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Developing a Methodology for Certifying Heavy Duty Hybrids based on HILS

Work allocated to TUG

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Content

1. Introduction = conclusions from last meeting
2. Harmonisation of methods for conventional engine testing, HDV CO_2 test procedures and HILS
3. Vehicle related data, WHDHC test cycle
4. WHVC weighting factors
5. Inclusion of PTO operation

Introduction

Conclusions from last HDH meeting:

•Engine test cycle resulting from HILS shall be harmonised with WHTC for conventional engines (i.e. a “very mild” Hybrid shall result in a power curve very close to the WHTC).

•Measurements and simulation for CO_2 has different demands than for regulated pollutants (NOx, PM, PN, CO, HC).

***CO_2 needs representative test cycles and vehicle related driving resistance values to set incentives for optimisation on power pack and vehicle design.**

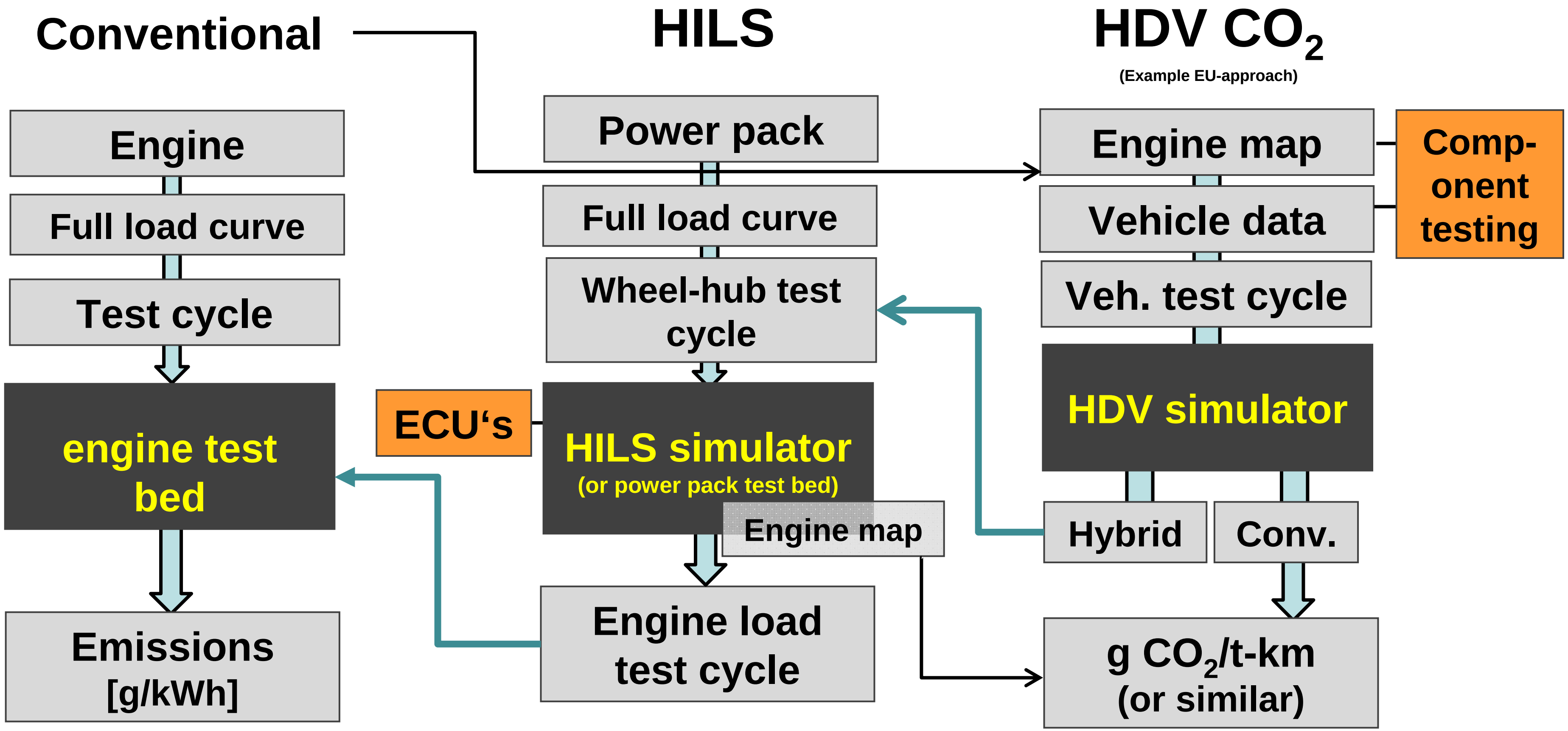
***Pollutant tests shall cover all relevant load conditions for an engine but not necessarily need to consider vehicle model related data (avoid high test burden)**

→ WHDHC (World Heavy Duty Hybrid Cycle) to be designed either as WHVC with generic vehicle data or as wheel-hub power cycle derivate from WHTC.

•PTO inclusion seems to be important for CO_2 result but not so much for pollutants (conventional engine test also does not consider PTO)

•Methods for component testing could be harmonized between HILS and CO_2 test procedures and also between different regions.

Harmonisation of test procedures



Input test cycle:
WHTC

Engine load cycle:
Depends on full load curve
Vehicle independent

Input test cycle:
WHTC + WHVC

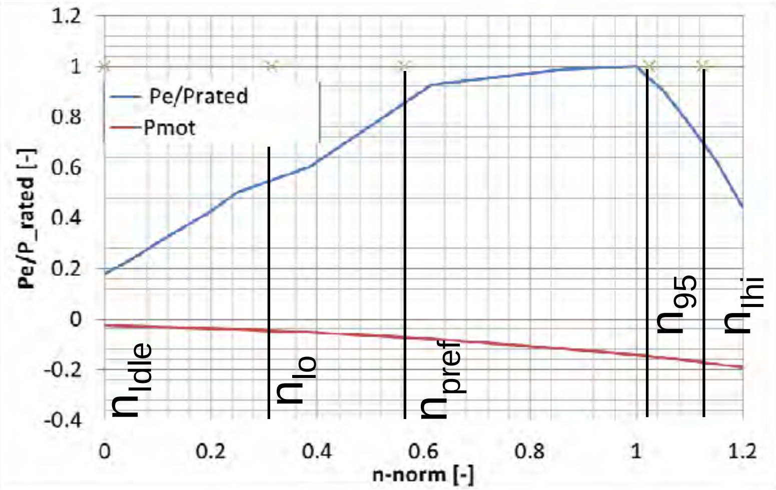
Engine load cycle:
Depends on full load curve
Vehicle independent

Input test cycle: vehicle class specific target speed cycle

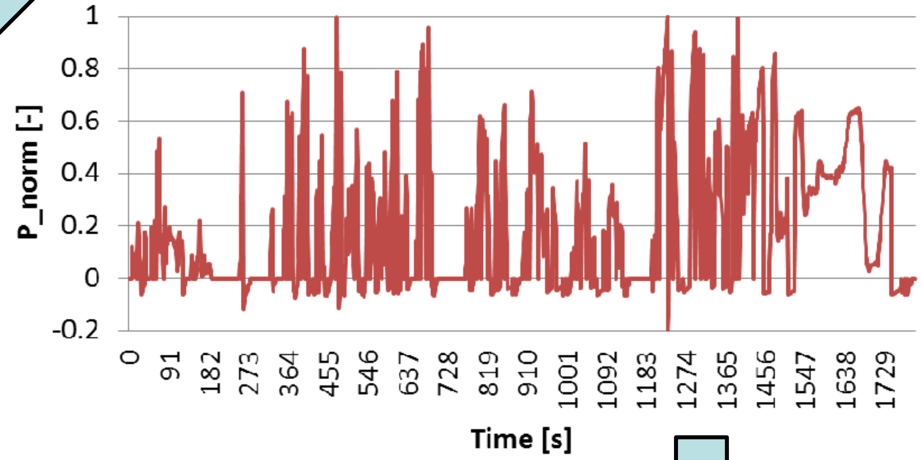
Engine load cycle:
Vehicle dependent and full load curve dependent

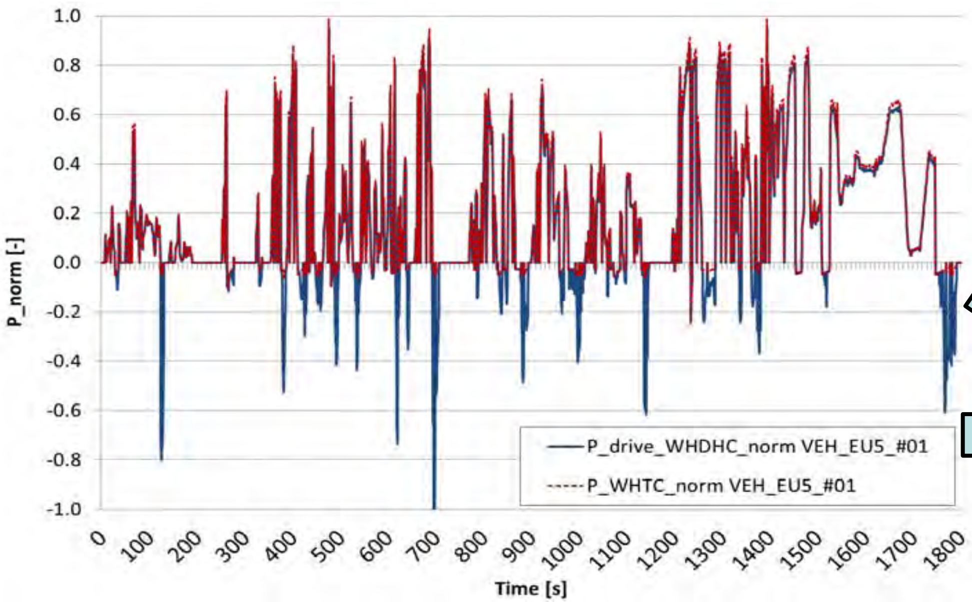
Method for the WHDHC (World Heavy Duty Hybrid Cycle)

Full load engine or power pack



Power course of WHTC





WHTC = effective engine power
+ losses in drive train
+negative power mechanical brakes
Power course at the wheel hub
(=P-drive-WHDHC)

WHDHC as input into HILS
+WHVC speed if necessary for ECU's (adapt max. speed?)

Validation of WHDHC

Work done to validate the method yet:

•Simulation of 15 conventional HDV in WHVC and WHTC with sensitivity runs on aerodynamic drag and rolling resistance

→cycle work different but emissions in [g/kWh] are nearly not affected by variations in vehicle data (FC: ~+/-2%, NOx: +/-6%, PM: +/-25%; 7th HDH meeting)

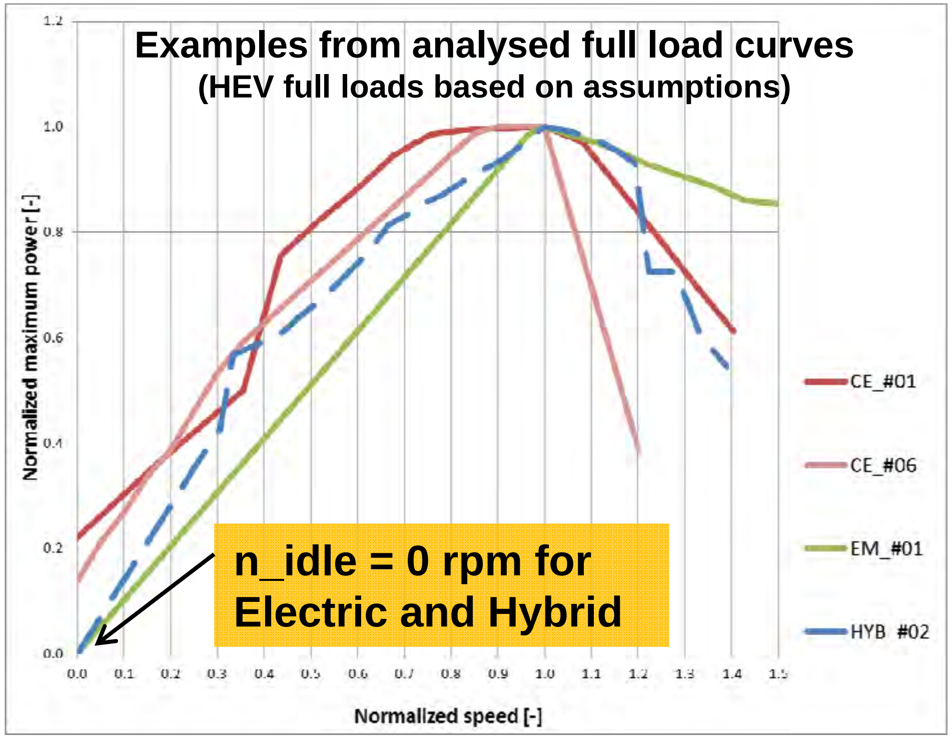
→ neglecting specific vehicle data seems to be acceptable.
Benefit: only 1 test cycle per HDH power pack-family possible.

•Analysis if driver model is capable of controlling P-drive instead of vehicle velocity → from theory possible.

•Analysis if different shape of full load curve from hybrids leads to unrealistic P-drive-WHDHC courses compared to conventional engine full load curves (see next slides)

Validation of WHDHC method with different full load curves

Analysis of different full load curves (as discussed at 7th HDH meeting in Vienna)



Different shapes lead to different characteristic engine speeds in absolute values

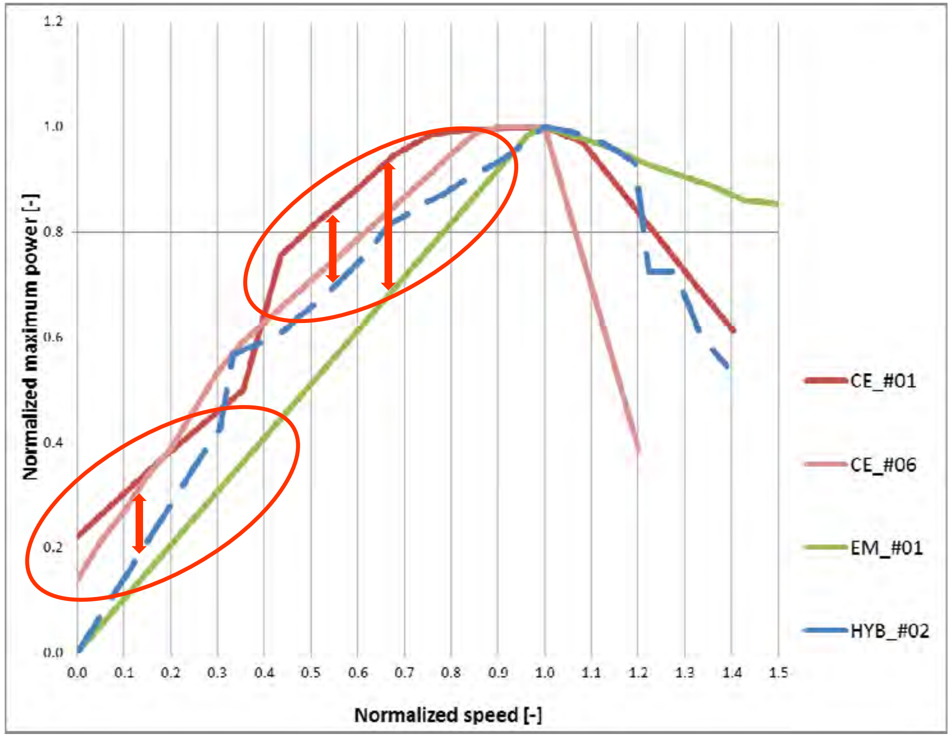
	n_pref [rpm]	n_pref_norm [-]
CE_#01	1300	0.60
CE_#06	1372	0.55
EM_#01	1641	0.59
HYB_#02	922	0.51

$$n_{ref} = n_{norm} \times (0.45 \times n_{lo} + 0.45 \times n_{pref} + 0.1 \times n_{hi} - n_{idle}) \times 2.0327 + n_{idle}$$

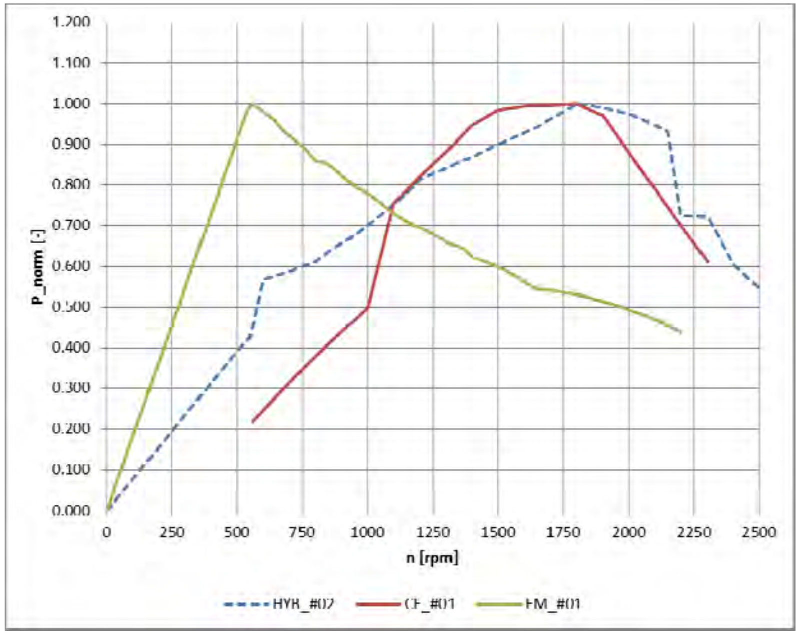
Parallel Hybrids are operated at lower speeds in WHTC
→ lower maximum power in this speed ranges

Validation of WHDHC, influence of full load curve design

Analysis of different full load curves



Due to shape of full load curve Electric Motors and Parallel Hybrids have less normalized power at lower normalized speeds

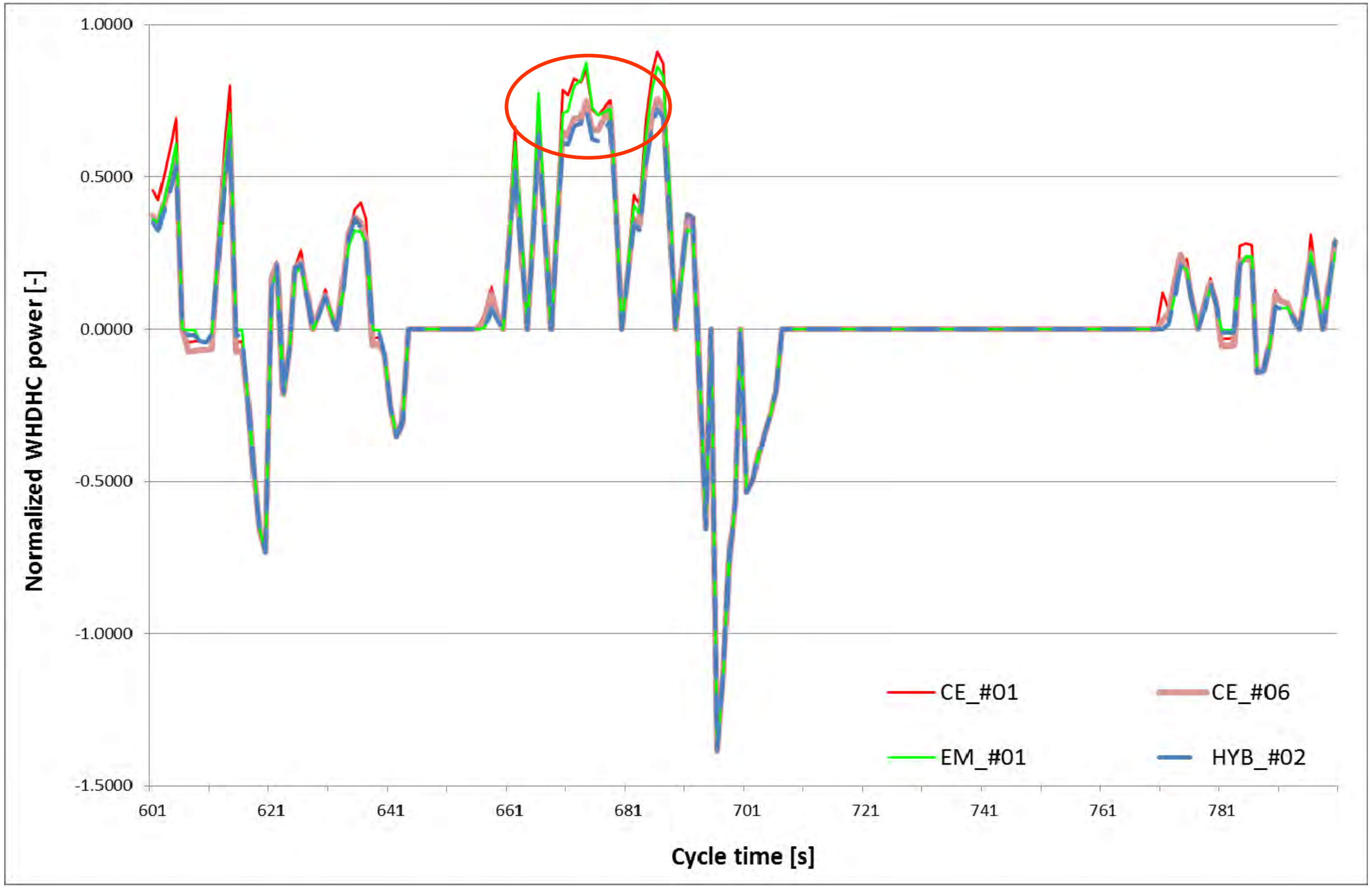


Of course more power at absolute lower speeds

Slightly lower normalized power at respective speeds in WHTC / WHDHC cycle

Validation of WHDHC, influence of full load curve design

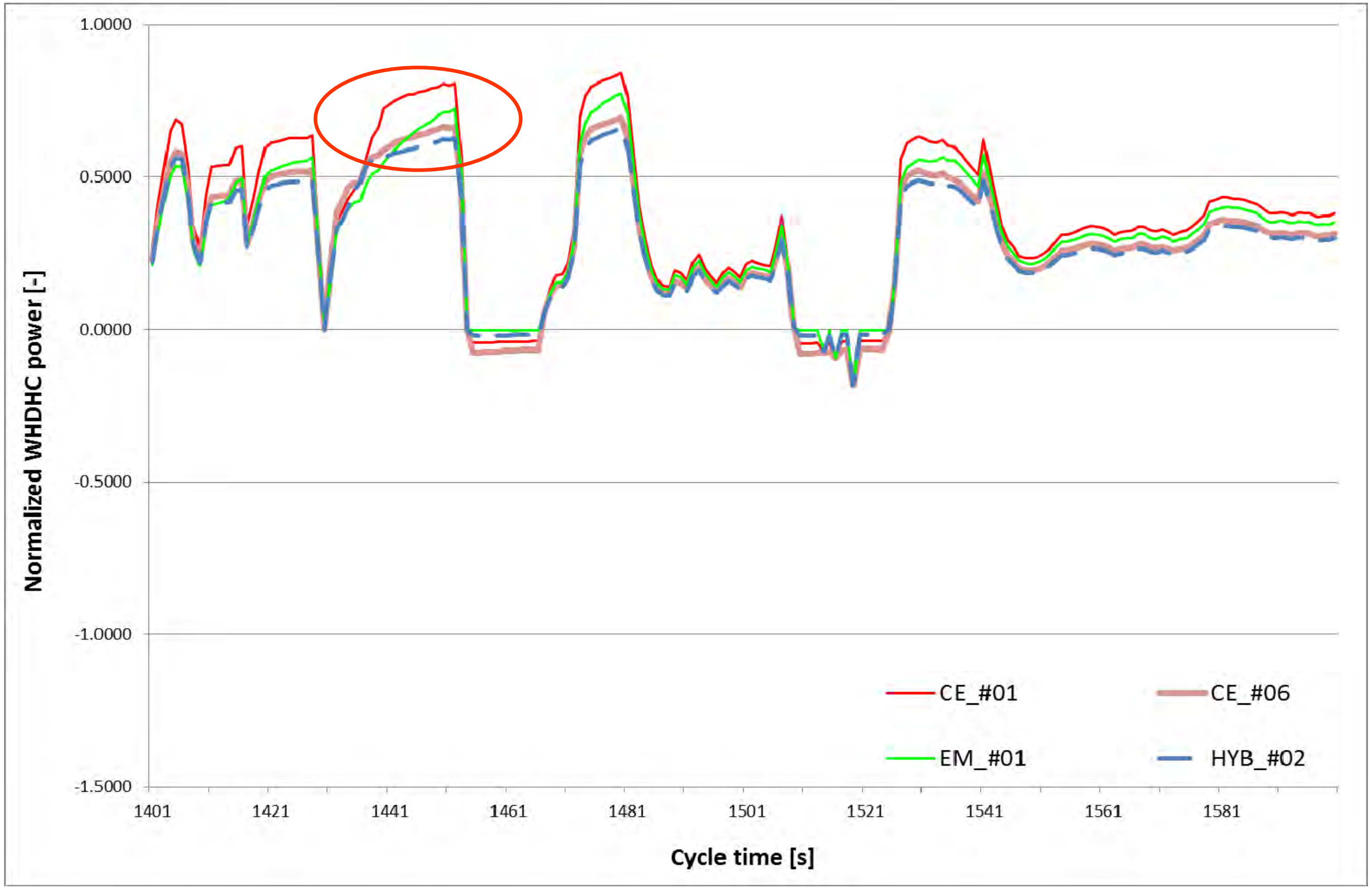
Analysis of different full load curves



Slightly lower normalized power at respective speeds in WHTC / WHDHC cycle

Validation of WHDHC, influence of full load curve design

Analysis of different full load curves



Slightly lower normalized power at respective speeds in WHTC / WHDHC cycle

Validation of WHDHC with real world driving data

At TUG available:

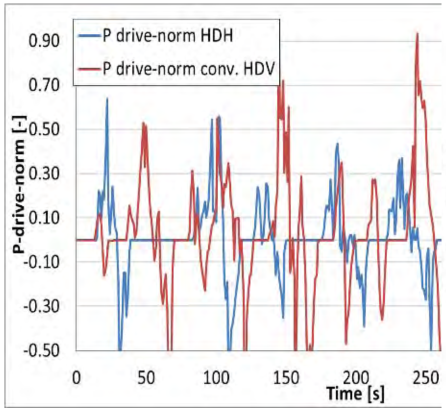
•on board measurements on 3 bus lines in city of Graz
(Volvo Hybrid bus and Evobus conventional)

•on board measurements on 3 bus lines in city of Vienna
(Volvo, Solaris, MAN hybrid buses and Evobus, Solaris, MAN, IVECO, VDL, Temsa conventional diesel buses, MAN, Evobus, IVECO CNG buses)

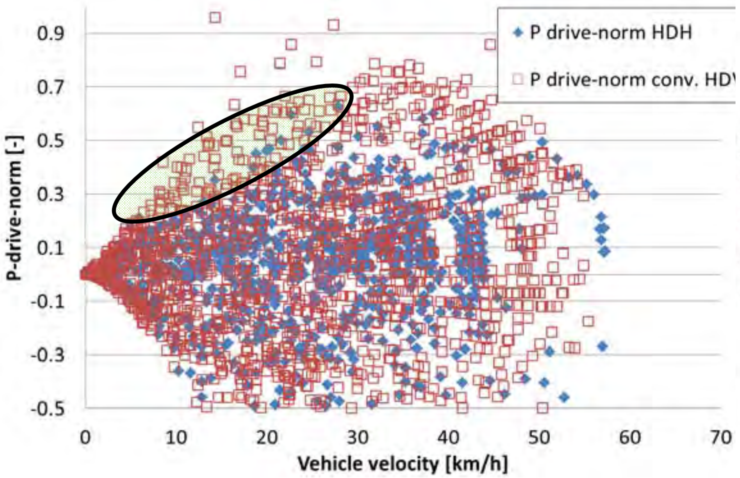
Missing: reasonable full load curves for the hybrid buses

→ define method to gain full load curve for power pack + get values from OEMs

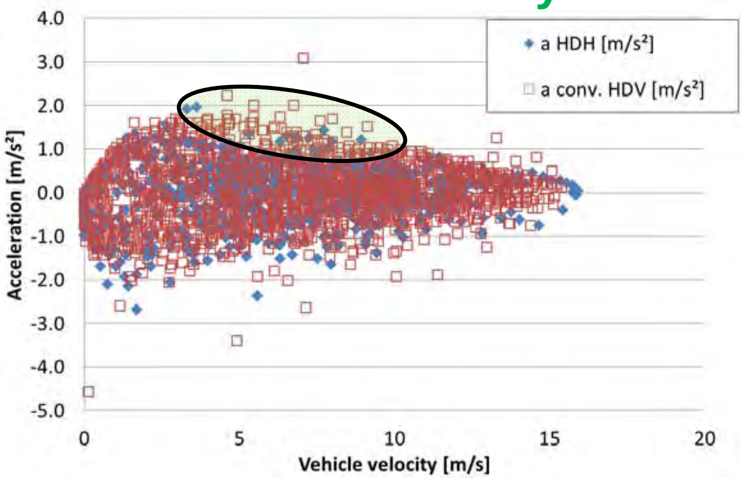
P-drive-norm over time



P-drive norm over velocity



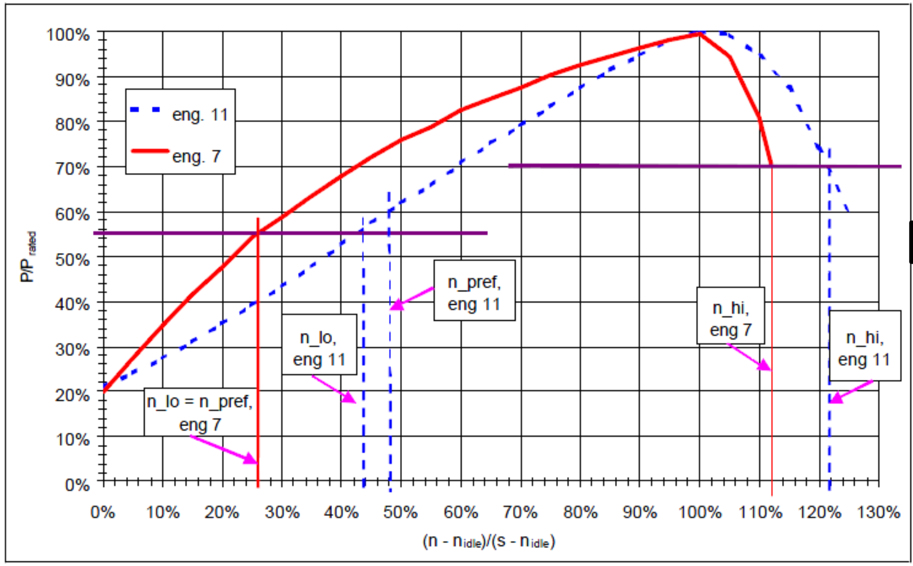
Acceleration over velocity

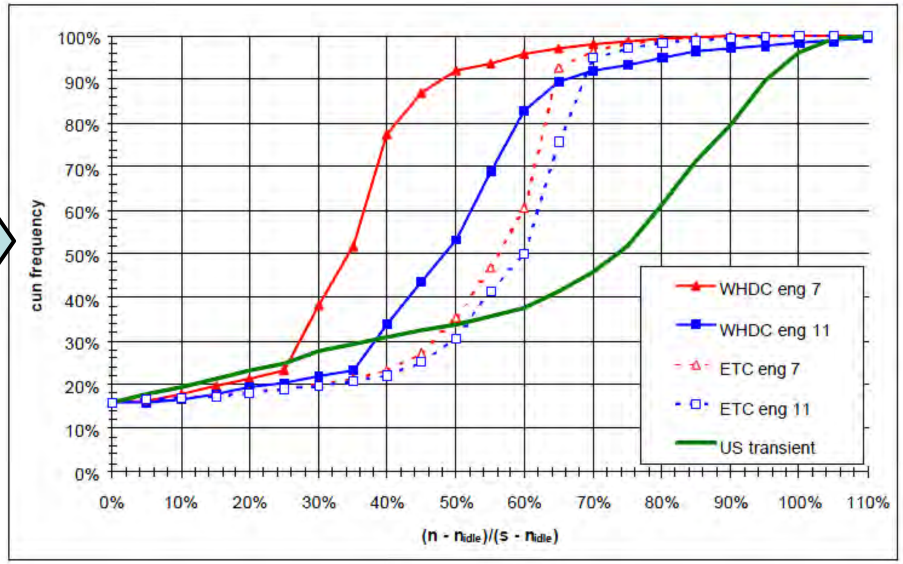


→Lower P-norm drive + acceleration seems to be realistic (depending on HDH design)

Validation of WHDHC with existing WHTC analysis

Results for conventional engines taken from WHTC final report "Development of a Worldwide Harmonised Heavy-duty Engine Emissions Test Cycle" [TRANS/WP29/GRPE/2001/2]





2 different full load curves of combustion engines → 2 different speed distributions for the WHDC

WHTC method levels out influence of different forms of full load curves on resulting power course already quite reasonable.

Next steps:

•<u>Must</u>: Define method to set up full load curve for hybrid power pack!

•Collect more real world driving measurements of HDH and conventional HDV to further validate WHDHC method (<u>necessary?</u>)

•<u>Must</u>: Discuss methods and open questions with (OEM) experts.

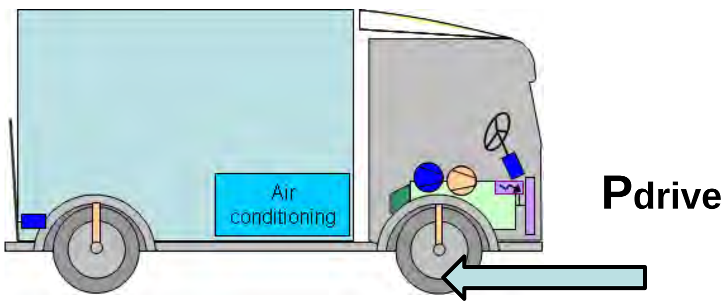
Adaptations in HILS method for suggested approach

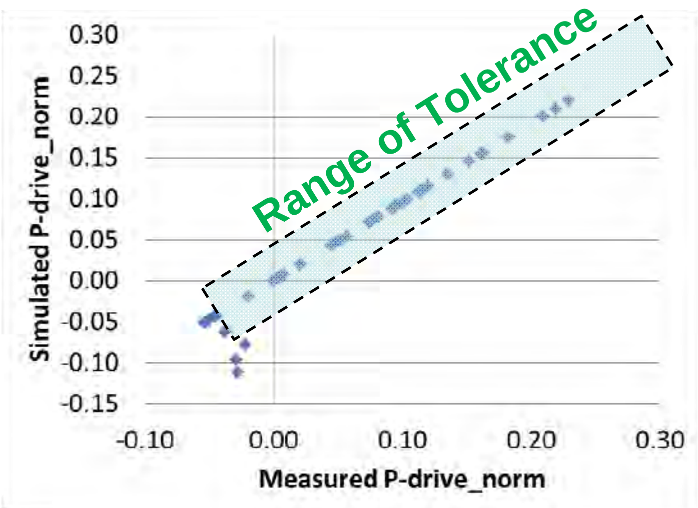
1. **Adapt driver model to control P_drive instead of velocity**
2. **Adapt validation of HILS set up during type approval. Options are:**

Run HDH on the road or on a chassis dyno or at “post transmission” power pack test stand and measure torque at wheel hub (method under development for EU HDV-CO_2 test procedure) together with torque and speed of combustion engine and RESS energy levels.

→P-drive-WHDHC measured (for any driving cycle) to be used as HILS input

Compare simulated and measured course for torque and speed of combustion engine. Define tolerances for deviation for fail/pass criterion.





WHVC weighting factors, HDV classes in HDV-CO_2 test procedure (1/2)

HGV

Identification of vehicle class					Segmentation (vehicle configuration and cycle allocation)					Norm body allocation		
Axles	Axle configuration	Chassis configuration	Maximum GVW [t]	<-- Vehicle class	Long haul	Regional delivery	Urban delivery	Municipal utility	Construction	Standard body	Standard trailer	Standard semitrailer
2	4x2	Rigid	>3.5 - 7.5	0		R	R			B0		
2	4x2	Rigid or Tractor	7.5 - 10	1		R	R			B1		
		Rigid or Tractor	>10 - 12	2	R	R	R			B2		
		Rigid or Tractor	>12 - 16	3		R	R			B3		
		Rigid	>16	4	R+T	R		R		B4	T1	
		Tractor	>16	5	T+S	T+S						S1
	4x4	Rigid	7.5 - 16	6				R	R	B1		
		Rigid	>16	7					R	B5		
		Tractor	>16	8 etc.					T+S			W1?

HGV:
17 classes
5 cycles

Bus + Coach

Identification of vehicle class						Segmentation and cycle allocation				
Axles	Axle configuration	Chassis configuration	Characteristics	Maximum GVW [t]	<-- Vehicle class	Heavy Urban	Urban	Suburban	Interurban	Coach
2	4x2	City	Class I + low floor or low entry, no luggage compartment	<18	B1	HU	UR	SU		
		Interurban	Class II + luggage compartment and/or floor height ≤0.9m	<18	B2				IU	
		Coach	Class III + floor height ≥0.9m and/or double decker	<18	B3					CO
3	6x2	City	Class I + Low floor or low entry, no luggage compartment	>18	B4	HU	UR	SU		
		Interurban	luggage compartment and/or floor height ≤0.9m	>18	B5				IU	
		Coach	floor height ≥0.9m and/or double decker	>18	B6					CO

Bus&Coach:
6 classes
2 cycle-sets

R = Rigid & Body
R+T = Rigid & Body & Trailer *)
T+S = Tractor & Semitrailer
W = no ($C_d \cdot A_{cr}$) measurement suggested

Source: Final report „Reduction and Testing of Greenhouse Gas Emissions from Heavy Duty Vehicles - LOT 2" Classes still may change before introduction!

WHVC weighting factors, necessary HDV classes (2/2)

HGV:	17 classes	5 cycles
Bus & Coach:	6 classes	2 cycle (sets)
Total	23 HDV classes	7 cycles

→ 23 different sets of weighting factors if HDV class specific influences shall be considered.

→ or 7 sets of weighting factors if only cycle specific influences shall be considered (suggested)

To be discussed: how shall the WHVC-weighting factors be applied?

For CO_2 not relevant, if vehicle class specific cycles are simulated.

For pollutant emissions the weighting of engine test results is possible but would then be different compared to conventional engines.

Method to gain the weighting factors is rather independent from later application.

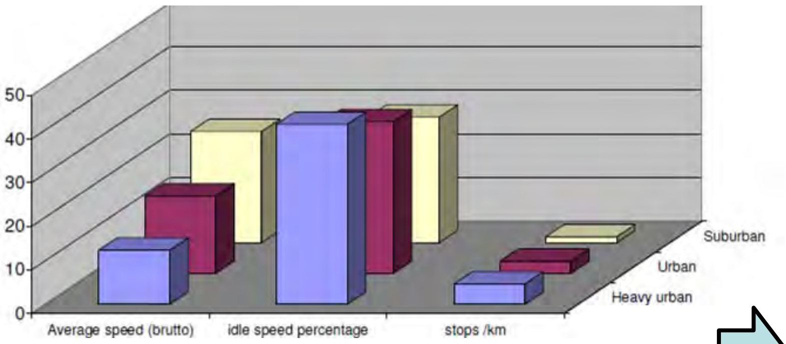
WHVC weighting factors, HDV CO_2 test cycle for city buses as example

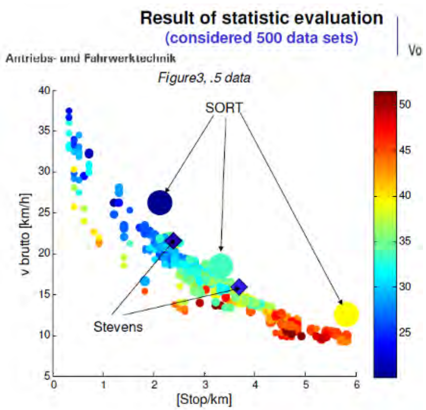
Actual work: use measured driving data, e.g. city buses:

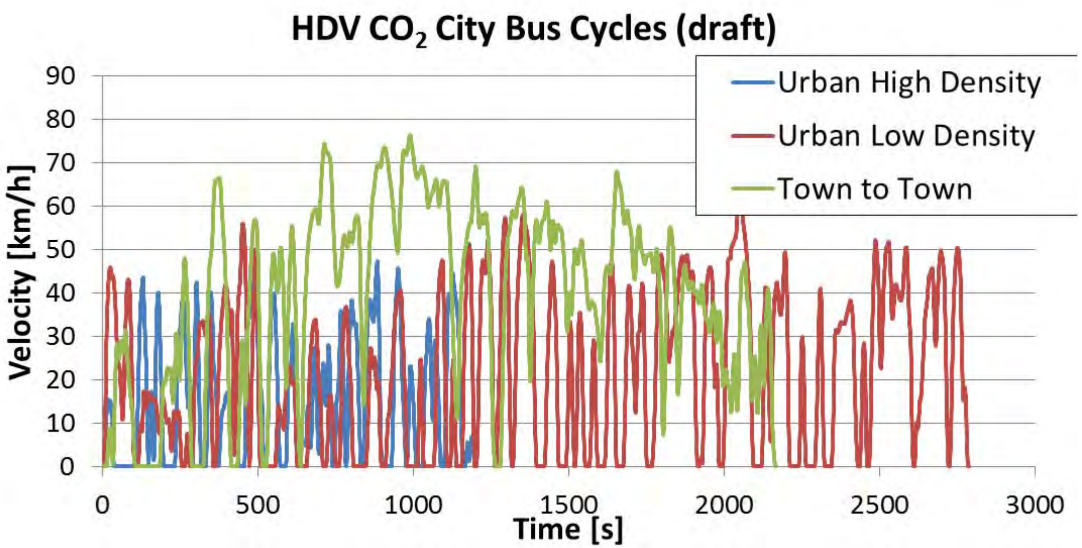
*** data base from WHTC development, HBEFA data base**

*** Extensive recording from Voith and ZF** (Population of 43112 transmissions of TOP 60 operators considered, 1000 operational data sets evaluated)

Analysis for HDV-CO_2 test procedure by ACEA and LOT2:







VOITH

ZF

HDV-CO2 LOT2

ACEA

Method to calculate WHVC weighting factors, example for city buses (1/2)

- **Simulate kinematic parameters for the WHVC-sub-cycles (Urban, Road Motorway)**
- **Simulate kinematic parameters for "representative" HDV CO_2 test cycles.**
- **Calculate the weighting factors (WF) by following equations:**

1) $WF_{WHVC\text{-}Urban} + WF_{WHVC\text{-}Road} + WF_{WHVC\text{-}Motorway} = 1.0$

2) Deviation of kinematic parameters between weighted WHVC and representative cycle is minimum

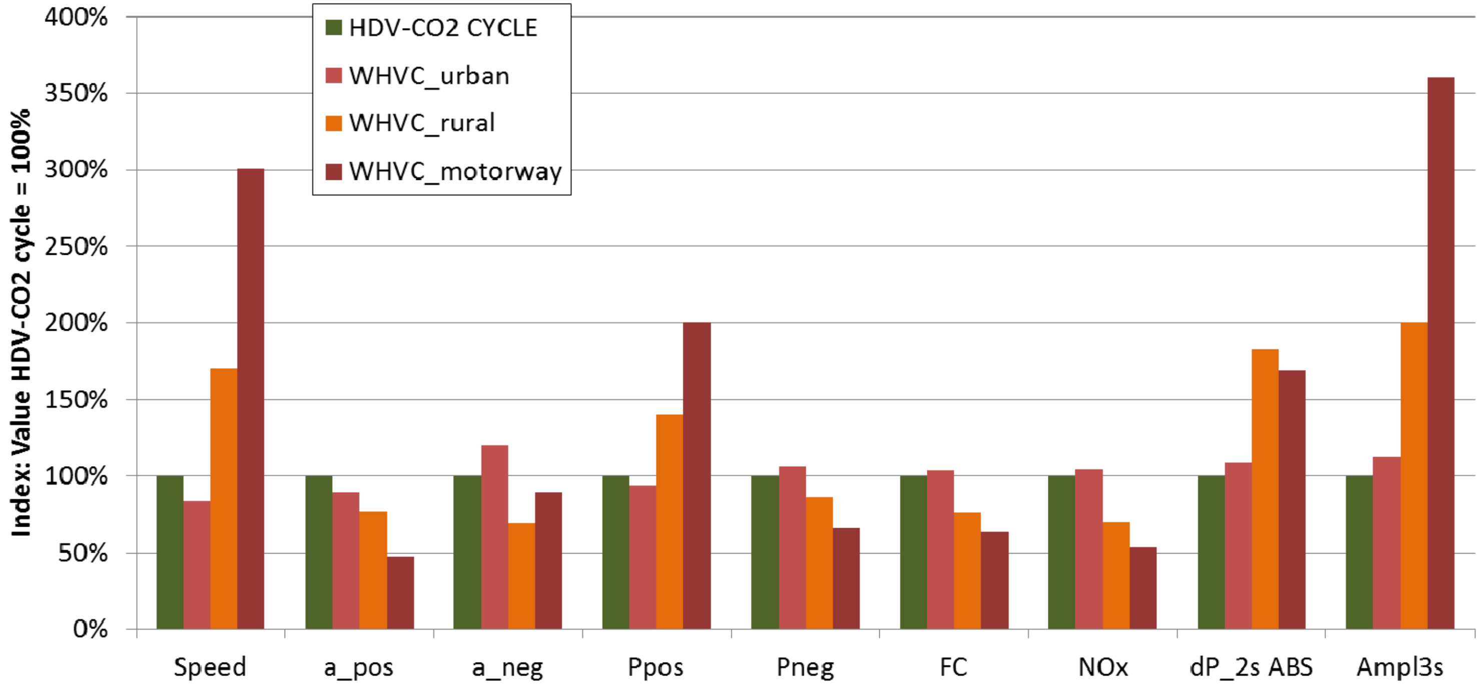
$$\sum_{n=Urban,Road}^{Motorway}\left(WF_{WHVC-n}\times\sum_{i=\text{Kin.Param1}}^{\text{Kin.Param j}}WF_{Ki}\times\left(\frac{KPi_{RS}-KPi_{WHVC-n}}{KPi_{RS}}\right)^2\right)=KP_{Tot}=Minimum$$

- WF_{WHVC-n}: **WHVC-Weighting Factor**
- WF_{Ki}: **Weighting of the kinematic parameter i**
- KPi_{RS}: **Kinematic parameter i in representative cycle**
- KPi_{WHVC-n}: **Kinematic parameter i in WHVC-Sub-cycle**

3) Maximum deviation for single kinematic parameters is in tolerance range

Method to calculate WHVC weighting factors, example for city buses (2/2)

Kinematic parameters calculated for WHVC and for HDV-CO_2 city bus cycle for a generic EURO VI, 2-axle city bus



WF_{Ki} :

Speed	a_pos	a_neg	Ppos	Pneg	FC	NOx	dP_2s ABS	Ampl3s	Total
0.15	0.12	0.12	0.15	0.15	0.15	0.06	0.05	0.05	1.00

Variation WHVC weighting factors:

	WF_WHVC	KP_{tot}	WF_WHVC	KP_{tot}	WF_WHVC	KP_{tot}
WHVC_urban	0.34		0.7		1	
WHVC_rural	0.33		0.2		0	
WHVC_motorway	0.33	0.544	0.1	0.3414	0	0.0997

→ **Minimum at WF_{Urban} = 1.0**

Including PTO into the test procedure (1/2)

PTO power demand is not included in WHTC test cycle for conventional engines.

From the options analysed yet to include PTO in the WHDHC method, not any seems to be reasonable for pollutant emissions:

Basic assumption: the hybrid vehicle has less engine power demand due to PTO operation than a conventional vehicle → options:

•Since WHTC has zero load at idling, a “PTO reduction factor” can not be applied where it should be applied for many HDV categories, i.e. at idling.

•As alternative the P_drive curve as input to the HILS model could be reduced accordingly.

•Reduced P_drive does not depicture real situation accordingly, since it would avoid all full load situations for the combustion engine

General:

•Small variations on cycle work show minor influences on g/kWh results

•To obtain the “PTO reduction factor” a high effort is necessary (e.g. applying method applied by US EPA, 40 CFR 1037.525.)

Including PTO into the test procedure (2/2)

→ **Suggestion:**

Elaborate method to consider PTO in the CO_2 test procedure for HDH and for conventional HDV in comparable way, i.e.

Option a) include PTO load cycle(s) in simulator

Option b) follow US approach (measure PTO on HDH and on conventional HDV)

HDV categories to be considered:

- **Garbage trucks (compression work)**
- **City bus (air conditioning system; this would allow to include in future also efficiency of AC system and glazing quality in the CO_2 test procedure)**
- **Municipal utility (extra load cycle necessary, e.g. road sweepers or like garbage truck cycle?)**
- **Construction (e.g. work of a crane)**
- **Others?**

Example for option a) will be elaborated by TUG in the contract (city bus due to data availability suggested, to be discussed)

Example for and experience on option b) available at US EPA (?)

Summary to work performed

- Wheel power cycle (WHDHC) de-normalised with extended WHTC-methodology seems to work properly for hybrids
- Method to define and to normalise full load curve for hybrid power packs needs to be established (available already somewhere?)
- WHVC weighting factors and HDV-CO_2 test cycles shall be harmonised
- WHVC weighting factors can be calculated from HDV-CO_2 test cycles (or from any other representative cycles), applicability open
- Final versions of HDV-CO_2 test cycles not available yet (~end 2012)
- It is not suggested to include PTO loads into the proposed HILS method for pollutant emission tests
- PTO loads can be included in CO_2 test procedures for conventional and for hybrid vehicles in comparable way
- Effort to include equipment driven by PTO also, seems to be high (e.g. efficiency of hydraulic press or of a air conditioning circuit)

Thank you for your attention!