WAYS TOWARDS LOW CO2 AND LOW EMISSION POWERTRAINS

Solihull; 01 March 2018

Bernhard Biermann; Jörn Behrenroth; Tim Burchell
CO₂ and PM/NOₓ emissions are the major drivers to reduce fuel consumption and harmful emissions especially in inner cities.

Global warming

- CO₂ concentration in atmosphere have never been higher in the past three million years.

Atmospheric CO₂ at Mauna Loa Observatory

Decreasing harmful NOₓ locally (example Germany)

- NO₂ Emissions at locations with high traffic density has permanently improved, but is still too high.

NO₂ annual mean value [µg/m³]

Source: https://www.theguardian.com/environment/2017/oct/30/global-atmospheric-co2-levels-hit-record-high; Environmental Agency Germany; ADAC
By 2030 CO₂ emission target values will be reduced significantly in all major automotive markets (EU, USA, China)

**FUEL ECONOMY / GHG / CO₂ REGULATION**

<table>
<thead>
<tr>
<th>Confirmed</th>
<th>Proposed target (under review)</th>
<th>Scenario*</th>
</tr>
</thead>
</table>

**EPA 2-cycle CO₂ emission in g/mi**

- Target 2015: 272
- Target 2020: 211
- Target 2025: 163
- Target 2030: 130-135

**NEDC (WLTP from 2021)**

- CO₂ emission in g/km

**Target 2015**

- Target 2020: 130
- Target 2025: 95
- Target 2030: 60-65

**POLITICAL-REGULATORY ENVIRONMENT**

**NEDC CO₂ emission in g/km**

- Target 2015: 167
- Target 2020: 117
- Target 2025: 80-90
- Target 2030: 60-65

NEDC = New European Driving Cycle; GHG = Greenhouse Gas

* EU: based on GHG reduction targets for transport sector by European Commission; US: 4% annual reduction assumed after 2025; China: convergence with EU targets expected

/ CN figures are converted from l/km

Source: ICCT, European Commission, ACEA, FEV

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CO₂ emission of new vehicle registrations in EU market are at 118 g/km in 2016, reduction of ~45% has to be achieved to reach 2030 scenario target.

FLEET-AVERAGE PASSENGER CAR CO₂-EMISSION BY AUTOMAKER¹ IN EUROPE

automaker indicated w/ hollow symbols are < 300,000 units per year
¹considering manufacturer pooling;
²new provision expected as WLTP will be applied after 2021;
Source: EEA (provisional EU-28 data for 2016); FEV

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Scenarios for achieving the +2°C target
Work packages in the passenger car powertrain

BOSCH PRESENTATION DURING ZERO CO2 MOBILITY CONFERENCE 09 NOV. 2017

Share (2050)
- Fuel Cell EV: 18%
- EV: 23%
- PHEV gasoline: 31%
- PHEV diesel: 4.6%
- Diesel hybrid: 0.4%
- Gasoline hybrid: 14%
- CNG/LPG: 4.0%
- Diesel: 0.9%
- Gasoline: 4.1%

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For European market FEV expects a major shift to plug-in and battery electric vehicles – distribution mainly depending on customer preferences.
Compatibility of e-fuel with current vehicle fleet is required to have high impact on CO₂ emission reduction

MARKET PENETRATION AND ITS IMPACT ON GHG REDUCTION

- Introduction of new technology and its market penetration takes time
- Disruptive technology changes will have an impact with a significant delay time
- E-fuels which are compatible with current vehicle fleet have highest potential for a significant CO₂ emission reduction short term

http://ec.europa.eu/eurostat: Stock of vehicles by category and NUTS 2 regions

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Vehicle hybridization can come in various forms from simple stop-start systems to full electric drive modes.

Conventional Vehicle

- Gear Box
- Fuel Tank

Hybrid Electric Vehicles

- Micro Hybrid
- Mild Hybrid
- Full Hybrid (Parallel/Power-Split/Serial)
- Plug-In Hybrid / Range Extender
  - Pure Electric Drive
  - Charging from grid
  - Electric Take-off
  - Engine Assistance
  - Kinetic Energy Recovery

Start-Stop

Hybridization aims at assisting the combustion engine

Hybridization aims at running the vehicle by electric propulsion

Increasing electrical power & voltage level

Battery Electric Vehicles

- Battery

Fuel-Cell Electric Vehicle

- Fuel Cell
- H₂ Storage
- Air Compr.

Battery size/price

CO₂-emissions

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FEV Water Injection Demo Car – Water Injection is considered by several OEM for future engines as it helps both for CO₂ and for exhaust emissions.

- Baseline enrichment without water injection: Lambda = 0.82
- Enrichment with water injection and 10 % more power: Lambda = 0.9
- ~ 71 kW/l @ Lambda = 1 @ 22 bar BMEP
- ~ 90 kW/l @ Lambda = 1 @ 22 bar BMEP (without dedicated calibration to achieve highest possible spec. power at Lambda = 1)

Δ 20 kW/l+ @ λ=1

IEM, 980 °C, RON98, TC
Introducing synthetic diesel fuel could lower the well-to-wheel CO$_2$ emissions drastically on current vehicle fleet.

**CONVENTIONAL VEHICLE**

Advanced paraffinic / alcoholic fuels have been tested on TMFB* demonstrator:
- 4-cylinder Diesel engine (OM651)
- EURO VI Legislation
- DOC & DPF exhaust aftertreatment
- High- and low pressure EGR

Changing the fuel used by the currently existing vehicle fleet can reduce well-to-wheel CO$_2$ emissions immediately (if compliant with fuel norm EN590 → 20% 1-Octanol)

* TMFB: Excellence cluster Tailor-Made Fuels from Bio-mass
Source: FEV
Outlook Future Diesel Powertrain reflects electrification trend - Results overview for SUV-like Application with 48 V eCompressor

DIESEL POTENTIAL THROUGH HYBRIDIZATION

Source: FEV

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FEV has developed Electric Drive Units for different applications; these units appear to be very powerful to reduce CO$_2$ and support drivability.

**FULL HYBRID (PARALLEL / POWER-SPLIT / SERIAL)**

**Coaxial EDU**
- Integrated unit of E-motor, transmission, park lock & dual inverter
- High power density up to 3 kW/kg; designed for 6 Phase EM
- E-Motor 500 Nm / 230 kW; wheel torque 3500 Nm, max speed 180 km/h

**2-speed powershift EDU with neutral function**
- Power: 300 kW peak / 150 kW cont.
- Maximum torque: E-motor 500 Nm / axle 6.000 Nm
- Vehicle top speed capability: > 200 km/h
- System weight (total, dry): < 85 kg
Still high barriers to purchase BEVs – trend to range extender ICEs

**PLUG-IN HYBRID / RANGE EXTENDER**

Barriers to purchase electric vehicle
Most commonly cited barriers to purchase are related to limitations in EV technology and current EV model selection …

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Percentage of responses, US &amp; Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase price</td>
<td>25</td>
</tr>
<tr>
<td>Driving range</td>
<td>24</td>
</tr>
<tr>
<td>Charging</td>
<td>18</td>
</tr>
<tr>
<td>Model variety</td>
<td>13</td>
</tr>
</tbody>
</table>

Solution Range Extender (fully balanced)

- **Save battery size**
- **Extend driving range**
- **Less dependency on infrastructure**

Dedicated gasoline engine: small operating range with high efficiency, compact design, lightweight and best NVH

PLUG-IN HYBRID / RANGE EXTENDER

Less important are …

… low-end-torque, engine dynamics and part load efficiency

operation strategy charge sustain mode
To achieve the targeted CO$_2$ emission reductions, a simultaneous use of fleet electrification, fuel cell vehicles and synthetic fuels is mandatory.

WELL-TO-WHEEL CO2 EMISSIONS

Source: CLEPA European Association of Automotive Suppliers

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Conclusions

All different solutions to lower CO₂ emissions need to be applied:
- Higher Efficiency
- E-mobility
- Synthetic fuels, fuel cells

Not one route only

For higher market penetration
- costs,
- legislation and
- consumer behavior are the main challenges to be solved.

Market challenges

In any case to achieve 2050 targets, a significantly higher ratio of renewable energy production is required.

Demand on energy

Source: FEV
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AND LOW EMISSION POWERTRAINS

Thank you!
Questions?