HDV efficiency program development

G20 Transport Task Group: Deep Dive to Support Heavy-Duty Vehicle Efficiency Labeling and Standards Meeting #6

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23 May 2018
Outline

1. Overview of HDV CO$_2$ standards around the world

2. Standard design: CO$_2$ targets are just part of it.
   a. CO$_2$ determination: Vehicle simulation and testing procedure
   b. Segmentation and duty cycles
   c. Baseline determination
   d. Flexibilities
   e. Incentives for emerging low carbon technologies
   f. Trailer and engine standards
Overview of HDV CO$_2$ standards around the world
The European Commission just announced its proposal for HDV CO₂ standards for the years 2025 and 2030. They aim to reduce CO₂ emissions of the regulated categories 15% and 30% by 2025 and 2030 respectively, compared to 2019.

## Details of HDV standards developments around the globe

(Presentation of EU HDV CO\textsubscript{2} standards proposal will take place on a separate future call)

<table>
<thead>
<tr>
<th>Type</th>
<th>FE &amp; CO\textsubscript{2} (ex. Canada); CAFE</th>
<th>FE; individual vehicle</th>
<th>FE; CAFE</th>
<th>FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle scope</td>
<td>GVWR &gt; 3.85t 19 sub-categories, by vehicle type / duty cycle and GVW</td>
<td>GVW &gt; 3.5t 66 sub-categories, by vehicle type / duty cycle and GVW</td>
<td>GVW &gt; 3.5t 25 sub-categories, by type (bus/lorry) and GVW</td>
<td>&gt;12t 10 sub-categories, by GVW, axles, and type (rigid or tractor)</td>
</tr>
<tr>
<td>Certification</td>
<td>Component testing and simulation. Separate engine standard.</td>
<td>Chassis dyno (base vehicles) or whole vehicle simulation (variants).</td>
<td>Engine testing (map) and vehicle simulation. Second phase includes aero and tires testing.</td>
<td>Constant speed fuel consumption (CSFC) standards.  Track testing at 40/60km/h</td>
</tr>
<tr>
<td>ZEV incentives</td>
<td>Super-credits</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
Standard design: CO$_2$ targets are just part of it.
Setting a fuel consumption or CO\textsubscript{2} target is just one aspect of the regulatory design. Other aspects include:

- a. CO\textsubscript{2} determination: Vehicle simulation and testing procedure
- b. Segmentation and duty cycles
- c. Baseline determination
- d. Flexibilities
- e. Incentives for emerging low carbon technologies
- f. Trailer and engine standards
Regulatory design

CO₂ determination: Vehicle simulation and testing procedure

This topic was covered in calls #2 and #3.
Recording call #2: https://vimeo.com/252227039 (Password: ZB9a4YuW)
Recording call #3: https://vimeo.com/256666466 (Password: 4py3eu14)
Most regions use HDV simulation in combination with component certification to determine CO₂ emissions.
Both GEM and VECTO can be adapted to account for the differences across regions. VECTO’s engineering mode provides a user friendly interface to modify drive cycles, payloads, and vehicle details. GEM can also be modified accessing the source code, however, this implies more effort.

VECTO and GEM show very good agreement when simulated over a large set of identical vehicles.

The accurate simulation of CO₂ emissions of HDVs is more dependent on the component input data than on the selected model (VECTO vs GEM). Harmonization of component certification benefits the implementation of future regulatory measures.
The US and EU component certification methodologies have several common points.

- Axles, tires, and engine mapping procedures are similar.
- Key differences include the aerodynamic drag determination methodology and the engine transient correction.

Harmonization of component certification has many advantages:

- Facilitates transparent comparison of performance between different markets.
- Facilitates the implementation of future regulatory measures.
- Facilitates adapting GEM/VECTO to country-specific needs.
- Streamlined processes and reduced cost of compliance for international manufacturers.
This topic was covered in call #4.
Recording call #4: https://vimeo.com/261558268 (Password: n9ye7k)
Segmentation comparison by GVW around the world

1) Further divided into four subsegments by maximum payload, 2) Further divided into six subsegments by roof height and cab type, 3) Further divided into three subsegments by roof height, 4) Each EU segment further divided into two to seven subsegments by axle, chassis, and body configuration and weight.
The market segmentation and definition of duty cycles are country specific exercises. However, experiences and concepts applied in other regions can be adapted.

There is no perfect segmentation, nor duty cycle. A balance between complexity and representativeness is necessary.

The market segmentation divides the vehicle fleet into different segments with similar application and fuel consumption. Typical differentiators are vehicle weight, chassis configuration, and axle configuration. Further segmentation can be achieved by cabin type, engine power, intended vehicle use, among others.

The development of duty cycles for fuel consumption certification must be a data-driven process. A good characterization of the vehicle fleet is necessary. Similarly, the topography and typical traffic conditions of the road network are also required.
Regulatory design | Baseline determination

This topic was covered in call #5
Recording call #5: https://vimeo.com/266179381/ (Password: 67n7jt)
Setting the baseline consist in estimating fleet-representative component performance metrics

The baseline determination does not require to collect real world on-road data, but must rely on the certification procedure. That is vehicle simulation from certified component data.

- Axle configuration, GVW, drag area, rolling resistance
- Fuel consumption map
- Type, gearbox spread, axle ratio, efficiencies
Example of ICCT’s baselining exercise.

Baseline specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Tractor-trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross vehicle weight (t)</td>
<td>40</td>
</tr>
<tr>
<td>Vehicle curb weight (t)</td>
<td>14.4</td>
</tr>
<tr>
<td>Axle configuration</td>
<td>4×2</td>
</tr>
<tr>
<td>Aerodynamic drag area (m²)</td>
<td>6.0</td>
</tr>
<tr>
<td>Tire rolling resistance (N/kN)</td>
<td>5.5</td>
</tr>
<tr>
<td>Engine emissions</td>
<td>Euro VI</td>
</tr>
<tr>
<td>Engine displacement (L)</td>
<td>12.8</td>
</tr>
<tr>
<td>Engine power (kW)</td>
<td>350</td>
</tr>
<tr>
<td>Engine peak BTE (%)</td>
<td>44.8</td>
</tr>
<tr>
<td>Transmission type</td>
<td>AMT</td>
</tr>
<tr>
<td>Transmission gear number</td>
<td>12</td>
</tr>
<tr>
<td>Transmission gear ratios</td>
<td>14.93–1.0</td>
</tr>
<tr>
<td>Rear axle ratio</td>
<td>2.64</td>
</tr>
<tr>
<td>Accessory power (kW)</td>
<td>5.6</td>
</tr>
</tbody>
</table>

http://www.theicct.org/EU-HDV-fuel-efficiency-tech-2020-2030
Regulatory design  Flexibilities
Regulatory flexibilities typically come in three different forms.

1. Averaging (A): Targets are defined as a fleet-average, and not on an individual vehicle basis.
2. Banking (B): Manufacturers can accumulate (bank) credits when over complying with the banking threshold.
3. Trading (T): Manufacturers can “trade” the credits to another manufacturer.

A well-designed ABT program can also provide important environmental and energy security benefits by increasing the speed at which new technologies can be implemented.
Averaging

- Targets are defined as a fleet-average, and not on an individual vehicle basis.
- The averaging sets usually correspond to the regulatory categories.
- Averaging is one of the basic flexibility provisions as it allows to set stringent targets. In the case of not-to-exceed limits (i.e., limits that apply to each individual vehicle) requires a very granular segmentation, or a lenient stringency.
Banking requires careful oversight and transparency.

Credits and deficits must have a limited life (e.g., a limited life of 3 years)

The flexibility that banking brings in terms of technology deployment timing needs to be accompanied by stringent standards

Flexibilities should provide opportunities for OEMs to introduce technology and reduce cost, *without compromising overall environmental objective*

In the case of step wise targets (as opposed to annual targets), the banking threshold should be defined to reflect the natural evolution of the technological improvement and prevent “over-banking” of credits.

Trading

- As with banking, trading requires careful oversight and transparency.
- Trading imposes an administrative burden for the regulators.
- Trading can be allowed either only between the same vehicle groups or also between different vehicle groups.
- Allowing credits / debits trading between different regulatory can result in market distortions, as the product portfolio of each manufacturer is different, and the flexibility could benefit some OEMs and disadvantage some others.
- If the trading credits / debits between different categories is allowed, a careful consideration of the characteristics of the different regulatory categories is required (e.g., lifetime mileage, in-use payloads, average fuel consumption).
- Credit trading should be in units of absolute tons of CO2 over the lifetime of the vehicle (that is why you need certain assumptions)
Regulatory design | Incentives for emerging low carbon technologies
### HD ZEV freight: Long Haul -- simultaneously the most important and most challenging segment

<table>
<thead>
<tr>
<th>Segments</th>
<th>Definition</th>
<th>Duty Cycle</th>
<th>Range</th>
<th>Payload Requirements</th>
<th>Battery/ Hydrogen Requirements</th>
<th>Infrastructure Requirements</th>
<th>CO₂ Footprint</th>
<th>Current Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Delivery</td>
<td>• Light and Medium Duty trucks and vans</td>
<td>Low speed, transient</td>
<td>&lt;200 km/day</td>
<td>&lt;5 ton</td>
<td>&lt;100 kWh &lt;10 kg H₂</td>
<td>Limited</td>
<td>10-15%</td>
<td>&gt;20 models</td>
</tr>
<tr>
<td>Drayage</td>
<td>• Transport freight from ports</td>
<td>High speed, constant</td>
<td>&gt;500 km/day</td>
<td>&gt;20 ton</td>
<td>&gt;800 kWh &gt;30 kg H₂</td>
<td>Extensive</td>
<td>65-75%</td>
<td>None</td>
</tr>
<tr>
<td>Regional Delivery</td>
<td>• Return to base</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Haul</td>
<td>• Tractor-trailers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
De-carbonization scenario for European tractor trailers (ICCT)

Lifecycle CO₂e emissions from Europe heavy-duty tractor-trailer fleet with base case, efficiency improvements, fuel cell-intensive, and electric-intensive scenarios.

Fuel cell intensive: 50% fuel cells in 2050 / 15% electric

Electric intensive: 50% electric / 15% fuel cell in 2050.

Lifecycle emissions (million metric tons CO₂e)

Base case
Fuel cell-intensive
Electric-intensive
Efficiency improvements

2005 2015 2025 2035 2045

ZE-HDV are necessary to meet long-term CO2 reduction targets

Transitioning to zero-emission heavy-duty freight vehicles

Lifecycle emissions (tonnes CO\(_2\))

<table>
<thead>
<tr>
<th>Year</th>
<th>Diesel</th>
<th>Diesel hybrid</th>
<th>Fuel cell (Hydrogen)</th>
<th>Electric (overhead)</th>
<th>Electric (dynamic induction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Lifecycle emissions per kilometer (gCO\(_2\)/km)

- Diesel
- Diesel hybrid
- Fuel cell (Hydrogen)
- Electric (overhead)
- Electric (dynamic induction)

Missing from this analysis is the battery electric long-haul tractor trailer ...
Principle 1: Clearly define how the advanced technology credit (ATC) values are determined

**Scenario 1**: advanced technologies and credit values are explicitly defined

- **ATC eligible**
  - Plug-in HDVs
  - Hydrogen fuel cell HDVs
  - Automated HDVs

- **Not ATC eligible**
  - Fossil fuel-based technologies
  - Biofuels
  - Synthetic fuels

**Advantages**
- Simple to understand and administer
- Ability to assign credit multipliers to certain fuel/technologies

**Disadvantages**
- Can be seen as ‘picking winners and losers’
- Dual-fuel and/or complicated propulsion architectures may be difficult to classify

**Scenario 2**: No advanced technology credits beyond that of zero rating for ZEVs

**Advantages**
- Simple to understand and administer

**Disadvantages**
- Fails to incentivize technologies that currently are not cost competitive
Principle 2: Promote emerging fuel efficiency and zero emission technologies in all HDV types

**Scenario 1:** credit trading allowed across various vehicle weight classes

- Free-flowing credits across vehicle weight classes

**Potential negative outcomes**
- Manufacturer over-complies in one category and uses excess credits to delay technology deployment in another category
- Manufacturers that sell across multiple categories have advantage vs. manufacturer that focus on one (or two) categories

**Positive outcomes**
- Regulation encourages development and deployment of fuel-saving and zero emission technologies in all categories
- Creates more equitable conditions for all manufacturers, regardless of product mix

**Scenario 2:** no credit trading across various vehicle weight classes

- Autonomous regulatory category
- Autonomous regulatory category
- Autonomous regulatory category
Principle 3: Incentivize non-regulated HDV categories to engage in early action

**Scenario 1**: no opportunity for non-regulated vehicle classes to generate early credits

- **Regulation goes into effect for HDV classes A, B, and C**
  - 2018 → 2019 → 2020 → 2021

- **No early credit generation for HDV classes X, Y, and Z**
  - 2022 → 2023 → 2024 → 2025

**Potential negative outcome**
- Manufacturer of HDV classes X, Y, and Z have no regulatory incentive to accelerate introduction of advanced technologies

**Scenario 2**: non-regulated vehicle classes have opportunity to build up early credits with sales of advanced technologies

- **Regulation goes into effect for HDV classes A, B, and C**
  - 2018 → 2019 → 2020 → 2021

- **HDV classes X, Y, and Z can build up early credits**
  - 2022 → 2023 → 2024 → 2025

**Positive outcomes**
- Fuel use and GHG reductions can be achieved from non-regulated HDV classes
- Opportunity to bring manufacturers into the regulatory fold early

**Early credits for classes X, Y, and Z cannot be applied to classes A, B, and C**
Principle 4: Link advanced technology multiplier values to sales targets

Scenario 1: advanced technology credits have constant value over life of the regulation

Potential negative outcome
- As sales of advanced technology increase, the stringency of the overall regulation can be compromised

Scenario 2: value of advanced technology credits is linked to sales thresholds**

Positive outcomes
- Sends clear signal to industry about decreasing value of credits over time
- Lowers risk that a surge in advanced technology sales will erode stringency of overall regulation

** Thresholds can be percentages of total sales or absolute values
Concept for a flexible advanced technology (or “ZEV”) mandate: progressive incentives and penalties

Examples (mandate target = 1,000 units)

Overcompliance

Sales = 1,500 units
Total credits =
\[(1,300 - 1,000)X + (1,500 - 1,300)(1.5X) = 600X\]

Undercompliance

Sales = 200 units
Total penalty =
\[(1,000 - 700)(-X) + (700 - 300)(-1.5X) + (300 - 200)(-2X) = -1,100X\]

** Thresholds can be percentages of total sales or absolute values
Regulatory design  Trailer and engine standards
Example of successful implementation of engine standards: US Phase 1 and Phase 2 GHG HDV regulation.

### Summary of U.S. Phase 1 heavy-duty diesel engine standard CO₂ limits

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>GVW (tons)</th>
<th>Base (2010) g/kWh</th>
<th>Step 1 (2014) g/kWh</th>
<th>Step 2 (2017) g/kWh</th>
<th>Phase 1 reduction (%)</th>
<th>Test Cycle</th>
<th>Full Vehicle Reduction (%)</th>
<th>Engine share of full vehicle reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor</td>
<td>11.8 to 15</td>
<td>695</td>
<td>673</td>
<td>653</td>
<td>6.0</td>
<td>SET (Phase 1)</td>
<td>10.2-13</td>
<td>46-59</td>
</tr>
<tr>
<td></td>
<td>15+</td>
<td>657</td>
<td>637</td>
<td>617</td>
<td>6.1</td>
<td>SET (Phase 1)</td>
<td>9.1-23.4</td>
<td>26-67</td>
</tr>
<tr>
<td>Non-tractor</td>
<td>3.9 to 8.8</td>
<td>845</td>
<td>805</td>
<td>772</td>
<td>8.6</td>
<td>Composite FTP²</td>
<td>8.6</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>8.8 to 15</td>
<td>845</td>
<td>805</td>
<td>772</td>
<td>8.6</td>
<td>Composite FTP</td>
<td>8.9</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td>15+</td>
<td>783</td>
<td>760</td>
<td>744</td>
<td>5.0</td>
<td>Composite FTP</td>
<td>5.9</td>
<td>85</td>
</tr>
</tbody>
</table>

a. The cycle is run as both a cold- and a hot-start test. The composite FTP results are obtained by using a weighting factor of 1/7 for the cold-start results and 6/7 for the hot.

Engine standards accelerate the development and deployment of engine technologies.

### Estimated technology adoption necessary to meet the Phase 2 engine standards in the United States

<table>
<thead>
<tr>
<th>Technology</th>
<th>SET weighted reduction (%)</th>
<th>Market penetration (2021) (%)</th>
<th>Market penetration (2024) (%)</th>
<th>Market penetration (2027) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbocompound with clutch</td>
<td>1.9</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Waste heat recovery</td>
<td>3.6</td>
<td>1</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Parasitic/Friction reduction</td>
<td>1.5</td>
<td>45</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>Improved aftertreatment</td>
<td>0.6</td>
<td>30</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>Air handling</td>
<td>1.1</td>
<td>45</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>Improved combustion</td>
<td>1.1</td>
<td>45</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>Downsizing</td>
<td>0.3</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Weighted reduction (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downspeeding optimization (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total reduction (%)</td>
<td>1.8</td>
<td>4.2</td>
<td>5.1</td>
<td></td>
</tr>
</tbody>
</table>

The Phase 1/2 standards can be used as a blueprint for other regions. EU and US duty cycles can be correlated for CO$_2$ emissions.

Comparison of 26 different engine maps over a simulated environment were used to estimate the correlation coefficients between the stationary WHSC and SET cycles, as well as between the transient cycles WHTC and FTP.

Engine standards bring along a number of benefits

a) Link between CO$_2$ and NOx
b) Benefits over the complete life of the vehicle
c) Incentivize new engine technologies
d) Cover segments not included in a 1$^{st}$ phase of a whole vehicle CO$_2$ standard
e) Easy to implement with the existing regulatory framework
f) Ensure R&D in engine technologies
g) Are easy to harmonize across regions
Trailers are responsible for a significant share of the energy losses in tractor-trailers.

Improvements in trailer road-load losses are a key lever to reduce long-haul CO₂ emissions. A trailer certification procedures, and trailer CO₂ standards are important regulatory measures. Key trailer technologies are illustrated below.

- Reduce drag at the rear-end:
  - Boat tails
  - Vanes
  - Active flow control

- Reduce drag under the trailer:
  - Side-skirts
  - Under-body devices

- Reduce rolling resistance:
  - Low rolling resistance tires
  - Automatic tire inflation systems
  - Tire pressure management systems

- Reduce drag in the tractor-trailer gap:
  - Cab-side extenders
  - Gap reducers
In the EU, ICCT estimates that trailer-only technologies can bring about 12% fuel consumption reduction. The US Phase 2 program includes a set of regulatory standards to promote the efficiency attributes of commercial trailers, targeting a reduction of up to 10% by 2027 from a 2017 baseline. However, the future of the trailer standard in the US is uncertain.
Questions? Contact the HDV team at the ICCT

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