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(10th HDH meeting, 05 June 2012)

Developing a Methodology for Certifying Heavy Duty Hybrids based on HILS

10th MEETING OF THE GRPE INFORMAL GROUP ON

HEAVY DUTY HYBRIDS (HDH)

5th June 2012

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Content

1. Overview on work done and results
2. Test cycle and vehicle related parameters
3. Harmonisation with CO_2 test methods
4. Inclusion of PTO
5. WHVC weighting factors

Overview on the work done

Analysis of vehicle related input data into HILS model led to:

- WHVC (vehicle speed) + adapted gradient course and vehicle data sets
- WHDHC wheel hub cycle
- WHDHC power pack shaft cycle

All cycles give in similar power course as WHTC and depend on full load curve of the power pack.

Analysis of options to include PTO led to:

- Not recommended in test cycle for regulated pollutants
- Could be included in test procedure for CO_2-emissions from entire vehicle (similar as auxiliaries)

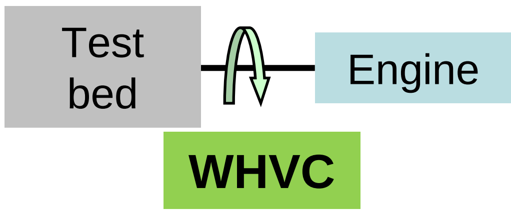
Elaboration of WHVC weighting factors led to:

- Methodology applicable to all combinations of cycles and vehicles
- Result for city bus available. For other categories the “representative real world cycles” are not finalised from DG CLIMA project yet
- Recommendation for a classification scheme for HDH (as for HDV)

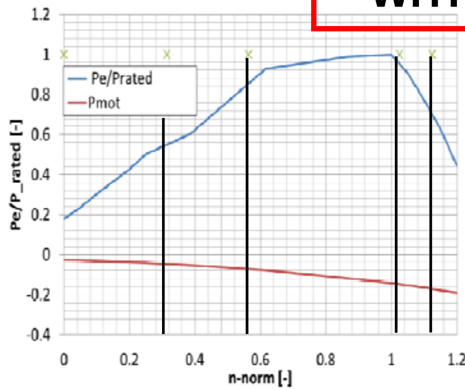
Analysis of options for harmonisation of HILS and HDV-CO_2 test procedures led to proposal which avoids parallel work and uses synergies.

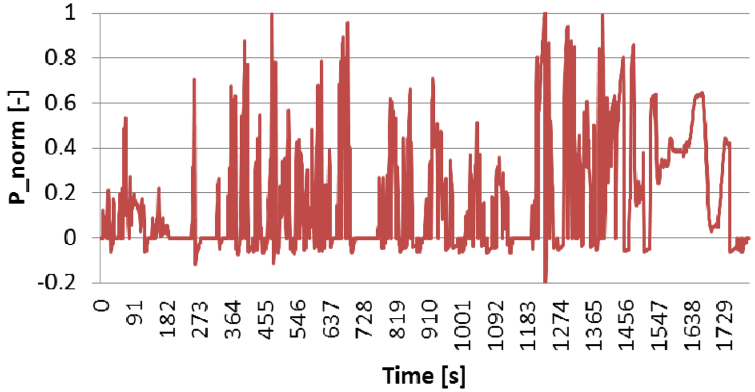
Vehicle related parameters & test cycle analysis

Basis) conventional engine



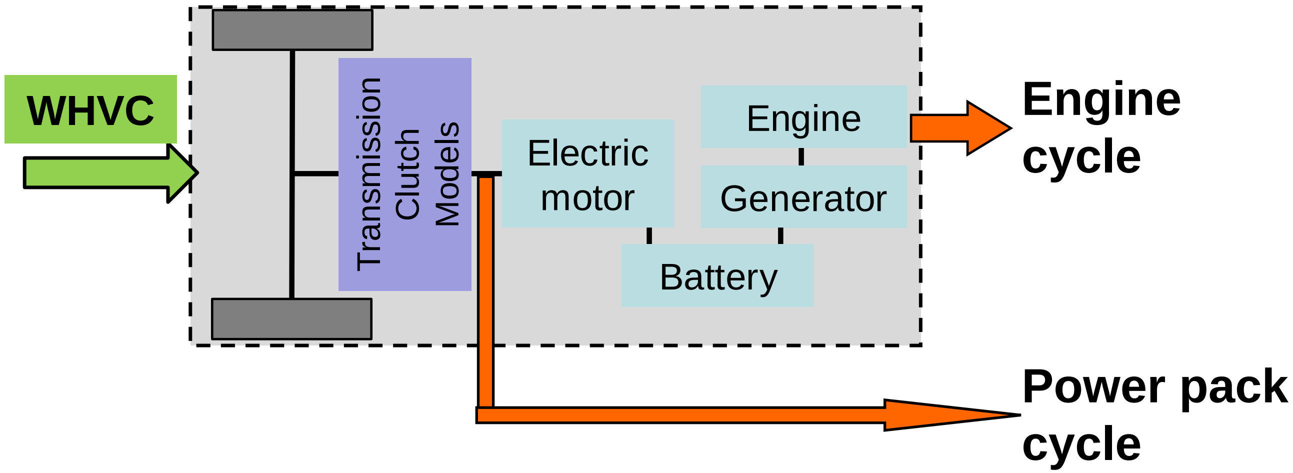
WHTC depends on full load curve of engine





WHDC = reference for typical load distributions for HDV driving

<u>HILS) for hybrid vehicle</u> converts vehicle speed cycle into power/rpm cycles



Resulting power pack cycle depends on full load curve only in phases, where full load acceleration is demanded

Vehicle related parameters & analysis of test cycles

Approaches followed to test options:

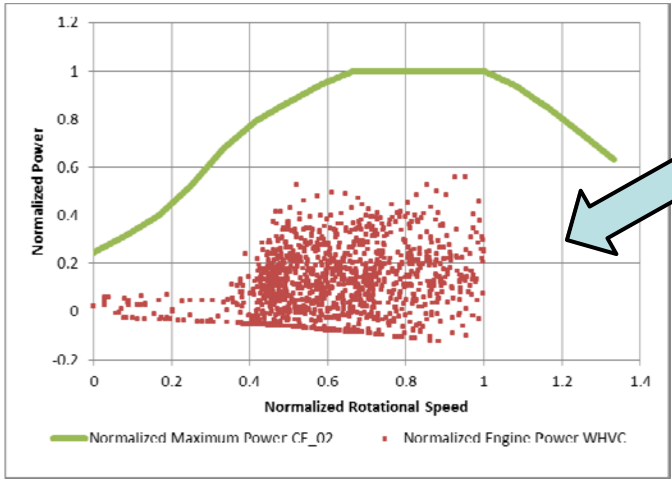
•Simulation runs with model PHEM from TUG (vehicle longitudinal dynamics + interpolations from engine maps) for 25 different HDV

•Analysis of on board measurements on hybrid buses and standard buses in the cities of Vienna and Graz.

Conclusions:

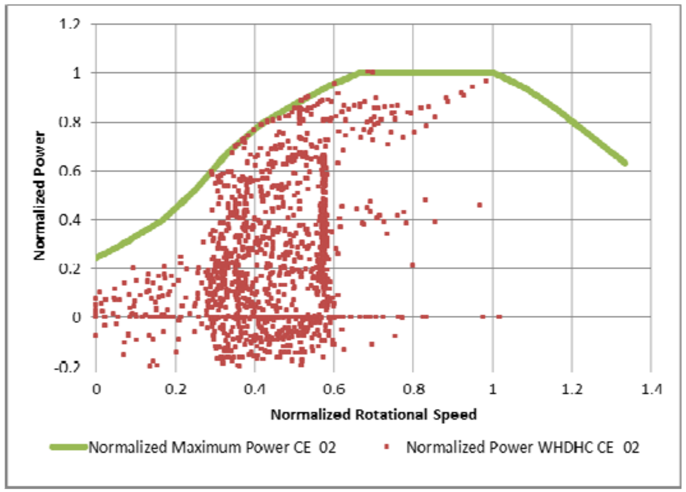
1) Simple vehicle speed cycle has high risk not to cover operating points in a representative way → recommended to relate test cycle to engine full load

<u>WHVC</u> + HDV T4 with 240 kW rated engine power



No full load =unrealistic load profile

<u>WHTC</u> fit load points to any full load curve



Conclusions test cycle & vehicle parameters (2)

2) To obtain full load phases for all power packs several acceleration phases in the WHVC would need to be replaced by target speeds or gradients
→ WHTC is used as target power course (recommended)

3) WHTC would underestimate brake energy recuperation for HDH since it includes engine motoring brake only

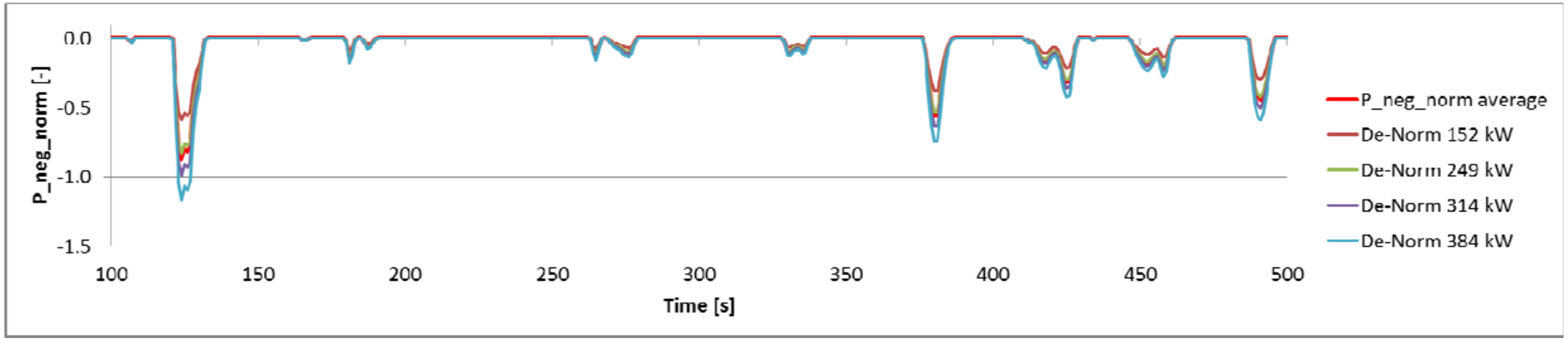
4) Brake energy recuperation from HDH is determined by negative power (braking) in the cycle. Normalised negative power does not depend on shape of engine full load curve but on vehicle size.

5) Rated engine power is related to vehicle size. Thus it is recommended to normalise negative power to rated engine power to have the entire test cycle independent of the vehicle.

$$P\_neg\_norm = P\_neg\_norm\ avg * P_{rated}\text{-factor}$$

With: P_{rated}**-factor = 0.00376 * P_rated**

Example: 1st 500 seconds of WHVC



Vehicle related parameters & analysis of test cycles

From these results a set of three World Heavy Duty Hybrid Cycles (WHDHC) were elaborated:

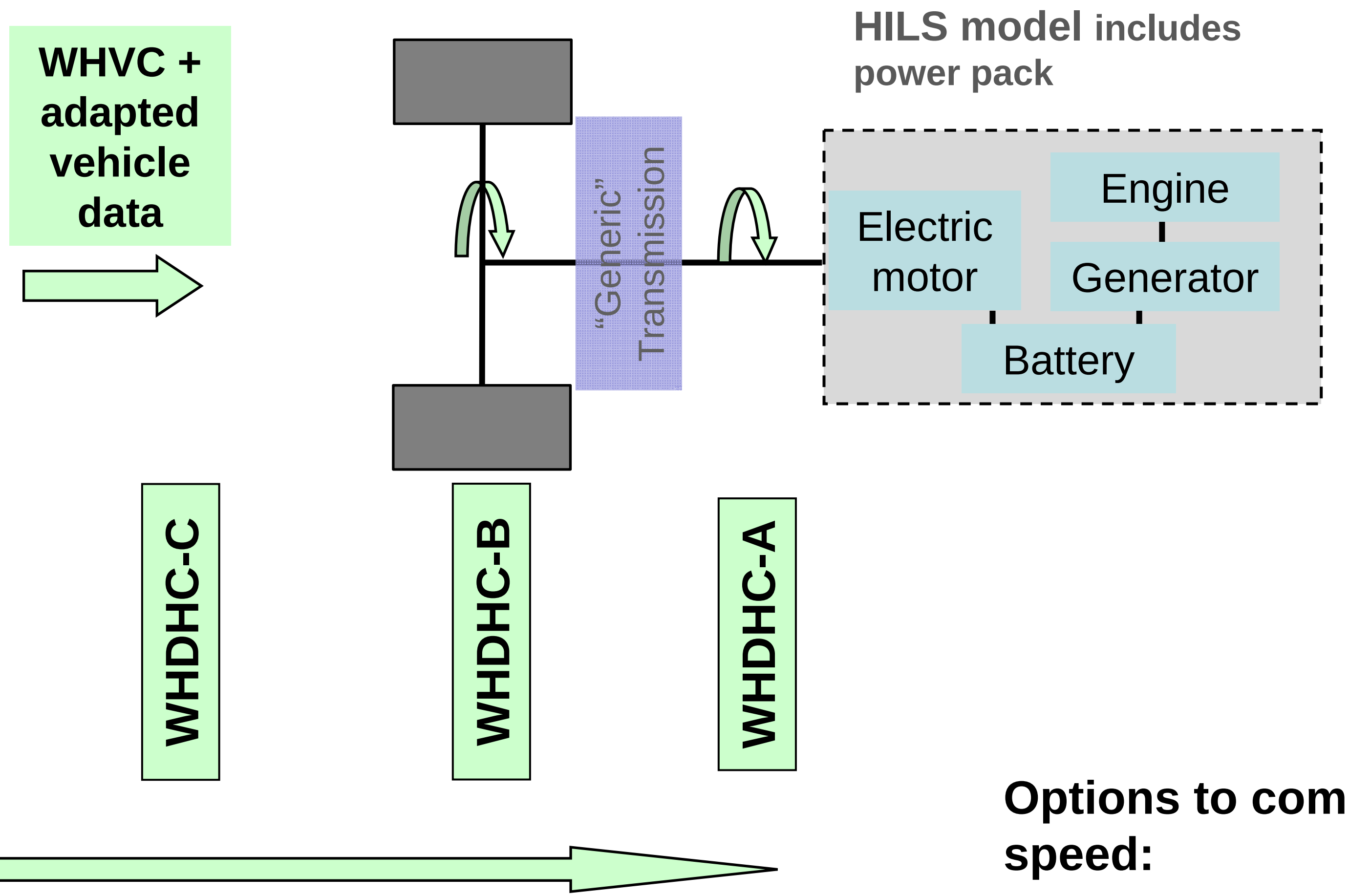
A) WHTC + normalised braking power = WHDHC at power pack shaft

B) WHDHC at power pack shaft + losses in transmission =WHDHC at wheel hub

C) WHVC with adapted vehicle mass, rolling resistance, Cd*A and road gradient = WHDHC for the vehicle

All cycles are calculated automatically as function of the full load curve of the power pack.
Excel Tool can be distributed.
(together with final report to provide necessary background information?)

Options for HDH test cycles Example for simple serial hybrid



$$rpm = 60 * v_{WHVC} * I_{transmission} / (3.6 * D_{wheel} * \pi)$$

$$rpm_{\_wheel} = rpm_{\_WHTC} / I_{transmission}$$

Options to compute rotational speed:

1) from vehicle speed

2) from WHTC-rpm

Both to be tested in next phase

Excel tool available to test the approach

Microsoft Excel - Denorm_WHDHC_norm.xlsm

	A	B	C	D	E	F	G	H	I
1	P rated [kW]:	240		Generate WHDHC from Full load data					
2	n rated [min^{-1}]:	1900							
3	n @ idling [min^{-1}]:	600							
4									
5	n_norm	Pe/Prated	Pe/Pmot		n [min^{-1}]	P_max [W]	T_max [Nm]	P_mot [W]	T_mot [Nm]
6	0.000	0.178	-0.025		600	42713	680	-6000	-95
7	0.050	0.236	-0.028		665	56574	812	-6600	-95
8	0.100	0.302	-0.030		730	72526	949	-7239	-95
9	0.150	0.367	-0.033		795	87983	1057	-7923	-95
10	0.200	0.428	-0.036		860	102729	1141	-8684	-96
11	0.250	0.501	-0.040		925	120231	1241	-9489	-98
12	0.385	0.604	-0.051		1100	144906	1258	-12168	-106
13	0.615	0.928	-0.076		1400	222792	1520	-18318	-125
14	0.865	0.990	-0.117		1725	237600	1315	-28135	-156
15	1.000	1.000	-0.142		1900	240000	1206	-34080	-171
16	1.050	0.904	-0.154		1965	216877	1054	-36840	-179
17	1.100	0.772	-0.165		2030	185228	871	-39678	-187
18	1.150	0.627	-0.178		2095	150463	686	-42606	-194
19	1.200	0.443	-0.190		2160	106356	470	-45600	-202
20									

Button: Start calculation of WHDHC

Green cells: Input data from full load curve

Red cells: absolute values for full load (calculated)

F	G	H	I	J	K
Denormalized WHDHC					
time [s]	n [min^{-1}]	T [Nm]	P_neg [kW]	P [kW]	
0	600	0	0.00	0.00	
1	600	0	0.00	0.00	
2	600	0	0.00	0.00	
3	600	0	0.00	0.00	
4	600	0	0.00	0.00	
5	600	0	0.00	0.00	
6	600	0	0.00	0.00	
7	623	80	0.00	4.96	
8	841	354	0.00	29.62	
9	1018	17	0.00	1.72	
10	1097	10	0.00	1.09	
11	1130	17	0.00	1.91	
12	1152	107	0.00	12.26	
13	1165	89	0.00	10.31	
14	1178	147	0.00	17.23	
15	1203	177	0.00	21.18	

Results: Second by second data for WHDHC

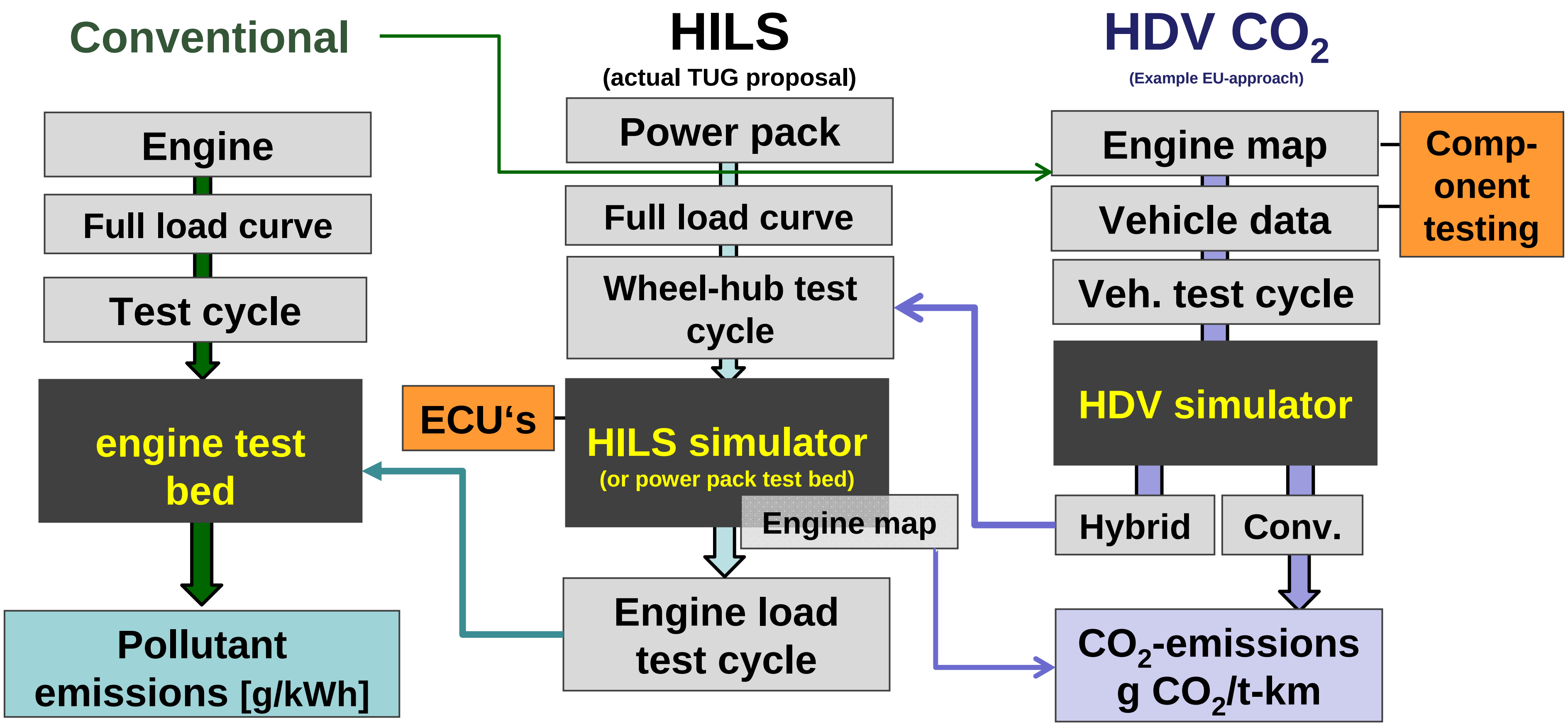
Summary of +/– for HDH test cycle options

Option	Advantage	Disadvantage
A) WHVC +vehicle data	*Similar to existing Japanese tool	*Velocity cycle + vehicle data can result in unrealistic load cycles for power pack (no full load phases or higher power demand than full load) *Different load cycle than for conventional engines (WHTC)
B1) Power at wheel hub	*Similar load cycle than for conventional engines	*Generic or vehicle specific gear box to be included in model. Very complex for automatic gear boxes! *Application of generic gear box may lead to unrealistic load cycles?
B2) Power at power pack shaft	*Same load cycle than for conventional engines *No simulation of transmission necessary	*Combination of torque and rpm may be unrealistic for some HDH (same problem for A) and B1 if generic gear box is used).
B1) and B2)		*Not applicable, if electric motor and ICE drive different axles. *Japanese tool needs to be adapted

Open tasks for next project phase: vehicle related work

- Define method to set up full load curve for hybrid power pack
- Discussions with experts from OEMs
- Implement driver model for WHDHC versions A and B in HILS
- Simulations in HILS with WHDHC-A, -B and -C
  * with generic HDH-ECU as software
  * later with real ECU
- Compare resulting engine load cycles with load cycle of real HDH
- Analyse if all versions can be used in parallel (allow to select version according to HDH architecture and eventual alternative test methods, e.g. power pack test bed?)
- Analyse which option to compute rotational speed signals is more realistic
- Analyse demands for simulation of gear box in HILS for rpm-version 1)
- Decide on version to compute rpm course
- Recommend version(s) of WHDHC

Option for harmonisation of test procedures



Input test cycle:
WHTC

Engine load cycle:
Depends on full load curve
Independent of vehicle

Input test cycle:
WHTC + WHVC

Engine load cycle:
Depends on full load curve
Independent of vehicle

Input test cycle: vehicle class specific target speed cycle

Engine load cycle:
Vehicle dependent and
full load curve dependent

Options to include PTO in the test procedure

For regulated pollutants:

Neglect PTO and auxiliaries in HILS application
→comparable to WHTC test for conventional engines
→auxiliaries necessary to drive engine are already considered at engine test bed tests

For CO_2 test procedure:

Option A): simulation based

•Create interfaces for mechanical power demand (shaft), for hydraulic power demand (accumulator) and for electric power demand (battery or alternator)

•Define load cycles for relevant PTOs and auxiliaries:
Garbage trucks (compression work); City bus (air conditioning system); Municipal utility (road sweepers); Construction (work of a crane); Others?

Run HILS model in simulation loop for CO_2 with additional PTO power demand

Same PTO load cycles have then to be used for conventional HDV and same model set up for PTOs have to be implemented in the HDV-CO_2 simulator!

→Coordination with CO_2 test procedure essential

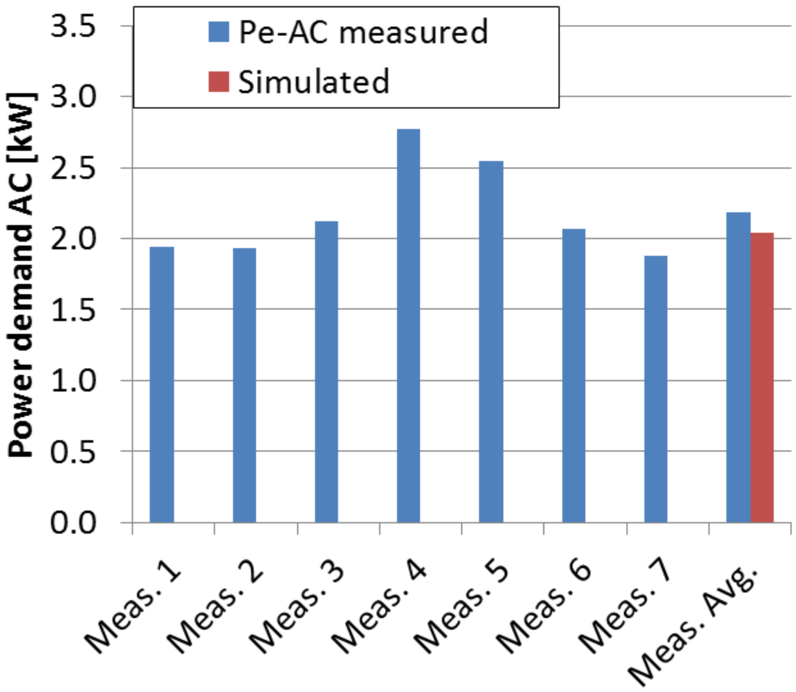
TUG has set up tool to calculate AC mechanical power (compressor) and electrical power (blower) as function of ambient conditions (see 9th HDH meeting)

First validation of AC simulation tool

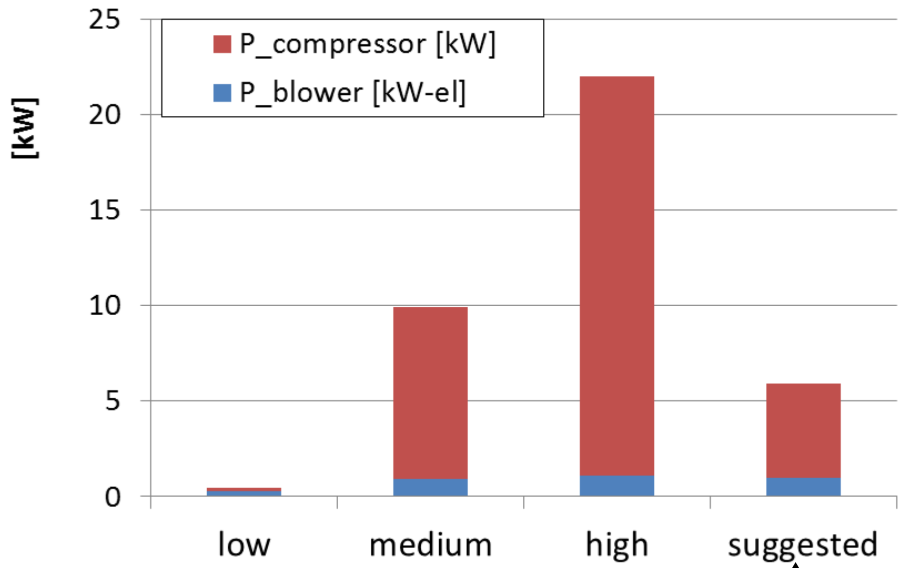
Measurements on a Hybrid City Bus in the City of Graz in March 2012

T-ambient :	**19°C to 23°C**
T-cabin:	**21°C to 25°C**
RH:	**40% to 73%**
Sun Radiation:	**360 to 730 W/m²**

Measurement + Validation
(no passengers in the bus!)



Simulation at different ambient conditions
(20 passengers in the bus)



24°C, 50%RH, 550 W/m²
→ 1 kW blower
+ 4.9 kW Compressor

Options to include PTO in the test procedure

<u>Option b)</u>

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

Apply “PTO correction” to result for HDH

if CO_2-value for conventional vehicles is without PTO

Example for option a) elaborated by TUG for a air conditioning load cycle of a city bus. Also a simplified method of a correction factor was developed (presented in 9th HDH meeting in Tokyo)

Experience with option b) available from US EPA (?)

<u>Open tasks for next project phase for PTO and auxiliaries</u>

1)Coordinate with CO_2 test procedure for conventional vehicles

2)Common decision include/not include PTO is advantageous. If included:

3)Define PTO and auxiliaries to be considered (per vehicle class)

4)Define PTO load cycles

5)Implement interfaces to mechanical, hydraulic and electric power in HILS

WHVC weighting factors

Weighting factors for different vehicle categories need several definitions and data:

•Definition of „vehicle classification“ (bus, coach, delivery, long haul,..)

•Representative „real world“ driving cycles for each class to compare with the WHVC

Corresponding work is performed in course of the development of an European CO_2 test procedure for HDV.

Final report: „Reduction and Testing of Greenhouse Gas Emissions from Heavy Duty Vehicles - LOT 2” next phase of project under preparation
→ Classes still may change before introduction!
Classification scheme was presented in 9th HDH meeting already

HGV:	17 classes	5 cycles
Bus & Coach:	6 classes	3 cycle (sets)
Total	23 HDV classes	8 cycles

→ 8 sets of WHVC weighting factors to be produced

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

(presented already in 9th HDH meeting in Tokyo)

- **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

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

WHVC-Weighting Factor

Weighting of the kinematic parameter i

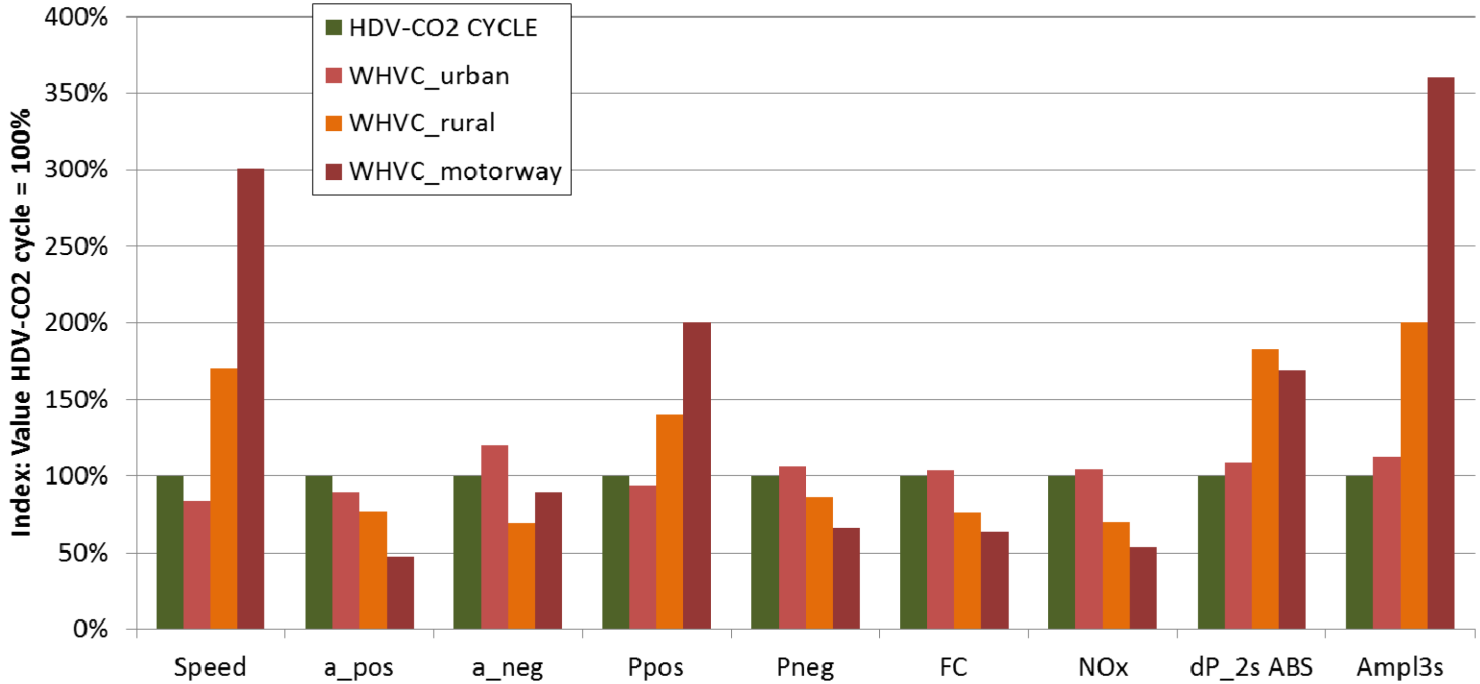
Kinematic parameter i in representative cycle

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

Next steps for WHVC weighting factors

- HDV CO_2 test cycles still under development
- As soon as the cycles are available, the method described before will be applied to calculate the corresponding weighting factors for each HDV class
- This work is included in the actual project and should be finalised until end of 2012 (cycles from HDV-CO_2 project not to be expected before end 2012)

→ Description of method in final report from TUG until June 2012

→ Report with results for all classes provided by TUG later without additional budget demand

Summary to work performed

- Test cycles + vehicle related parameters finalised. The three versions shall be tested in HILS model in phase 2
- Method for WHVC weighting factors finalised. Weighting factors will be computed, as soon as the "representative" CO_2 test cycles are available.
- It is suggested not to include PTO loads into the proposed HILS method for test cycle development for the regulated emissions
- Options how to consider PTO in CO_2 related test procedure are presented. All options would need further work.

Thank you for your attention!