Comparative Study on Exhaust Emissions from Diesel- and CNG-Powered Urban Buses

Patrick COROLLER & Gabriel PLASSAT
(French Agency of Environment and Energy Management)

Presented by
Dr. Thierry SEGUELONG
(Aaqius&Aaqius)
Outlines of the presentation

- ADEME Program
- Program Evaluations on Diesel & CNG Buses
- Tests Results
  - Exhaust Emissions
  - Consumption
- Green House Gas Emissions
- Economical Study
- Conclusions
Outlines of the presentation

- ADEME Program
- Program Evaluations on Diesel & CNG Buses
- Tests Results
  - Exhaust Emissions
  - Consumption
- Green House Gas Emissions
- Economical Study
- Conclusions
Objective:

- development of Public Transports in urban area with clean image and reduction of exhaust emissions:
  - improvement of performance of existing fleet vehicles, using new fuels (Diesel, reformulated fuels, CNG, LPG, RME...) and adapted exhaust emission control systems...
  - replacement of old vehicles with promoting clean technologies (Diesel, hybrid, electric, fuel-cells...)
- diversification in energy source for Public Transports
- customers acceptance

- Long term evaluations in the real urban area started in 1998
Outlines of the presentation

- ADEME Program
- Program Evaluations on Diesel & CNG Buses
- Tests Results
  - Exhaust Emissions
  - Consumption
- Green House Gas Emissions
- Economical Study
- Conclusions
ADEME National Fleet Evaluations

Part of a comprehensive program based on evaluation of 6 sites between 1998 and 2003+

- evaluation of emissions
- follow-up on city site
- technical diagnosis
- customers acceptance
Specific Evaluated Bus Vehicles

3 CNG-powered Buses (3 technologies)

AGORA Renault VI:
- lean combustion, w/ carburetor, w/ Oxicat

HEULIEZ Volvo engine:
- lean combustion, w/multipoint injection, w/ Oxicat

Mercedes:
- stoichiometric combustion, w/ TWC

4 Diesel-powered Buses (EURO 2 – 1995/1996)

AGORA 10 L Renault VI (x2)

Mercedes 12 L O405 (x2)
Comparative Study (UTAC*)

“In situ” tests in term of technical and environmental performance

Exhaust emissions (CO, HC, NOx, PM), Carbon balance and technical diagnosis of bus fleets

* Union Technique de l’Automobile, du Motocycle et du Cycle

AQA-RATP Cycle
Paris City line # 21
(average speed of 10,5km/h)
Outlines of the presentation

- ADEME Program
- Program Evaluations on Diesel & CNG Buses
- Tests Results
  - Exhaust Emissions
  - Consumption
- Green House Gas Emissions
- Economical Study
- Conclusions
CO Exhaust Emissions

in g/km

DIESEL

CNG
HC Exhaust Emissions

**DIESEL**

**CNG**
NOx Exhaust Emissions

DIESEL

CNG
PM Exhaust Emissions

DIESEL

CNG
at the initial point, mainly Methane, C2 (ethane, ethene), C3 (propane, propene); no significant emissions of other hydrocarbons (except for carburetor-based technology)
  - with carburetor-based technology, high non-regulated hydrocarbons levels were observed, with ethane (732mg/km), C3, C4, C5, C6, acetaldehyde (150mg/km) and acrolein (about 10 times higher than other CNG technologies)

after one year service, increase of aldehydes, regardless of CNG technologies, and heavy hydrocarbons (> C5)
  - effect of lubricant (consumption, combustion)

Diesel non-regulated emissions: more specific, without significant difference between buses types.
  - heavy hydrocarbons (>C5),
  - oxygenated related to formaldehydes (50%) and acetaldehyde (25%).
DPF Effect on Exhaust Emissions

Over the RATP Cycle (g/km):
- 75% reduction of CO
- 65% reduction of HCs
- no significant effect on NOx
- around 98% reduction of PM
- no significant impact on fuel consumption
CNG Consumption

**Over AQA-RATP Cycle:** +30 to +60% depending on the bus

**On Site:** +20 to +45% (depending on the bus technology, urban conditions, air conditioning, compartment heating)

1 Nm3/100km is equivalent to 1 l /100km Diesel fuel

**NICE area** (South of France)
- **Winter:** 78 Nm3/100km
- **Summer:** 85 Nm3/100km

» Air conditioning system
Outlines of the presentation

- ADEME Program
- Program Evaluations on Diesel & CNG Buses
- Tests Results
  - Exhaust Emissions
  - Consumption
- Green House Gas Emissions
- Economical Study
- Conclusions
Green House Gas Emissions

- Production
- Compression
- Refinery
- CH4, GWP=25
- CO2, Exhaust
Outlines of the presentation

- ADEME Program
- Program Evaluations on Diesel & CNG Buses
- Tests Results
  - Exhaust Emissions
  - Consumption
- Green House Gas Emissions
- Economical Study
- Conclusions
## Preliminary Cost Study

<table>
<thead>
<tr>
<th>CNG</th>
<th>EURO 2 Diesel fitted w/DPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over-cost : average of 30,000€/bus</td>
<td>Average cost of DPF System: 4,500 to 6,000€ (passive)</td>
</tr>
<tr>
<td>- fuel penalty: +1,34</td>
<td>Low Sulfur Fuel: 0,03 €/l</td>
</tr>
<tr>
<td>- and compressed gas station: 450 to 500,000 € (investment)</td>
<td>- DPF regeneration machine (passive)</td>
</tr>
<tr>
<td>Security, Refilling speed, Maintenance (spark-plug, engine parts…)</td>
<td>- DPF cleaning (60 to 100,000km)</td>
</tr>
<tr>
<td></td>
<td>- additional cost for Active DPF</td>
</tr>
<tr>
<td></td>
<td>- and NOx after-treatment</td>
</tr>
</tbody>
</table>
Outlines of the presentation

- ADEME Program
- Program Evaluations on Diesel & CNG Buses
- Tests Results
  - Exhaust Emissions
  - Consumption
- Green House Gas Emissions
- Economical Study
- Conclusions
### Average performance summary

<table>
<thead>
<tr>
<th>Pollutants (g/km)</th>
<th>RVI AGORA Diesel</th>
<th>Mercedes Diesel</th>
<th>RVI AGORA CNG</th>
<th>Volvo CNG</th>
<th>Mercedes CNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Power</td>
<td>110 kW</td>
<td>136 kW</td>
<td>103 kW</td>
<td>127 kW</td>
<td>103 kW</td>
</tr>
<tr>
<td>CO</td>
<td>3,90</td>
<td>1,8</td>
<td>5,4</td>
<td>0,6</td>
<td>12,0</td>
</tr>
<tr>
<td>HCs</td>
<td>1,2</td>
<td>1,2</td>
<td>8,4</td>
<td>5,3</td>
<td>5,0</td>
</tr>
<tr>
<td>NOx</td>
<td>30,2</td>
<td>20,0</td>
<td>14,8</td>
<td>13,5</td>
<td>8,3</td>
</tr>
<tr>
<td>PM</td>
<td>0,42</td>
<td>0,28</td>
<td>0,036</td>
<td>0,025</td>
<td>0,026</td>
</tr>
<tr>
<td>Consumption (line 21) /100km</td>
<td>61 lit.</td>
<td>56 lit.</td>
<td>78 Nm3</td>
<td>91 Nm3</td>
<td>81 Nm3</td>
</tr>
<tr>
<td>GHGE (g/km)</td>
<td>1800</td>
<td>1670</td>
<td>2200</td>
<td>2090</td>
<td>2240</td>
</tr>
</tbody>
</table>

1 Nm3/100km is equivalent to 1 l /100km Diesel fuel
## Comparison trends & Summary

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>HC</th>
<th>NO\textsubscript{x}</th>
<th>PM</th>
<th>NRP</th>
<th>GHE</th>
<th>D</th>
<th>I</th>
<th>O</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diesel (EURO 2)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diesel w/ DPF</strong></td>
<td>+</td>
<td>+</td>
<td>=</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>=</td>
<td>=</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>CNG</strong></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Worse**  | - - | - | EURO 2 | + | + |  
**Better** |    |   |         |   |   |   

**D:** Diversification (energy)  
**I:** Investment  
**O:** Operation  
**A:** Adaptation
Trends and Perspectives

**Diesel:** fitted with DPF and NOx control
improved Direct Injection Diesel Engine
Diesel fuel quality

**CNG:** technology developments and improvements
specific exhaust emissions control devices
- sensors, specific CH₄ after-treatment
adapted maintenance
specific lubricant
combustion improvements (» CO₂ emission)
local organization (central compressed machine)

**Target:** 20% CNG in Public Transports in Y2020