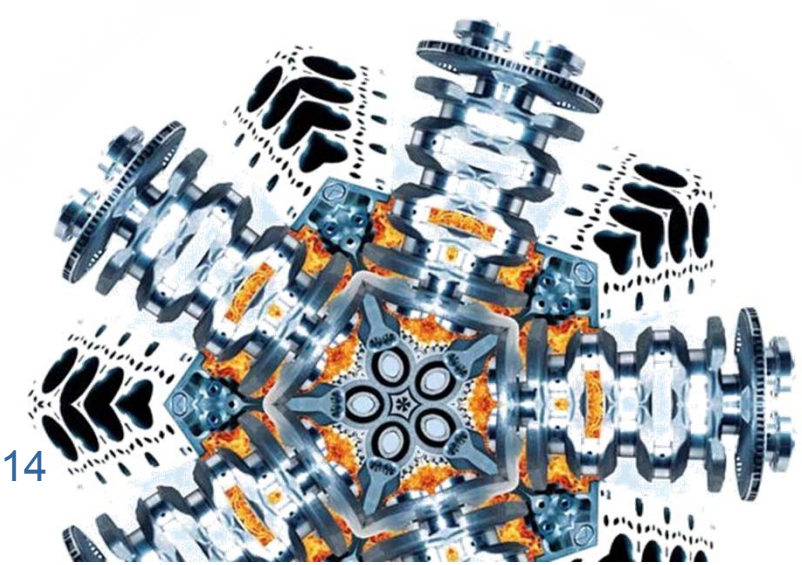
Niedrigster Verbrauch und höchste Leistung: ein Widerspruch? Ausblick auf die Zukunft des Ottomotors

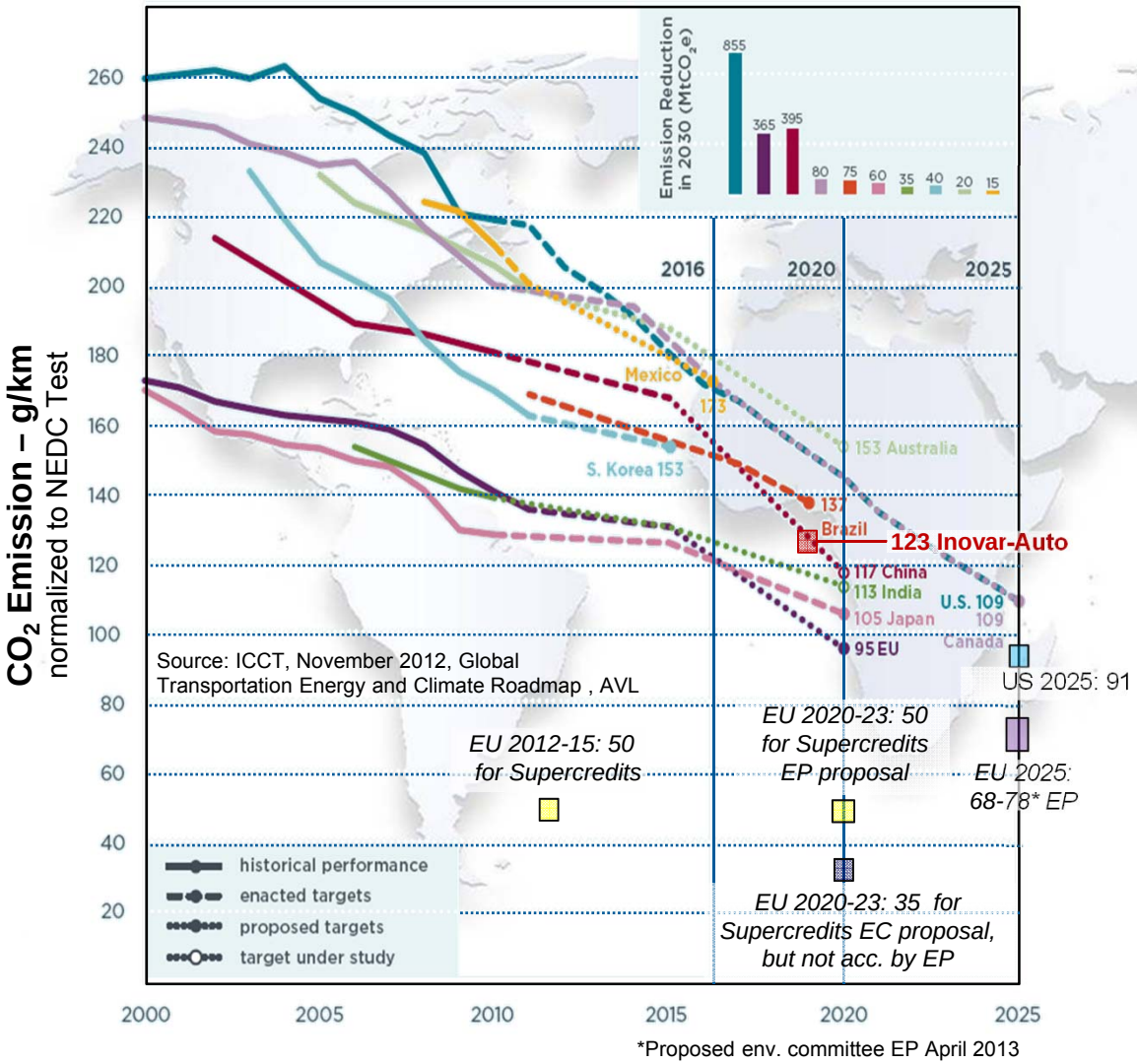
Lowest Consumption and Highest Performance – a Contradiction? Outlook on the Future of the Gasoline Engine

P. Kapus
Leiter Entwicklung Ottomotoren und Konzeptfahrzeuge
AVL List GmbH, Graz

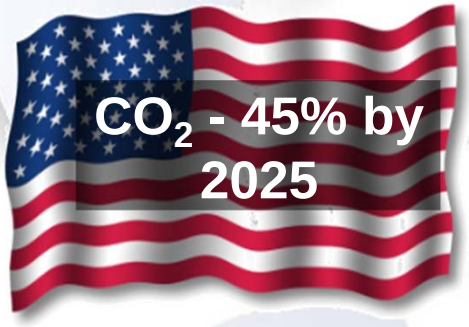


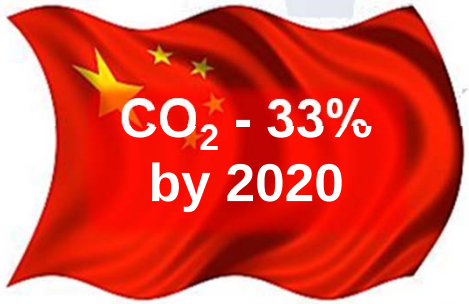
Vortrag an der FH Joanneum Graz, 15. Oktober 2014

CO_2 / Fuel Economy Limitations are the Major Technology Drivers

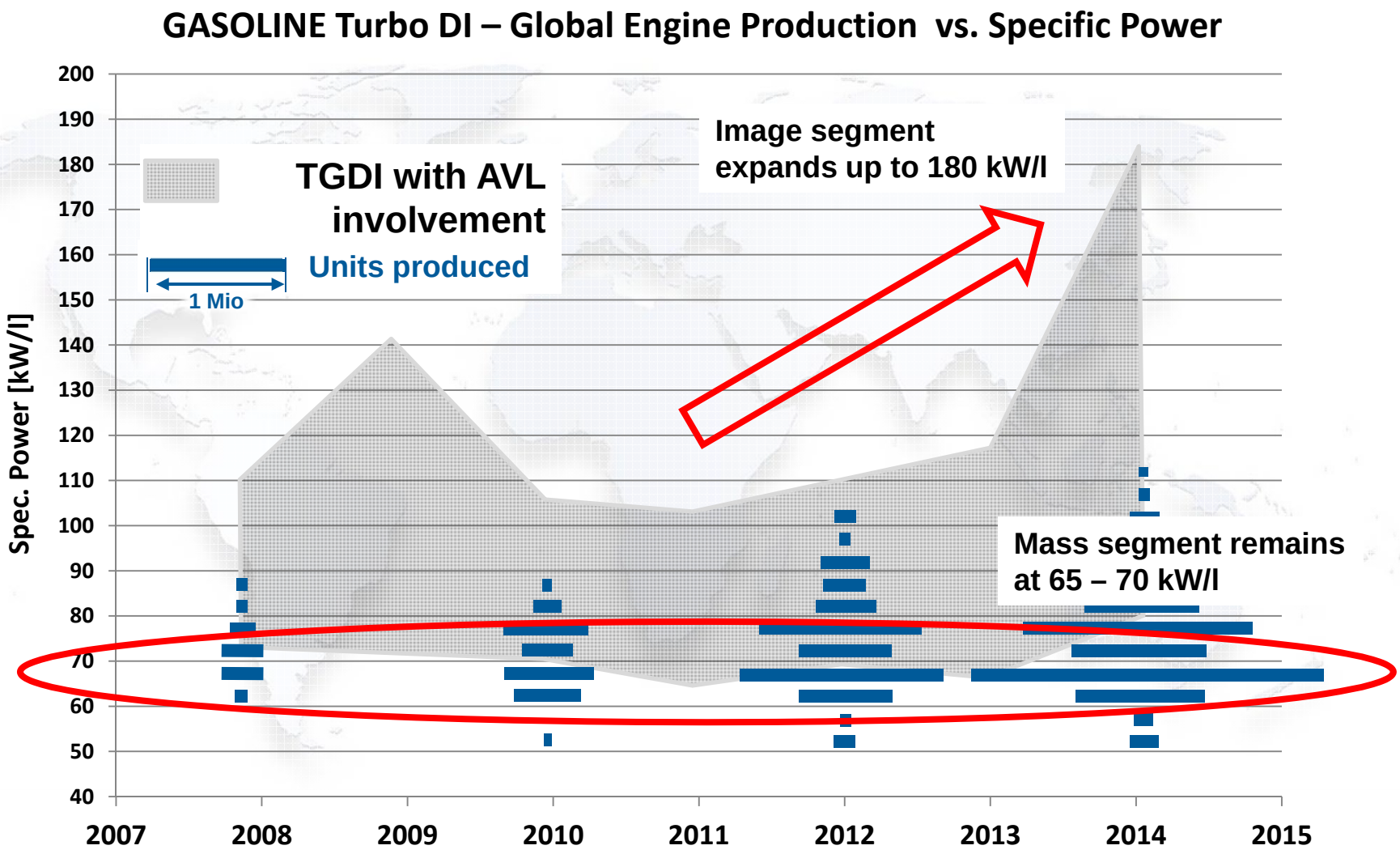


*Proposed env. committee EP April 2013





Development Trends TGDI
Spec. Power vs. Production Volumes



Fuel Consumption and Performance In Former Times…

…was also important and checked by authorities…

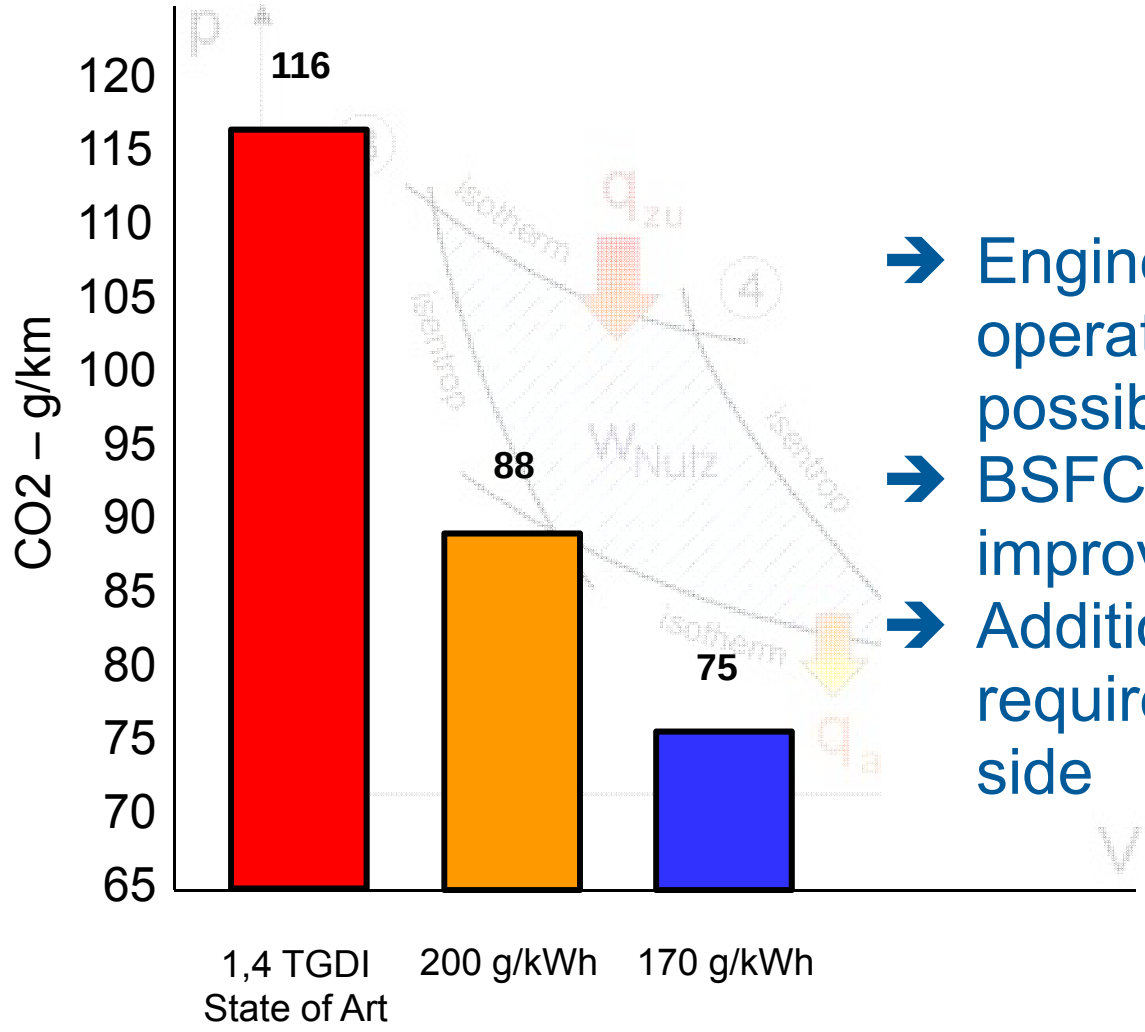
…and was optimised!

From: HÄGAR the horrible by DIK BROWNE legs the way

1991 King Features Syndicate Inc.

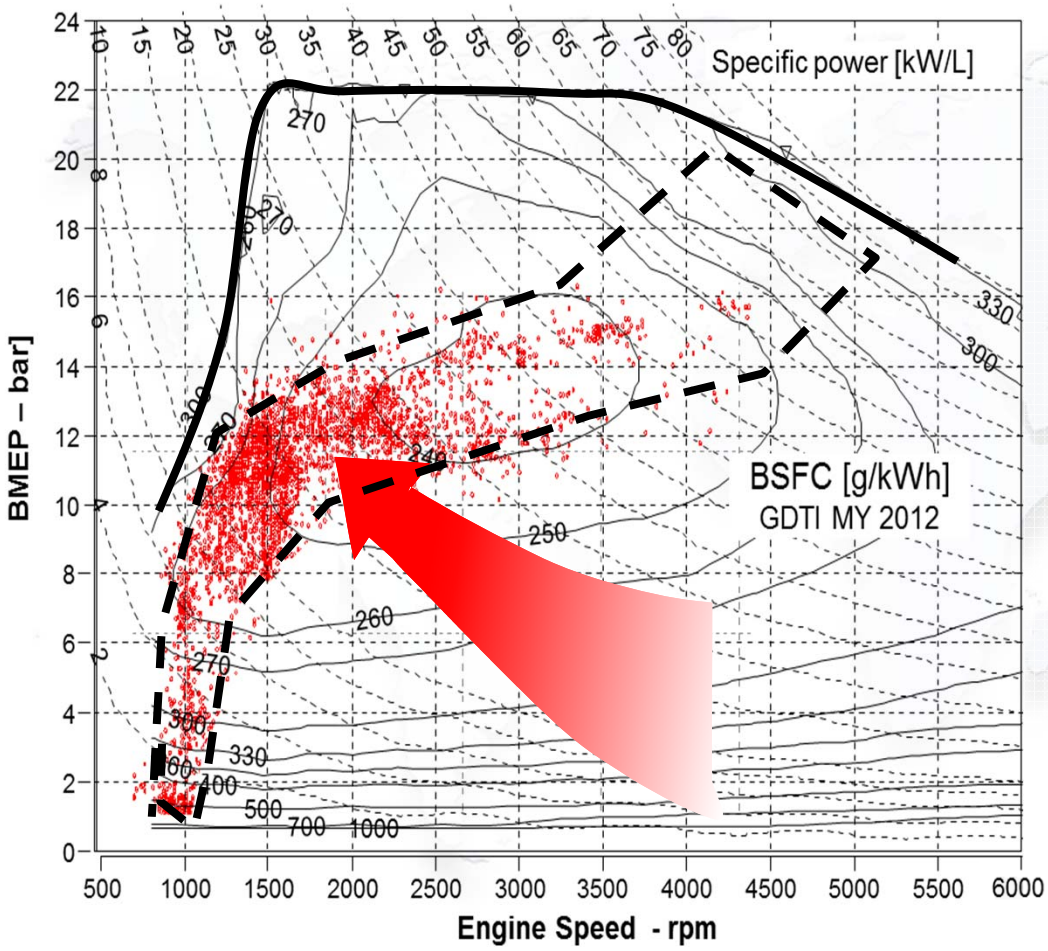
CO2 Reduction – Sedan in WLTP

Base Engine: 1.4L, 4-cyl, TGDI, Start/stop, smart alternator control



- ➔ Engine needs to be operated as close as possible to BSFC min
- ➔ BSFC min needs to be improved
- ➔ Additional measures required on the vehicle side

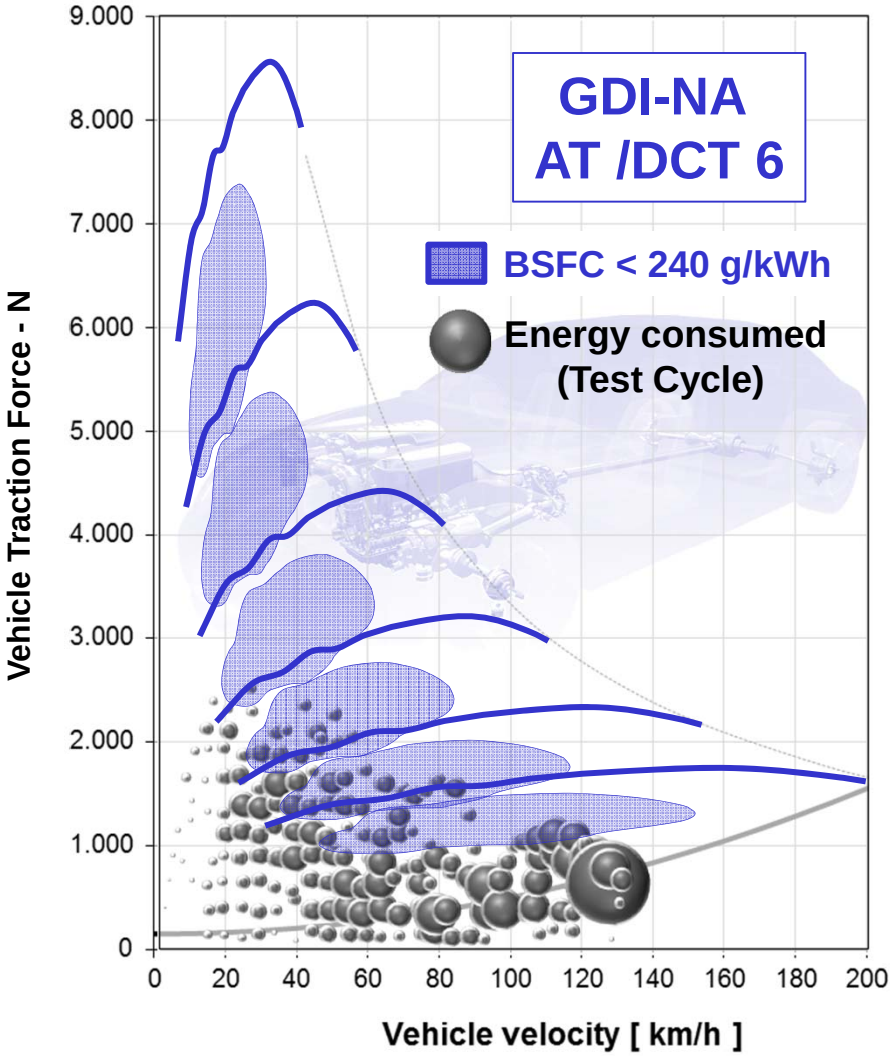
ICE Operating Range with Future Powertrain Strategies

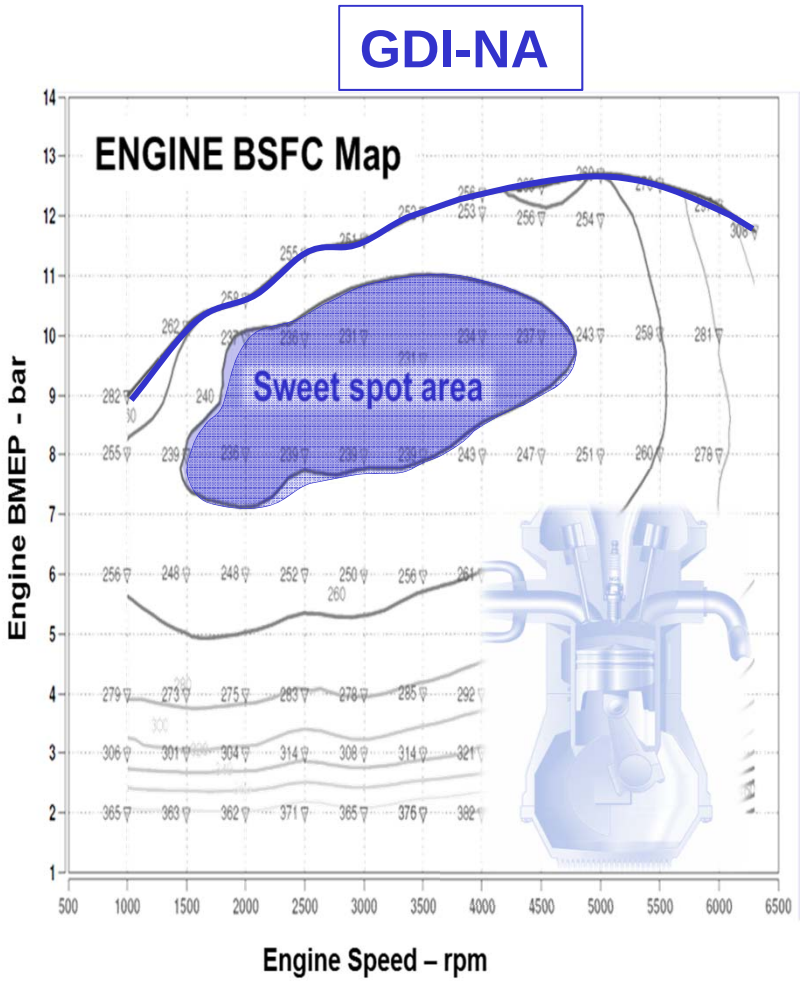


- Downsizing / Down speeding, advanced transmission strategies and Hybridization will shift main engine operation significantly towards higher engine loads

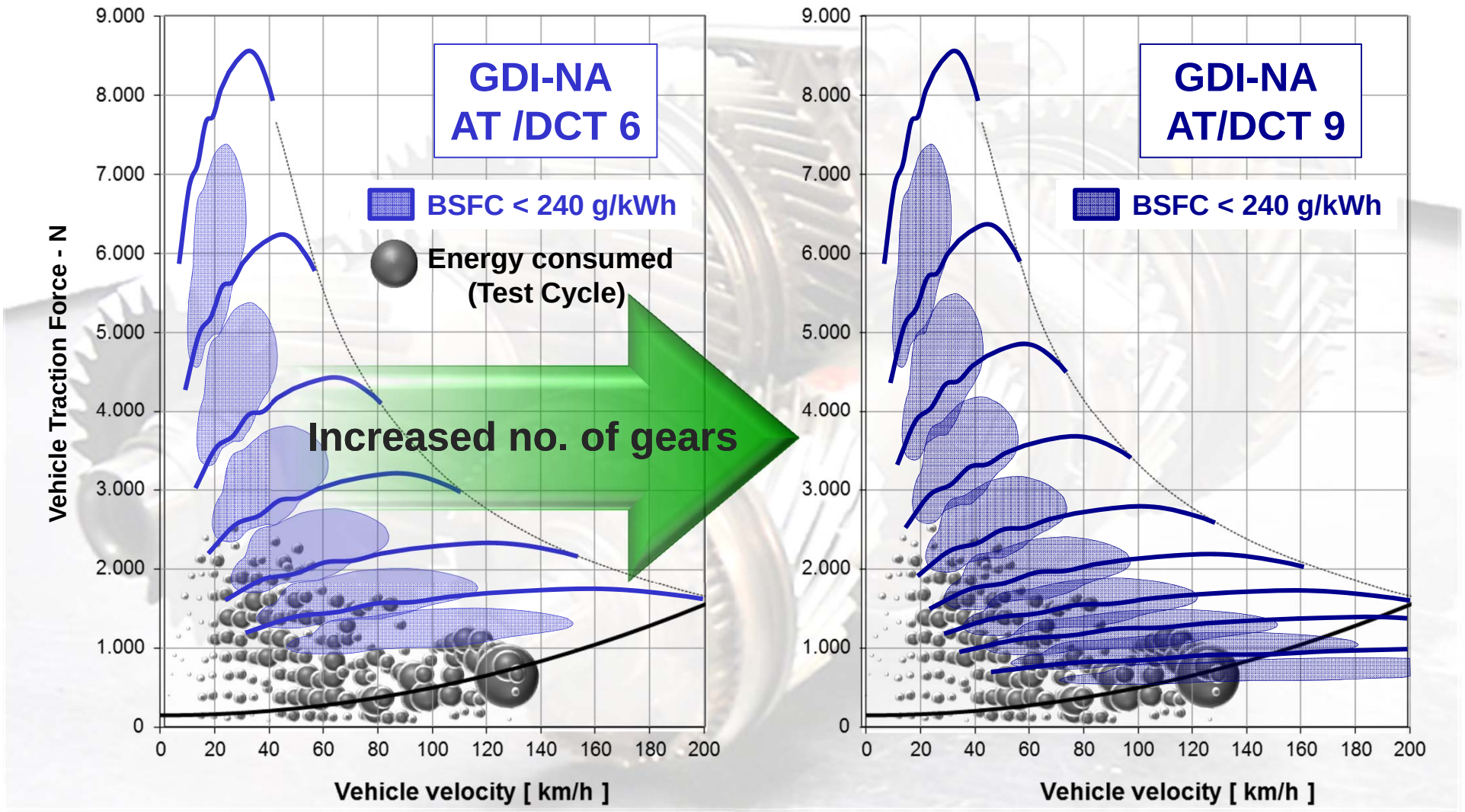
The future powertrain needs to be a sweet spot follower

Assessing the Engine from a Systems Perspective

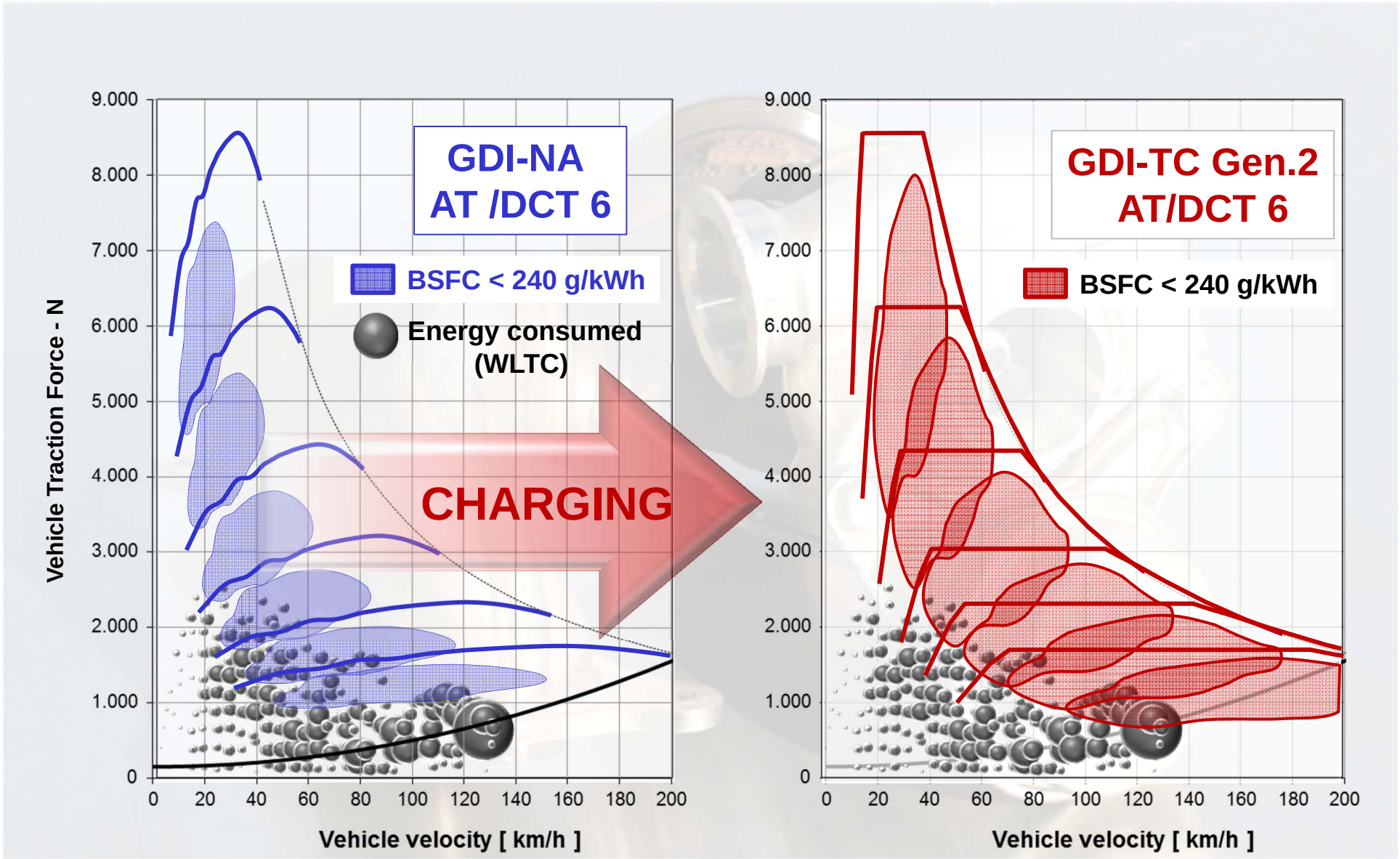




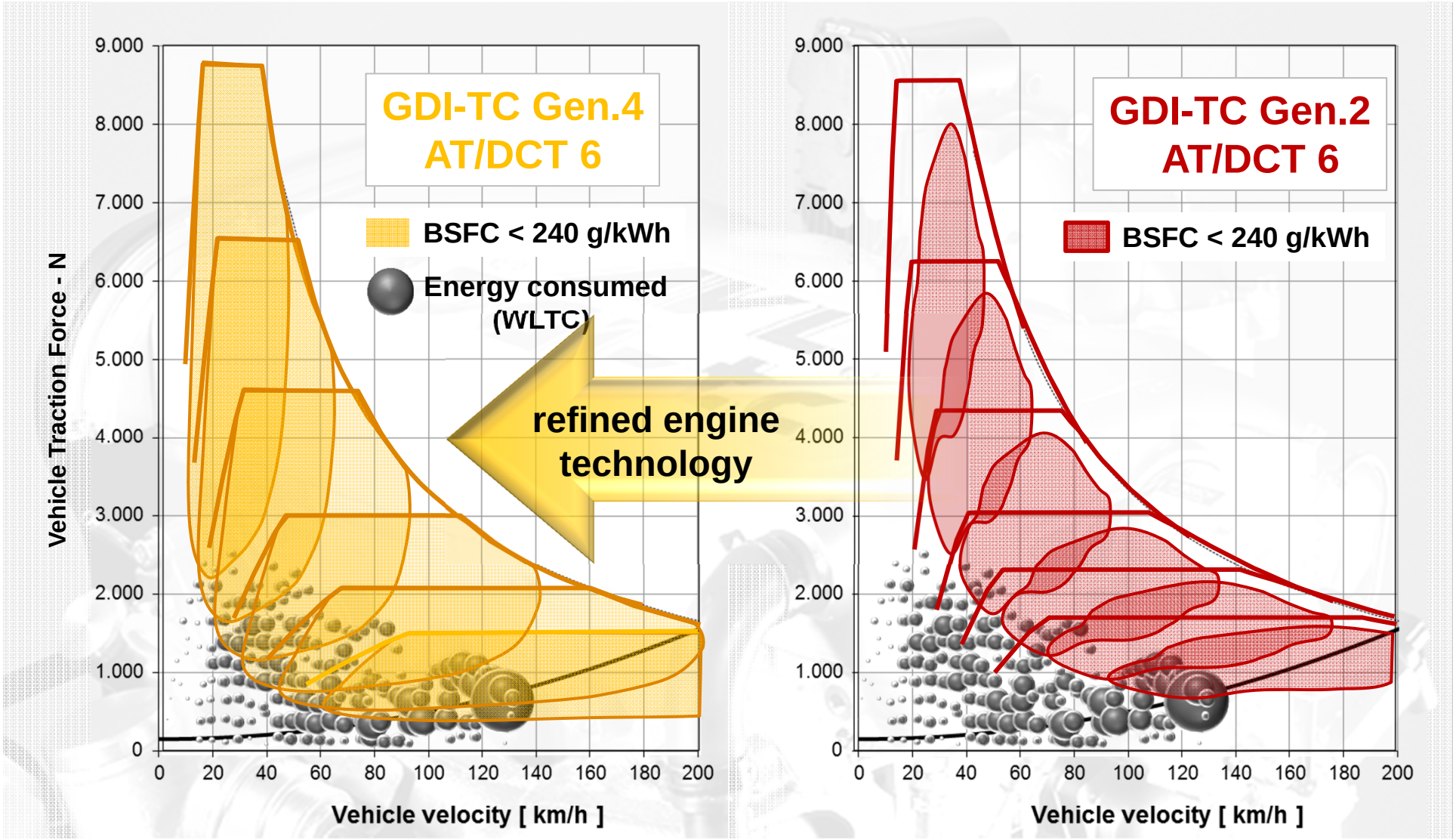
Fuel Economy Improvements by Transmission Measures



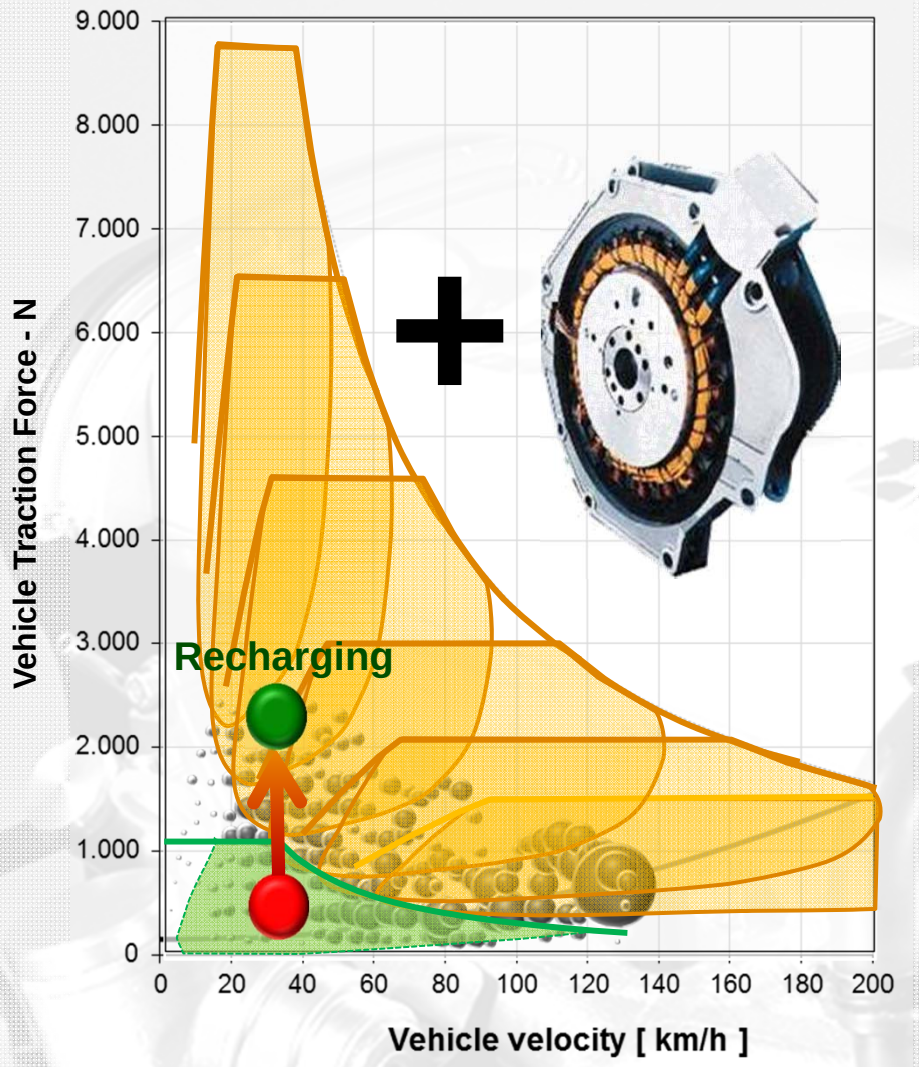
Fuel Economy Improvement with Gasoline Engines - Charging



Evolution of Turbocharged GDI

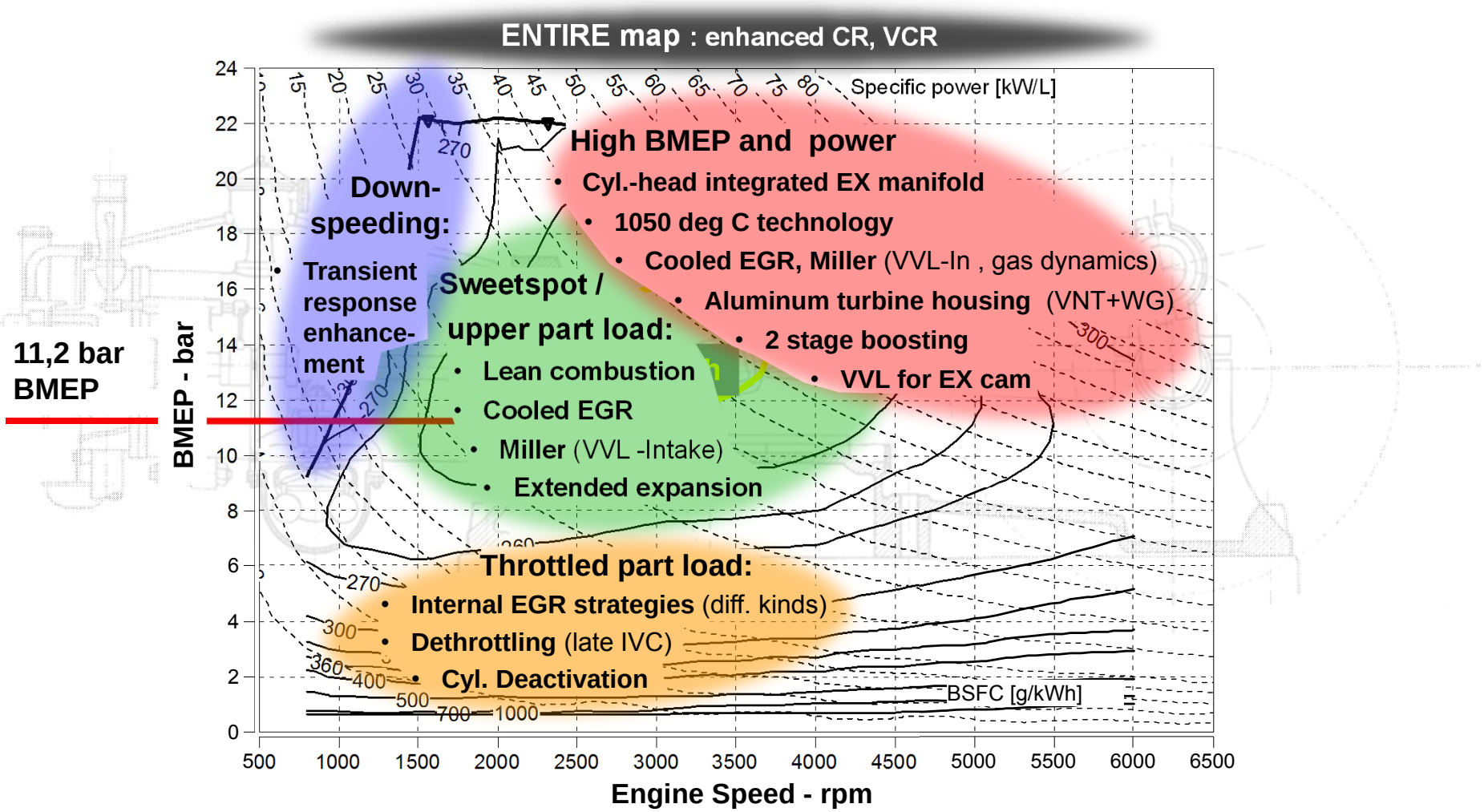


Fuel Economy Improvement by Hybridization



Hybridization allows electric driving at low power requirements where the ICE would otherwise operate inefficiently

Development Directions for Future TC GDI Engines

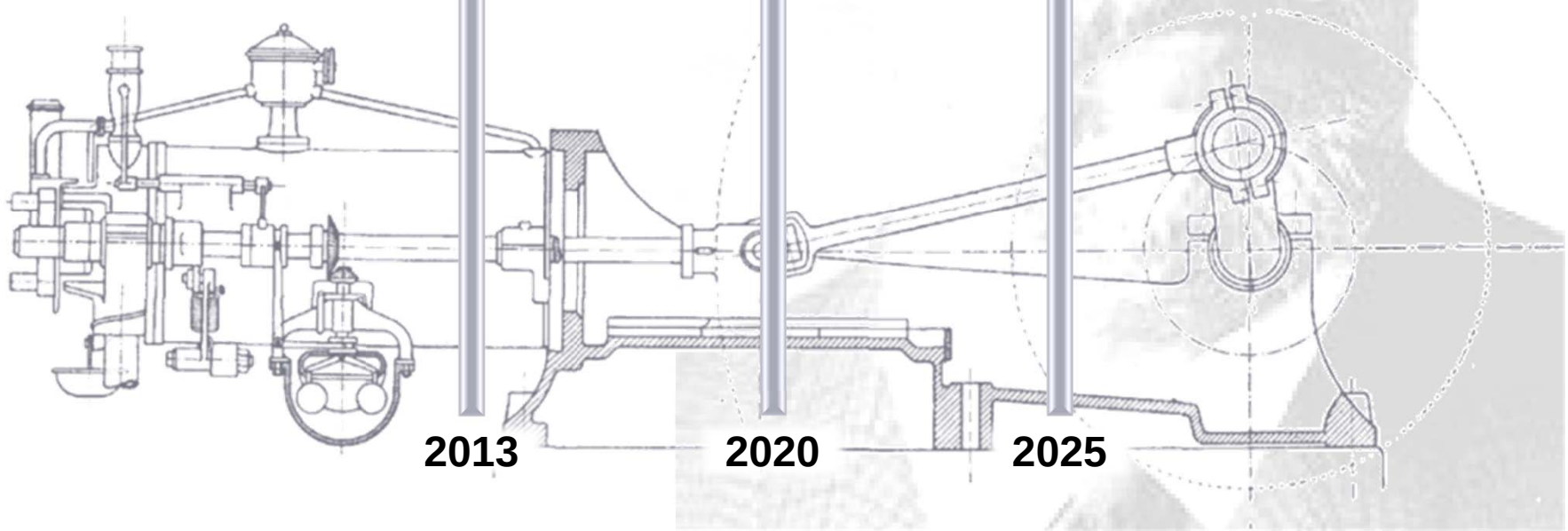


Generic Technology Roadmap Gasoline Engine

Mainstream | Premium | Niche | To be confirmed

Combustion System

Homogeneos DI (side, central) Integrated Exhaust

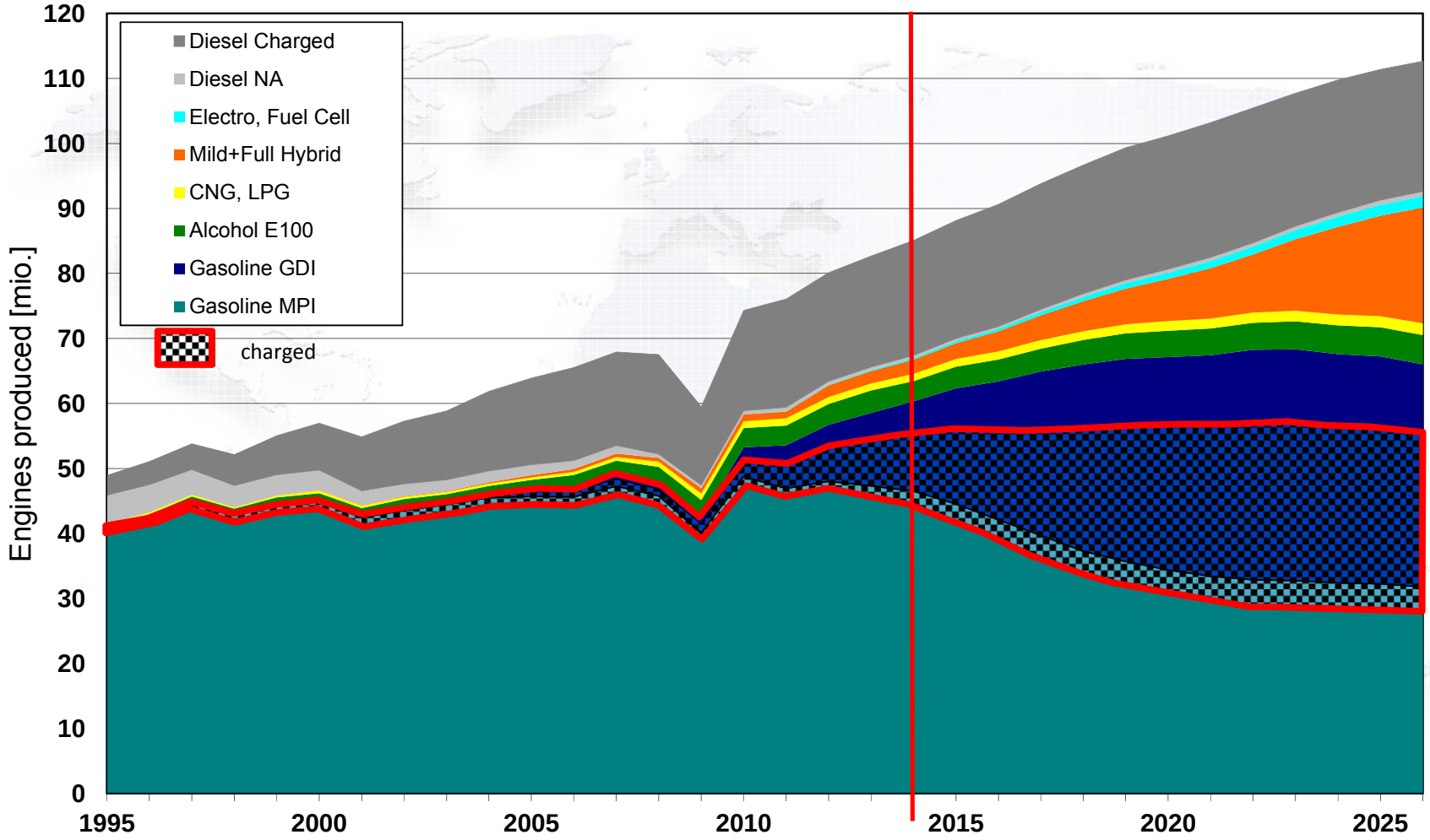


2013 2020 2025

Market Data

Global Share of Production

Source: IHS 8-2014



Gasoline Engine

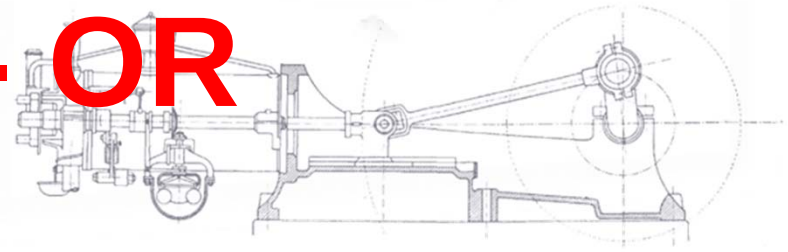
2020

0 g/KWh

0 kW/l

? when

EITHER - OR



Gasoline Engine

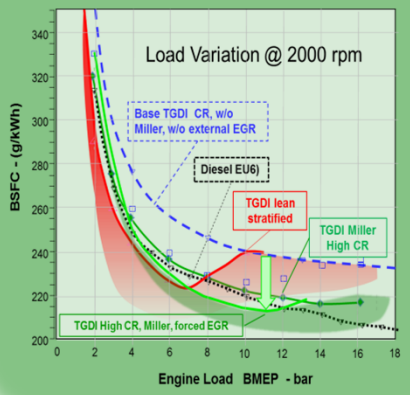
FE-Concepts

Miller+High CR+ext.EGR

$BSFC_{min}$ ➔ 200*)g/kWh

P = 65 - 80 kW /l

BMEP = 17 - 20 bar



Mainstream currently

BSFCmin 235*)g/kWh

P = 65 - 95 kW /l

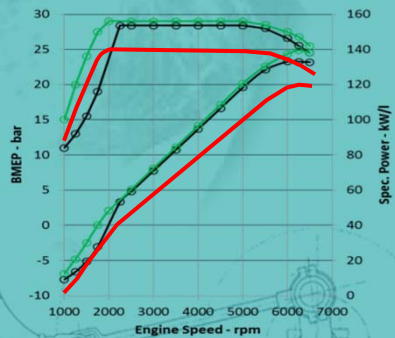
BMEP = 17 - 25 bar

“Image / Top Performance“ Concepts

$BSFC_{min}$ >230*) g/kWh

P = 110 - 180 kW /l

BMEP = 28 - 30 bar



EITHER - OR

*) … 2l displacement

Gasoline Engine

FE-Concepts

Miller+High CR+ext.EGR

$BSFC_{min}$ ➔ 200*)g/kWh

P = 65 - 80 kW /l

BMEP = 17 - 20 bar

Mainstream currently

BSFCmin 235*)g/kWh

P = 60 - 90 kW /l

BMEP = 17 - 25 bar

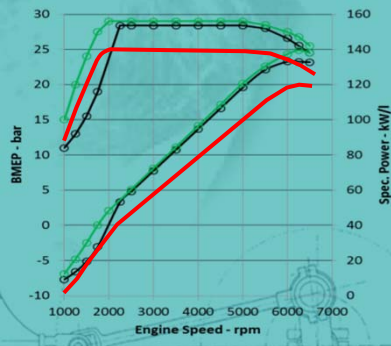
EITHER - OR

"Image / Top Performance" Concepts

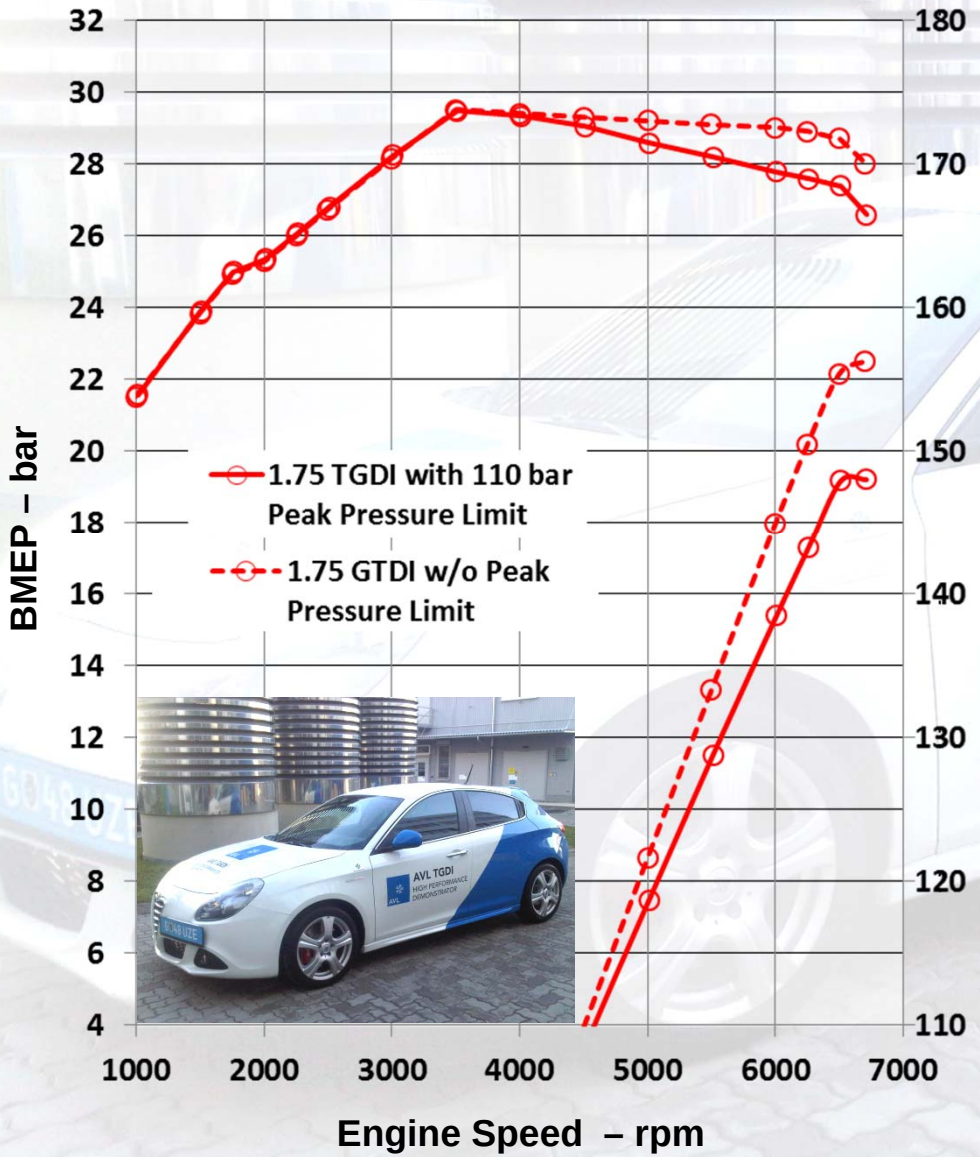
$BSFC_{min}$ >230*) g/kWh

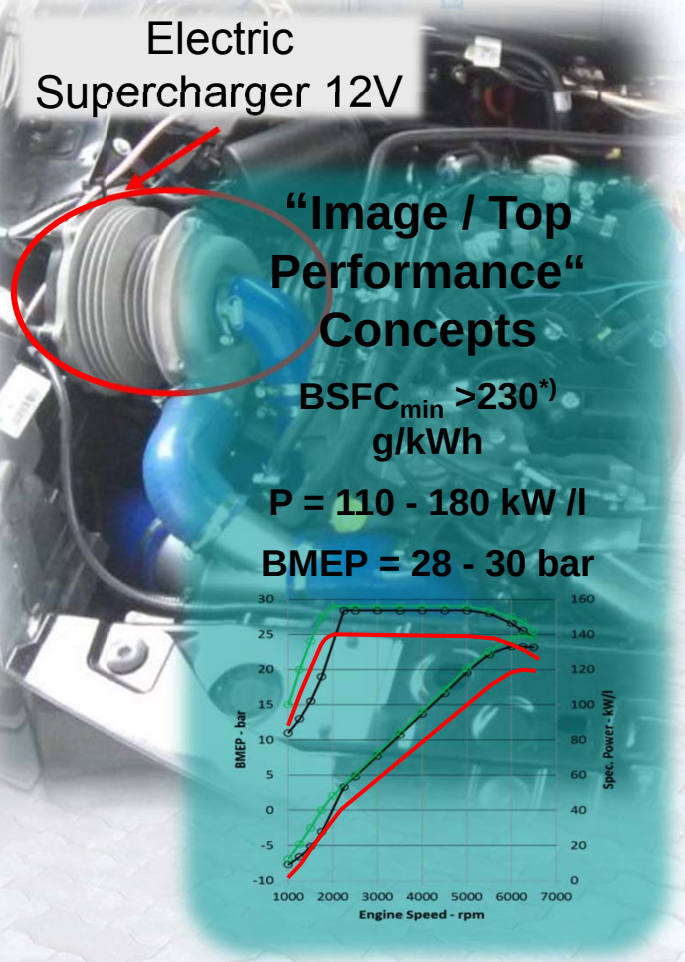
P = 110 - 180 kW /l

BMEP = 28 - 30 bar



TGDI High-Performance Concept with add. Electric Charging (12V)





Gasoline Engine

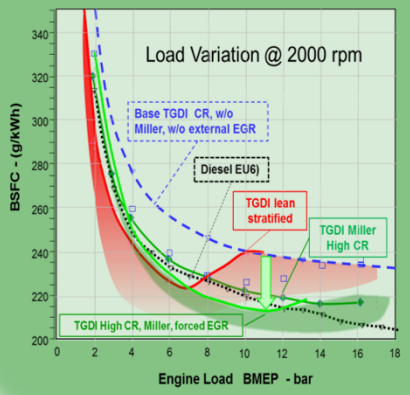
FE-Concepts

Miller+High CR+ext.EGR

$BSFC_{min}$ ➔ 200*)g/kWh

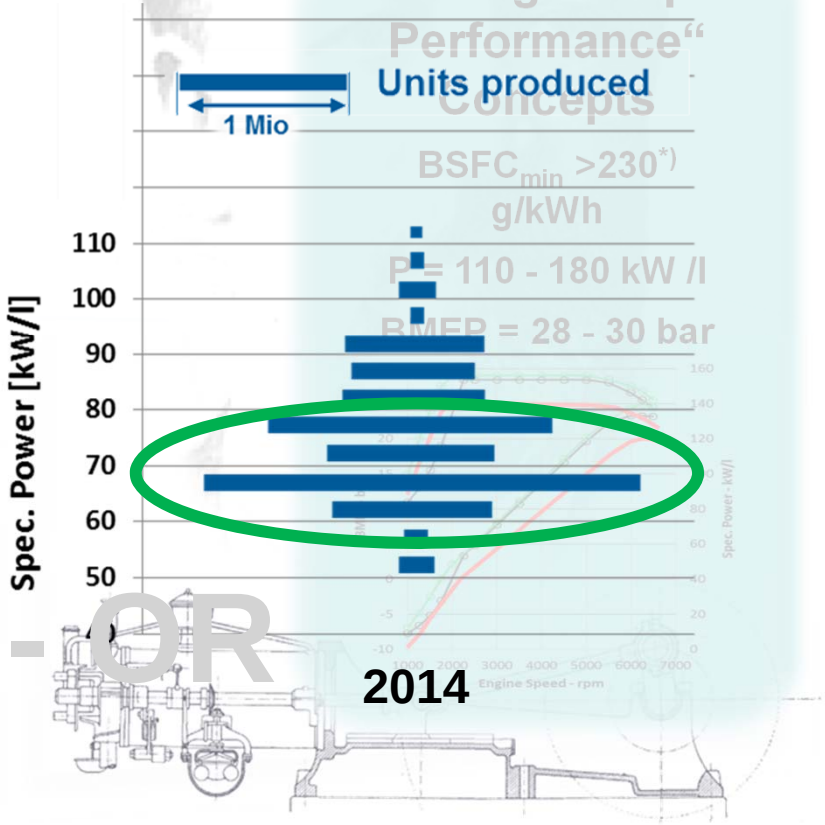
P = 65 - 80 kW /l

BMEP = 17 - 20 bar



EITHER - OR

"Image / Top Performance" Concepts



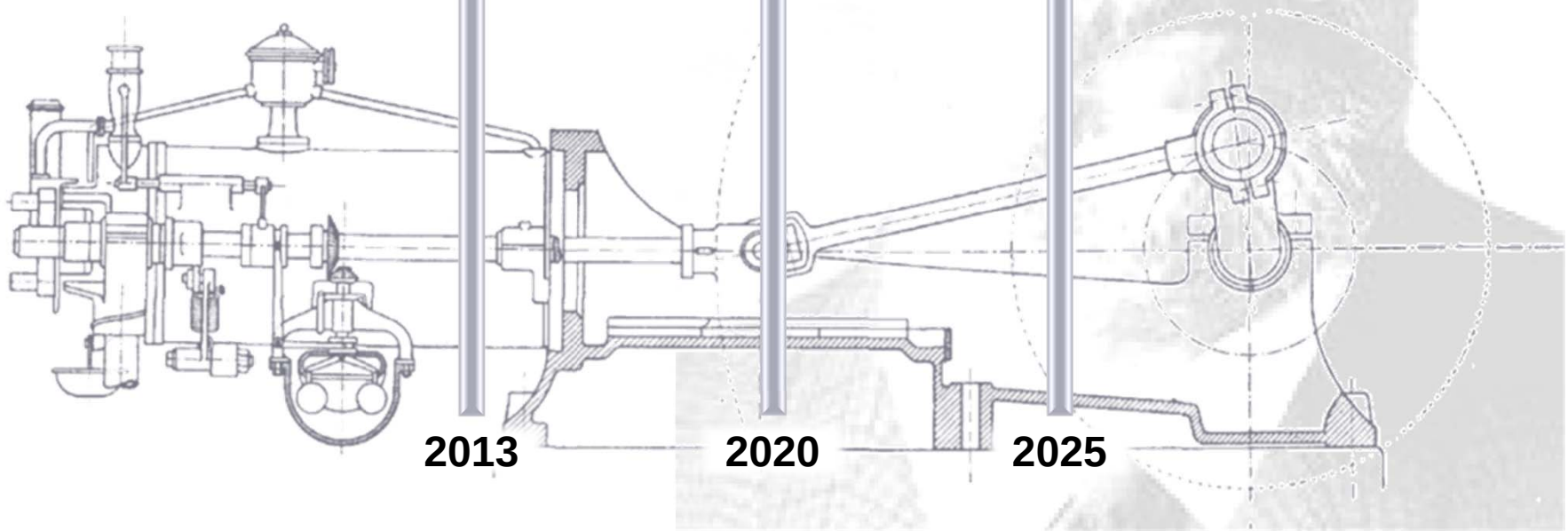
2014

Generic Technology Roadmap Gasoline Engine

Mainstream | Premium | Niche | To be confirmed

Combustion System

- Homogeneos DI (side, central) Integrated Exhaust
- CNG BiFuel → Monofuel



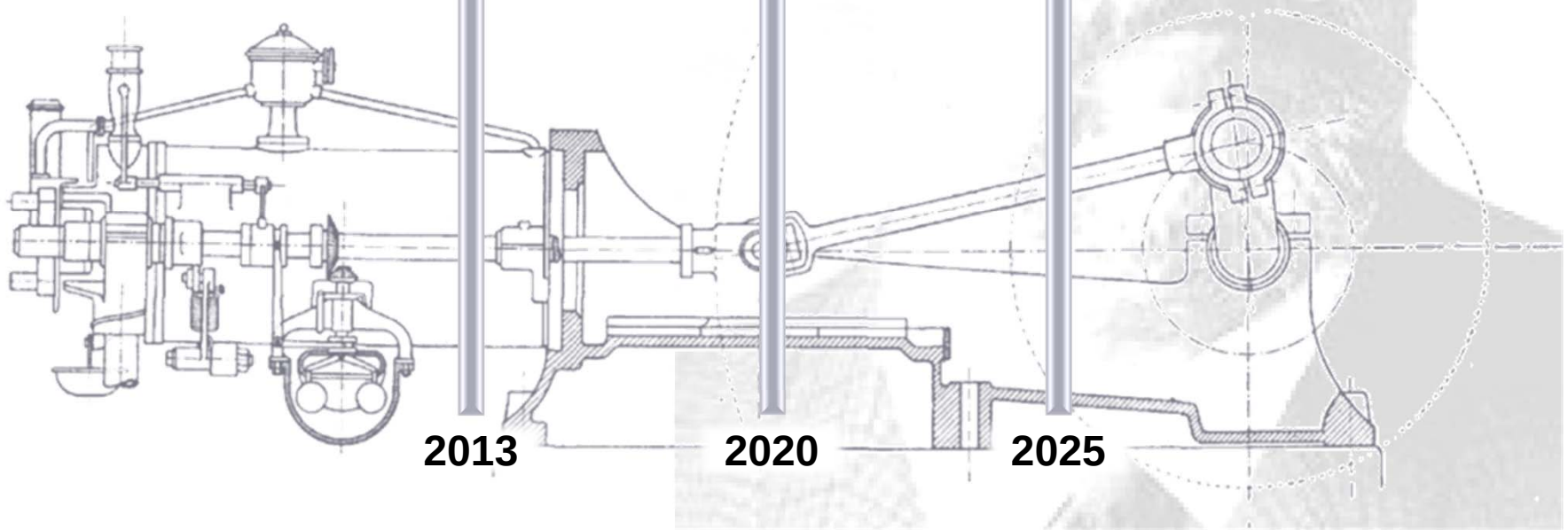
2013 | 2020 | 2025

Generic Technology Roadmap Gasoline Engine

Mainstream | Premium | Niche | To be confirmed

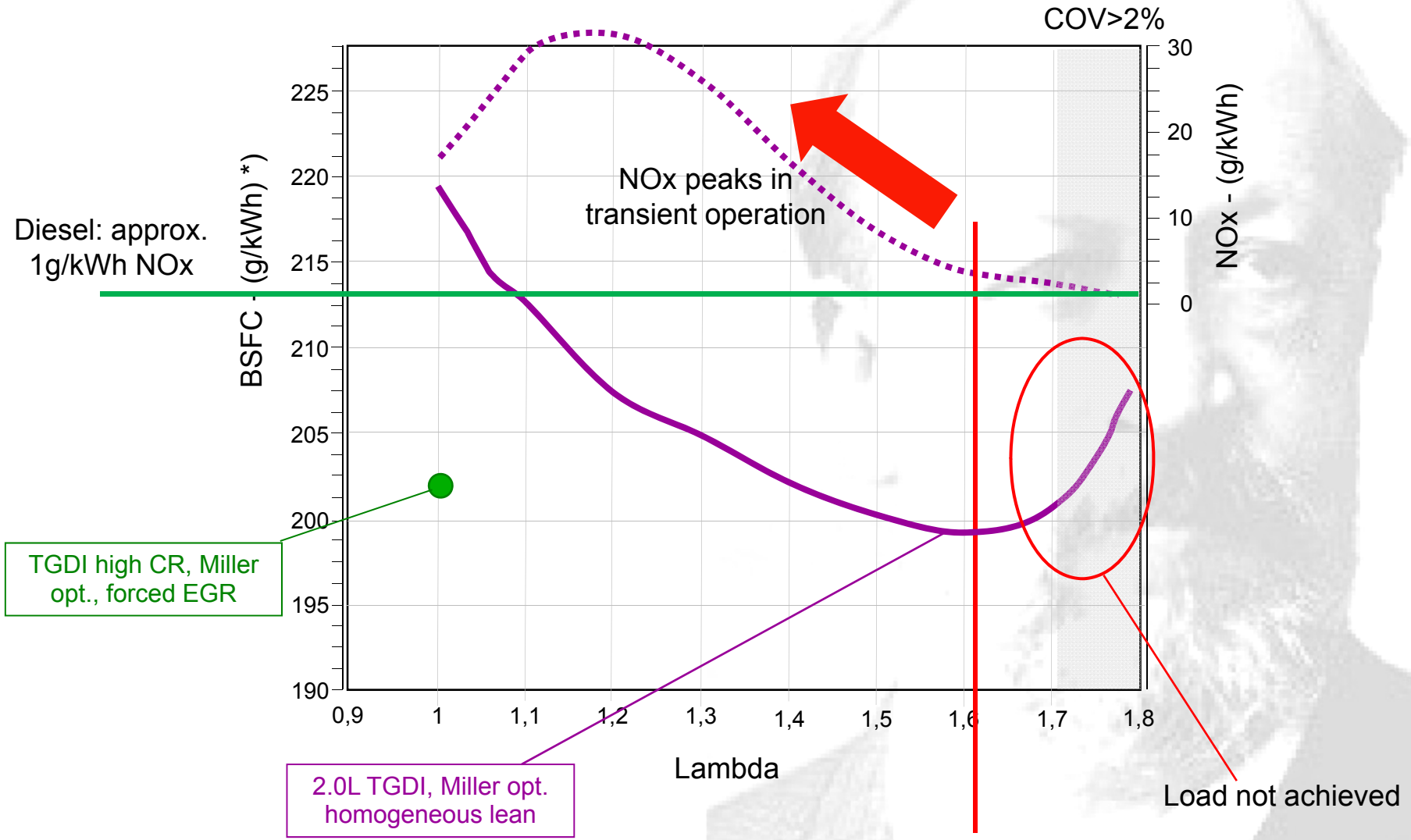
Combustion System

- Homogeneos DI (side, central) Integrated Exhaust
- CNG BiFuel → Monofuel
- Lean



2013 | 2020 | 2025

Lambda and NOx of Homogeneous Lean Combustion
2000 rpm – 12 bar BMEP; Optimised Miller



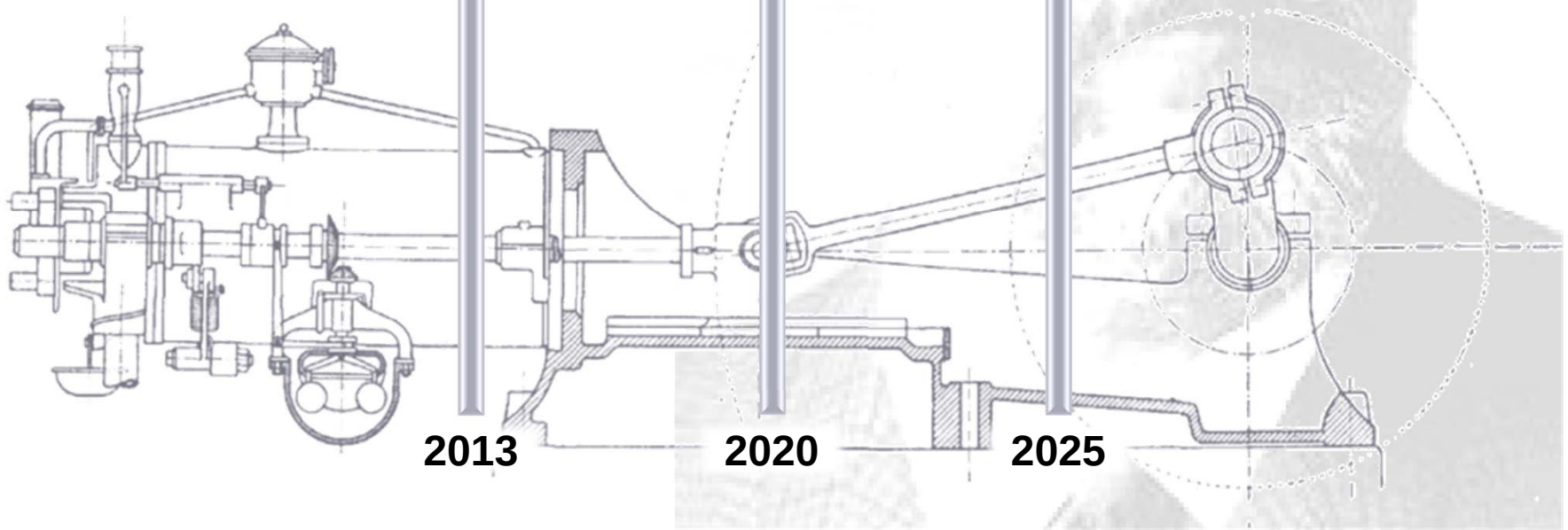
*) lower calorific value 42,75 MJ/kg

Generic Technology Roadmap Gasoline Engine

Mainstream | Premium | Niche | To be confirmed

Combustion System

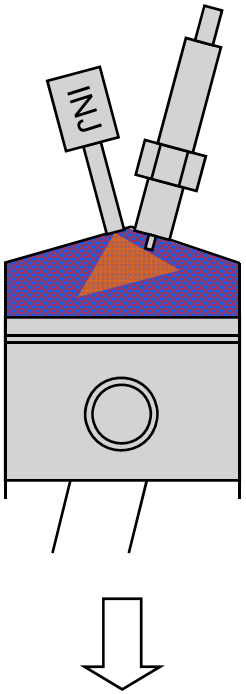
- Homogeneos DI (side, central) Integrated Exhaust
- CNG BiFuel ⇒ Monofuel
- HCCI
- Lean



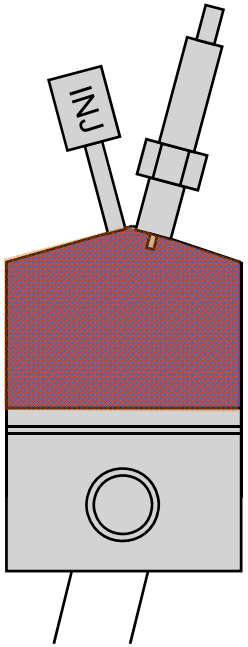
2013 2020 2025

JCAI – Jet Controlled Auto Ignition

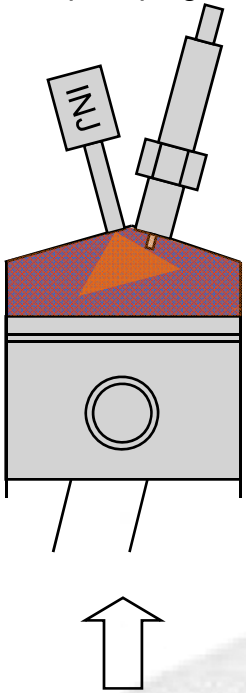
Intake stroke:
-Fresh air + residual gas
-Homogeneous injection



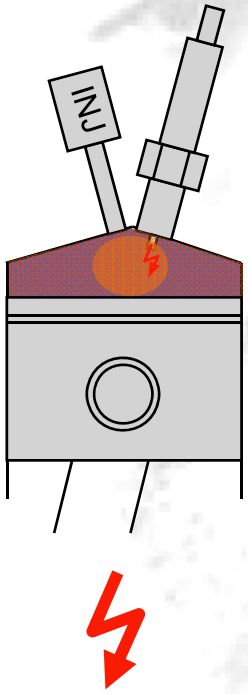
BTD:
-Homogeneous lean charge at 95% CAI conditions



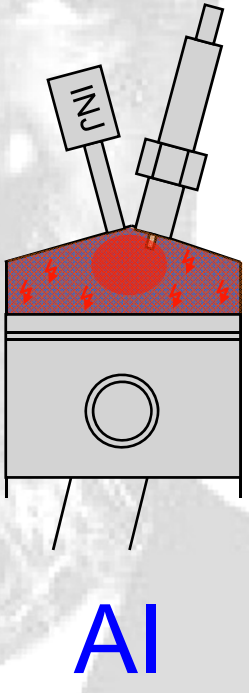
Compression stroke:
-Late injection for rich mixture cloud around spark plug



Ignition:
-Ignition of the rich cloud by spark event

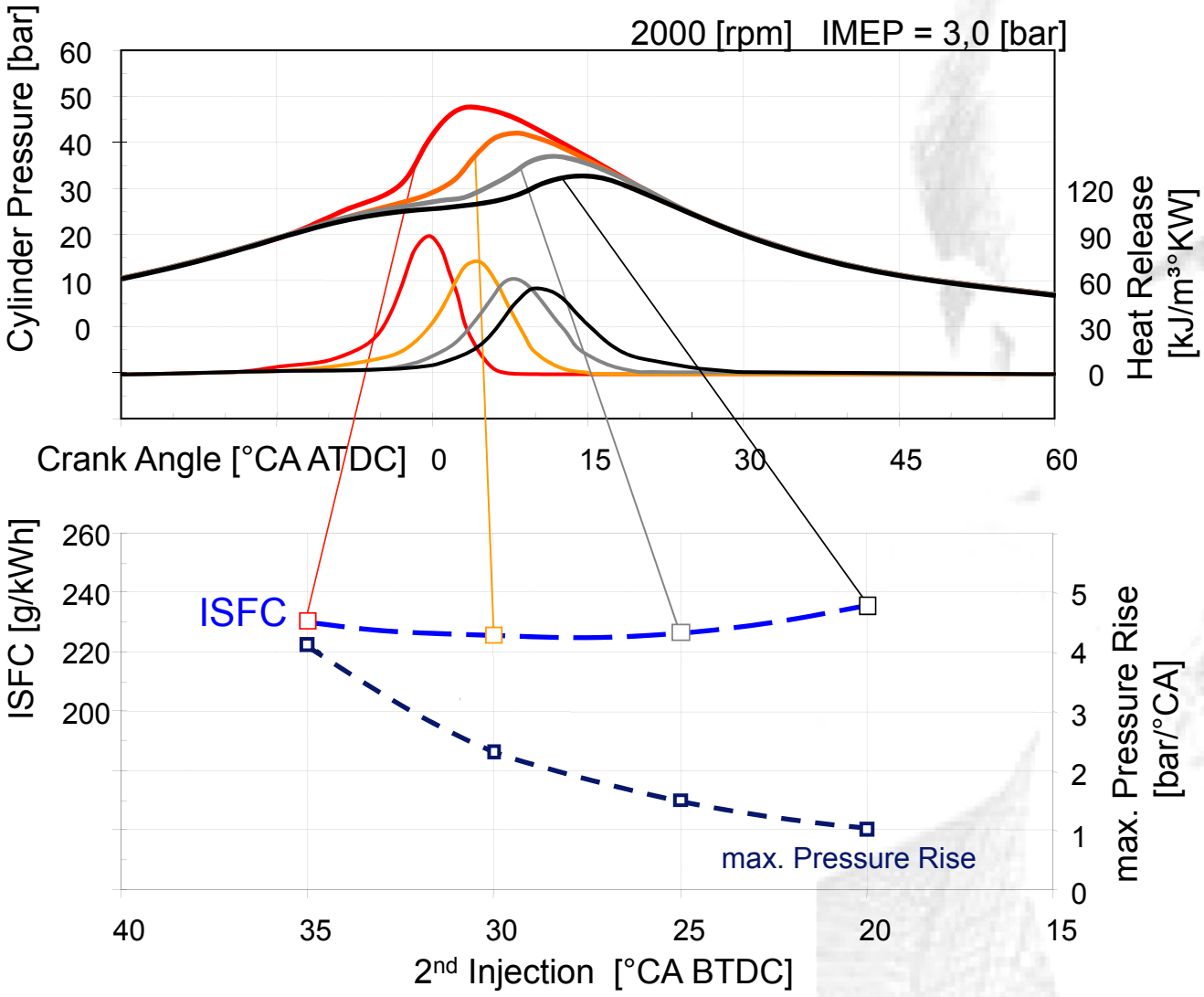


CAI Combustion:
-Pressure and temperature increase initiates auto ignition



AI

JCAI – Jet Controlled Auto Ignition



Tests with a global lean approach showed excellent controllability of the AI combustion part

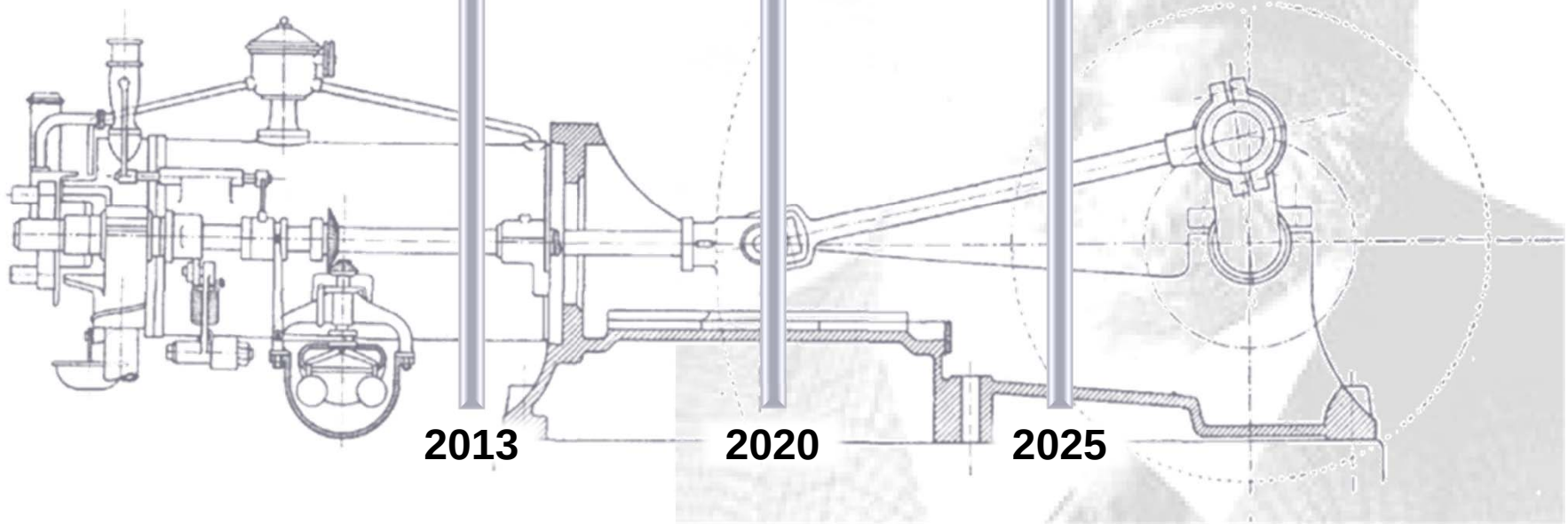
Remaining NOx emissions are treated by lean NOx aftertreatment

Generic Technology Roadmap Gasoline Engine

Mainstream | Premium | Niche | To be confirmed

Combustion System

- Homogeneos DI (side, central) Integrated Exhaust
- CNG BiFuel ➔ Monofuel
- HCCI
- Lean
- Miller / Atkinson



2013 2020 2025

Measures to Improve BSFC: Extended Expansion

Miller- / Atkinson Cycle

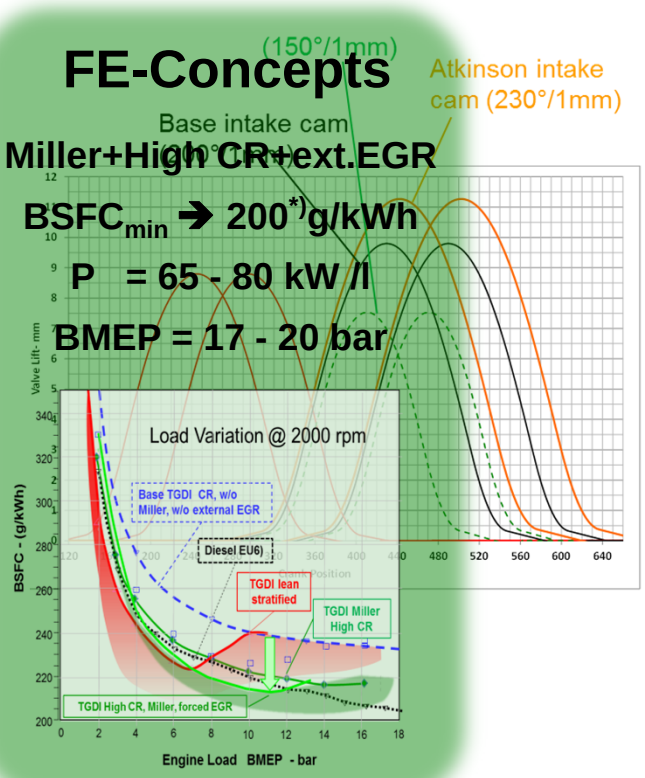
FE-Concepts

Miller+High CR+ext.EGR

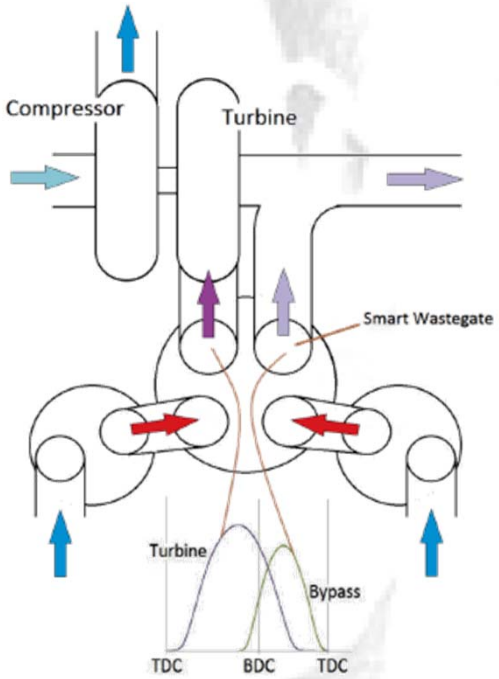
$BSFC_{min}$ ➔ 200*)g/kWh

P = 65 - 80 kW /l

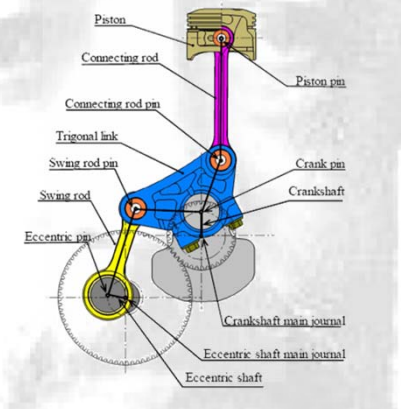
BMEP = 17 - 20 bar

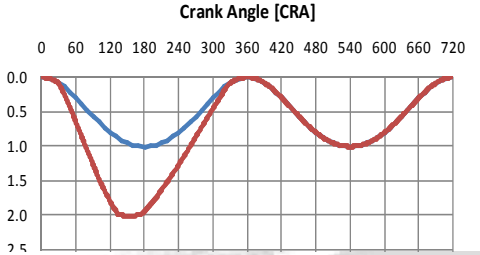


Split Cycle

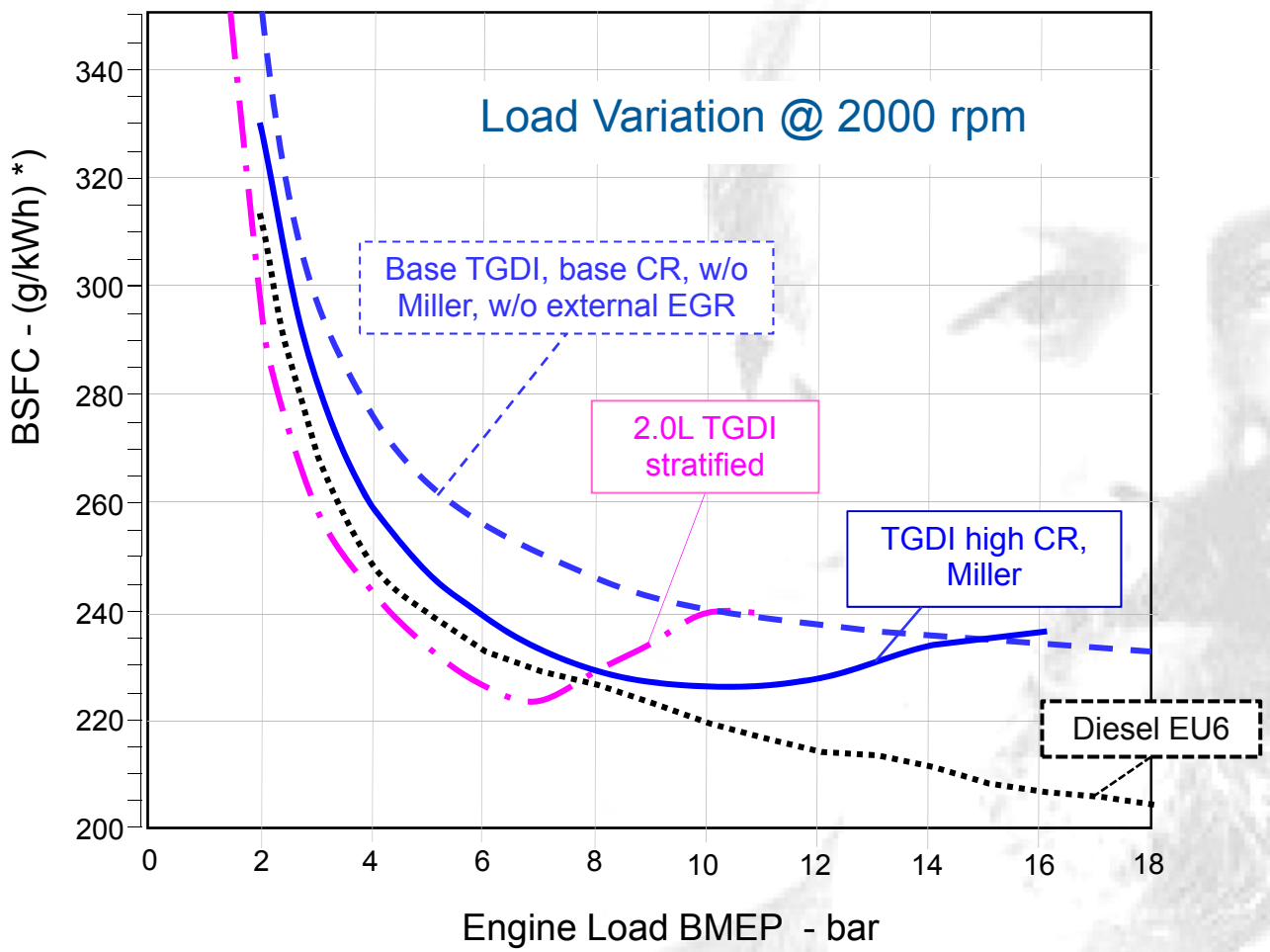


Multi-link cranktrain



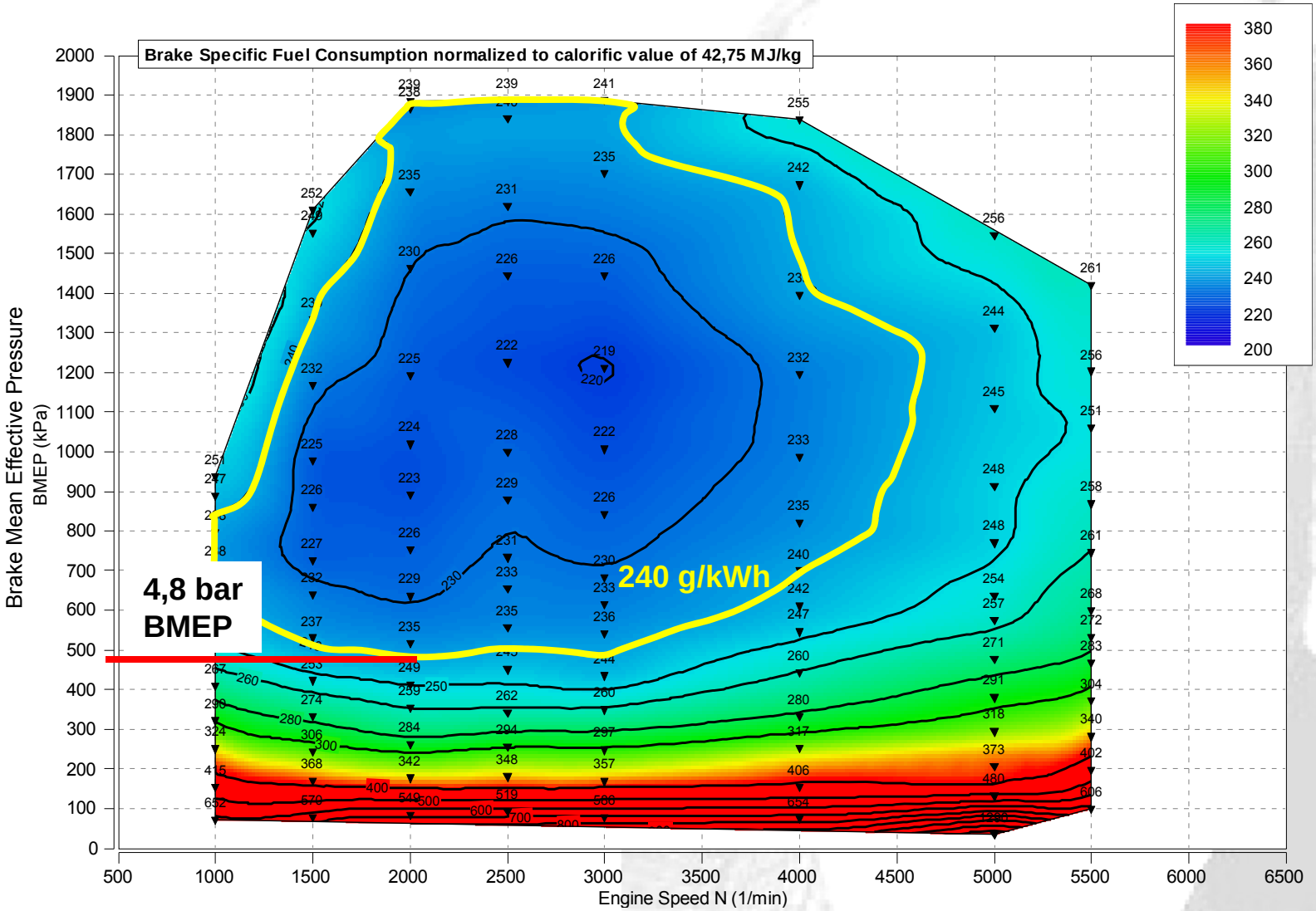


SI Combustion Technologies for Best High Load Efficiency – Miller Cycle



*) lower calorific value 42,75 MJ/kg

BSFC Map AVL R&D 1,6l Miller w/o EGR



Generic Technology Roadmap Gasoline Engine

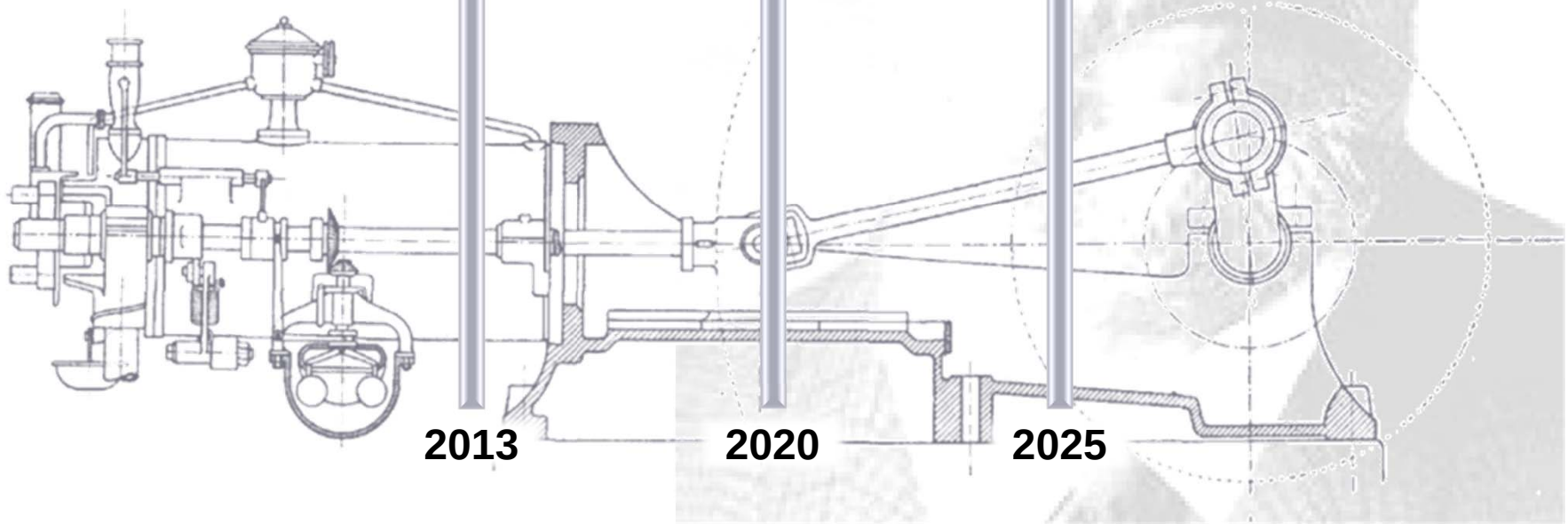
Mainstream | Premium | Niche | To be confirmed

Combustion System

- Homogeneos DI (side, central) Integrated Exhaust
- CNG BiFuel → Monofuel
- HCCI
- Lean
- Miller / Atkinson

Gas Exchange

- Variable Valve Actuation (VVT / VVL)



2013 | 2020 | 2025

Generic Technology Roadmap Gasoline Engine

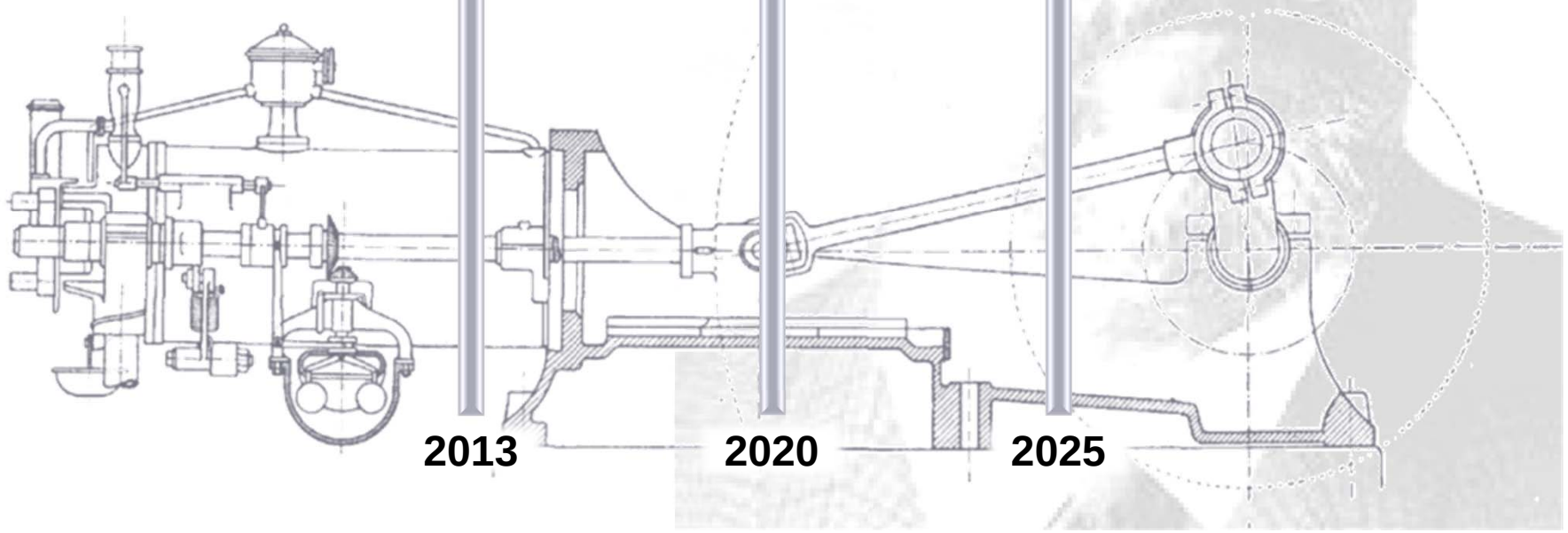
Mainstream | Premium | Niche | To be confirmed

Combustion System

- Homogeneos DI (side, central) Integrated Exhaust
- CNG BiFuel → Monofuel
- HCCI
- Lean
- Miller / Atkinson

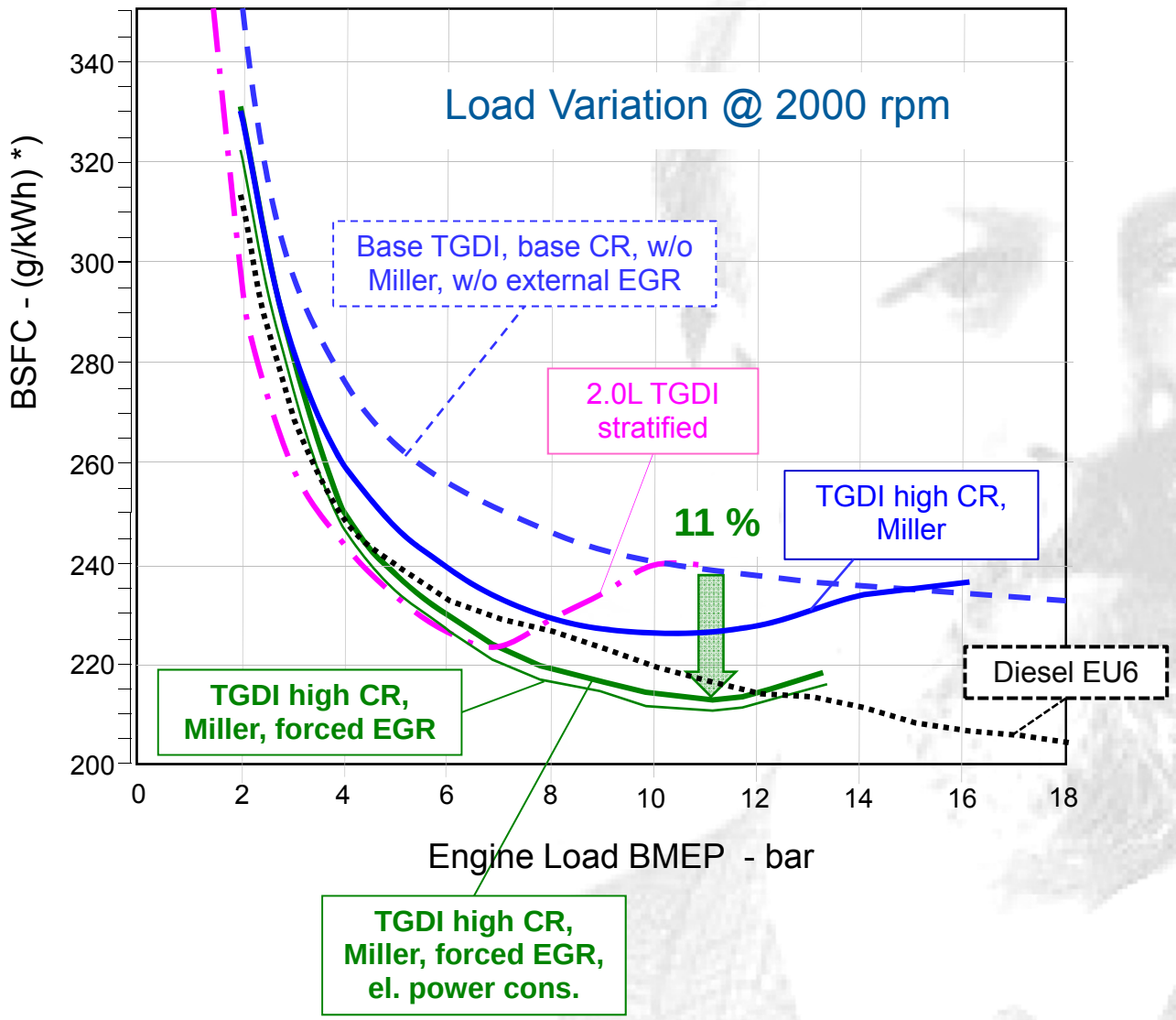
Gas Exchange

- Variable Valve Actuation (VVT / VVL)
- Cooled EGR (LP, HP, Forced)



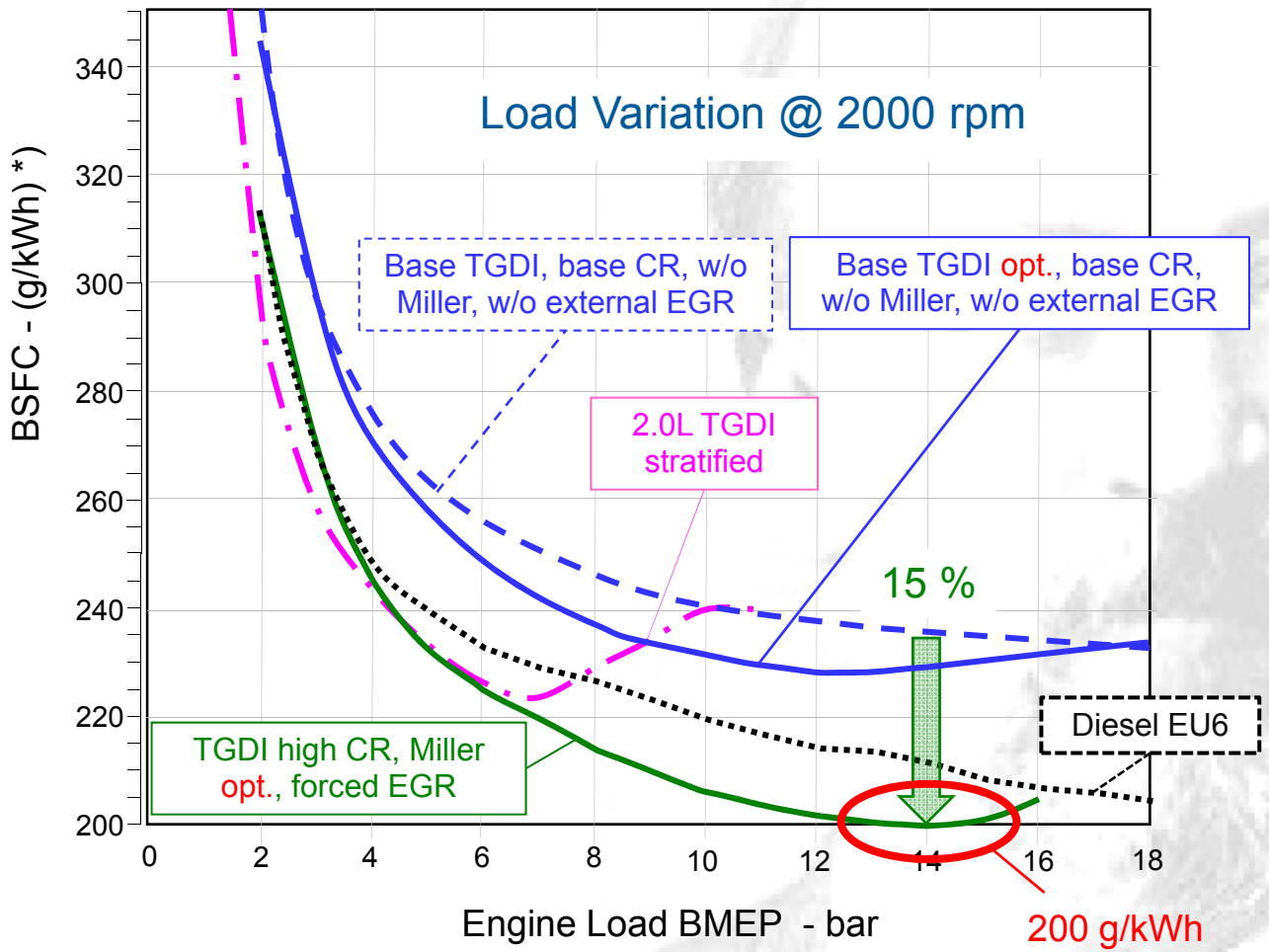
2013 | 2020 | 2025

SI Combustion Technologies for Best High Load Efficiency – Miller + Ext. Cooled EGR



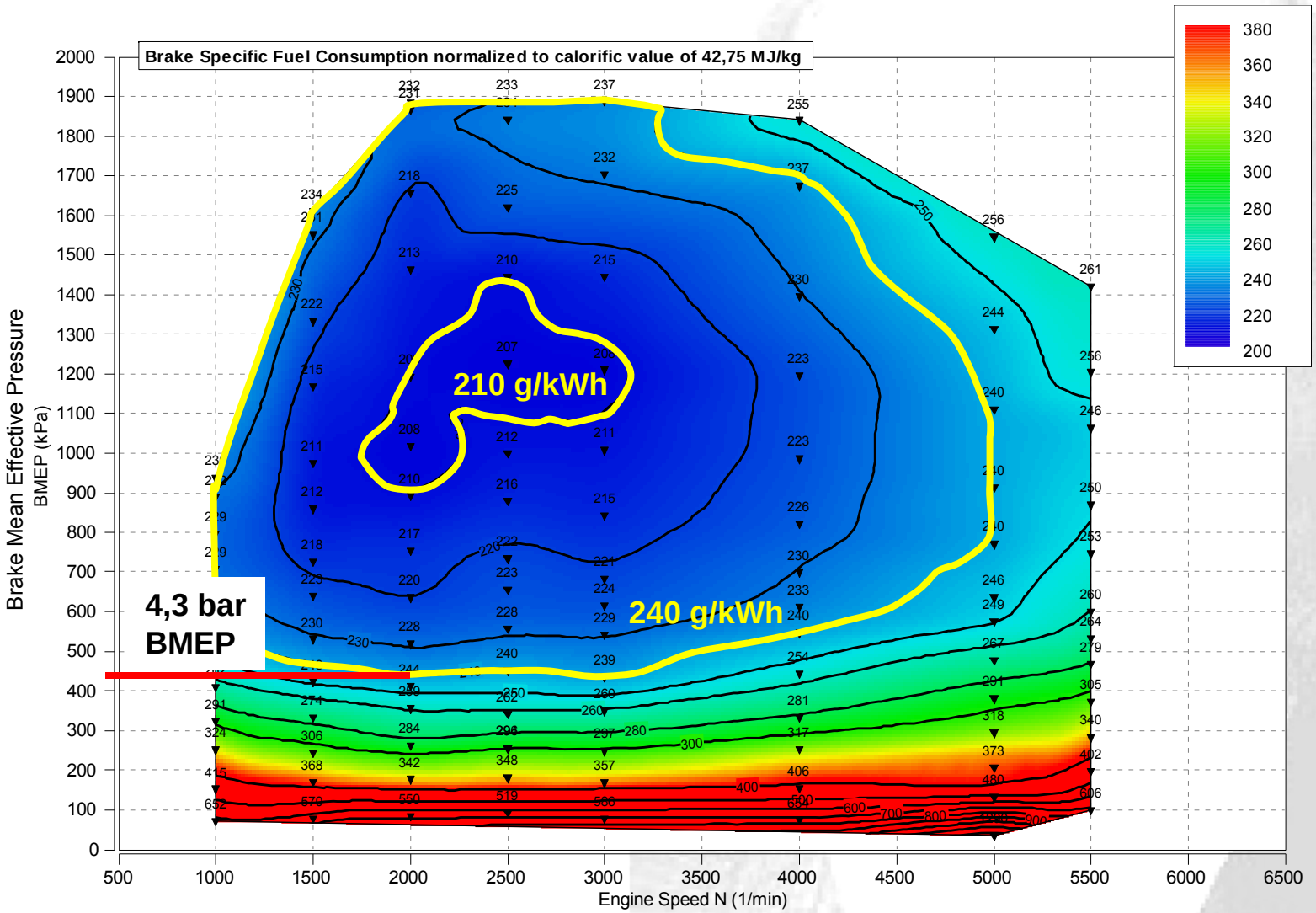
*) lower calorific value 42,75 MJ/kg

SI Combustion Technologies for Best High Load Efficiency – Miller + Ext. Cooled EGR – Optimised Base Engine



*) lower calorific value 42,75 MJ/kg

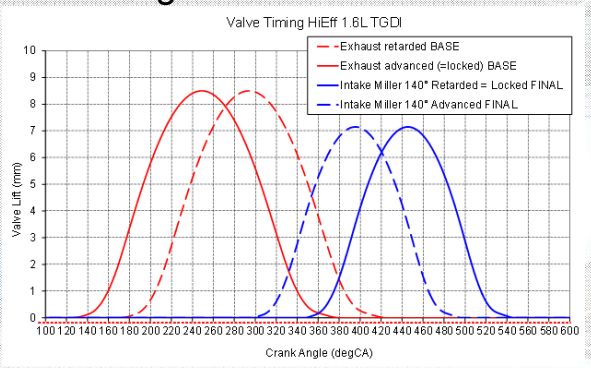
BSFC Miller Cycle
AVL R&D 1,6l Engine with EGR (V2)

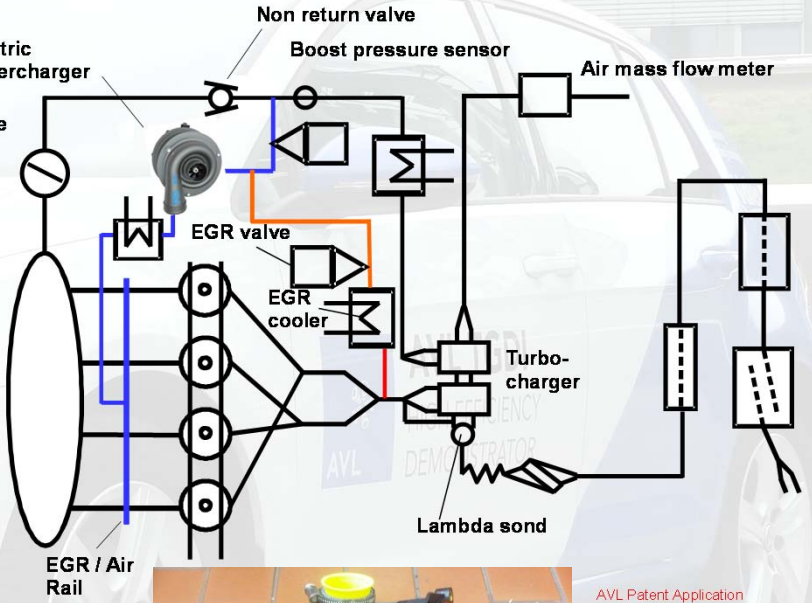


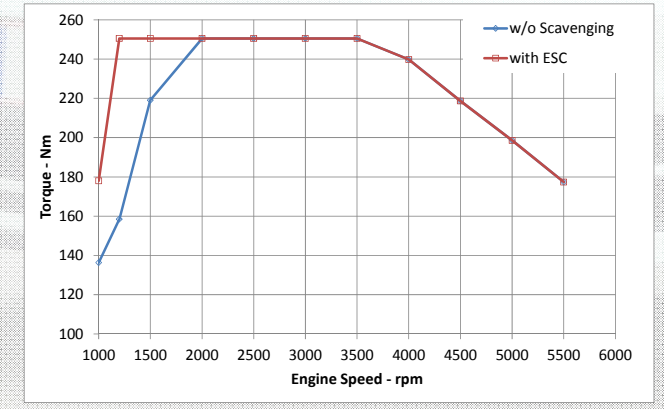
Miller TGDI Democar Golf 7 HiEff

- 1,6l TGDI; 104 kW/4500 rpm
- Cooled Exhaust Manifold
- Increased Compression Ratio
- Miller Cycle
- Cooled Forced EGR (HP)
- Engine min. BSFC <210 g/kWh
- 90 g/km CO2 in NEDC

High Pressure EGR







EGR / air feed pipe

EGR / air rail

AVL Patent Application

Throttle body flange

Generic Technology Roadmap Gasoline Engine

Mainstream | Premium | Niche | To be confirmed

Combustion System

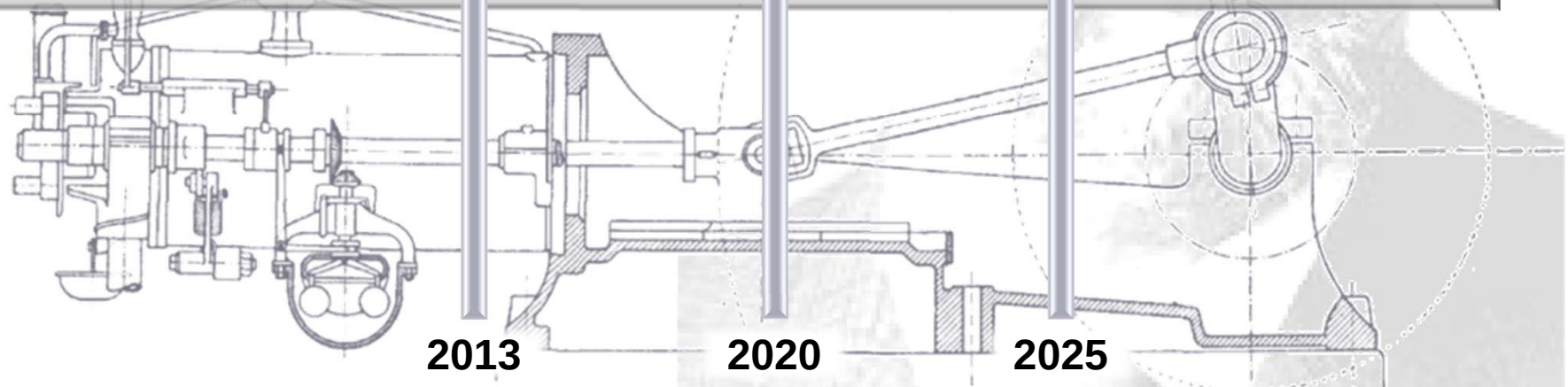
- Homogeneos DI (side, central) Integrated Exhaust
- CNG BiFuel ➔ Monofuel
- HCCI
- Lean
- Miller / Atkinson

Gas Exchange

- Variable Valve Actuation (VVT / VVL)
- Cooled EGR (LP, HP, Forced)

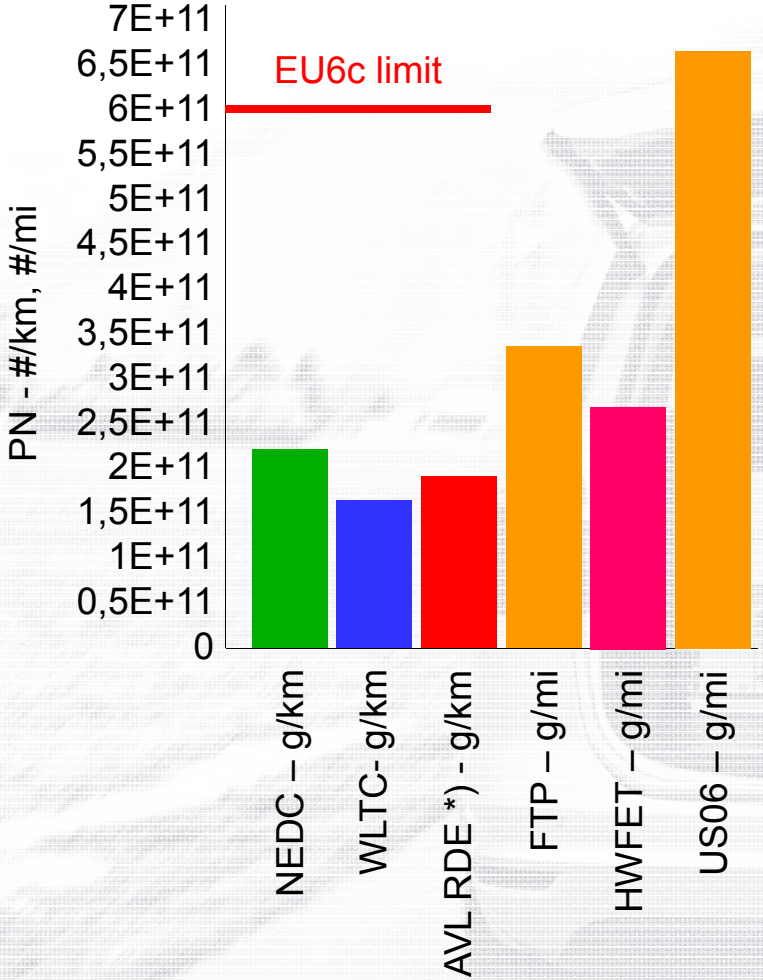
Aftertreatment

- GPF
- Lean Aftertreatment

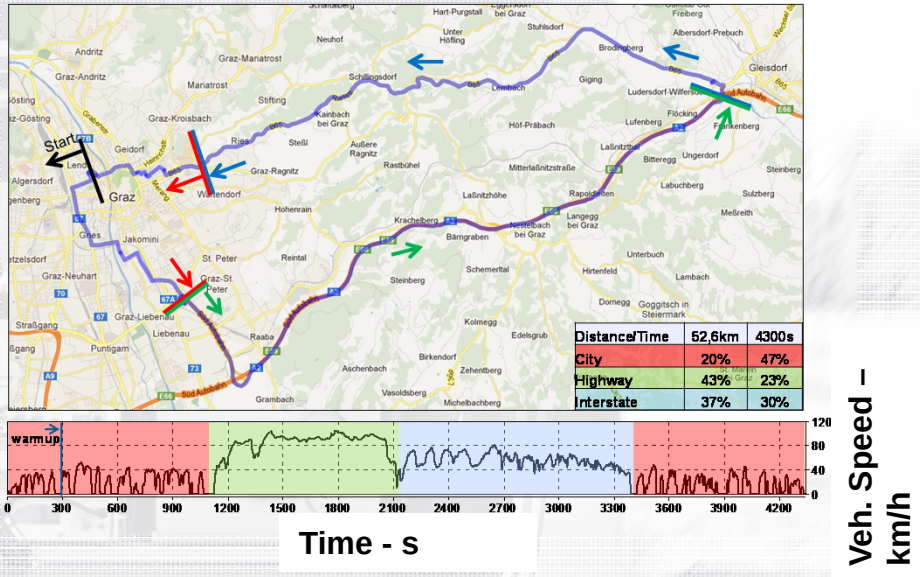


2013 | 2020 | 2025

PN in Different Cycles – 2,3t SUV, >3l Charged

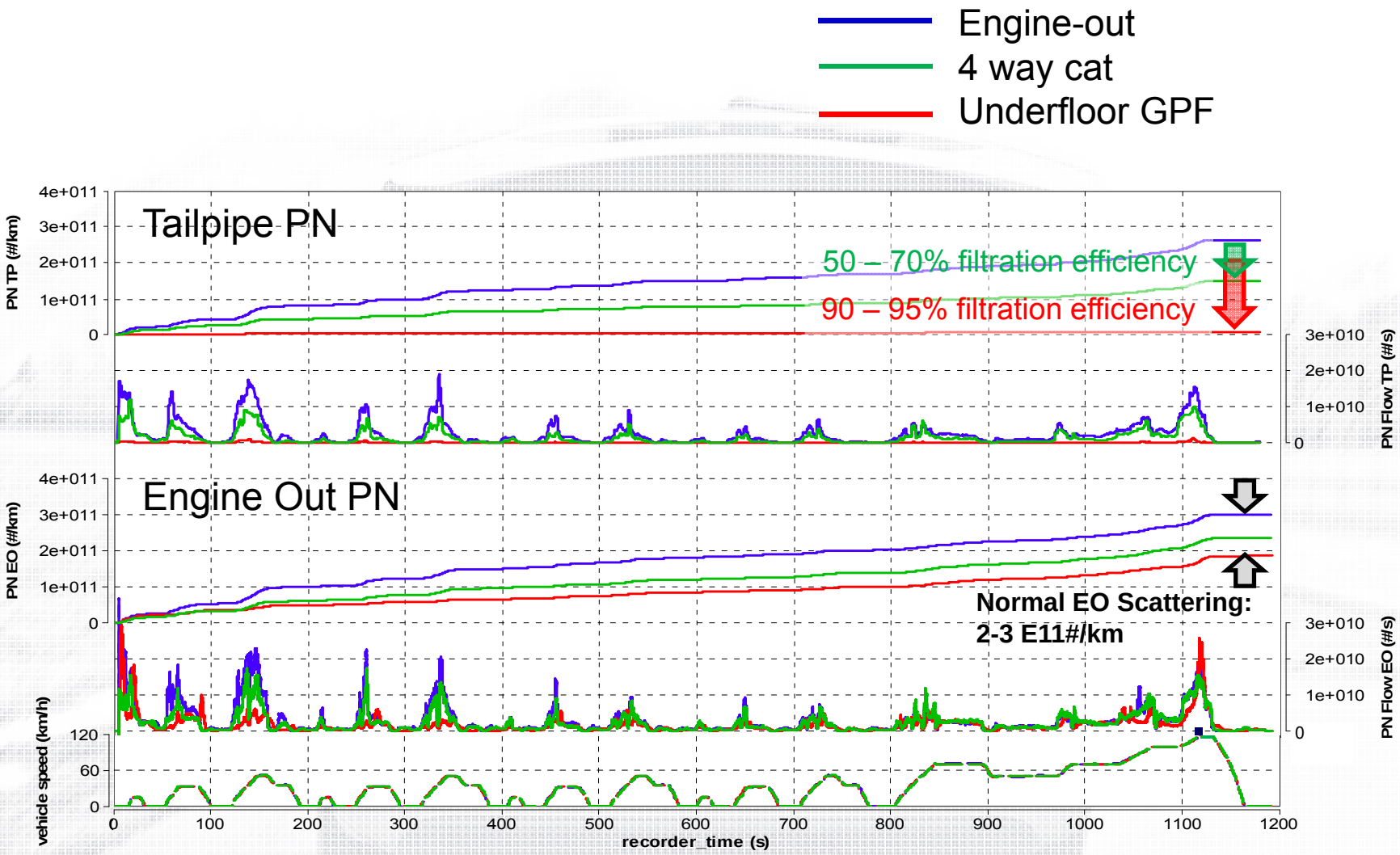


*) AVL RDE Test Round

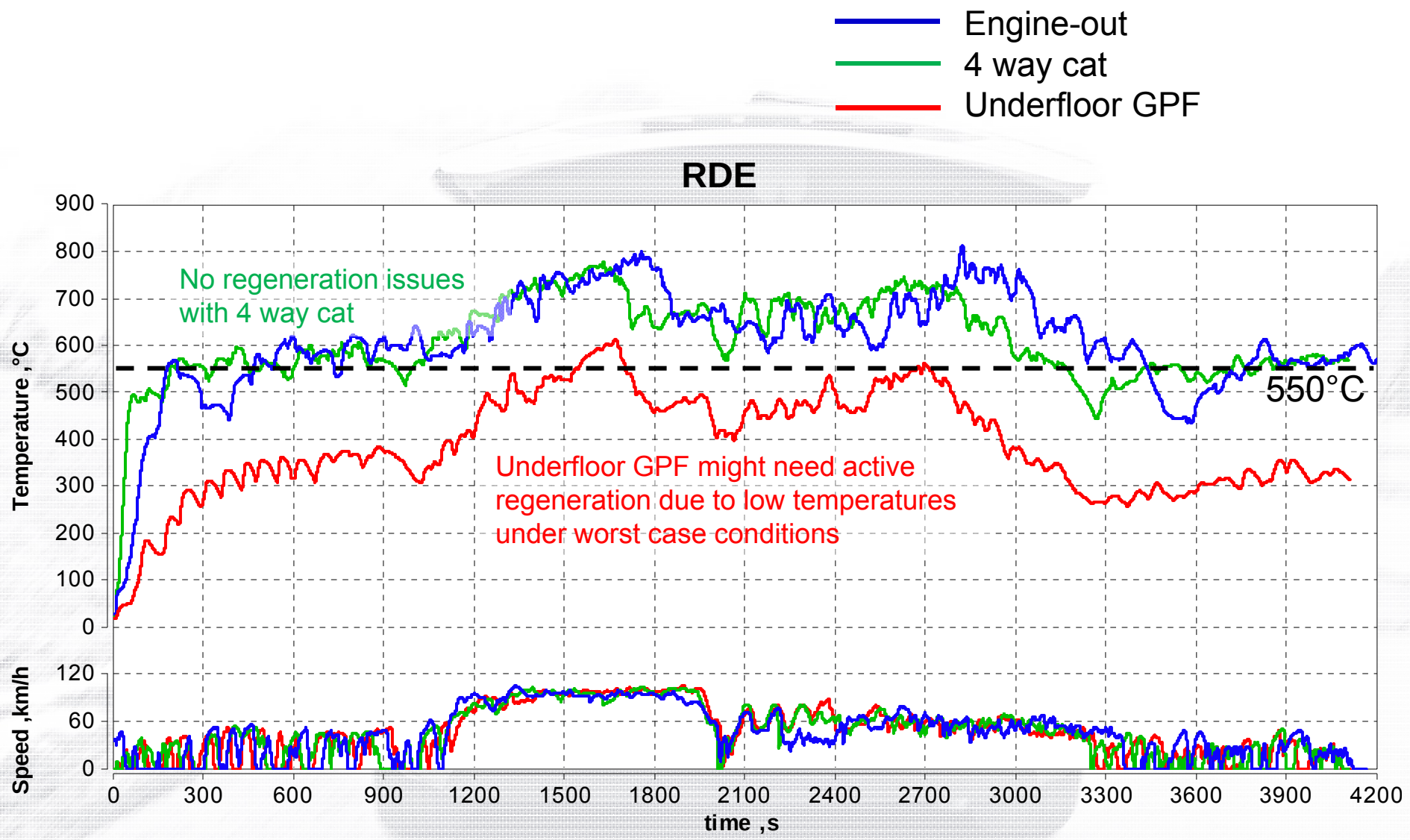


www.avl.com/real-life

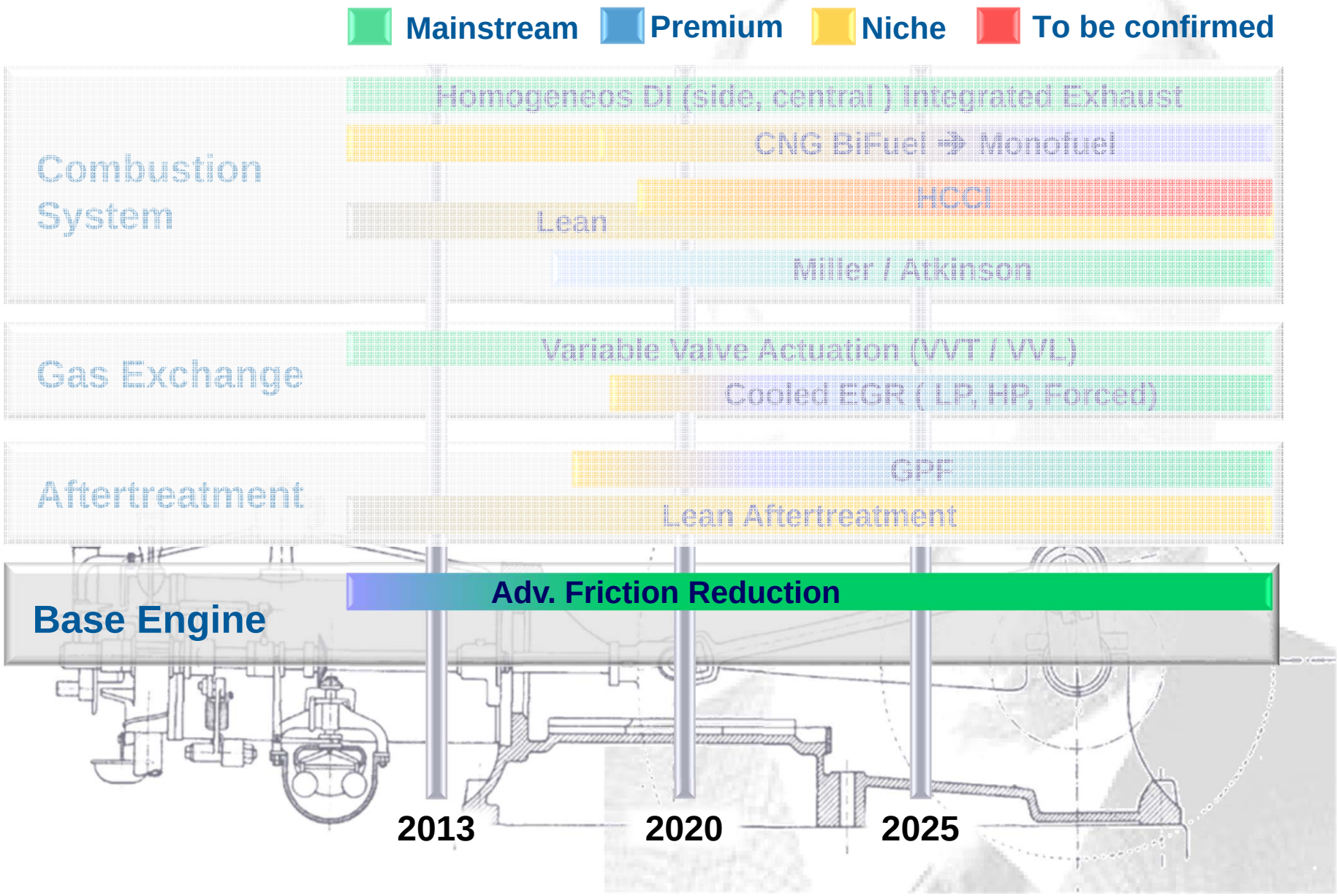
Effect of Gasoline Particle Filter in NEDC



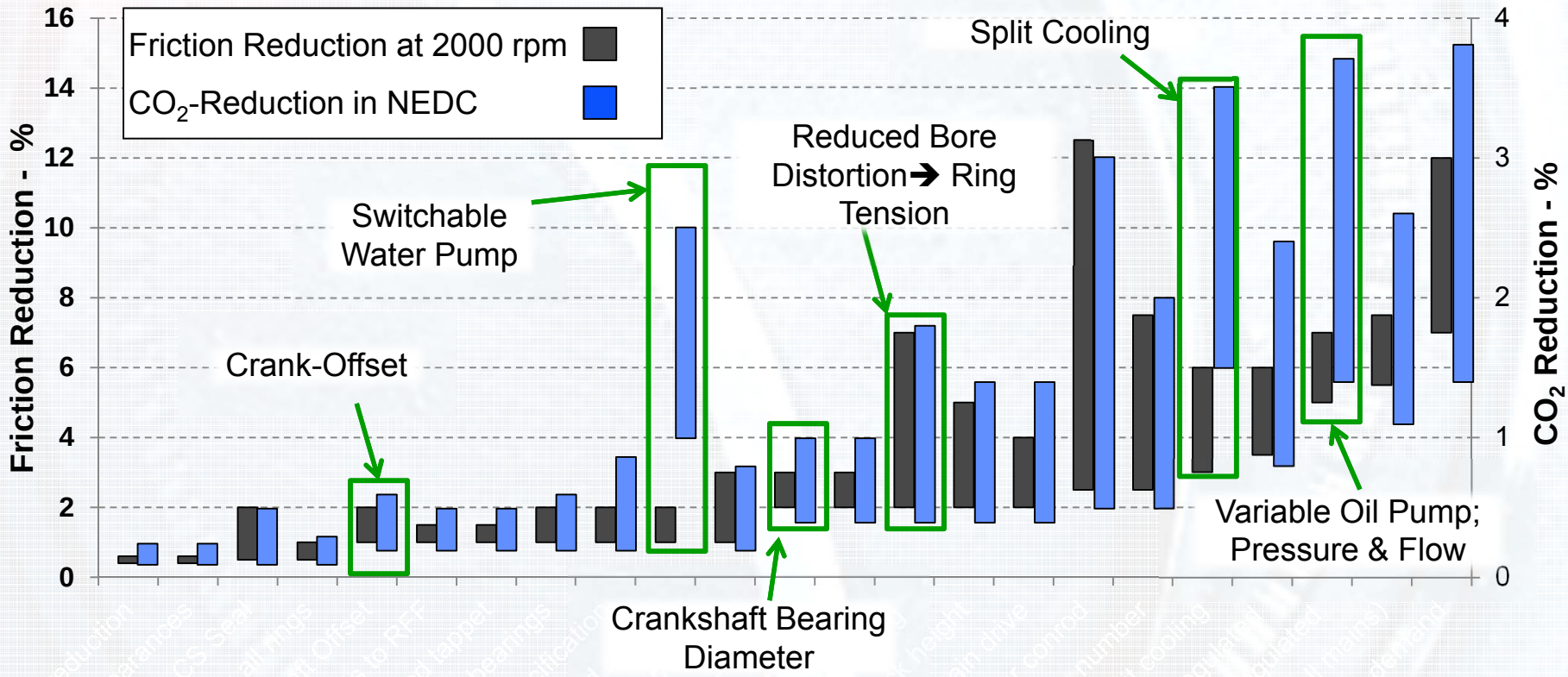
Temperature of Gasoline Particle Filter in RDE



Generic Technology Roadmap Gasoline Engine



Friction Reduction Measures and Effect on CO2



Gasoline Engine

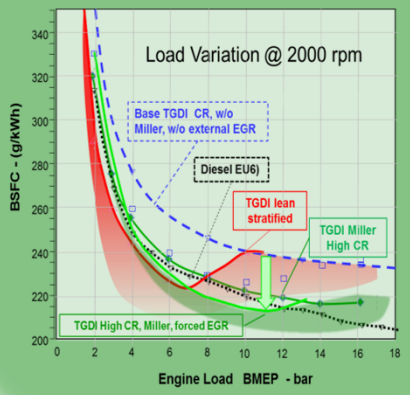
FE-Concepts

Miller+High CR+ext.EGR

$BSFC_{min}$ ➔ 200*)g/kWh

P = 65 - 80 kW /l

BMEP = 17 - 20 bar



Mainstream 2013

BSFCmin 235*)g/kWh

P = 65 - 95 kW /l

BMEP = 17 - 25 bar

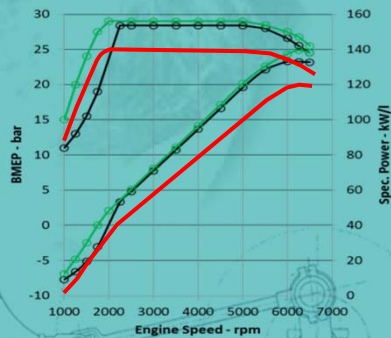
EITHER - OR

"Image / Top Performance" Concepts

$BSFC_{min}$ >230*) g/kWh

P = 110 - 180 kW /l

BMEP = 28 - 30 bar



*) … 2l displacement

Gasoline Engine

FE-Concepts

Miller+High CR+ext.EGR

$BSFC_{min}$ ➔ 200*)g/kWh

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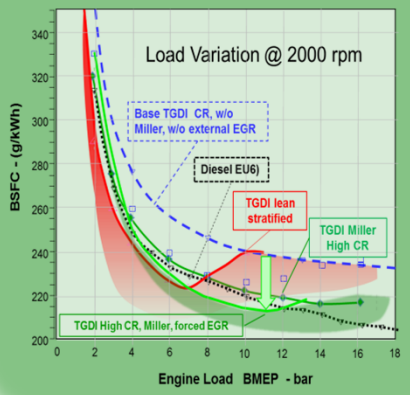

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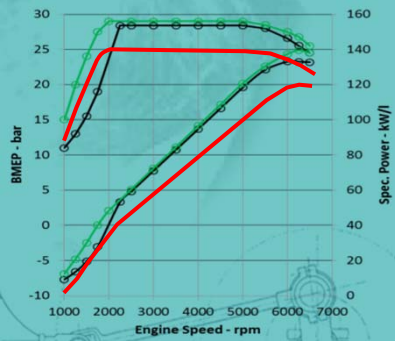
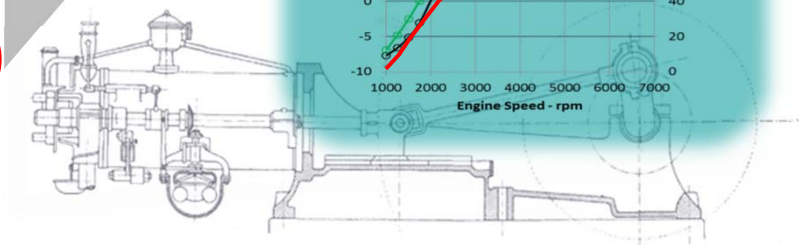
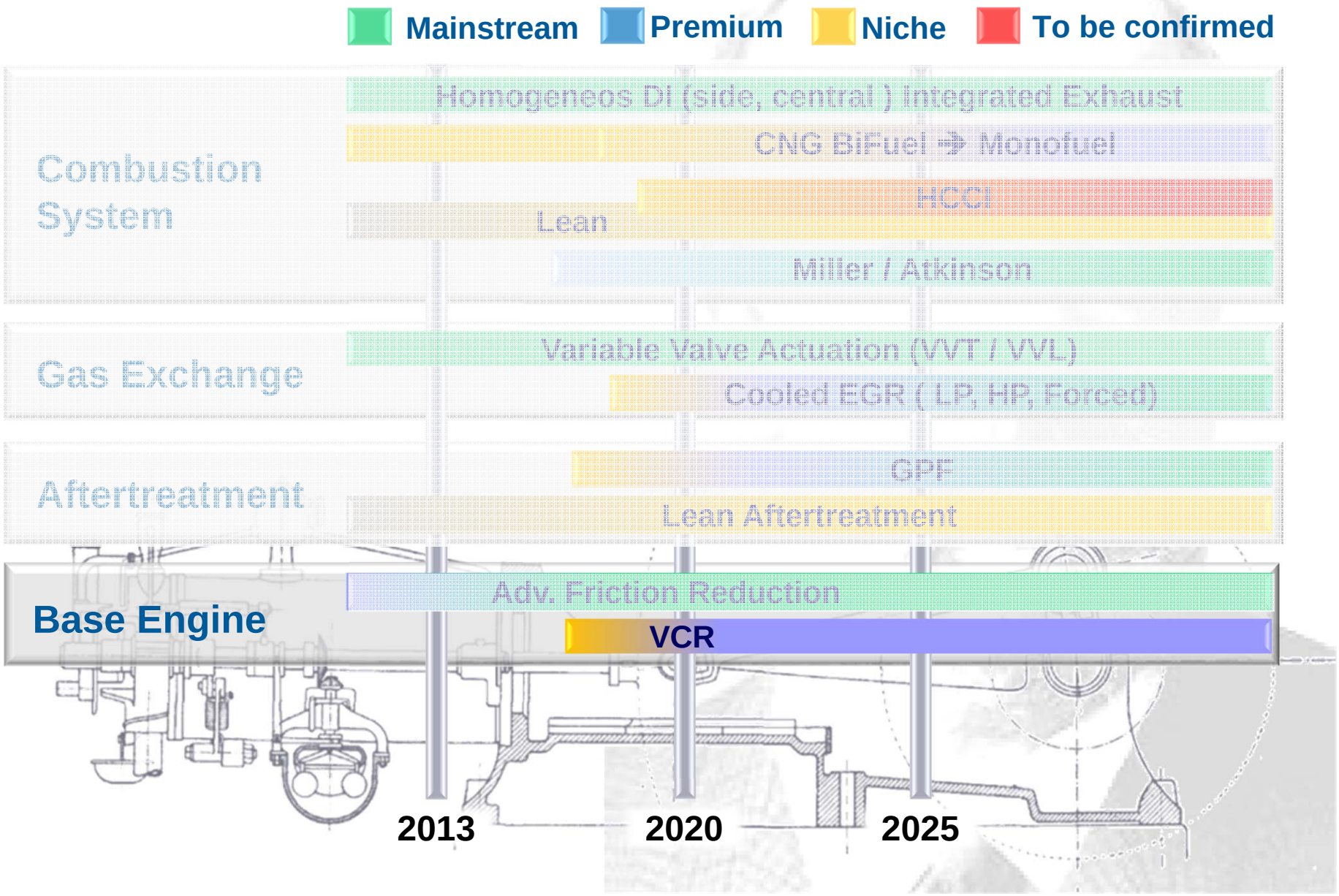


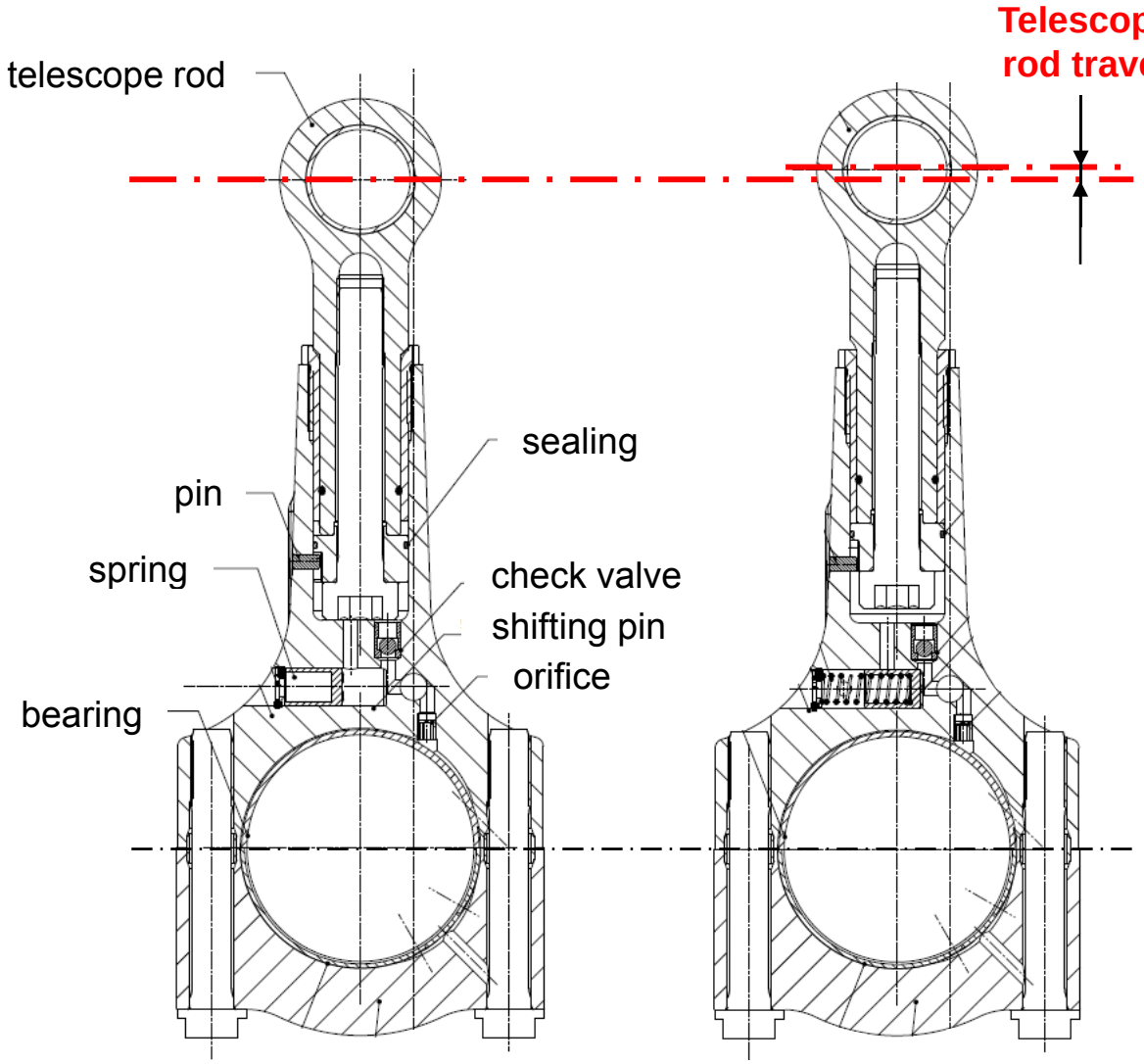


*) … 2l displacement

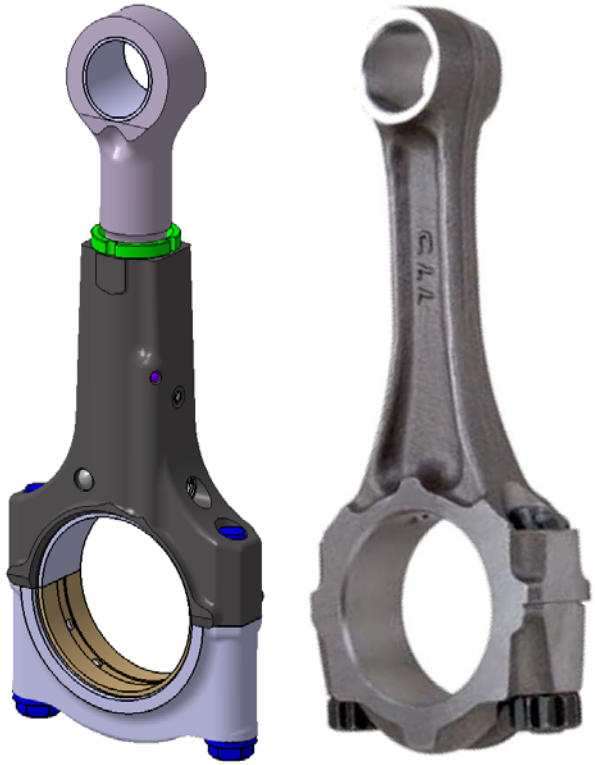
Generic Technology Roadmap Gasoline Engine



Variable Compression Ratio – Switchable Con Rod

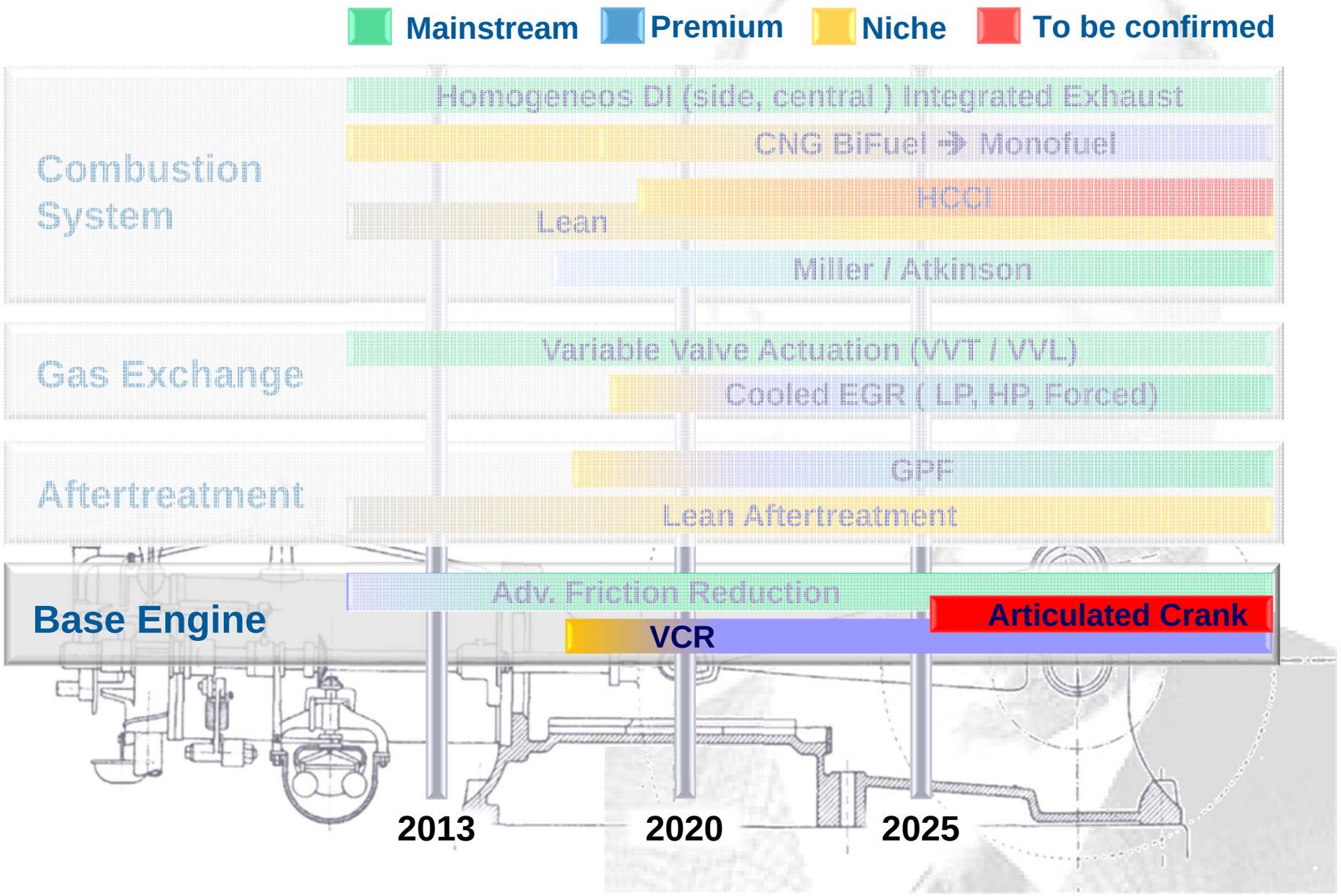


Nearly same size as conventional conrod



AVL patent application

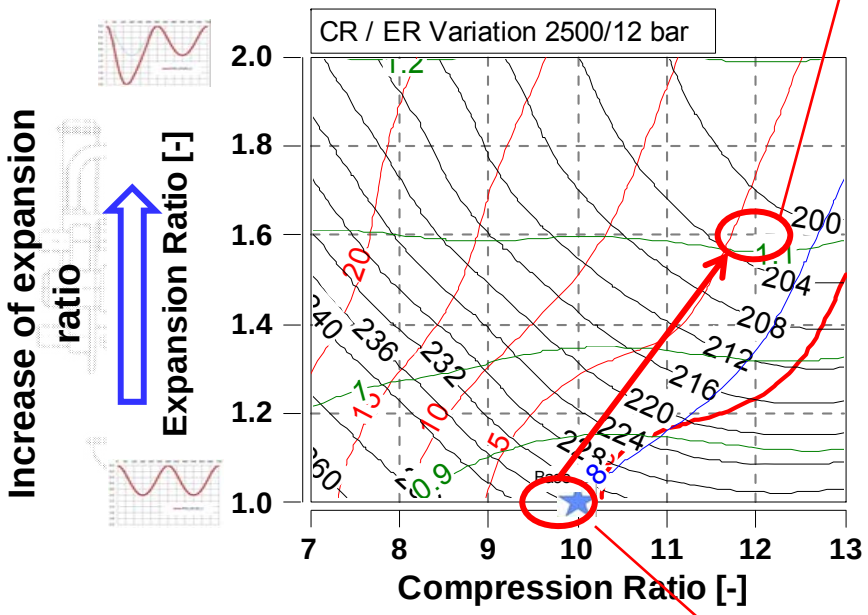
Generic Technology Roadmap Gasoline Engine



Increased Expansion Ratio (ER): Articulated Crank Train (Boost Simulation; 2,0l TGDI)

Variation of CR and Expansion Ratio (new Crank Train)

Low consumption engine (CR 12:1; expansion ratio 1.6); <205 g/kWh



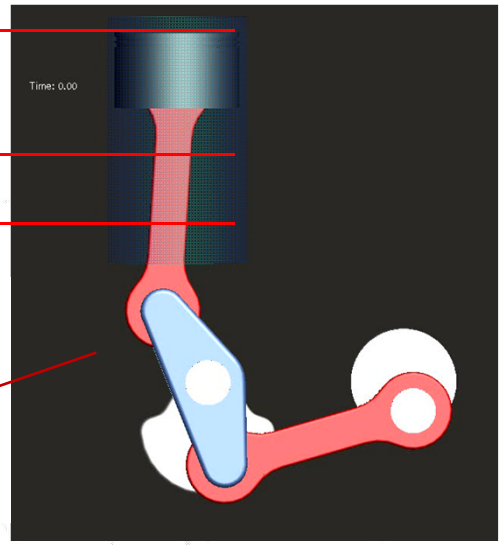
Increase of geometric compression ratio

Current engines (CR 9.5 - 10:1; expansion ratio 1); approx 240 g/kWh

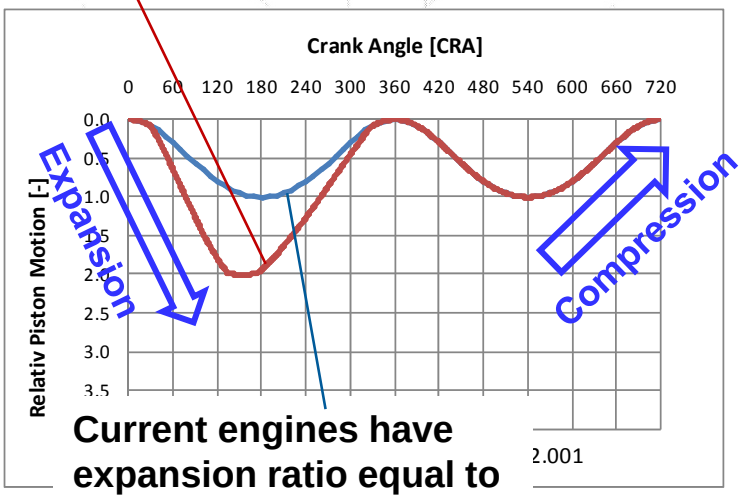
TDC

BDC Compr.

BDC Exp.



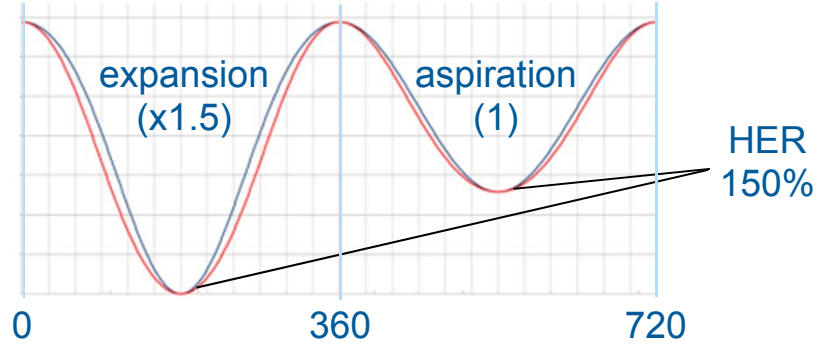
An articulated crank mechanism can separate expansion ratio from compression ratio

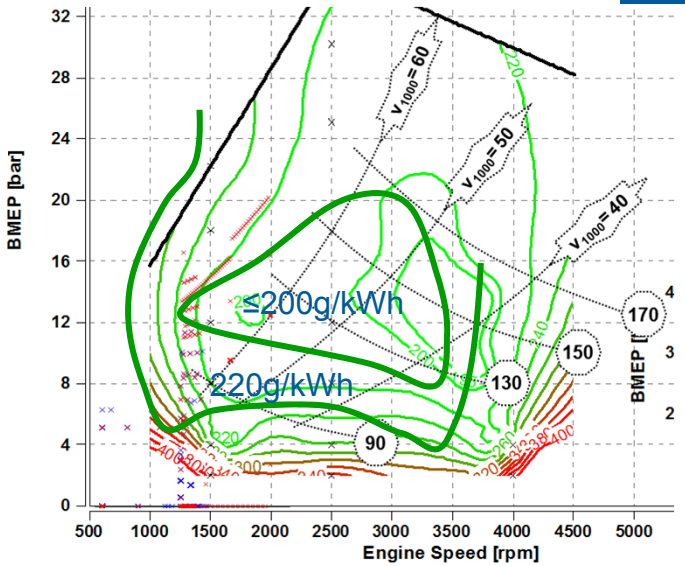


Current engines have expansion ratio equal to compression ratio

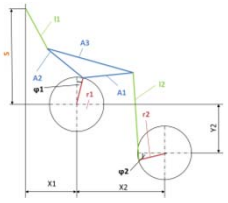
High Expansion Ratio – Geometric Separation of Compression and Expansion

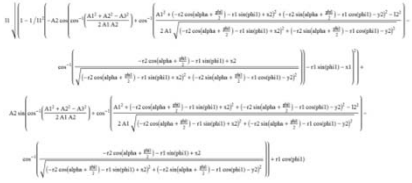
HER Potential: With a HER of 150% BSFC of less than 200 g/kWh can be achieved in combination with EGR.

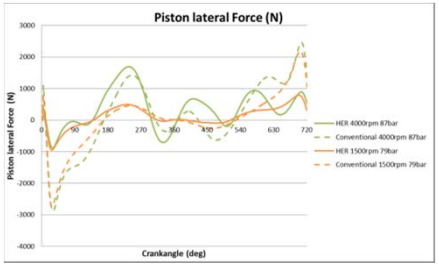


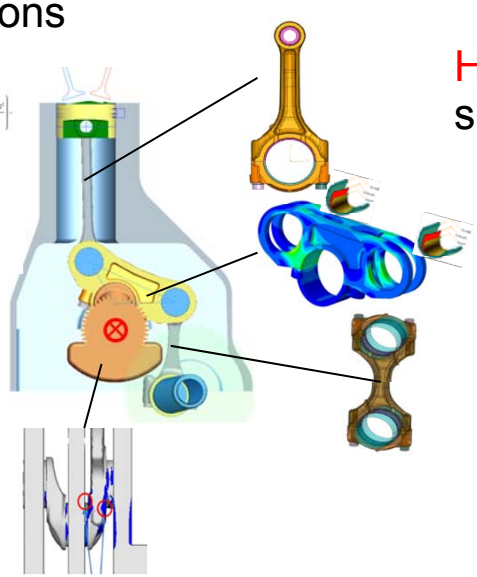


HER Finding 1: HER can be realized (kinematics, forces, dynamics, basic dimensions

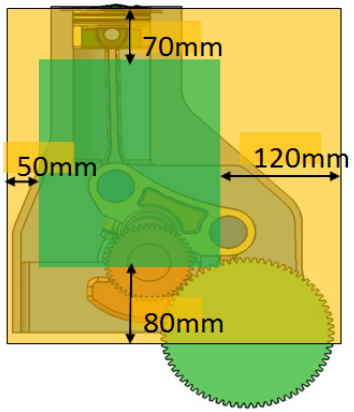








HER Finding 2: HER needs more space



Niedrigster Verbrauch und höchste Leistung: ein Widerspruch?
Ausblick auf die Zukunft des Ottomotors

Lowest Consumption and Highest Performance – a Contradiction?
Outlook on the Future of the Gasoline Engine

2 Democars are exhibited:

High performance: 200 HP/l

Low consumption: 210 g/kWh