HDV fuel efficiency technologies

Decarbonising Road Freight
EXPERT WORKSHOP
28-29 June 2018
Why policy makers should pay attention to HDVs

Long-haul tractor-truck CO₂ standards around the globe
4 key barriers delay technology uptake

**Uncertain return on investment**
Will the technologies perform as expected?
What will fuel prices be in the future?

**Capital cost constraints**
Can the fleet get access to additional capital?

**Split incentives**
Are the equipment owner and operator different entities with different motivations?
Who makes the technology purchase vs. who pays for fuel?

**Lack of technology availability**
Are the technologies available in the market?
Are they available from a preferred supplier?

Why regulate HD efficiency?

Drivers for CO$_2$ emissions from on-road freight and market barriers
Drivers for tailpipe CO$_2$ emissions from road freight transport

CO$_2$ emissions [g CO$_2$]

- Fuel WTW carbon [g CO$_2$/MJ$_{\text{fuel}}$]
- Vehicle efficiency [MJ$_{\text{fuel}}$/veh-km]
- Freight activity [tonne-km]
- Loading factor [veh/tonne]
Life-cycle carbon intensity of different fuels

- Fuel WTW carbon: $[g \text{ CO}_2/\text{MJ}_\text{fuel}]$
- Vehicle efficiency: $[\text{MJ}_\text{fuel}/\text{veh-km}]$
- CO$_2$ emissions: $[g \text{ CO}_2]$
- Freight activity: $[\text{tonne-km}]$
- Loading factor: $[\text{veh/tonne}]$

Data sources:
- European Commission proposal for recast Renewable Energy Directive to 2030;
- Valin et al. (2015);
- Searle et al. (2017);
- Malins, C. (2017)

Tractor-trailer efficiency for different regions in the year 2015

- Fuel WTW carbon: \([\text{g CO}_2/\text{MJ}_{\text{fuel}}]\)
- Vehicle efficiency: \([\text{MJ}_{\text{fuel}}/\text{veh}-\text{km}]\)
- Freight activity: \([\text{tonne-\text{km}}]\)
- Loading factor: \([\text{veh/tonne}]\)

**2015 fuel consumption in region’s metric**

<table>
<thead>
<tr>
<th>Region</th>
<th>Fuel Consumption</th>
<th>GCVW (t)</th>
<th>Payload (%)</th>
<th>Cycle Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>2.84 km/L</td>
<td>38</td>
<td>50</td>
<td>JE05 (55%), 80 km/h (45%)</td>
</tr>
<tr>
<td>EU</td>
<td>33.1 L/100 km</td>
<td>40</td>
<td>19.3</td>
<td>Long Haul</td>
</tr>
<tr>
<td>U.S.</td>
<td>7.3 gal/1000 ton-mi</td>
<td>36</td>
<td>17.2</td>
<td>95% constant speed cycles</td>
</tr>
<tr>
<td>China</td>
<td>40 L/100 km</td>
<td>40</td>
<td>100</td>
<td>C-WTVC (90% motorway)</td>
</tr>
</tbody>
</table>

**Notes on cycle and payload**

* With the exception of the EU, the fuel consumption corresponds to the mandatory limits set in HDV standards. The EU vehicle efficiency is based on ICCT’s own work. The EU will propose HDV CO\(_2\) standards in May 2018.
Direct use of electricity has benefits on the vehicle efficiency, and results in a lower overall energy consumption.

- **CO₂ emissions [g CO₂]**
- **Fuel WTW carbon [g CO2/MJ]**
- **Vehicle efficiency [MJ/km]**
- **Freight activity [tonne-km]**
- **Vehicle loading [tonne]**

**Sources:** Öko-Institut (2016). Decarbonisation of road transport. Webinar.
Vehicle efficiency is the biggest lever to reduce freight’s energy demand

CO₂ emissions [g CO₂]

Fuel WTW carbon [g CO₂/MJ fuel]

Vehicle efficiency [MJ fuel / veh-km]

Freight activity [tonne-km]

Loading factor [veh/tonne]

Cost-effective technology potential
Tractor-trailers account for the majority of HDV CO₂ emissions

Vehicle groups 5 and 10 (i.e., tractor-trailers) account for over 70% on the CO₂ emissions of on-road HDVs


http://www.theicct.org/EU-HDV-fuel-efficiency-tech-2020-2030
Reference 2015 tractor-trailer used for our analysis

<table>
<thead>
<tr>
<th>Baseline specifications</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>4x2</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>

Vehicle Simulation

# List of technologies considered in analysis

<table>
<thead>
<tr>
<th>Engine Optimization</th>
<th>Aerodynamics</th>
<th>Rolling Resistance</th>
<th>Mass Reduction Area / System</th>
<th>Driveline / Transmission</th>
<th>Auxiliaries</th>
<th>Driver Assistance Systems</th>
<th>Hybridization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion optimization</td>
<td>Roof spoiler</td>
<td>Low rolling resistance tires</td>
<td>Engine</td>
<td>Automated man. transmission</td>
<td>Variable speed cooling fan</td>
<td>Stop-start / idle reduction</td>
<td>Integrated Mild Hybrid</td>
</tr>
<tr>
<td>Advanced turbocharging</td>
<td>Cabin side turning vanes</td>
<td>Single wide tires</td>
<td>Coolant circuit</td>
<td>Dual clutch transmission</td>
<td>Variable/clutched air compressor</td>
<td>Eco-roll</td>
<td>Parallel hybrid</td>
</tr>
<tr>
<td>EGR reduction / advanced SCR</td>
<td>Tractor/truck side skirts</td>
<td>Tire pressure monitoring</td>
<td>Fuel circuit</td>
<td>Downspeeding</td>
<td>LED lighting</td>
<td>Speed limiter</td>
<td>48-V electric architecture</td>
</tr>
<tr>
<td>Friction reduction</td>
<td>Active grille shutter</td>
<td>Automatic tire inflation</td>
<td>Exhaust system</td>
<td>Improved mech. efficiency</td>
<td>Electro-hydraulic power steering</td>
<td>Predictive cruise control</td>
<td>24-V brake energy recovery</td>
</tr>
<tr>
<td>On demand / improved pumps</td>
<td>Cabin underbody devices</td>
<td>Rearview cameras</td>
<td>Transmission</td>
<td>Top-torque control</td>
<td>High efficiency HVAC</td>
<td>Adaptive cruise control</td>
<td></td>
</tr>
<tr>
<td>Turbocompound</td>
<td>Air dam</td>
<td></td>
<td>Electrical system</td>
<td>Engine/trans. deep-integration</td>
<td>High efficiency alternator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste heat recovery</td>
<td>Tractor side panels</td>
<td></td>
<td>Chassis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trailer side skirts</td>
<td>Wheel covers</td>
<td></td>
<td>Suspension</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Vented mud-flaps</td>
<td>Trailer rear-end device</td>
<td></td>
<td>Braking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trailer underbody devices</td>
<td></td>
<td></td>
<td>Wheels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cabin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Trailer Body</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Not captured by VECTO | Partially captured by VECTO | Captured by VECTO |
How efficient can diesel long-haul tractor trailers be in the future?

- Engine: 55% peak efficiency
- Aerodynamic drag: 0.35
- Rolling resistance: 4 N / kN
- Lightweighting: -2300 kg
- Hybrid: P2, 120 kW, 2 kWh

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The Supertruck II program from the US Department of Energy aims to show a pathway to 55% brake thermal efficiency. Participants include Cummins, Daimler, Navistar (VW), Volvo, and Paccar (DAF).

Daimler, Cummins, Navistar, and Volvo already demonstrated 50%+ peak efficiency.

The pathway to 55% peak efficiency could include the use of waste heat recovery (WHR), variable valve timing, back-pressure reduction, low EGR/high SCR concepts, low high peak combustion pressures, optimized combustion bowl, optimized injector, closed-loop injection rate shaping, reduced heat transfer, reduced friction in piston ring pack and bearings, opposed piston architecture, low temperature combustion, among others.
The technologies for 43% reduction increase the tractor-trailer cost by approximately 20%.


The technologies for 43% reduction will have a payback between 1.4 to 2.7 years in 2030

Main study assumptions:

- Fuel price: 0.7 to 1.4 €/L
- Discount rates: 4% to 10%
- Evaluation years: 2025 and 2030
- Trailers per tractor: 1.4
- Vehicle lifetime: ~1 M km
- First owner annual use: ~110k km


HD ZEV freight
HD ZEV freight: Long-haul is 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>• Medium Duty rigid (straight) trucks and vans</td>
<td>Low speed, transient</td>
<td>&lt;200km/day</td>
<td>&lt;5 ton</td>
<td>&lt;100kWh &lt;10kg 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></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Travel high volume freight corridors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional Delivery</td>
<td>• Return to base</td>
<td>High speed, constant</td>
<td>&gt;500km/day</td>
<td>&gt;20 ton</td>
<td>&gt;800kWh &gt;30kg H₂</td>
<td>Extensive</td>
<td>65-75%</td>
<td>Unknown</td>
</tr>
<tr>
<td></td>
<td>• Mix of urban and highway</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Haul</td>
<td>• Mostly tractor-trailers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>
The carbon intensity of the fuels is the only lever available for full decarbonization of on-road freight. Direct use of electricity results in the lowest CO₂ emissions.
Questions? Contact the HDV team at the ICCT

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