ECT 2019 Conference & Exhibition- Addressing CO_2 Reduction

Prepared for

12th International Conference,
Emission Controls Manufacturers
Association

Emission Controls Manufacturers Association

OPPORTUNITIES AND CHALLENGES OF GDI TECHNOLOGY IMPLEMENTATION IN INDIA

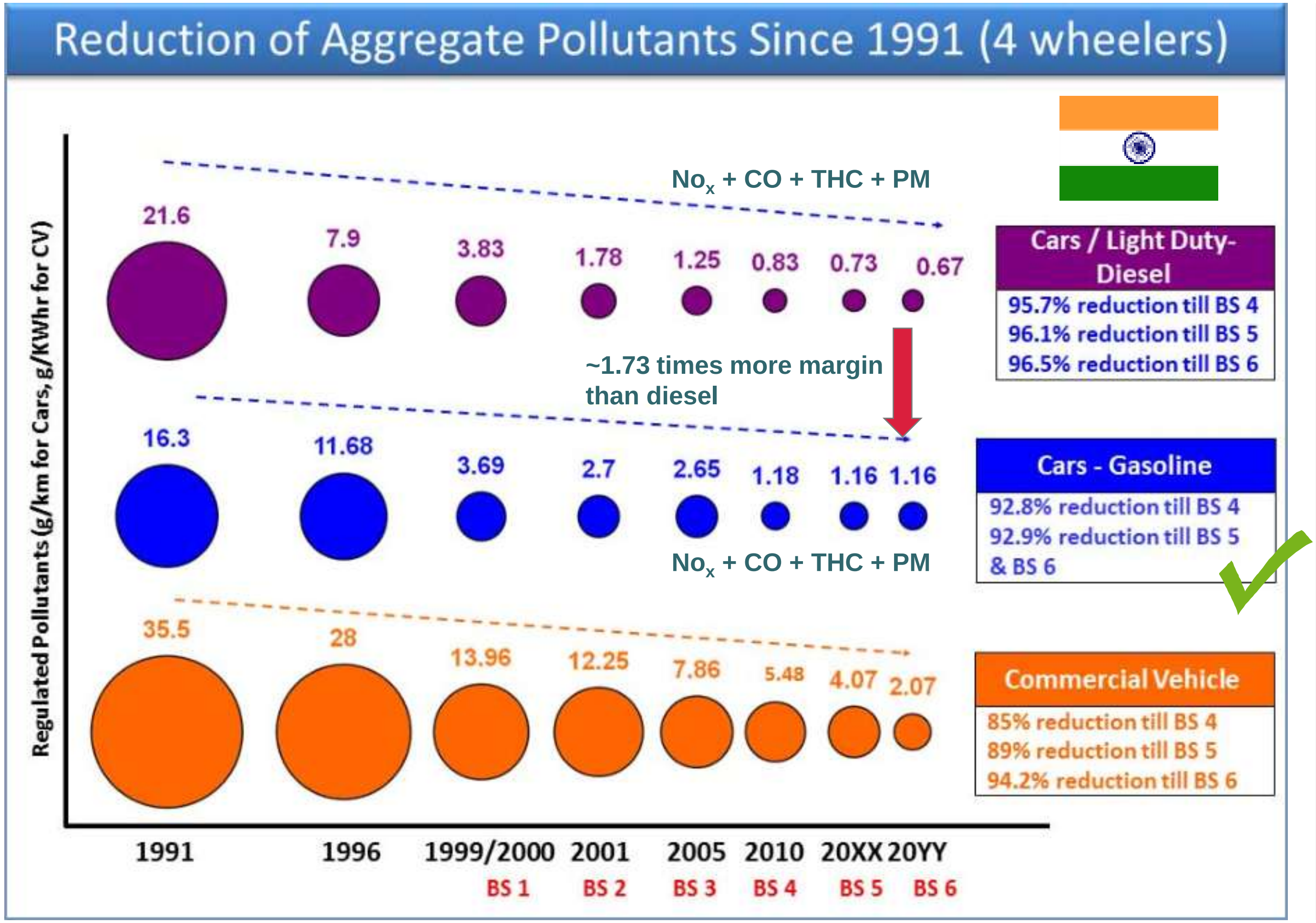
Pune, 14th November 2019
Milap Patel, Gasoline Powertrain

Agenda

- Indian Emission Road Map → Why Gasoline over Diesel?
- Gasoline Direct Injection → Potential Technology for CO_2 Reduction
- CNG Direct Injection → A step ahead of GDI for CO_2 Reduction
- Challenges in Emission Control with GDI engines → GPF Calibration
- FEV's Contribution

Indian Legislative Cumulative Emission Limits
Gasoline Engine Turns Out to be Forerunner for Emission Reduction

CUMULATIVE EMISSION- A LOOK BACK AND WAY AHEAD…

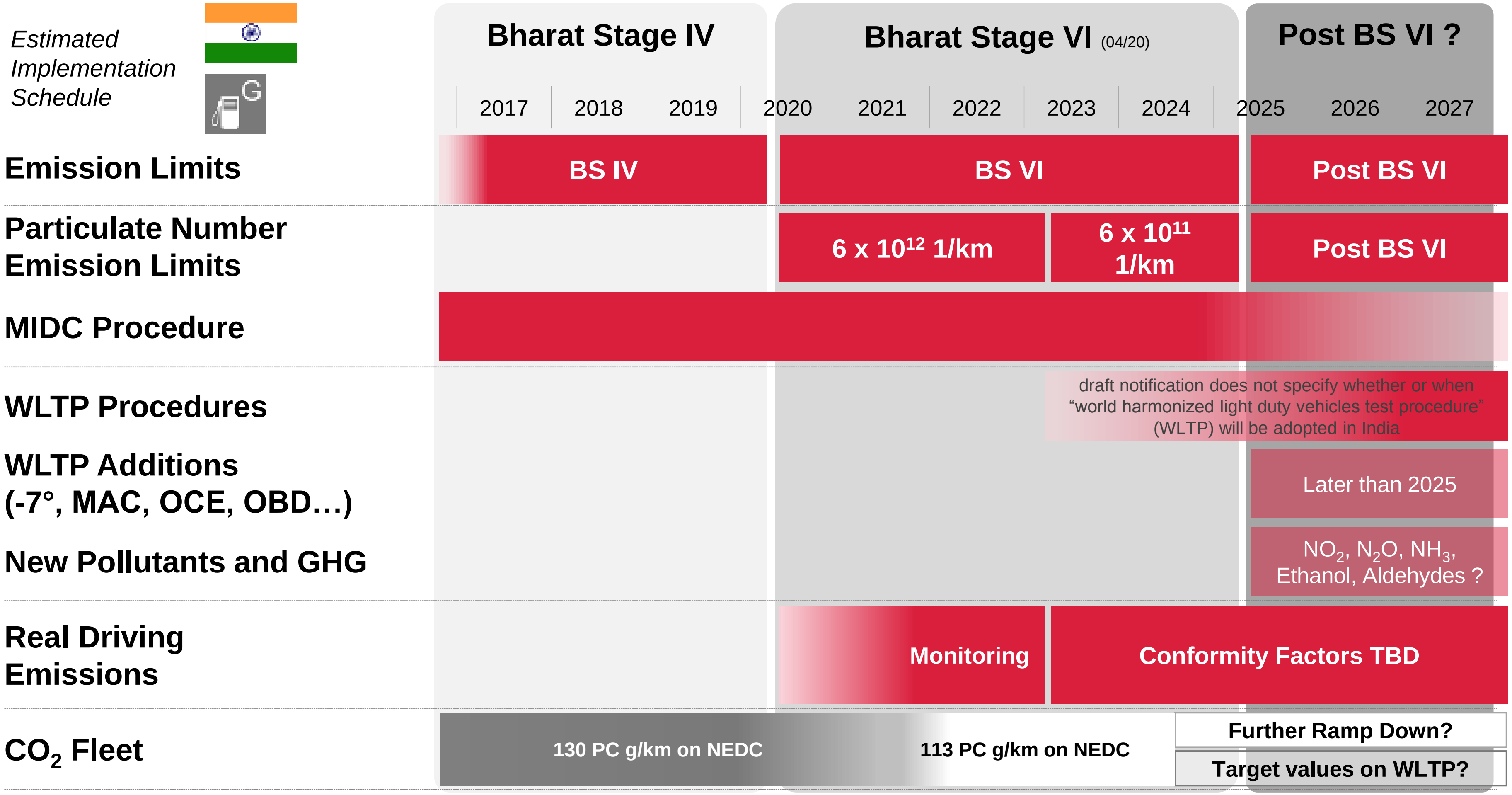


Source: SIAM, siamindia.com

Description

- The legislative limits for cumulative emission pollutants provide ~1.73 times more margin for gasoline emissions above diesel emissions, making gasoline engines a preferred choice.
- Comparatively, gasoline engines need less complex EATS for emission control and thus brings down overall cost of product development.
- GDI, a promising technology towards reduced CO_2 emission, increased power rating with scope of down sizing becomes imperative.

Emission Roadmap: India
BSVI and Ahead → CO_2 Emission Reduction Becomes Imperative



Estimated Implementation Schedule

Bharat Stage IV

Bharat Stage VI (04/20)

Post BS VI ?

2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

Emission Limits
- **BS IV**
- **BS VI**
- **Post BS VI**

Particulate Number Emission Limits
- **6×10^{12} 1/km**
- **6×10^{11} 1/km**
- **Post BS VI**

MIDC Procedure

WLTP Procedures
- draft notification does not specify whether or when "world harmonized light duty vehicles test procedure" (WLTP) will be adopted in India

WLTP Additions (-7°, MAC, OCE, OBD…)
- Later than 2025

New Pollutants and GHG
- NO_2, N_2O, NH_3, Ethanol, Aldehydes ?

Real Driving Emissions
- **Monitoring**
- **Conformity Factors TBD**

CO_2 Fleet
- **130 PC g/km on NEDC**
- **113 PC g/km on NEDC**
- **Further Ramp Down?**
- **Target values on WLTP?**

Sources: FEV research and analysis; EC, "Commission Regulation (EU) 2016/427", March 31st 2016;

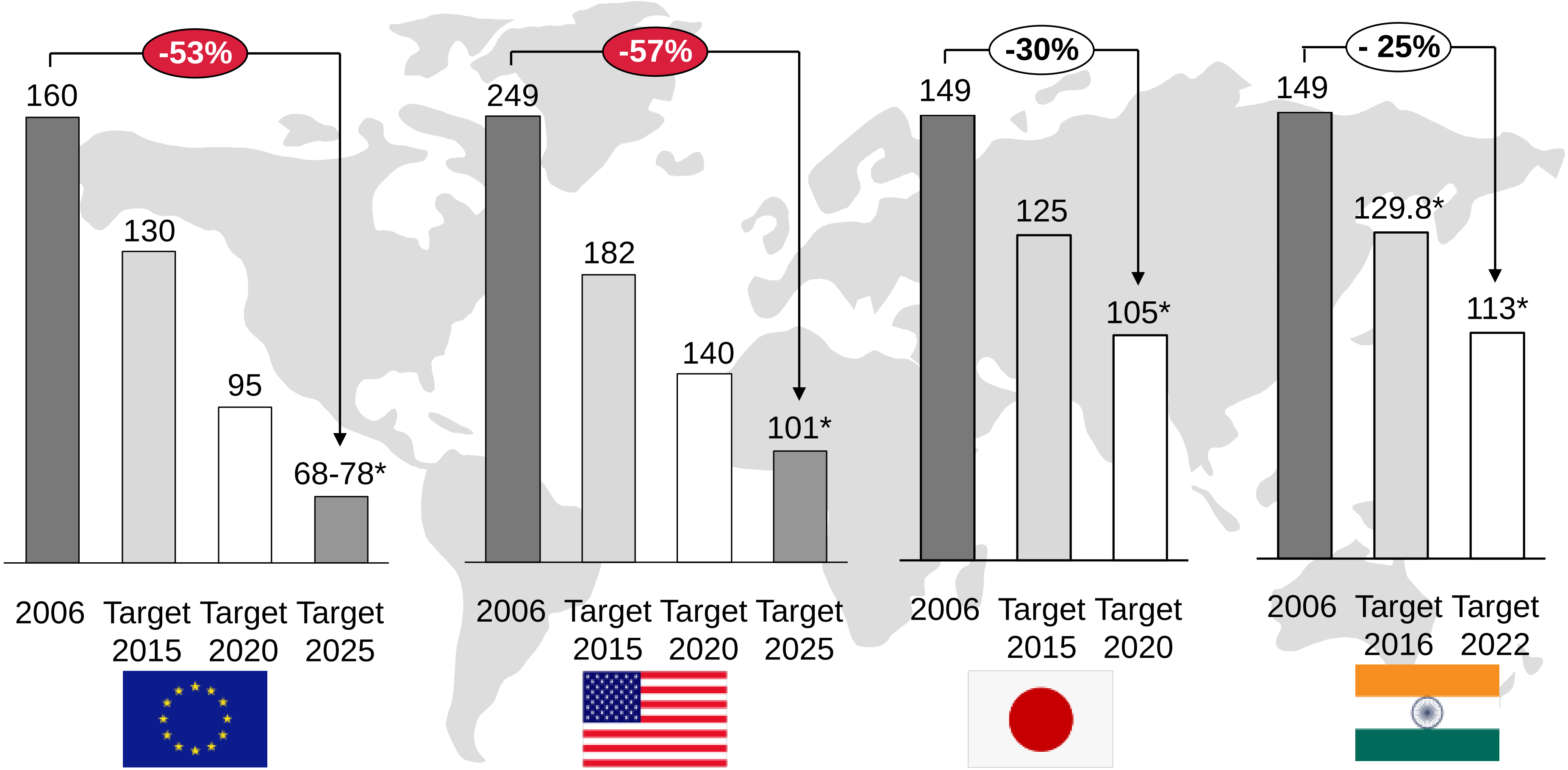
* M, N1 vehicles starting Jan. 2020

** may be changed according to measurement technique

RE/BG

CO_2 Emission Targets
Demand of Efficient engines → Gasoline engines with less CO_2 emissions

Worldwide regulations for CO_2 reduction – CO_2 fleet targets (g/km) NEDC based



* Proposed Target

Recent Technologies for CO_2 Reduction
GDI emerges as a Superior Solution

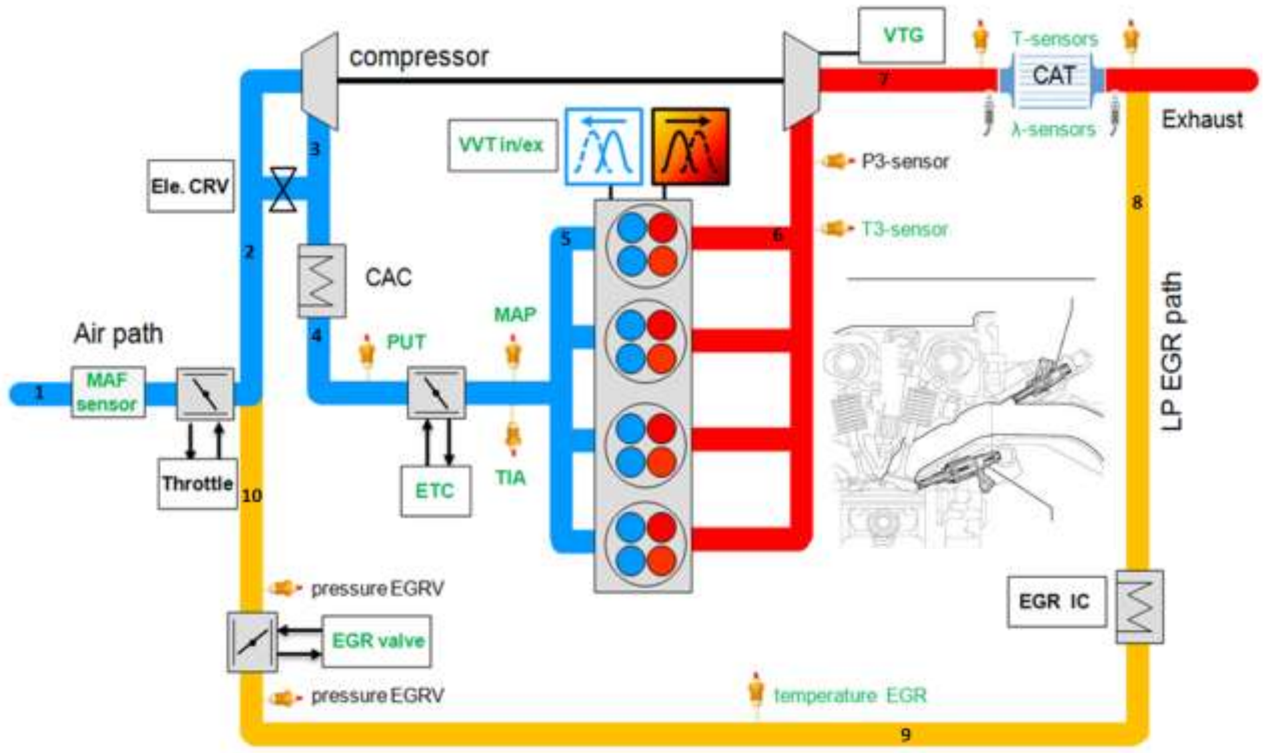
FEV

2010 2015 2020 2025 2030

Gasoline Direct Injection	45% (US) Market Penetration in 2015	LIKELY 2025 MARKET PENETRATION →	Greater than 75% ✓
Turbocharged (Mechanical)	20% (US) Market Penetration in 2015	LIKELY 2025 MARKET PENETRATION →	Greater than 60%
Atkinson Cycle	Mazda sky Active and Hybrid application	LIKELY 2025 MARKET PENETRATION →	Highly uncertain
Variable Compression Ratio	Nissan launched in 2018	LIKELY 2025 MARKET PENETRATION →	Less than 10%
Homogenous Charge Compression Ignition	Mazda launched in in 2019	LIKELY 2025 MARKET PENETRATION →	Less than 10%
12 Volt Start/Stop	10% (US) Market Penetration in 2015	LIKELY 2025 MARKET PENETRATION →	Greater than 50%
48 Volt Stop/Start Mild Hybrid	0% NA Market Penetration	LIKELY 2030 MARKET PENETRATION →	Market acceptance in Asia and Europe –NA Market very uncertain **~8~10%**
HEV Power Split/P2	**Key Technologies**: Electric Motor, Infra.	LIKELY 2030 MARKET PENETRATION →	Currently dominant Architecture. More efficient. More cost **~5~6%**
Plugin Electric Vehicle	**Key Technologies**: Electric Motor, Infra.	LIKELY 2030 MARKET PENETRATION →	Very few products in market **~3%**
Battery Electric Vehicle	**Key Technologies**: Electric Motor, Infra.	LIKELY 2030 MARKET PENETRATION →	Battery development dependent **6~9%**
Fuel Cell Electric Vehicle	**Key Technologies**: Fuel cell Stack, Infra.	LIKELY 2030 MARKET PENETRATION →	Significant cost and Infrastructure issue, >10%

Source: *CAR Research, USEPA/NHTSA Technical Assessment Report; Various media publications*

Gasoline Direct Injection- Generic System Layout & Hardware Requirements



Not shown in this chart: Coolant-, Crankshaft-, Camshaft-, Knock-Sensor

🟦 *Intake fresh air path*
🟥 *Exhaust gas path*
🟨 *EGR path*

System Configuration

- Engine size → 1.0 - 2.0 l
- Torque range → Upto 400 Nm
- Power range → Upto 150kW
- Boosting → Upto 2.5 bar (gauge)
- Fuel Rail pressure → Upto 300 bar
- Fuel Injector → 6-8 holes, piezo type
- EGR → Low pressure EGR
- VVT → Continues phasing
- VVL → 2 stage

Comparison of Air Induction- GDI vs. MPI
Higher Compression Ratio in GDI leading to Better Thermal Efficiency

ADVANTAGE OVER MPI- HIGHER COMPRESSION RATIO

Stratified Combustion

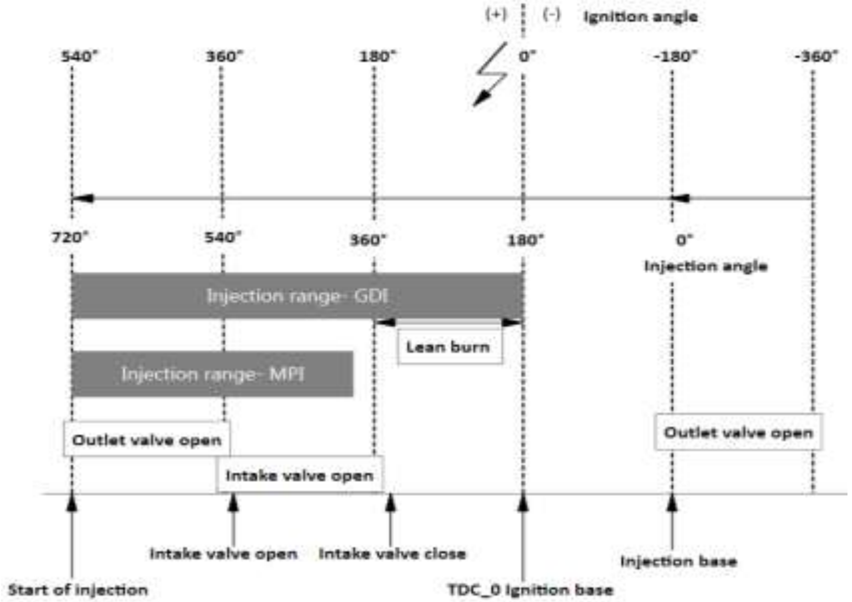
- Typical injection range in GDI:
  - From exhaust value open till end of compression stroke
  - Lean combustion possible due to late injection
  - Higher injection pressure leading to better atomization

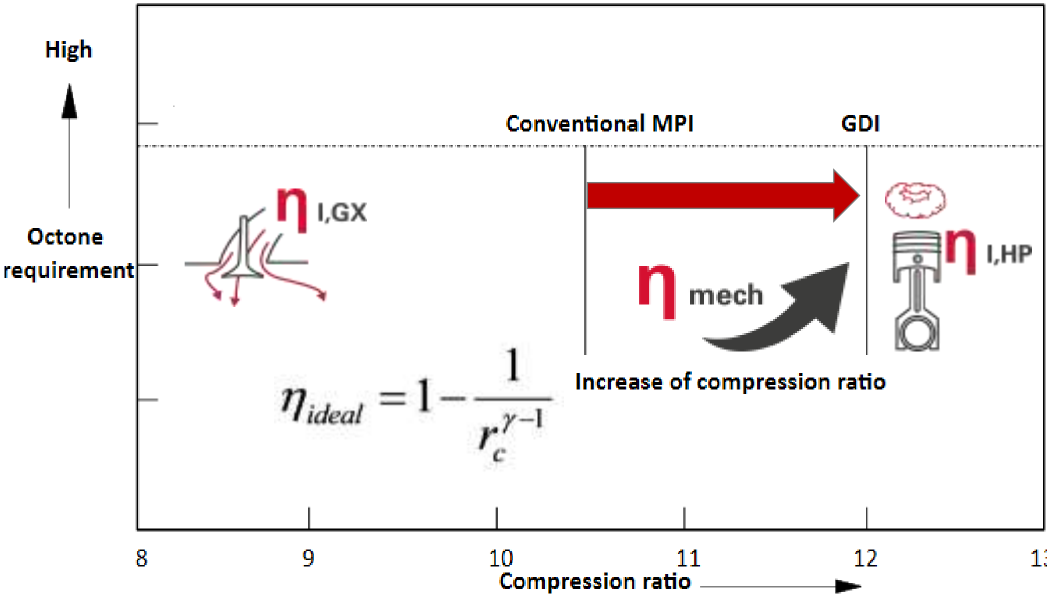
Higher CR

- Only Air intake and Late Injection
  - Induction of only “Air” in combustion chamber, higher volumetric efficiency
  - Less time for local fuel pocket formation leading to less knock

Better Performance

- High torque
  - Upto 30%more torque output compared to MPI engine of same size
  - **Effective downsizing possible**





Source: FEV

Comparison of GDI vs. MPI → Market Case Study
Possible Benefits due to Downsizing

POSSIBLE BENEFITS DUE TO DOWNSIZING → 1.2 L MPI VS. 1.0 L GDI

#Case Study

1.2L, K12M, MPI

- Engine size: 1.2 L, 4 cylinder
- Torque: 115 Nm @ 4000 rpm
- Power: 83.1 bhp @ 6000 rpm
- CO_2: 110.8 gm/Km
- F.E : 21.4 km/l

MPI Vs. GDI

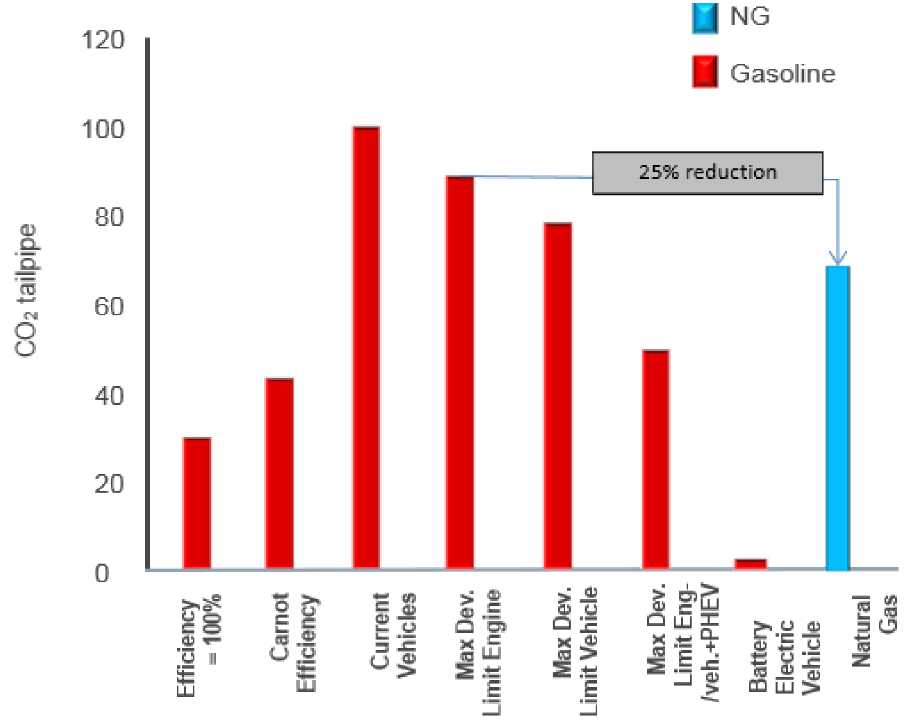
1.0L, BoosterJet, GDI

- Engine size: 1.0 L, 3 cylinder
- Torque: 150 Nm @ 1700 rpm
- Power: 101 bhp @ 5500 rpm
- CO_2: 112.4 gm/Km
- F.E : 21.1 km/l 👍

Source: SIAM, Cardekho.com, TeamBHP
Courtesy: Maruti Suzuki India Limited

Compressed Natural Gas
Motivation for Using CNG as a Cleaner Fuel

$CH_4 + 2O_2 \rightarrow \mathbf{CO_2} + 2H_2O$ $C_8H_{18} + 12.5O_2 \rightarrow \mathbf{8CO_2} + 9H_2O$



Source: NGVA, Center of Automotive Research

Lowering Fleet Emissions

- Lesser CO_2 emission (upto 25%)
  - *Beneficial considering "CAFE"*

Possible Market Growth

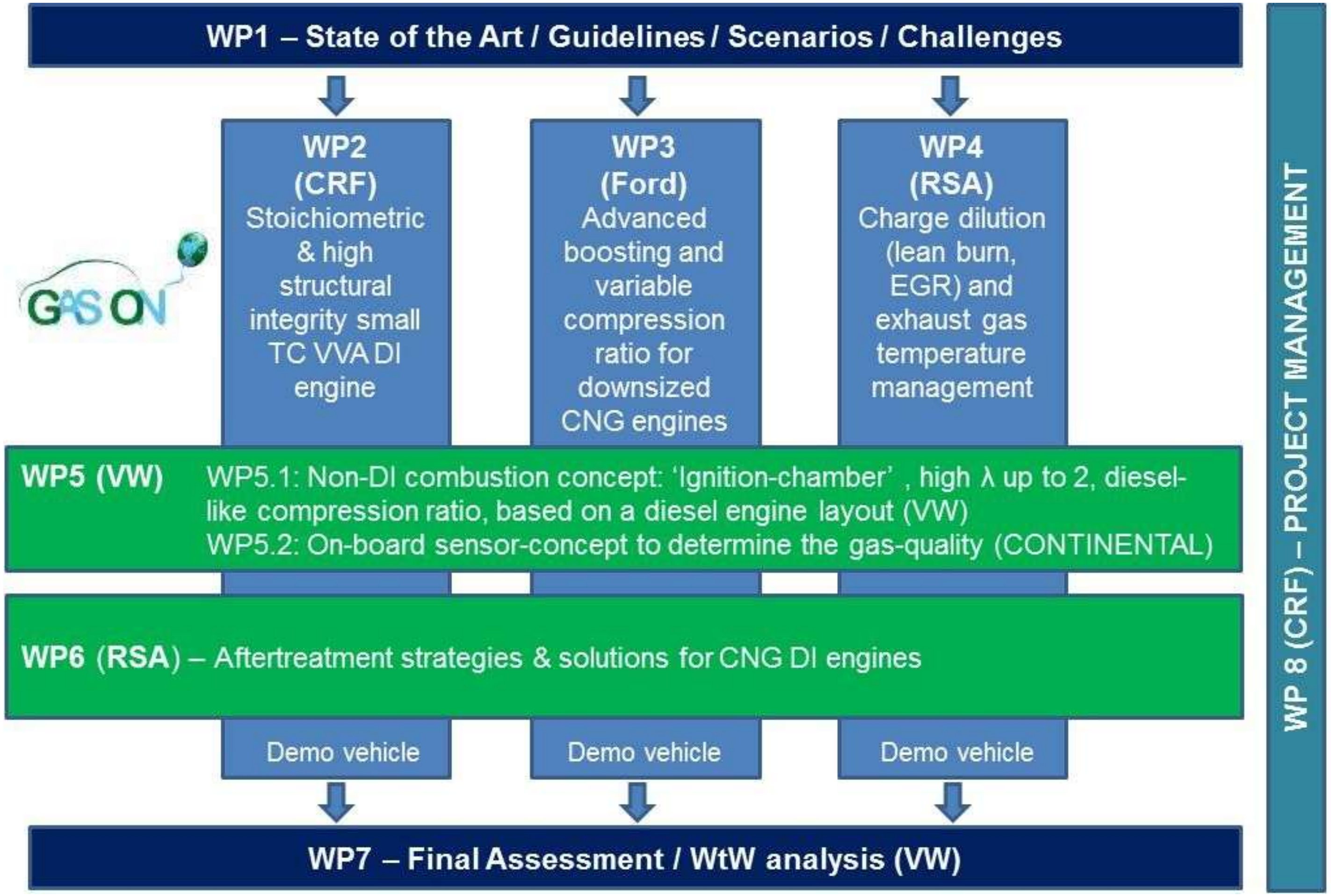
- Cheaper cost of operation (upto 55%) compared to gasoline engines
  - *Fuel efficient vehicles*

Green Image

- Lower Scope-1 GHG emission
  - *Improved brand image*

CNG DI- State of Art technology for Emission Reduction
GAS Only- GASON EU Summit May'15 to March '19

FEV'S INVOLVEMENT IN GASON WP4 WITH RSA AND CONTINENTAL



WP1 – State of the Art / Guidelines / Scenarios / Challenges

WP2 (CRF) Stoichiometric & high structural integrity small TC VVA DI engine

WP3 (Ford) Advanced boosting and variable compression ratio for downsized CNG engines

WP4 (RSA) Charge dilution (lean burn, EGR) and exhaust gas temperature management

WP5 (VW) WP5.1: Non-DI combustion concept: 'Ignition-chamber' , high λ up to 2, diesel-like compression ratio, based on a diesel engine layout (VW)
WP5.2: On-board sensor-concept to determine the gas-quality (CONTINENTAL)

WP6 (RSA) – Aftertreatment strategies & solutions for CNG DI engines

Demo vehicle | Demo vehicle | Demo vehicle

WP7 – Final Assessment / WtW analysis (VW)

WP 8 (CRF) – PROJECT MANAGEMENT

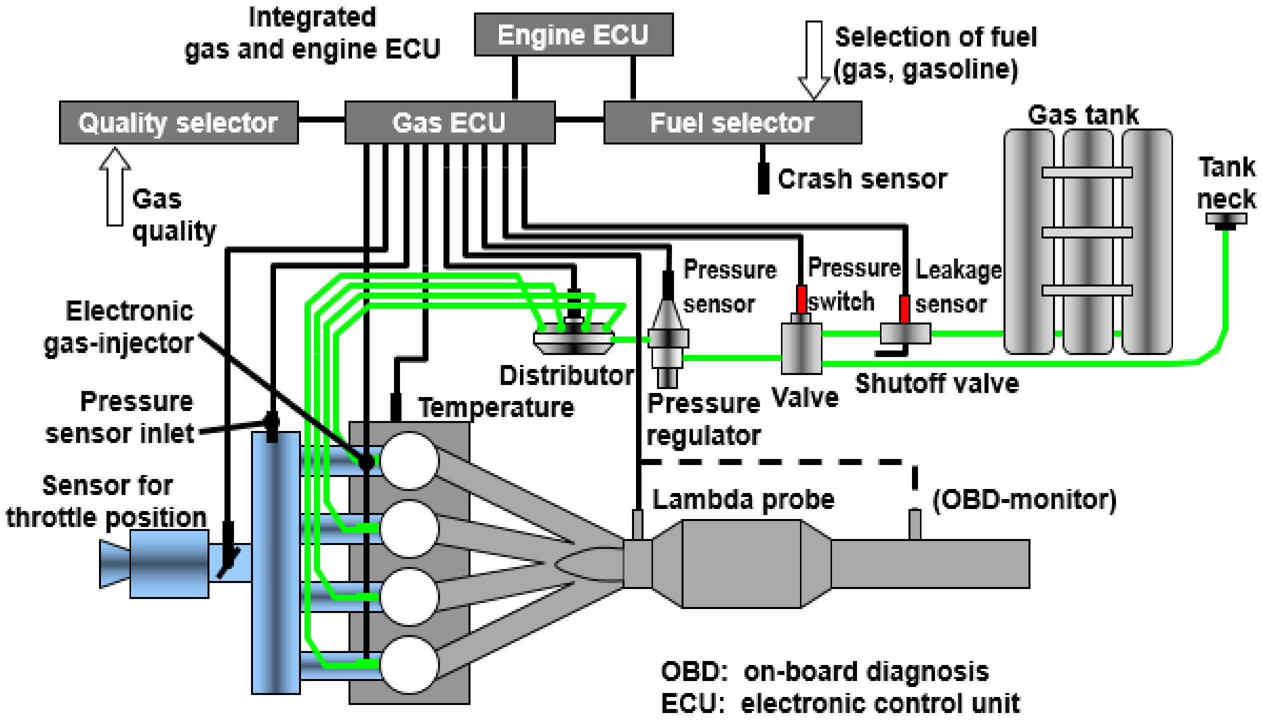
- Hardware
- Software
- Calibration

xCAL

Source: Gason
The GASON project has been funded by the Horizon 2020 EU Research and Innovation programme, under Grant Agreement no. 65281

CNG Direct Injection
System Layout and Hardware Requirements

GENERIC HARDWARE LAYOUT



OBD: on-board diagnosis
ECU: electronic control unit

System Configuration

- Gas tank: Upto 250 bar pressure
- CNG rail: Upto 30 bar pressure
- Fuel pressure regulator: 2 stage, electronically controlled
- EMS: Master-Slave configuration, slave CNG injection controller
- CNG Injector: Solenoid type, 6-8 holes
- Turbocharging: Yes, to be designed for higher exhaust gas temperature

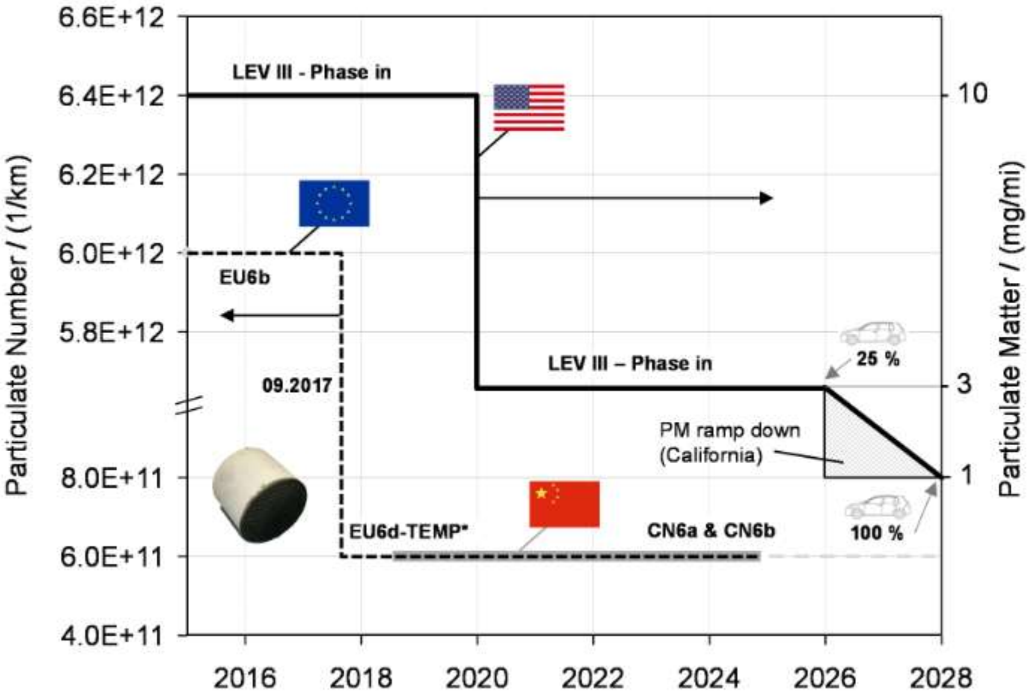
Source: VKA, RWTH Aachen

BHARAT 6 Emission Standards for ‘M’ Type 4 Wheeler
Comparison with EU6, CN6 for PM and PN emissions

UPCOMING BS-VI NORMS- IMPACT ON GDI ENGINES

Type	Reference mass	CO	THC	NMHC	NO_X	PM	PN
M (M1 & M2)	<3500 kg	1 g/km	0.1 g/km	0.068 g/km	0.060 g/km	0.0045 g/km	$6.0*10^{11}$ /km
D.F	-	1.5	1.3	1.3	1.6	1	1

- BS-VI emission norms to introduce limit on particulate matter (PM) and particulate number (PN)
- Current BS-VI limits for PM and PN in line with EU 6d-TEMP (Sept ’17) and CN6a & CN6b (July ’18)
- Further revision of deterioration factor may add to calibration efforts
- Introduction of RDE to add further to the development efforts

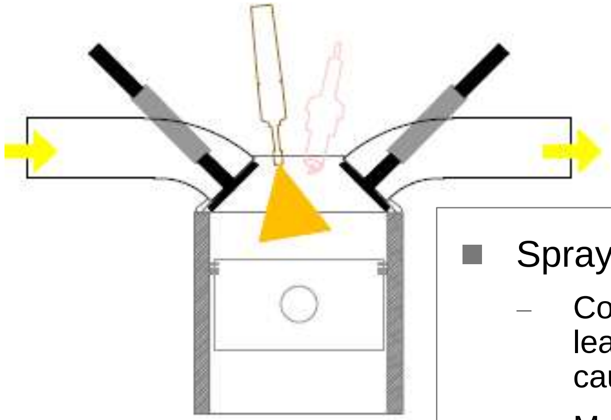


*EU6c PN limits equivalent to EU6d-TEMP

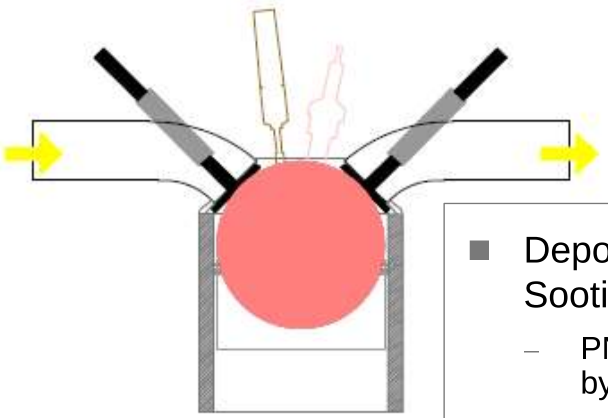
Source: ARAI, 26th Aachen Colloquium, 2017

Particulate Emission Generation
Motivation for Integrating Gasoline Particulate Filter (GPF)

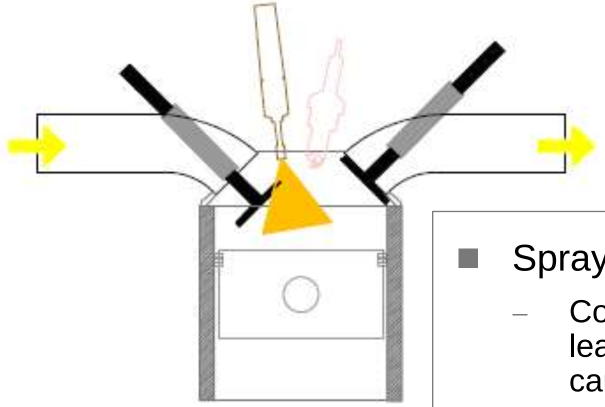
REASONS FOR PARTICULATE EMISSION GENERATION → NEED FOR GASOLINE PARTICULATE FILTER



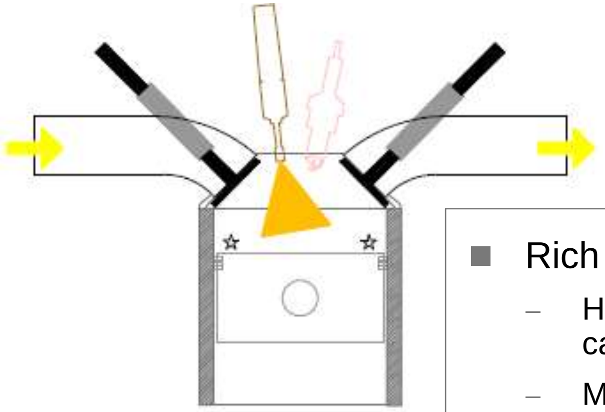
- Spray-wall interaction
  - Cold wall temperature leads to bad combustion causing high PN
  - Mainly during cold start



- Deposit formation (Tip Sooting)
  - PN emission can increase by factor of 10
  - Mainly due to ageing



- Spray-valve interaction
  - Cold valve temperature leads to bad combustion causing high PN
  - Mainly due to injection advance

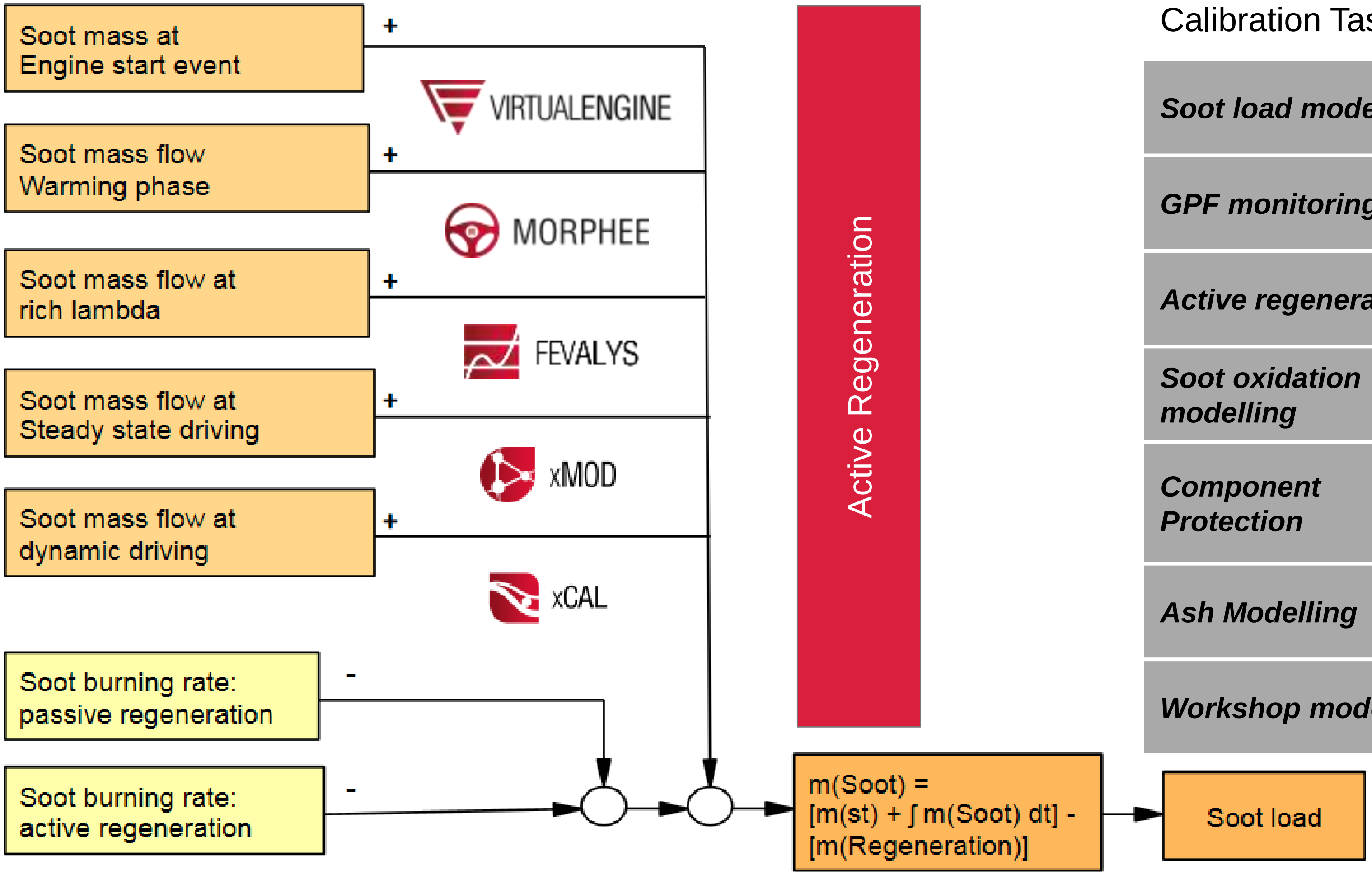


- Rich mixuture, λ < 1
  - Heterogeneous mixture causing high PM, PN
  - Mainly due to transient, full load driving conditions

Source: FEV

GPF Hardware and Calibration Overview
Requirements and Challenges in GPF Calibration

INTEGRATION OF GPF BRINGS A NUMBER OF ADDITIONAL TASKS → AIM IS TO MINIMIZE EFFORTS



Calibration Task	Content
Soot load modelling	Engine out emissions Dynamic correction
GPF monitoring	Sensor calibration On-board diagnosis
Active regeneration	Triggering (soot mass limit), Execution
Soot oxidation modelling	Duration of active regeneration
Component Protection	Temperature monitoring and control
Ash Modelling	Generation of ash
Workshop mode	Forced regeneration GPF replacement

Source: FEV magazine, Nov'18

Example of Successful Engine Development by FEV for HONDA
Honda VTEC 1.0 Turbo GDI

HONDA VTEC 1.0 TURBO

- **Start of Production:**
  - China / Wuhan: Nov. 28, 2016
  - UK / Swindon: Feb. 02, 2017
- **Positive feedback from magazines**:
  - "…1.0 l engine is a gem"
  - "…punchy acceleration, impressive refinement…"

Key Figures

- **Max power:**
  95 kW @ 5900 rpm
- **Max. torque:**
  200 Nm @ 2250 rpm
- **Low-end-torque:**
  170 Nm @ 1650 rpm
- **Min BSFC:**
  229 g/kWh
- **Friction motored:**
  0.46 bar FMEP
- **Emission level:**
  EU 6b

❖ Specs for EU market

FEV's Responsibilities

Cooperation development with OEM for:
Engine development for series production

- Design & CAE support for 2 prototype stages
- System development with supplier, incl. parts procurement for prototype stages
- Prototype engine build
- Combustion development
- Engine functional and durability testing
- Engine calibration, series maturity

Engine integration into OEM's vehicle

- Design for vehicle package
- Vehicle rebuild with prototype engines
- Vehicle functional and durability testing
- Vehicle calibration (drivability, emiss, NVH): OBD 1, EOBD, E-Gas ISO 26262
- Certification support for target markets CN/EU

FEV’s Integration with Ford Motor Company
FORD ECOBOOST 1.0 T-GDI with Flex Fuel Adaptation

FEV

FORD ECOBOOST 1.0L

Ford

INTERNATIONAL engine of the year awards 2012

INTERNATIONAL engine of the year awards 2013

INTERNATIONAL engine of the year awards 2014

INTERNATIONAL engine of the year awards 2015

INTERNATIONAL engine of the year awards 2016

INTERNATIONAL engine of the year awards 2017

ENGINE OF THE YEAR: 2012 TO 2017

Project Details

- **Technical Highlights and Data**
  - In Line 3 Gasoline Engine with 92 kW / 170 Nm @ 1300 – 4500 rpm / overboost 200 Nm
  - 109 CO_2 g/Km
  - DI-VCT / Integrated exhaust manifold / Oily belt for timing drive and oil pump drive / Split cooling / Variable flow oil pump
- **FEV´s Project Involvement**
  - Design and CAE for Pre-XO
  - Procurement and QS 1
  - Engine built, commissioning, run-in and sign-off for 36 engines
  - Combustion development for Stage 1

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