Working Paper No. **HDH-09-06**
(9th HDH meeting, 21 to 23 March 2012)

Developing a Methodology for Certifying Heavy Duty Hybrids based on HILS

9th MEETING OF THE GRPE INFORMAL GROUP ON

HEAVY DUTY HYBRIDS (HDH)

21.-23. March 2012

TU Graz
Institute for Internal Combustion Engines and Thermodynamics

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Content

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 correct 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 specific data (avoid high test burden)**

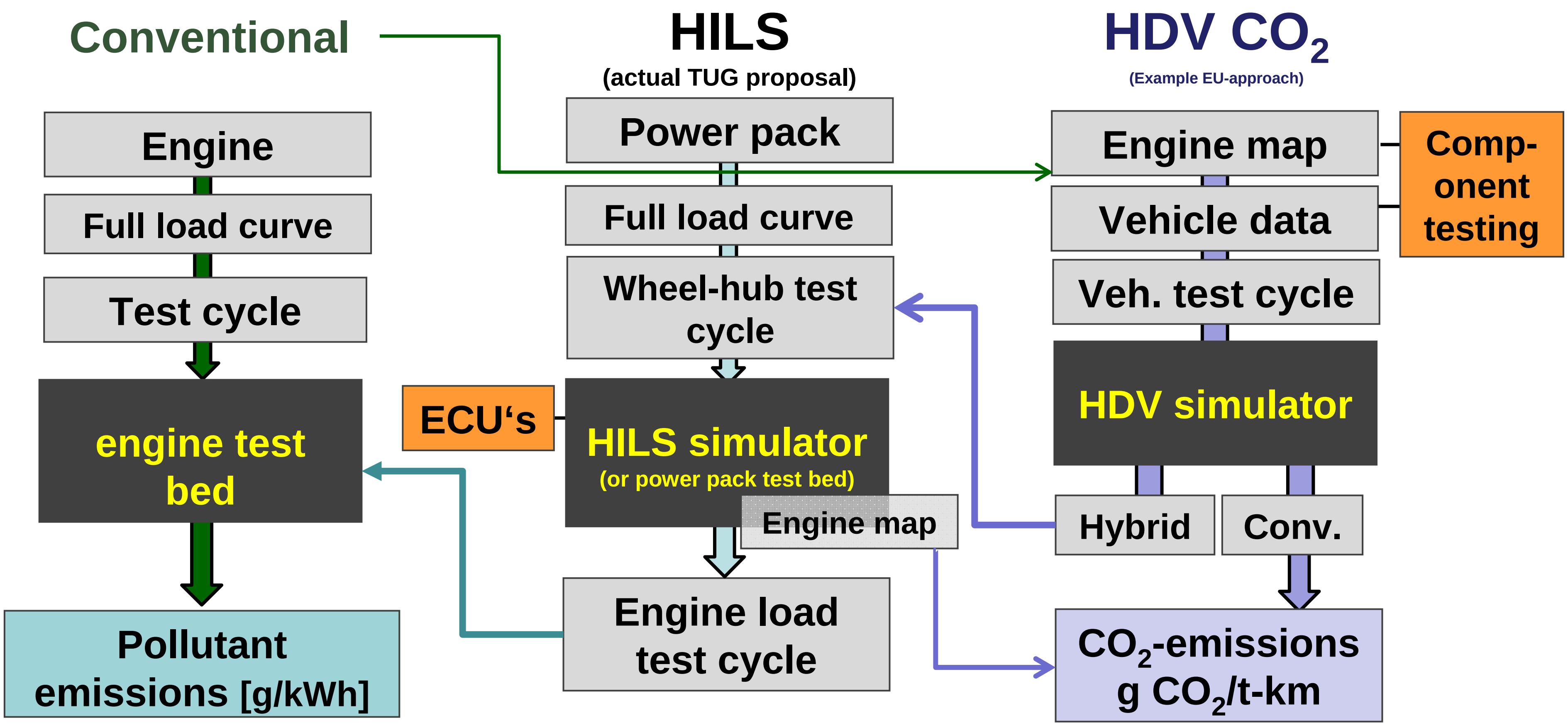
→ Different test cycles for regulated pollutants and for CO_2 reasonable.

→ WHDHC (World Heavy Duty Hybrid Cycle) for pollutant tests 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.

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

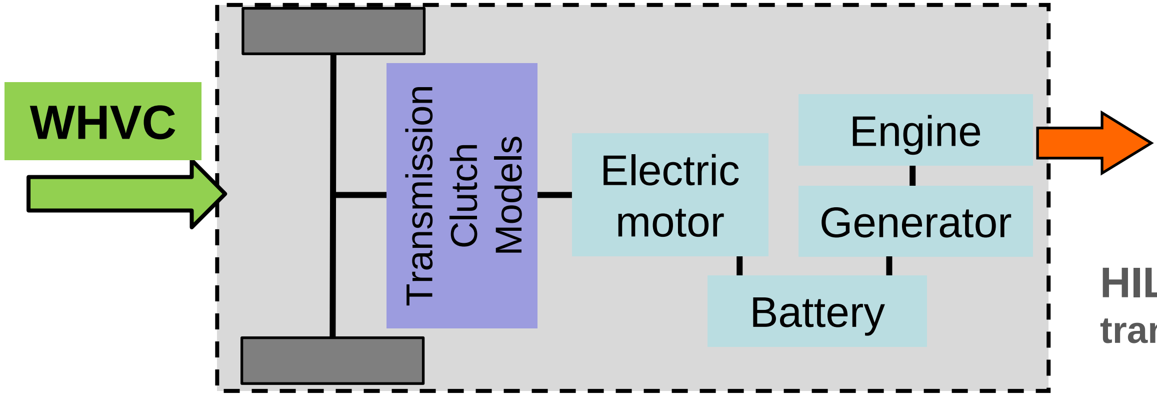
Engine load cycle:
Depends on full load curve
Independent of vehicle

Input test cycle: vehicle class specific target speed cycle

Engine load cycle:
Vehicle dependent and
full load curve dependent

Options discussed for HDH test cycles
Example for simple serial hybrid

A) Input: vehicle velocity + generic vehicle driving resistance data

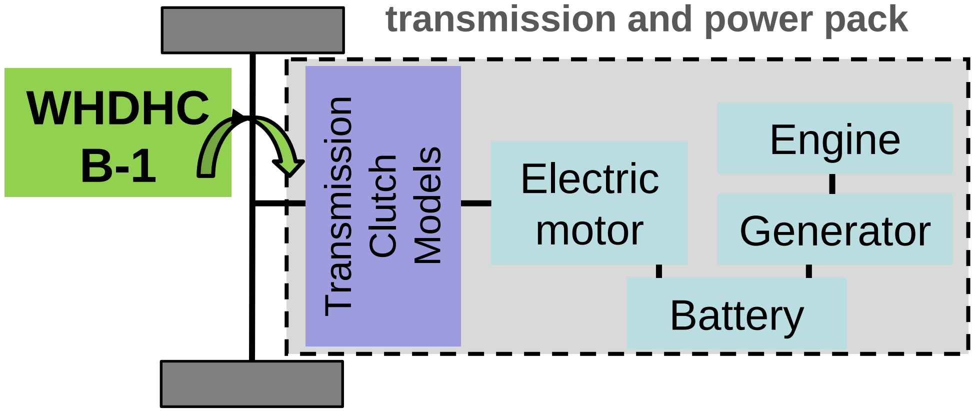


Cycle for ICE engine test bed

HILS model includes (generic) vehicle + transmission and specific power pack

B1) Input: power + rpm at wheel hub

HILS model includes transmission and power pack



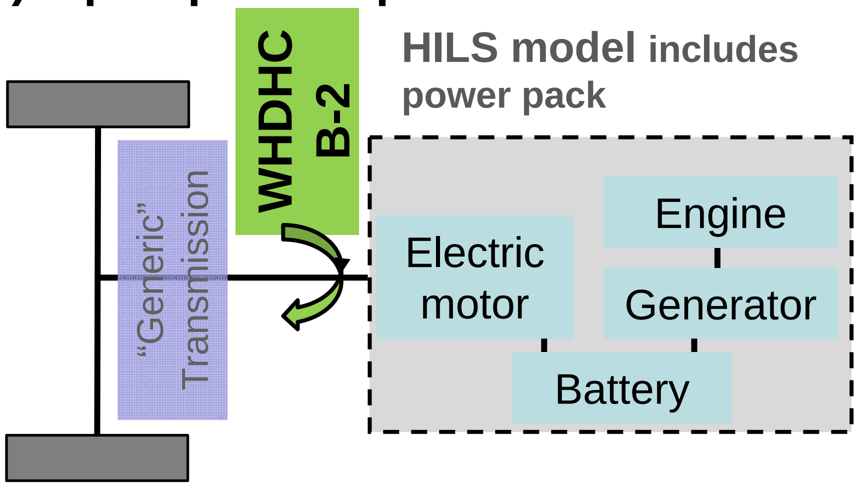
$P_{\_wheel} = P_{\_WHTC} * Eta_{Transmission} - P_{mech. Brakes}$

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

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

B2) Input: power+rpm at shaft

HILS model includes power pack

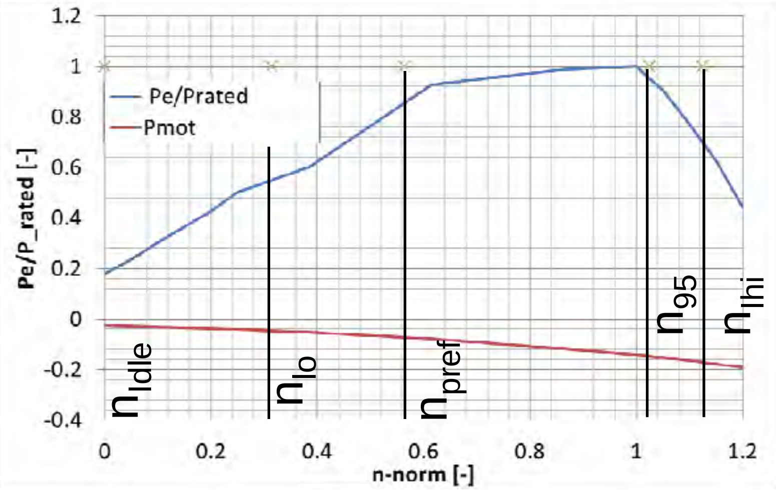


$P_{\_shaft} = P_{\_WHTC} - P_{mech. Brakes} * Eta_{Transmission}$

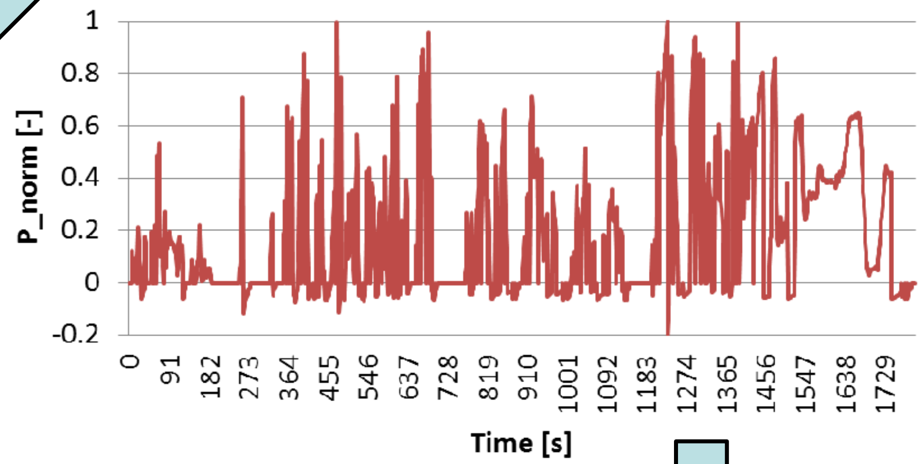
$rpm_{\_wheel} = rpm_{\_WHTC}$

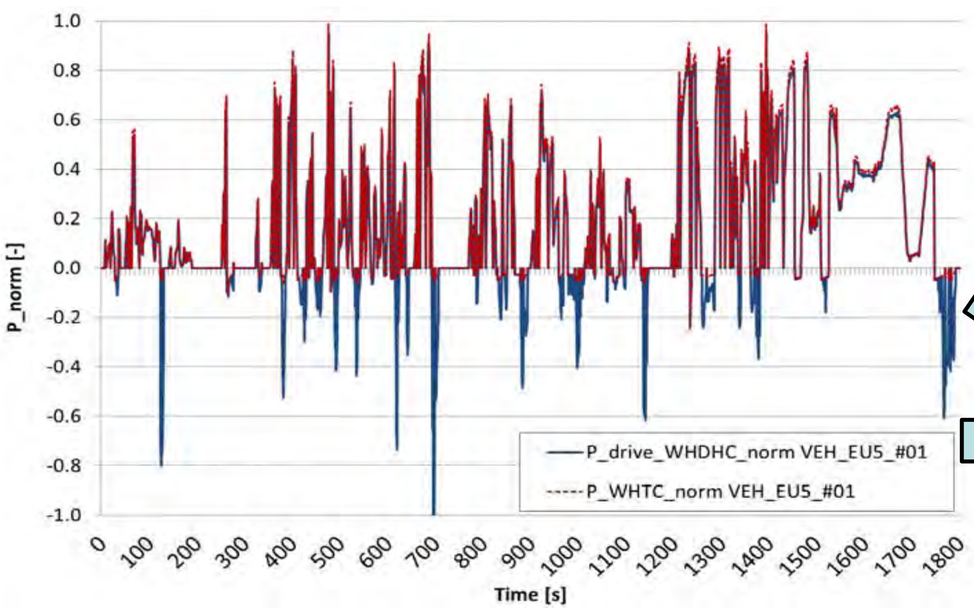
Method for the WHDHC (World Heavy Duty Hybrid Cycle)

Full load engine or power pack



Power course of WHTC





WHTC = effective engine power
+ for B1): losses in drive train
- power mechanical brakes

Power course at the wheel hub
(=$P_{drive-WHDHC}$)

WHDHC as input into HILS

Method for the WHDHC – Normalizing negative power

Main question:

How can negative power (mechanical brakes + engine) be normalised to be representative for all vehicle categories?

Options:

a) Normalise as % of motoring curve at given engine speed (similar to positive engine power in WHTC)

b) Normalise as % of rated engine power

c) Add further parameters to a) or b)

Related questions:

1) Does the drivers deceleration behaviour depend on shape of full load curve?

→ Analysis of measured real world driving cycles for several buses on same route in city of Vienna with different engines. Is average negative power higher for engines with higher torque at low engine speeds? Yes→a), No→b)

2) Is the average negative power different for different vehicle categories?

→Analysis of different vehicles in WHVC (delivery truck, bus, tractor-trailer,..): is normalised negative power significantly different between HDV categories?

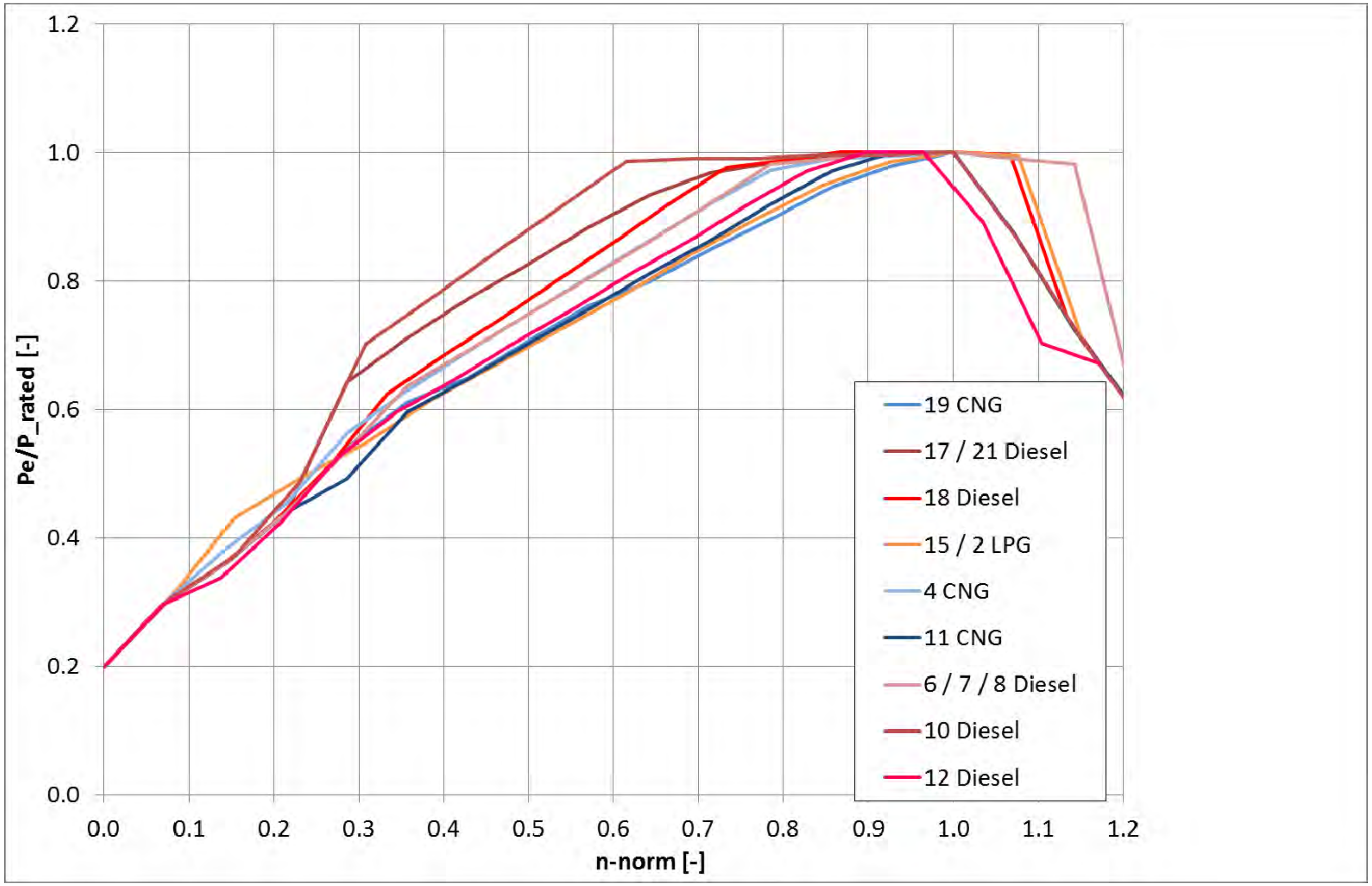
Yes→ find further parameter for normalisation

No → use a) or b) from above directly

Question 1: Dependency of negative power on shape of full load curve

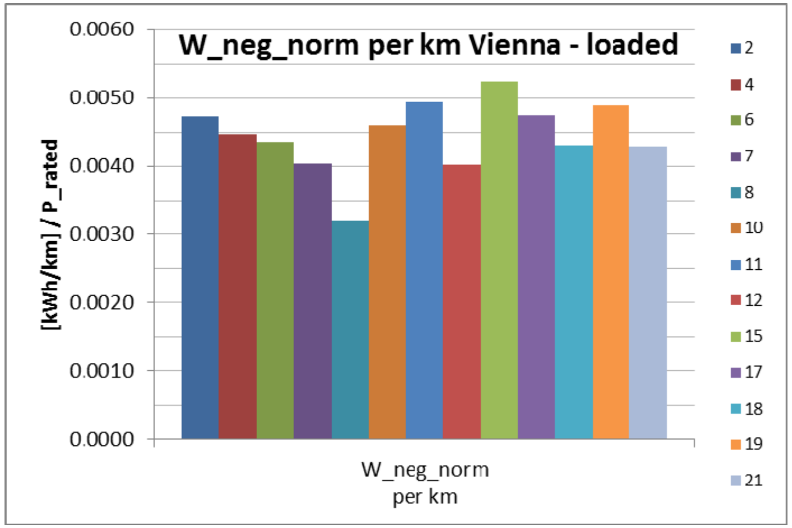
13 different city buses on line 15 and 26 in the city of Vienna.

The full load curves are:



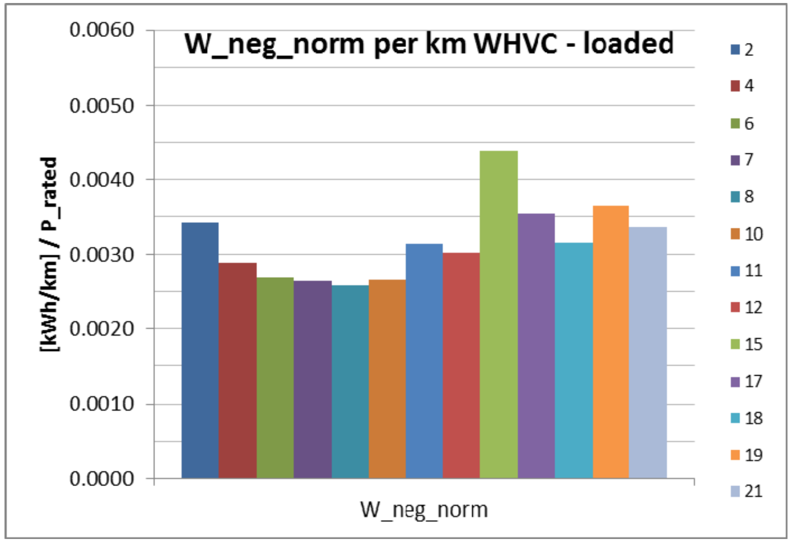
Result: with normalisation to rated power the ratios between the vehicles are similar in WHVC and in real world traffic (with normalisation to max torque they are not)

Measured real world



independent of full load curve shape

WHVC

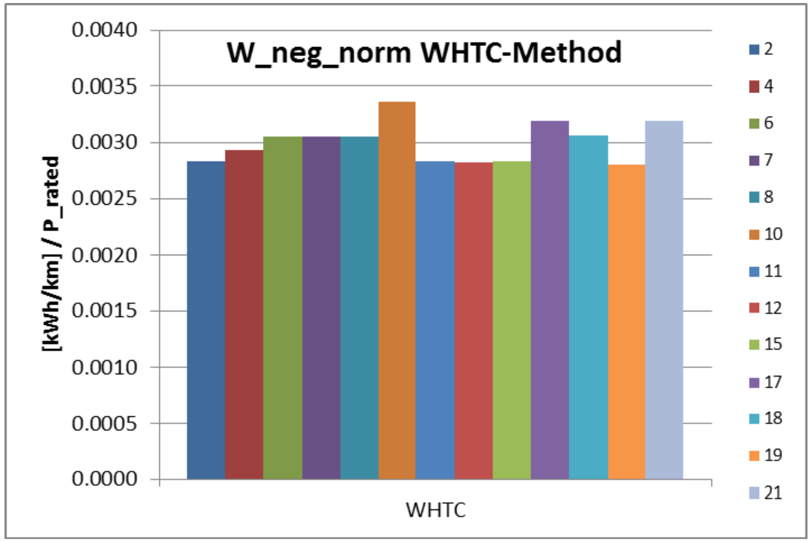


Normalisation to rated engine power gives similar ratios between vehicles for WHVC-cycle as for the real world driving in Vienna city bus lines

→ Normalisation to rated engine power

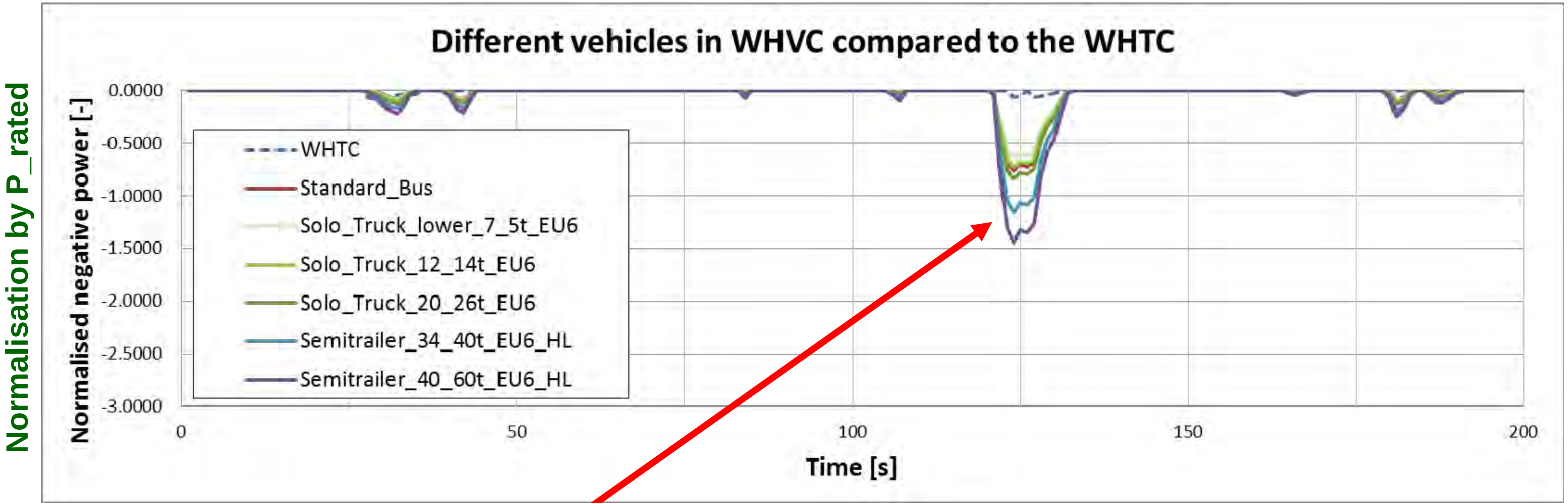
For comparison: de-normalisation with Md_{max} at given rpm (WHTC method) gives different ratios
→ P_{neg} independent from shape of full load curve

WHTC method



Question 2: Dependency of negative power on vehicle category

Simulation of WHVC, picture shows first 200 seconds:

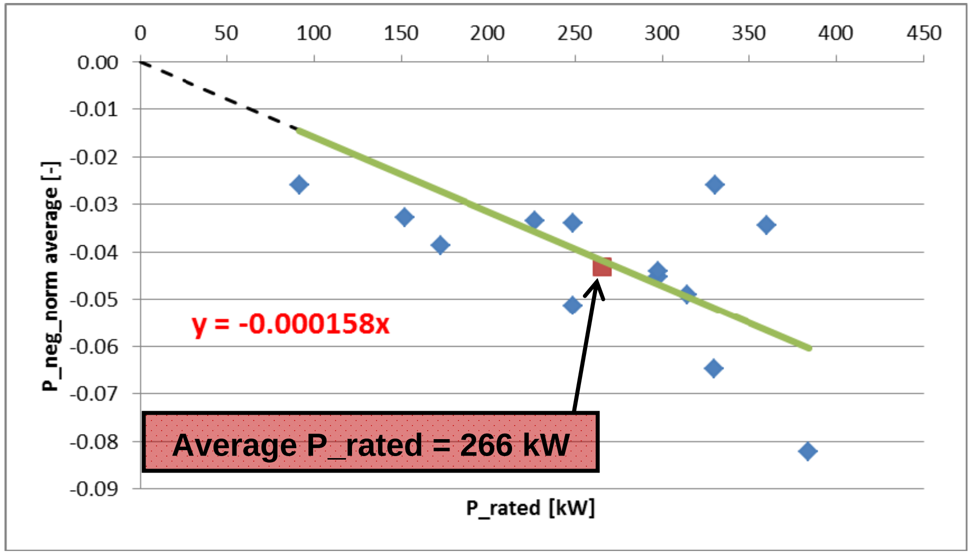


Different negative power according to vehicle category!

Explanation: long haulage vehicles have lower air resistance per ton of vehicle → more mechanical braking necessary per kW rated engine power than e.g. for delivery trucks.

Correction for different vehicle size classes possible, see next slide

Option: Correction for dependency of negative power on vehicle category

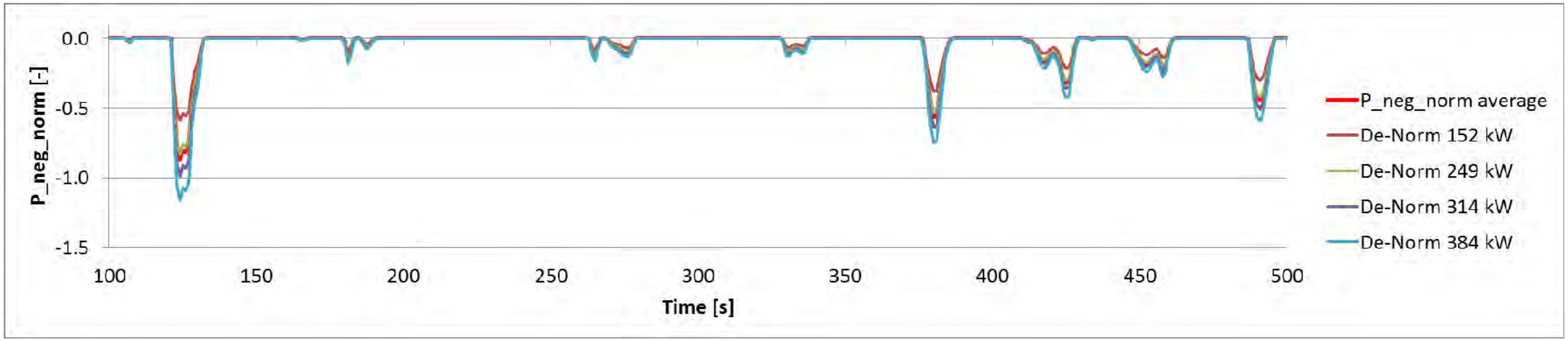


$$P_{rated}\text{-factor} = \frac{(P\_rated * 0.000158)}{(266 * 0.000158)} =$$

$$P_{rated}\text{-factor} = 0.00376 * P\_rated$$

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

→ **Adapts average „P_neg_norm" to different levels of rated engine power**



Suggested method for normalisation

Definition of $P_{neg\_norm\_average}$:

1)Calculate for single vehicles P_{neg} [kW].

2)Normalised with division by vehicles rated engine power → P_{neg_norm}

3)Calculate $P_{neg\_norm\_average}$ from all simulated vehicles in WHVC

= „standardised P_neg_norm", similar for all engines, independent of vehicle

4) Define „P_{rated}-factor" as function of rated engine power

= standardised equation for all engines

Application by user:

Enter rated engine power

→ P_{neg} is defined

Enter full load curve

→ P_{pos} is defined (By WHTC method)

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)

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

WHVC versus WHDHC: examples for resulting engine loads

3 vehicles according to Japanese categorisation simulated with model PHEM in **WHVC**

Each vehicle virtually equipped with 3 different power-packs in the simulation (same rated power but 3 different shapes of full load curve)

Resulting engine load distribution compared with **WHDHC** result

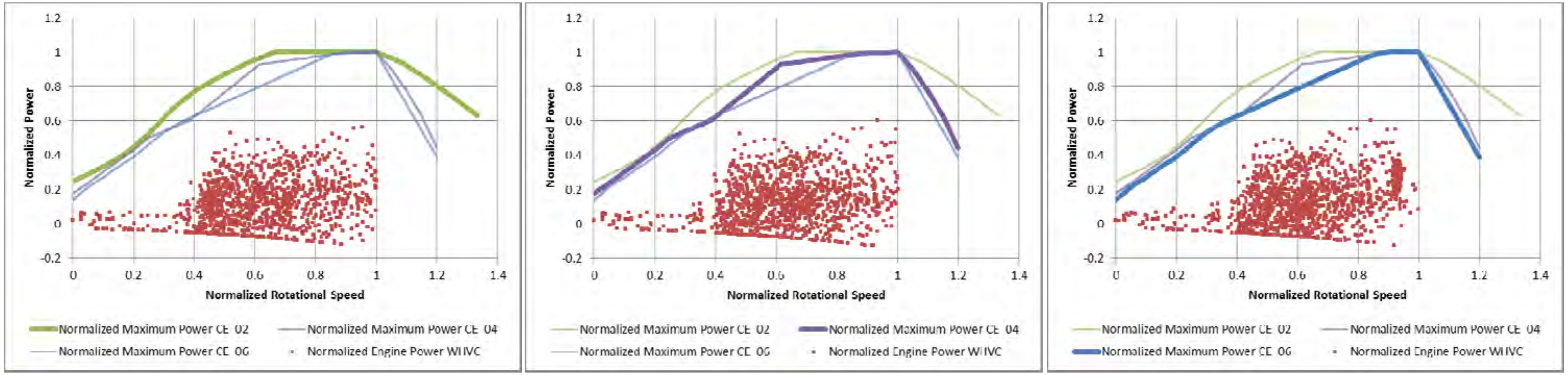
Standard vehicle specification by MLIT for exhaust gas (selected T4, T6, T7):

truck/tructor category			bus category			empty vehicle mass	maximum payload	number of persons	test vehicle mass	tire dynamic radius	overall hight	overall width	transmission gear ratio							diff gear ratio
category	vehicle mass range	pay load range	category	vehicle mass range																
NO	GVW/GCW(kg)		NO	GVW(kg)	fuel	(kg)	(kg)		(kg)	(m)	(m)	(m)	1st	2nd	3rd	4th	5th	6th	7th	
T1	3.5t<&≦7.5t	≦1.5t	-	—	D・LPG・CNG	1957	1490	3	2757.0	0.313	1.982	1.695	5.076	2.713	1.529	1.000	0.795			4.615
					G・LPG・CNG	1659	1458	3	2443.0	0.303	1.975	1.695	4.942	2.908	1.568	1.000	0.834			4.477
T2		1.5t<	B1	3.5t<&≦6t	D・LPG・CNG	2482	2396	3	3735.0	0.343	2.106	1.780	5.080	2.816	1.587	1.000	0.741			5.275
					G・LPG・CNG	2259	2016	3	3322.0	0.327	2.052	1.722	5.089	2.773	1.577	1.000	0.777			6.051
T3	7.5t<&≦8t	—	B2	6t<&≦8t	G・D・LP G・CNG	3543	4275	2	5735.5	0.388	2.454	2.235	6.350	3.876	2.301	1.423	1.000	0.762		4.771
T4	8t<&≦16t	—	B3	8t<&≦16t	G・D・LP G・CNG	4527	7737	2	8450.5	0.469	2.617	2.374	6.416	4.096	2.385	1.475	1.000	0.760		5.208
T5	16t<&≦20t	—	B4	16t<&≦20t	G・D・LP G・CNG	8688	11089	2	14287.5	0.502	3.049	2.490	6.331	4.224	2.410	1.486	1.000	0.763	0.612	6.309
T6	20t<&≦25t	—	B5	20t<	G・D・LP G・CNG	8765	15530	2	16585.0	0.473	2.934	2.490	6.304	4.170	2.393	1.456	1.000	0.752	0.604	5.102
T7	25t<	—	-	—	G・D・LP G・CNG	12120	24974	2	24662.0	0.507	2.961	2.490	6.147	4.000	2.281	1.434	1.000	0.760	0.597	6.061

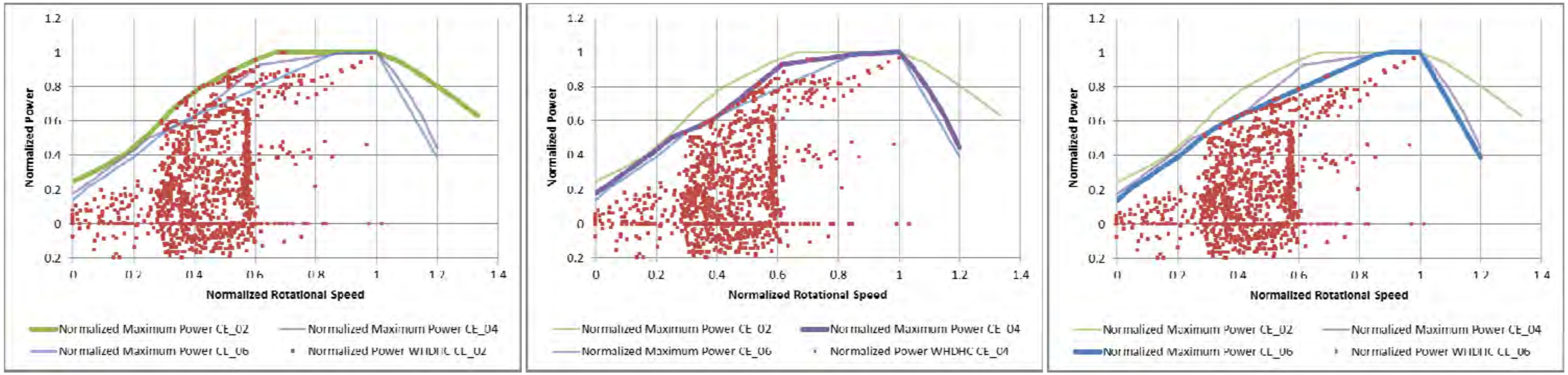
WHVC versus WHDHC: examples for resulting engine loads

- vehicle category **T4** (test vehicle mass **8,450kg,** rated engine power **240 kW**)

WHVC (engine power normalised to rated power):



WHDHC (engine power normalised to rated power; negative power only plotted up to -0.2 normalised):

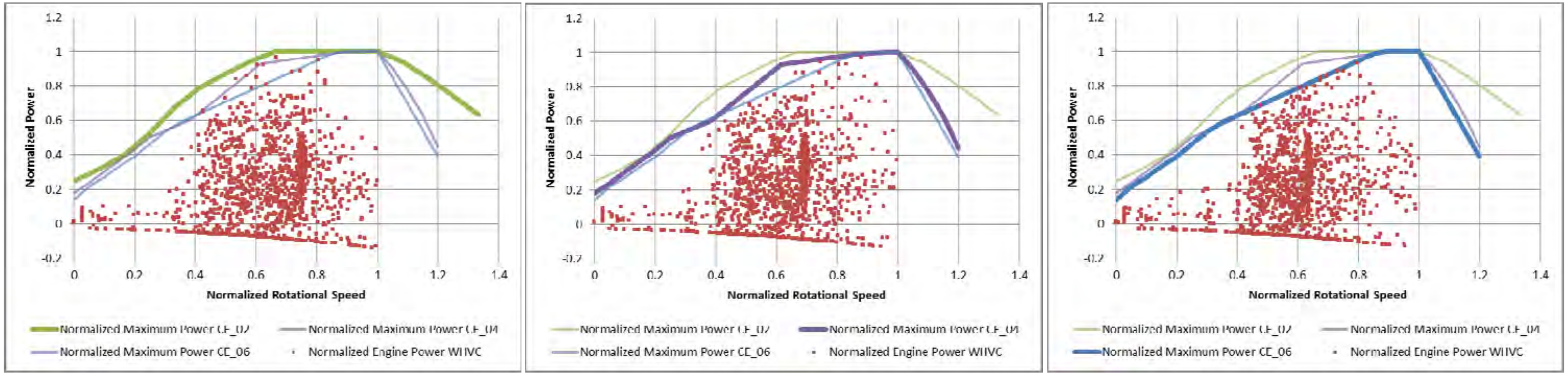


WHVC: No full load phases. Same engine torque and speed course for all engines
WHDHC: delivers full load phases for all engines (as WHTC would)

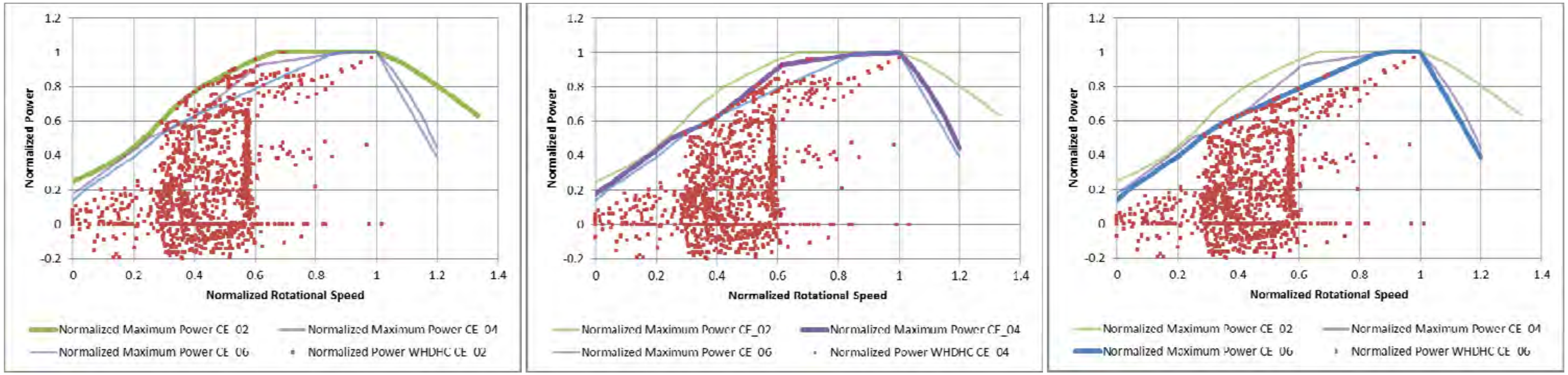
WHVC versus WHDHC: examples for resulting engine loads

- vehicle category **T6** (test vehicle mass **16,585kg,** rated engine power **240 kW**)

WHVC (engine power normalised to rated power):



WHDHC (engine power normalised to rated power; negative power only plotted up to -0.2 normalised):

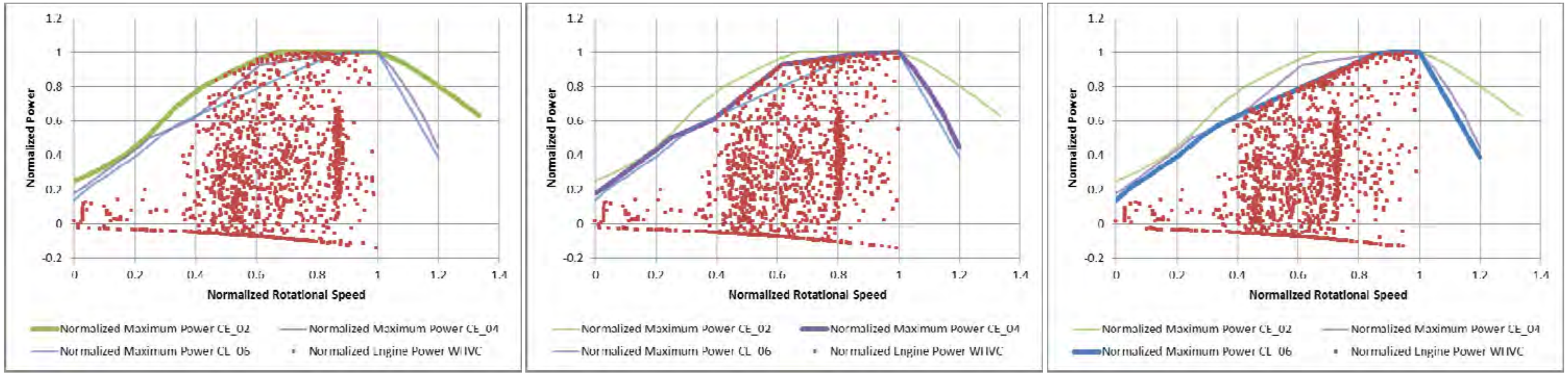


⇨ **For vehicle category T6 full load phases occur for engine CE_06**
Nearly same engine torque and speed trajectories for all 3 engines

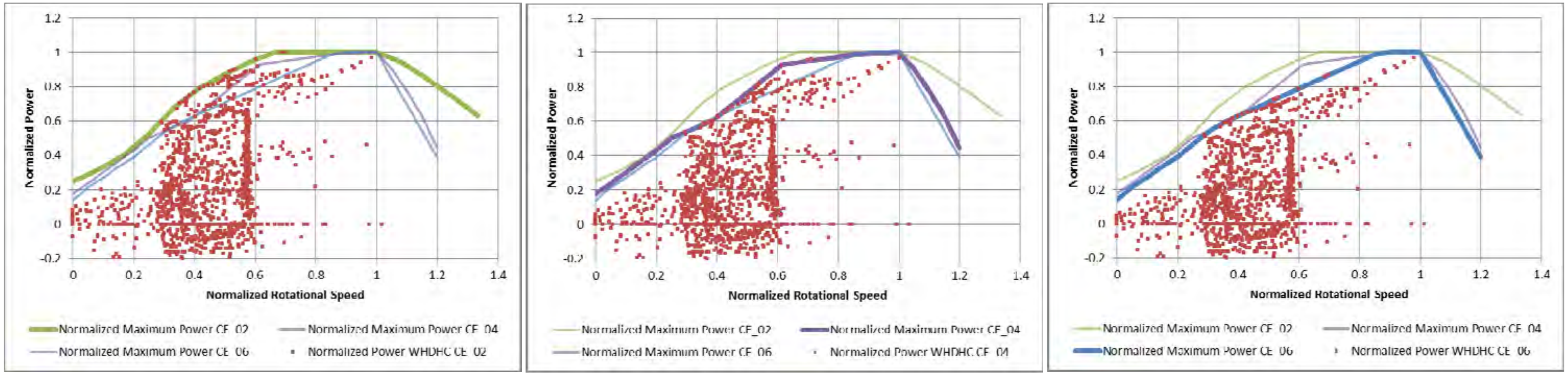
WHVC versus WHDHC: examples for resulting engine loads

- vehicle category **T7** (test vehicle mass **24,662kg,** rated engine power **240 kW**)

WHVC (engine power normalised to rated power):



WHDHC (engine power normalised to rated power; negative power only plotted up to -0.2 normalised):

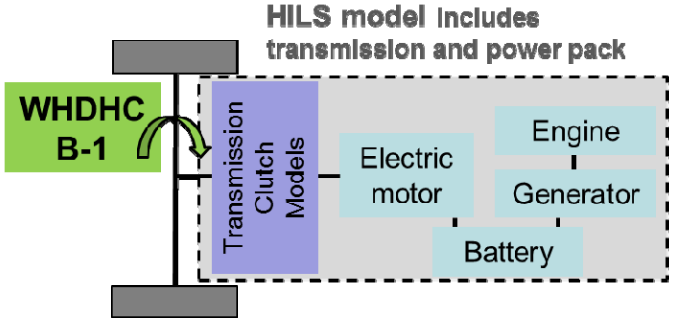


For vehicle category T7 full load phases occur for all engines.
Different engine torque and speed trajectories for all 3 engines

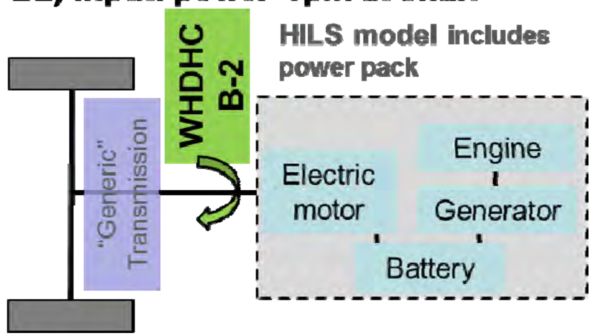
Discussion of possible HDH test cycles

- **Generic vehicle data + WHVC lead to engine loads which are quite different than the WHTC**
- **High powered vehicles will have no high engine loads in a power-pack cycle resulting from WHVC → WHVC for pollutant emissions not recommended**
- **Combining power cycle at wheel hub with generic gear box leads to same torque and rpm cycle at power pack shaft for all vehicles → either Option B1) with specific gear box model (can be complicated) or Option B2)**
- **Option B2) seems to be the simplest method which also matches the WHTC for conventional engines**
- **Normalisation of rpm for HDH power packs needs to be validated and eventually adapted**

B1) Input: power + rpm at wheel hub



B2) Input: power+rpm at shaft



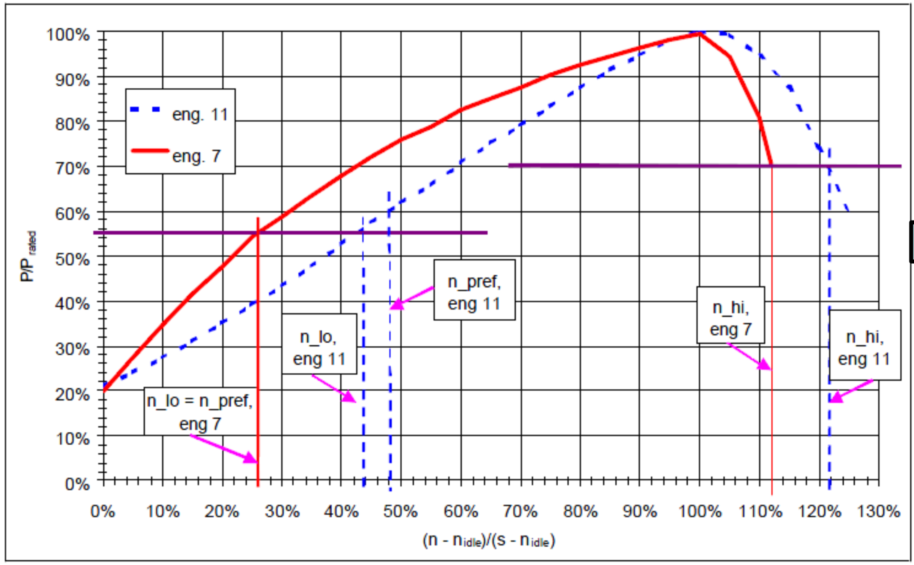
Summary of +/– for HDH test cycle options

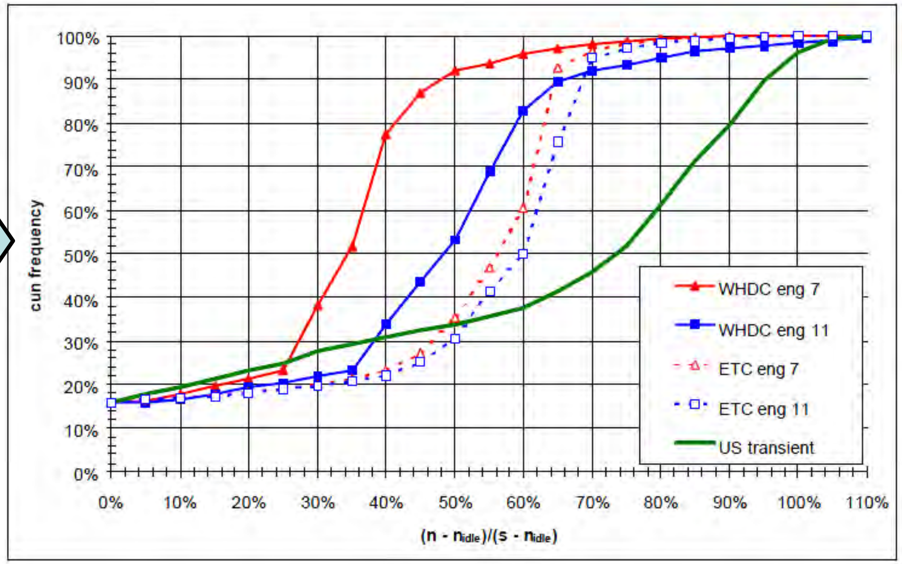
Option	Advantage	Disadvantage
A) WHVC +vehicle data	*Similar to existing Japanese tool	*Velocity cycle + vehicle data can result in unrealistic load cycles for power pack (no full load phases or higher power demand than full load) *Different load cycle than for conventional engines (WHTC)
B1) Power at 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

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]

WHTC takes into consideration, that full load characteristic influences the preferred engine speed range.





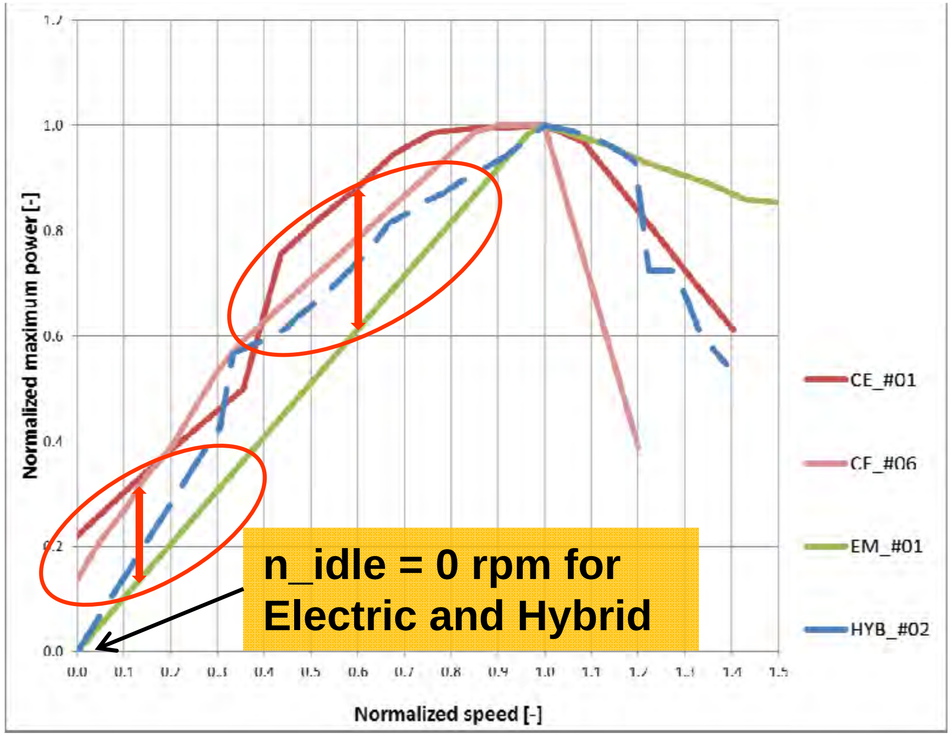
2 different full load curves of combustion engines → 2 different speed distributions for the WHTC

Is this relation also valid for HDH? (why should this relation not be valid for HDH?)

How can full load characteristic for HDH be defined? (electric motor allows overload for restricted time)

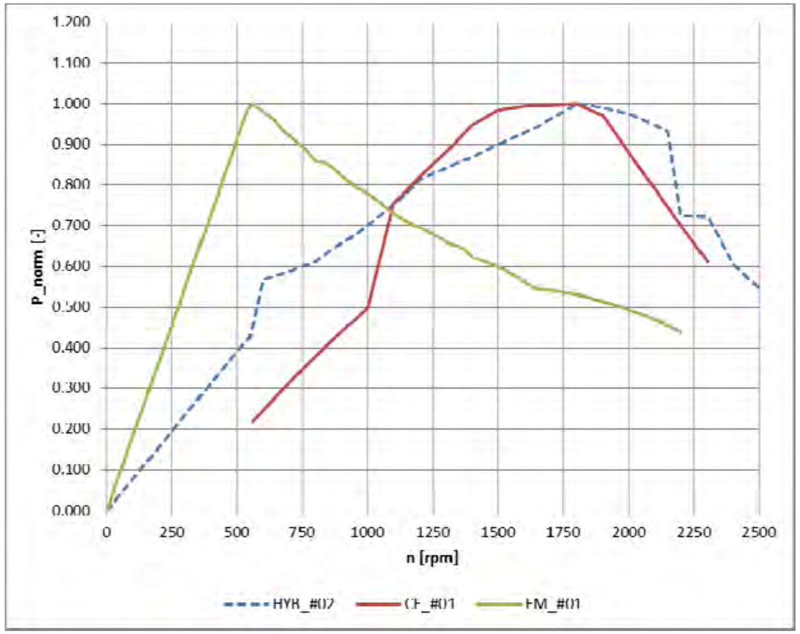
Validation of WHDHC, influence of full load curve design

Analysis of different full load curves



	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

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

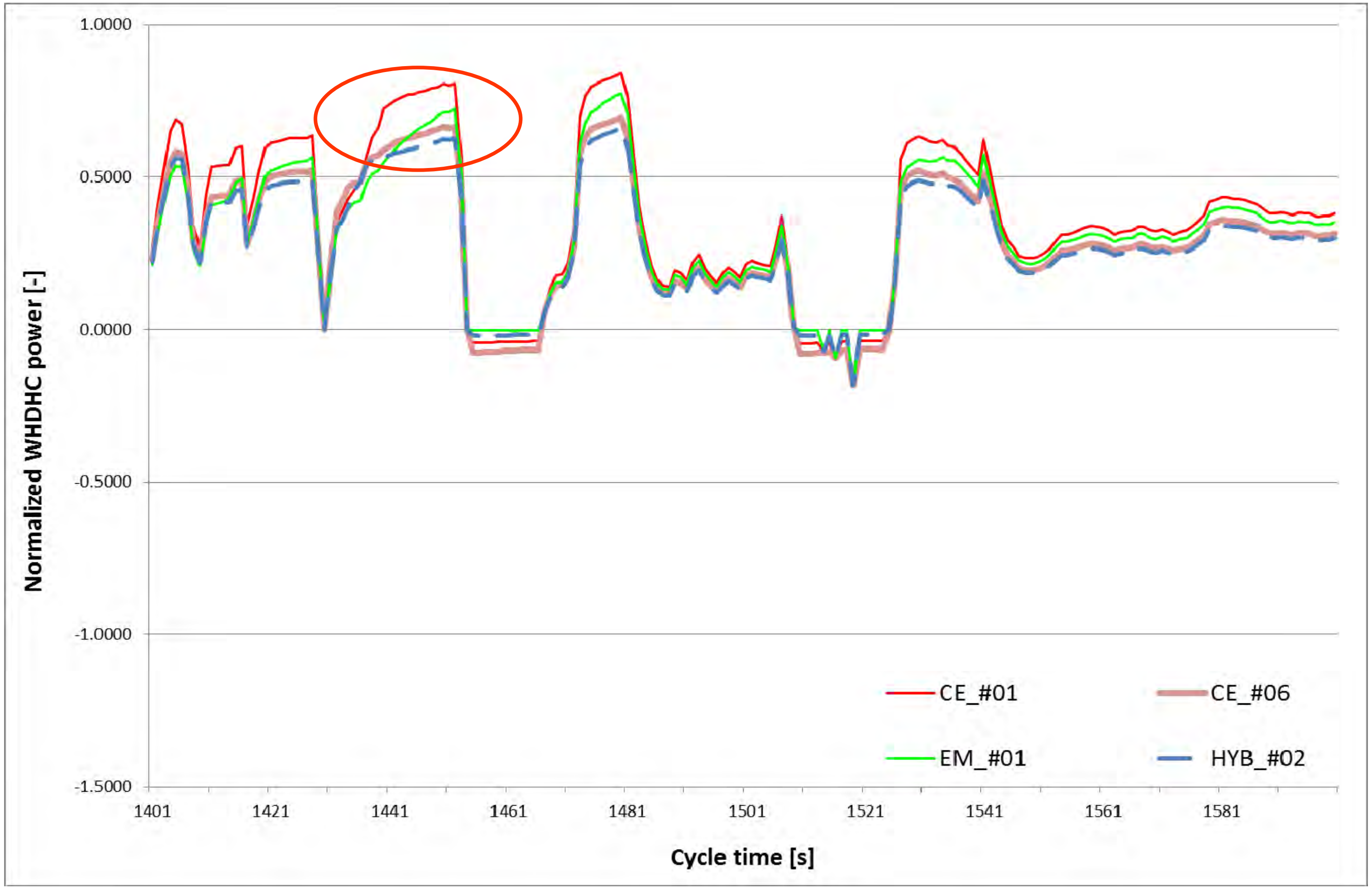


Of course more power at absolute lower speeds

→ Slightly lower normalized power at respective speeds in WHTC

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:

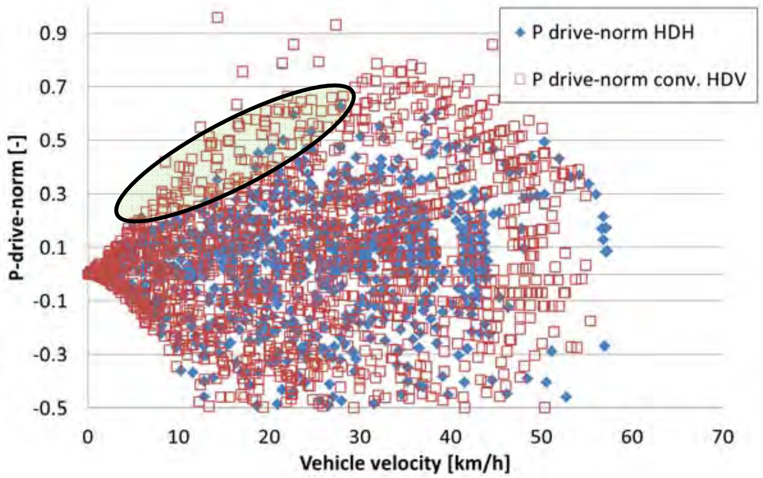
•on board measurements on 3 bus lines in city of Graz
(Volvo Hybrid bus and Evobus conventional)

•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)

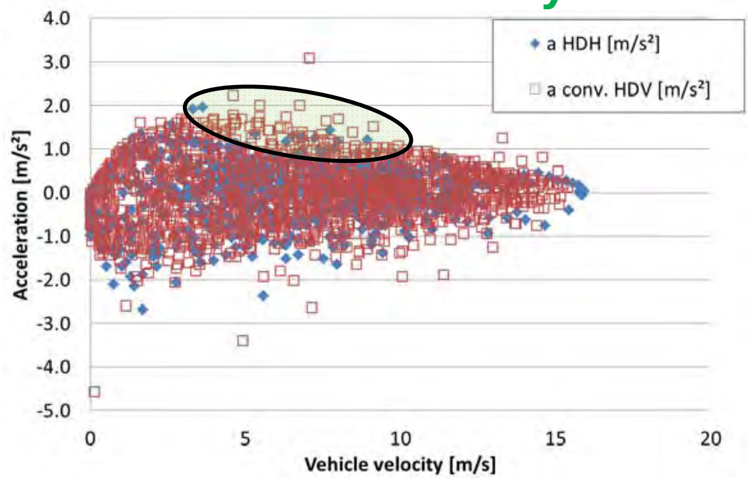
Missing: reasonable full load curves for the hybrid buses

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

P-drive norm over velocity



Acceleration over velocity



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

Next steps for WHDHC

- Must: Define method to set up full load curve for hybrid power pack!
- Must: Discuss methods and open questions with (OEM) experts (until now we had no possibility for meetings with experts)

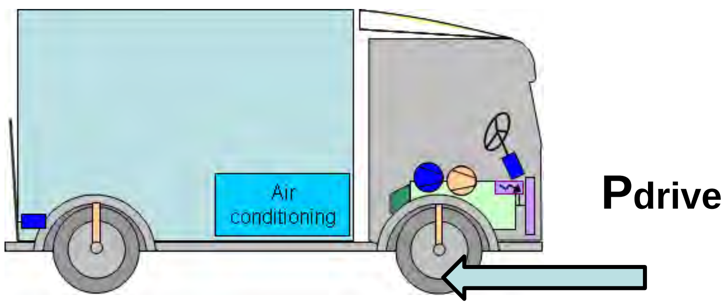
Adaptations in HILS method for suggested approach

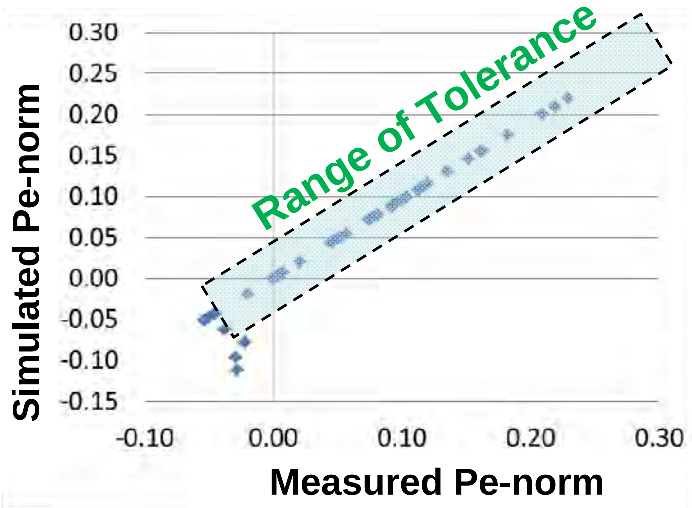
1. **Adapt driver model to control P_drive instead of velocity**
   control torque to meet rpm or simple backward model to deliver corresponding gas pedal position
2. **Adapt validation of HILS set up during type approval. Options are:**

   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.

   →Use P-drive measured (for any driving cycle) as HILS input instead of WHDHC

   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 (1/9)

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

•Definition of „vehicle classification“

•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”

“LOT 3” shall start soon to finalise the test procedure and perform pilot test phase

→ Classes still may change before introduction!

Next 3 slides are taken from the Final report of LOT 2

Vehicle classification for Heavy Goods Vehicles

Vehicle design characteristics → Classification & mission profile → Segmentation
→ typical CO2-test cycles, vehicle loading and „norm bodies" allocated to each vehicle

	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					T+S			W1?
3	6x2/2-4	Rigid	all weights	9	R+T	R		R		B6	T2	
		Tractor	all weights	10	T+S	T+S						S2
	6x4	Rigid	all weights	11					R	B7		
		Tractor	all weights	12					R			S3
	6x6	Rigid	all weights	13					R	W7		
		Tractor	all weights	14					R	W7		
4	8x2	Rigid	all weights	15		R				B8		
	8x4	Rigid	all weights	16					R	B9		
	8x6 & 8x8	Rigid	all weights	17					R	W9		

R…Rigid, T…Trailer, T+S..Tractor+semi-trailer, W…only weight (no drag tests)

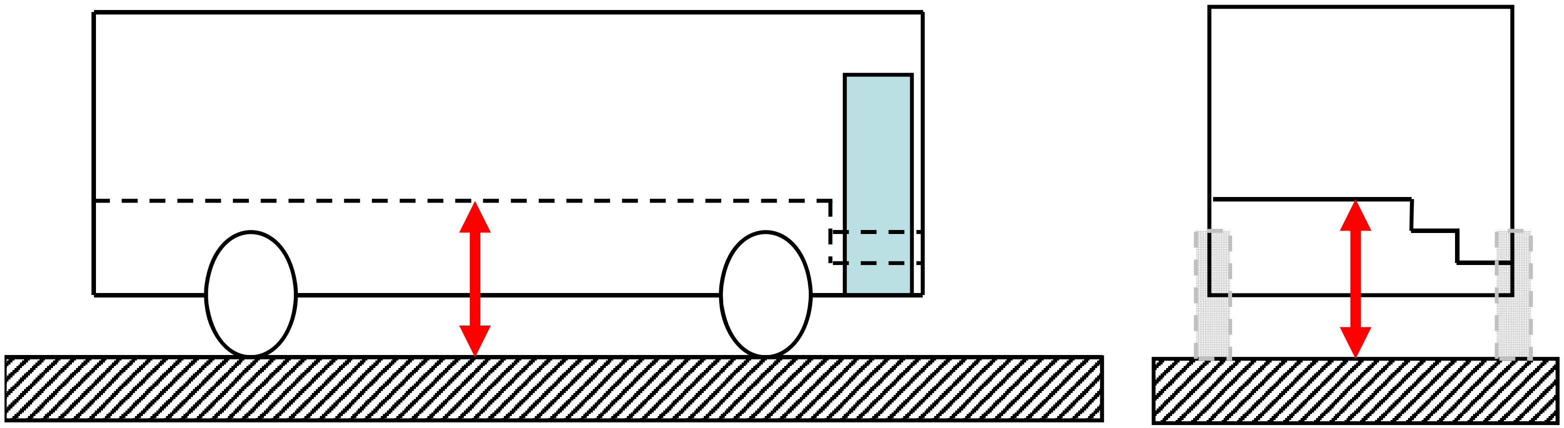
Vehicle classification for buses

Follow Directive 2001/85/EC: Class I ….seats and standing passenger
Class II….smaller number of standing passengers
Class III ...seated passenger only.

Additional definitions to distinguish between City, Interurban and Coach:

Luggage compartment: yes/no

Low floor entry : yes/no



Source: ACEA White Book

Vehicle classification for buses

Resulting segmentation:

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

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

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

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

→ or 8 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 used.

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 application.

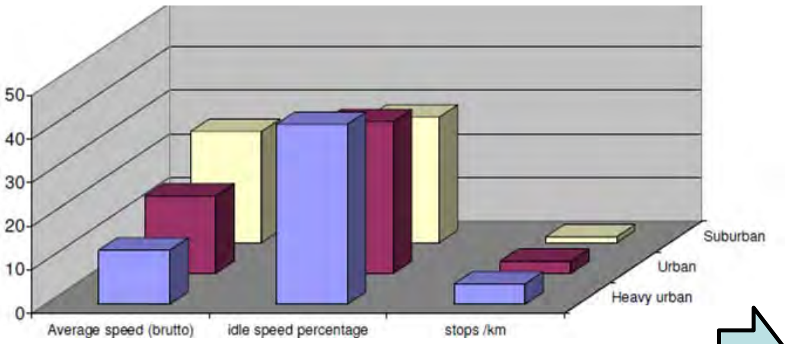
WHVC weighting factors, HDV CO_2 test cycle for city buses as example

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)

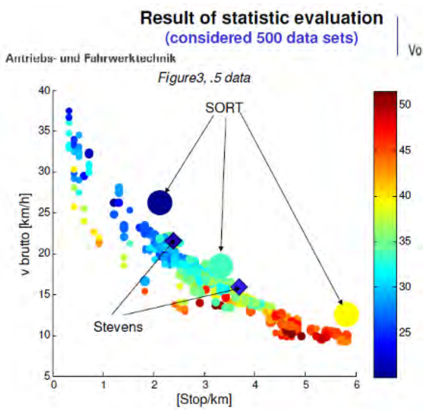
Analysis for HDV-CO_2 test procedure by ACEA and LOT2:

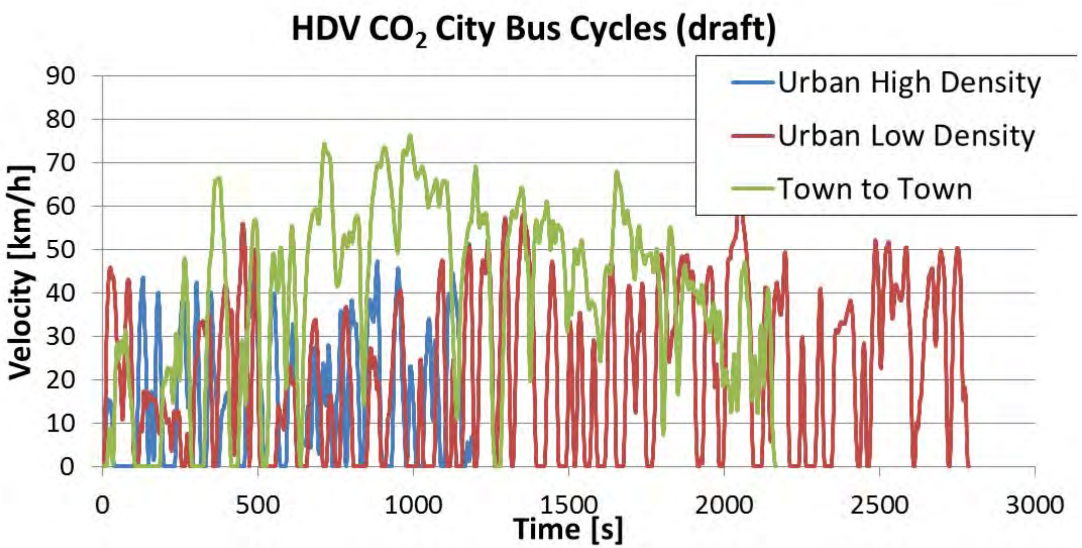


VOITH

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

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

Kinematic parameter i in WHVC-Sub-cycle

WHVC-Weighting Factor

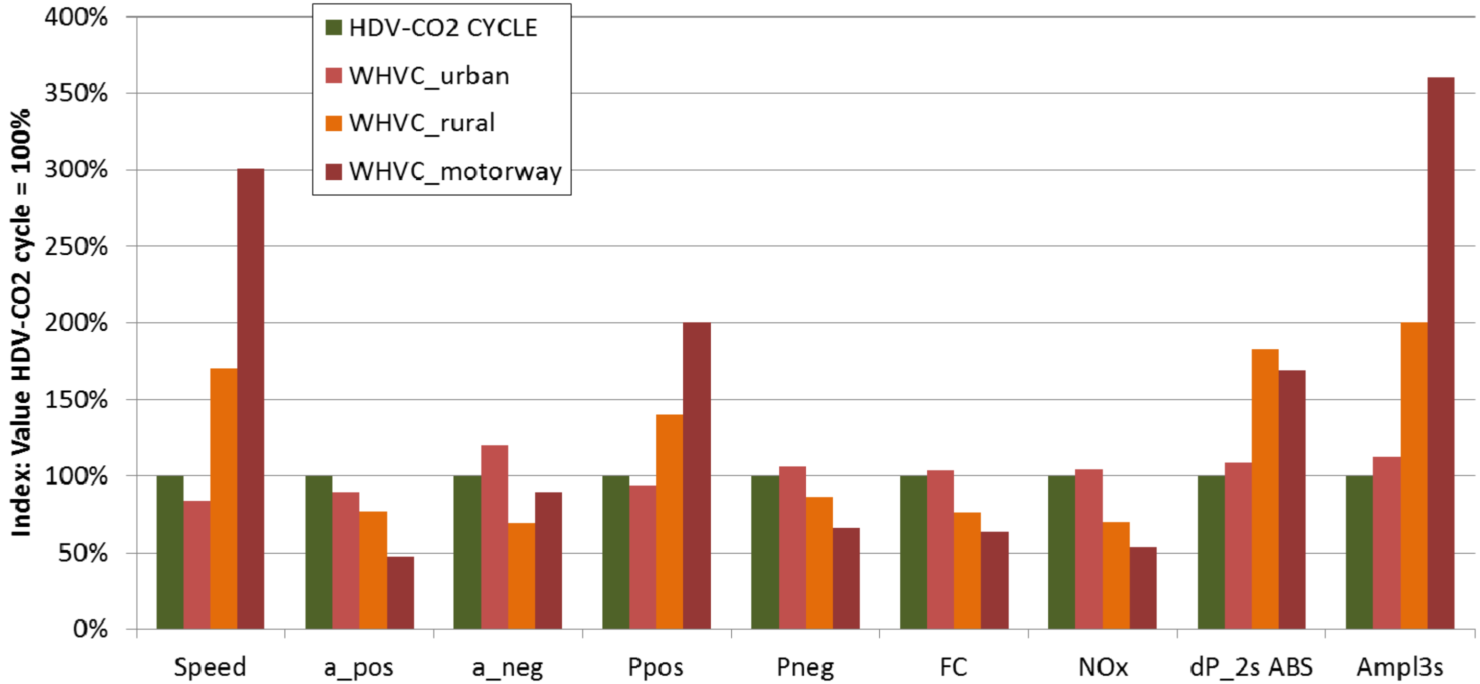
Kinematic parameter i in representative cycle

Weighting of the kinematic parameter i

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

Including PTO into the test procedure (1/9)

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.

•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

→ **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) elaborated by TUG in the contract
(city bus due to data availability)

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

Air conditioning for City buses: influencing factors

Mechanical driven compressor at conventional engines

Electrical driven at HDH (part load can be controlled by different compressor speed)

Cooling demand depends on:

1. Ambient temperature and humidity
2. Target temperature in the cabin
3. Sun radiation & area and quality of glazing
4. Air mass flow through AC system and % recirculated air
5. Technology of the air conditioning system

AC compressor power demand to provide cooling capacity = load cycle.

HILS model would need to provide this power by electric motor or by mechanical connection to engine

Influences 1. to 4. have to be considered when load cycle for AC is defined.

No data found in literature yet on these influences

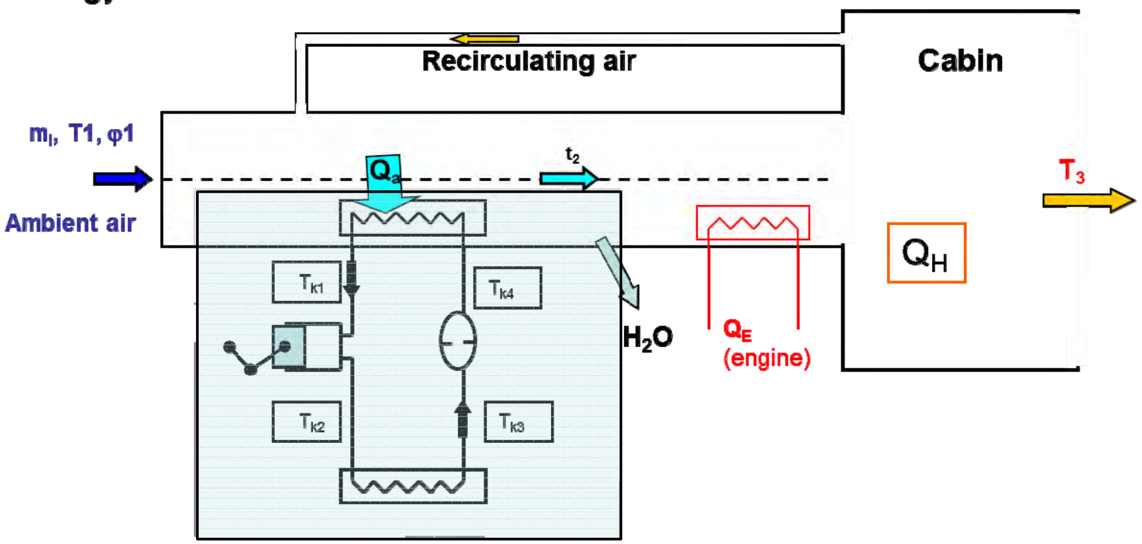
→ Simulation of variability in cooling capacity demand (CAP) and resulting compressor work

Simulation of variability of demanded cooling capacity (CAP)

Simplified coolant circuit, blower of HVAC driven with motor, compressor driven by ICE

Simulation tool developed for passenger cars for DG Enterprise and Industry in project: Collection and evaluation of data and development of test procedures in support of legislation on mobile air conditioning (MAC) efficiency and gear shift indicators (GSI); Performed under Framework Service Contract ENTR/05/18

Energy balance to calculate CAP:



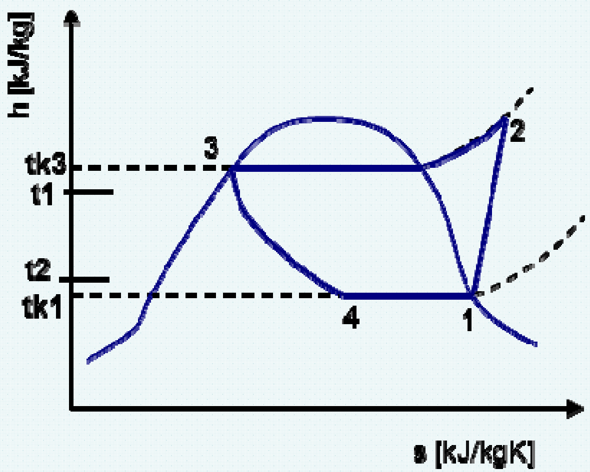
$$Q_a = m_l * [h_{3(1+x)} - h_{1(1+x)} + (x_1 - x_2) * C_w * t_w] + Q_E + Q_H$$

blower position — Enthalpy (3 -1) — Condensation — heating — „sun radiation“

$\dot{m}_l$ | T1, φ1, Ti, φi | T1, T2, φ1 ⟵ **Influence of ambient conditions**

T_{k4}…setting of MAC evaporator temperature

Simple coolant cycle to calculate compressor power demand (a = h_2-h_1)



Simulation of air conditioning for city buses, boundary conditions

"Typical" ambient conditions in Europe:

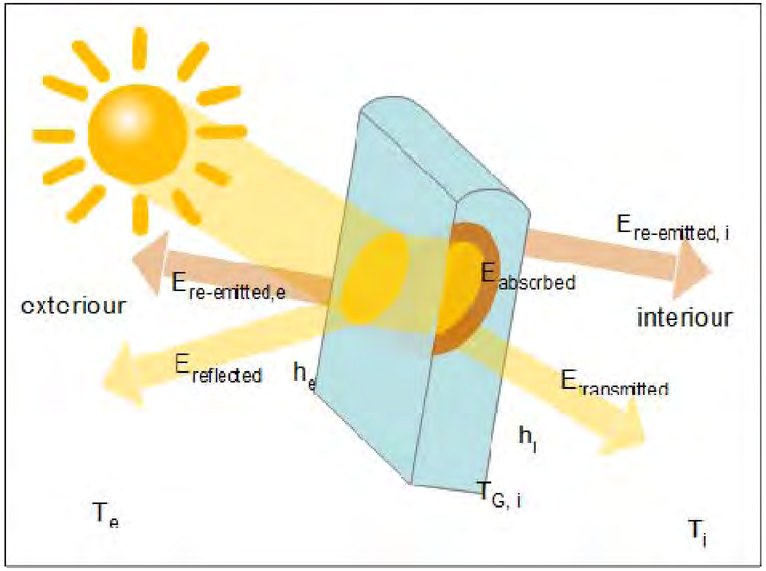
- **Hot: 30°C, 40 % RH, 700 W/m² sun radiation (~Athens)**
- **Mild: 20°C, 65 % RH, 500 W/m² sun radiation (~Frankfurt)**
- **Cold: 15°C, 75 % RH, 300 W/m² sun radiation (~Helsinki)**

Total heat entrance (Q_E+Q_H) = sun radiation + ambient + passengers

Sun radiation (Q_H):

Assumed vehicle data:
15 m² glasses with 7° angle
and T_{TS} value of 60% (30% for wind screen)

T_{TS}: total solar transmittance of a glazing
= solar direct transmittance +secondary heat transfer factor q_i of the glazing towards the inside (ISO 13837)



⇨ 4.5 kW heat entrance for 500 W/m² sun radiation

Ambient + passengers: assumed 0.1 kW/passenger + 0.3 kW from door opening, engine heat transfer etc.

Simulation of air conditioning for city buses, boundary conditions

Conditions simulated:

2 axle 12 m city bus

Target cabin temperature: 22°C

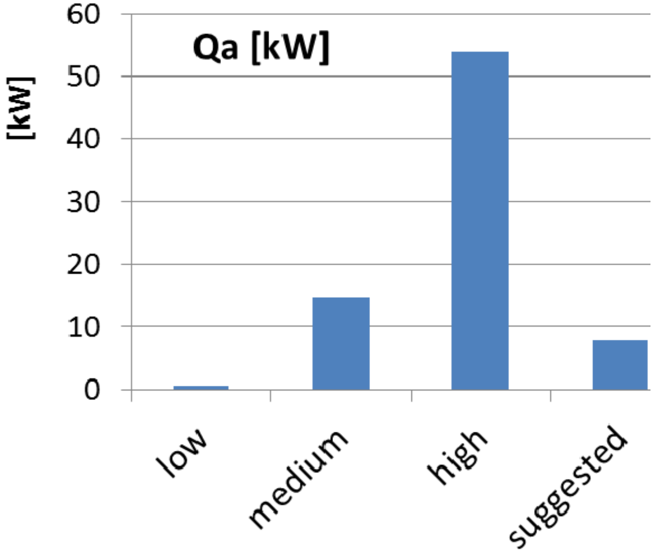
Heat entrance cabin: 2.6 kW low (200W/m² sun radiation with 5 passengers)
6.8 kW medium (500W/m² sun radiation with 20 passengers)
12.5 kW high (800W/m² sun radiation with 50 passengers)

Ambient conditions: 15°C / 75 RH low
24°C / 65 RH medium
30°C / 60 RH high
40°C / 90 RH extreme (with target temperature = 28°C)

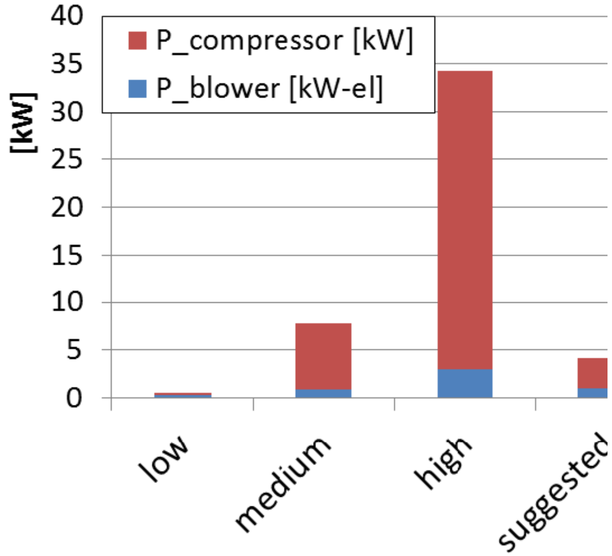
Intake air mass flow: 1000 kg/h low
3000 kg/h medium
10 000 kg/h high
14 000 kg/h extreme

Simulation of air conditioning for city buses, Results

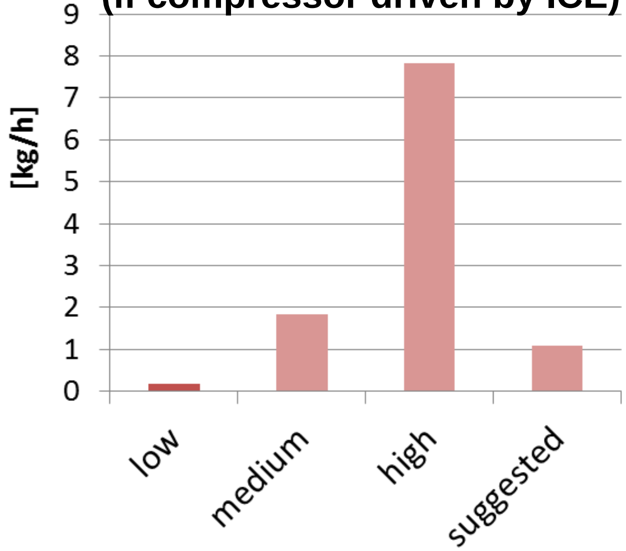
Demanded cooling capacity



Resulting power demands



Resulting additional fuel consumption
(if compressor driven by ICE)



→ COP = 3.1 2.1 1.7 2.5
(Coefficient of Performance) = Qa / $P_{compr.}$

"Suggested" value between "low" and „medium load" shall reflect yearly average (including winter)

→ 8 kW CAP with 3.2 kW for compressor and 1 kW_{el} for blower
adds approx. 1,1 kg/h fuel consumption, i.e. 6.5 l/100km at 20 km/h, for conv. Bus.
Quick measurement on Volvo HEV bus showed comparable magnitudes.

Options to include air conditioning in the test procedure

For regulated pollutants:

Neglect AC in HILS application

(to be comparable to conventional engines with resulting engine test cycle)

For CO_2 test procedure:

Define average Cooling Capacity demand (CAP = 8 kW) and blower (1 kW)

Simulate AC system with default Coefficient Of Performance (COP = 2.5)

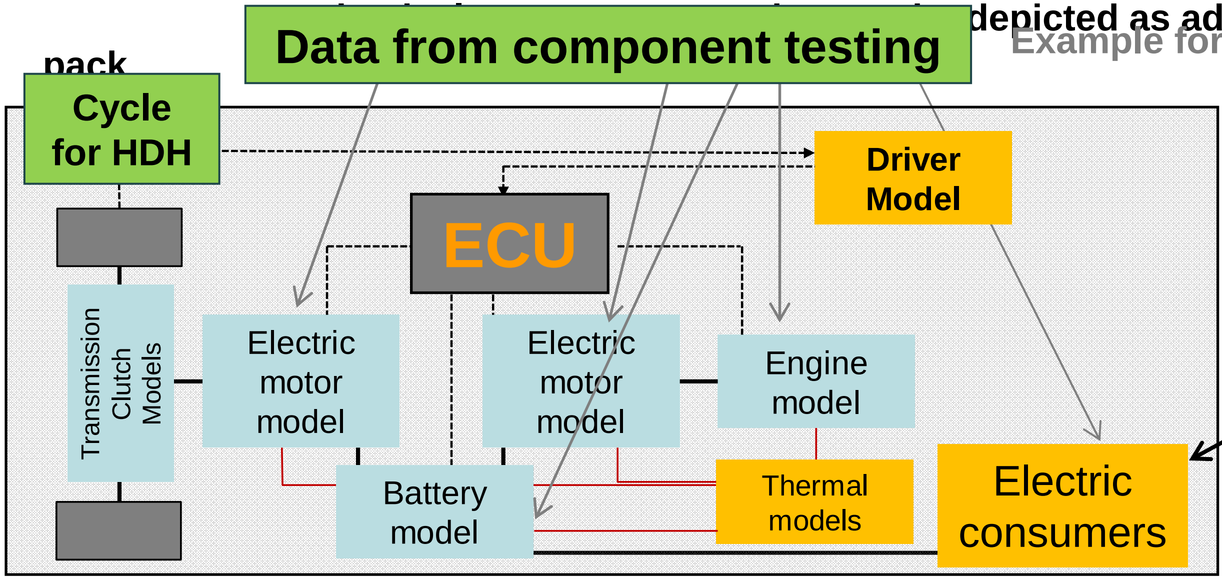
→ Default compressor power demand = 3.2 kW

Detailed simulation in HILS model would need additional component:

*** electric consumer connected to battery (el. motor for compressor, typical 28V)**

... depicted as additional power demand from power pack

Example for WHDHC option B1



Mechanical consumers: connected to shaft

Hydraulic consumers: connected to hydraulic accumulator (see Chalmers ppt)

Options to include air conditioning in the test procedure

Alternatively a simple bonus system can be introduced:

additional fuel consumption from AC for conventional HDV as basis

$FC_{AC\text{-}basis}$ = e.g. 1100 g/h

additional fuel consumption from AC in HDH

$FC_{AC\text{-}HDH} = be_{ICE} * (CAP/COP + P_{mech\text{-}blower}) / (\eta_{Gen} * \eta_{Bat} * \eta_{mot})$

with be, CAP, COP and P_{blower} to be defined as default values

Basic assumption for this approach: advantage of the recuperated brake energy is applied to 100% for electric motor of power pack in the HILS model.

→ Electric energy for PTO needs to be generated via ICE-generator-battery chain

The "bonus fuel consumption FC_{bonus}" can then be subtracted from the result from the basic fuel consumption delivered by the HILS model

$FC_{Bonus} = (FC_{AC\text{-}basis} - FC_{AC\text{-}HDH})$

For both options, improved AC and glazing quality can be taken into consideration on demand of the OEM:

•OEM can demonstrate better COP for given boundary conditions

•OEM can demonstrate lower CAP demand due to improved glazing

Summary to work performed

- **Drive 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 suggested not to include PTO loads into the proposed HILS method for test cycle development of the regulated emissions**
- **PTO loads can be included in CO_2 test procedures for conventional and for hybrid vehicles in comparable way**
- **Example with AC-system as PTO shows feasibility in HILS method. Final values for input data need further validation**
- **For detailed AC simulation an additional component “electric consumer” has to be established. For other PTOs “hydraulic consumer” and “mechanic consumer” can be added accordingly.**
- **“Bonus-System” for PTO would also work but may be less sensitive**

Suggested next steps

Task 1) Adaptation of the Japanese HILS Simulator for serial hybrid

Task 1.1) Programming of ECU as software in the loop
as basis for further programming and software development

Task 1.2) Add "driver model" for power & rpm at wheel hub and at shaft

Task 1.3) Extend the Simulator with a library for non electric components

Task 1.4) Survey on relevant components to be included in a first version of a "GTR-HILS model" as basis for tasks 1.5 and 1.6

Task 1.5) Extend HILS with library for new components (e.g. planetary gear box)

Task 1.6) Extend the HILS Simulator with thermal models (exhaust gas after treatment components, coolant, lube oil, battery, electric motor where relevant according to task 1.4)

Task 1.7) Simulation runs and validation of basic functions

Task 2) Adaptation of the HILS Simulator for parallel hybrid

Subtasks similar to Task 1

Task 3) Adaptations and improvements

Task 4) Define and provide the interface system for real ECU's

Task 5) Reporting on test procedure and writing a user manual for software

Task 6) Validation of the entire test procedure
with real HDH vehicles and ECU's in the HILS.

Thank you for your attention!