Technologies to achieve the CO2-targets for passenger cars

Martin Rauscher

Gasoline Systems
Technologies to achieve the CO2-targets for PC

Agenda

Market drivers for future vehicle developments

CO2 – emissions legislation

Status

  CO2 emissions of vehicles sold in Europe
  Technology trends

Potentials of powertrain measures

  Engine measures
  Start stop coasting
  E-mobility

  Combinations of different measures

Summary
Major market drivers for powertrain improvement

**Fuel Economy / CO₂**
- CO₂ fleet targets
  - W-EU: 130/95g CO₂/km
  - US CAFE: 34,1 mpg in 2016
- Fuel availability ("Peak Oil")

**Driving comfort**
- Noise, vibration, harshness
- Shift- & launch quality
- Easy driving

**Emissions & Diagnosis**
- EU6 (PM/PN, ext. EOBD)
- LEV III (SULEV20, PM)
- Worldwide Driving Cycle
- Real Driving Emissions

**Variants**
- Globalization
- Powertrain & vehicle diversification
- Fuel differences

**Fun to Drive**
- Power and low end torque
- Response time (dynamics)

**Quality and Safety**
- Reliability, Robustness
- ISO26262

**City Restrictions**
- Ban on driving
- Specific traffic lane, parking

**Image & Emotions**
- Fuel Economy Labeling
- Willingness to pay for green image and emotions

**Costs**
- Affordable mobility (price, TCO)
- OEM entry efforts (invest, E&A)
- Incentives and taxation

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Technologies to achieve the CO2-targets for PC

Development CO2 Fleet Targets

CO2 (g/km) vs. L/100 km graph showing targets for EU, US, Japan, China, and Korea for 2010, 2015, and 2020.

CAFE = Corporate Average Fuel Economy  PC = Pass. Cars  LT / LDT = Light Trucks (pick-ups, vans, SUVs)  MD(P)V = Medium Duty (Pass.) Vehicles  LCV Light Commercial Vehicles

gasoline (diesel)

<table>
<thead>
<tr>
<th>Year</th>
<th>EU PC</th>
<th>US CAFÉ</th>
<th>Japan</th>
<th>China</th>
<th>Korea</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>183</td>
<td>229</td>
<td>192</td>
<td>175</td>
<td>146</td>
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<tr>
<td>2015</td>
<td>166</td>
<td>217</td>
<td>192</td>
<td>175</td>
<td>146</td>
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<tr>
<td>2020</td>
<td>147</td>
<td>166</td>
<td>166</td>
<td>146</td>
<td>119</td>
</tr>
</tbody>
</table>

CAFE LT/MDV

proposed

mpg

8.6
7.5
6.4
5.7
4.3
3.8
2.1
1.9

g/km

22.3
24.9
36.5
41.6
54.8
62.3
110
125

EU LCV

EU PC

CAFE PC

CAFE LT/MDV
Technologies to achieve the CO2-targets for PC

Overview GS engine measures for efficiency

**ICE PT Efficiency**

- **De-throttling**
- **ICE Operation points**
- **Best Efficiency Operation**
- **Energy Recuperation**

### Technologies

- **eDZ**
  - Extreme Downsizing
  - (downsizing to 1.1L)

- **CDA**
  - Cylinder Deactivation
  - half engine operation w/ switching

- **LB**
  - Lean Burn
  - (lambda >1 combustion, EGR)

- **OC**
  - Optimized Combustion
  - (charge motion, $\varepsilon$)

- **FR**
  - ICE Friction Reduction
  - (electric auxiliaries & extr. mech. friction)

- **DoSp**
  - Downspeeding
  - (gear ratios, shifting, $n_{max}$)

- **S/S**
  - Start/Stop
  - (no idle operation in stand-still)

- **SSC**
  - Start/Stop Coasting

- **ReCu**
  - Electric Recuperation
  - (for example w/ 48V BRS)
Technologies to achieve the CO2-targets for PC

Europe: Overview Vehicle CO₂ emissions

<table>
<thead>
<tr>
<th>Curb weight [kg]</th>
<th>Diesel SI</th>
<th>Hybrid</th>
<th>Best in Class SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1200</td>
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<td></td>
</tr>
<tr>
<td>1400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1600</td>
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<td></td>
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<tr>
<td>1800</td>
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<td></td>
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<tr>
<td>2000</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2200</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CO₂ emission [g/km]

- Diesel
- SI
- Hybrid
- Best in Class SI

Quelle: DAT CO₂Leitfaden
Europe: Cars with low CO$_2$ emissions

Technologies to achieve the CO2-targets for PC

Gasoline Systems

Quelle: DAT CO$_2$Leitfaden
Technologies to achieve the CO2-targets for PC

FE for Compact Class vehicle *

<table>
<thead>
<tr>
<th>CO2 g/km</th>
<th>Base</th>
<th>Downspeeding</th>
<th>Optimized combustion</th>
<th>De-throttling lean-burn</th>
<th>friction reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>140</td>
<td>130</td>
<td>120</td>
<td>110</td>
<td>95</td>
</tr>
</tbody>
</table>

**ASSUMPTIONS**

- **DoSp**: Further Downspeeding: adaption of final drive (20%) improved boosting system
- **OC**: Optimized Combustion: reduction of unburned fuel ε +2 units (const. knock)
- **LB**: Red. of throttling losses red. by 70%: stratified and/or lean burn, ideal exhaust after-treatment
- **FR**: Engine friction reduction

**Geometric Mean**

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>I4, 1.4 l, DI / TC, 100 kW</td>
<td></td>
</tr>
<tr>
<td>I3, 1.1 l, DI / TC, 100 kW</td>
<td></td>
</tr>
</tbody>
</table>

*) 1400 kg, MT

Gasoline Systems

Technologies to achieve the CO2-targets for PC

Evolution of Start/Stop

-$\sim$120 km/h

Advanced Start/Stop, Stop-in-Gear

$10 - 20 \text{ km/h}$

Start/Stop Coasting

$\sim 120 \text{ km/h}$

Start/Stop & Start/Stop Eco

$\sim 0 \text{ km/h}$

CO$_2$ targets 2012

CO$_2$ targets 2015ff

CO$_2$ targets beyond 2015ff

Time line
Technologies to achieve the CO2-targets for PC

„Start/Stop Coasting“ (SSC): Overview

**Start/Stop Coasting**
- drivetrain open & engine off
- effect: reduced drag torque
- increased rolling distance

**starter system**
- starter cycles, CoM ability, start time, NVH
- pinion starter & clutch start OR advanced starter systems/BRS (up to 600k starts)

**power net**
- cyclic load & redundancy (~37% engine-off time in comparison to ~10% with Start/Stop)
- two energy sources (e.g. 2 batt.-PN)

**transmission**
- DCT - dry, AMT
- AT, CVT, DCT - wet
- none
- advanced hydr. system, el. oil pump, ...

**steering**
- electrification: el./el.-hydr. power steering
- base in most vehicles
Technologies to achieve the CO2-targets for PC

**CO2 benefit**

<table>
<thead>
<tr>
<th>Official test cycles TODAY</th>
<th>Official test cycle ≥2014...2020</th>
<th>Real-life cycle (Stuttgart cycle)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NEDC</strong></td>
<td><strong>WLTC (V4)</strong></td>
<td><strong>normal</strong></td>
</tr>
<tr>
<td>no Coasting</td>
<td>21% SSC share</td>
<td>27% SSC share</td>
</tr>
<tr>
<td>base: 6.18 l/100km</td>
<td>base: 6.36 l/100km</td>
<td>base: 6.62 l/100km</td>
</tr>
<tr>
<td><strong>FTP75</strong></td>
<td></td>
<td><strong>max. eco.</strong></td>
</tr>
<tr>
<td>20% SSC share</td>
<td></td>
<td>47% SSC share</td>
</tr>
<tr>
<td>base: 6.21 l/100km</td>
<td></td>
<td>base: up to 6.62 l/100km</td>
</tr>
</tbody>
</table>

**Start/Stop**

- **Coasting**
  - SSC: ~0% (NEDC), ~0% (FTP75)
  - IDC: 5%
- **Start/Stop**
  - SSC: ~2% (WLTC)
  - IDC: ~2% (NEDC)

**New legislation**

- SSC: up to 9% (NEDC), up to 10% (FTP75), up to 10% (WLTC)
- IDC: ~2% (NEDC), ~2% (FTP75), ~2% (WLTC)

**base:** Compact Class, 1.4L DI-TC gasoline, 7-gear DCT (dry, el-hyd), w/o St/St, w/ intelligent generator control, Power net: P_e=300W
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Powertrain Electrification

Electrification of Auxillaries

- Mechanical Coupled, e.g.:
  - engine fan
  - water pump
  - steering pump

- Electrified, e.g.:
  - switched fan
  - elec. water pump
  - elec. steering

- Sophisticated Control, e.g.:
  - PWM fan
  - thermal management
  - generator control

Overall energy efficient vehicle, e.g.:
- X by Wire
- C2X
- Smart HMI
- ...

Electrification of Propulsion

- Start / Stop
- Advanced Recuperation
- Mild Hybrid
- EV with REX

- Start / Stop Coasting
- Electrical Torque Assist
- Strong Hybrid
- Pure EV
- Plugin Hybrid
- ...
Technologies to achieve the CO2-targets for PC

**e-Drive System**

<table>
<thead>
<tr>
<th>Hybrid Systems</th>
<th>Electr. Vehicle Systems</th>
<th>Bosch Electric Powertrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild HEV</td>
<td>70%</td>
<td>e-Machine as Performance EV</td>
</tr>
<tr>
<td>Strong HEV</td>
<td>20%</td>
<td>Separate Motor Generator</td>
</tr>
<tr>
<td>Plug-in HEV</td>
<td>20%</td>
<td>e-Machine as Integrated Motor Generator</td>
</tr>
<tr>
<td>City EV</td>
<td>40%</td>
<td>Inverter with Integrated Converter</td>
</tr>
<tr>
<td>Compact EV</td>
<td>40%</td>
<td></td>
</tr>
</tbody>
</table>

Market shares 2015

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Technologies to achieve the CO2-targets for PC

CO2-benefit vs. cost for CC vehicle base 2020

- **ICE power reduction**
- **Vehicle size reduction**
- **PHEV**
  - Real-life CO2 depends on driving range patterns.
  - Higher driving performance due to electric add-on torque.
  - Min e-range required to satisfy consumer expectations of e-motion

- **SI-ICE**
  - Highest CO2/cost-benefit w/ cost efficient measures.
  - 95g for gasoline w/ ICE measures possible

- **OEM add-on system cost**
- **Base**
  - I4, 1.4 l, DI / TC, 100 kW
- **PHEV**
  - G0 20km
  - G1 10km
  - G1 30km
  - G1 HEV

- **Gasoline Systems**

Summary

The CO2 limit of 130 g/km can be achieved with today’s technologies for SI engines in compact class.

This was achieved by a summary of detail optimizations.

Downsizing and Gasoline direct injection are mainstream measures.

Coasting allows further reduction of more than 10%.

Additional improvements are only achievable with hybridisation.

Willingness to pay for electrified powertrains depends on tangible end consumer benefits.