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Delivering Excellence Through Innovation & Technology

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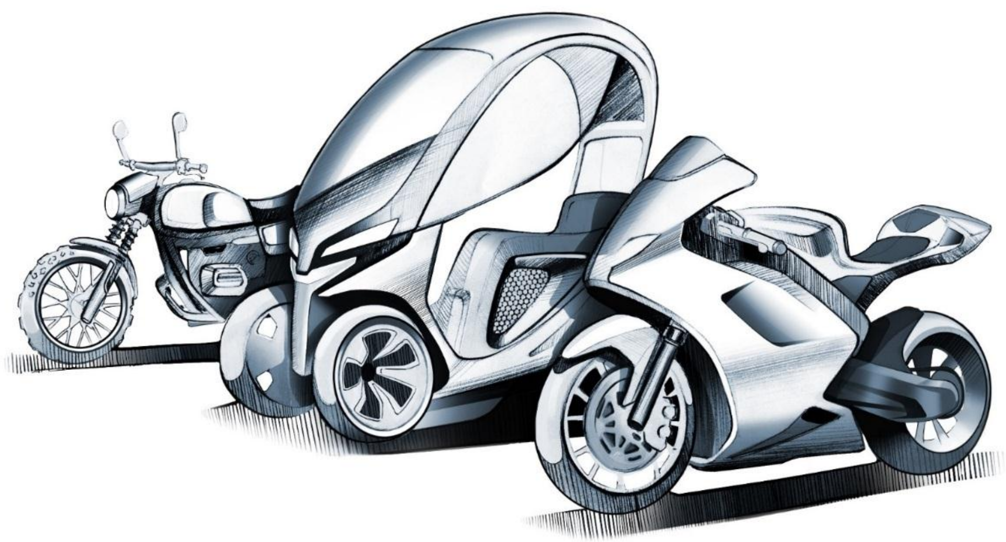
"BS VI and Real Driving Emissions ......Path Forward"

25th and 26th October 2018, Hotel Hyatt Regency, Nagar Road, Pune



Two Wheeler – BS VI Challenges

The Leap from BS IV to BS VI

by Ricardo Motorcycle

www.ricardo.com

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The challenge, Bharat Stage VI and OBD implications

- The Indian motorcycle market is large and growing fast but HUGELY competitive and the differentiating factor apart from others is - **fuel efficiency**.
- Up to BS IV, manufacturers concentrated on FE using lean techniques with the carbureted engines (which increased NOx) and addressed the NOx issue with aftertreatment.
- **1st April 2020 Bharat Stage VI** will be introduced and this will cut massively emission limits and will require monitoring of all features which have influence on emissions. In order to meet the much more stringent norms fuel injection with electronic control is an imperative and OEM´s are forced to remain stoich., which would mean a compromise on FE. Furthermore the low emissions must be guaranteed during the time and a check after a durability test will be required.
- Good fuel efficiency, meeting the new emissions standards and low cost are contradictory targets which require a thorough approach.
- **1st April 2023 OBD stage II** will be introduced to monitor pollutant emissions generation.

  OBD II is nowadays normal in the passenger car world, but something almost new in the motorcycle world.
- This document will give an **overview to the incoming legislation** and explain the main differences between Bharat Stage IV and Bharat Stage VI.
- The most influent features in the generation of emissions will be presented, as well will be highlighted the **key actions** that should be taken to achieve the emission limits in order to create growth opportunities from challenging targets.

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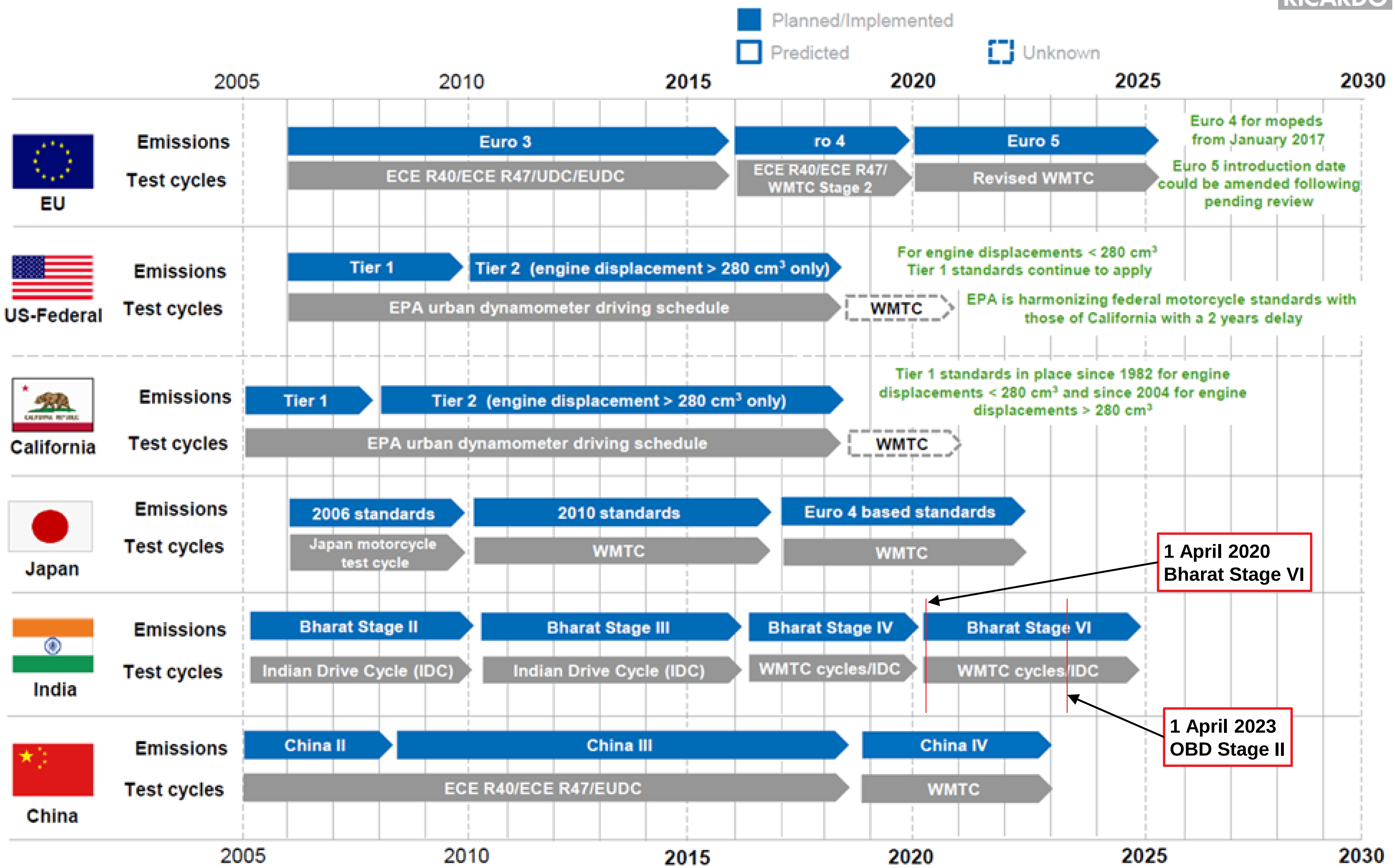
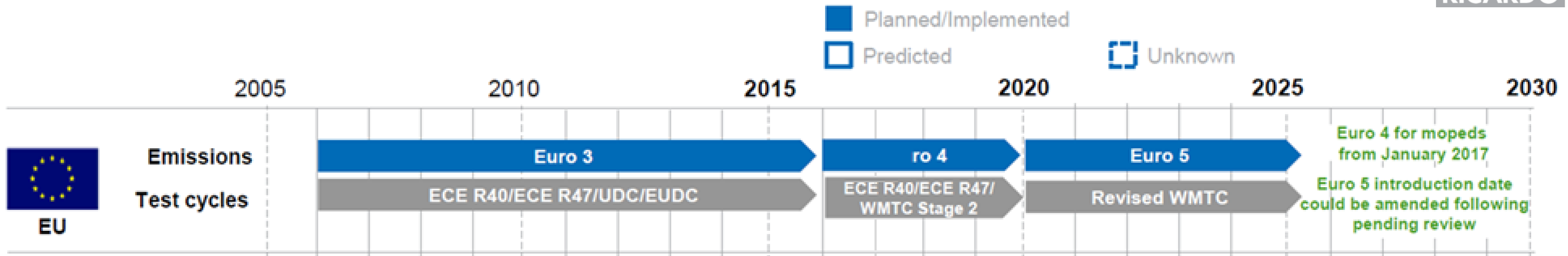
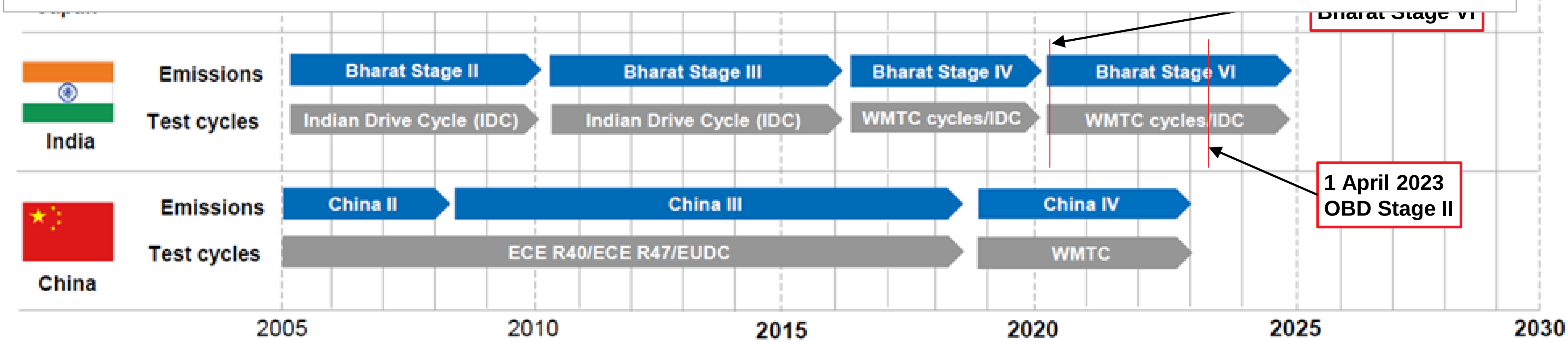
A view to the new legislations all over the world



A view to the new legislations all over the world

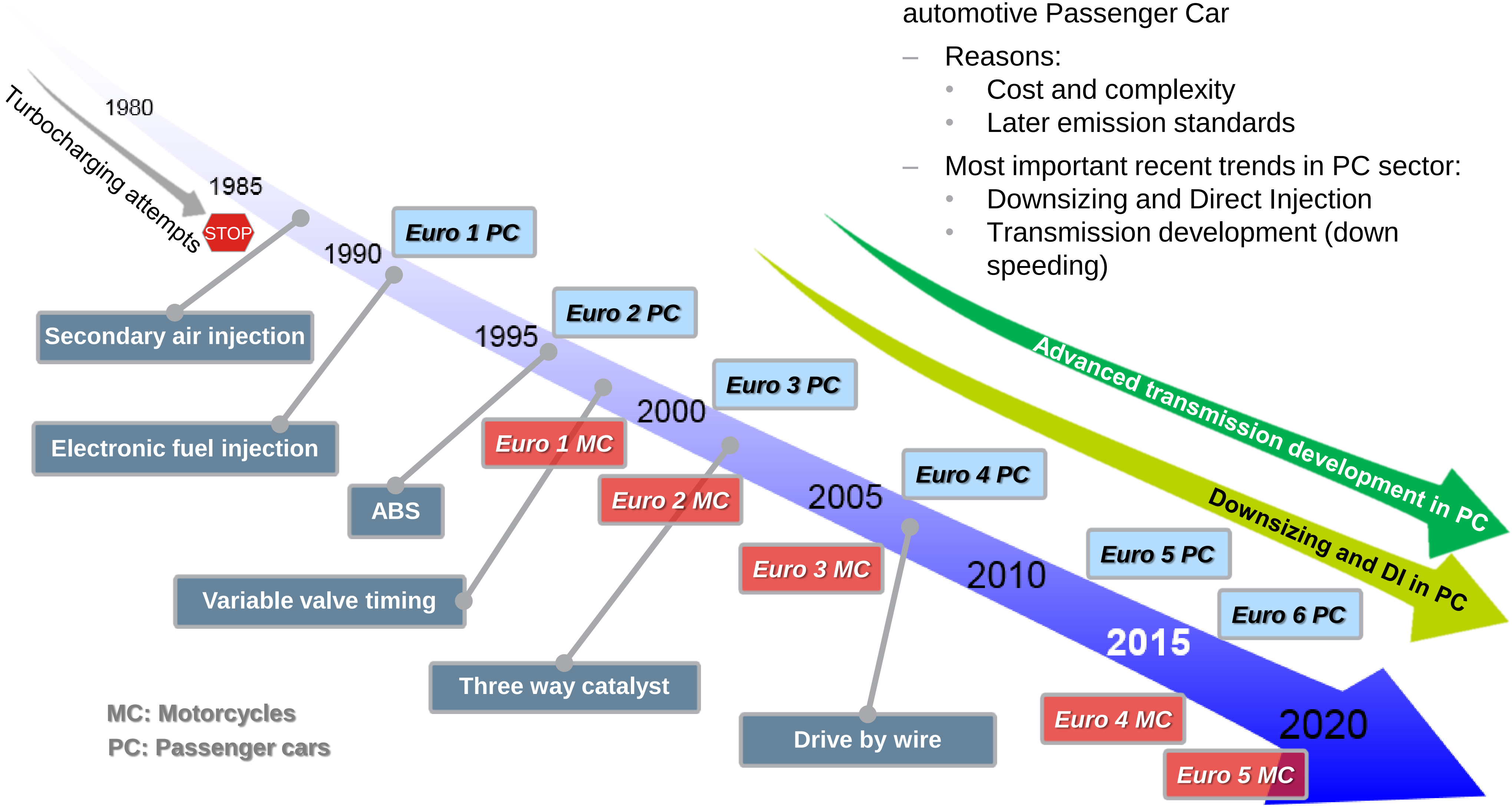


Standard	Reference	Date
Bharat Stage II	Euro 2	1 April 2005
Bharat Stage III	Euro 3	1 April 2010
Bharat Stage IV	Euro 4	1April 2017
Bharat Stage VI	Euro 5	1 April 2020 (expected)



A view of automotive technology in motorcycles world wide trends

- Motorcycle technology has always followed automotive Passenger Car
  - Reasons:
    - Cost and complexity
    - Later emission standards
  - Most important recent trends in PC sector:
    - Downsizing and Direct Injection
    - Transmission development (down speeding)



MC: Motorcycles
PC: Passenger cars

Emissions regulations for *developing* markets still lags behind *developed* markets, but aims to catch up over the next 5 years

Legislation – Emissions

- Internal Combustion Engine based motorcycles are a major source of pollution, especially in developing countries where they are the primary source of transport
- Developed markets have more stringent emissions legislation, with additional requirements on evaporative emissions and for on-board diagnostic (OBD)
  - Current emission limits in Europe and US require the use of catalytic converters
- Emissions regulations for motorcycles in developing countries lags behind the regulations in the developed countries on account of quality of fuel available, and the rate of adoption of greener technologies. However several emerging economies have announced plans to introduce stricter emission limits
  - India Bharat Stage IV standards (equivalent to Euro 4) have applied since April 2017. Bharat Stage VI emissions standards are to apply from April 2020
- There is move internationally towards adopting standard test cycles and procedures, using the World Motorcycle Test Cycle, developed by the United Nations' World Forum for Harmonisation of Vehicle Regulations (WP.29)

Pictures: Scooters in China (BBC); 2-wheel commuting in Nigeria (The Guardian); Indonesian woman riding scooter in thick haze in Indonesia (The Guardian)

Source: EMLEG

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Bharat Stage IV => Bharat Stage VI

Comparison of Emission Limits for Two Wheelers

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Bharat Stage IV Motorcycle and Moped Exhaust Limits (since April 2016)

Bharat Stage VI Motorcycle and Moped Exhaust Limits (from April 2020)

The Bharat Stage VI (BS VI) standards will apply to all vehicles manufactured from 1 April 2020 and are summarised in the following sections. Full details of all the test procedures relating to BS VI will be included in the upcoming AIS-137 standard. The published document however indicates that WMTC cycles will be used for 2-wheelers of Class 1 and higher; for mopeds and 3-wheelers the Indian Drive Cycle (IDC) will be used.

Class / Sub class	Engine Type	Engine Displacement	Maximum speed	CO [mg/km]	HC + NOx [g/km] Opt. 1	HC + NOx [g/km] Opt. 2	HC [mg/km]	NOx [mg/km]	NMHC [mg/km]	PM [mg/km] (1)	Evaporative Emissions [mg/test]	Durability [km]
1	PI	50 ≤ D ≤ 150	V_{max} ≤ 50	1000 1403	790	590	100	60 390	68	4.5[1]	1500	20000
1	PI	D ≤ 150	50 < V_{max} ≤ 100									
2.1	PI	D ≤ 150	100 < V_{max} ≤ 115									
2.1	PI	D >150	V_{max} ≤ 115									
2.2	PI	-	115 < V_{max} ≤ 130	1000 1970	670	470	100	60 340	68	4.5[1]	1500	
3.1	PI	-	130 < V_{max} ≤ 140	1000 1970	400	200	100	60 200	68	4.5[1]	1500	35000
3.2	PI	-	V_{max} >140									
All	CI			500 380	380		100	90	68	4.5 42.5		35000
Moped	PI	≤ 50	V_{max} ≤ 50	500 750	750		350	150				

Notes:

1. Applicable to gasoline direct injection engines only.

In addition to the requirements reported in the table, no emission of gases from the crankcase ventilation system is permitted.

Source: EMLEG

Bharat Stage IV => Bharat Stage VI

Additional Information for Comparison Table of Emission Limits for Two Wheelers

Bharat Stage IV

1. Option 1 is used in conjunction with an evaporative emissions limit of 2 g/test.
2. Option 2 is used if the evaporative emissions limit is 6 g/test.
3. Deterioration factors (CO: 1.2, NOx: 1.2 and HC+NOx: 1.2 based on 30,000 km durability) are built into the mass emission standards specified.
4. For CNG fuelled vehicles, HC is replaced by Non-Methane Hydrocarbon (NMHC), where NMHC = 0.3 x measured HC.
5. For LPG fuelled vehicles, HC is replaced by Reactive Hydrocarbon (RHC), where RHC = 0.5 x measured HC

Evaporative emissions
The regulation of evaporative emissions for gasoline engined vehicles with engines of more than 50 cm3 displacement and maximum design speed exceeding 50 km/h, is being introduced at Stage IV. Emissions are limited to either 2 g/test or 6 g/test, depending on whether the HC + NOx standard adopted by a manufacturer is taken as Option 1 or Option 2 in the above table.

Diesel
The published Stage IV legisation for 2-wheelers states that the standards for diesel engined 2-wheelers are the same as those for diesel 3-wheelers.

Bharat Stage VI

The Bharat Stage VI assigned deterioration factors are as follows. Alternatively, manufacturers may opt for the evaluation of deterioration factors according to the procedure that will be outlined in AIS-137.

Deterioration Factors Bharat Stage VI						
Engine Type	Vehicle Class	CO	HC	NOx	NMHC	PM
Spark ignition	All	1.3	1.3	1.3	1.3	-
Compression ignition			1.1	1.1	1.1	1.0

Bharat Stage IV => Bharat Stage VI

Comparison of Emission Limits for Three Wheelers

Bharat Stage IV

Bharat Stage VI

Engine Type	Standard		CO [mg/km]	HC + NOx [g/km] Opt. 1	HC + NOx [g/km] Opt. 2	NOx [mg/km]	PM [mg/km]	Evaporative Emissions [mg/test]	Durability [km]	Test Cycle
PI	Emissions Limit	Gasoline	440 940	435 940	435 740	130	-	1500	35000	IDC
		CNG / LPG	940	940	940					
	Deterioration Factor		1.2 1.2	1.2 1.2		1.2	-	-		
CI	Emissions Limit		220 380	200 380		160	25 42.5	-		
	Deterioration Factor		1.1 1.1	1.0 1.0		1.0	1.2 1.2	-		

Bharat Stage IV:
1. For gasoline engines, Option 1 would be used in conjunction with an evaporative emissions limit of 2 g/test.
2. For gasoline engines, Option 2 would be used if the evaporative emissions limit were 6 g/test.
3. For CNG or LPG fuelled vehicles evaporative emission tests are not applicable.
4. For CNG fuel, HC is replaced by Non-Methane Hydrocarbon (NMHC), where NMHC = 0.3 x measured HC and for LPG fuel, HC is replaced by Reactive Hydrocarbon (RHC), where RHC = 0.5 x measured HC
Evaporative emissions: *The regulation of evaporative emissions for gasoline engined vehicles with engines of more than 50 cm3 displacement and maximum design speed exceeding 50 km/h, is being introduced at Stage IV. Emissions are limited to either 2 g/test or 6 g/test, depending on whether the HC + NOx standard adopted by a manufacturer is taken as Option 1 or Option 2 in the above table.*
Diesel: *The published Stage IV legisation for 2-wheelers states that the standards for diesel engined 2-wheelers are the same as those for diesel 3-wheelers.*

Bharat Stage VI:
In addition to the requirements in the table, no emission of gases from the crankcase ventilation system is permitted.

Source: EMLEG

Bharat Stage VI - WMTC Test Procedure
(for two wheelers)

India is a party to the development of the WMTC and the GTR 2. The following table gives the test sequences and weighting factors for each vehicle class. Note that some of the "reduced speed" options are used in the Indian regulation.

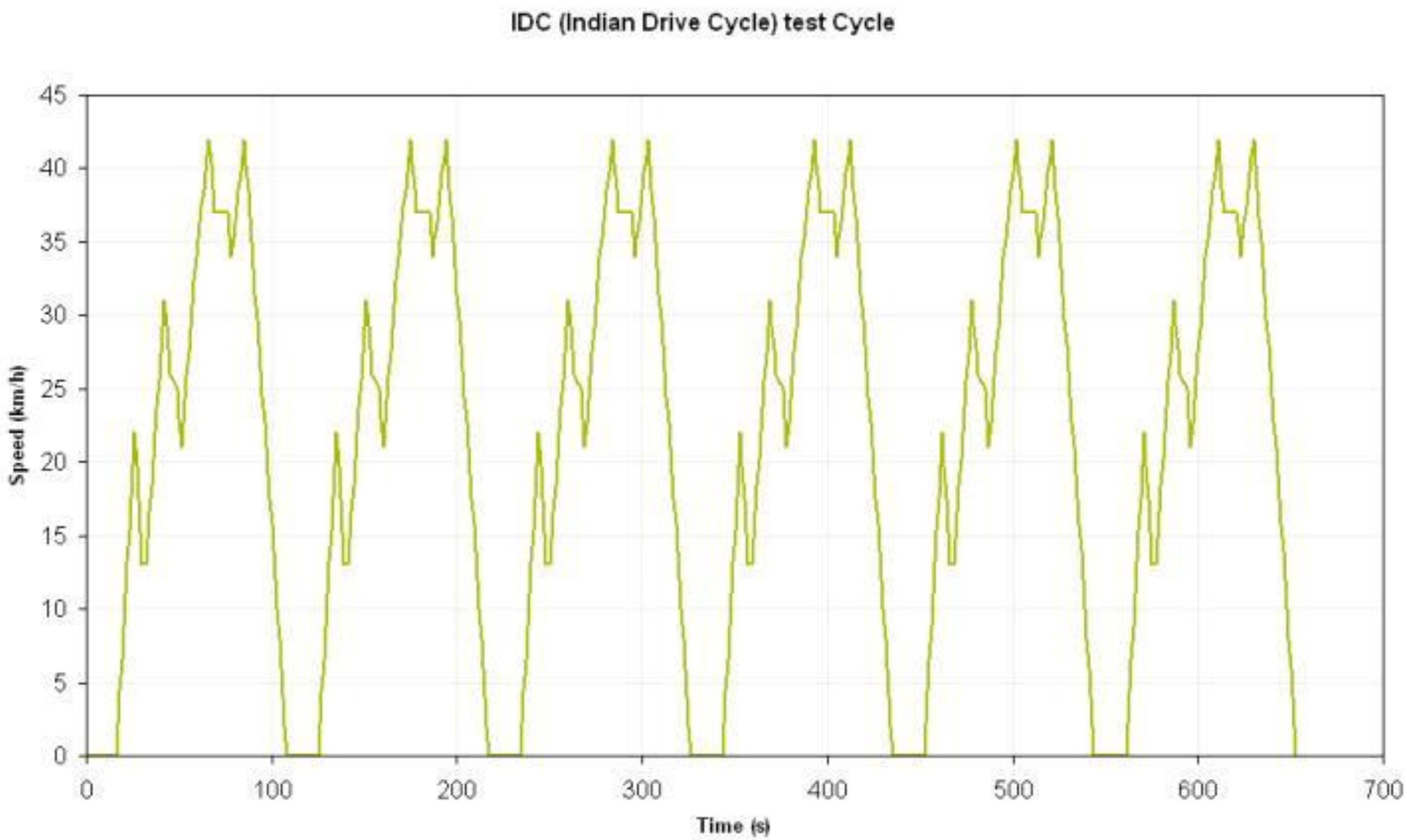
Weighting Factors for Motorcycle Tests

Vehicle Class	Cycle	Weighting
Classes 1 and 2.1	Part 1, reduced speed, cold	50%
	Part 1, reduced speed, hot	50%
Class 2.2	Part 1, cold	30%
	Part 2, hot	70%
Class 3.1	Part 1, cold	25%
	Part 2, hot	50%
	Part 3, reduced speed, hot (1)	25%
Class 3.2	Part 1, cold	25%
	Part 2, hot	50%
	Part 3, hot (1)	25%

Notes:
1. Reference [4] does not indicate hot or cold for this part. It is assumed to be hot, which is as per the GTR 2.

Bharat Stage VI – Indian Drive Cycle (IDC)
(for three wheelers and mopeds)

The IDC was used for all vehicles pre-2000, but is now only used for 2/3-wheelers.



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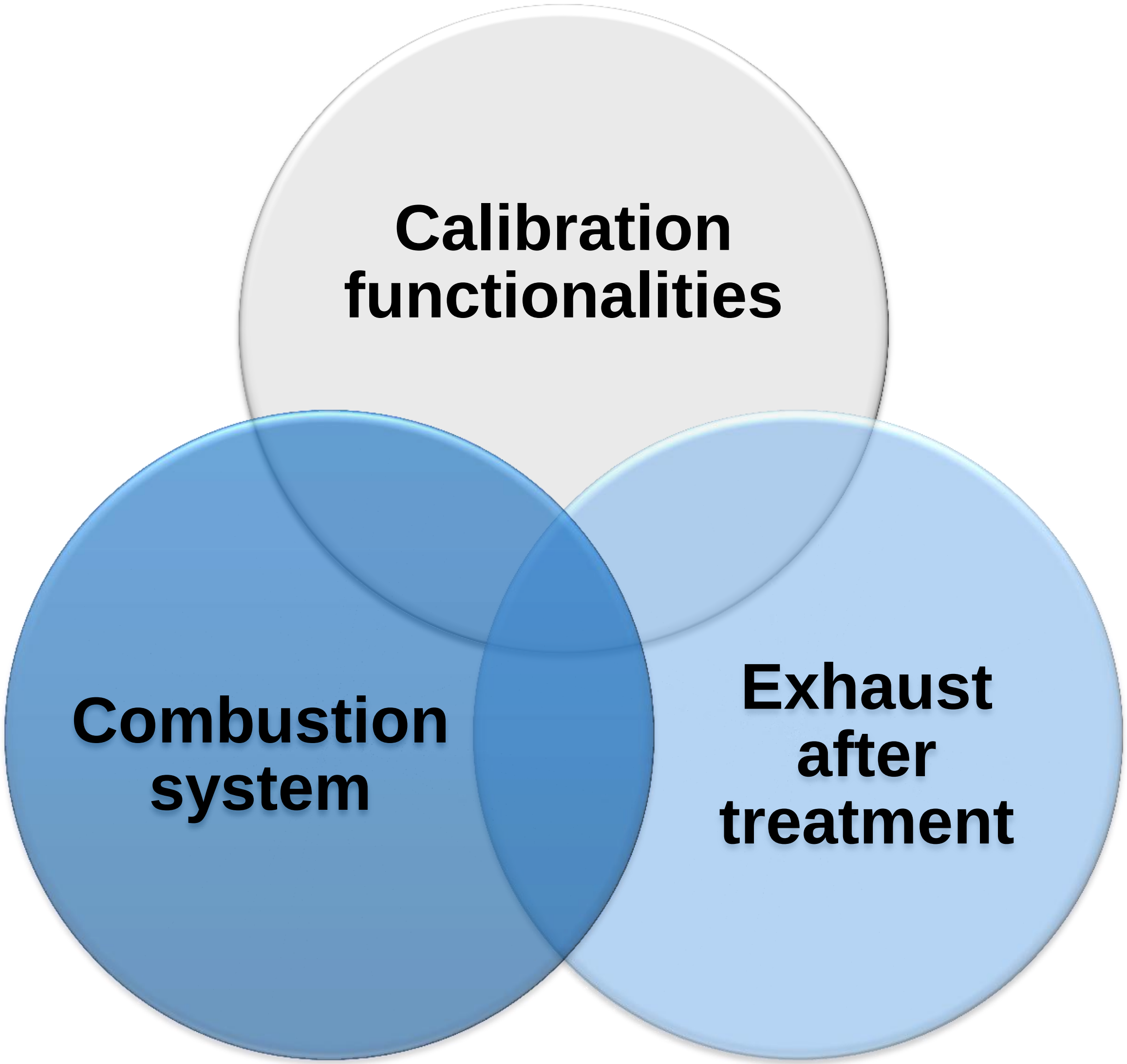
Fields of improvement to achieve Bharat Stage VI legislation

- Based on the previous challenges the **complete powertrain has to be considered** to achieve the required improvements
- **The quantity and complexity depends on the baseline situation**, where different challenges exist e.g. for a low cost vehicle compared to a super sports motorcycle
- The following slides give an overview of technology options, which need to be selected individually



Improvement of combustion system in terms of raw emissions – general example

- Possible technology packages:

Software

ECU

Optimized fuel management

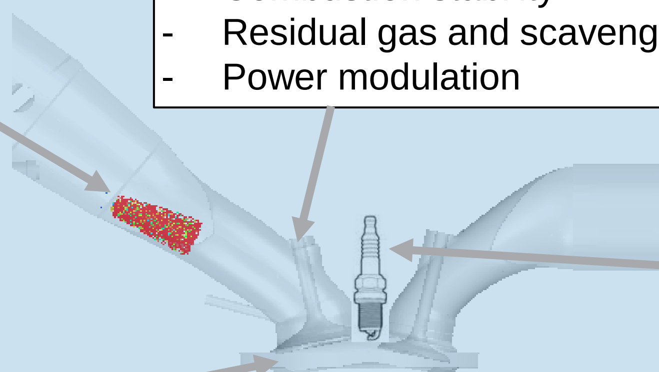
VVT control:
High specific output engines only

Optimized ignition strategies

Hardware

Injection optimization:
- Spray target and beam
- Mixture preparation
- Fuel quantity accuracy

Variation of Valve Timing and/or lift:
- Combustion stability
- Residual gas and scavenging
- Power modulation



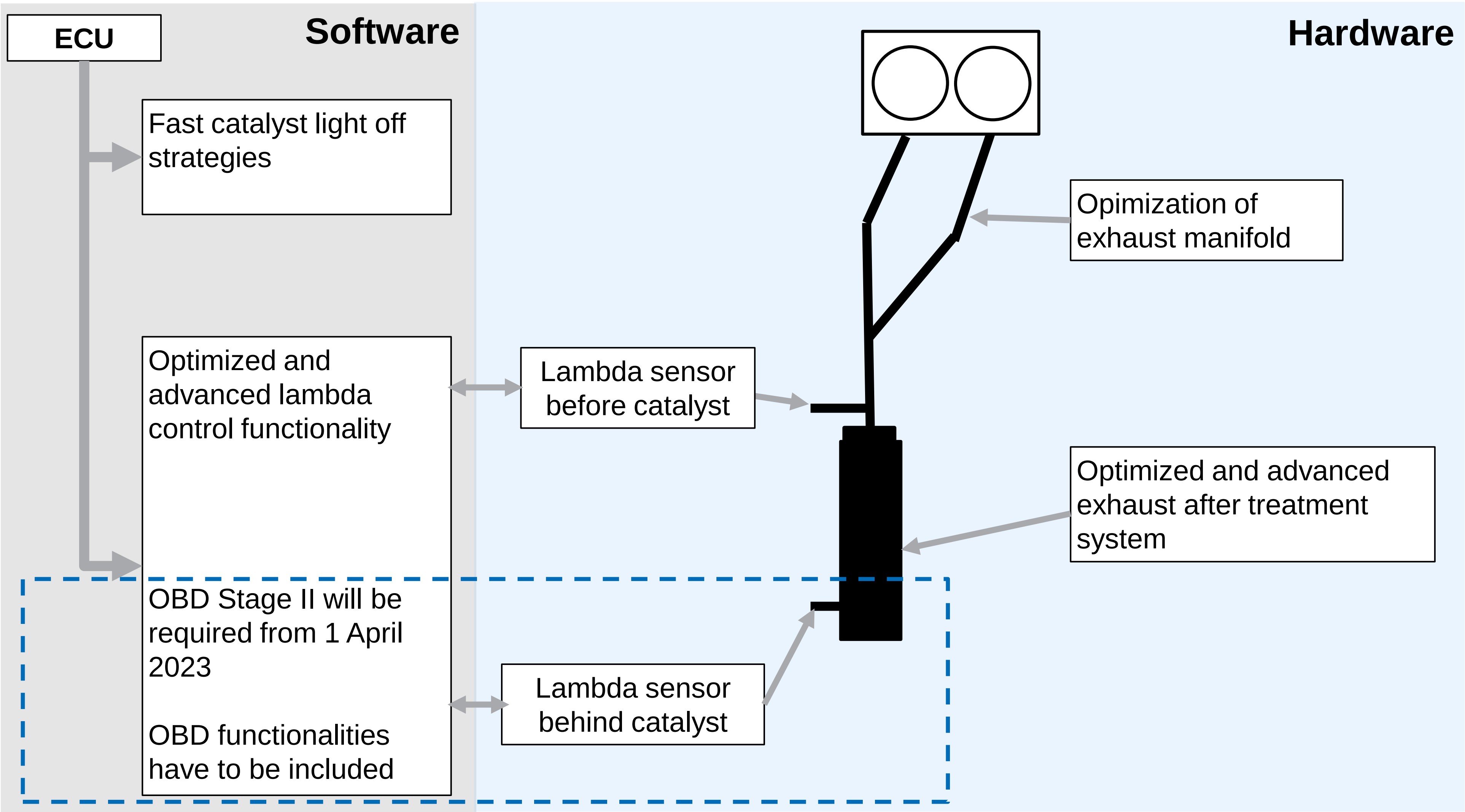
Ignition optimization:
- Ignition accuracy
- Stable inflammation
- Ignition energy

Cylinder turbulence levels:
- Stable inflammation (ignition delay)
- Stable combustion
- Mixture preparation

ECU regulated carburettors also could be a possibility to be used instead the Fuel Injection. But the development efforts are rated as very high. Therefore this will not be considered furthermore in this presentation.

Exhaust system and after treatment – general example

- Possible technology packages:



Detailed Technology Potential Evaluation – Engine (1)

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⊙: Very Positive / O: Positive / Δ: Neutral / X: Negative / XX: Very Negative

Technical Item	HC	NOx	Perfor mance	Price	Reason / Influencing Factor
Complete System DoE	O	O	O	O	Interdependency of the parameters can be analysed and a best possible combination can be achieved
Compression Ratio	O	O	O	Δ	Increase of CR can lead to Improved and faster combustion
In-Cylinder Combustion	O	O	Δ	Δ	optimised in-cylinder mixing formation, turbulence, spark position & knock detection leads to improved combustion
Cooling / Water Jacket (CFD/CHT simulation)	O	O	O	Δ	Reducing hotspots and risk of knocking Tailored cooling system
Low Friction (valid for whole powertrain + wheels and tyres)	O	O	O	X	Efficiency improvements due to lowered friction
Low Weight (valid for powertrain and vehicle components)	O	O	O	X	Efficiency improvements due to low weight

Detailed Technology Potential Evaluation – Engine (2)

RICARDO

⊙: Very Positive / O: Positive / Δ: Neutral / X: Negative / XX: Very Negative

Technical Item	HC	NOx	Performance	Price	Reason / Influencing Factor
Injector type (Low flow rate → SMD↑)	O	Δ	Δ	Δ X	Best possible vaporization of fuel
Carburettor (ECU Regulated)	X	X	Δ	X	Instability w/r to production variability Cost increase associated for aftertreatment (cat) Fine tuning for startability in cold condition Challenging for calibration issues
Fuel pressure (Increased → SMD, Droplet Breakup↑)	O	Δ	Δ	X	Increased fuel pressure helps in vaporization and evaporation of fuel
Throttle body size (smaller diameter)	O	Δ	X	Δ	One throttle body per cylinder with optimized diameter (small) gives best response in transient engine operation and also good stability in IDLE
Throttle body position (close to port)	O	Δ	O	Δ	Throttle position near intake port gives best response in transient engine operation and minimizes wall film effects
Optimized port design (higher tumble, if performance allows)	O	X	Δ	Δ	Optimized port design with high tumble, acceptable flow performance and lowest possible wall film to reach best behaviour in transient operation

Notes: SMD = Sauter Mean Diameter

Detailed Technology Potential Evaluation – Engine (3)

RICARDO

⦿: Very Positive / O: Positive / Δ: Neutral / X: Negative / XX: Very Negative

Technical Item	HC	NOx	Performance	Price	Reason / Influencing Factor
Intake valves					Always trade-off between emissions and performance
IVO → late	⦿	Δ	X	Δ	Late inlet valve opening decreases overlap; scavenging and residual gas but has negative effect on performance
IVC → trade-off	Δ	Δ	O / X	Δ	Early intake valve closing prevents back-flow of mixture to inlet port and maintains high effective CR; Late intake valve closing with low overlap helps to decrease NOx with no impact to HC
Exhaust valves					Always trade-off between emissions and performance
EVO → Late	⦿	X	X	Δ	Late exhaust valve opening provides longer combustion in cylinder which leads to more complete burning of fuel
EVC → Early	O	Δ/X	X	Δ	Early exhaust valve closing decreases overlap; scavenging and residual gas but has negative effect on performance

Detailed Technology Potential Evaluation –Engine (4)

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⦿: Very Positive / O: Positive / Δ: Neutral / X: Negative / XX: Very Negative

Technical Item	HC	NOx	Perfor mance	Price	Reason / Influencing Factor
Ignition system (Optimized spark location and higher energy)	O	Δ	Δ	X	Stable and robust ignition especially in cold and low load conditions
IDLE speed (Increased)	O	Δ/X	Δ	Δ	IDLE speed in cold and warm condition is important to warm up the catalyst as fast as possible and to keep it above 300 °C in warm idle conditions

Detailed Technology Potential Evaluation – Exhaust System (1)

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⦿: Very Positive / O: Positive / Δ: Neutral / X: Negative / XX: Very Negative

Technical Item	HC	NOx	Performance	Price	Reason / Influencing Factor
Layout (Individually optimized for emissions for specific vehicle)	O	O	Δ	X	For Bharat Stage VI different layouts of exhaust systems have to be considered
Runner length (Short distance to catalyst with acceptable gas exchange)	O	O	Δ	Δ	Runner length is very important regarding fast catalyst warm up and power output; there has to be a trade-off between those variables
Catalyst layout (Defined by analysis of cycle and cold start performance)	⦿	⦿	Δ/X	XX	Different catalyst layouts for different vehicle types are necessary (single catalyst; serial catalyst; parallel catalyst; pre- and main-catalyst)
Pre-catalyst	Fast warm up for cold part of test cycle; helps to warm-up main catalyst				
Position → close	O	O	X	Δ	As near as possible to exhaust port to ensure fast warm up; trade-off between warm-up and performance-loss
Size → tradeoff	O	O	X	X	Thermal mass should be kept much lower than main catalyst
Cell density → high	O/Δ	O/Δ	X	X	Trade-off between emissions and performance (high cell density does not always give best emissions)

Detailed Technology Potential Evaluation – Exhaust System (2)

⦿: Very Positive / O: Positive / Δ: Neutral / X: Negative / XX: Very Negative

Technical Item	HC	NOx	Performance	Price	Reason / Influencing Factor
Main-catalyst	Important for emissions reduction over complete test cycle				
Position → close to port, but defined gap to precatalyst	⦿	⦿	X	Δ	For best emissions reduction and warm-up catalyst should be as close as possible to exhaust port (defined gap to pre-catalyst); trade-off between emissions and performance
Size → tradeoff	O	O	X	X	Enough capacity for good conversion rate but not too much to reduce thermal mass and performance loss → diameter better than length
Cell density → high	O	O	X	X	Trade-off between emissions reduction and performance-loss
Precious metal content (high, but optimized for conversion of target emission at target lambda)	⦿	⦿	Δ	XX	Precious metal loading is directly related to conversion performance of catalyst
Exhaust flap (normally used for acoustic)	O	O	Δ	X	Flap increases exhaust back pressure and gas exchange losses which increases engine load *→ Not known yet if the final legislation will continue to allow exhaust flap*

Detailed Technology Potential Evaluation – ECU and Calibration (1)

⦿: Very Positive / O: Positive / Δ: Neutral / X: Negative / XX: Very Negative

Technical Item	HC	NOx	Performance	Price	Reason / Influencing Factor
Torque management	Δ	Δ	O	Δ	Better catalyst heating control
EFI system (Port injection against carburettor)	⦿	⦿	O Δ	X	Advantage on emissions due to better controlled air-fuel-ratio, better pre-control and cold start abilities
Cylinder individual maps (For injection and ignition)	O	O	O	Δ	Better pre-control for fuelling and ignition
Ride by wire	O	O	O	XX	Enables full potential of catalyst heating capabilities
Pre-cat lambda sensor / wideband	⦿	⦿	O	XX	With wideband sensor AFR can be controlled in all engine operation areas
Post-cat lambda sensor	Δ	Δ	O Δ	X	Needed for OBD II capabilities (not needed before 1 April 2023)
Lambda sensor heating	⦿	⦿	Δ	Δ	Fast responding lambda sensor gives rapid control over AFR after cold start
Temperature correction (Adapted injection and ignition over engine temperature)	O	O	O	Δ	Improves cold and warm start emissions

Detailed Technology Potential Evaluation – ECU and Calibration (2)

⦿: Very Positive / O: Positive / Δ: Neutral / X: Negative / XX: Very Negative

Technical Item	HC	NOx	Performance	Price	Reason / Influencing Factor
Transient fuel compensation	O	O	O	Δ	Compensates changes in wall film due to transient engine operation and prevents rich / lean AFR
Lambda control (Basic against no control)	⦿	⦿	O	Δ	Very big improvement of emissions especially in test cycle area
Advanced Lambda control functions	O	O	Δ	X	Further improvement of conversion capabilities of catalysts; wideband lambda sensor needed
Catalyst heating (Retarded ignition and fast idle)	⦿	⦿	Δ	Δ	Important functionality to get very fast catalyst light-off and lowest possible cold start emissions (to enable best potential ride by wire is necessary)

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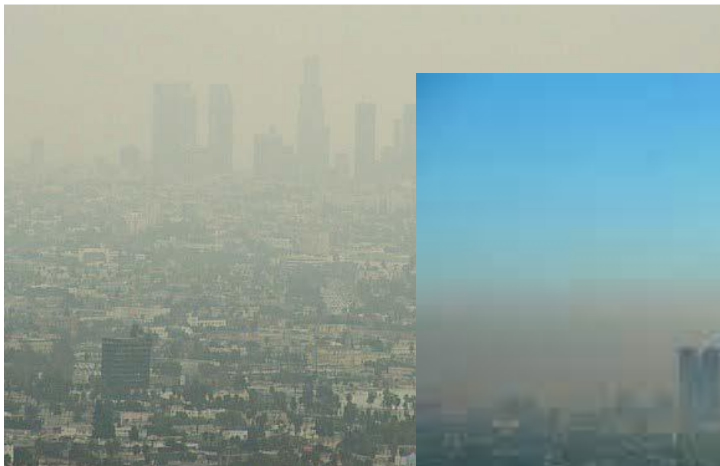
Market Driver for OBD: California

- Severe environmental problems in parts of California (e.g. Los Angeles), the photochemical smog…..



- Number of smoggy days in Greater LA has decreased 41% since 1990
- Population increased by 21% over the same duration

Adopted Approach to Improve Air Quality

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- In order to combat the severe pollution problems the California Motor Vehicle Pollution Control Board (CMVPCB) was established around 1959
  - The CMVPCB were given the task to implement air quality standards required to clear up the state
- Two main points of focus were identified for improving air quality:
  - Regulating amount of pollution a motor vehicle can release into the atmosphere
  - Introducing Inspection and Maintenance (I/M) programme
- In 1967, California's Legislature combined the Bureau of Air Sanitation and the CMVPCB to establish the California Air Resources Board (CARB)
- The first major Clean Air Act was adopted by US Congress in 1970 and at the same time the Environmental Protection Agency (EPA) was established

CALIFORNIA
AIR RESOURCES BOARD

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Brief History of OBD

Late 1970's – Mid 1980's	First diagnostic implementations on several US vehicles
1988	Society of Automotive Engineers (SAE) recommends a standardised diagnostic connector and signals
1989 – 1991	California Air Resources Board (CARB) requires that all new vehicles sold in California have basic OBD capability (OBD-I)
1994	CARB introduces OBD-II. Mandatory for all cars sold in California
1996	OBD-II mandatory for all cars sold in the US
2001	EU makes EOBD mandatory for all petrol vehicles sold in the EU
2003	EU makes EOBD mandatory for diesel vehicles
2003 onwards	Standards refined and emission thresholds lowered every 3-4 years

Future legislation for motorcycles is likely to include OBD requirements, and enable bike to bike connectivity

Future Legislation Trends

- The next generation motorcycles will feature more on-board diagnostic tools to measure the motorcycle's in-use emission performance, and to inform the rider of any malfunction within the motorcycle
  - This will be a regular feature in motorcycles once fuel injected systems are in widespread use in motorcycles
  - Developed countries have OBD tools but these are yet to feature in all the motorcycles in developing countries
- Future motorcycles are also expected to have a host of connectivity features, such as smartphone connectivity, connectivity to the internet, and heads up display
- Component suppliers such as Bosch, Continental, and Yokohama are working on connected bike platforms, enabling users to:
  - Track the status of motorcycle (engine oil, fuel, tyre pressure etc.) on their smartphone well before riding
  - Understand traffic warning, fastest routes, speed limits, etc. on the heads up display
  - Send a warning message to other riders in a given perimeter if they detect any obstacle on the route

Source: Public domain information, BMW newsletter

Bharat Stage VI – OBD Stage II

The minimum OBD (Stage II) requirements for emissions Stage VI, for 2-wheelers (Class 1 and larger) and 3-wheelers [15] are summarised as follows; these will apply from 1 April 2023:

Required OBD Features
Circuit continuity for all emission related power train components
Distance travelled since the malfunction indicator lamp (MIL) is illuminated
Electrical disconnection of the electronic evaporative purge control device (if fitted and active)
Catalytic converter monitoring
EGR system monitoring
Misfire detection
Oxygen sensor deterioration

The Stage II OBD thresholds, which will apply from 1 April 2023, are summarized in the following two tables for two wheels and three wheels vehicles respectively.

Stage II OBD (Emissions Stage VI) thresholds for 2-wheelers (Class 1 and larger)

Vehicle Class	Fuel Type	Emissions thresholds (mg/km)			
		CO	NMHC	NOx	PM
All	Gasoline	1,900	250	300	50(1)
	Diesel	1,900	320	540	50

Notes:
1. Applicable to gasoline direct injection engines only.

Stage II OBD (Emissions Stage VI) thresholds for 3-wheelers

Vehicle Class	Fuel Type	Emissions thresholds (mg/km)	
		CO	NOx
All	Gasoline	880	425
	Diesel	440	300

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CONCLUSION – BSVI and OBDII - Challenges or opportunities ?

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INDIAN MC INDUSTRY- main outlook:

- Performance / Fuel Efficiency orientation:
  - Motorcycle engines are almost exclusively N/A engines with medium - high specific power output. Engine parameters affect emissions in a negative way:
    - Large overlap: High EGR rates at idle and scavenging of liquid fuel in cold condition
    - Short stroke: In-cylinder turbulence is low, large bore sizes compromise combustion
- Cost orientation:
  - Even though performance is high, powertrain cost must be low:
    - Automotive applications with similar specific power use advanced technologies like active secondary air, Direct Injection, Advance Variable Valve Timing etc.
- Complexity in terms of work load:
  - Compared with automotive technology, calibration effort is relatively low in current motorcycles. Increased and more complex functionalities will require a much higher modularity in future applications

As a consequence, the BSVI / OBDII can be **an opportunity of market / profit growth,** if OEM investing timely in:

- **Re-think holistically** the powertrain taking in account of the all engine aspects / outlook
- **Not focus on single topic**, or HW/SW area mainly supplier driven,
- **No last minute / action** to survive
- Move forward technology (i.e. FIE) based on a **commonality across their platforms** rather than developing a new BSVI system for each engine size

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