Optimization of Engine-out Emissions from a Diesel Engine to meet Tier2 Bin5 Emission Limits

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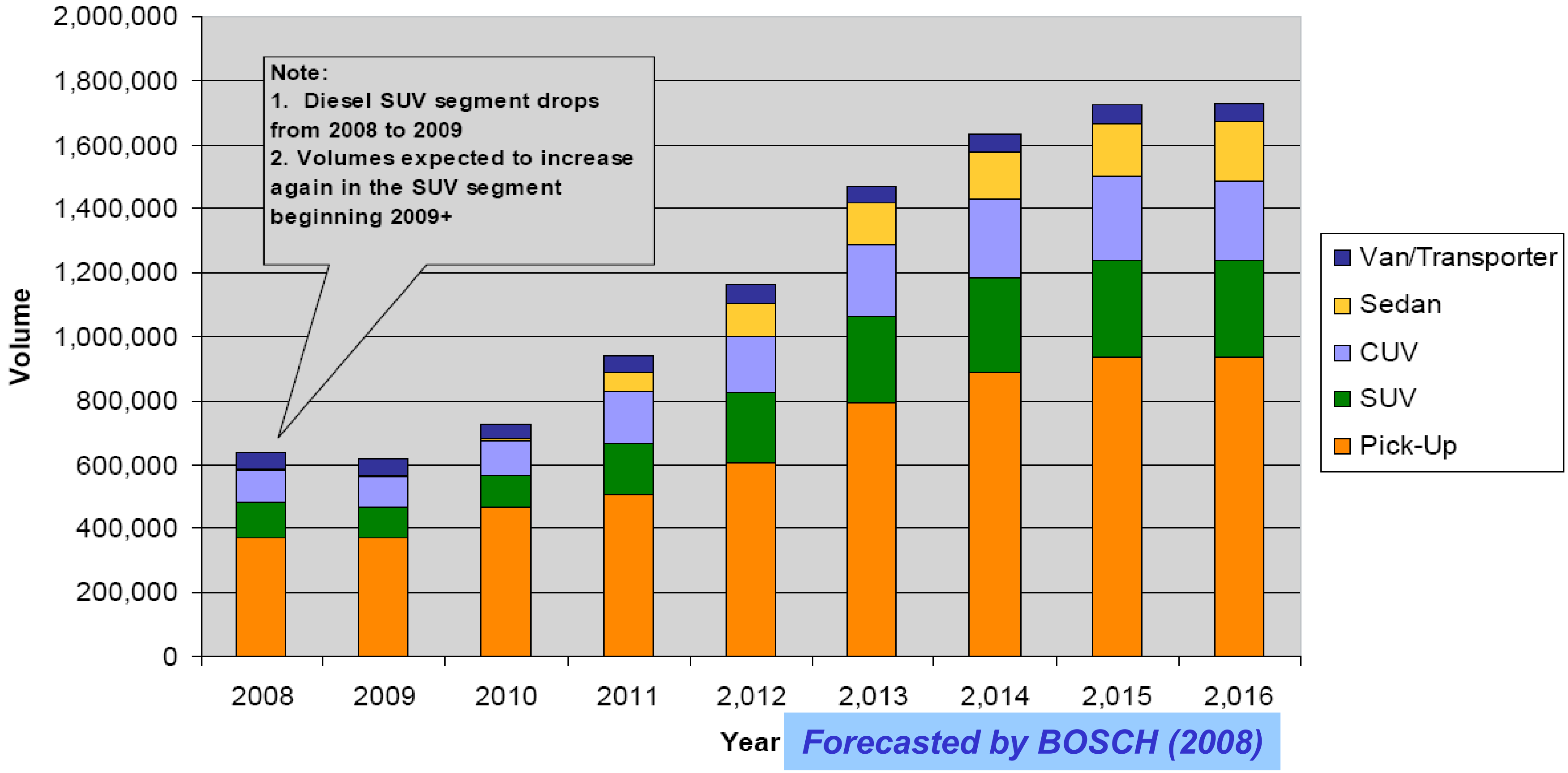
Contents

- The US Diesel Market
  - ✓ Fuel price higher than ever
  - ✓ Strong demand for good mileage (CO_2 cut-down)
  - ✓ Growing interest in passenger diesel vehicle
- Challenge for US Diesel Market
  - ✓ Stringent emission regulation
- Strategy to meet Tier2 Bin5 Emission Standard
  - ✓ Engine Hardware improvement
  - ✓ Calibration optimization
  - ✓ DeNOx after-treatment
- Summary

US Diesel Market

Forecast Diesel Demand for US Market

- ✓ Excellent driving performance and good mileage
- ✓ Increasing demand



Forecasted by BOSCH (2008)

Barriers to US Diesel Market

- **Stringent Emission Limit**
  - ✓ Tier2 bin5 standard requires extremely low NOx level
  - ✓ Emission level should be satisfied even at high altitude
  - ✓ Various diesel fuel qualities have to be considered

- **Customers Expectation for Excellent NVH (Noise, Vibration and Harshness)**

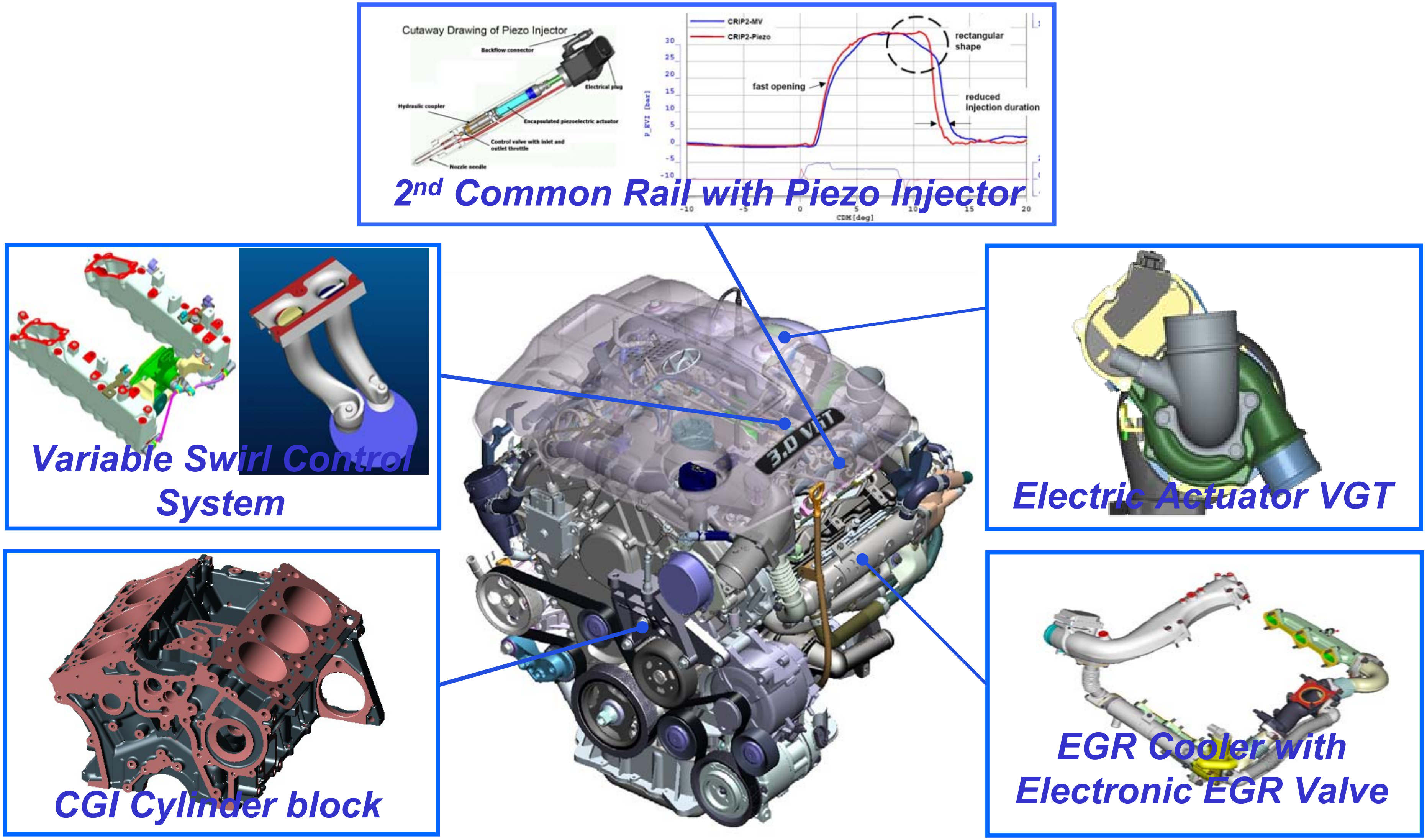
- **Outstanding Fuel Efficiency to attract drivers**

➡ ***Not only extremely low but robust emission level with excellent NVH behavior and outstanding fuel efficiency***

V6 3.0 litre Diesel Engine (Euro4)

	Base Engine
Engine Type	V-6 DOHC 4V
Displacement (cc)	2,959
Bore x Stroke (mm)	84 X 89
Compression Ratio	17.3
FIE System	1600bar Piezo
Air Handling	E-VGT, Variable Swirl System
Glow System	ISS with GCU
Emission Target	EURO IV
Exhaust System	DOC+DPF

Technical Features of Base Engine



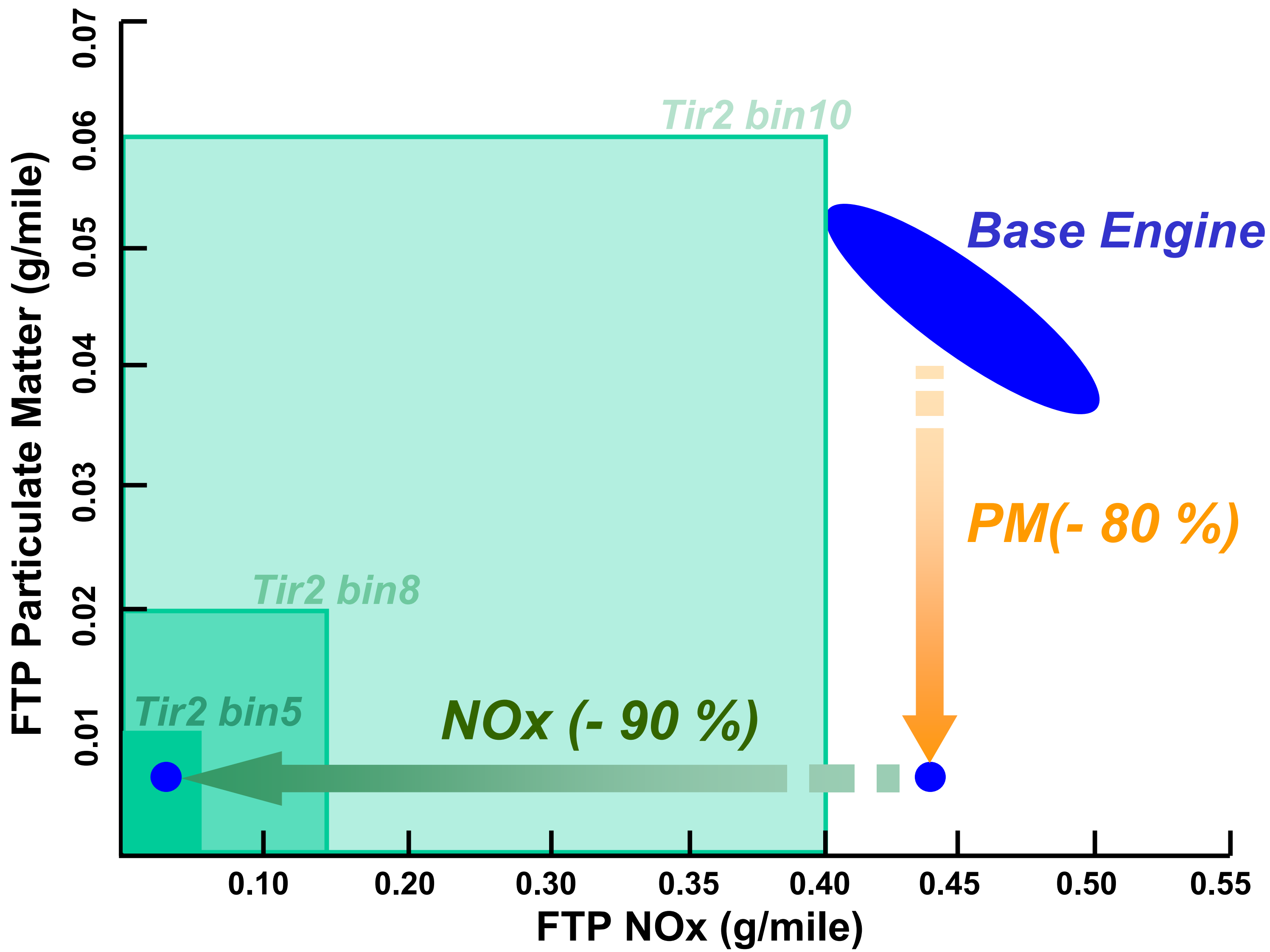
Heavy SUVs : Veracruz and Mohave

- ✓ diesel and gasoline engines for domestic and European markets
- ✓ currently gasoline engine only for US market

MOHAVE (Kia):
- Domestic (2008)
- Rear Wheel Drive
- Max Power/Troque: 184KW / 540Nm

VERACRUZ (Hyundai):
- Domestic (2006), Europe (2008)
- Front Wheel Drive
- Max Power/Troque: 176KW / 451Nm

Emissions : Challenge for US Market

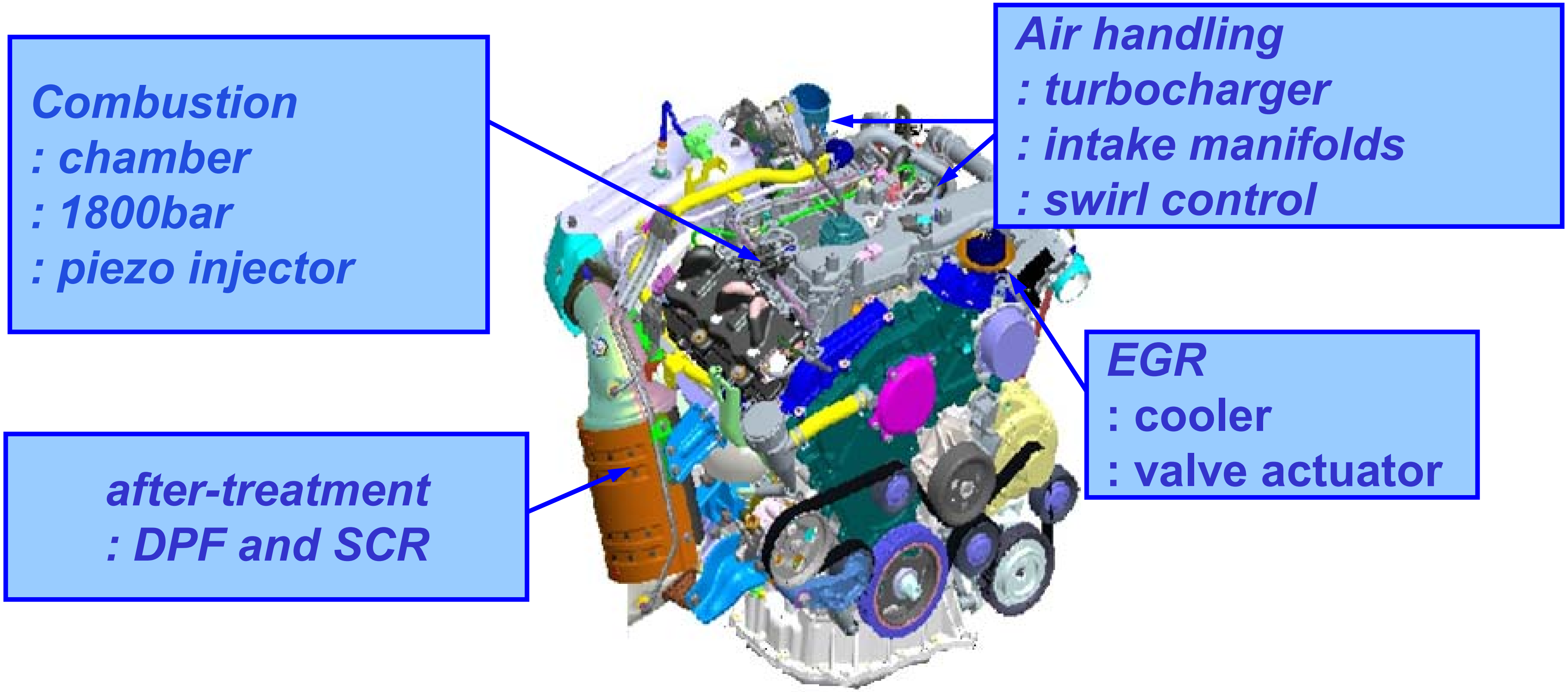


Strategy to meet Tier2 bin5

- Strategy to meet NOx and PM requirement
  - ✓ Hardware Improvement
    1. combustion
       - chamber, fuel injection, air handling
    2. EGR
       - switchable cooler
       - fast and precise actuator
    3. exhaust after-treatment
       - DPF and SCR
  - ✓ Optimization of Operating Area acc. Emission Cycle
    1. gear reduction ratio
  - ✓ Calibration Optimization
    1. best trade-off of emissions, NVH and fuel efficiency
    2. DoE calibration: modeling of mapping parameter
    3. transient calibration at engine test bench for FTP cycle

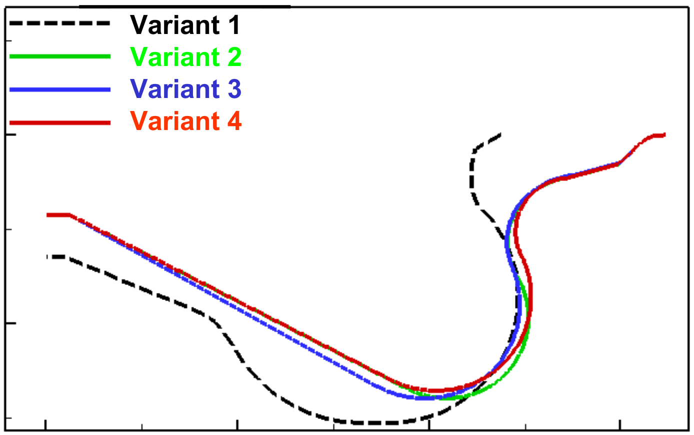
Hardware Improvement

- ✓ engine-out emission: combustion / air handling / EGR
- ✓ tail-pipe emission: after-treatment

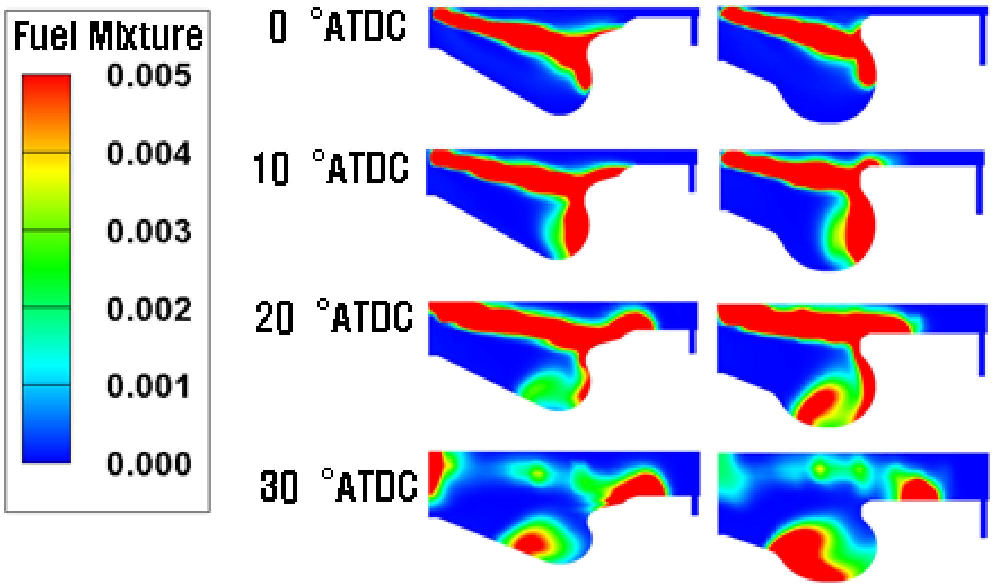


Combustion Chamber

- ✓ lower compression ratio
- ✓ bowl shape, mixing pattern, and swirl motion



Combustion Chamber



numerical simulation of combustion pattern

H/W Improvement – Combustion (Fuel Injection)

FIE

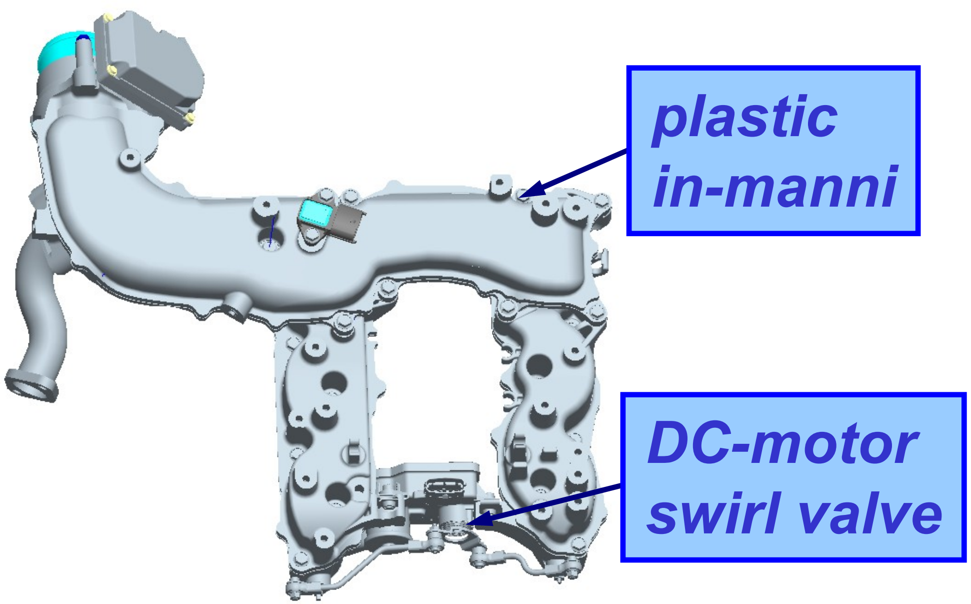
- ✓ Bosch 3rd Generation 1800bar Common Rail System

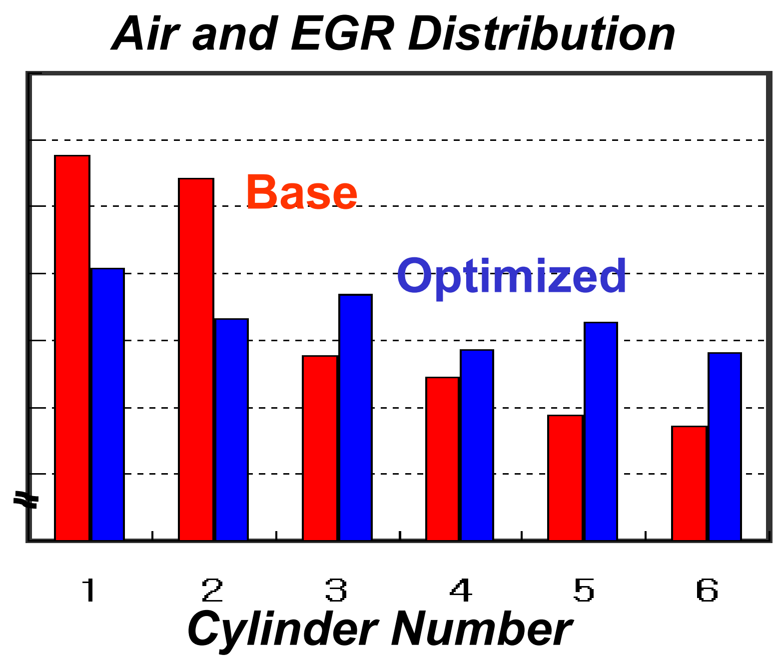
- ✓ CRS3.2 Piezo Injector
  - higher injection rate and efficiency
  - precise injection control for robust emission behavior
  - smaller tolerance of injection quantities
  - multiple injection up to 5 shots per cycle

- ✓ Re-matching with the New Combustion Chamber
  - nozzle hole number / diameter / length
  - hydraulic flow rate

Air Handling

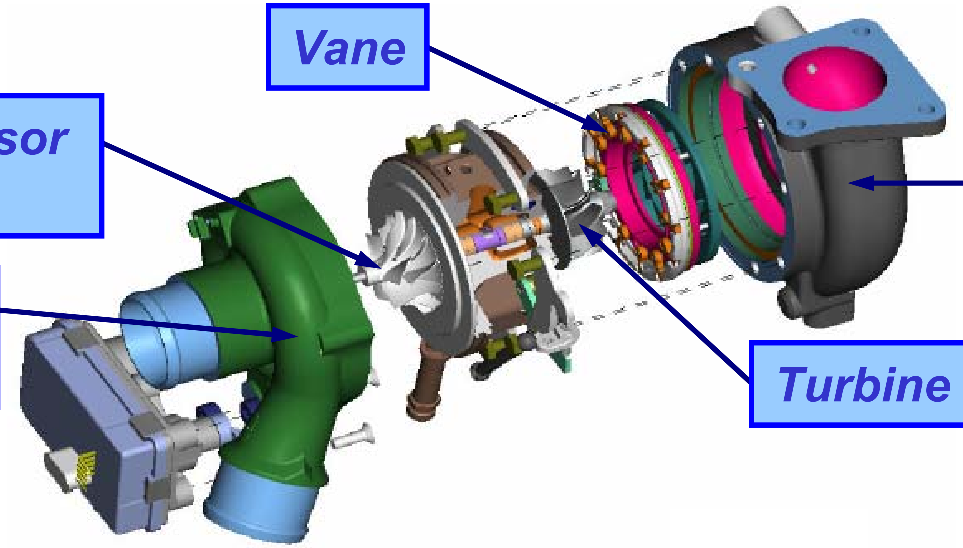
- ✓ **Plastic In-manni**
  - improved intake air charging efficiency
  - uniform EGR distribution
- ✓ **Head and Swirl Valve**
  - optimization of intake air charge and swirl intensity





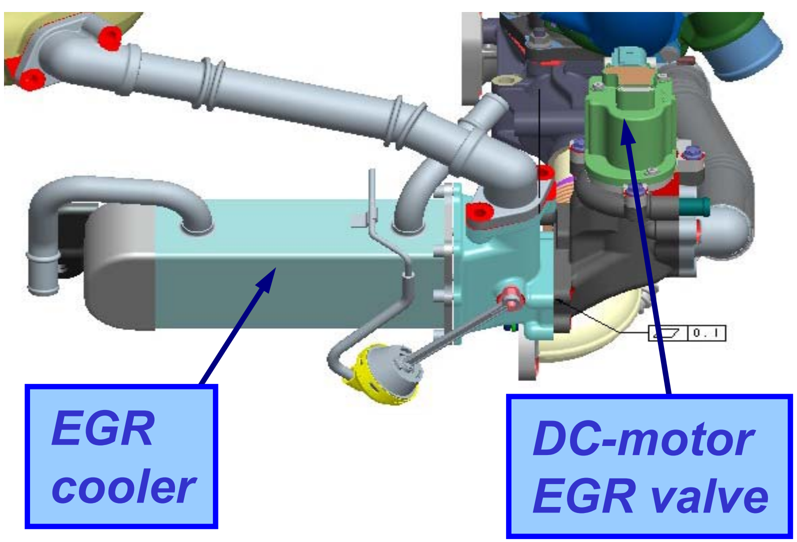
Turbocharger

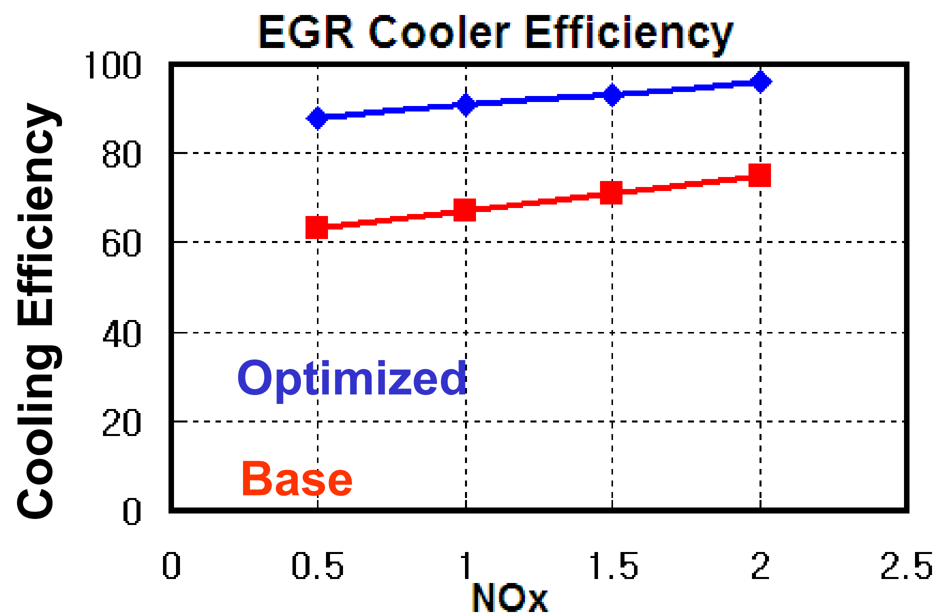
- ✓ **Compressor**
  - enhanced boost potential during cycle operation by wheel/housing shape optimization
- ✓ **Turbine**
  - low inertia
  - improved efficiency by shape optimization of guide vanes and wheels



EGR System

- ✓ Cooler
  - U type structure with higher cooling efficiency
  - switchable (bypass)
- ✓ Actuator
  - DC-motor type valve
  - model based charge control : fast response in dynamic operation





H/W Improvement – Exhaust After-treatment

- **DPF (Diesel Particulate Filter)**
  - catalysed DPF
  - regeneration strategy considering filter durability and fuel economy
  - PM filtering more than 90% in FTP Cycle
- **SCR (Selective Catalytic Reduction)**
  - oxidation reduction reaction of NH_3 and NOx
  - urea Injection, mixer, and catalyst
  - dosing strategy optimized for high NOx conversion ratio and minimum ammonia slip
  - NOx reduction more than 80% in FTP cycle

Calibration Optimization

❑ Calibration Procedure

✓ **Simulation of Emission Cycle**

- Identification of engine operating area in FTP cycle

✓ **Steady State Calibration : DoE (Design of Experiment)**

- modeling of engine mapping parameters
- optimization for the best trade-off of emissions, NVH and fuel economy using a model function

✓ **Transient Calibration**

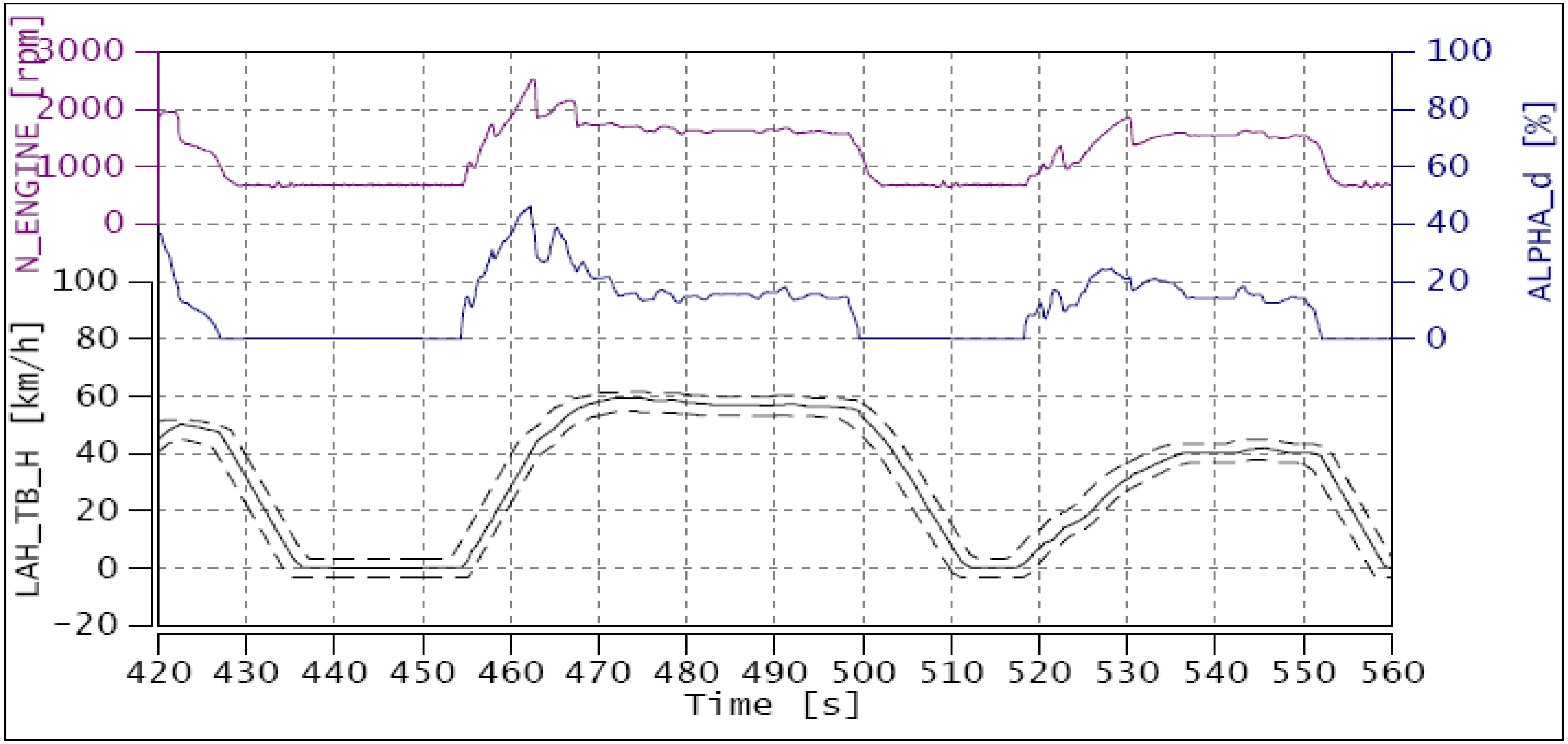
- emission cycle test at the engine test bench
- validation and re-calibration of mapping parameters

Optimization for Emission Cycle

❑ Simulation of Emission Cycle

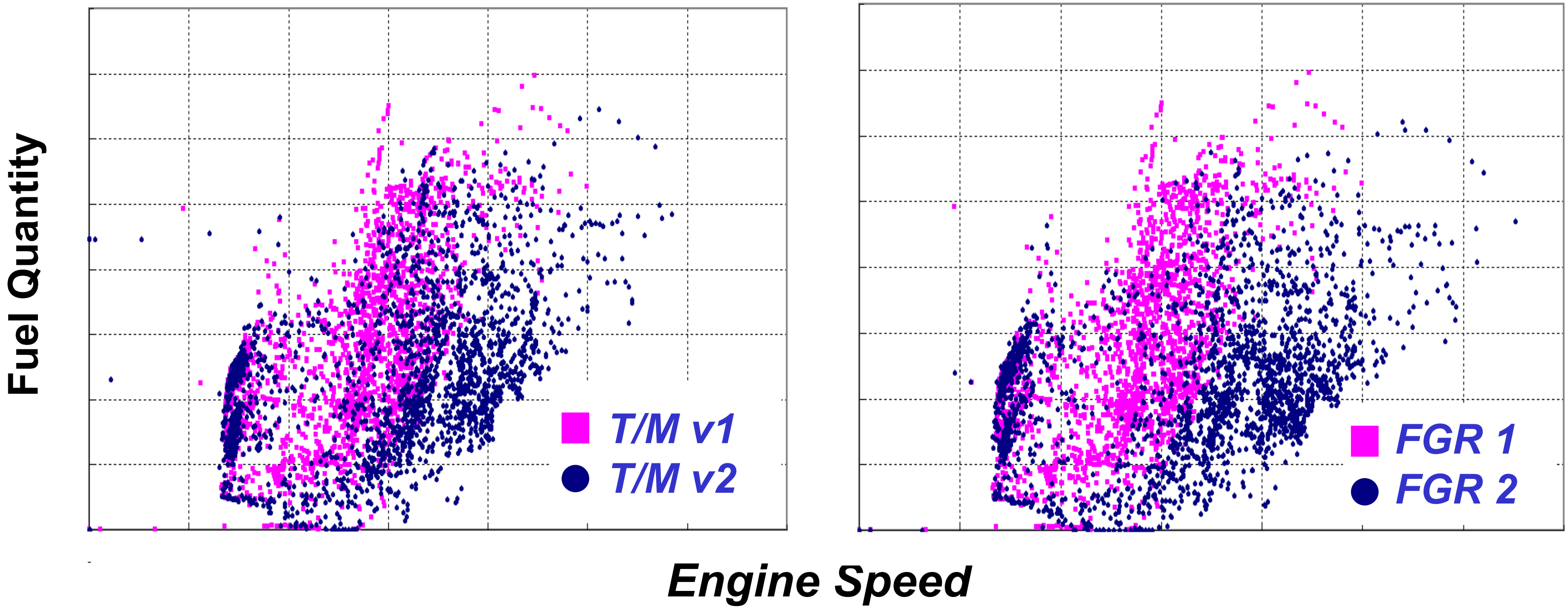
✓ **simulation of vehicle operation at engine test bench**

- input of transmission, gear shift pattern and the vehicle data
- engine operation to follow vehicle speed / load in emission cycle



FTP Emission Cycle

- ✓ engine operation area was optimized in FTP emission cycle
- ✓ pre-evaluation prior to vehicle test
  : consider different transmissions and gear reduction ratios
  : determine the best engine operation area for our engine



Steady State Calibration

✓ DoE calibration procedure at engine operation area

Test Plan → **Test Run** → **Modeling** → **Optimization** → **Map Calculation** → **Validation**

Operating Points | **Variation** | Measurement | Limit Monitoring | Set Value

Operating Points — Selection: <Selected> — Merge

View — Normal — List

Operating Point — No.: 1 — SPEED: 877.0 — TORQUE: 95.9 — Type: 1

Point	Type	Stab. Time	InjCrv_phi	InjCrv_tiPi	InjCrv_qPi	AirCtl_mD	PCR_rCtlB	Rail_pSet
1	C	90	-2	2800	1.15	350	80	425000
2	D	90	-3	1800	1.65	340	73.333333	458333.33
3	D	90	-1	3133.3333	1.65	380	90	458333.33
			-5	3800	0.65	380	70	475000
			0	2800	1.65	320	90	375000
			1	1800	0.65	320	90	475000
			-5	3800	1.65	320	90	375000
			1	3800	0.65	320	70	375000
			1	1800	1.65	380	70	375000
			-2	2800	1.15	350	80	425000
			1	3800	1.65	320	70	475000
			1	3800	0.65	380	90	375000
			-5	3800	1.65	380	70	375000
			1	1800	0.65	380	70	475000

$f(speed^3, qcurr^3, qpoi2^3, phipoi1^3, qpoi1^3)$

$620.6176 + 32.28014*speed + 109.332*qcurr + 42.52692*qpoi2 + 140.4046*qpoi1 +$

$19.95151*speed*qpoi2 + 55.59516*speed*phipoi1 + 31.29267*speed*qpoi1 +$

$48.99015*qcurr*qpoi2 + 53.33887*qcurr*phipoi1 - 40.27005*qcurr*qpoi1 +$

$88.18286*qpoi2^2 + 79.33995*phipoi1^2 + 30.14849*qpoi1^2 +$

$24.2883*speed^2*qcurr + 82.90625*speed*qcurr^2 + 55.40991*speed*qcurr*qpoi2 +$

$39.97514*speed*qcurr*phipoi1 + 18.14786*speed*phipoi1^2 +$

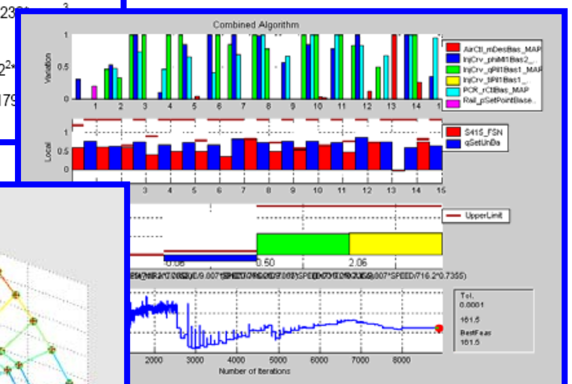
$40.59881*speed*phipoi1*qpoi1 + 17.57898*speed*qpoi1^2 - 116.223$ …

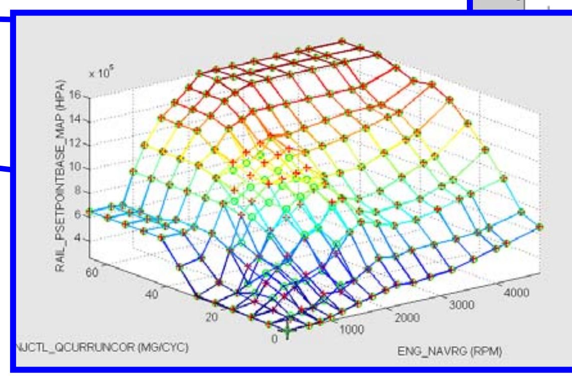
$79.85871*qcurr*qpoi2*phipoi1 + 108.9509*qcurr*phipoi1^2 +$

$52.63596*qcurr*phipoi1*qpoi1 - 23.87614*qpoi2^3 + 64.7092*qpoi2^2$ …

$58.34495*qpoi2*phipoi1^2 + 64.84334*qpoi2*phipoi1*qpoi1 + 62.8179$ …

$76.60446*phipoi1*qpoi1^2 - 55.77077*qpoi1^3$

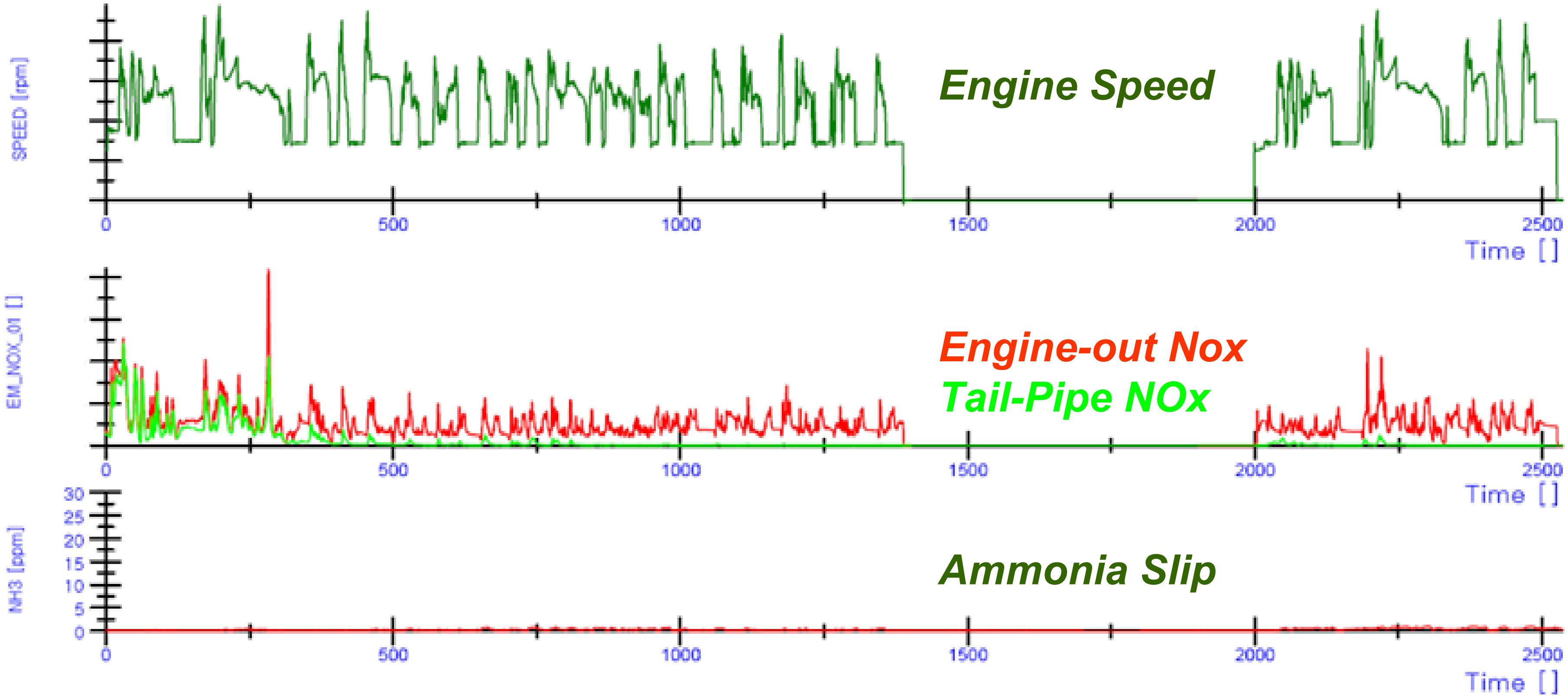




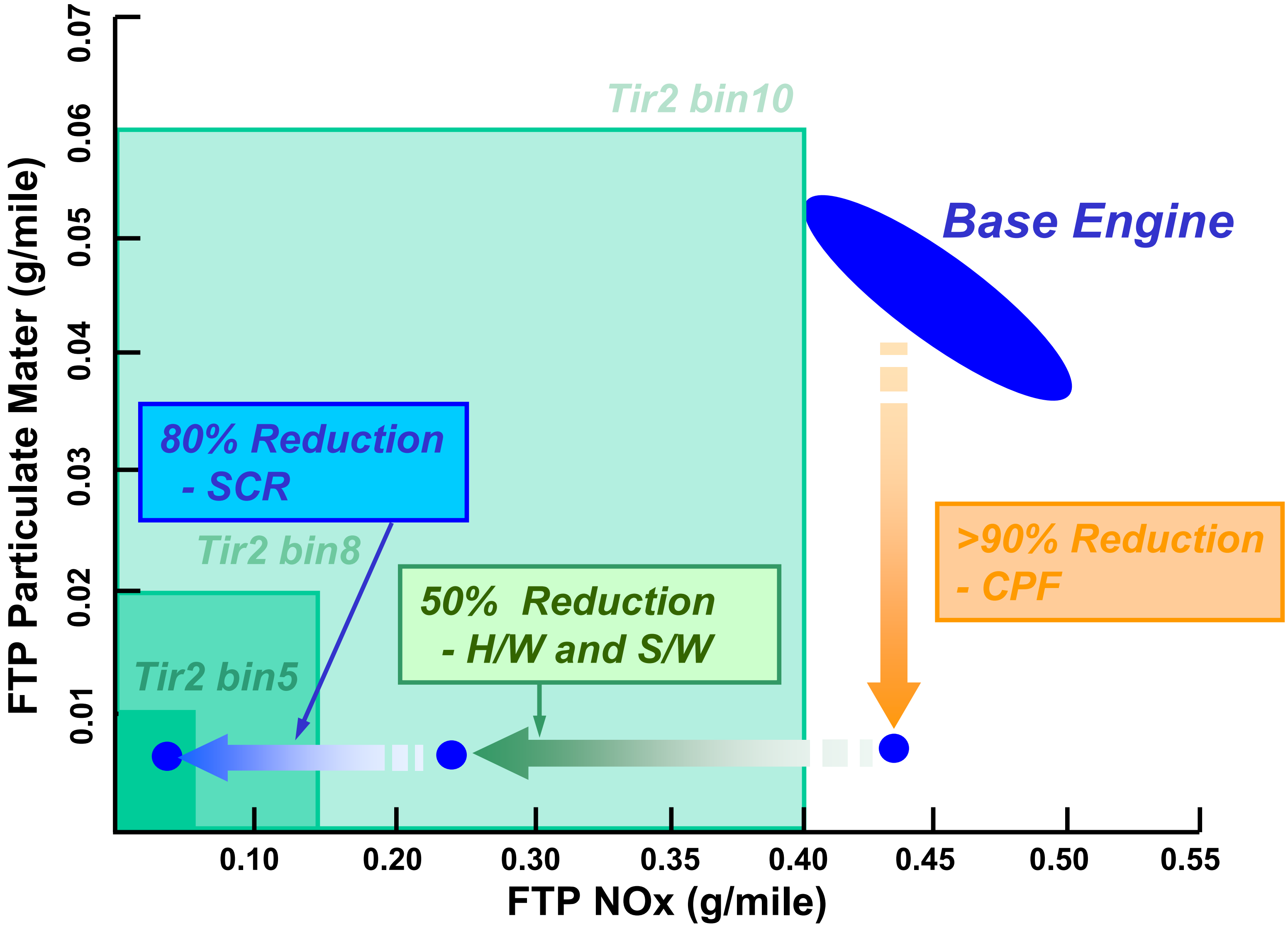
Transient Calibration for FTP Cycle Operation

✓ validation and recalibration of steady state optimization

- H/W, calibration optimization: 50% reduction of engine-out NOx
- SCR system: 80% reduction of tail pipe NOx



Final Results



Summary

- Tier2 Bin5 Limit have been successfully fulfilled

- Strategy to Meet Tier2 Bin5 Emission Limits
  - ✓ combustion refinement
  - ✓ calibration optimization at steady state and transient operation
  - ✓ gear reduction ratio re-matching
  - ✓ after-treatment consisting of DPF and SCR

- Future Work
  - ✓ robust calibration in terms of emission, drivability and NVH, covering wide range of fuel properties
  - ✓ further optimization at high altitude

Thank you !!

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