On-road emissions of light-duty vehicles in Europe

Real Road, Real Driving, and Real Emissions Seminar
National Institute of Environmental Research (NIER)
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Pierre Bonnel
DG - Joint Research Centre (JRC)
IET - Institute for Energy and Transport
Content

• The Joint Research Centre

• Vehicle emissions legislation in the European Union

• On-road emissions testing at the JRC
  • Design
  • Results

• Implications
The Joint Research Centre (JRC) is the in-house scientific and technical service of the European Commission

Mission:

• to provide scientific advice and technical know-how to the European Commission

• to support a wide range of EU policies independent of private or national interests
The Joint Research Centre

Headquarters located in Brussels
7 institutes; 2750 employees; annual budget of €330 million ($430 million)
European emissions legislation

Type 1 Test - Tail-pipe emissions: type approval and in-service conformity testing in the laboratory based on the New European Driving Cycle (NEDC)
European emissions legislation

Type I: Tailpipe emissions after cold start

Light-duty vehicles
CO, NO$_x$, HC, particles
Euro 1 (1993)
Euro 4 (2005)

Regulation 715/2007
Euro 5 (2009)
NO$_x$ -28% (diesel)
-25% (gasoline)

Euro 6 (2014)
NO$_x$ -56% (diesel)

- ensure that real world emissions correspond to type approval measurements
- procedures shall be adapted to if necessary

Air quality
European emissions legislation

Background: Urban NO$_2$ pollution in the EU

Annual mean, nitrogen dioxide, 2009, based on daily averages with percentage of valid measurements 75% in µg/m$^3$

- $\leq$ 20
- 20–40
- 40–42
- $\geq$ 42

Source: Copyright EEA (2011)
PEMS testing at JRC

- Regulation 715/2007 provides the basis for PEMS testing at the JRC

- Since 2007: PEMS testing of >15 light-duty diesel and gasoline vehicles (Euro 3-6)

- Experience since 2004: heavy-duty vehicle testing (feasibility of in-service conformity testing; pilot testing)
- Power supply by batteries for test durations of up to 2 h
- PEMS (including batteries) 120 kg + 80 kg of the co-driver
Test routes

Distance in km

Altitude in meter above sea level

Route 1: rural-motorway
Route 2: rural-urban
Route 3: rural-uphill/downhill
Route 4: rural-motorway
On-road emissions – THC/CO

**THC emissions in g/km**

- Euro 3
- Euro 4
- Euro 5
- Euro 6

**CO emissions in g/km**

- Euro 3
- Euro 4
- Euro 5
- Euro 6

**Route 1:** rural-motorway

**Route 2:** rural-urban

**Route 3:** rural-uphill/downhill

**Route 4:** motorway

**NEDC laboratory testing**

**Applicable emissions standard**
On-road emissions - NO\textsubscript{x}

**Euro 3**
- Route 1: rural-motorway
- Route 2: rural-urban
- Route 3: rural-uphill/downhill
- Route 4: motorway
- NEDC laboratory testing
- Applicable emissions limit

**Euro 4**
- Route 1: rural-motorway
- Route 2: rural-urban
- Route 3: rural-uphill/downhill
- Route 4: motorway
- NEDC laboratory testing
- Applicable emissions limit

**Euro 5**
- Route 1: rural-motorway
- Route 2: rural-urban
- Route 3: rural-uphill/downhill
- Route 4: motorway
- NEDC laboratory testing
- Applicable emissions limit

**Euro 6**
- Route 1: rural-motorway
- Route 2: rural-urban
- Route 3: rural-uphill/downhill
- Route 4: motorway
- NEDC laboratory testing
- Applicable emissions limit

**NO\textsubscript{x} emissions in g/km**
- 0.00
- 0.25
- 0.50
- 0.75
- 1.00
- 1.25
- 1.50
- 1.75
- 2.00
- 2.25
- 2.50

**Routes**
- Route 1: rural-motorway
- Route 2: rural-urban
- Route 3: rural-uphill/downhill
- Route 4: motorway
- NEDC laboratory testing

**Emissions Limit**
- Applicable emissions limit

**Vehicles**
- A (diesel)
- B (gasoline)
- C (diesel)
- D (diesel)
- E (diesel)
- F (gasoline)
- G (gasoline)
- H (diesel)
- I (diesel)
- J (diesel)
- K (diesel)
- L (gasoline)
- M (gasoline)
- N (gasoline)
- O (diesel)
Emissions analysis - $\text{NO}_X$

Route 1: rural-motorway

Route 2: rural-urban

Route 3: rural-uphill/downhill

Route 4: rural-motorway

Cumulative frequency vs. $\text{NO}_X$ emissions as Deviation Ratio
No emissions standard for individual light-duty vehicles but a fleet-average target of 130 g/km
Implications

- Substantially elevated NO$_x$ emissions of diesel vehicles during real-world on-road driving
- Persisting air quality problems in urban areas
- European Commission establishes a complementary emissions test procedure
  - Two candidates:
    - Laboratory testing with a random driving cycle
    - On-road emissions testing with PEMS
Implications

• Factors potentially explaining elevated on-road emissions
  • Polluting driving conditions covered only for a short time by the laboratory driving cycle
  • Polluting driving conditions not covered in the laboratory
  • Operating conditions not covered in the laboratory
  • Overall test duration
NEDC: NO\textsubscript{x} emissions as function of engine start temperature

Source: Kühlwein et al. (2012)
### Critical aspects

<table>
<thead>
<tr>
<th>Vehicle speed in km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>0  20 40 60 80 100 120 140</td>
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</table>

<table>
<thead>
<tr>
<th>Acceleration in m/s²</th>
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</thead>
<tbody>
<tr>
<td>0.0 0.5 1.0 1.5 2.0 2.5 3.0</td>
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</table>

#### Routes
- Route 1: rural-motorway
- Route 2: rural-urban
- Route 3: rural-uphill/downhill
- Random cycles 1-5
- NEDC
Critical aspects

**NOX emissions in g/km**
- 0.5
- 1.5
- 2.5
- 3.5

**Speed in km/h**
- 0 20 40 60 80 100 120

**Routes**
- Route 1: rural-motorway
- Route 2: rural-urban
- Route 3: rural-uphill/downhill

**Emissions Standards**
- Euro 5
- Euro 6

**Graphs**
- Euro 5
- Euro 6

- Red dashed line represents emissions standard for Euro 5 and Euro 6.
- Black circles indicate NEDC.
- Gray circles indicate random cycles.
- Green circles indicate rural-uphill/downhill.
Outlook

- Decision about a complementary Type1 test procedure by June 2012
- Development and pilot testing until the end of 2013
- Definition of boundary conditions, data characterization, and ‘not-to-exceed’ limits
- Gradual implementation from 2014 onwards?

- NO$_2$ air pollution vs. distance-specific NO$_X$ emissions of light-duty vehicles...

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On-Road Emissions of Light-Duty Vehicles in Europe

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Supporting Information
Regulation 715/2007 specifies emission standards; for passenger cars:

<table>
<thead>
<tr>
<th>in g/km</th>
<th>THC/NMHC</th>
<th>CO</th>
<th>NO\textsubscript{X}</th>
<th>NO\textsubscript{X}+THC</th>
<th>PM</th>
<th>PN</th>
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</thead>
<tbody>
<tr>
<td>Euro 5 spark ignition</td>
<td>2009-2012</td>
<td>0.100/0.068</td>
<td>1.000</td>
<td>0.060</td>
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<td>6<em>10^{12}/6</em>10^{11}</td>
</tr>
<tr>
<td>Euro 5 diesel</td>
<td>2009-2012</td>
<td>-</td>
<td>0.500</td>
<td>0.180</td>
<td>0.005/0.0045</td>
<td>6*10^{11}</td>
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<td>Euro 6 diesel</td>
<td>From 2014</td>
<td>-</td>
<td>0.500</td>
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CO\textsubscript{2}: fleet-average emissions target of 130 g/km
• 2004-2005: feasibility of PEMS for in-service conformity testing of heavy-duty vehicles
• 2007-2008: PEMS heavy-duty pilot program
• Since 2007: PEMS testing of >15 light-duty vehicles
• Since 2010: PEMS pilot program for non-road machinery

• Light-duty vehicles: diesel and gasoline cars; Euro 3-6
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Device</th>
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<tbody>
<tr>
<td>THC</td>
<td>Heated-flame ionization detector</td>
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<tr>
<td>CO+CO₂</td>
<td>Non-dispersive infrared analyzer</td>
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<tr>
<td>NO+NO₂</td>
<td>Non-dispersive ultraviolet analyzer</td>
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<tr>
<td>Exhaust flow rate</td>
<td>Exhaust flow meter (EFM)</td>
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<tr>
<td>Exhaust temperature</td>
<td>EFM temperature sensor</td>
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<tr>
<td>Vehicle speed</td>
<td>GPS/ECU</td>
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<tr>
<td>Vehicle position and altitude</td>
<td>GPS</td>
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<tr>
<td>Acceleration</td>
<td>GPS/ECU</td>
</tr>
<tr>
<td>Distance</td>
<td>GPS/ECU</td>
</tr>
<tr>
<td>Ambient humidity</td>
<td>Humidity sensor</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>Temperature sensor</td>
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<tr>
<td>Ambient air pressure</td>
<td>Barometer</td>
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</tbody>
</table>

- Emissions testing from cold start, including cranking
- Use of commercial fuels
Supplemental slides

Vehicle D
Vehicle E
Vehicle H
Vehicle I
Vehicle J
Vehicle K
Vehicle O

NO$_2$ share on NO$_X$ emissions in %

Route 1: rural-motorway
Route 2: rural-urban
Route 3: rural-uphill/downhill
Route 4: rural-motorway

Euro 4
Euro 5
Euro 6
Supplemental slides

<table>
<thead>
<tr>
<th>CO₂ emissions in g/km</th>
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<th>Euro 4</th>
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<th>Euro 6</th>
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<td>NEDC laboratory testing</td>
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<td>NEDC type approval</td>
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<tr>
<td>Fleet-average emissions target</td>
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The averaging window approach: