UPCOMING CO2 LEGISLATION FOR COMMERCIAL VEHICLES IN EUROPE AND US

Lukas Walter, AVL
CHALLENGES FOR OUR CUSTOMERS

- CO2 Legislation
- Competition in TCO
- Advanced Emission in Emerging Markets
- Automated Drivelines
- PT System Integration
- Connected Driving ADAS
- Electrification & Zero Emission CV’s

Shift to new areas and teams
Follow this shift fast
EMISSIONS CURRENT STATUS

Particle Number
\[5.0 \times 10^{10} \text{ 1/kWh}\]

Euro VI close to zero emissions?

\[\text{NOx} = 0.4 \text{ g/kWh}\]
\[\text{PM} = 0.01 \text{ g/kWh}\]

Particle Number
\[2.8 \times 10^8 \text{ 1/kWh}\]

Measured with AVL489 Particle Counter
Drivers of New Technologies

1. 01/04/2016: municipal vehicles in east China (Beijing, Tianjin, Hebe, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Henan). Municipal vehicles nationwide: 01/01/2017. All HDV nationwide: July 1, 2017
2. From 2016: new public HDV: DPF
3. For urban areas: additional WHTC test required

Status: 05/2017

1, 2, 3
USA EPA CO2 AND FUEL CONSUMPTION PHASE 1 AND PHASE 2 – ENGINE STANDARDS

<table>
<thead>
<tr>
<th>MY</th>
<th>(g CO₂/ hp-hr)</th>
<th>~BSFC Minimum g/kWh</th>
<th>BSFC in RMC g/kWh</th>
<th>Heavy Heavy Duty - Tractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014-</td>
<td>191</td>
<td>199</td>
<td>475</td>
<td></td>
</tr>
<tr>
<td>2017-</td>
<td>185</td>
<td>193</td>
<td>460</td>
<td></td>
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<td>2021-</td>
<td>180</td>
<td>187</td>
<td>447</td>
<td></td>
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<td>2024-</td>
<td>176</td>
<td>183</td>
<td>436</td>
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<tr>
<td>2027-</td>
<td>173</td>
<td>181</td>
<td>432</td>
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</table>

Test cycles: RMC (tractor engines), transient duty cycle (other engines); certification as tractor and vocational engine: both duty cycles.
Reweighting of RMC modes for Phase 2.
CH₄: 0.10 g/hp-hr (transient duty cycle)
N₂O: 0.10 g/hp-hr (transient duty cycle)
LHD: use in Class 2b-5 vehicle, MHD: Class 6-7, HHD: Class 8

BTE ~ 49%
EMISSION CONCEPTS FOR ULTRA LOW NOX STANDARDS

<table>
<thead>
<tr>
<th>NOx_EO hot</th>
<th>No EGR</th>
<th>EGR</th>
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</thead>
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<tr>
<td></td>
<td>15 g/kWh</td>
<td>10 g/kWh</td>
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<tr>
<td>SCR eff. hot %</td>
<td>99.5</td>
<td>99.5</td>
</tr>
<tr>
<td>SCR eff. cold %</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>NOx_TP 0.2 g/kWh (incl. 30% margin)</td>
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<td></td>
</tr>
<tr>
<td>SCR eff. hot %</td>
<td>99.7</td>
<td>99.7</td>
</tr>
<tr>
<td>SCR eff. cold %</td>
<td>98</td>
<td>96</td>
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<tr>
<td>NOx_TP 0.067 g/kWh (0.05 g/bhp-hr) (incl. 30% margin)</td>
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<tr>
<td>SCR eff. hot %</td>
<td>99.9</td>
<td>99.9</td>
</tr>
<tr>
<td>SCR eff. cold %</td>
<td>99</td>
<td>99</td>
</tr>
<tr>
<td>NOx_TP 0.027 g/kWh (0.02 g/bhp-hr) (incl. 30% margin)</td>
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</table>
NEXT GENERATION DIESEL ENGINES FOR 2027

ROADMAP TO MY 2027

- Downspeeding
- Variable valve actuation
- Low & high pressure EGR
- Friction reduction
- High peak firing pressure
- WHR
- High efficiency charging
- Light weight structure

Publication: VDI engine congress 2017; Effects of CO2 & Ultra-Low NOx legislation on Commercial Base Engines
GHG REDUCTION REQUIREMENT FOR VEHICLE

Class 8 applications: -19 to -27%

Source: ICCT
VEHICLE FUEL CONSUMPTION REQUIREMENT

- Vehicle aerodynamics: ~8-10%
- Rolling resistance: ~6%
- Driveline losses: ~9-11%
- Mass reduction: ~8-10%
- Mass reduction: ~8-10%

US DoE SuperTruck Program
- Engine system demonstration of 50% or greater BTE
- Tractor-trailer vehicle demonstration of 50% or greater freight efficiency improvement

Source: Peterbilt, Volvo, Navistar, Freightliner
GHG PHASE 2 EVALUATION PROCESS

GEM v3.0 simulation result

<table>
<thead>
<tr>
<th>Standard credits</th>
<th>Off-cycle credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>e.g. Engine thermal efficiency</td>
<td></td>
</tr>
<tr>
<td>e.g. Engine displacement &lt;14L</td>
<td></td>
</tr>
<tr>
<td>e.g. Extended aux. on demand</td>
<td></td>
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<tr>
<td>e.g. Downspeeding</td>
<td></td>
</tr>
<tr>
<td>e.g. Intelligent controls</td>
<td></td>
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<tr>
<td>e.g. Predictive thermal mgmt.</td>
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<tr>
<td>e.g. Driveline efficiency</td>
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<tr>
<td>e.g. Accessory load</td>
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<tr>
<td>e.g. Waste Heat Recovery</td>
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</tr>
<tr>
<td>e.g. High efficiency AC</td>
<td></td>
</tr>
<tr>
<td>e.g. Extended idle reduction</td>
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</tr>
<tr>
<td>e.g. Waste Heat Recovery</td>
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</table>

= g

= tonmile

GEM v3.0 simulation
g tonmile
## GHG PHASE 2 TECHNOLOGY OPTIONS

<table>
<thead>
<tr>
<th>Technology</th>
<th>Comment</th>
<th>GHG reduction credit [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intelligent Controls</td>
<td>Predictive cruise control GPS based</td>
<td>2</td>
</tr>
<tr>
<td>Accessory load</td>
<td>Electric steering and electric engine coolant pump</td>
<td>1</td>
</tr>
<tr>
<td>High efficiency AC</td>
<td>Electric AC compressor</td>
<td>0,5</td>
</tr>
<tr>
<td>Tire Pressure systems</td>
<td>Monitor or auto inflate</td>
<td>1, 1.2</td>
</tr>
<tr>
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<td>Automated engine stop, fuel heater, APU (battery powered)</td>
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</tr>
</tbody>
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<tr>
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<td>Weight reduction</td>
<td>0,4</td>
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<tr>
<td>6x2 configuration</td>
<td></td>
<td>1,25, 2</td>
<td></td>
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<tr>
<td>WHR</td>
<td></td>
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<tr>
<td>Engine downspeeding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL GHG REDUCTION [%]</strong></td>
<td></td>
<td><strong>6,6</strong></td>
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<tr>
<th>Technology</th>
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<th>GHG reduction credit [%]</th>
<th>State of the art</th>
<th>Mild-Hybrid</th>
<th>WHR</th>
<th>Credit Builder</th>
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<td>Predictive cruise control GPS based</td>
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<td>3</td>
<td>6</td>
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<tr>
<td>Engine displacement &lt;14L</td>
<td>Weight reduction</td>
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<td>1,5</td>
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<td>1,5</td>
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<tr>
<td>TOTAL GHG REDUCTION [%]</td>
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<td>6,6</td>
<td>13,9</td>
<td>12,4</td>
<td>19,1</td>
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</table>
TECHNOLOGY MAIN ROUTES

25% GHG

Target 9–11%

Mild-Hybrid
(benefit 13.9%)
Electric auxiliaries
E-boosting
Downspeeding
48V Battery APU

WHR
(benefit 12.4%)
Mechanical
Downspeeding
POWERTRAIN CONFIGURATION FOR FUTURE CO2 LEGISLATION

- Electric Driven A/C Compressor (E-A/C)
- Electric Driven Coolant Pump (ECP)
- Electro Hydraulic Power Steering (EHPS)
- Electric/Hybrid Fan
- 48V Motor / Generator
- Electric Waste Heat Recovery (E-WHR)
- EGR Cooler / WHR Evaporator
- Electrical Assisted Turbo
- Fast shifting AMT Transmission
TRANSFER OF TECHNOLOGIES FROM THE US TO EUROPE

Europe: CO₂ test procedure for HDV

Model Input
- \( C_D \times A_c \)
- Mass, ...
- \( r_{\text{dyn}} \), RRC
- Loss maps
- \( i_{\text{gear}}, \text{max. torque} \)

Component test procedures

- Engine
- Gearbox
- Tires
- Vehicle

Full load curve
- Fuel map
- WHTC-Corr. Factors

Auxiliaries
- *generic data for trucks*
- *specific for buses*

HDH System
- Motor, battery

Simulation of power demand, engine speed, fuel consumption, etc. in standardised target speed cycles.
VECTO TIMELINE

CO₂ test procedure for HDV

Already agreed actions for HDV are:
1) Establish a certification system for fuel consumption and CO₂ emissions of HDV.
2) Use results for monitoring and for customer information
3) Develop proposal for CO₂ limits

Comparable systems for trucks yet in US, Japan, China

Timeline EU:
1. Legislation and software for truck shall be finalised in 2017
2. Draft timetable for mandatory CO₂ certification:
   ? / 2018: Long-haul trucks (HDV classes 4, 5, 9, 10)
   ? / 2019: Other truck classes
   ? / ?: Coaches and city busses ≥1 year after trucks
3) Study on limit values ongoing.

Timeline is agreed
Implementation steps for different applications
Background of the Selected Method
First study “Lot 2” started with selection and elaboration of the best methodology (2010-2012)

Customer can select between various types of cabin, body or trailer, tires, transmission and engine.
→ Huge variety of component mix in each HDV model

<table>
<thead>
<tr>
<th>Option</th>
<th>Pro's</th>
<th>Con's</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chassis dyno</td>
<td>Reasonable reproducibility. Vehicle specific control systems for e.g. auxiliary engagement covered.</td>
<td>Expensive to test all HDV variants. Systems may be optimised for test conditions.</td>
</tr>
<tr>
<td>On-Road</td>
<td>Specific optimisations for test conditions (almost) not possible.</td>
<td>Poor reproducibility. Expensive to test all HDV variants.</td>
</tr>
<tr>
<td>Engine test</td>
<td>Already established. Good reproducibility.</td>
<td>Other relevant components of the HDV not covered.</td>
</tr>
<tr>
<td>Component test + simulation</td>
<td>Cost efficient Good reproducibility Covers most relevant components of the HDV</td>
<td>Vehicle specific control algorithms can hardly be considered. Regular update of methods + software necessary.</td>
</tr>
</tbody>
</table>

• Selection of method to provide sufficient accuracy and reproducability
VECTO INTEGRATION IN OEM SYSTEMS

Concept of Data Handling

For efficient data handling VECTO can be linked to OEM specific IT system by “API” that just translates data base values into VECTO input structures.

- First real back-to-back comparison between vehicles
- Future tool for truck sales organization
VECTO COMPONENT TESTING

Component testing

- Constant speed test with „standard body“ and/or trailer. Measure torque at wheels and air speed.
- Drum test according to regulation EC1222/2009
- Loss map options:
  1) default values
  2) measured idle losses + calc. torque dependency
  3) Complete measurement
- Engine test bed acc. R49: WHTC, full load curve, motoring curve and steady state fuel map

### How to create reproducible component input

### Extensive component testing
MODELLING PARAMETERS CONSIDERED IN VECTO

TODAY:
- Vehicle class
- Axle and chassis configuration
- Maximum gross vehicle weight
- Engine maps including transient correction
- Transmission, torque converter
- Axle
- Air drag
- Tire
- Auxiliaries:
  - Engine cooling fan
  - Steering pump
  - Electric system
  - Pneumatic system
  - AC system
  - Transmission power take off (PTO)

FUTURE DISCUSSED:
Short term:
- Improved alternator
- Wide base singles
- Tire pressure monitoring
- Improved oil pumps
- Vehicle speed limiter
Mid term:
- PACC
- WHR
- Electric hybrids
- Electric TC
- A/C efficiency
- Active flow systems
- DCT
- Neutral idle
Long term:
- Cooling fan
- Air compressor
- Vehicle body redesign
- Adjustable fifth wheel
- CVT
- Hydraulic hybrids
- ECU/Engine software optimization

GEM v3.0

Mid-term plan considers the Mild-hybrid and WHR technologies

<table>
<thead>
<tr>
<th>Credit Builder</th>
<th>State of the art</th>
<th>Mild-hybrid</th>
<th>WHR Credit</th>
<th>Builder</th>
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<td>18,6</td>
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</tbody>
</table>
COMPLEX SCENARIO FOR OEMS

When?
2021, 2024, 2027

Vehicle
Technology
Balancing

Powertrain
Technology
Balancing

Engine

ABT
Averaging, banking and trading
MODEL-BASED ATTRIBUTE BALANCING FOR END CUSTOMER VALUE

Attributes balanced in virtual environment

Published in 2015 at 8th AVL International Commercial Powertrain Conference
SUMMARY

- Two main routes are establishing, Mild-hybrid and WHR
- Technologies are available
- Legislation environment will be much more complex for OEMs

AVL has invested significantly in the preparation for such legislation, technology and methodology!
PLEASE USE THE OPPORTUNITY TO LOOK AT THE INTEGRATION MODEL

- Electric Waste Heat Recovery (E-WHR)
- Starter Motor Generator (SMG)
- Hybrid Fan
- Electric Driven Coolant Pump (ECP)
- EGR Cooler / WHR Evaporator
- Electrical Assisted Turbo