Vehicle energy efficiencies

IEA EGRD Workshop
“Mobility: Technology Priorities and Strategic Urban Planning
Nils-Olof Nylund
VTT Technical Research Centre of Finland
Outline

- General introduction
- Ways to reduce fuel consumption
  - engine technology
  - reduced need for power
  - electrification
- Trends for
  - passenger cars
  - buses
  - heavy-duty trucks
- ICE vs. EV
- Summary
Elements determining the environmental impacts of traffic

- Community structure
- Traffic volumes & choice of transport mode
- Energy for transport
- Vehicles and user behaviour

Policy orientation  Technology orientation
Formation and control of CO$_2$ emissions

Total emissions = \text{Transport work (km)} \times \text{Energy use (MJ/km)} \times \text{Carbon intensity (g CO2/MJ)}

Measures for reduction:
- Reduction of traffic flows
- Energy efficiency & modal shift
- Renewable energy

*passenger/tonkilometre
Environmental friendliness
Multi-dimensional contemplation

A fluent intelligent transport system
Service and safety

Local emissions
\( \text{NO}_x, \text{PM} \)

Energy consumption

\( \text{CO}_2 \) emissions

Global effects

Local effects

Noise
Current status of vehicles

- The current passenger car is:
  - reliable
  - comfortable
  - relatively safe
  - environmentally friendly regarding regulated emissions
  - in most cases a "high-performance" vehicle

- What should be improved?
  - fuel efficiency
  - the ability to use renewable or CO$_2$-neutral energy
  - rational use of cars

- Traditionally heavy-duty vehicles have been fuel efficient but dirty, but with the JPN 2009, US2010 and Euro VI emission regulations the situation will change
Factors affecting energy consumption/CO₂ emissions

Vehicle use
- Mileage
- Traffic fluidity
- Information system
- Driving behaviour

Load

Environmental conditions
- Fuel/energy carbon intensity
- Driving res.
  - weight
  - aerodynamic drag
  - rolling res.

Powerplant characteristics
- manual/automatic
- hybrid

Technology
Technical tool box for a cleaner future

- Improved engine technologies
  - Combustion, AMT
- Reduced need for power
  - AMT
- Hybridisation
  - HEV
- Electrification
  - HEV, AFC
- Fuel cell technology
  - AFC, HEV, Hydrogen
- Alternative fuels
  - AMF, Bioenergy, Combustion, Hydrogen
Improving engine efficiency

- For all ICE types the pathway into the future includes:
  - reducing the physical size of the engine and increasing relative load (“downsizing”)
  - improving boosting technologies
  - implementation of direct fuel injection
  - reduction of friction
  - increase in control parameters
  - powerful control systems
  - electrification of auxiliaries

- The main challenge
  - simultaneous reduction of fuel consumption and regulated exhaust emissions

- Future possibilities
  - combining the best features of Diesel and Otto (spark-ignited) engines
  - waste heat recovery
    (with a focus on heavy-duty engines)
Reducing CO\textsubscript{2} Adds Cost to Vehicle Powertrain

**Graph: Cost versus Fuel Consumption Improvements for Powertrain Technologies**

- **Euro 4/5 Diesel**
- **Gasoline**
- **Hybrids**

<table>
<thead>
<tr>
<th>Percentage Cost Increase (relative to Euro 4 Petrol Engine)</th>
<th>Percentage NEDC CO\textsubscript{2} Improvement (relative to Euro 4 Petrol Engine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel (E4) - no DPF</td>
<td>0%</td>
</tr>
<tr>
<td>Diesel (E5) - DPF</td>
<td>20%</td>
</tr>
<tr>
<td>Stop-start (Super Starter)</td>
<td>10%</td>
</tr>
<tr>
<td>Stop-start (Super Starter)</td>
<td>10%</td>
</tr>
<tr>
<td>Twin Phase 117</td>
<td>0%</td>
</tr>
<tr>
<td>STOP hybrid (12+X BSG)</td>
<td>10%</td>
</tr>
<tr>
<td>Mild hybrid (+20% DS)</td>
<td>30%</td>
</tr>
<tr>
<td>Full hybrid (+30% DS)</td>
<td>60%</td>
</tr>
<tr>
<td>Full hybrid (+30% DS Att)</td>
<td>60%</td>
</tr>
<tr>
<td>Full hybrid (+30% DS Att)</td>
<td>60%</td>
</tr>
</tbody>
</table>

**Source:** Ricardo analysis communicated to CONCAWE (2008)
Effect of engine type and curb weight on passenger car fuel consumption
Reducing the need for power

- We should reduce curb weight, rolling resistance and aerodynamic drag.

- Weight reduction can be achieved through reduction of size (passenger cars) and by utilizing lighter materials (all types of vehicles):
  - high-strength steels
  - aluminium and aluminium alloys
  - magnesium and magnesium alloys
  - titanium and titanium alloys
  - carbon fiber composites
  - nanocomposites

- The effect of weight:
  - For passenger cars a weight reduction of 10 % reduces fuel consumption some 6 – 7 %.
  - For buses 1,000 kg of added weight as curb weight or passengers increases fuel consumption some 2.5 l/100 km (6 %) in city driving (e.g. Helsinki)

- Aerodynamic drag becomes significant at higher speeds.
More small cars needed?

smorsche

smorvette

smamborgini

smerrari
60 ton Tractor & Trailer, Full Payload, Freeway at 80 km/h

```
<table>
<thead>
<tr>
<th>Fuel Feed in</th>
<th>Heat Rejection Losses</th>
<th>Cycle Efficiency</th>
<th>Gas Exchange Losses</th>
<th>Engine Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% 371 kW</td>
<td>97 kW 26%</td>
<td>52%</td>
<td>193 kW 4%</td>
<td>44% 168 kW</td>
</tr>
<tr>
<td>44,5 L/100km</td>
<td>82 kW 22%</td>
<td></td>
<td>15 kW 4%</td>
<td></td>
</tr>
</tbody>
</table>

```

- **Exhaust Heat**
- **Cycle Efficiency**
- **Gas Exchange Losses**
- **Engine Efficiency**

```
<table>
<thead>
<tr>
<th>Fuel-Feed in</th>
<th>Engine Losses</th>
<th>Engine Out</th>
<th>Auxiliaries</th>
<th>Diveline &amp; Tyre Losses</th>
<th>Traction Work</th>
<th>&quot;Hysteresis&quot;</th>
<th>Rolling Resistances</th>
<th>Air Drag</th>
</tr>
</thead>
<tbody>
<tr>
<td>371 kW 100%</td>
<td>204 55%</td>
<td>168 44%</td>
<td>15 3%</td>
<td>12 3%</td>
<td>108 77%</td>
<td>10 6%</td>
<td>68 18%</td>
<td>64 kW 38%</td>
</tr>
<tr>
<td>100%</td>
<td>55%</td>
<td>44%</td>
<td>3%</td>
<td>3%</td>
<td>35%</td>
<td>3%</td>
<td>41%</td>
<td>17%</td>
</tr>
</tbody>
</table>

**Combined Total Mass**

- **60 000 kg**

"Hysteresis" = irreversible losses in uphill/downhill driving

- **Rolling Resistance**
- **Driveline & Tyre Losses**
- **Auxiliaries**
- **Traction Work**
- **Engine Out**

- **Air Drag**

- **Combined Total Mass**

- **Fuel Feed in**
- **Engine Losses**
- **Engine Out**
- **Auxiliaries**
- **Diveline & Tyre Losses**
- **Traction Work**
- **"Hysteresis"**
- **Rolling Resistances**
- **Air Drag**
Improving aerodynamics of HD vehicles

30 % smaller drag: fuel savings 10 – 15 %
# Steps in Electrification

<table>
<thead>
<tr>
<th>Internal combustion engine</th>
<th>Mild Hybrid</th>
<th>Full Hybrid</th>
<th>Plug-In Hybrid</th>
<th>Electric vehicle</th>
<th>Fuel Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2 l 77 kW TSI&lt;sup&gt;®&lt;/sup&gt;</td>
<td>Start-Stop system recuperation</td>
<td>Touareg Hybrid&lt;sup&gt;®&lt;/sup&gt;</td>
<td>Golf twinDRIVE&lt;sup&gt;®&lt;/sup&gt;</td>
<td>E-Up!</td>
<td>Tiguan Hymotion&lt;sup&gt;®&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

The share of electricity increases
Diesel predominant in the heavy end

Several options available

No Silver Bullet !!!

Source: GM
Key technical measures to promote energy efficiency for various vehicle classes

Passenger cars:
- smaller and lighter vehicles
- reduced performance
- hybridization, electrification

City buses:
- reduced weight
- hybridization, electrification

- HD trucks for highway use
  - improved aerodynamics

<table>
<thead>
<tr>
<th>Energiamerkinnän päästöluokka</th>
<th>Raja-arvot CO2-päästöille g/km</th>
<th>CO2-päästöä vast. polttoaineenkulutus (pyörrettynä 0,1 l/km100 km tankkausen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>max 100</td>
<td>max 4,3</td>
</tr>
<tr>
<td>B</td>
<td>101 - 120</td>
<td>4,3 - 5,1</td>
</tr>
<tr>
<td>C</td>
<td>121 - 130</td>
<td>5,1 - 5,5</td>
</tr>
<tr>
<td>D</td>
<td>131 - 150</td>
<td>5,6 - 6,4</td>
</tr>
<tr>
<td>E</td>
<td>151 - 175</td>
<td>6,4 - 7,4</td>
</tr>
<tr>
<td>F</td>
<td>176 - 200</td>
<td>7,4 - 8,5</td>
</tr>
<tr>
<td>G</td>
<td>201 -</td>
<td>8,6 -</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7,5 -</td>
</tr>
</tbody>
</table>
Development of CO\textsubscript{2} limit values for passenger cars

Fuel Consumption is translated into CO\textsubscript{2}

<table>
<thead>
<tr>
<th>Year</th>
<th>CO\textsubscript{2} (g/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>280</td>
</tr>
<tr>
<td>2004</td>
<td>240</td>
</tr>
<tr>
<td>2006</td>
<td>200</td>
</tr>
<tr>
<td>2008</td>
<td>160</td>
</tr>
<tr>
<td>2010</td>
<td>120</td>
</tr>
<tr>
<td>2012</td>
<td>80</td>
</tr>
<tr>
<td>2014</td>
<td>40</td>
</tr>
<tr>
<td>2016</td>
<td>40</td>
</tr>
<tr>
<td>2018</td>
<td>40</td>
</tr>
<tr>
<td>2020</td>
<td>40</td>
</tr>
<tr>
<td>2022</td>
<td>40</td>
</tr>
</tbody>
</table>

- **Commercial vehicles**
- **USA**
- **Japan**
- **China**
- **EU**
- **India**

**Both developed and emerging countries have similar tendencies to enhance CO\textsubscript{2} regulations.**

95 g/km (~4.0 l petrol /100 km)

Source: Tanaka/Toyota 2011
Development of passenger car CO₂ emissions in Europe

185 g CO₂ ~ 7.9 l petrol/100 km
140 g CO₂ ~ 6.0 l petrol/100 km
What is the fuel consumption of a Volvo V40?
It depends!.....

Volvo V40 T5 automatic
8,1 l/100 km
185 g CO2/km

Volvo V40 D2
3,6 l/100 km
94 g CO2/km

I.e. a reduction of 49 %!

Photo: Volvo Cars

## Technical progress

**VW Golf VII diesel 2013   VW Golf I diesel 1976 Audi A6 Avant 2013**

<table>
<thead>
<tr>
<th>Comparison Category</th>
<th>VW Golf VII diesel 2013</th>
<th>VW Golf I diesel 1976</th>
<th>Audi A6 Avant 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement (l)</td>
<td>1.6</td>
<td>1.5</td>
<td>3.0 twin-turbo</td>
</tr>
<tr>
<td>Max output (kW)</td>
<td>77</td>
<td>37</td>
<td>230</td>
</tr>
<tr>
<td>Torque (Nm)</td>
<td>250</td>
<td>84</td>
<td>650</td>
</tr>
<tr>
<td>Max speed (km/h)</td>
<td>192</td>
<td>144</td>
<td>250 (limited)</td>
</tr>
<tr>
<td>Acceleration 0 – 100 km/h (s)</td>
<td>10.7</td>
<td>18</td>
<td>5.3</td>
</tr>
<tr>
<td>Curb weight</td>
<td>1295</td>
<td>780</td>
<td>1930</td>
</tr>
<tr>
<td>Fuel consumption (EU comb. l/100 km)</td>
<td>3.8</td>
<td>6.4</td>
<td>6.4</td>
</tr>
<tr>
<td>CO₂ emission (g/km)</td>
<td>99</td>
<td>169</td>
<td>169</td>
</tr>
<tr>
<td>Particulate filter</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

**What would have happened if the technical potential would have been used for fuel efficiency only (keeping performance and weight constant)?**
IEA Technology Network Cooperation: Fuel and Technology Alternatives for Buses
Overall energy efficiency and emission performance

SAE 2012 Commercial Vehicle Engineering Congress
October 2-3, 2012
Rosemont, Illinois USA
Kati Koponen & Nils-Olof Nylund
VTT Technical Research Centre of Finland
Energy consumption of European vehicles
Braunschweig cycle

Energy Consumption - Braunschweig

MJ/km

Euro II 18.8
Euro III 15.8
EEV EGR 16.4
EEV SCR 14.9
EEV SCRT 15.2
EEV SCRT LW 12.6
Hybr 1 par 12.7
Hybr 2 par 11.3
Hybr 3 par 10.9
Hybr 4 ser 10.7
EEV CNG SM 21.1
Euro V CNG LB 20.0
Ethanol 16.4
DME proto 15.6
Fuel savings through hybridization
European vehicles

Conventional Vehicles vs. Hybrids

FC (l/100 km), Fuel savings %

NYBUS: 103, 38, 36, 37, 44, 32, 27, 31, 26, 18, 35, 32, 29, 27, 8, 8

ADEXE: 64, 36, 37, 44, 32, 27, 31, 26, 18, 35, 32, 29, 27, 8, 8

BRA: 58, 38, 36, 37, 44, 32, 27, 31, 26, 18, 35, 32, 29, 27, 8, 8

JE05: 0, 20, 40, 60, 80, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

UDDS: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

WHVC: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

COLORS:
- AVG EEV
- AVG HYBRID
- FUEL SAVINGS %
Reduced fuel consumption

Volvo FH12, 40 ton in traffic

-15%
Tested fuel consumption of 38/40 t truck combinations
Summary mode

- Instant feed-back on driving behaviour in the instrument cluster
- Tips given when good and bad events have been detected
- Evaluated situations
  - Hill-driving
  - Brake use
  - Anticipation
  - Gear selection

Source: Göran Lingström/Scania
Releases accelerator before passing crest

Goes downhill at selected speed

Uses momentum for next hill by accelerating before reaching bottom

Accelerates past crest

Brakes to reduce downhill speed

Begins to accelerate uphill

Source: Göran Lingström/Scania
Energy efficiency/CO₂ regulations for HD vehicles

- Japan has been the forerunner
  - fuel efficiency standards for heavy vehicles above 3.5 t as of 2006

- USA
  - the first US GHG emission and fuel consumption standards for heavy- and medium-duty vehicles were adopted on August 9, 2011

- EU
  - methodology and regulations under development
PERFORMANCE EVALUATION OF PASSENGER CAR, FUEL AND POWERPLANT OPTIONS

IEA AMF Annex XLIII

IEA ExCo 44
Jukka Nuottimäki
VTT Technical Research Centre of Finland
Annex 43: Content of the project

- The core of the comparison consists of benchmarking a set of passenger cars of such make & model that offer multiple choices for engine, i.e. gasoline, flex-fuel, diesel, CNG/LPG and perhaps also some hybrid and EV variations.

- The project will also demonstrate the differences in efficiency arising from the engine type and size.

- The test matrix will allow some modulation of duty-cycle and ambient temperature in order to give more application/environment specific data.

- Making this kind of back-to-back comparison can "neutralize" the vehicle itself from the equation, thus highlighting the role of the propulsion system.

- Combined to the results of the upstream fuel-cycle research conducted within the IEA Bus Project, this project can be enlarged to a comprehensive, full fuel-cycle evaluation.
Finnish Results:
Energy consumption of a medium sized vehicle on NEDC

Max 860 Wh/km (big gasoline engine), minimum 198 Wh/km (BEV)
Power generation profiles

Source: Ecofys 2010
Energy consumption EV vs. ICE

- Electric vehicle Nissan Leaf
  - energy consumption 0.21 kWh/km (motoring magazine TM 2012)
  - transmission losses 5%
  - total energy consumption 0.22 kWh/km (well-to-wheel WTW, renewable electricity)
  - total energy consumption 0.55 kWh/km (well-to-wheel WTW, gas turbine power plant)

- Diesel car VW Golf 1.6 D Blue Motion Technology
  - factual fuel consumption 5.0 l/100 km (own experience)
  - energy consumption 1.80 MJ/km (0.50 kWh)
  - total energy consumption 0.60 kWh/km (WTW)

Sources: Ecofys 2010, Climate Counter 2012
Summary

- Independent of the energy source, energy efficiency must be prioritized.
- Several technical measures are available for reducing energy consumption.
- Emphasis of measures varies from one vehicle category to another.
- Light-duty vehicles show greater potential for reduction of energy consumption than heavy-duty commercial vehicles.
- Driving behaviour has a major impact on energy consumption and emissions.
VTT creates business from technology