Thermodynamic Potential and Limits of IC Engines

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A3 PS Conference

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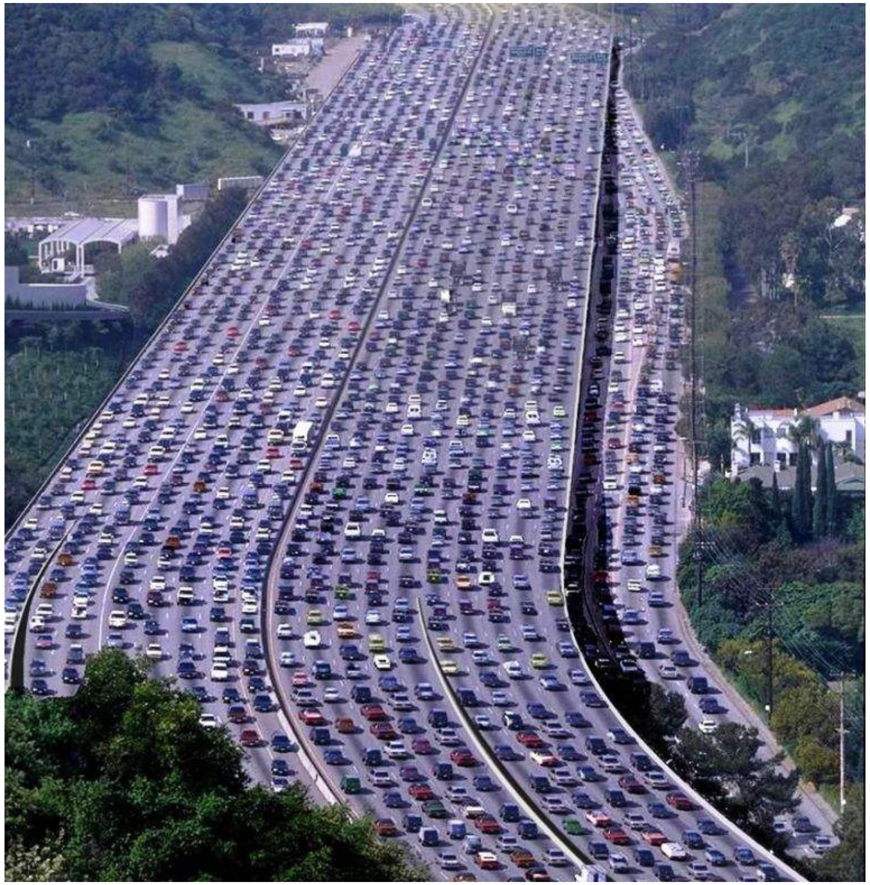
Thermodynamic Potential and Limits

Challenges and risks for IC engines

- **Introduction**
- **Boundary conditions**
- **Challenges today and tomorrow**
  - Efficiency
  - Emission
  - Specific Power
- **Additional Chances for the future**
- **Summary**

Today: More than 1000 million IC engines

Driving more than 99 % of passenger cars



IC engine is one of the most successful inventions

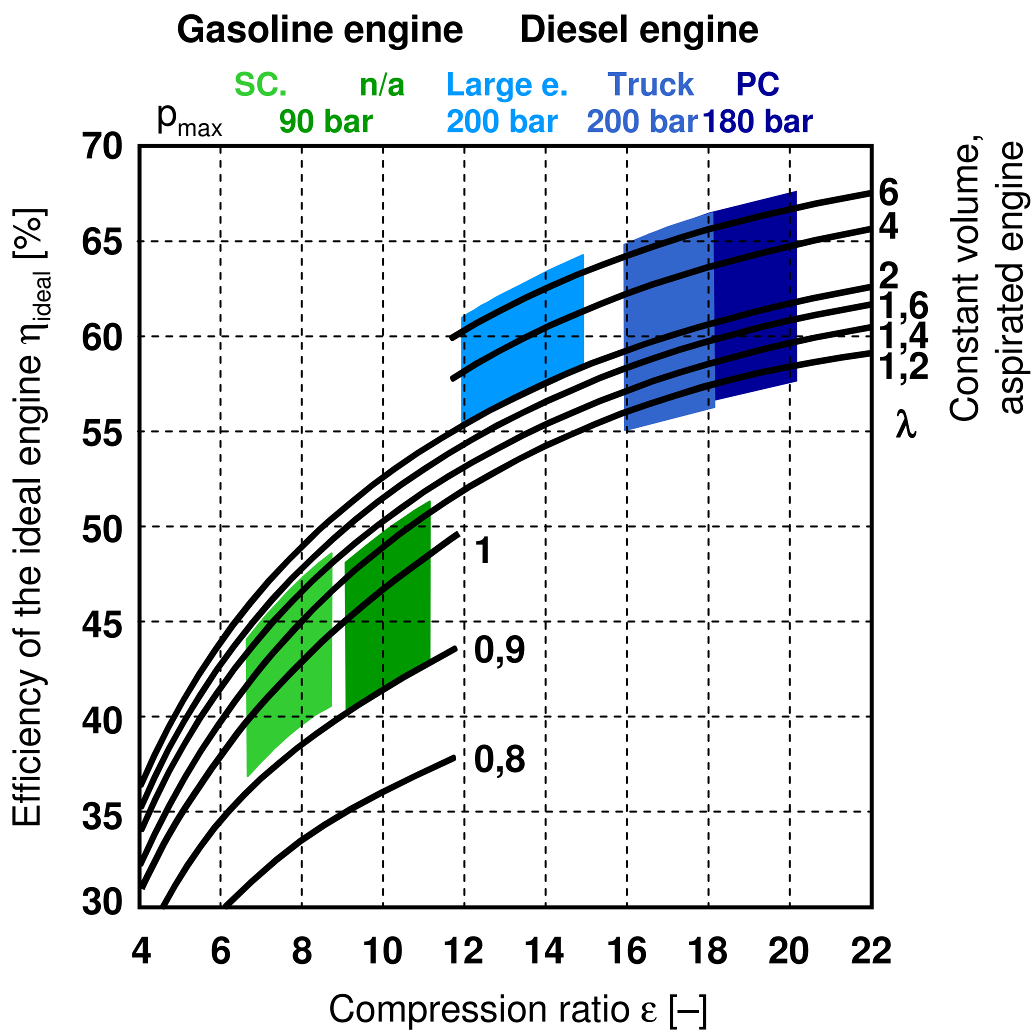
Production >70 mio. per year

But:

The biggest challenge for ICE is its success

Thermodynamic boundary conditions

Limit: Efficiency of the ideal engine

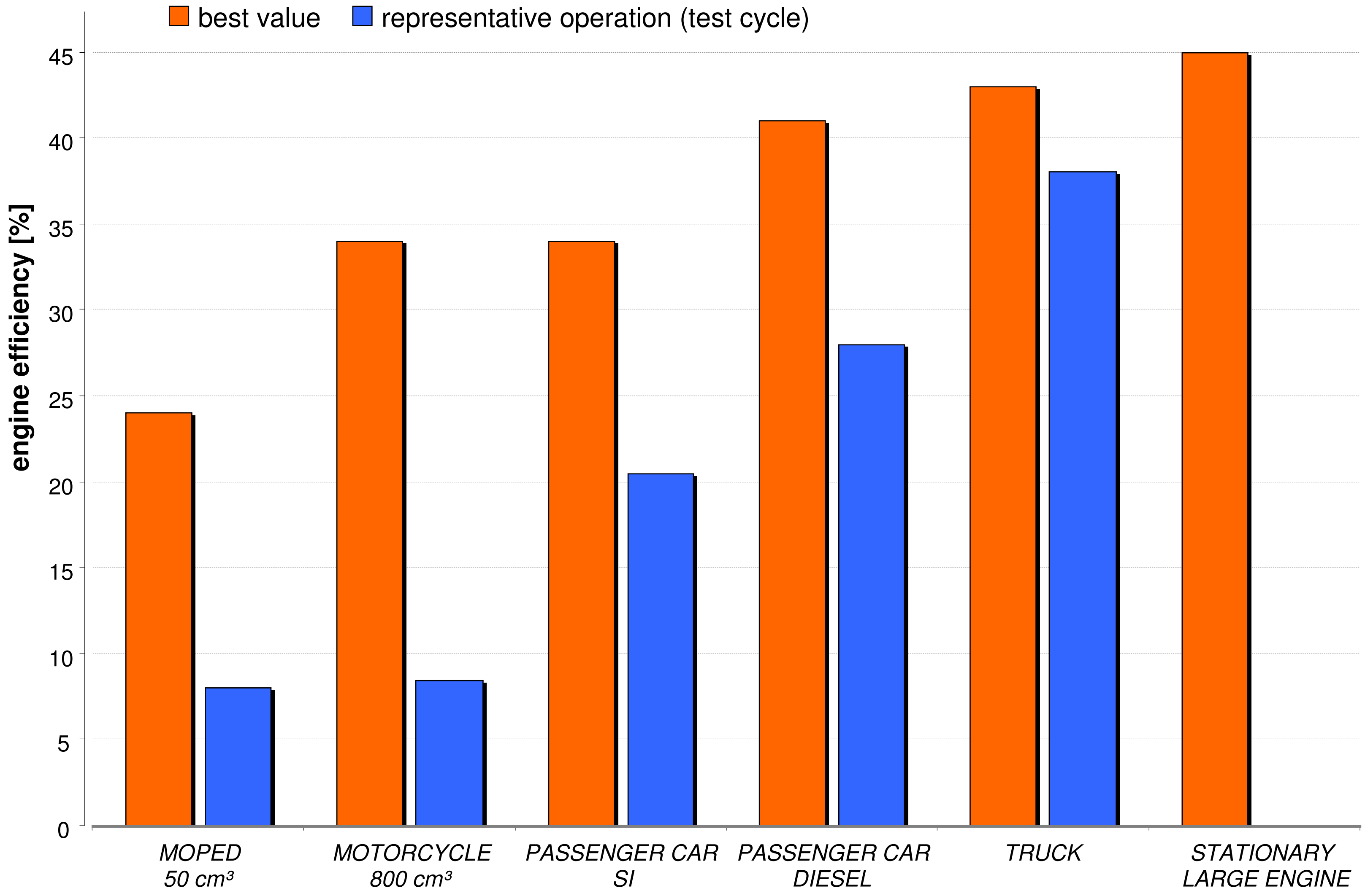


Efficiency of the ideal engine

- Constant volume-constant pressure combustion
- Peak pressure limitation

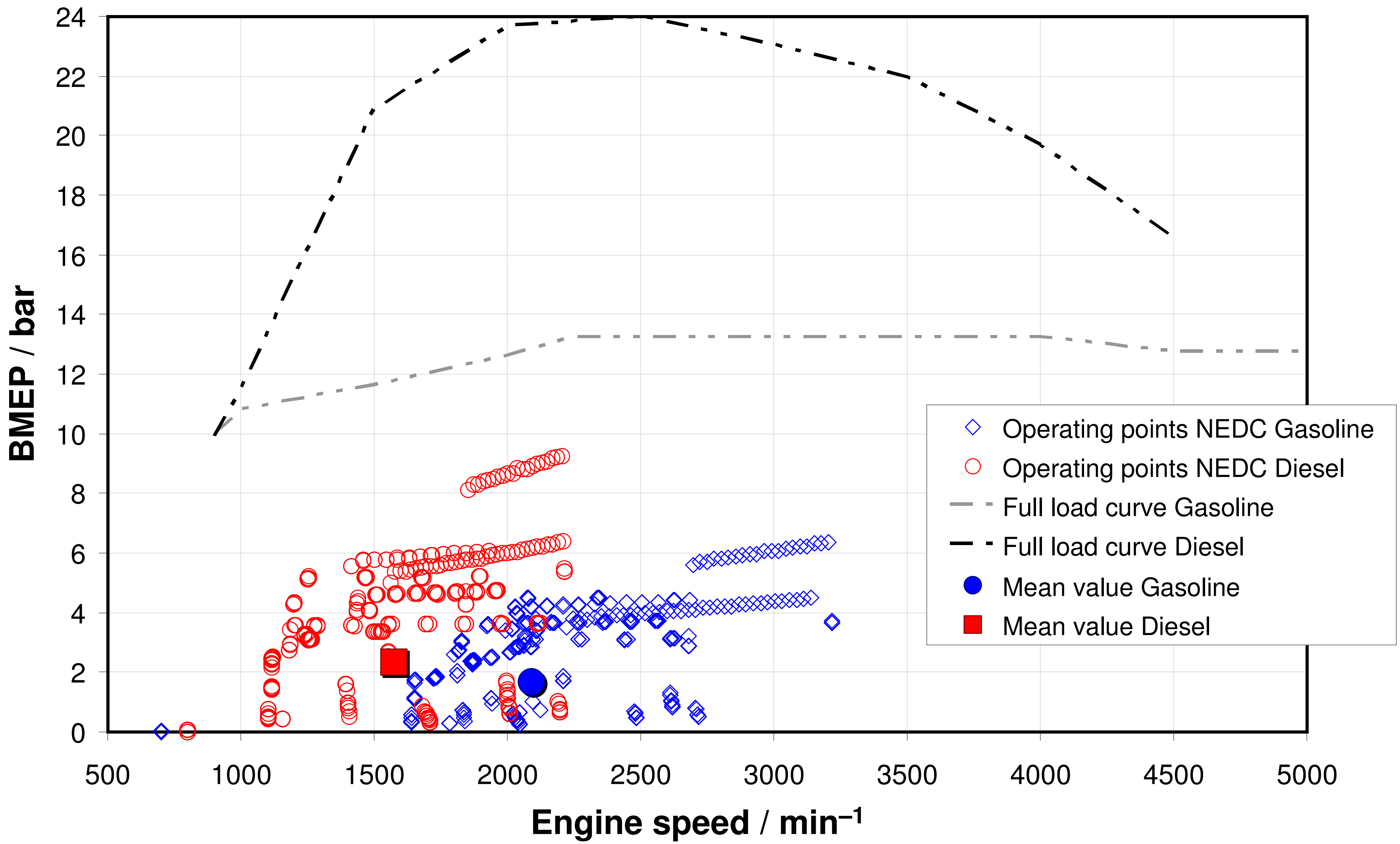
Efficiency of real engines

Engine Categories - Comparison



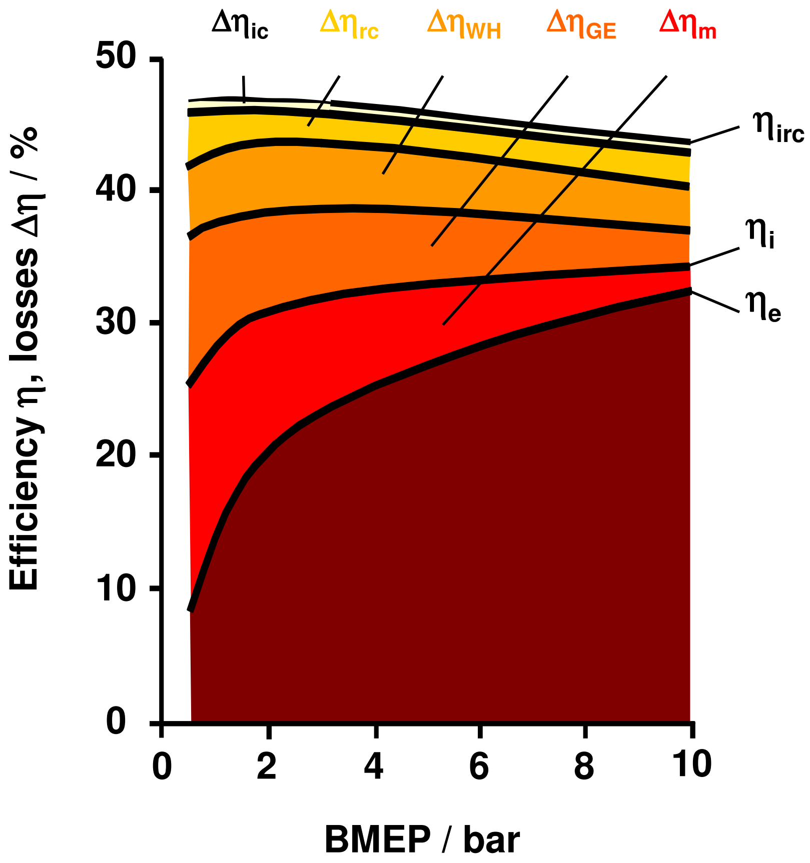
Efficiency increase by shift of operation point

Example Diesel vs. Gasoline: 2.0 dm^3 engine in equal vehicle



Efficiency increase by de-throttling and load shift

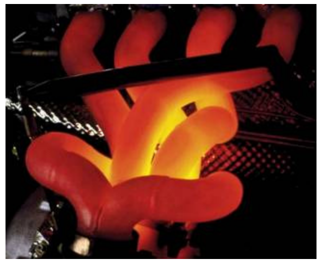
Example: MPI Gasoline engine ($\lambda = 1$)



Lean Operation

Fully variable valve train

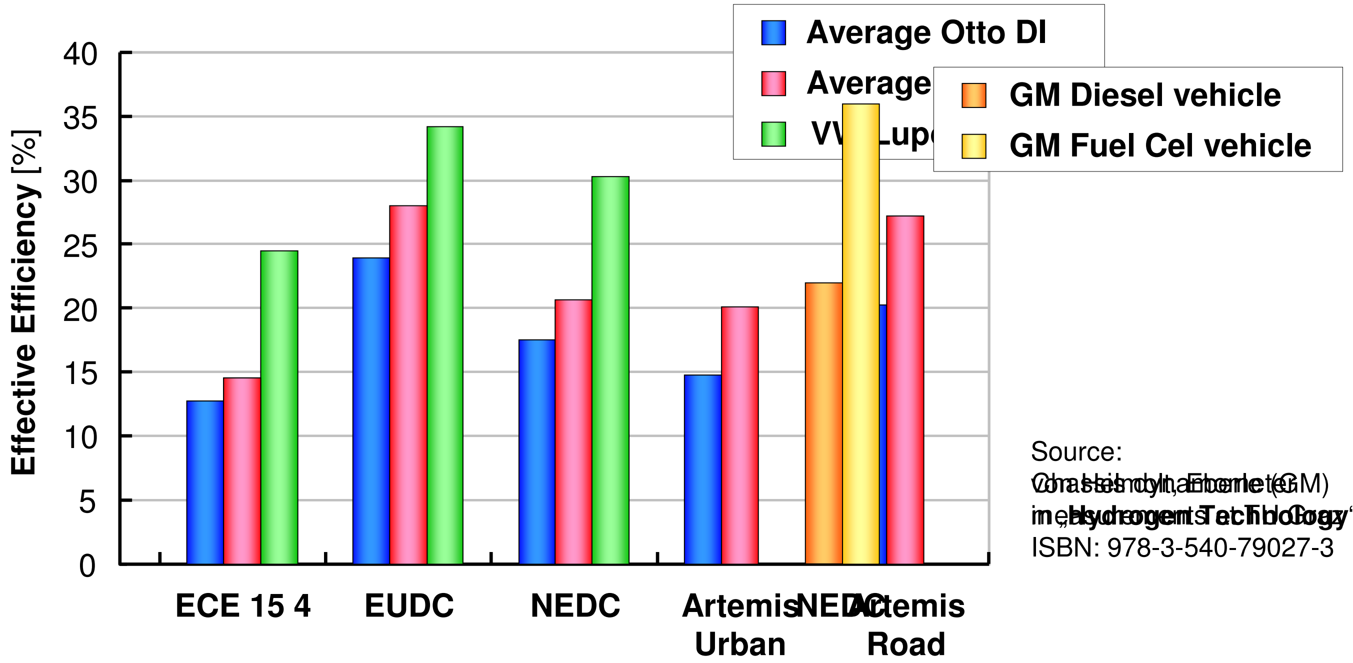
Cylinder deactivation



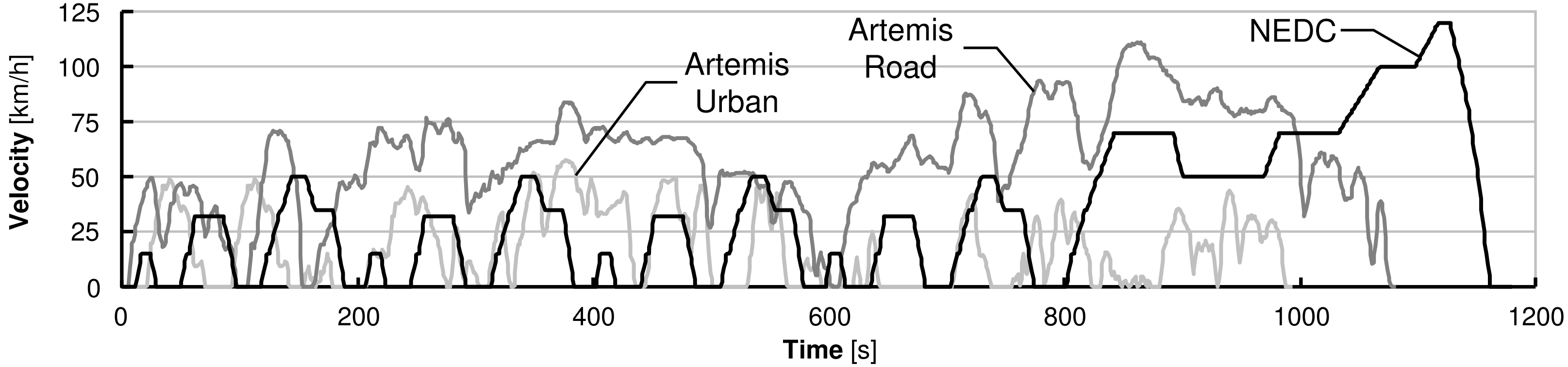
Downsizing
(Gasoline DI TC, Diesel 2stage TC)

Electrification/ Hybrid

Effective efficiency of passenger car drivetrains



Source:
von Helmolt, Eberle (GM)
in „Hydrogen Technology“
Chassis dynamometer
measurements at TU Graz
ISBN: 978-3-540-79027-3



Further potential for efficiency improvement

- **Electrification / Hybridization**
  - Start/Stop
  - Shift of operating point
  - Energy recovery
  - Electric drive in low load/speed
- **Thermal management for improved warm up**
- **Waste heat recovery**

Increase of system efficiency

Waste heat recovery – Concepts

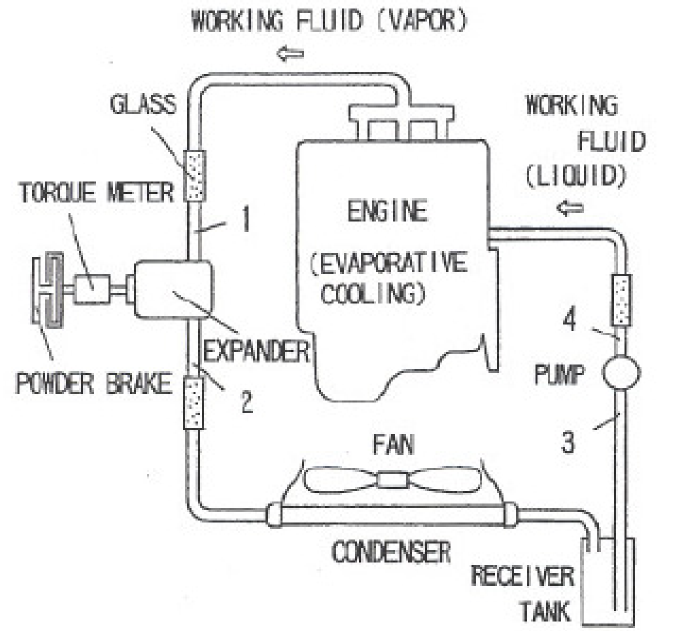


Fig. 5 Evaporative engine cooling system and rankine bottoming system

Lit.: SAE 930880, 1993 (Toyota)

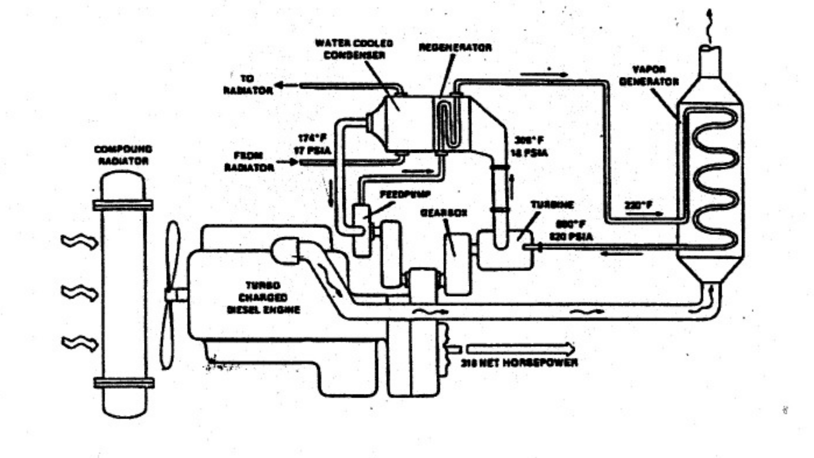
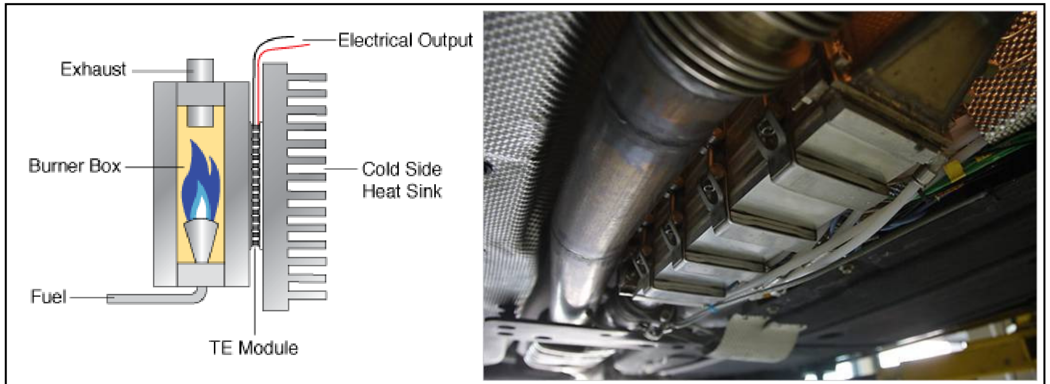


Fig. 1 – Schematic of the diesel-organic Rankine compound engine for long-haul trucks

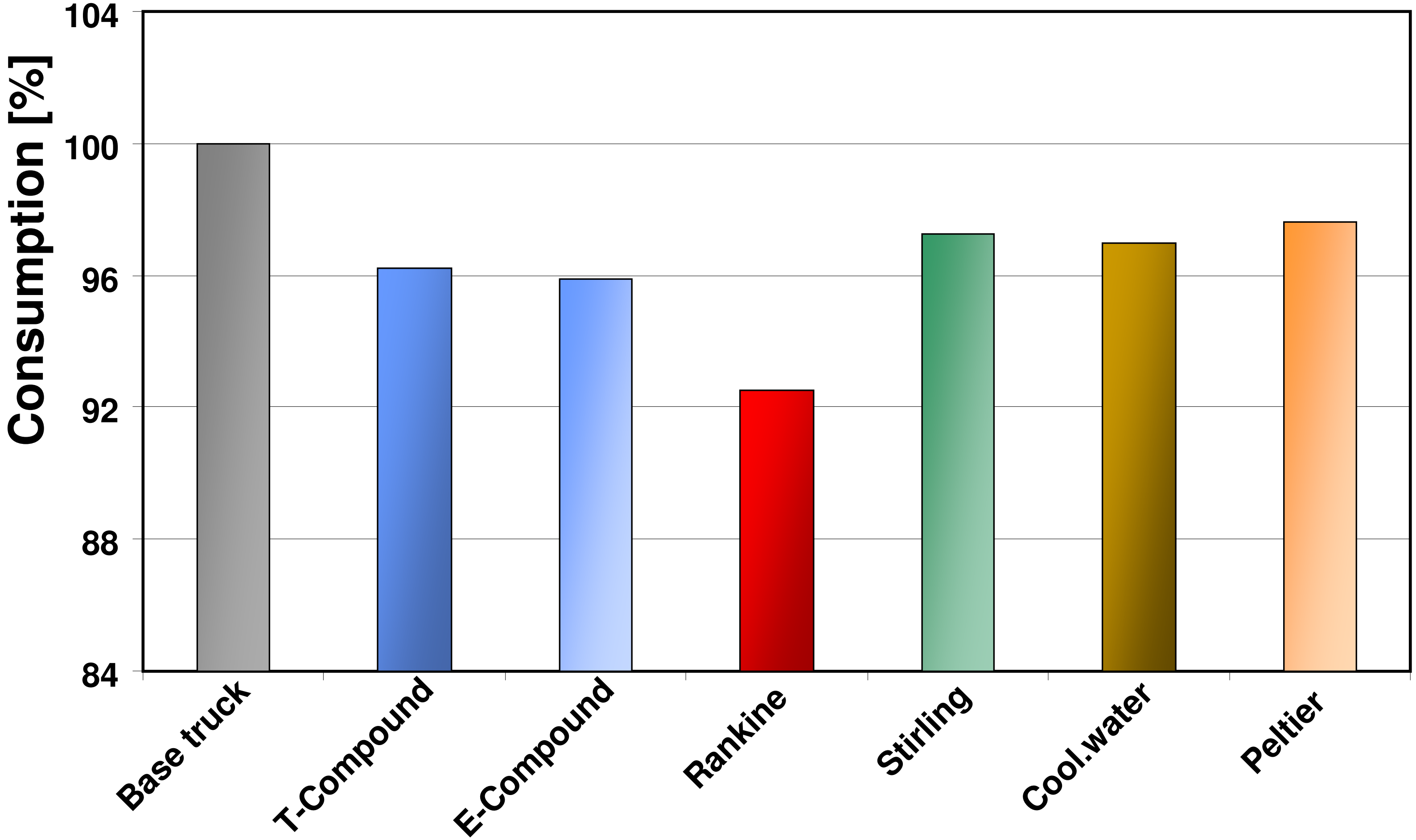
Lit.: SAE 790646, 1979



Thermoelectric generator / source: BMW

Increase of system efficiency

Waste heat recovery – Potential for trucks



Source: Gstrein, FPT (Iveco)

Thermodynamic Potential and Limits

Challenges and risks for IC engines

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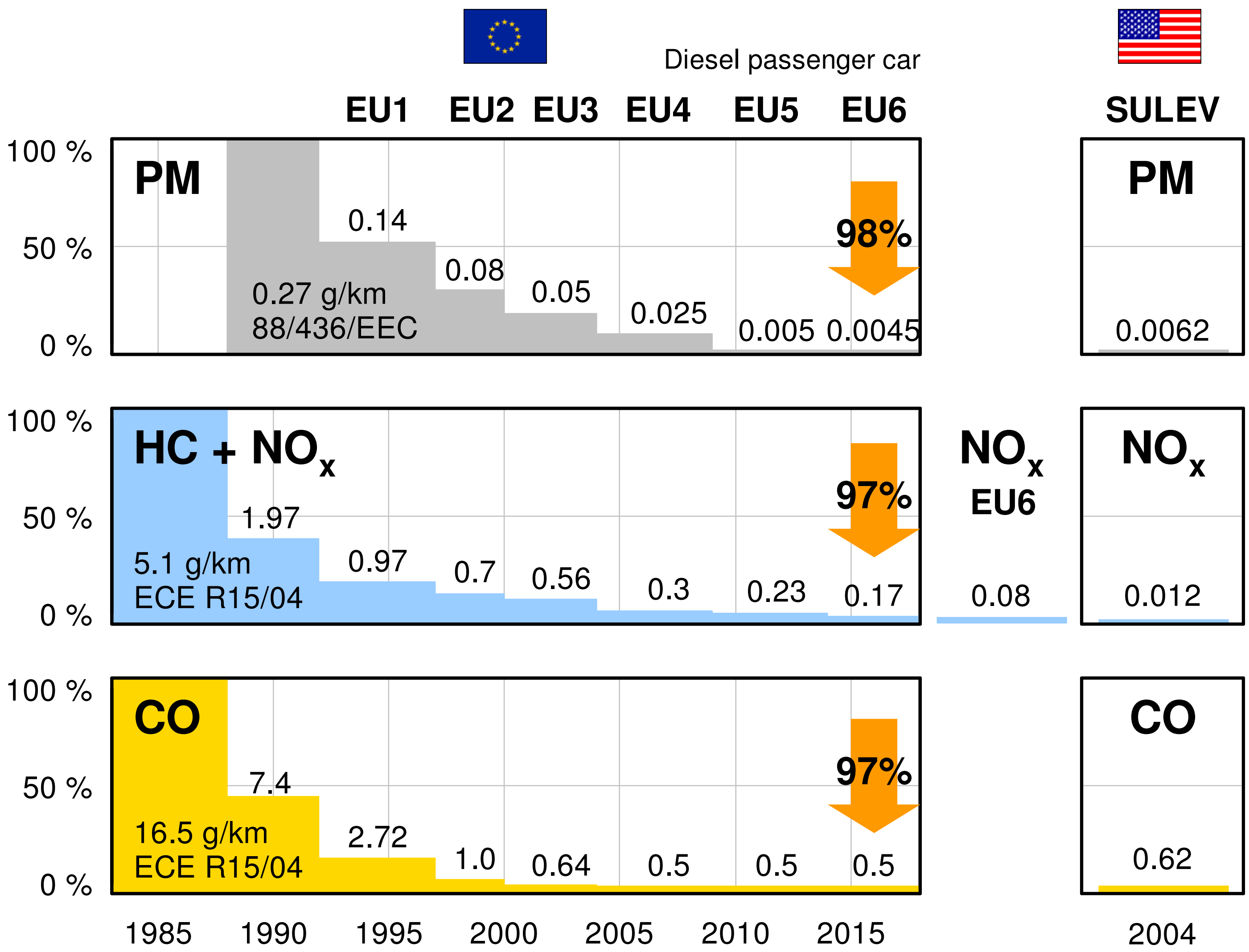
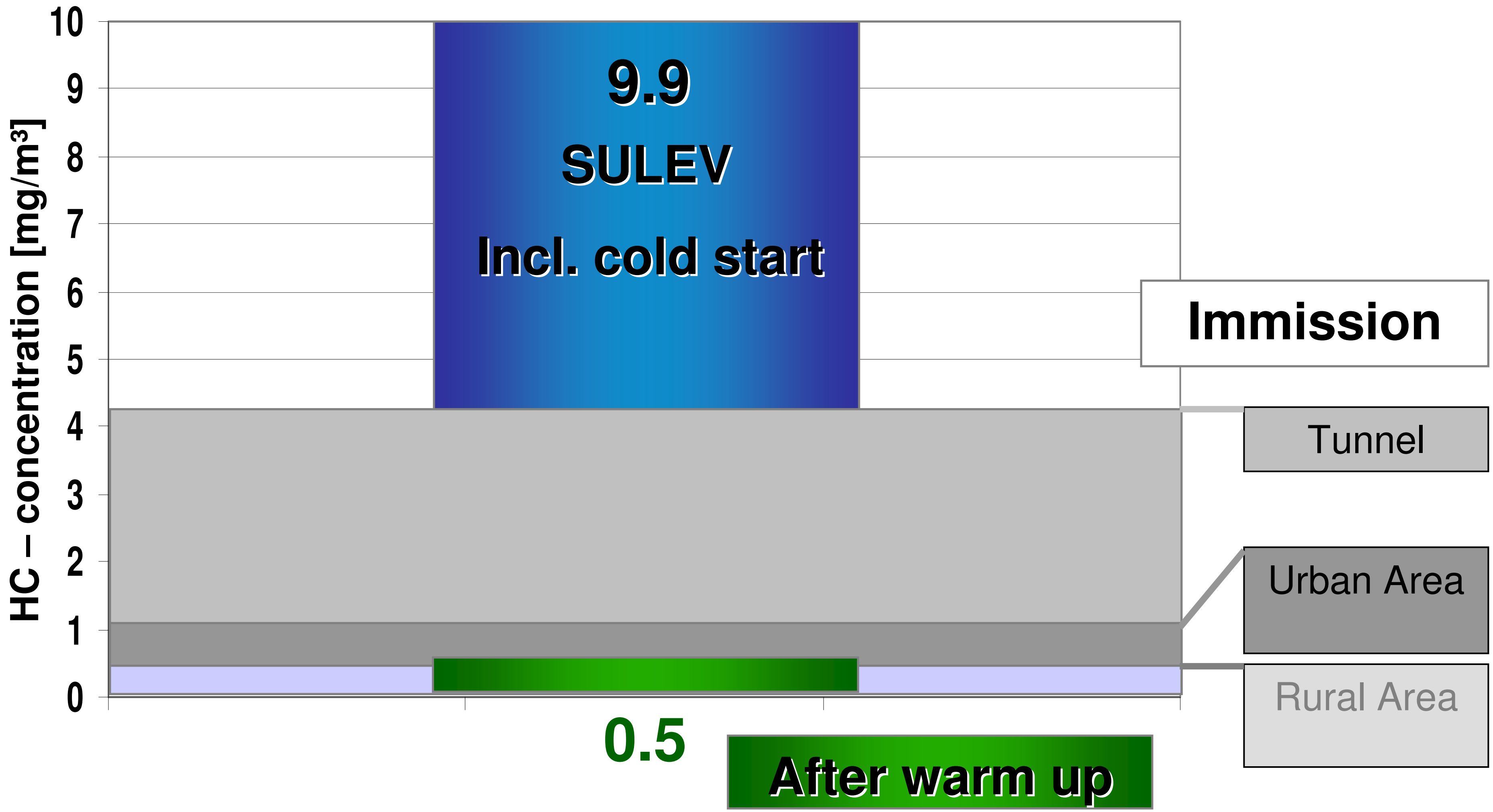
Emission – standards

Example: Passenger car diesel engines



Emission Legislation

SULEV HC Emission and Immission



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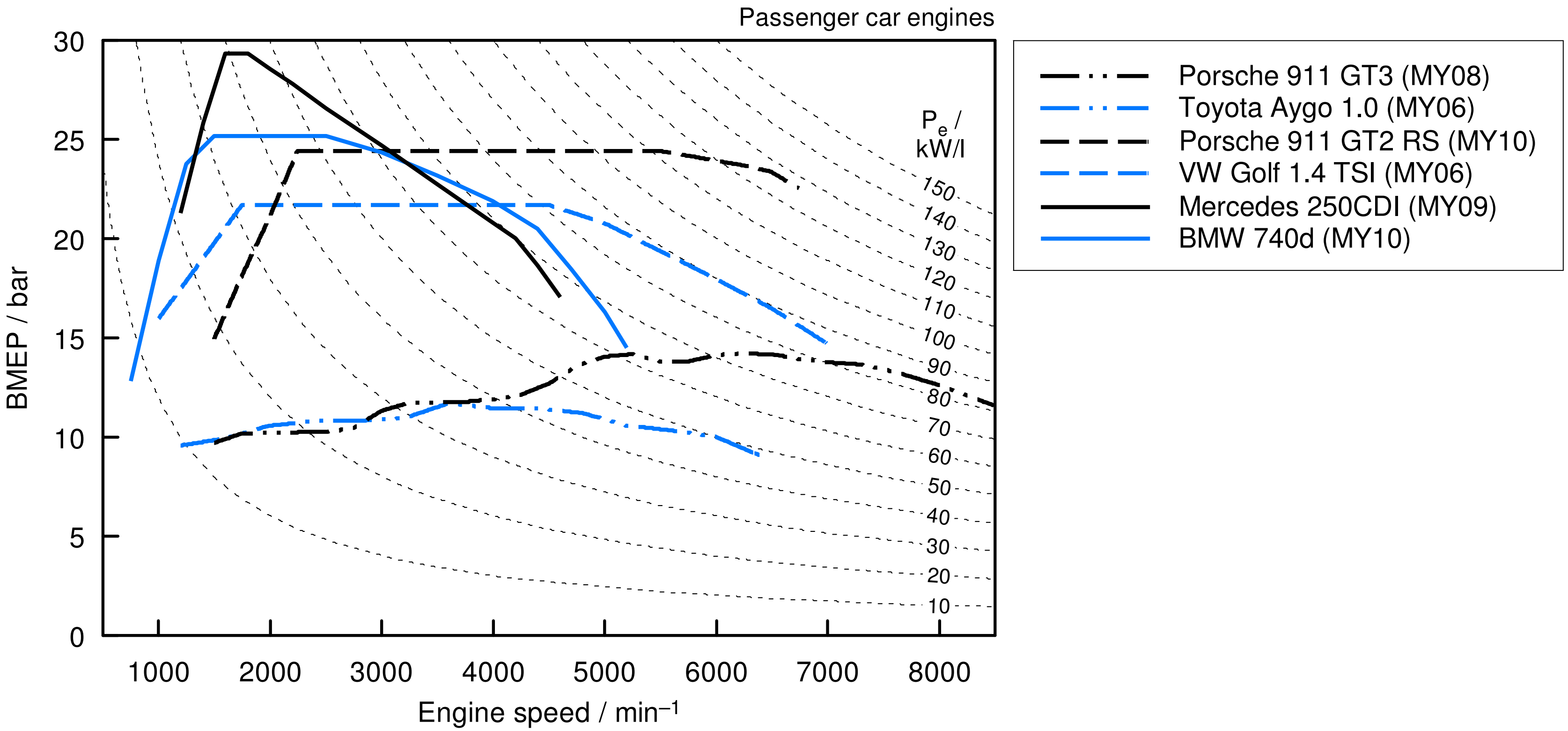
BMEP of NA and Supercharged Engines

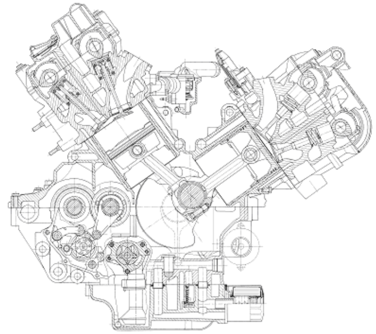


Specific power – potential Gasoline

Speed

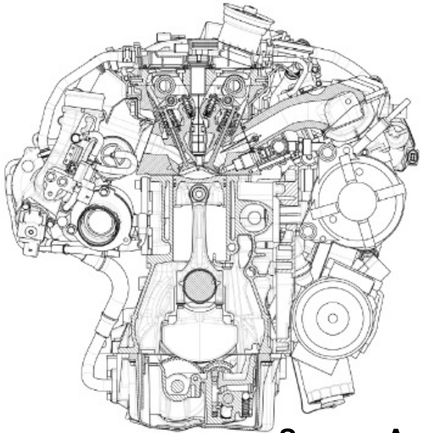

Source: BMW

- Exclusive applications
- Excellent transient behaviour
- Sport- and racing vehicles
- High effort

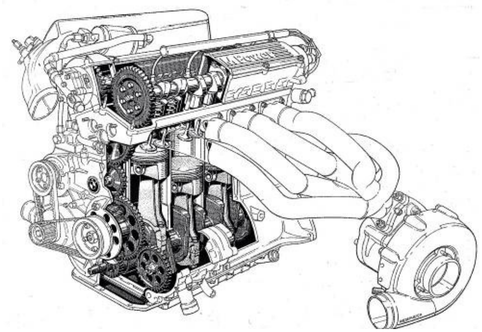


Specific power 140 kW/l in series (motorcycle)

Turbo-charging


Source: Audi

- Wide application
- Synergy with DI
- Downsizing possible
- Cost efficient

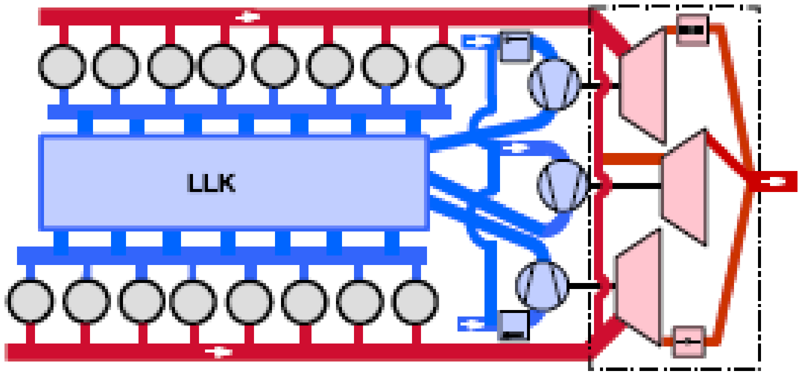


Specific power >700 kW/l
Durability 3 laps (qualifying)

Specific power – potential Diesel

- **High speed concept not possible due to combustion speed**

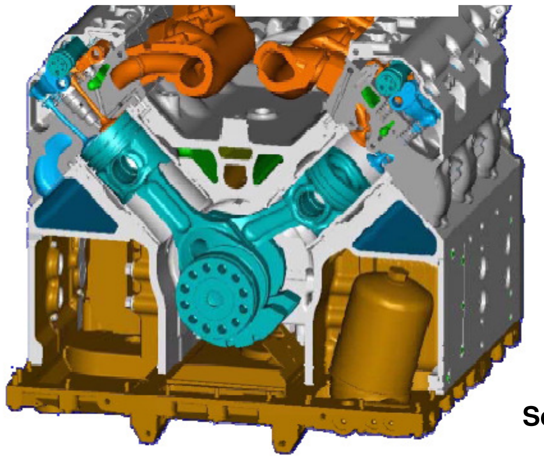
- **Increase of supercharging possible also as two stage TC no thermodynamic limit obvious, mechanic and thermal limit**



Source: MTU

- **Example for complex and effective turbocharging: power boats and military applications**

- **Spec. power 100 kW/l in series production**



Source: MTU

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Alternative fuels Assessment

	Use of existing Infrastructure	Application on engine	Environment (Greenhouse)	Environment (Local)	Remarks
Bio Diesel	++	+ (PM-Filter)	+ (-50%)	0	20% blending expected until 2020
Ethanol	++	+	+	0	Blending, Sugar Cane+
Natural Gas	-	+ (knock resist.)	+ (-25%)	+ (D) 0 (G)	Fossil Fuel; Operation Range
Auto Gas (Propane)	o	o/-	+ (-10%)	+ (D) 0 (G)	Fossil Fuel
BTL (Biomass to Liquid)	-	++	0/+	(+)	Energy demand for production
Biogas	--	+	++	0	similar to natural gas
Vegetable Oil	-	-	+	-	Limited Availability
Hydrogen	--	+	++ (renewable)	++	Energy Carrier !; ICE + FC
Electric Energy	-		++ (renewable)	++	Based on renewable energy

➢ **Increasing share and variety, but no single „patent“ solution**

Concept Vehicle TU Graz/HyCentA

Multi Fuel

Multivalent with
Methane, Biogas and Hydrogen
in one Fuel System and

Gasoline

Summary

Conclusions

- Essential efficiency improvement by advanced combustion concepts in combination with load shift technologies (downsizing) possible
- Technology variety of SI engines continued (TC, MPI/DI, cyl. deactivation, VVT, DI stratified), key technologies will be turbocharging+DI
- Electrification of ICE (mainly Mild Hybrid) increasing
- Remarkable potential of Energy management (warm up, use of waste energy) and friction reduction
- Important challenge is reduction of CO_2 fleet-emission, EU target of 95 g/km (2020) seems feasible (and most effective) with „reasonable"(cost-efficient) ICE
- IC engine with „zero impact" toxic emissions possible (λ=1 gasoline)
- ICE gives excellent base for Alternative Fuels
- ICE for > 20 years dominating propulsion system

Thank you for your attention

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