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Heavy-Duty Engine Validation of World Harmonized Duty Cycle (WHDC)

Test Programme of the COMMISSION OF THE EUROPEAN COMMUNITIES
ENTERPRISE DIRECTORATE GENERAL

Final Summary

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Scope

- cycle correlation
- comparison of full flow (CVS) PM vs. partial flow (ISO 16183) PM
- comparison of diluted gaseous components vs. raw gaseous components
- evaluation of variance of measurement procedures (CVS vs. ISO 16183)
- cycle driveability (validation / statistics)

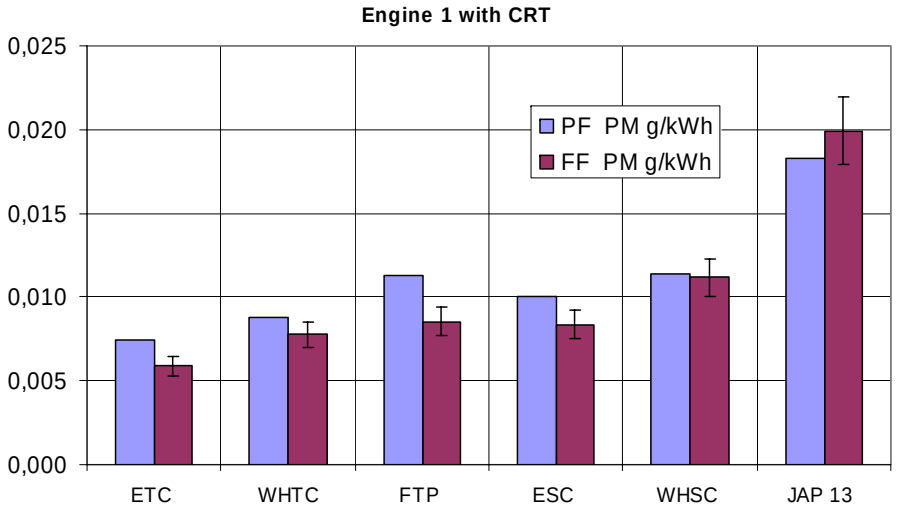
Engines, fuel, cycles

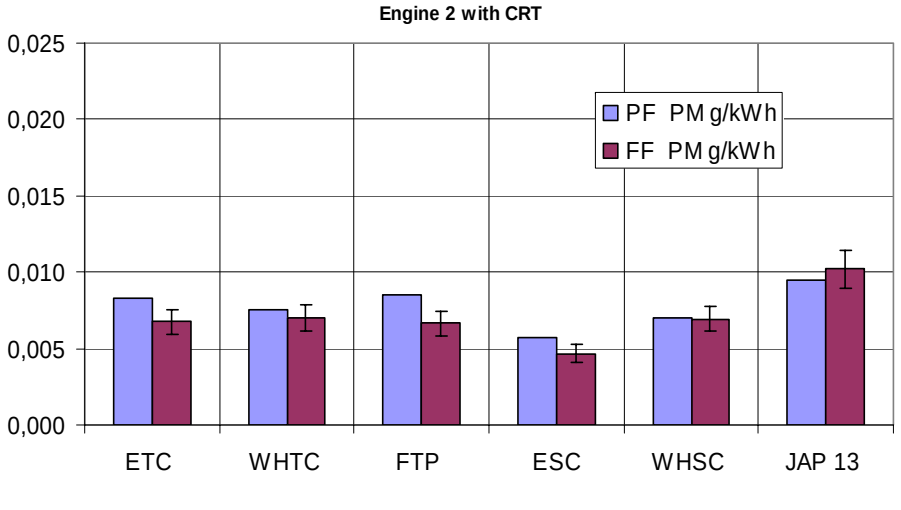
- **Engine 1**
  emission status Euro III with CRT
  VH = 11,1.9 l, P = 290 kW
- **Engine 2**
  emission status Euro III with CRT
  VH = 6.7 l, P = 189 kW
- **Engine 3**
  emission status Euro III without after-treatment
  VH = 15.6 l, P = 426 kW
- **Engine 4**
  emission status Euro III without after-treatment
  VH = 2.8 l, P = 92 kW

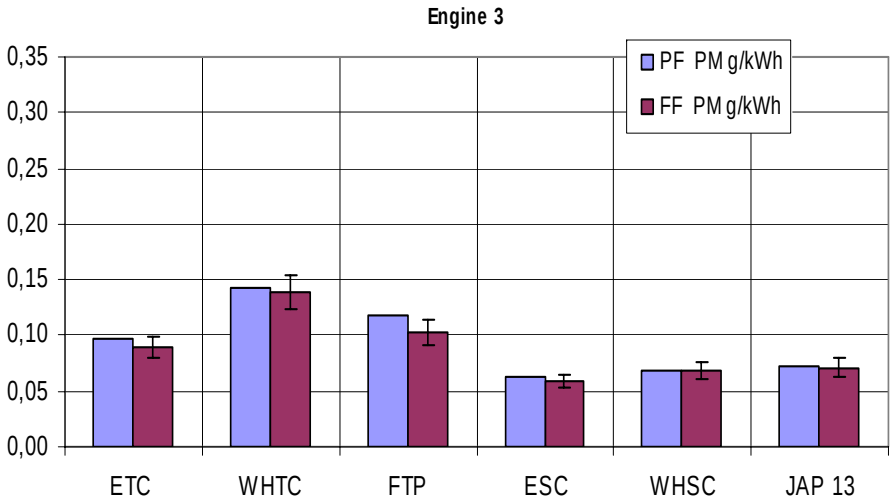
- **Reference fuel**
  CEC RF-06-99 diesel fuel, sulphur below 10 ppm

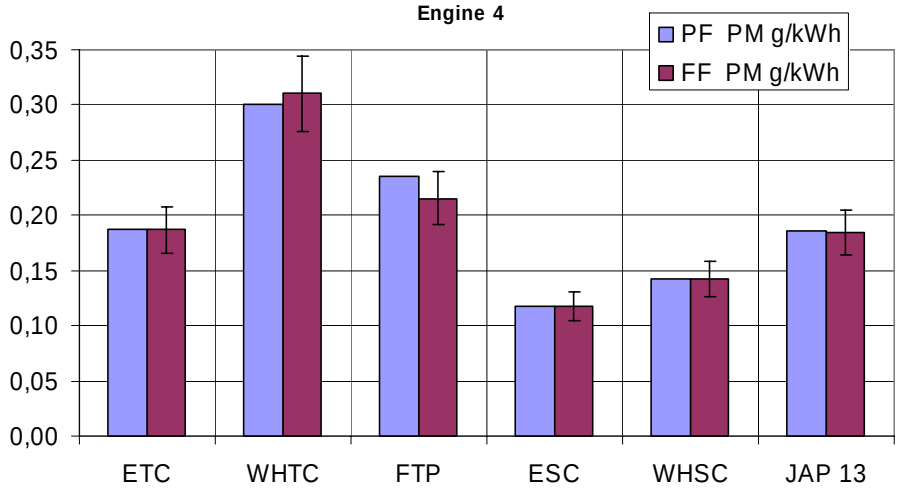
- **Cycles**
  steady-state: **ESC, WHSC, Japanese 13-mode test,**
  transient: **ETC, WHTC, US-FTP**

PM - gravimetric FF/PF results

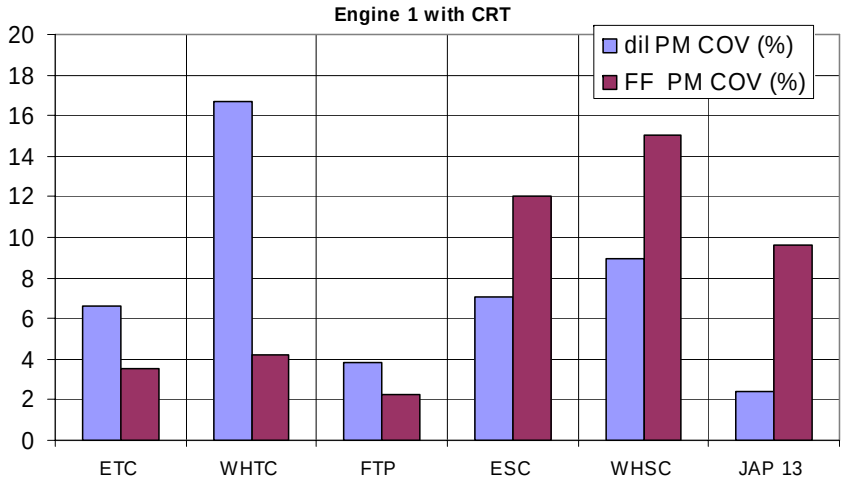


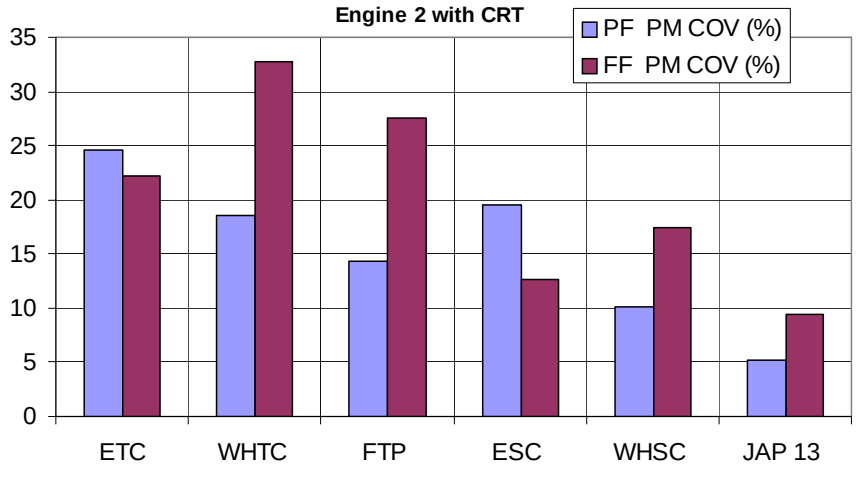


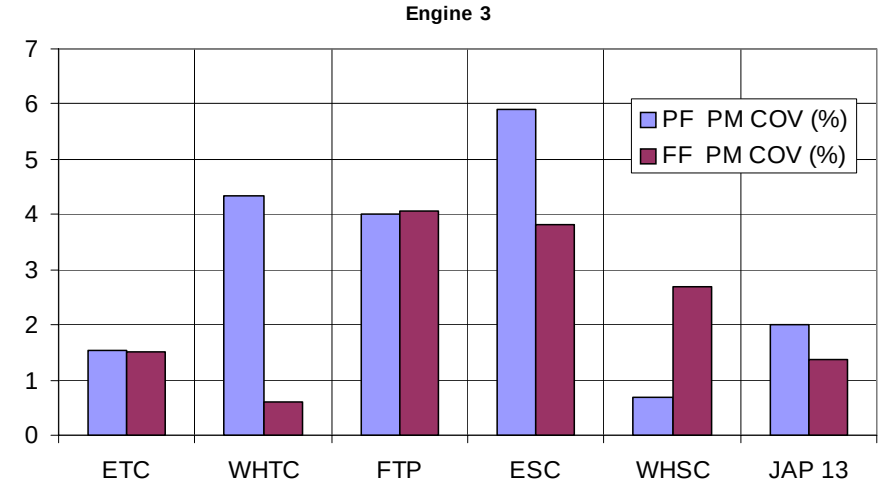


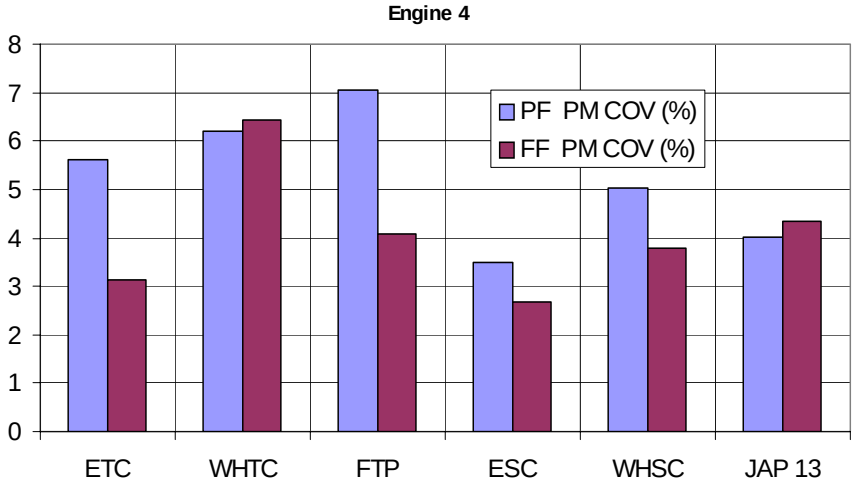


PM - Gravimetric COV

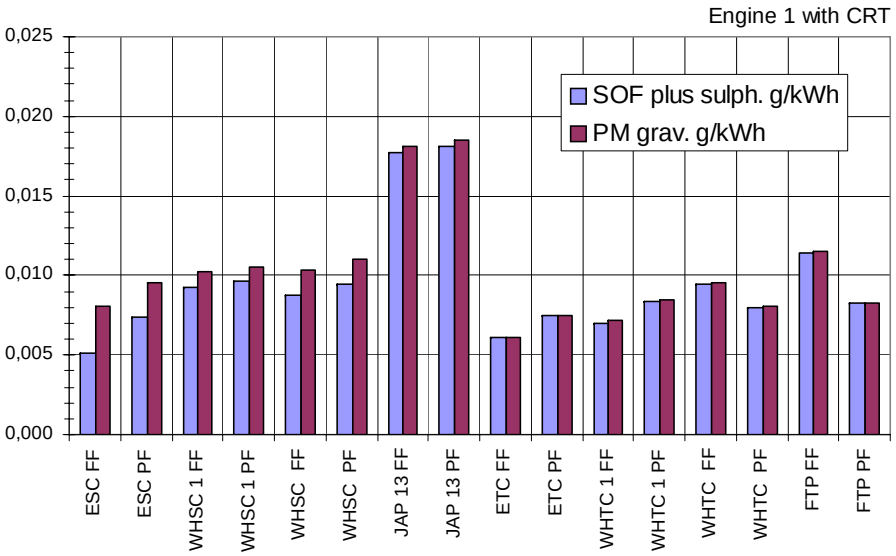


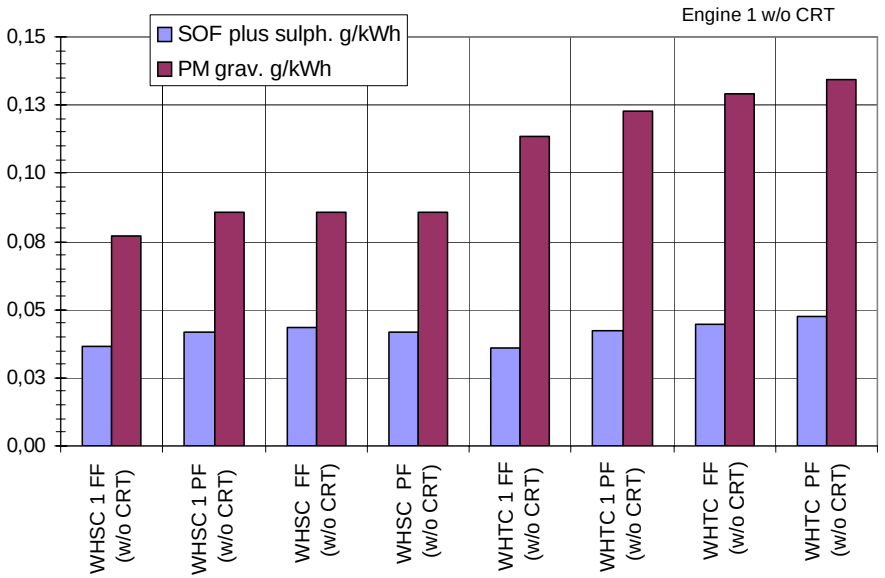


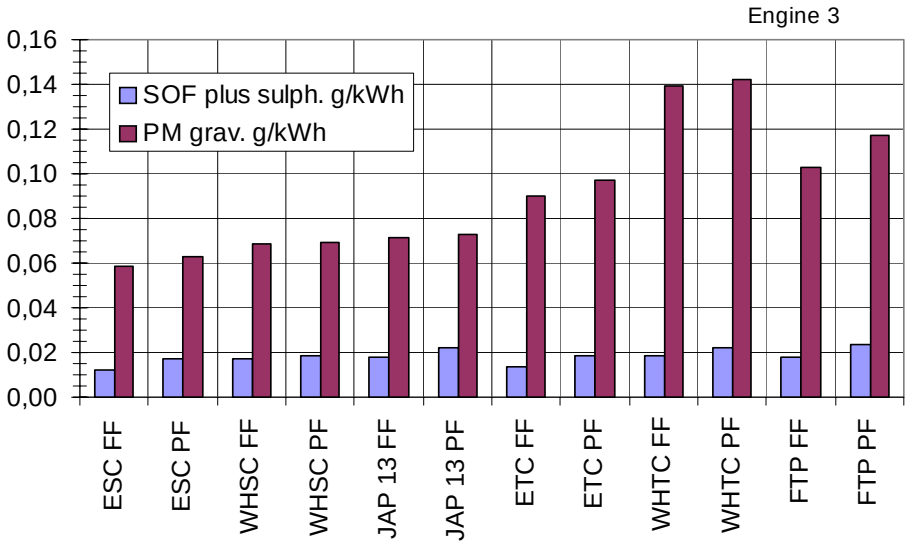


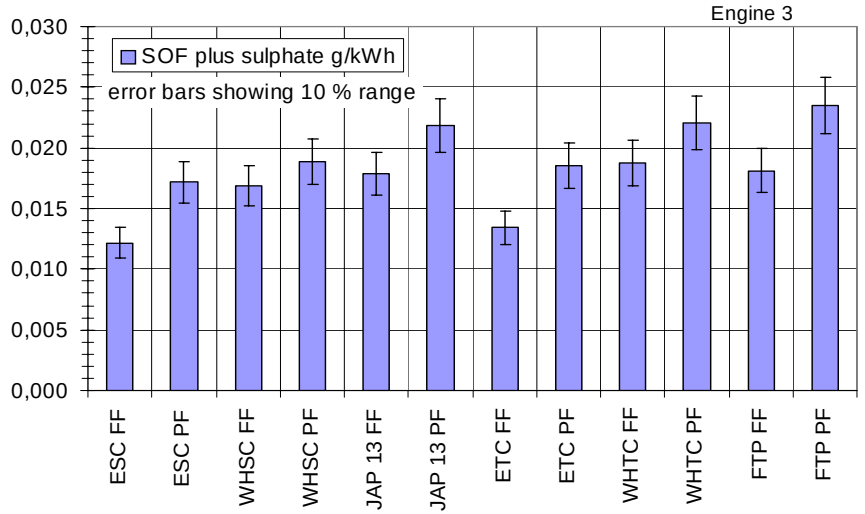


PM - SOF plus sulphate









PM - Summary and Conclusions

Both systems (FF and PF) are capable of monitoring the same PM emission map although there are slightly differences in the results.

The high COV for the CRT-Systems are not favourable, especially not for type approval. Since this high variability was observed for both systems, this gives evidence that partial flow dilution systems perform as well as full flow dilution systems.
The high COV is caused by the after-treatment system / the very low emissions value.

The absolute std. deviation between 0.001 and 0.002 g/kWh, as mostly achieved during this programme, shows a very low variability.

Nearly the total PM-emission consists of non-soot (SOF plus sulphate) on the CRT equipped engines. The mean fraction of the SOF plus sulphate to the total gravimetric PM-value is at 93% for engine 1.

The values are showing that there is no significant difference between the partial flow and full flow SOF plus sulphate portion at very low values.

For the engines without CRT-system the PM composition is different but the SOF plus sulphate level based on the mean values found on the partial flow system is only very slightly higher than for the full flow system.

The absolute SOF plus sulphate-level is more or less the same over all cycles.

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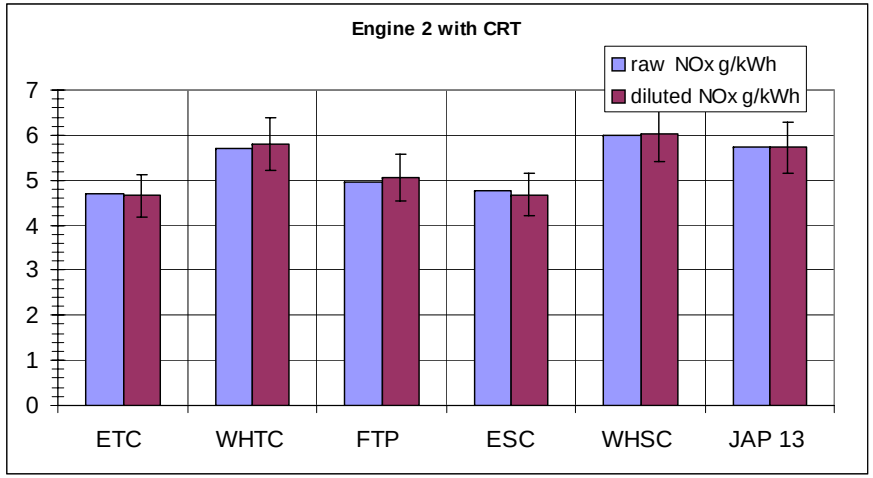
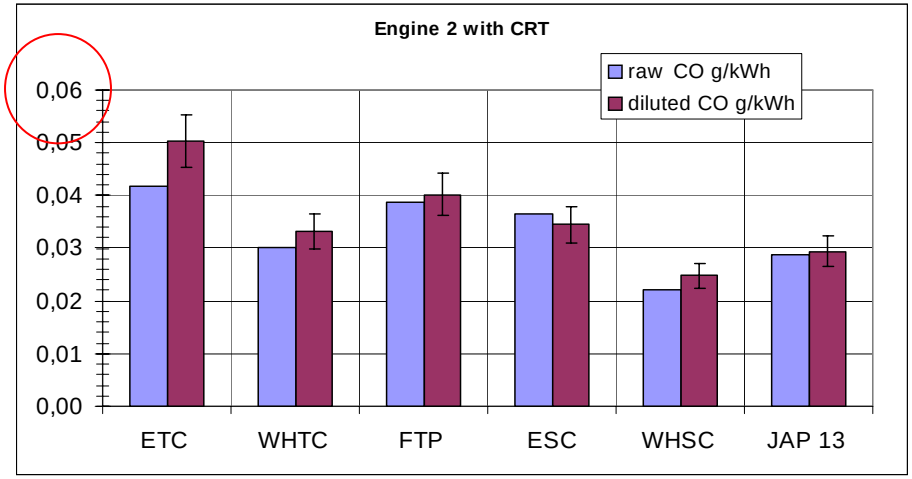
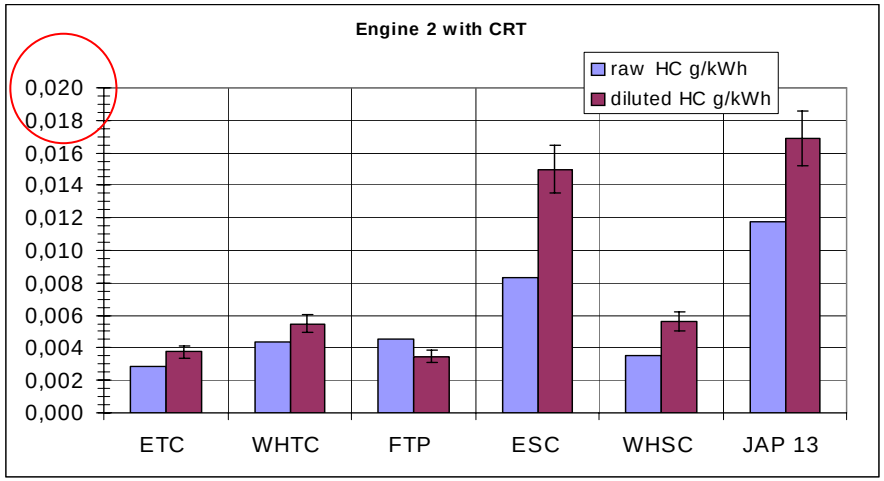
Gaseous Components (CRT equipped engine)

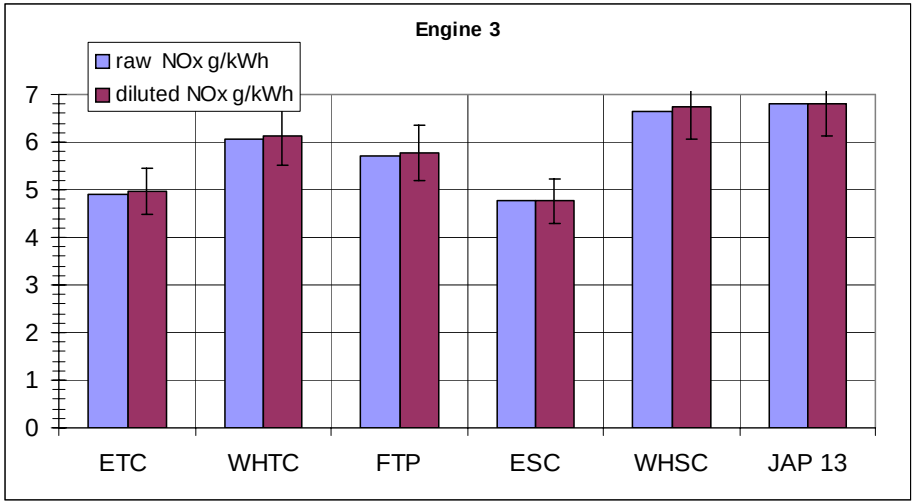


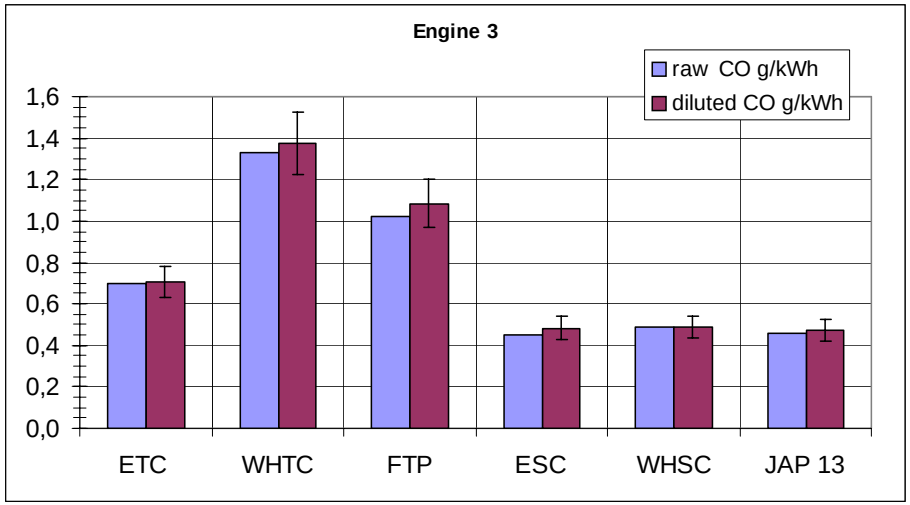


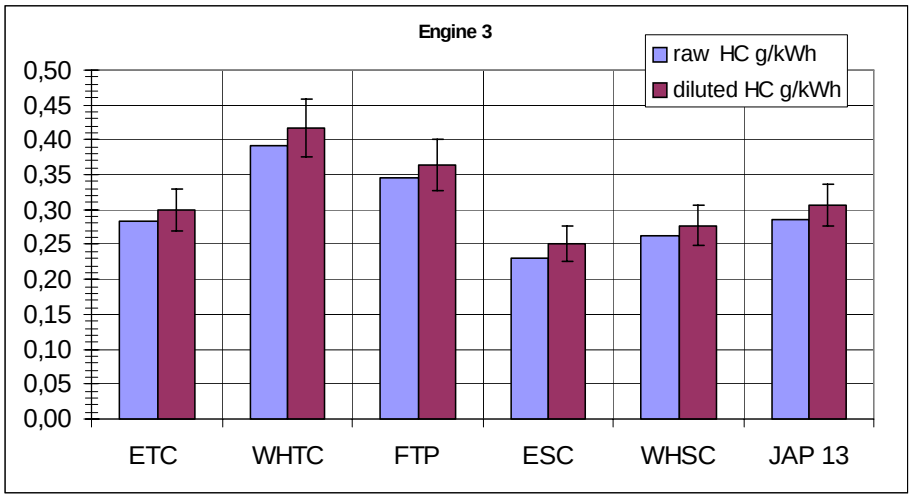


Good to very good agreement for NOx. CO and HC values some poorer due to very low absolute values.

Gaseous Components

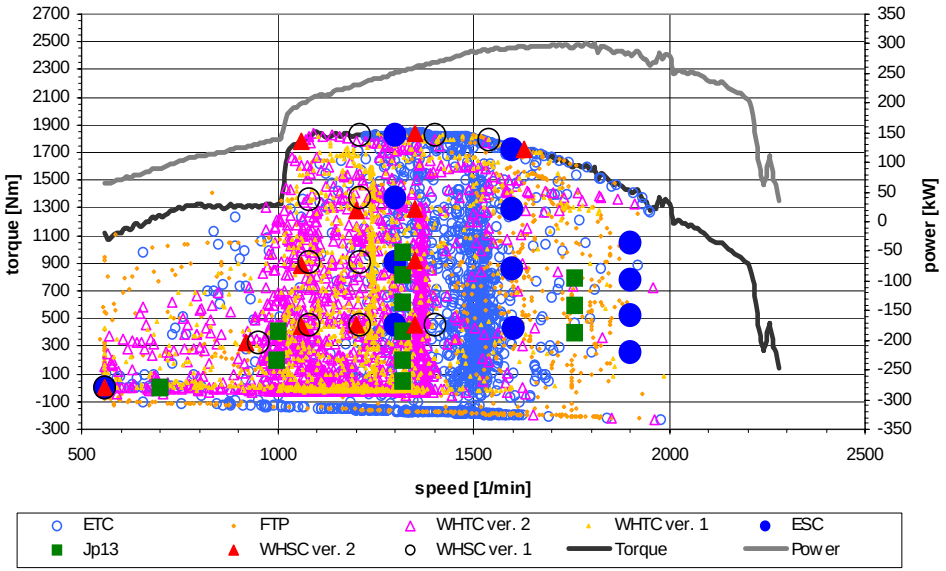


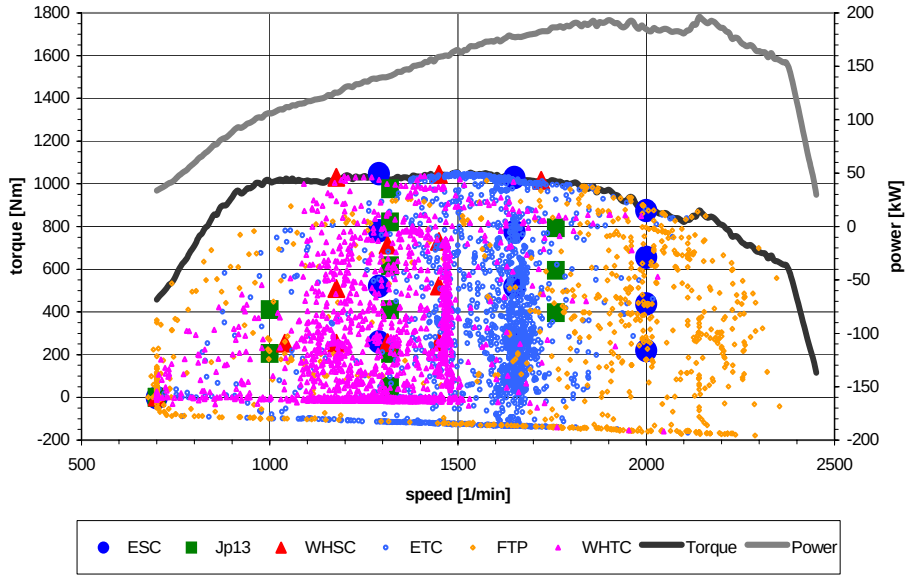


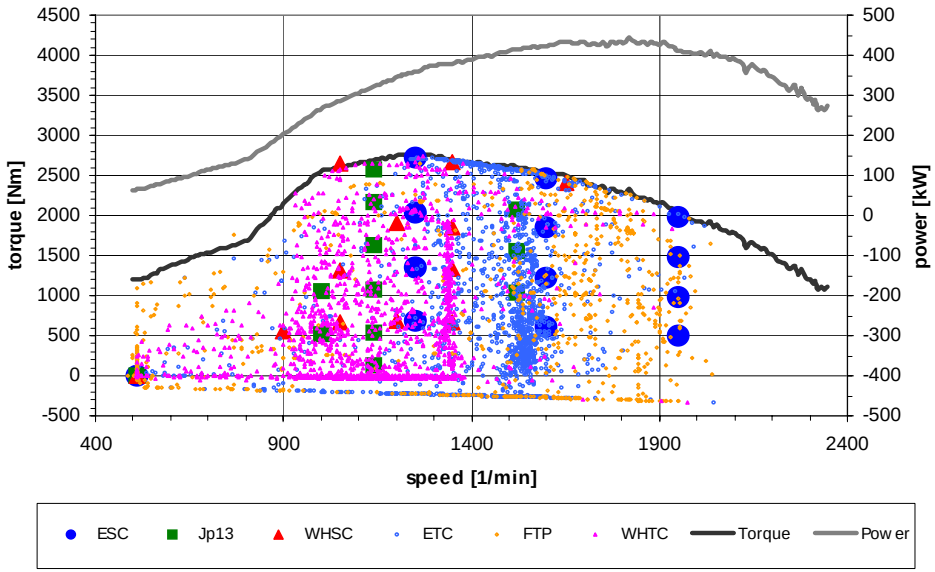


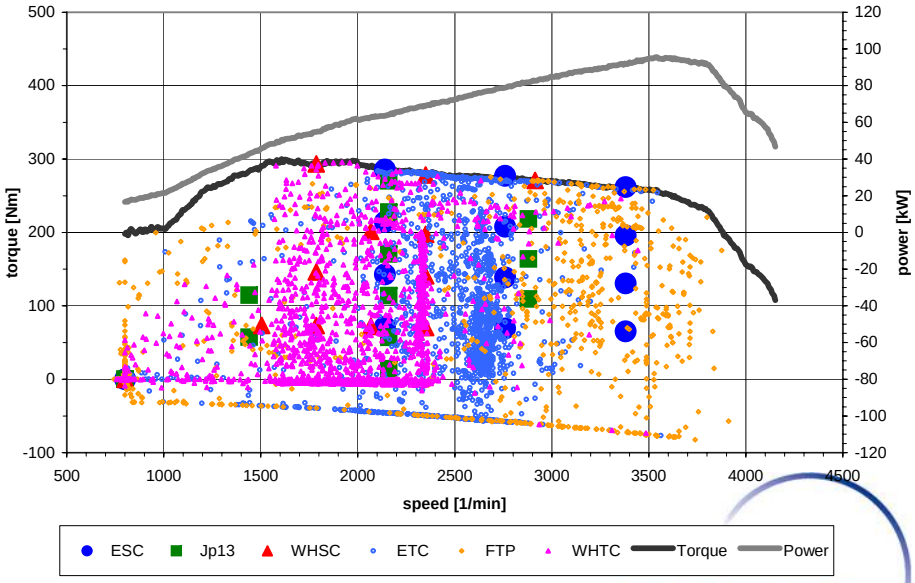
Good to very good agreement for
all components (dev. < 10%)

Comparison of engine maps

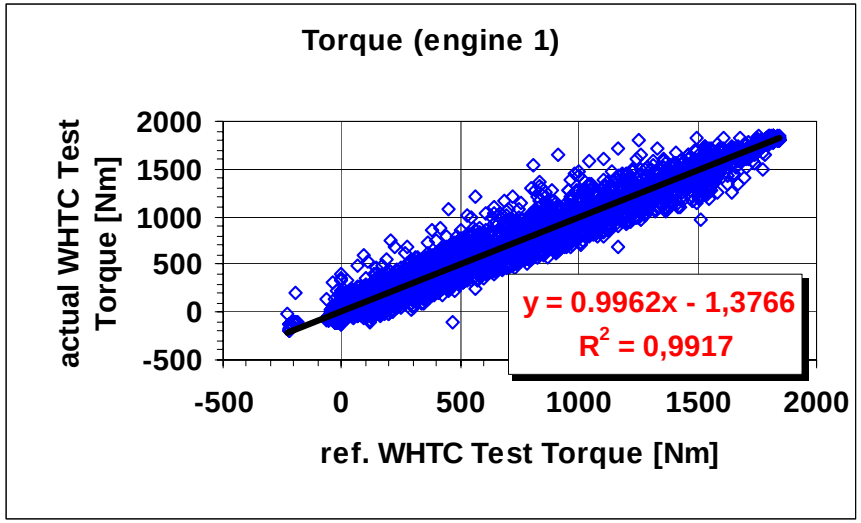


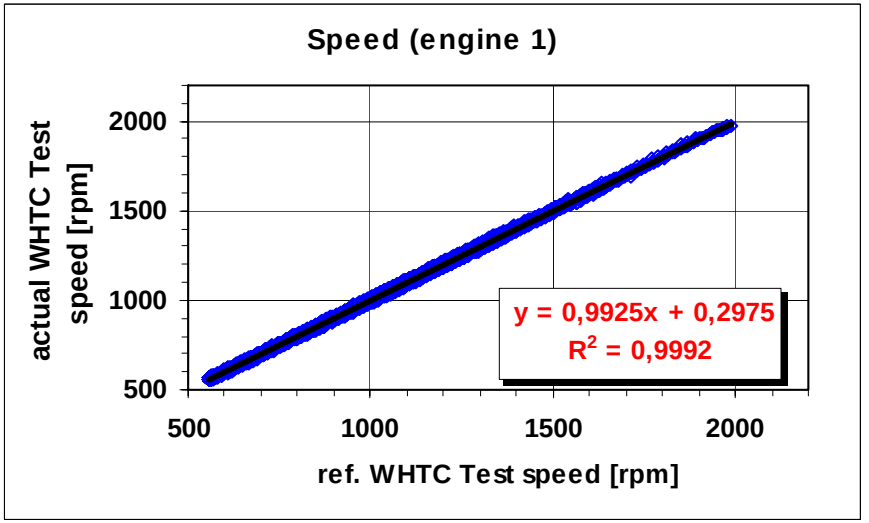


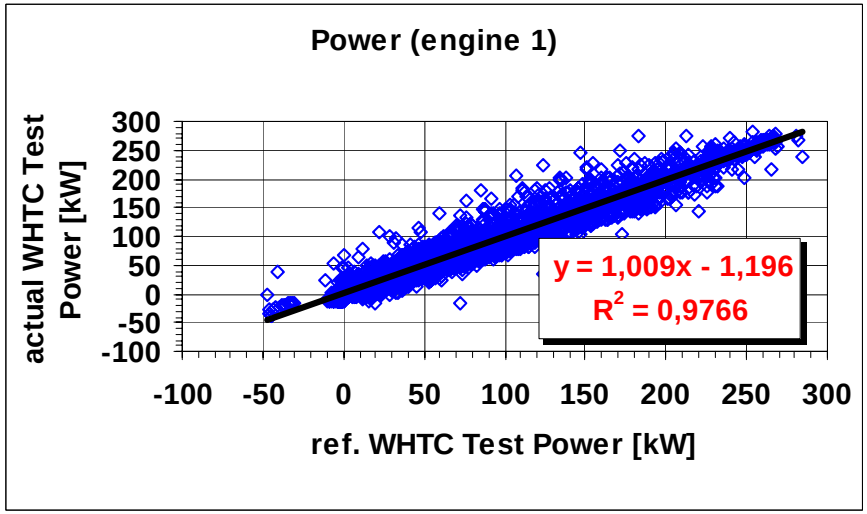




Driveability of final version WHTC



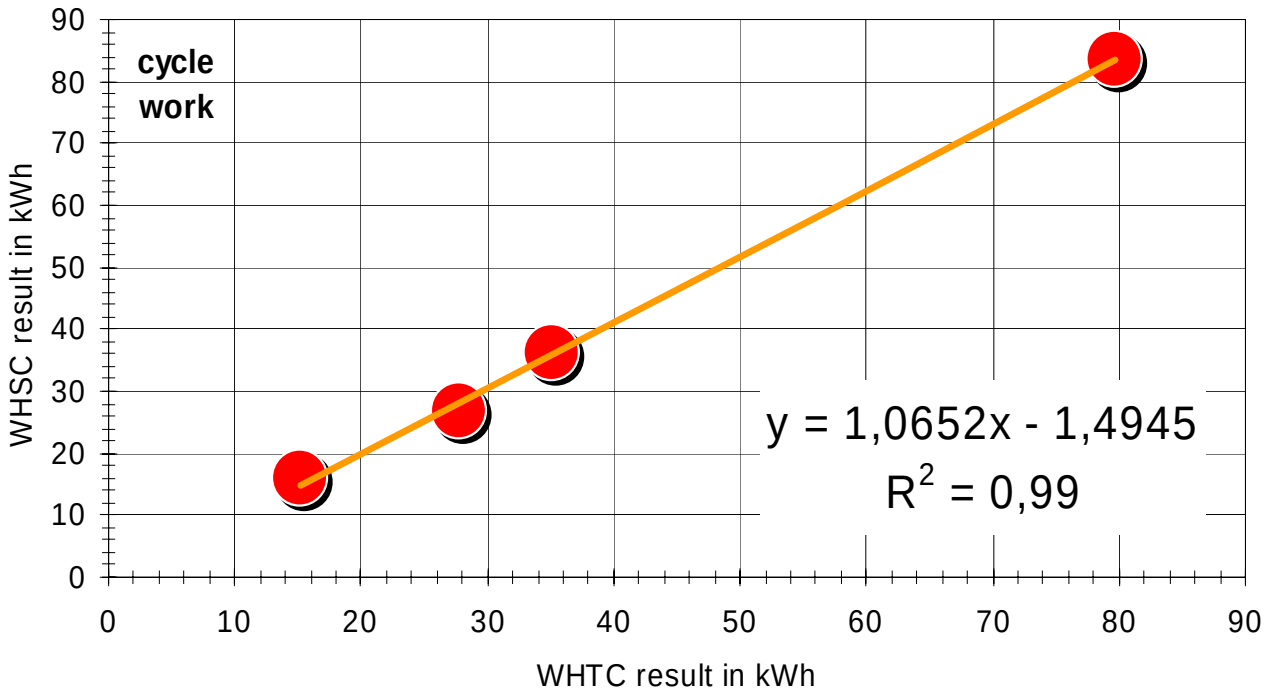




Good driveability based on the regression analysis procedures already applicable for the ETC and U.S.-FTP

WHTC / WHSC equivalency

Engine 1 with CRT	NOx (g/kWh)	W (kWh)
WHTC final mean	5.76	27.80
WHSC final mean	6.37	26.68
diff. SC to TC	0.61	-1.12
percentage SC to TC	9.57	-4.19



Summary and Conclusions

The final WHDC-cycles showed very good steady-state / transient cycle equivalence. Both cycles cover a wider range of the engine map than today's cycles.

The driveability of the WHTC in terms of the cycle validation criteria given in the EU and in the US is good to very good. Since more worldwide driving patterns are considered the final WHTC does not have as many dynamic parts as the ETC-cycle based only on European driving pattern.

The capability of partial flow dilution systems operated according to ISO 16183 for particulate matter measurement under transient conditions was proven. The partial flow system showed good to very good comparability to the well-established full flow dilution-CVS-system.

The PM analysis by extraction showed no significant differences in the particulate matter composition sampled by a partial flow system.

The provisions given in ISO 16183 for the raw measurement of the regulated gaseous components during transient engine operation provide a reliable tool for the application of this measurement and sample methodology. The agreement of both procedures (full flow / CVS and raw gas / partial flow) was good over the entire measurement programme.

For both the particulate matter and the gaseous components, good measurement accuracy becomes more difficult to achieve as soon as very low general emission levels are reached due to the fact that the limit of detection of the measurement systems is being approached.
Due to the higher gas concentrations in the raw gas the ISO 16183 procedure is more reliable. Some of the results of the engines equipped with CRT-System could not be used for comparison and correlation purposes due to the very low emission values reached by such technologies for PM, CO and HC. However, it was demonstrated that also in this case the new ISO 16183 procedures are fully applicable with even some advantage compared to the established CVS-procedure.

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