowed according to manufacturer specifications and up to the regulated speed
Vehicle Payload	Higher or equal than 10%	Less than 10%
Auxiliaries	Possible as per normal use	-
Internal combustion Engine Loading at cold start	Any	-
Trip composition	As per usual use	-

Extended test conditions of temperature, altitude, speed and trips make it stricter and more difficult to test

Euro7 emission limits Passenger Cars and Vans

	EU6e Gasoline	EU6e Diesel	EU7 COM(2022) 586	EU Council 22.09.2023		ENVI* 12.10.2023 M1,N1 Class1/2/3
				Gasoline M1,N1 Class1/2/3	Diesel M1,N1 Class1/2/3	
NOx [mg(km]	60	80	60	60	80	60/75/82
PM [mg(km]	4.5	4.5	4.5	4.5		4.5
PN [-]	$6*10^{11}$ >23nm	$6*10^{11}$ >23nm	$6*10^{11}$ >10nm	$6*10^{11}$ >23nm		$6*10^{11}$ >10nm
CO [mg(km]	1000	500	500	1000/1810/2270	500/630/740	500/630/740
THC [mg(km]	100	NOx+HC 170	100	100/130/150	NOx+HC 170/195/215	100/130/160
NMHC [mg(km]	68		68	68/90/108		68/90/108
NH3 [mg(km]	-	-	20	-		20
RDE CF	NOx 1.1/ PN 1.34	NOx 1.1/ PN 1.34	1.0	?		-
Cold start	(16km) ***		10km **	(16km) ***		10 km **
Durability	160kkm (ISC 100kkm 5y)		160kkm 8y 200kkm 10y *	160kkm 8y 200kkm 10y *		200kkm 10y 240kkm 12y *
Evap	2g @ 48h diurnal Refuelling 0.05g/L		0.5/test Refuelling 0.05g/L	2.0 g/test No refuelling		0.5/test Refuelling 0.05g/L
OBM	no	no	yes	yes		yes
RDE test conditions	Maximum dynamic parameters defines		Any test, with weak safeguard against bias	Euro 6 conditions		Any test, with stronger safeguard against bias

* Durability multiplier of 1.2 applicable between 160kkm and 200kkm
** EU7 Cold start budget [mg] = Distance x emission limit;
***EU6 minimum trip distance of urban phase RDE

*European Parliament's Committee on the Environment, Public Health and Food Safety (ENVI)

Euro7/VII emission limits Heavy duty vehicles

	EU VI	EU7 COM(2022) 586		EU Council 22.09.2023		ENVI* 12.10.2023	
		Cold	Warm	WHSC/WHTC	RDE	WHSC/WHTC	RDE
NOx [mg/kWh]	460 mg/kWh	350 mg/kWh	90 mg/kWh	230	300	200	260
PM [mg/kWh]	10 mg/kWh	12 mg/kWh	8 mg/kWh	8	-	8	10
PN [-]	$6*10^{11}$ >23nm	$5*10^{11}$ >10nm	$2*10^{11}$ >10nm	$6*10^{11}$ >23nm	$9*10^{11}$ >23nm	$6*10^{11}$ >10nm	$7.8*10^{11}$ >10nm
CO [mg/kWh]	4000 mg/kWh	3500 mg/kWh	200 mg/kWh	1500	1950	1500	1950
NMOG [mg/kWh]	160 mg/kWh	200 mg/kWh	50 mg/kWh	80	105	75	98
NH3 [mg/kWh]	10 ppm	65 mg/kWh	65 mg/kWh	65	85	60	78
CH4 [mg/kWh]	500 mg/kWh	500 mg/kWh	250 mg/kWh	500	650	500	650
N2O [mg/kWh]	-	160 mg/kWh	100 mg/kWh	200	260	160	208
Durability	500 kkm 7y	Main lifetime 700 kkm 15y Add. Lifetime: 875 kkm		N2,N3,M3* 300 kkm 8y / 375 kkm 10y N3,M3 700kkm 12y, 875 kkm 15y		N2,N3,M3* 340 kkm 10y / 400 kkm 12y N3,M3 750kkm 15y, 900 kkm 17y	
OBM	-	yes		yes		yes	
RDE test conditions	Optional ISC	Any test, with no explicit safeguard against bias		Euro 6 conditions		Any test, with stronger safeguard against bias	

* N2, N3 < 16t, M3 <7,5t

* N2, N3 < 16t, M3 <7,5t

*European Parliament's Committee on the Environment, Public Health and Food Safety (ENVI)

Expected Outcome

	EU Council 22.09.2023		ENVI 12.10.2023	
	WHSC/WHTC	RDE	WHSC/WHTC	RDE
NOx [mg/kWh]	**230**	**300**	200	260
PM [mg/kWh]	**8**	**-**	8	10
PN [-]	**$6*10^{11}$** >23nm	**$9*10^{11}$** >23nm	$6*10^{11}$ **>10nm**	$7.8*10^{11}$ **>10nm**
CO [mg/kWh]	**1500**	**1950**	1500	1950
NMOG [mg/kWh]	**80**	**105**	75	98
NH3 [mg/kWh]	**65**	**85**	60	78
CH4 [mg/kWh]	500	650	500	650
N2O [mg/kWh]	200	260	160	208
Durability	N2,N3,M3 300 kkm 8y / 375 kkm 10y N3,M3 700kkm 12y, 875 kkm 15y		N2,N3,M3 340 kkm 10y / 400 kkm 12y N3,M3 750kkm 15y, 900 kkm 17y	
OBM	yes		yes	

Special focus on CO2 for HD
CO2 regulation situation for HD (14th of Feb)

The standards will apply to all classes of heavy duty freight and passenger vehicles, whereby current CO_2 standards only apply to medium and long-haul trucks. The following are the proposed revisions of the CO_2 reduction targets (vs. the 2019 baseline), and estimates for implied fleet shares of zero-emission vehicles (ZEV):

For all heavy-duty trucks (>3.5 tonnes) and coaches (8 or more passenger seats):

2025 No change: 15%
2030 Reduction target changed from 30% to 43% (~35-40% ZEV fleet share required)
2035 New reduction target of 64% (~60% ZEV fleet share required)
2040 New reduction target of 90% (at least 90% ZEV fleet share required)

For urban buses:

2030 100% ZEVs

The definition of heavy-duty ZEV includes any vehicle with CO_2 emissions less than 5g/tonne-km or 5g/passenger-km (which would accommodate H_2ICE vehicles, including those with diesel pilot injection). This definition is likely to be resisted by some NGOs, who are fundamentally against ICEs. A potential compromise could be a tighter threshold, which would still define pure H_2ICE vehicles as ZEV.

- New Regulation introduction will generate huge change in HD powertrain approach in next decade :
  - 2025 : Possible with ICE => Further step possible, cylinder deactivation, thermal management, friction reduction, small electrification…
  - 2030 :
    - For urban buses : Electrification 100%? H2 ICE? H2 Fuel Cells?
    - For HD trucks : 35/40% ZEV fleet share required ! E-fuel ? H2 ? Electrification ? NGVs ?
  - Further 2035 : Strong reduction of pure ICE…Growth for alternative Powertrain system HPH2? Enhance Fuel Cells? Electrification ?

CO2 regulations still in negotiation but likely to have strong impact on current HD PWT definition

Euro 7 challenges

- Euro 7 will require FIE upgrades, emission control update and significant amount of software development
- FIE upgrades
  - Accuracy
  - Long term stability
  - Modelling
  - After treatment control
- After treatment
  - Close coupled DOC and deNOx
  - Double SCR systems
  - Preheating of catalyst

Legislation – Euro7 EMISSION REGULATION - HD

WP1- Wet System/Emissions WP4- System

Proposed implementation by July 2027
Euro VII emissions limts vs Euro VI

		Euro VII	Euro VII	Euro VI	*If Euro VII*
		Cold emissions[2]	Hot emissions[3]	Combined[4]	*was weighted*
NOx	mg/kWh	350	90	460	*126*
PM	mg/kWh	12	8	10	*9*
PN_{10}	Number	5.00E+11	2.00E+11	6.00E+11	
CO	mg/kWh	3500	200	4000	*662*
NMOG[5]	mg/kWh	200	50	160 (THC)	*71*
NH_3	mg/kWh	65	65	10ppm	
CH_4	mg/kWh	500	350	500	*371*
N_2O	mg/kWh	160	100	N/A	

- Cold and hot cycle tests now have their own specific limits in Euro VII (Euro VI is a weighted average of the two cycles).
- All limits are generally lower than Euro VI.
- NOx and N_2O limits will be challenging to meet – aftertreatment calibration.
- Total Hydrocarbon (THC) limit changed to NMOG to encompass emissions that could result from use of bio, paraffinic or synthetic fuels.

Comparison of engines and pollution control devices durability (ref. Article 6)

		Trucks and coaches (N_2, N_3, M_3)			
		N_2, N_3<16t, M_3<7.5t		N_3>16t, M_3>7.5t	
		Euro VI	Euro VII	Euro VI	Euro VII
Lifetime	Mileage	300,000 km	300,000 km	700,000 km	700,000 km
	Years	6	8	7	15
	CF	1.5	**1.0**	1.5	**1.0**
Additional lifetime[6]		-	**375,000 km**	-	**875,000 km**

- For HD vehicles, both mileage and duration are increased
- Conformity Factor (CF) is deleted from Euro VII, as PEMS systems are now considered sufficiently accurate.

Pollutant emissions	Emission budget for all trips less than 3*WHTC long	Optional idle emission limits[4]
	per kWh	*per hour*
NO_x in mg	150	5000
PM in mg	10	
PN_{10} in #	$3x10^{11}$	
CO in mg	2700	
NMOG in mg	75	
NH_3 in mg	70	
CH_4 in mg	500	
N_2O in mg	140	

- Specific emissions budget given if ISC test is shorter than 3x WHTC length (it was 4x at Euro VI).
- This is to give a tougher focus on the cold start portion of the test.
- The conformity limits are very low
- In addition an idle NOx limit is introduced – this is new for Euro VII
- Designed to prevent idling to warm the cab while driver is sleeping

- Strong reduction of pollutants !
- Introduction of cold phase limit & idle Nox limit
- Reduction of CF from 1.5 to 1.0 & both mileage & duration are increased.

⇒ Improved fuelling accuracy & stability required. Smallest pilot injection required (?) Highest inj pressure (?)

⇒ Multiple injections number will increase close to PC.

⇒ Close loop mandatory for performance stability vs lifetime.

⇒ Impact in control/strategies for Generic Platform to be considered.

Delphi - TVS Technologies

Euro 7 – Legislation update – Status

WP1- WetSystem/Emissions WP4- System

- For Diesel LCV programs Delphi-TVS / PHINIA system (wet system + strategies) can fulfill BS7 requirements with current data available.
- For MD/HD Diesel due to more severe emissions limits, increase mileage for in service conformity and reduced CF situation is more complex and three attributes need to be addressed :
  - **Engine out emissions reduction. (The ATS is controlled by OEMs &/or FIE supplier (SCR + DPF) with already strategies available).**

    ↳ Injection pattern close to latest pass car specification (high number of injections, small separation, improved fueling accuracy).

    ↳ HD/MD injector upgrade required (part to part, injection dispersion, etc..). Close loop control mandatory for EU7.
  - **CO2 reduction. The contribution of Fuel System is not key but to be considered.**

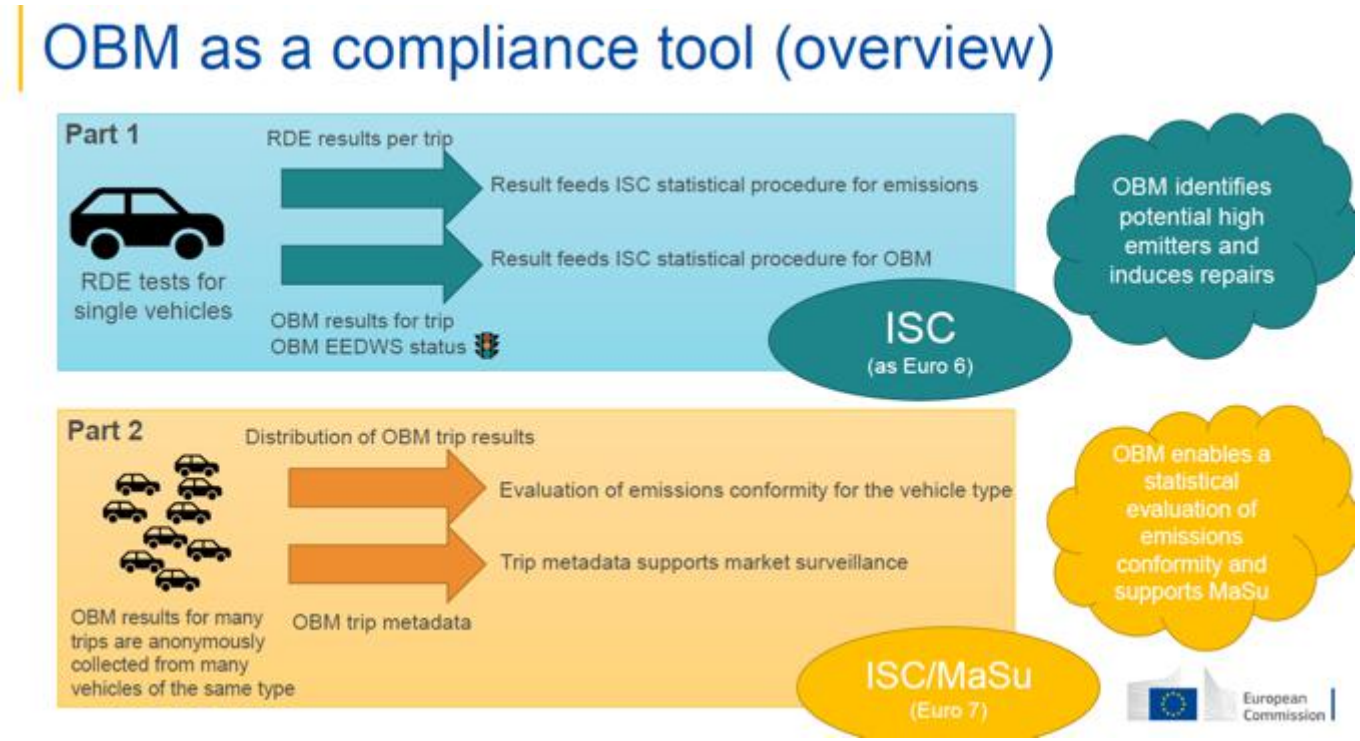
    ↳ Reduction of leakages (injector/pump), reduction of weight, increase of pumping efficiency.
  - **In service conformity**

    ↳ Mainly injector stability versus time and robust close loop control strategy.

EU7 OBM/OBD challenge & implementation PC/LCV/HD

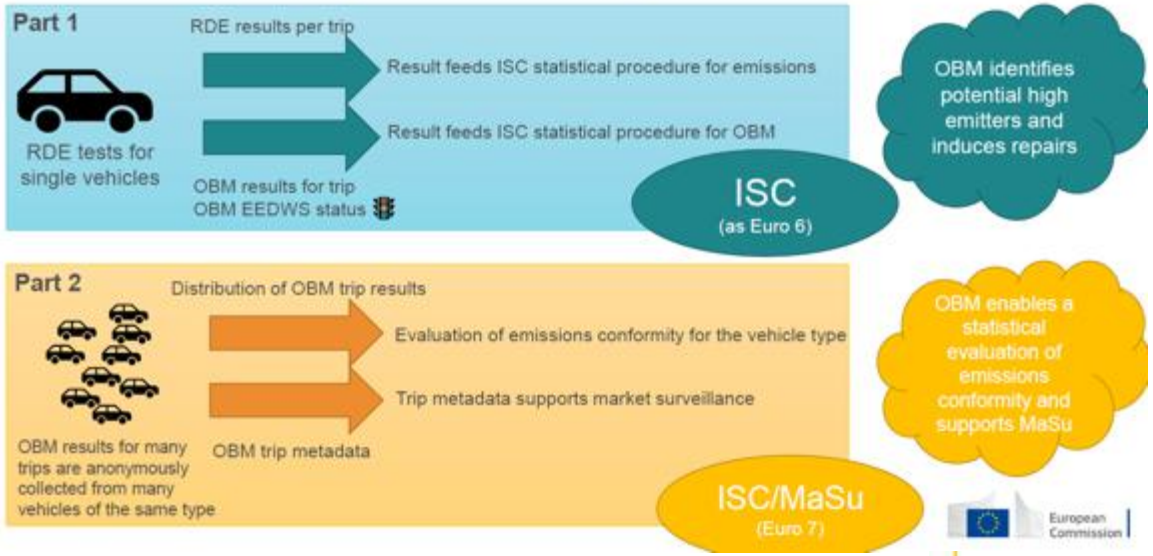
Exceedance Emission Driver Warning System (EEDWS)

- OBM is the most significant challenge for Euro 7
- Traffic light system with display to the driver
- Warn driver when emissions are inconclusive or 2.5x limit
- Access via OBD port
- Cold start emissions are included
- Most emissions to be covered
- Validation of OBMs across all use cases and durability
- EU commission expect OBM to be accurate even above 200k kms
- Will be used as ISC and for Market Surveillance
- Multi component ageing



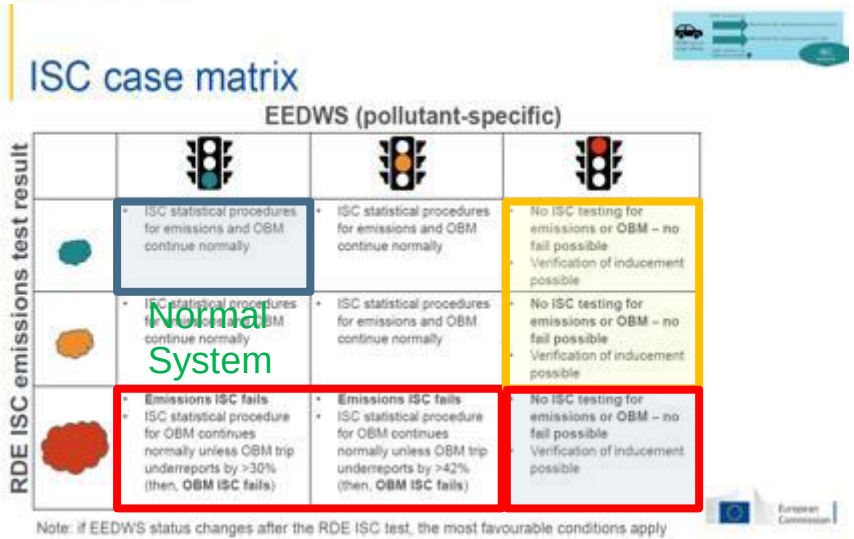
EU7 OBM/OBD challenge & implementation PC/LCV/HD

OBM as a compliance tool (overview)



- Good progress but not fully defined
- Introduction of OBM with real time pollutants survey could impact the EMS system (HW/SW)
- Sensors required
- Intensive introduction of virtual sensors, models, neural network.
- Increase of testing/Calibration/Validation effort…

Exceedance Emission Driver Warning System



Delphi - TVS Technologies

Summary

- Fuel agnostic, tighter, longer durability will be the aim of new norms
- Fuel Injection System and Controls will have a major role to play in meeting these norms
- OBM could a significant addition
- Adoption of future norms (BS 7?) for India to be discussed and evolved
- Significant effort required for calibration, modelling and software development.
- Sufficient time required for any new implementation.