Further improvement of conventional diesel NOx aftertreatment concepts as pathway for SULEV

October 5th, 2011, Detroit, MI

U.S. DEPARTMENT OF ENERGY
DEER 2011
DETROIT
DIRECTIONS IN ENGINE-EFFICIENCY AND EMISSIONS RESEARCH CONFERENCE

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Outline

2011 DEER conference, Detroit, MI, USA

- Introduction: Status of T2B5 LNT passenger car applications
- Improvement potential of engine out emissions
- Improvement potential of LNT aftertreatment
- Conclusions

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- **Introduction: Status of T2B5 LNT passenger car applications**
- Improvement potential of engine out emissions
- Improvement potential of LNT aftertreatment
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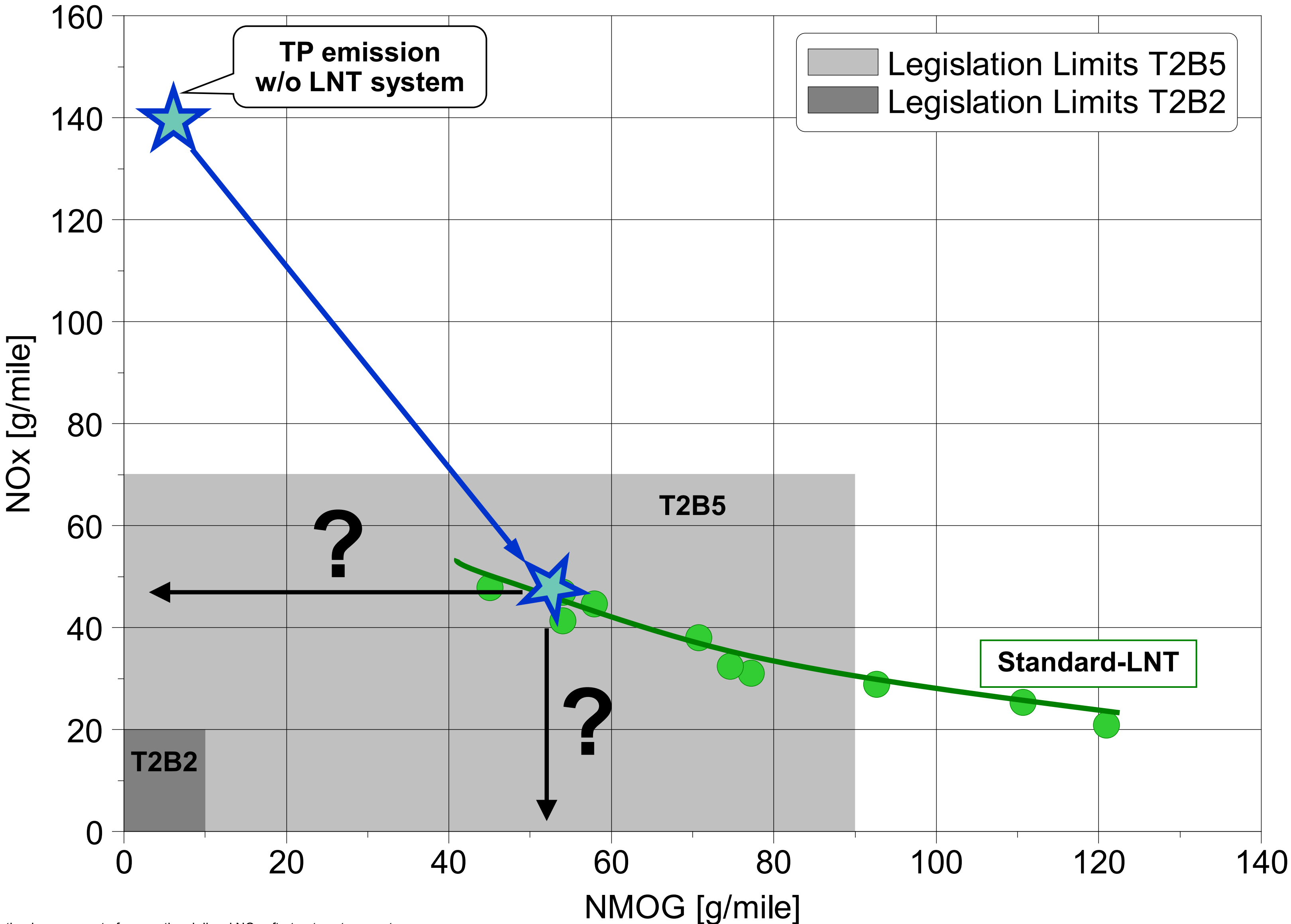
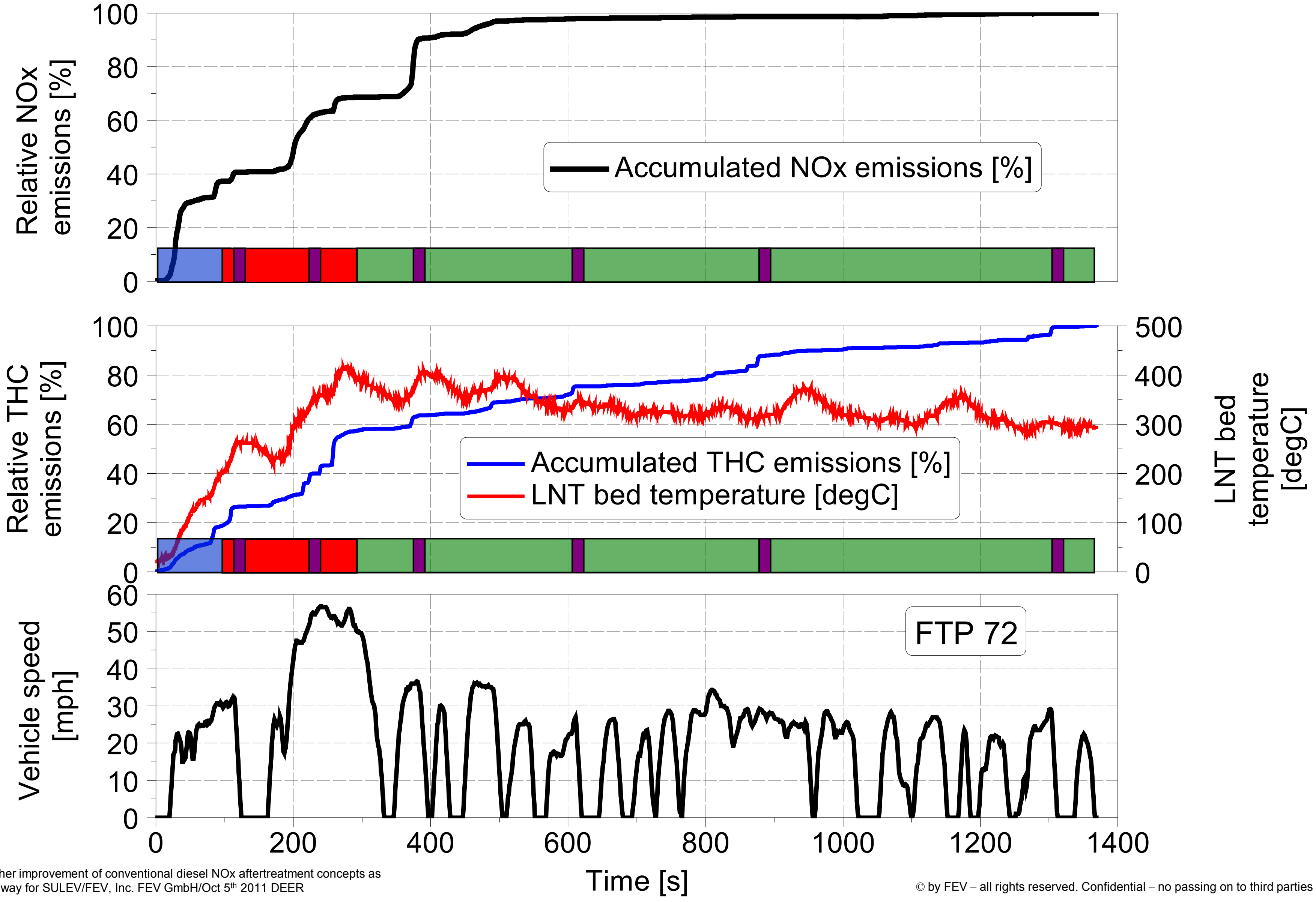
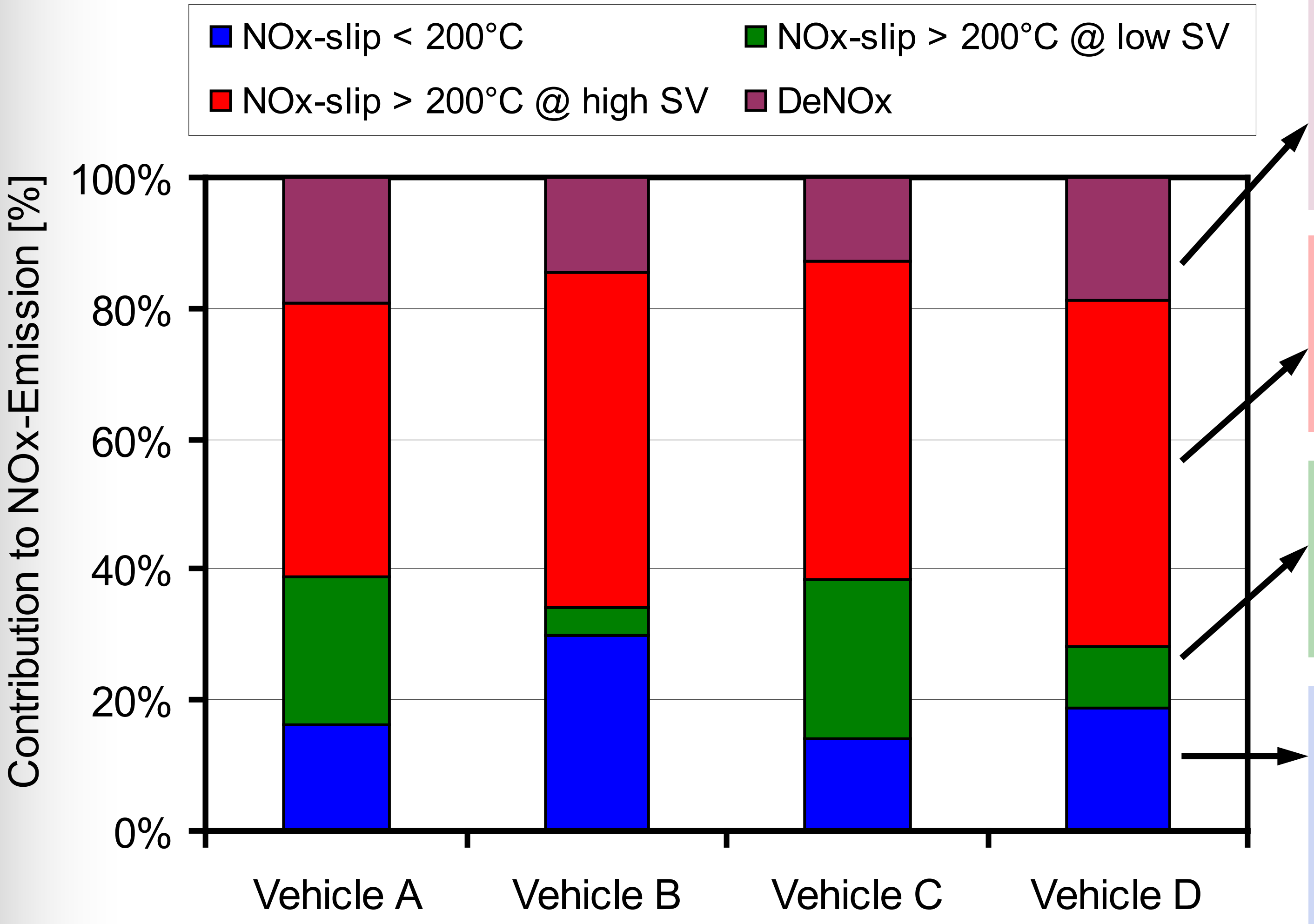
How can T2B2 emission targets be achieved?



Emission sources on FTP cycle



Emission source analysis on FTP cycle



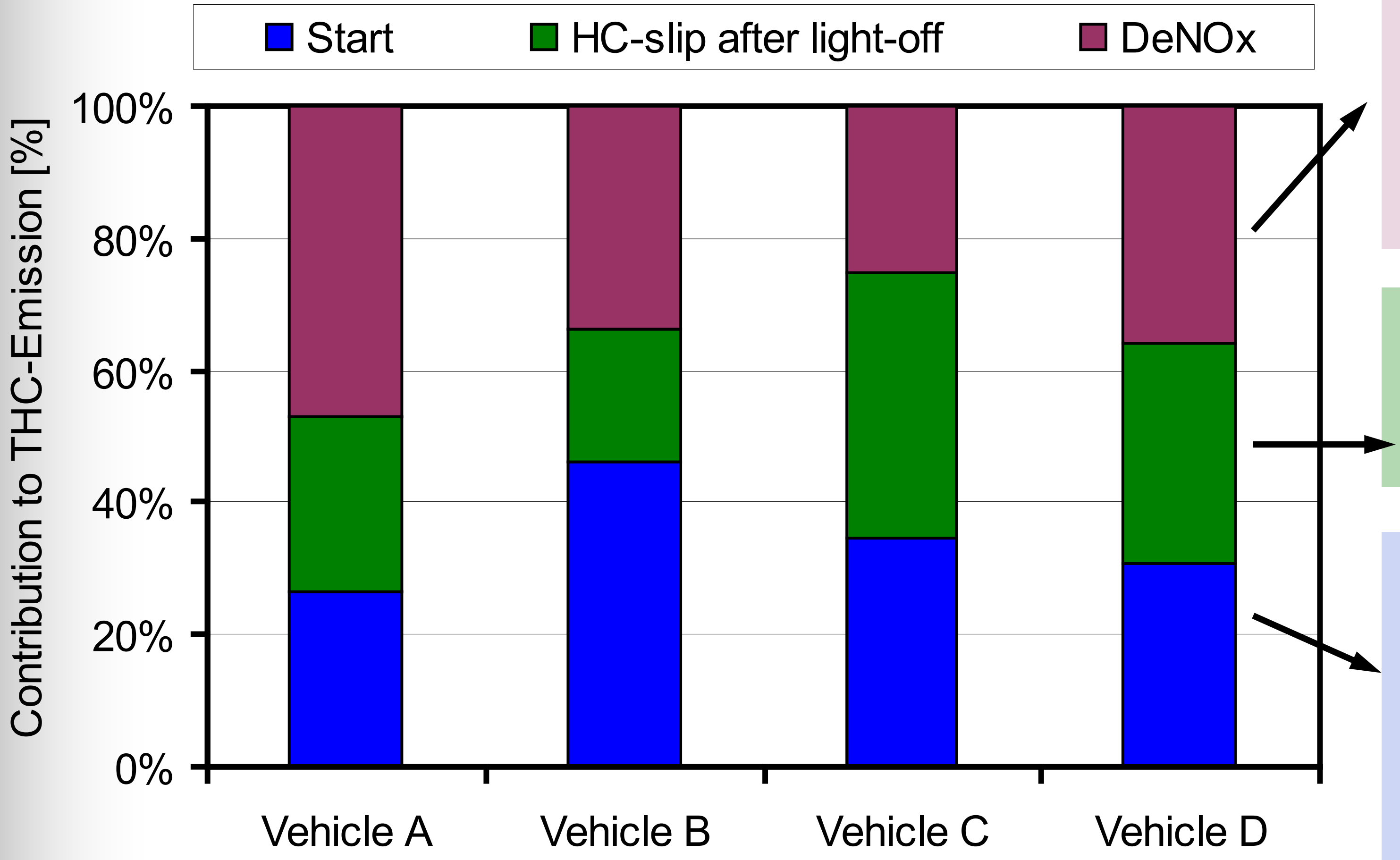
- Increase of regeneration temperature
- Decrease of SV
- **Improved reductant (high CO and H_2 content)**

- Larger / additional LNT-brick
- **Reduction of NOx raw emission @ high loads**

- Larger / additional LNT-brick
- Reduction of NOx raw emission @ medium load

- **Reduction of NOx raw emission during cold start**
- Improved LT-storage
- Larger / additional LNT-brick
- **Heating strategy**

Emission source analysis on FTP cycle



- Increase of regeneration temperature
- Decrease of SV
- **Improved reductant / alternative regeneration**

- Improved oxidation performance
- Reduction of HC raw emission @ high SV

- **Reduction of HC raw emission during cold start**
- Improved LO lean performance
- Increase of HC storage in EAS
- **Heating strategy**
- E-Cat

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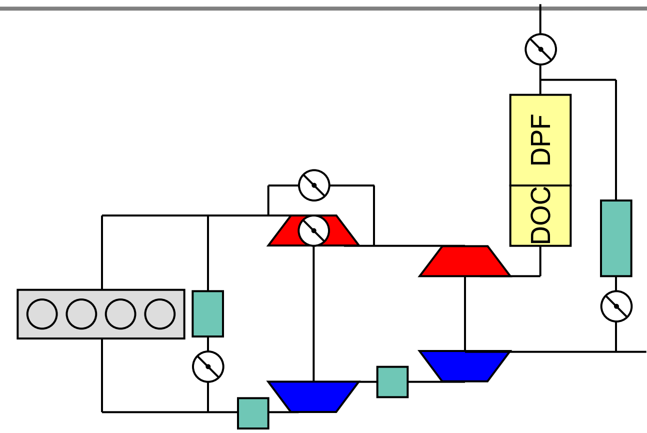
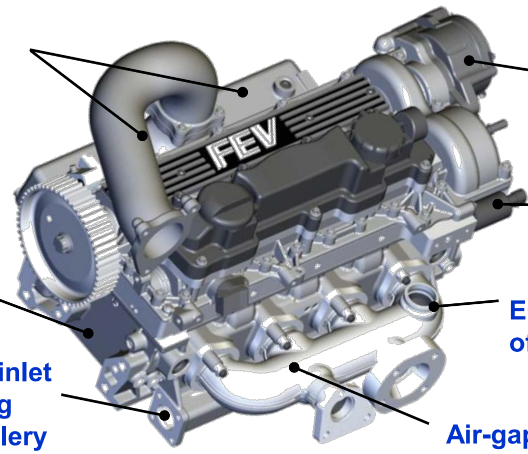
Demonstration of engine out emission reduction potential with FEV HECS concept



Air path concept

- Two stage boosting and LP-EGR
- Advanced control concept

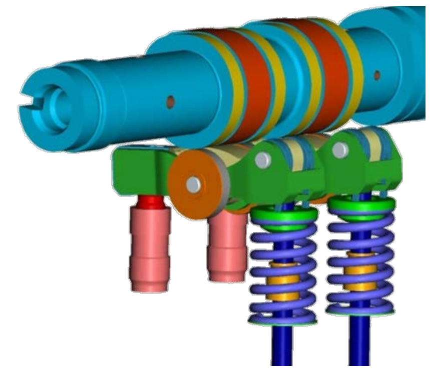


Cylinder head concept

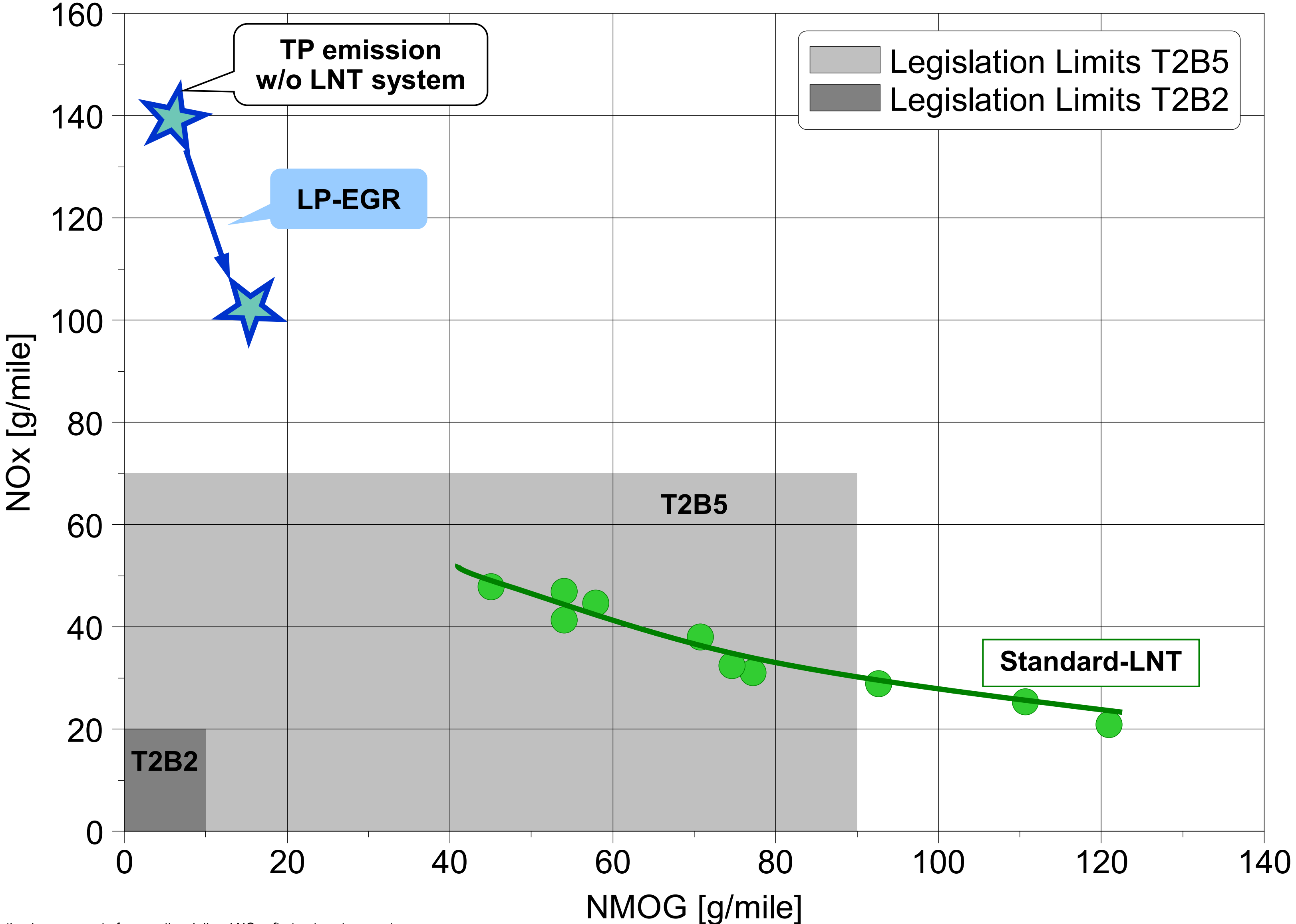
- 200 bar peak firing pressure
- Split-cooling
- Dethrottled intake ports with seat swirl chamfer

Valve train concept

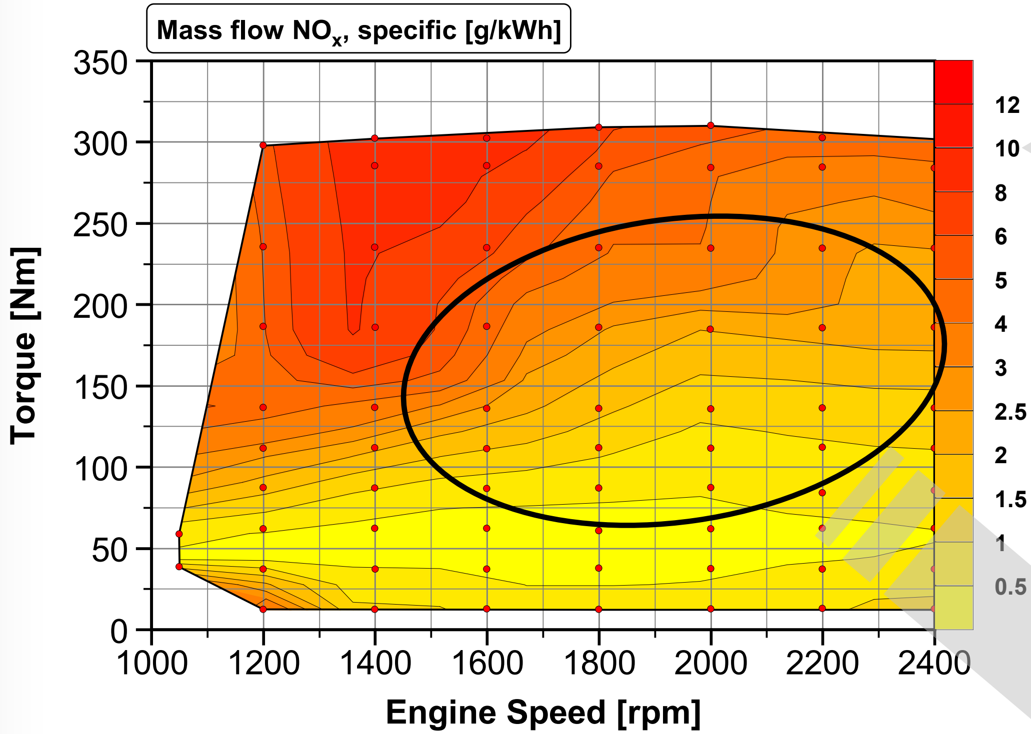
- Variable intake valve lift
- Exhaust cam shaft with cam phaser



How can T2B2 emission targets be achieved?
Engine out emission reduction measures

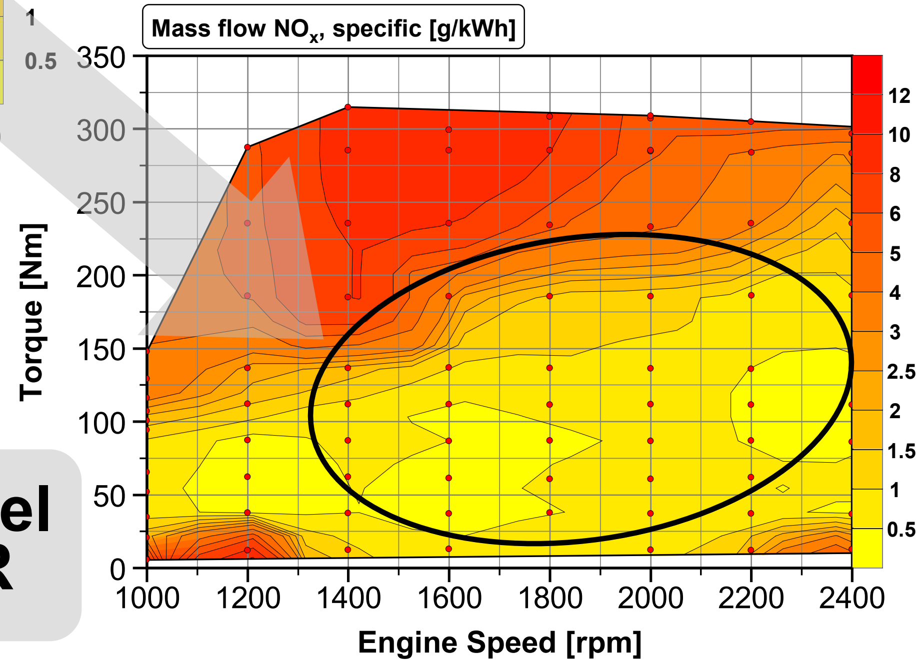


Reduction of engine out NOx emission by LP EGR
Engine out emission reduction measures



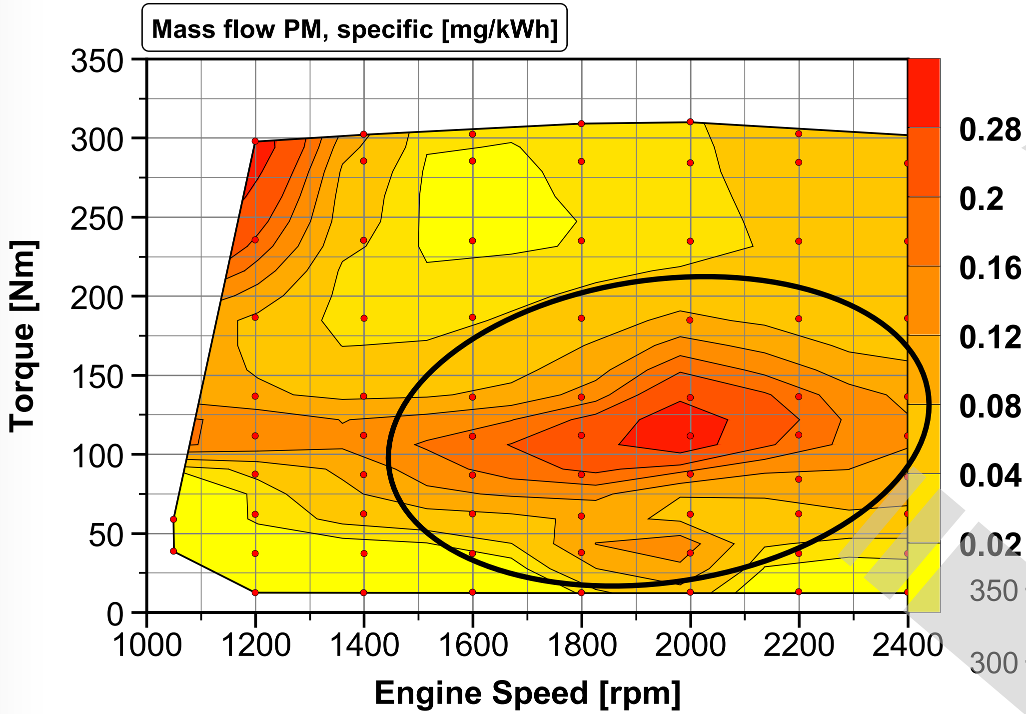
Optimized HP EGR

Optimized HP LP EGR



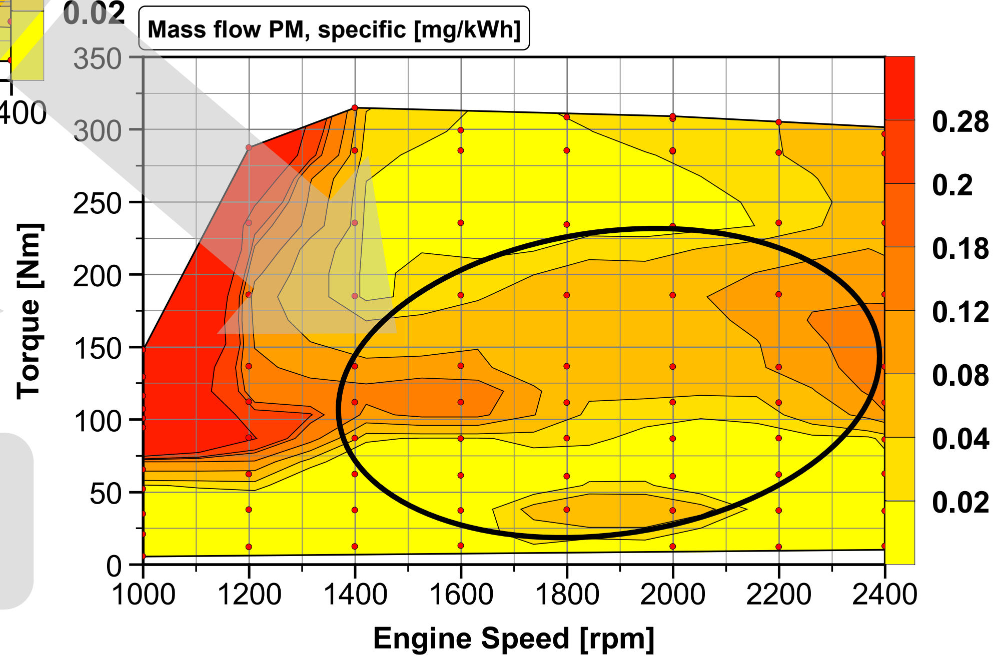
Significantly decrease NOx level with additional use of LP EGR

Reduction of engine out PM emission by LP EGR
Engine out emission reduction measures



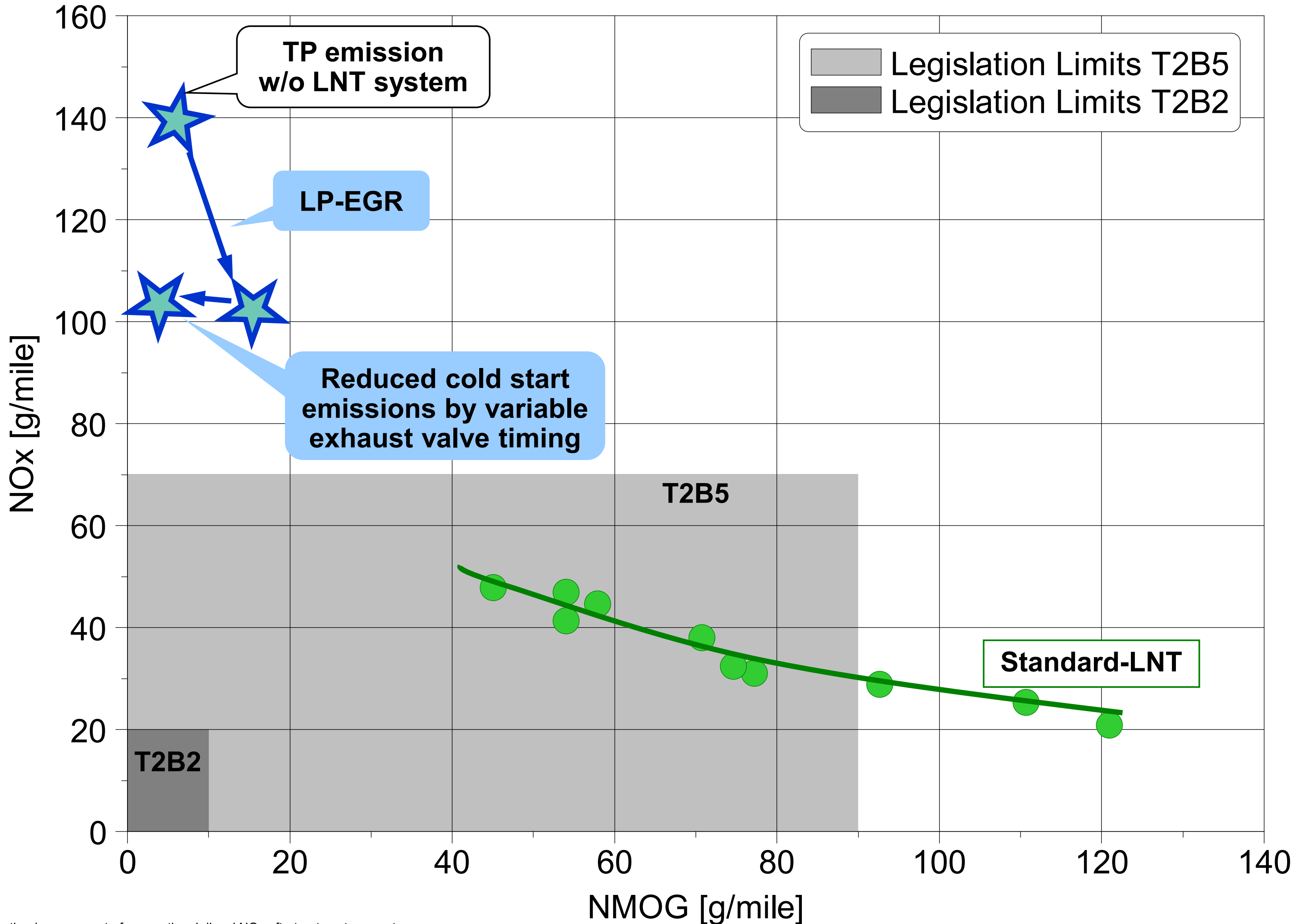
Optimized HP EGR

Optimized HP LP EGR



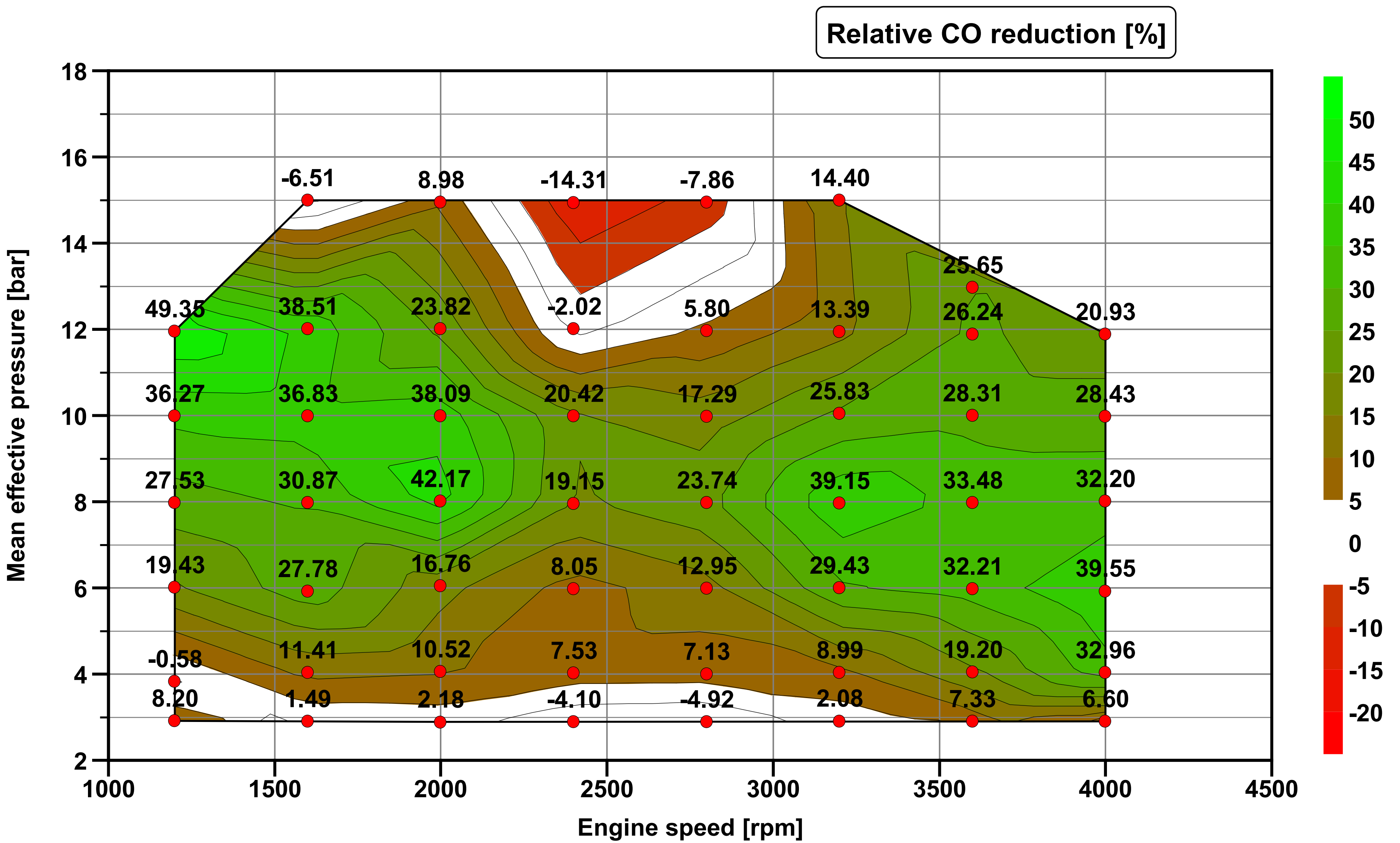
At the same time further reduce overall PM level

How can T2B2 emission targets be achieved?
Engine out emission reduction measures



Improvement of HC / CO by swirl optimization using Variable valve lift in combination with swirl chamfer

Relative change in CO emissions using higher swirl level by variable intake valve lift



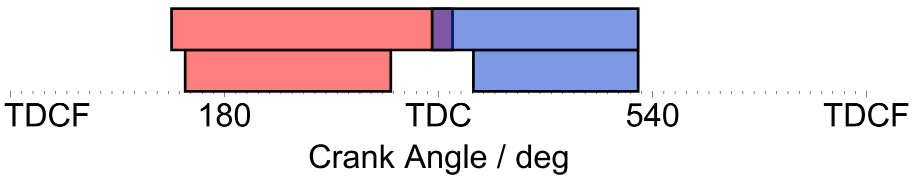
Improvement of HC / CO by swirl optimization using Internal EGR via variable valve train

HECS gas exchange concept:

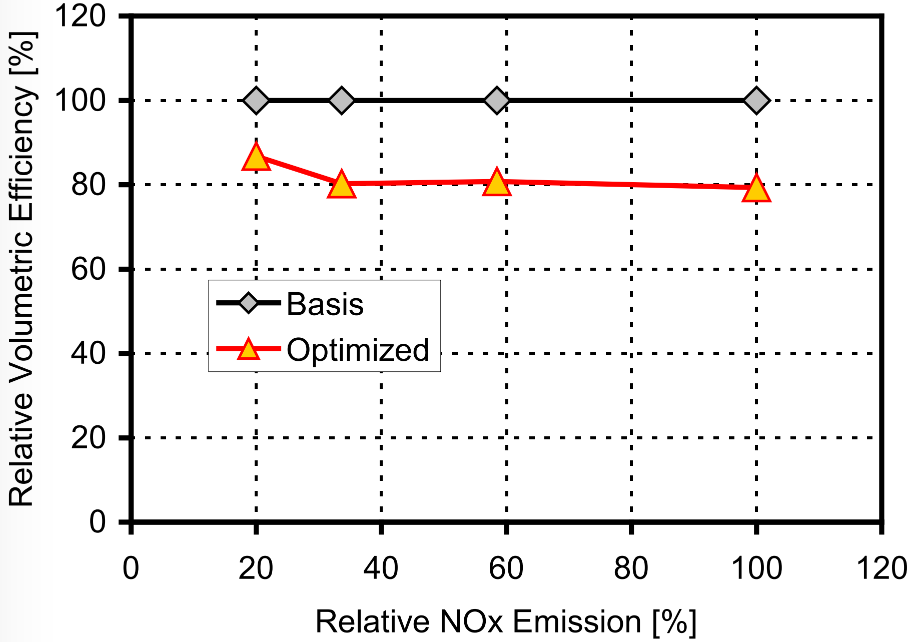
- Dethrottled cylinder head
- Variable intake valve lift
- Swirl chamfer for optimized charge motion
- Variable exhaust valve timing

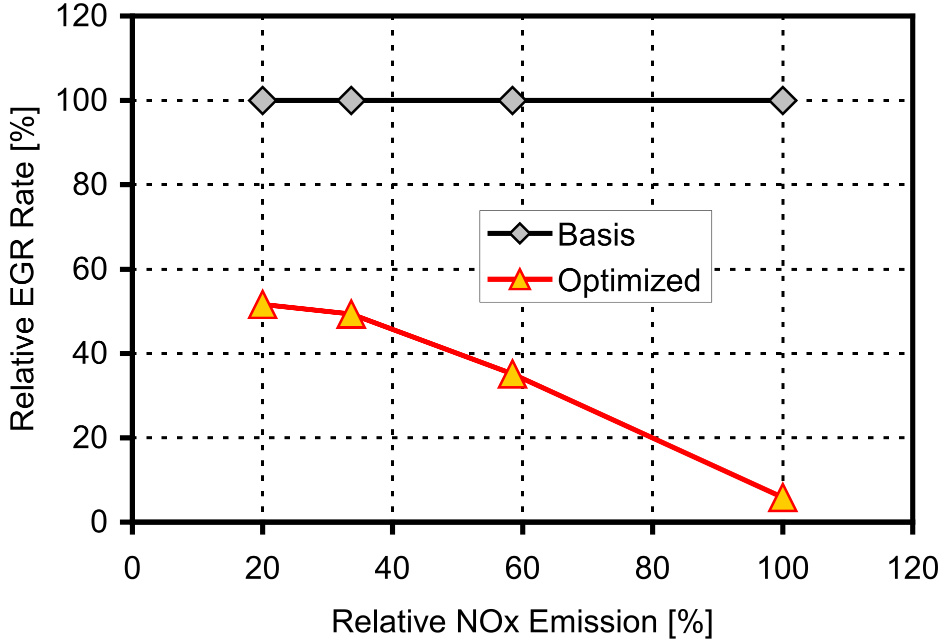
Additionally

- Variable intake valve timing
- Full variable exhaust valve

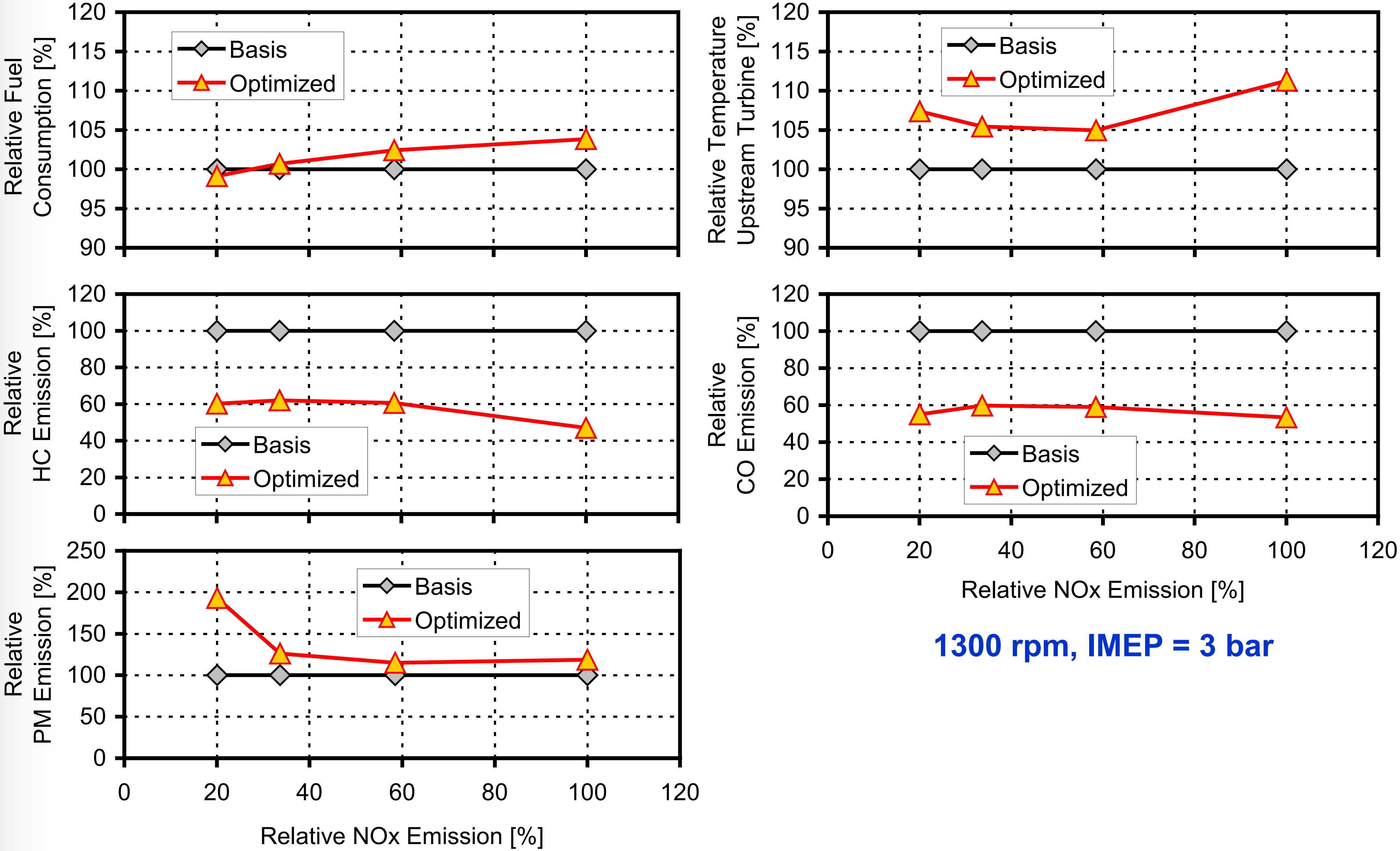


1300 rpm, IMEP = 3 bar





Improvement of HC / CO by swirl optimization using Internal EGR via variable valve train



1300 rpm, IMEP = 3 bar

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- **Improvement potential of LNT aftertreatment**
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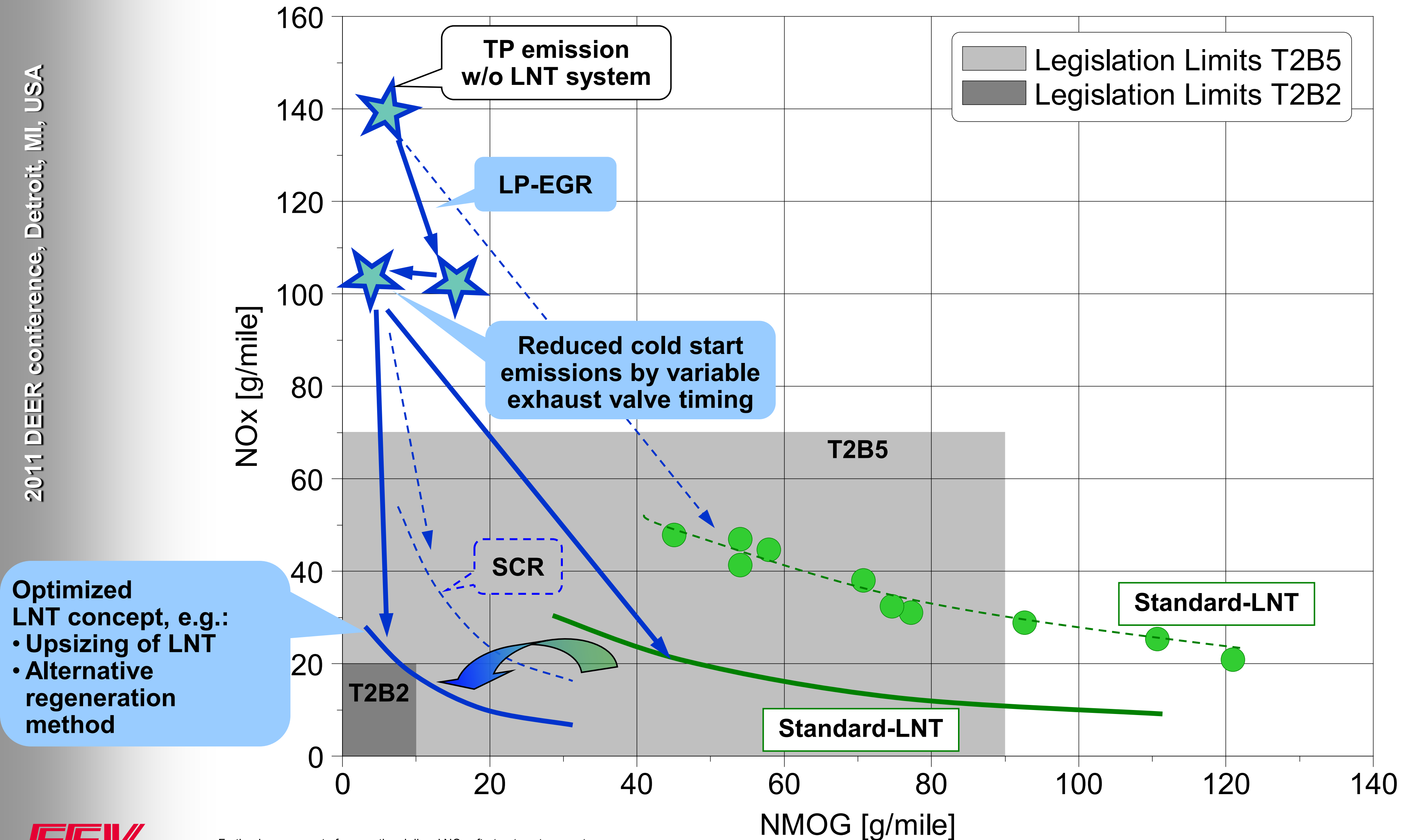
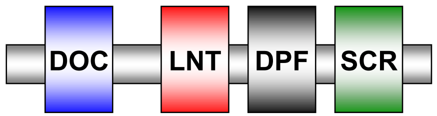
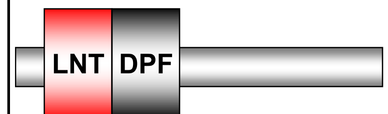
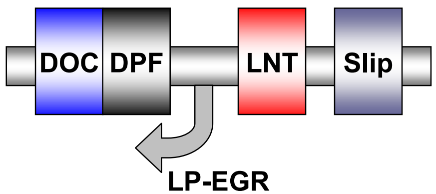
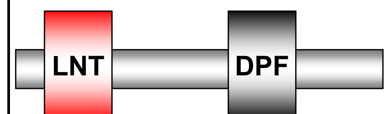
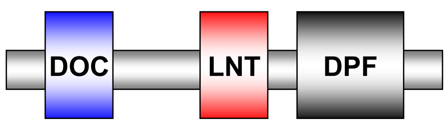
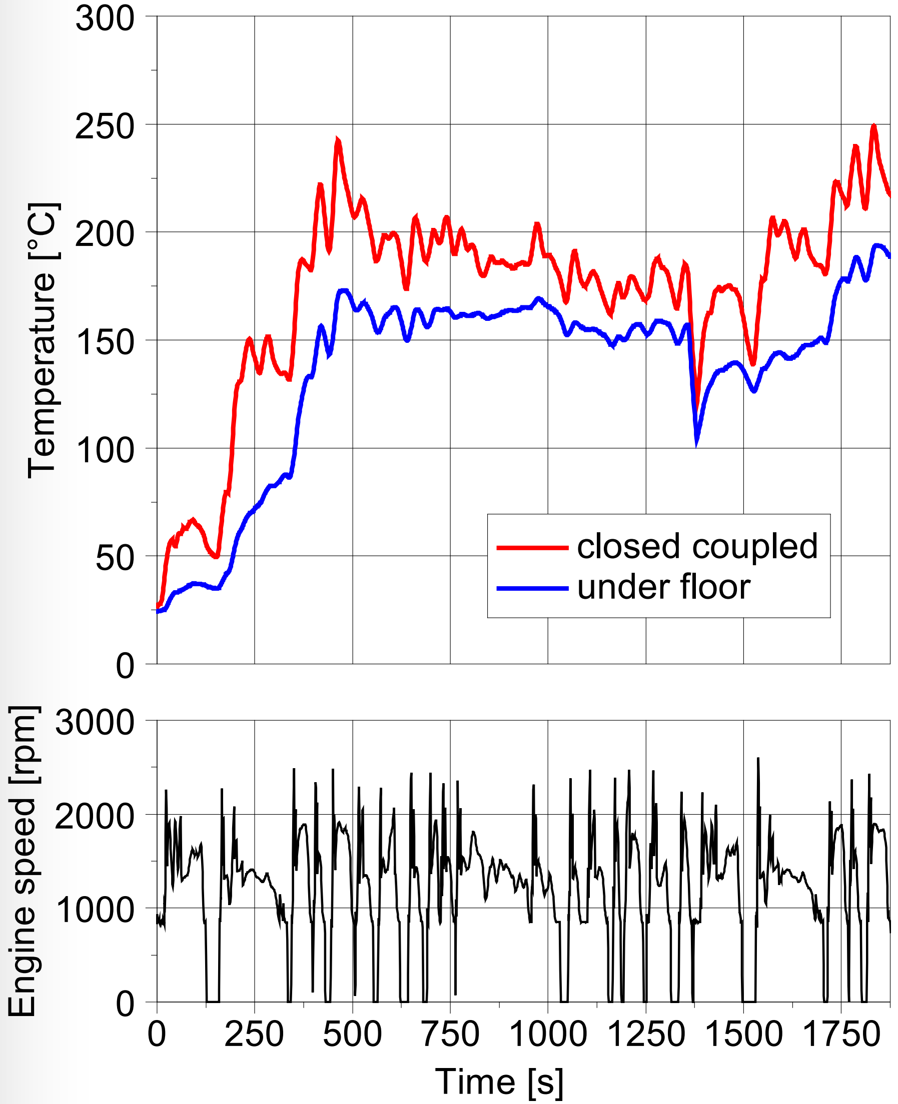
How can T2B2 emission targets be achieved? Aftertreatment measures

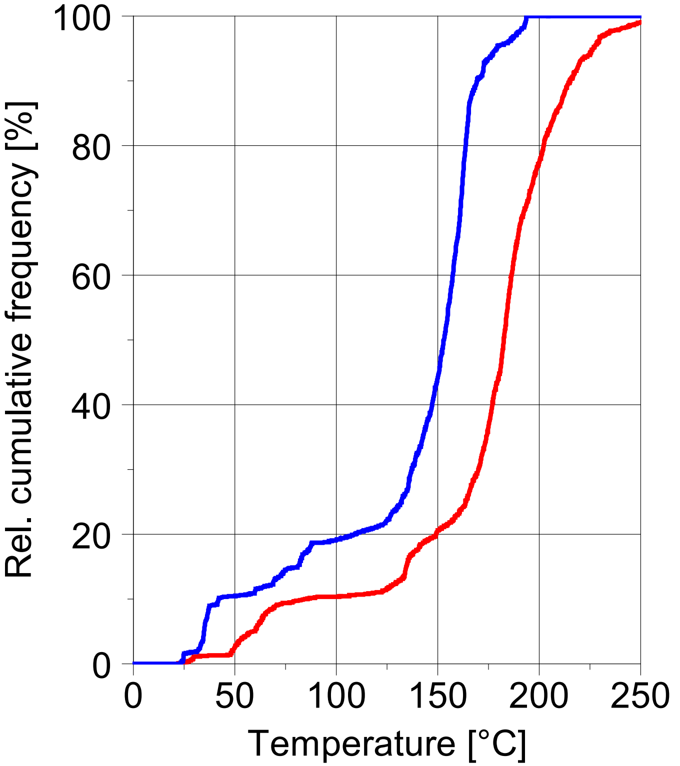


Aftertreatment measures targeting SULEV
Current production LNT systems

US Market			EU Market		
OEM	**Standard**	**Configuration**	**OEM**	**Standard**	**Configuration**
Daimler E320 Bluetec 	T2B8	DOC-LNT-DPF-SCR 	BMW Blue Perfor-mance (3, 5, 7 series) 	EU6	LNT-DPF 
Volkswagen Jetta 	T2B5	DOC-DPF-LNT-Slip 	Renault Espace (Cleantec) 	EU5 EU6	LNT-DPF 
Cummins Dodge RAM 	T2B5	DOC-LNT-DPF 			

FTP cycle temperature distribution
Advanced mid size passenger car





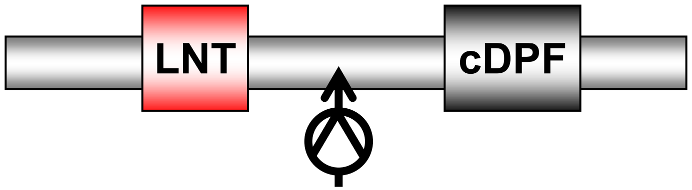
- IWC = 1590 kg w/ minimized vehicle drag forces
- Optimized engine friction, Start-Stop, calibration optimized for low BSFC

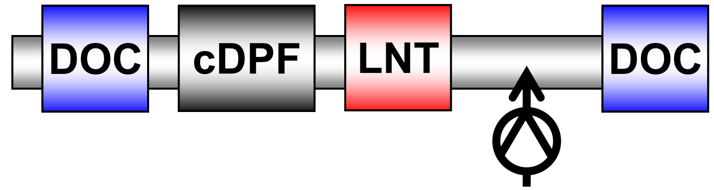
➔ Significantly decreased temperature level in future. Closed-coupled LNT position becomes favorable

Aftertreatment measures targeting SULEV
Alternate DeNOx strategies to minimize HC emissions

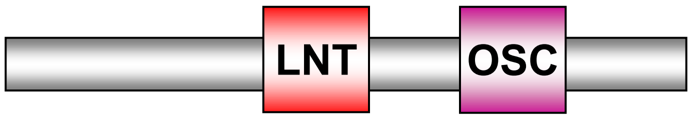
Approaches for oxidizing HC-slip during DeNOx:

- Oxygen supply downstream LNT by secondary air injector

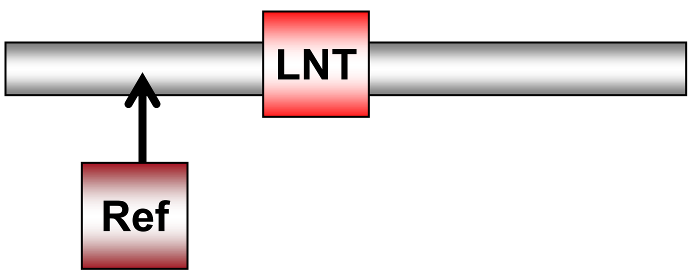




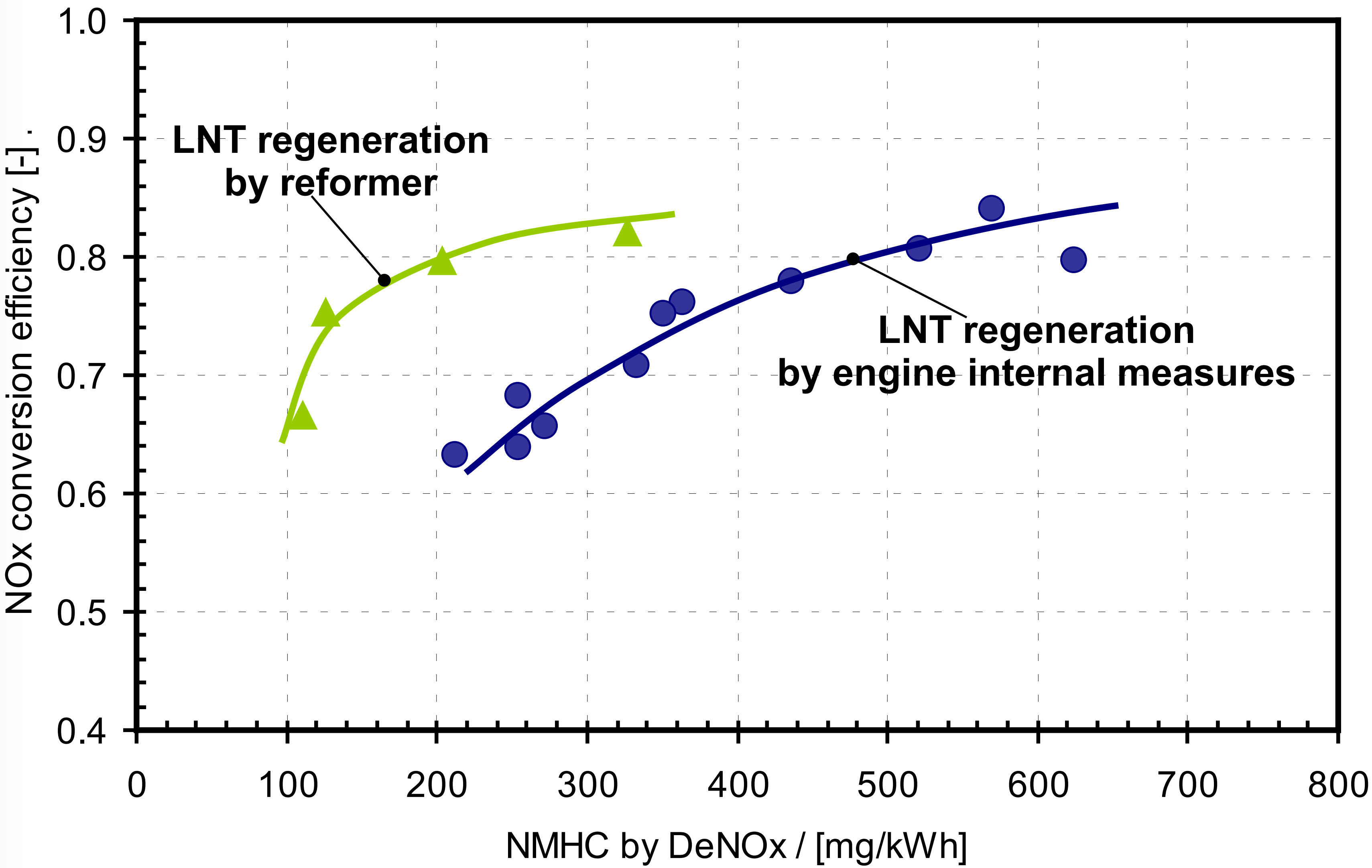
- Oxygen supply downstream LNT by stored oxygen on a catalyst (OSC)



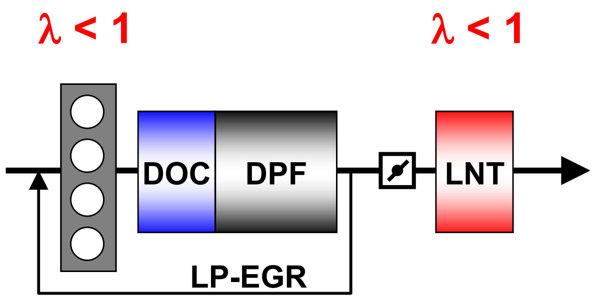
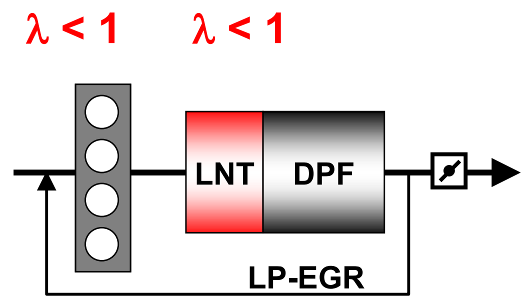
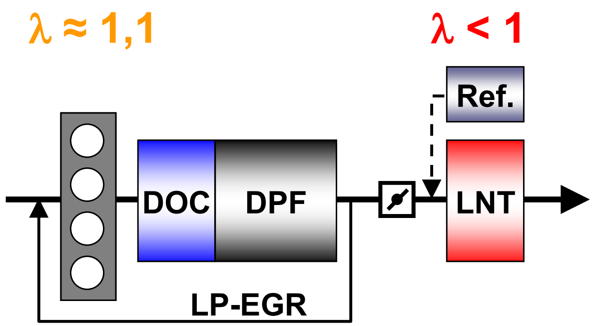
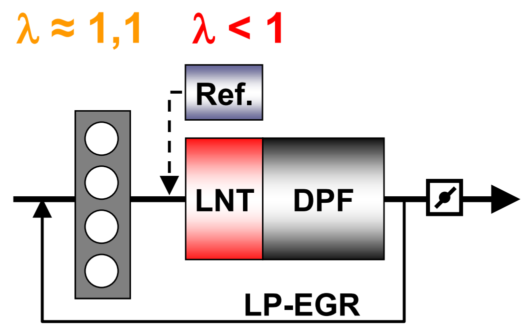
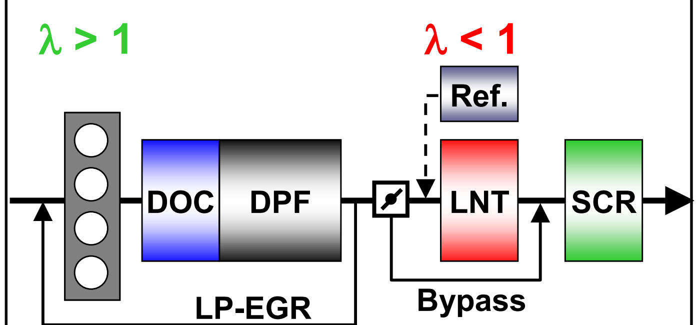
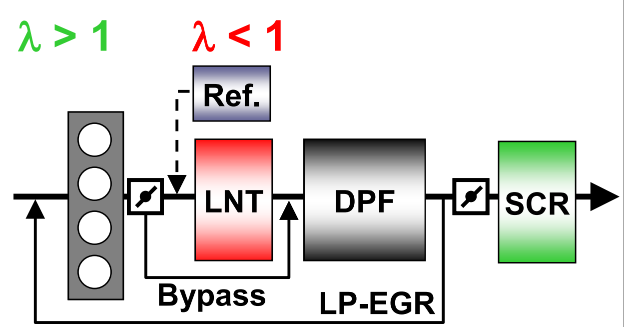
- Reductant without HC



Aftertreatment measures targeting SULEV
Merits of DeNOx strategies



Aftertreatment measures targeting SULEV
Possible LNT architectures and DeNOx strategies

	LNT underfloor	LNT closed coupled	Comment
LNT regeneration by engine enrichment only			**Need for engine enrichment**
LNT regeneration by reformer supported by engine throttling			**Need for engine throttling**
LNT regeneration by reformer only			**Engine independent regeneration possible**

Aftertreatment measures targeting SULEV
LNT aftertreatment challenges to overcome

General challenges of future Diesel exhaust aftertreatment

- Decreasing temperature levels
  - ➔ later catalyst light-off, lower conversion rates
- High engine out HC/CO concentration
  - ➔ risk of N_2O formation during catalyst light-off

Challenges of LNT operation inside LP-EGR loop

- Increase of space velocity (SV)
  - ➔ critical for NOx adsorption, especially at low temperature
- Increase of NOx mass flow (at constant concentration)
  - ➔ increased effort to regenerate LNT (higher fuel consumption for NOx reduction)
- Increase of HC/CO mass flow (at constant concentration)
  - ➔ higher risk of N_2O formation during catalyst light-off temperature

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Review : Engine and aftertreatment pathways presented to address SULEV emissions

		Aftertreatment				Engine	
		UF-LNT	CC-LNT	Second brick	Reformer	Exhaust Cam Phaser	LP-EGR
NOx conversion	Low temperature	-	+	(+)	++	(+)	(-) (increase of SV for CC-LNT)
	High temperature	+	-	+	No impact	No impact	+
	DPF regeneration	-	-	No impact	No impact	+	+
	Slip by high SV	O	-	(+)	No impact	(+)	(-) (increase of SV for CC-LNT)
HC-conversion	Slip before LO	-	O	No impact	No impact	+	(-) (increase of SV for CC-LNT)
	Slip by DeNOx	O	-	(+)	++	(+)	O
Cost		O	+	-	(-)	(-)	(-)

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Pathways to meet SULEV
Summary

- **LNT aftertreatment measures to address SULEV**
  - Application specific layout configuration help tradeoff NOx and THC
  - Additional LNT bricks and volume help address the conversion efficiencies
  - DeNOx efficiency vs. THC slip handling is crucial with engine only measures
  - DeNOx by secondary sources improve efficiency and handling while minimizing the THC slip. Cost and packaging to be studied
- **Engine out near term measures helping LNT to address SULEV**
  - LP EGR in low speed and load conditions significantly minimize NOx while improving overall efficiency
  - Application specific LP vs. HP EGR distribution handling is crucial for optimal tradeoff between emissions and efficiency
  - VVT optimization to address load dependent emissions greatly benefit aftertreatment efficiencies
  - Advanced boosting system help improve low end performance and overall BSFC while supporting the LP and HP EGR handling

Through strategically harnessing advanced engine and aftertreatment measures specific to the application the light-duty diesel engine shows significant potential in meeting SULEV

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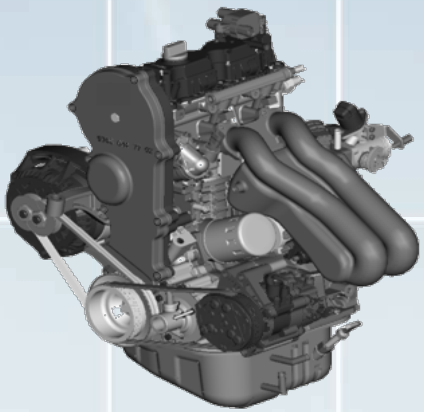
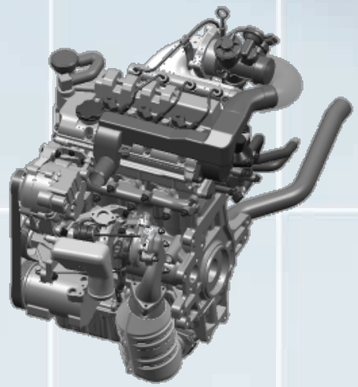
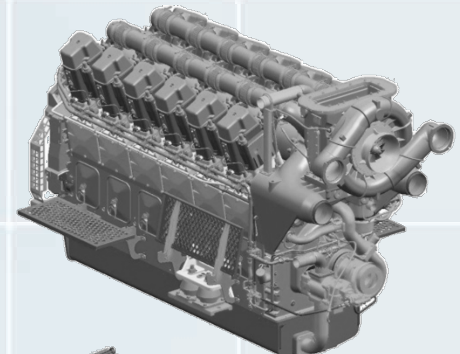
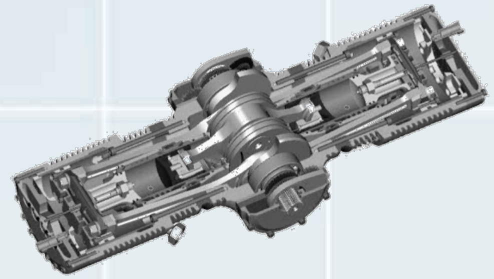
Thank You









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