Can Future Emissions Limits be Met with a Hybrid EGR System Alone?

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BorgWarner, Inc.

2008 Diesel Engine-Efficiency and Emissions Research (DEER) Conference
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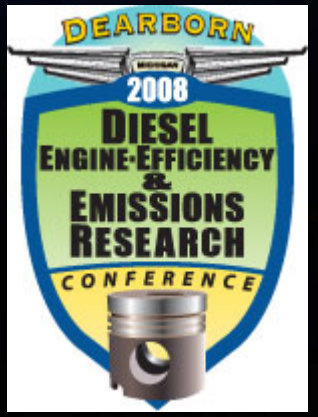

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- Introduction
- Hybrid EGR System
  - Low Pressure and High Pressure EGR
- Thermodynamic Analysis
- Transient Behavior and Controls
- Application Solutions
- Conclusions

Introduction

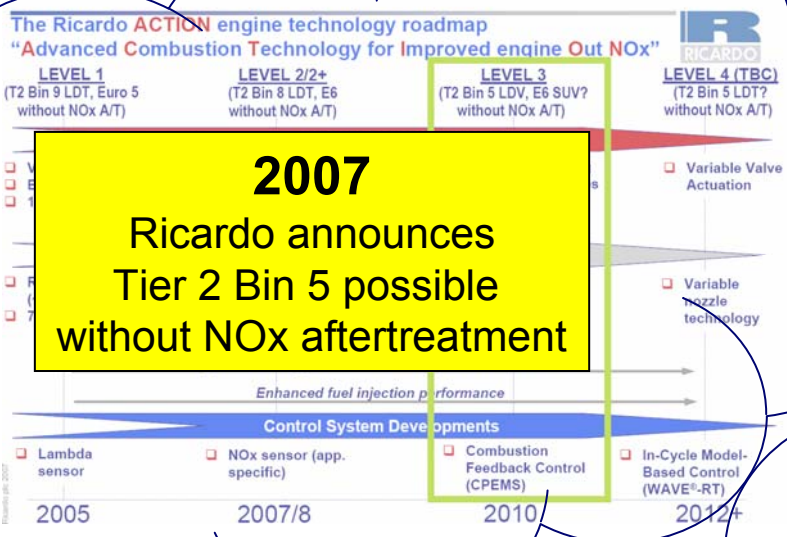
- Global tightening of vehicle emissions regulations
- Increasing cost of both diesel engines and aftertreatment
- Improvements in efficiency of spark ignition engines and hybridization

Unless costs are controlled, diesel engines in light duty vehicles could become uncompetitive

Introduction

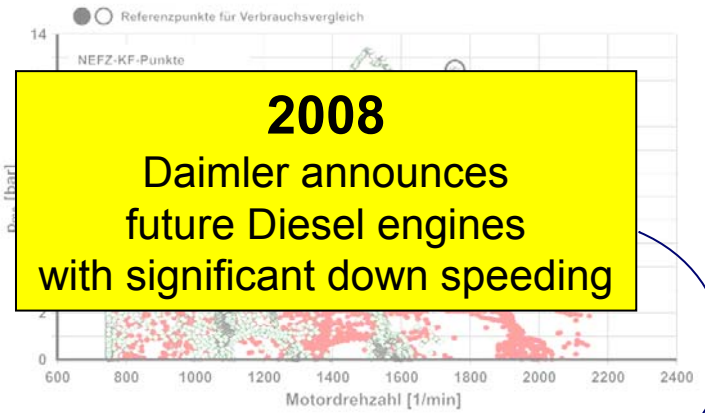
Trends in engine out emission reduction…

Ricardo, DEER 2007



2007
Ricardo announces
Tier 2 Bin 5 possible
without NOx aftertreatment

Diamler, Vienna 2008



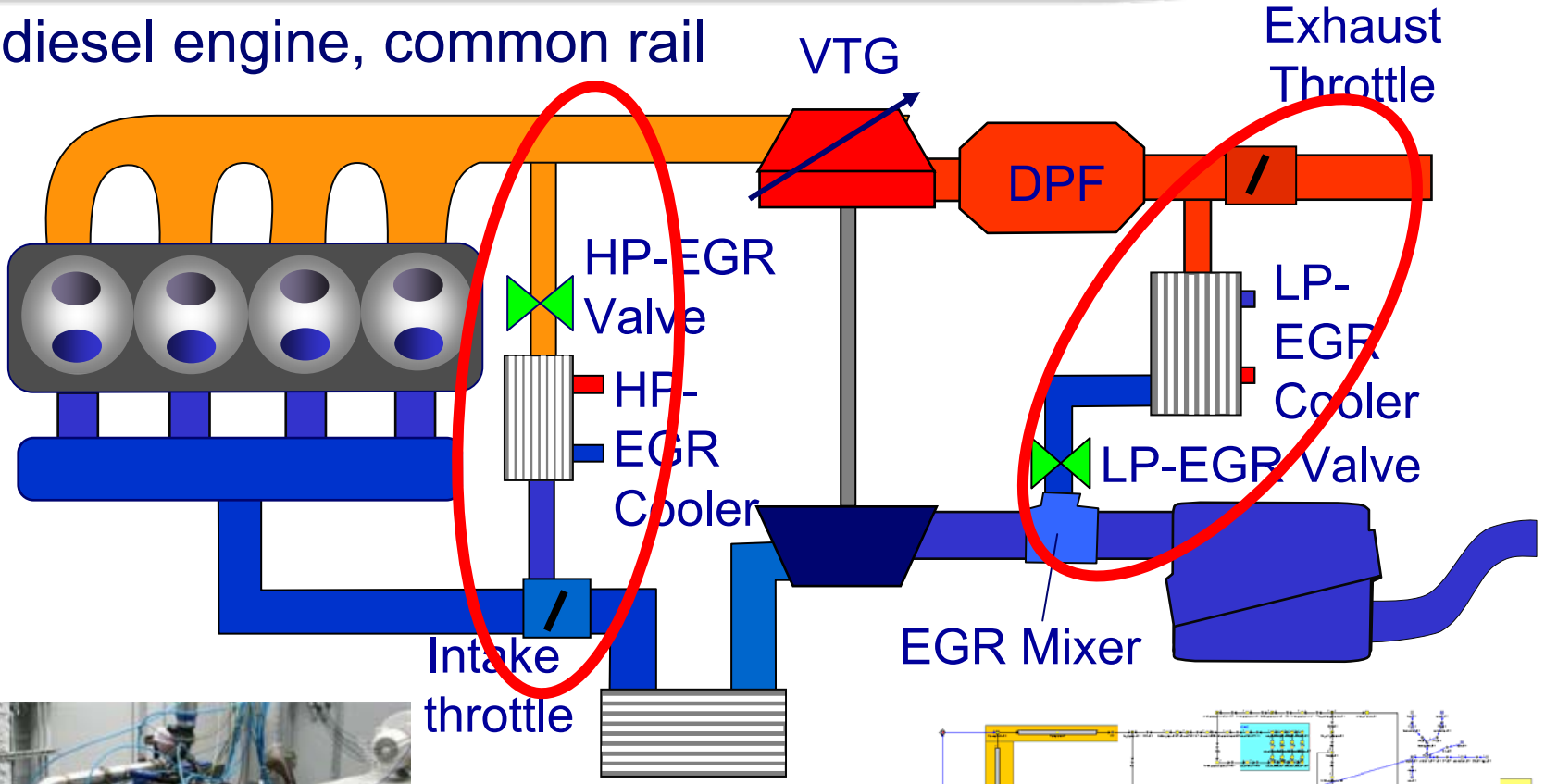
2008
Daimler announces
future Diesel engines
with significant down speeding

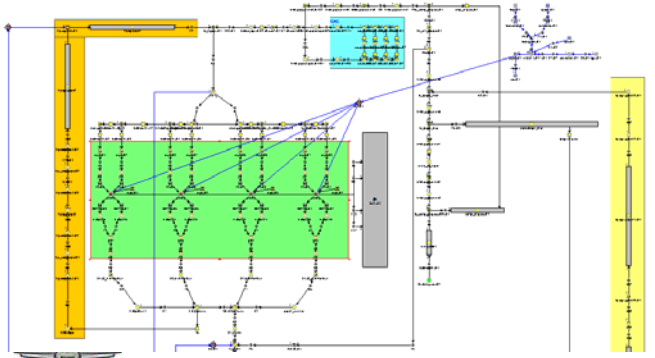
- **Two or more EGR loops used in synergy to minimize**
  - Engine out NOx emissions through highest possible EGR rates
  - Fuel consumption through reduced turbo charger pumping work
- **While providing**
  - Highest flexibility for the engine’s combustion calibration
  - Drivability improvements through optimized EGR / boosting controls
  - Cost effectiveness through simplified components

EGR & Turbo Charging System Architecture

Base "Hybrid" EGR system Layout

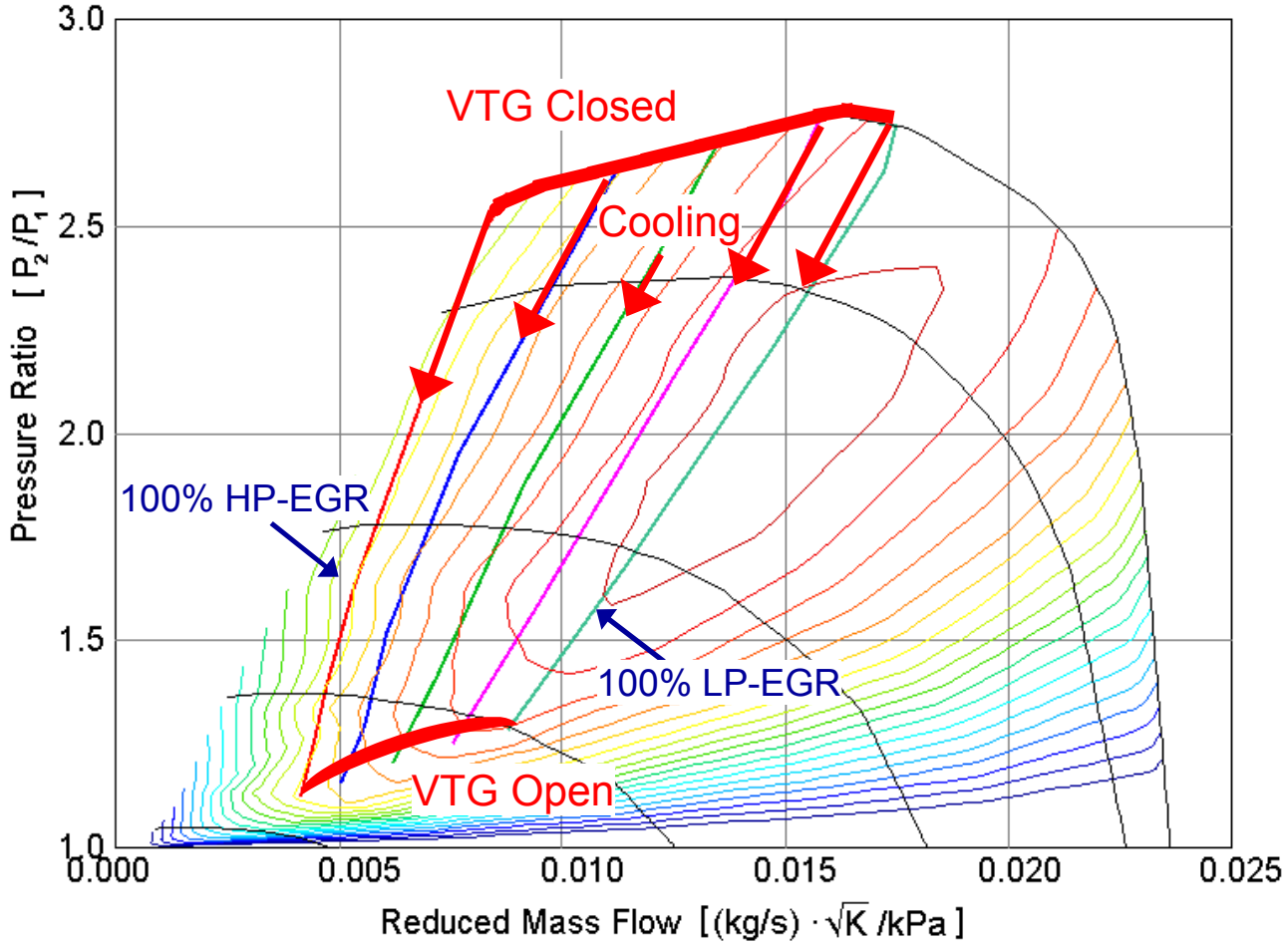
I4 diesel engine, common rail





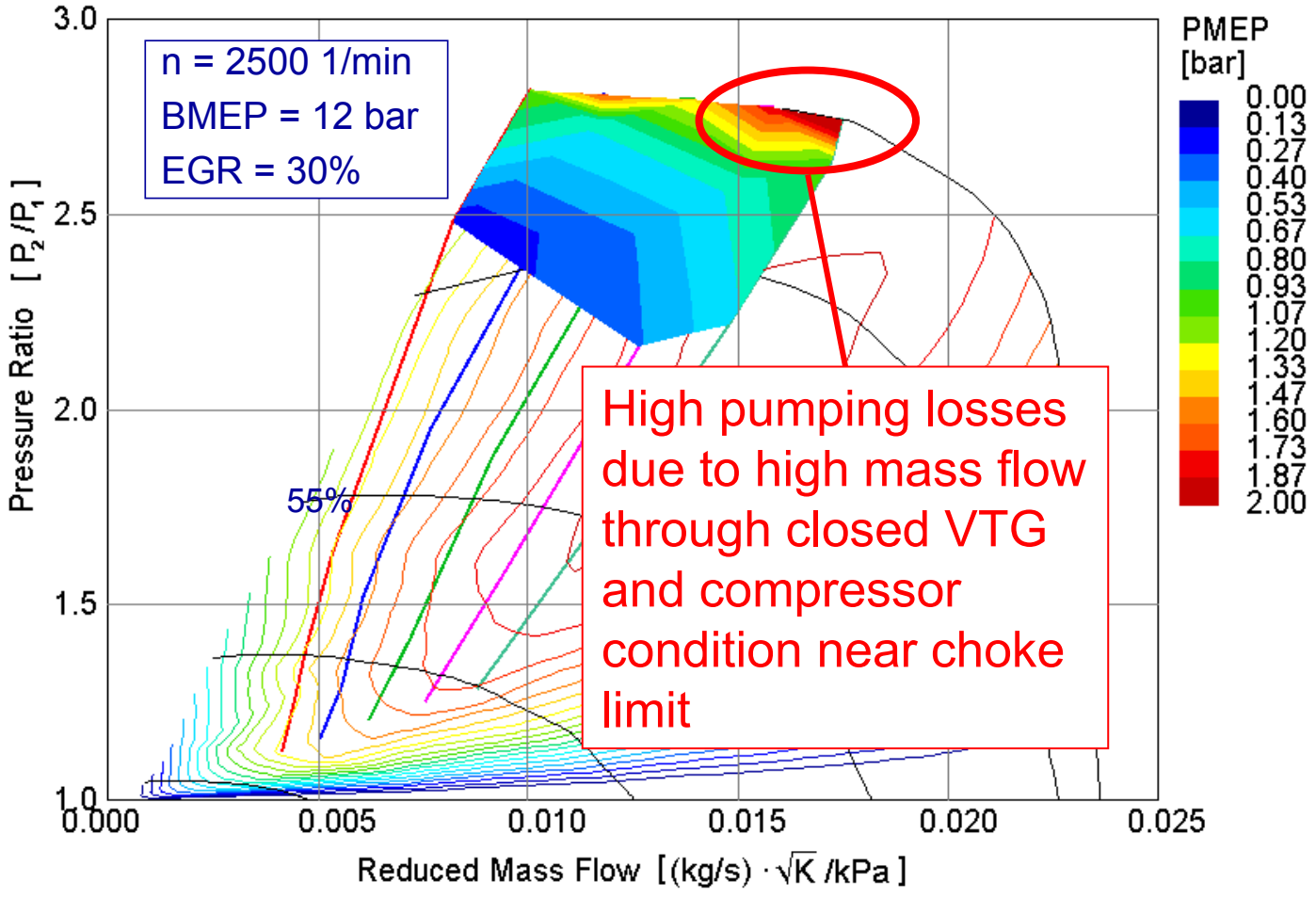
Thermodynamic Analysis HP&LP Loop

EGR-Turbo Mapping @ 2500RPM, 12bar BMEP, 30%EGR



Thermodynamic Analysis HP&LP Loop

Pumping losses at different HP/LP-EGR-splits



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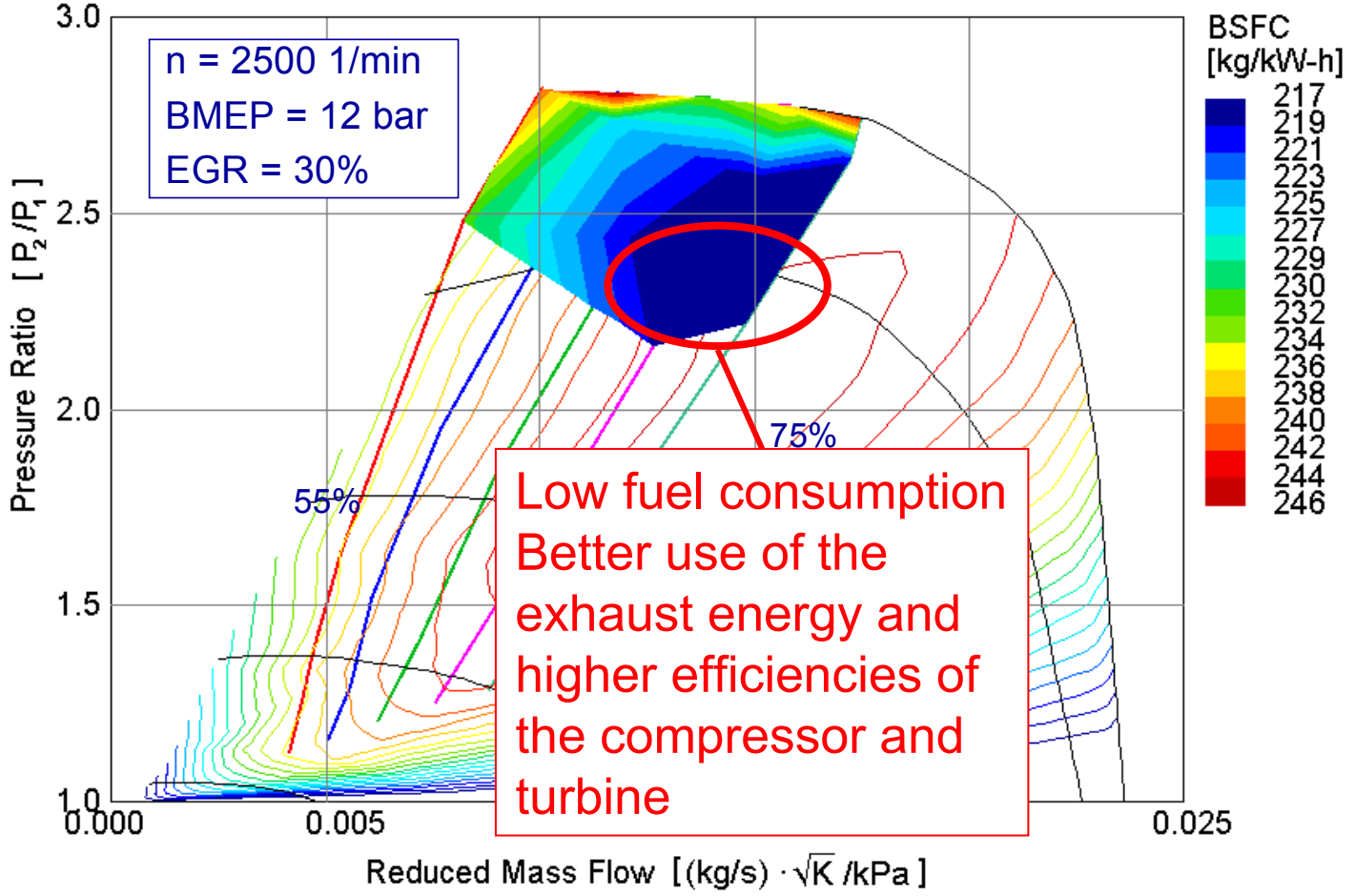
Thermodynamic Analysis HP&LP Loop

Specific fuel consumption at different HP/LP-EGR-splits



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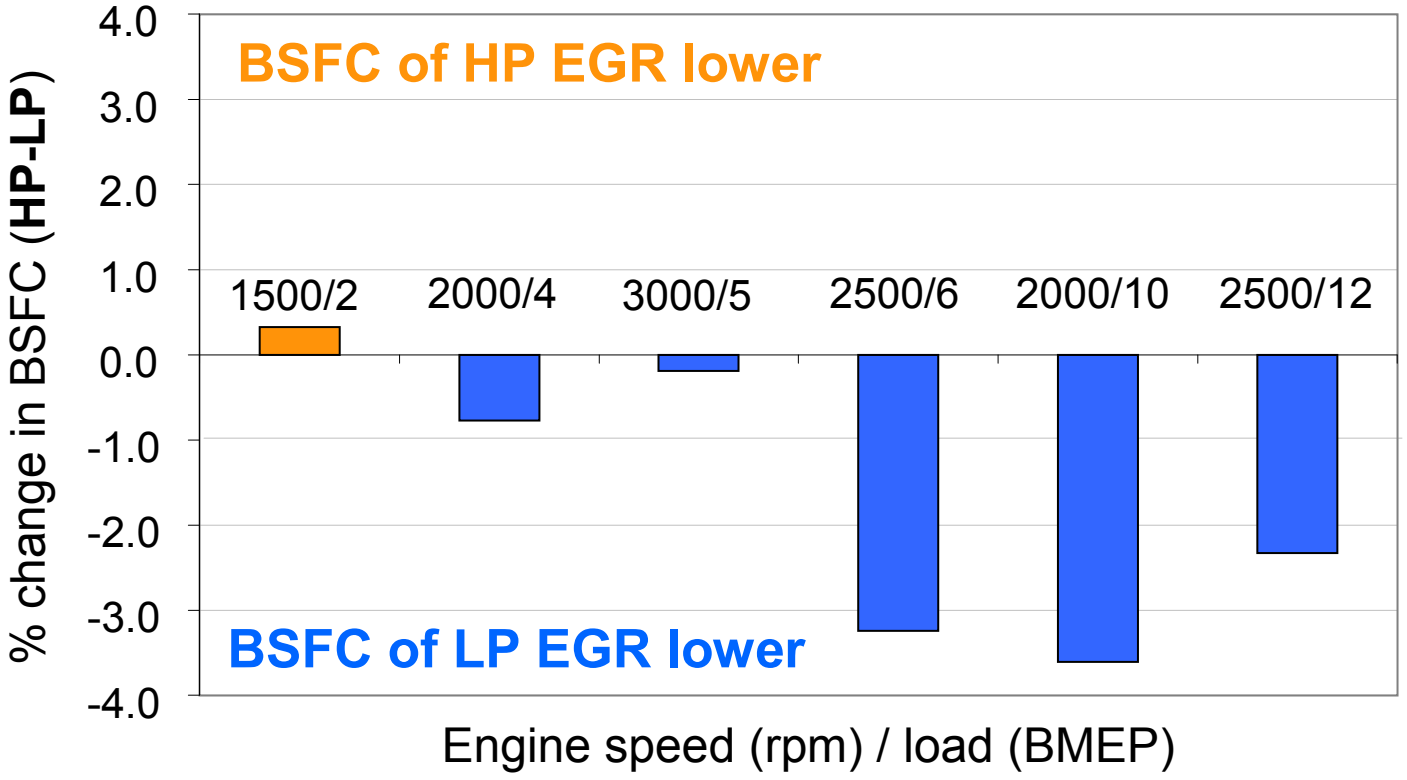
"Hybrid" EGR system performance
Low Pressure vs High pressure Loop Fuel Economy

Moderate LP-EGR Rates
(identical to HP-EGR Euro 4/5 Baseline)



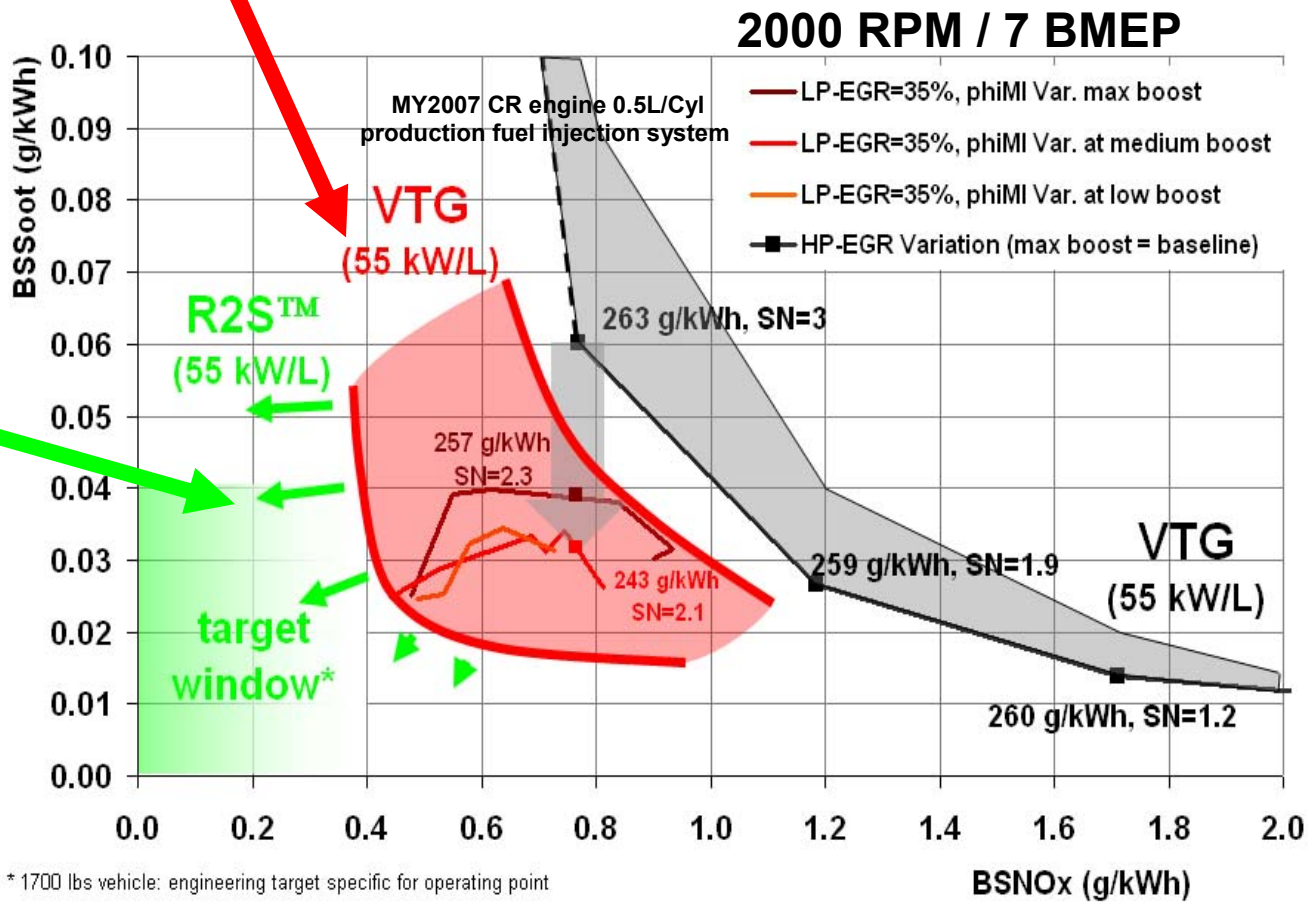
- BSFC improvement for LPL in most operating conditions

"Hybrid" EGR system performance

emissions tradeoff - HP-EGR versus LP-EGR

- Steady state tests applying an optimal LP-EGR system to EURO5 engine HW show approximately 30% benefit in BSNOx at constant EGR, BSSoot and BSFC.

- Improved A/F capability of two stage turbo charging (R2S™) will allow further increased EGR rates without suffering fuel economy penalties through higher pumping work.

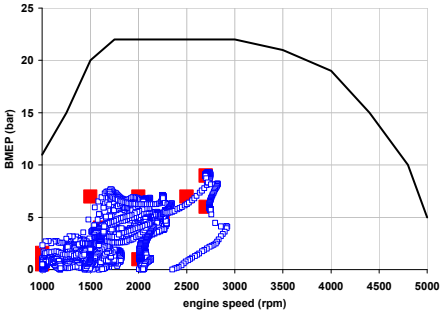


** IAV, Tietze, CTI 2006 AVL, Weissbaeck, SIA 2008

*1700 kg vehicle, 2L class engine, engineering target specific for operating point

“Hybrid” EGR system performance

NEDC Test cycle



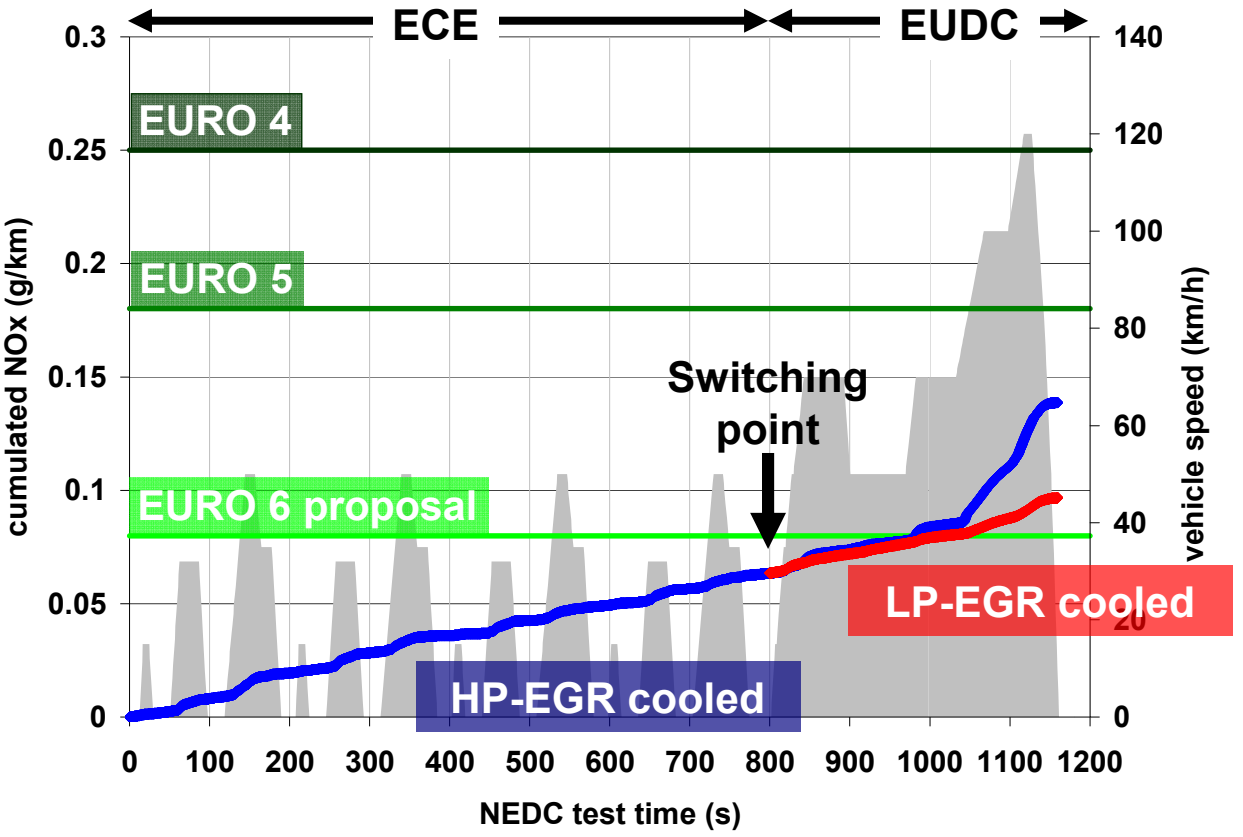
Base engine HW:
2L Inline 4 EURO4

Adjusted Parameters:
EGR-rate, Boost pressure

Combustion system:
standard Diesel (diffusive)

EGR-system:
cooled HP-EGR, cooled LP-EGR

Boosting system:
1-stage VTG



- use of HP-EGR for good FE in ECE, LP-EGR for NOx potential in EUDC
- Switching between HP-EGR and LP-EGR to avoid condensation
- <0.1 g/km NOx achieved with standard VTG (55kW/L) and w/o fuel economy hit!

Dynamic performance: HP vs. LP EGR

Influence on load step performance

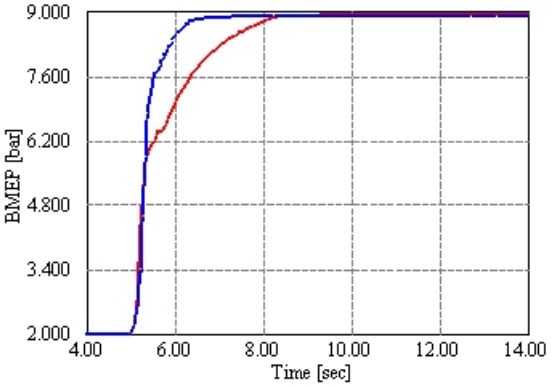
- LP EGR ⇒ enhanced dynamic performance
- influence of turbo charger speed dominant

1500 rpm / 2 bmep / 70% EGR → *1500 rpm / 9 bmep / 25% EGR*

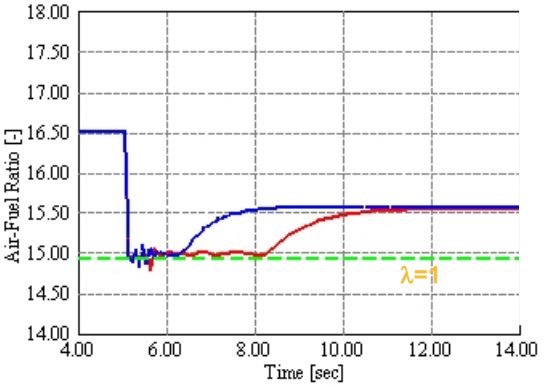
Low pressure EGR

High pressure EGR

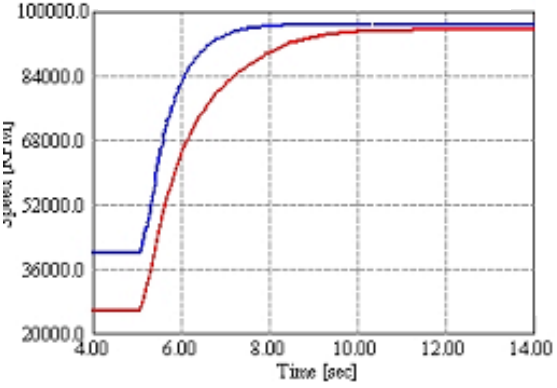
Load (Bar bmep)



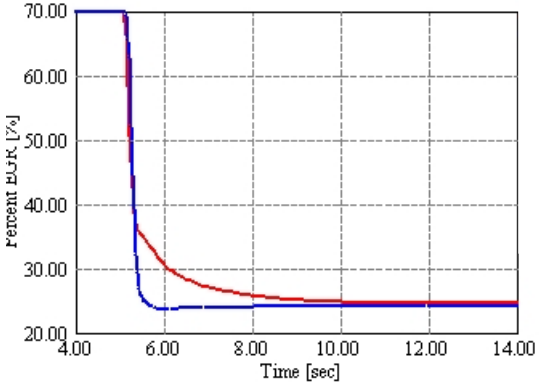
Air/Fuel ratio



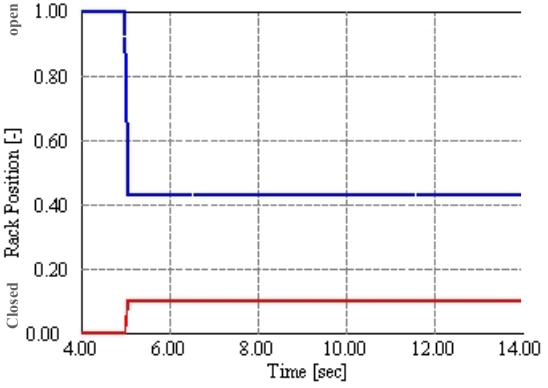
Turbo charger speed



Percent EGR



Turbo charger VTG position



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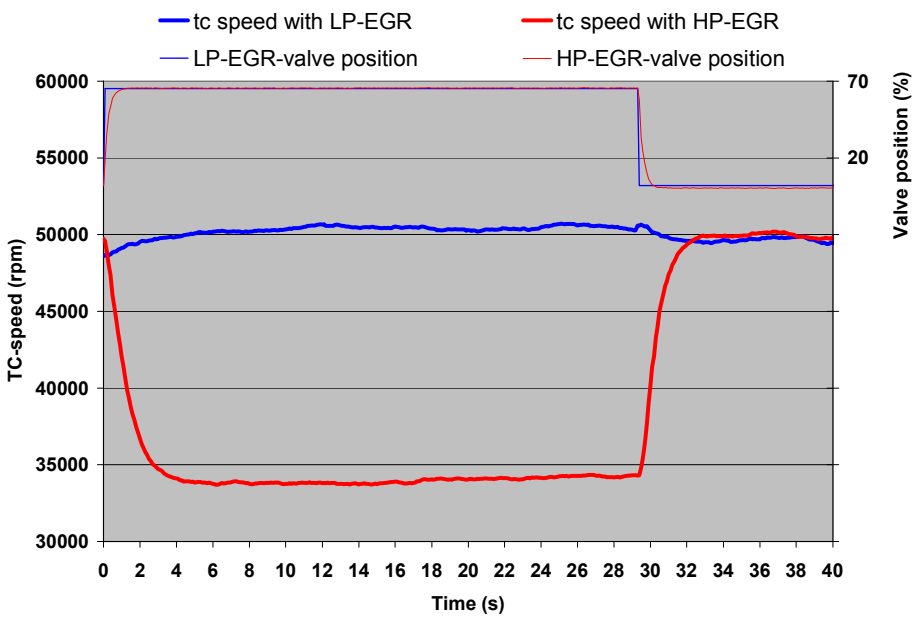
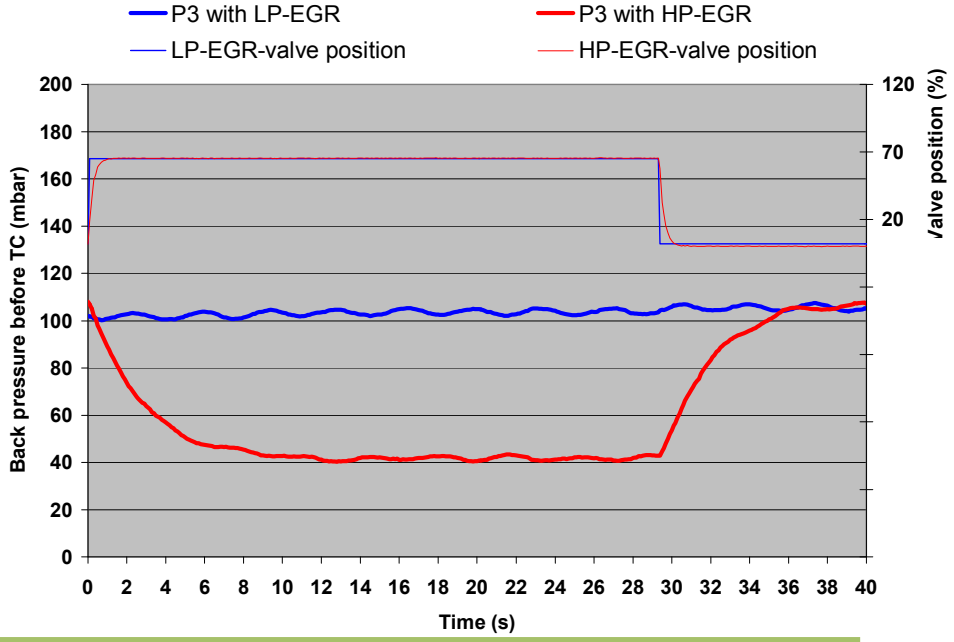
Dynamic controllability- influence of EGR on turbo

2000 rpm / 2 bmep / 30% EGR



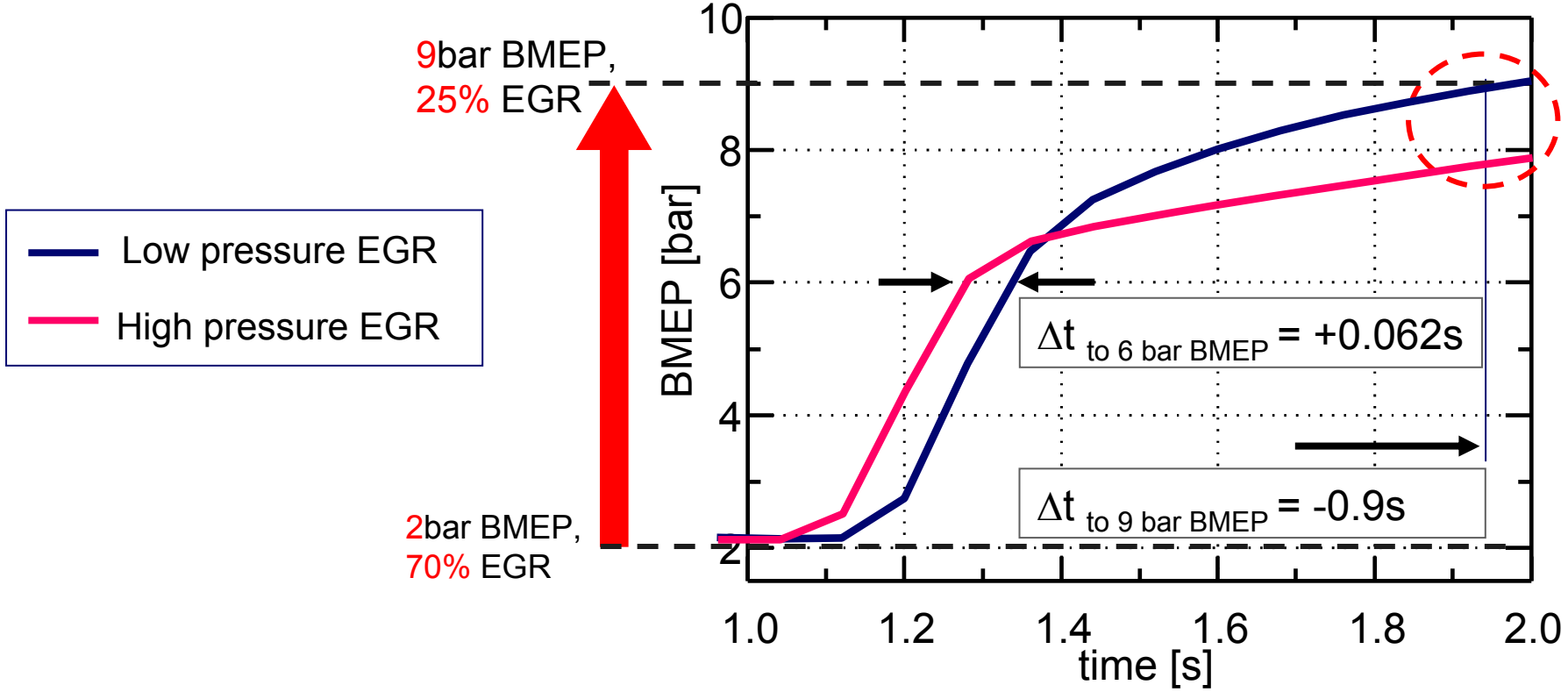


Influence of EGR on turbo charger boundary conditions

- Ex Man pressure and turbo charger speed are nearly constant with and w/o LP-EGR .
- the higher the EGR-rate, the bigger the difference between LP- and HP-EGR becomes
- decoupling the EGR-rate from TC performance greatly improves transient controllability

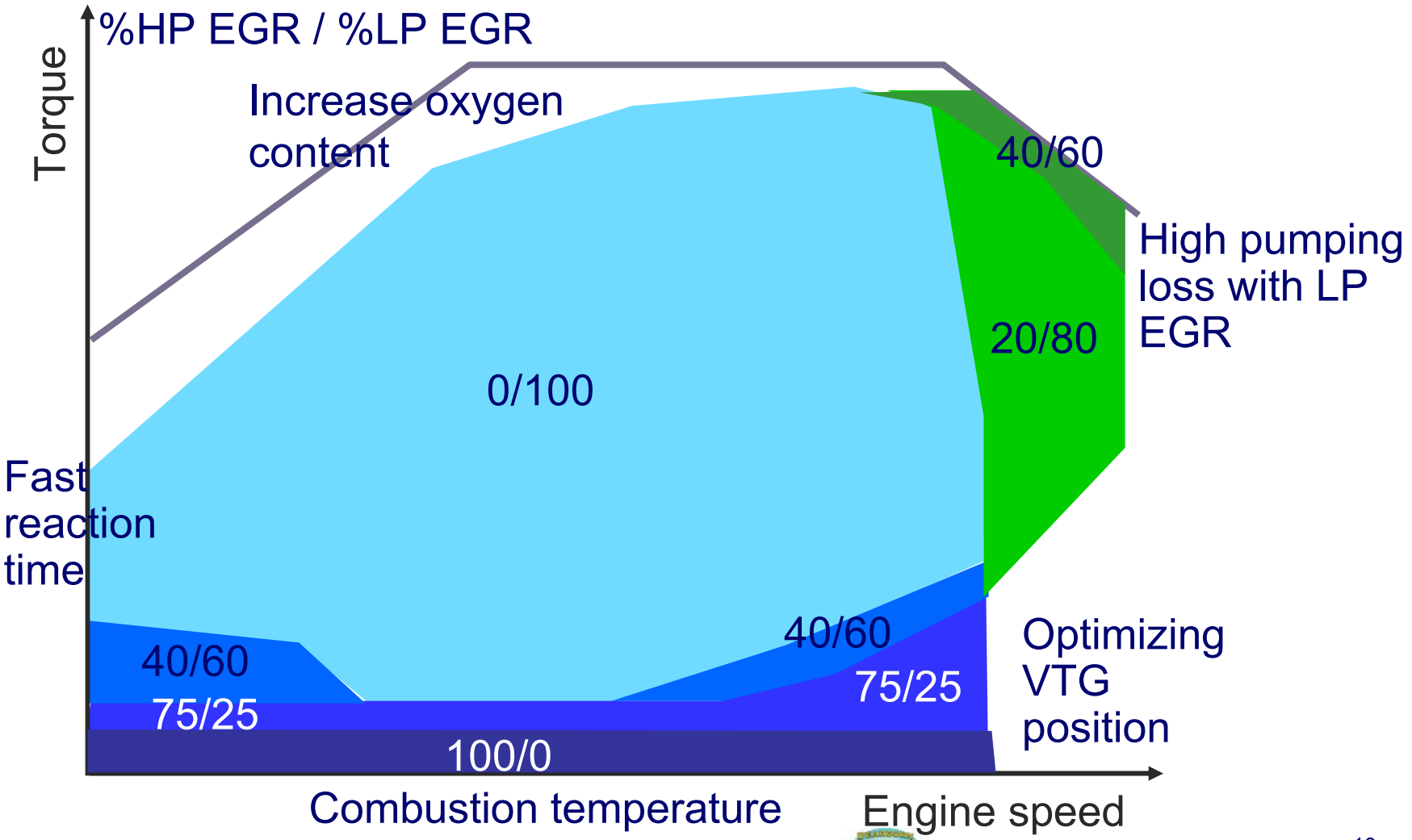
LP EGR vs. HP EGR: Transient behavior

Load step performance at low speed (1500rpm): Initial delay time

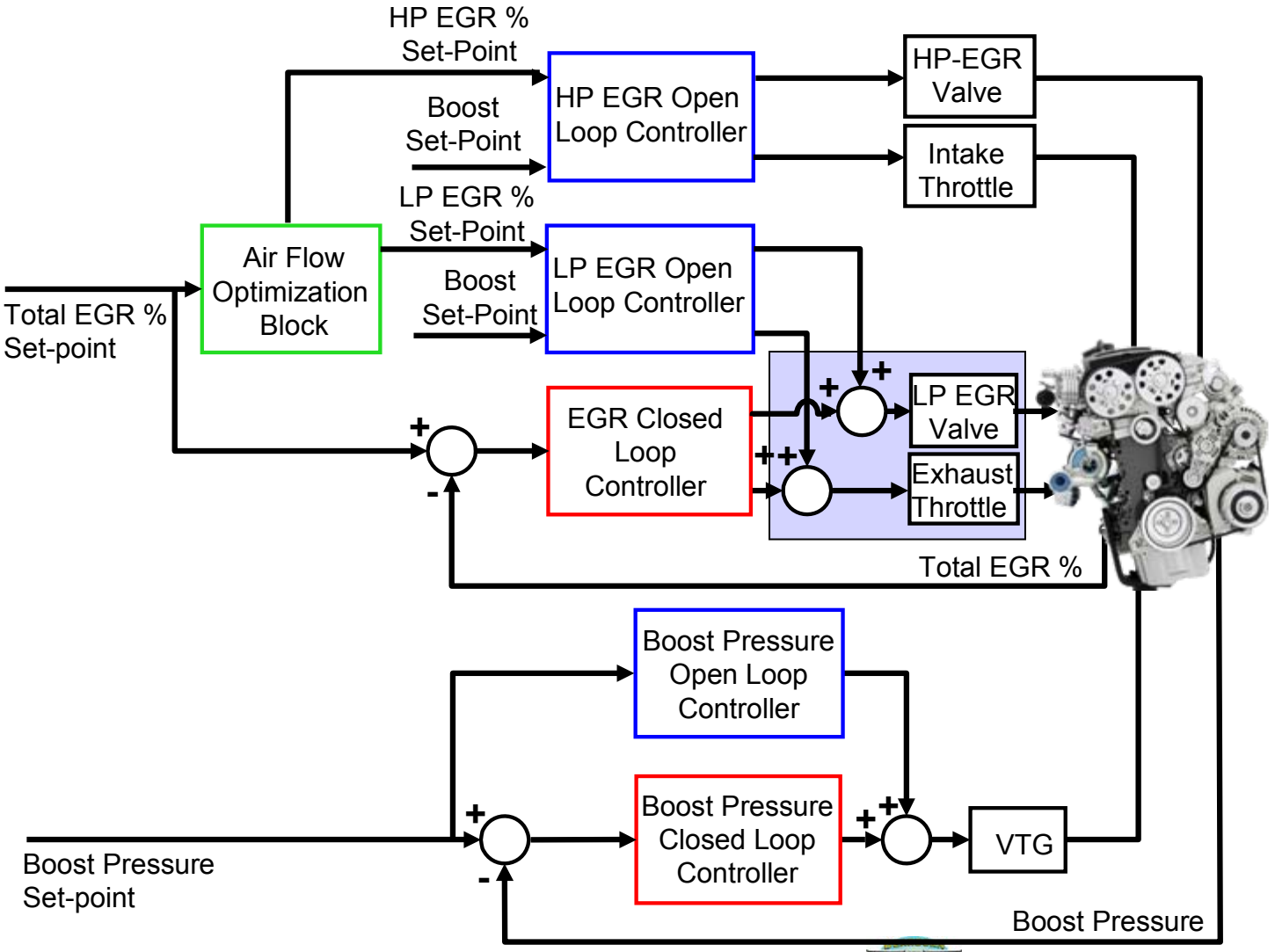


- HP-EGR version show a faster BMEP increase at the beginning, but LP-EGR version keeps up and reaches the target BMEP faster
- Low pressure EGR works optimally with closely packaged indirect charge air cooling.
- Using hybrid EGR, the HP-EGR fraction can be optimized for each speed/load point.

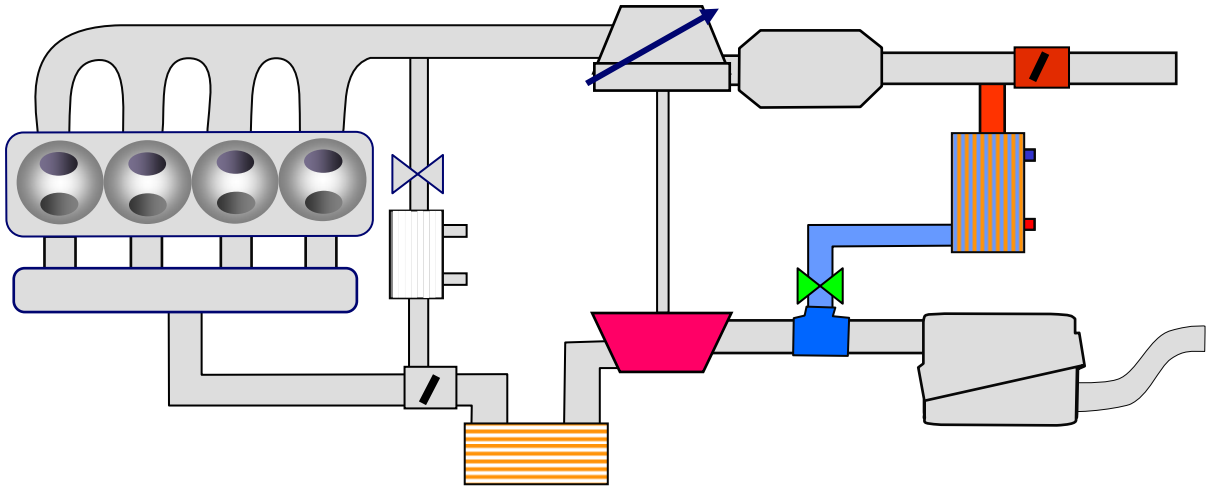
LP / HP EGR Split Strategy



Air Controller System Architecture



LP EGR Application Development



New components

- **Low pressure EGR valve**
- Low pressure EGR cooler
- **Exhaust throttle valve**
- **Mixer**
- **Air Flow Optimization Controls**

Changes to present components

- **EGR resistant compressor wheel**
- Condensate resistant charge air cooler
- **Larger TC possible, LP-EGR avoids surging with low compressor flow**

Conclusions

- Hybrid EGR offers significant advantages to reduce emissions and fuel consumption and can meet future emission requirements
- Aftertreatment system cost can be reduced with a hybrid EGR system
- Two stage boosting systems together with hybrid EGR allow further enhanced performance while utilizing down speeding to achieve CO2 targets.
- Dynamic performance can be improved with a hybrid EGR system
- System and component development are production ready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