Key Note Presentation

Prepared for

Automotive Congress Eindhoven 2018

Eindhoven; 23 Mai 2018
Edwin Kingma, Bernhard Biermann

FUTURE OF LOW EMISSION POWERTRAINS
FROM TECHNOLOGY PERSPECTIVE
Future of low emission powertrains from technology perspective

STORYLINE

- Short Intro FEV
- Drivers to reduce fuel consumption and current targets
- How to reduce pollutants and CO2 technology wise
- Realistic approach coming decennia
- Improve existing technologies
- Available new propulsion technologies
Your engineering partner worldwide

- Independent engineering company
- Supporting engineering developments from innovations up to SOP
- Optimizing customers products and processes
- ~530 M€ revenue in 2017
- Close to our customers:
  - 40+ subsidiaries on four continents
  - 200+ test cells for engines, transmissions, drivelines, e-machines, batteries
  - 5000+ employees globally
An independent engineering company

EXECUTIVE BOARD

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Global customers and business partners

ORIGINAL EQUIPMENT MANUFACTURER

[List of logos for various original equipment manufacturers]
Global customers and business partners

SUPPLIER

RESEARCH & DEVELOPMENT
PORTFOLIO OF SERVICES – ORGANIZATION BY BUSINESS UNITS

Including electrification
Future of low emission powertrains from technology perspective

STORYLINE

- Short Intro FEV
- Drivers to reduce fuel consumption and current targets
- How to reduce pollutants and CO2 technology wise
- Realistic approach coming decennia
- Improve existing technologies
- Available new propulsion technologies
CO₂ and PM/NOₓ emissions are the major drivers to reduce fuel consumption and harmful emissions especially in inner cities.

DIFFERENTIATE BETWEEN CO₂ AND POLLUTANTS

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

Atmospheric CO₂ at Mauna Loa Observatory

Decreasng 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]
By 2030 CO₂ emission target values will be reduced significantly in all major automotive markets (EU, USA, China)

**FUEL ECONOMY / GHG / CO₂ REGULATION**

- **Confirmed**
- **Proposed target (under review)**
- **Scenario***

NEDC (WLTP from 2021)

**CO₂ emission in g/km**

**EPA 2-cycle CO₂ emission in g/mi**

<table>
<thead>
<tr>
<th>Target 2015</th>
<th>Target 2020</th>
<th>Target 2025</th>
<th>Target 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>272</td>
<td>211</td>
<td>163</td>
<td>130-135</td>
</tr>
</tbody>
</table>

**Passenger Car and Light Trucks**

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
- Considering manufacturer pooling;
- New provision expected as WLTP will be applied after 2021;
- Source: EEA (provisional EU-28 data for 2016); FEV

1. Automotive Congress 2018

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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

**Scenarios for achieving the +2°C target**

**Work packages in the passenger car powertrain**

- **More efficient combustion engine**
- **Use of synfuels**
- **Breakthrough in e-mobility**
- **Hybridization**
- **Prepare FC technology**

**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%

**Millions of vehicles**

- 2000
- 2010
- 2020
- 2030
- 2040
- 2050

- 0
- 20
- 40
- 60
- 80
- 100
- 120
- 140
- 160

**Automotive Congress 2018**

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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.

**FUTURE POWERTRAIN SCENARIOS PASSENGER CAR – VEHICLE REGISTRATIONS**

**FEV Base Scenario**

- **2017**: 12% e-gas, 3% ICE only, 51% mild hybrid, 3% stop-start & 12V energy mgmt
- **2020**: 84% e-gas, 3% ICE only, 33% mild hybrid, 3% stop-start & 12V energy mgmt
- **2025**: 41% e-gas, 12% ICE only, 13% mild hybrid, 3% stop-start & 12V energy mgmt
- **2030**: 51% e-gas, 7% ICE only, 3% mild hybrid, 1% stop-start & 12V energy mgmt

**92% electrified drives**

**22% w/o ICE**

**CO₂ fleet emission:**
- **<95 g/km***: 84% (2017), 41% (2020), 12% (2025), 4% (2030)
- **<80 g/km**: 2% (2017), 9% (2020), 21% (2025), 21% (2030)
- **<65 g/km**: 2% (2017), 3% (2020), 4% (2025), 1% (2030)

**Scenario “Accelerated”**

- **2030**: 26% battery electric, 26% full hybrid, 3% plug-in hybrid, 5% mild hybrid, 3% stop-start & 12V energy mgmt

**Scenario “Hybrid”**

- **2030**: 3% battery electric, 44% full hybrid, 13% plug-in hybrid, 3% mild hybrid, 1% stop-start & 12V energy mgmt

Source: FEV

*Source: FEV, Kingma, Edwin, 2018-05-23_AutomotiveCongress.pptx

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Compatibility of e-fuel with current vehicle fleet is required to have high impact on CO$_2$ emission reduction

MARKET PENETRATION AND ITS IMPACT ON GREEN HOUSE GAS (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 CO$_2$ emission reduction short term

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

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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.
Introducing synthetic diesel fuel could lower the well-to-wheel CO₂ emissions drastically on current vehicle fleet.

**CONVENTIONAL VEHICLE**

- Changing the fuel used by the currently existing vehicle fleet can reduce well-to-wheel CO₂ emissions immediately (if compliant with fuel norm EN590 → 20% 1-Octanol)

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

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

**DIESEL POTENTIAL THROUGH HYBRIDIZATION**

- **WLTC**
- **RDE FEV Eifel**
- **RDE95**

<table>
<thead>
<tr>
<th></th>
<th>CO₂ emission in g/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-hybrid</td>
<td>203</td>
</tr>
<tr>
<td>P0 MHEV</td>
<td>194</td>
</tr>
<tr>
<td>P2 HEV</td>
<td>162</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Tailpipe NOx in mg/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-hybrid</td>
<td>155</td>
</tr>
<tr>
<td>P0 MHEV</td>
<td>147</td>
</tr>
<tr>
<td>P2 HEV</td>
<td>135</td>
</tr>
</tbody>
</table>

**Engine out NOx in mg/km**

- Non-hybrid
- P0 MHEV
- P2 HEV

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

Source: FEV

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

Save battery size

Extend driving range

Less dependency on infrastructure

Solution Range Extender (fully balanced)

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 CO₂ emission reductions, a simultaneous use of fleet electrification, fuel cell vehicles and synthetic fuels is mandatory.
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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Thank you!

Questions?

Eindhoven; 23 Mai 2018

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