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D6100.2 Report Concerning Standard Component Dimensioning Classes

Summary

In the Hybrid Commercial Vehicle project's (HCV) work package 6100, TNO objectives are drive cycle development and development of test procedures. These developments are based on vehicle measurements, data from SP4000 and SP5000, and other relevant work packages in the HCV project. The drive cycles will be used for vehicle testing on a powertrain chassis dynamometer to evaluate the validation of test procedures. Commonality opportunities of the hybrid component classes for these drive cycles and of the communication protocol for controlling the hybrid components are evaluated.

Advanced second generation hybrid commercial vehicles are being developed in the HCV project with the main objectives; cost reduction and further fuel economy improvement. The goal of this report is mainly focused on the cost reduction of hybrid vehicle components utilizing the strength of commonality and standardization possibilities. More exactly the task definition is stated as:

Based on the developed electrified components and outcome of HCV SP2000, the effect of the drive cycles (developed in HCV SP6000) will be investigated across various vehicle classes and types to enable component commonality.

In close cooperation with DAF and with the confirmation of all other partners in the HCV project, the vehicle classifications proposed by the European Automobile Manufacturers' Association (ACEA) for upcoming CO_2 certification were accepted. This means that the hybrid vehicles will fit in the classes that were proposed by ACEA for heavy duty trucks and buses.

Components considered in this report, based on the literature available from HCV SP2000, are; air-conditioning, air compressor, heating system, powered steering servo, actuated mechanical brakes. Electrification of the components will enable stop-start operation and electric driving with the engine shut off, without a lack of comfort (A/C and heating) and safety (steering and braking). Apart from efficient recuperation of energy during coasting or braking, stop-start and electric driving operations will also enhance fuel-consumption reduction in CO_2 certification drive cycles as well as in real world driving.

Looking at the actual electrification of components, challenges to overcome are for example packaging, routing, engineering, control, reliability, durability, efficiency, safety aspects, fault handling, communication protocols and complying to the desired automotive standards. If these challenges will be picked up with the goal of designing modular (sub)systems, a lot of effort can be saved when a system is interchangeable between different vehicle classes and types, and can cope with different system set-up and component sizes.

Electrically powered Air-conditioning systems (E-A/C), electro-hydraulic power steering, e-heating and e-braking systems that are already present in the passenger and Light Commercial Vehicles (LCV's) industry offer a good possibility for usage in hybrid electric heavy duty vehicles if the requirements suit the desired specifications. Vans and small trucks could benefit the most due to comparable or close to comparable specifications and requirements. For other vehicles like a large city bus, or heavy truck, only project specific or prototype systems of electrified heating, cooling or steering were found in literature. Where possible, existing standards, processes, methods, engineering, specifications and functionality of available automotive components could be used as a basis to adapt or develop the systems to heavy duty vehicle standards.

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1 Introduction

The evolving emission legislation and the increasing fuel prices accompanied by a global CO_2 emission reduction discussion represent an extremely challenging demand for vehicle research and development. Known improvement measures of pollutant emissions usually associate with deterioration of engine efficiency and vice versa, e.g. the NOx/fuel economy trade-off is well-known for diesel engines. Therefore the real challenge is to find new compromises on improved levels for both – fuel consumption and pollutant emissions. With this background, hybrid electric vehicle technology could provide an excellent option for simultaneous reduction of fuel consumption and exhaust emissions.

The HCV project aims to develop urban buses and delivery vehicles with advanced second-generation energy efficient hybrid electric powertrains. The advanced second generation hybrid vehicles are a follow-up of the first generation hybrids and early second generation hybrids. While first generation hybrids are vehicles with a gasoline engine and a power-split electrical driveline with NiMH batteries as an electrical storage device, early second generation hybrid vehicles use a diesel engine and a power-split electrical driveline in combination with lithium-ion batteries.

Objective:
Advanced second generation hybrid commercial vehicles are being developed in this project with main objectives of cost reduction and further fuel economy improvement. The goal of this report is mainly focused on the cost reduction of hybrid vehicle components utilizing the strength of commonality and standardization possibilities. More exactly the task definition is stated as:

Based on the developed electrified components and outcome of HCV SP2000, the effect of the drive cycles (developed in HCV SP6000) will be investigated across various vehicle classes and types to enable component commonality.

Methodology:
The structure of this report is as follows: The task definition and the scope of this report are set-out in chapter 2. Drive cycle performance of the HCV vehicles is the subject of chapter 3. Component performance across vehicle classes and their influence on the drive cycle is discussed in chapter 4. Finally, recommendations for standardized component classes and component commonality are suggested in chapter 5.

2 Task Definition

Task 6120: Analysis and determination of standard component dimensioning classes (TNO, DAF):
In cooperation with SP2000 and based on the results of Task 6110, the effect of the drive cycles on the various components in the hybrid vehicles will be investigated (TNO). This will be performed across the various vehicle classes and types (to be defined in cooperation with DAF), in order to enable component commonality. From this activity, standardized component classes will be recommended where it is possible. This information will prove useful to increase volume for component suppliers, leading to lower on-cost for hybrid technologies.

Component information for this task is gained from the work done in SP2000 represented by the deliverables D2200.1 [4] and D2300.1 [5] of the HCV project. The vehicles proposed in the project are used as a benchmark to analyze component performances together with the drive cycles developed in Task 6110. Furthermore, a logical choice for (hybrid) vehicle classes is made together with DAF. In this chapter the scope of vehicles, components, vehicle classes and drive cycles are defined, before going into depth in Chapter 3 Drive Cycle Performance and Chapter 4 Component Functionality

2.1 Scope of Vehicles

In total twelve hybrid commercial vehicles are considered in the HCV project consisting of a first generation hybrid vehicle, early second generation vehicles and during the project developed advanced second generation hybrid vehicles. The fleet of vehicles consists of both buses (VOLVO, SOLARIS) and delivery vehicles/trucks (IVECO-ALTRA, DAF). Technical specifications were gathered during a vehicle scoping investigation on both publically available resources and with the help of a questionnaire directed by TNO. A complete overview of the specifications can be found in Annex A.

2.1.1 First Generation Hybrid Vehicle (SOLARIS)

The first generation hybrid vehicle is equipped with a NiMH battery and a planetary series-parallel power-split device. The system is used in the first generation hybrid version of SOLARIS and is depicted in Figure 1. No electrification of components is present, which, as an example, mean electric driving in combination with stop-start is not possible.

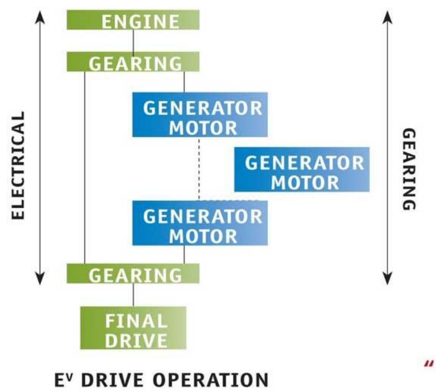

Figure 1: Series-parallel power split device of Allison, source http://www.allisontransmission.com 2010-04-21

2.1.2 Early Second Generation Hybrid Vehicles (DAF, IVECO-ALTRA, VOLVO, SOLARIS)

This generation of hybrid vehicles has already been present from the beginning of the project in the form of prototypes. These vehicles are in use across different cities in Europe with the purpose to gain experience and information. These vehicles have typical Li-ion batteries and parallel power split device.

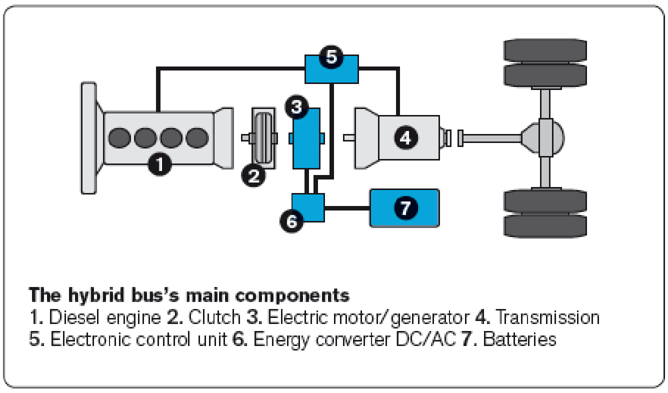

Figure 2: Parallel hybrid power split of Volvo, source Factsheet Volvo 7700 hybrid EN.pdf 2010-04-21

2.1.3 Advanced second generation hybrid vehicles (IVECO-ALTRA, VOLVO)

Advanced second generation hybrid vehicles are being developed in this project. Both IVECO-ALTRA and VOLVO will actually make such vehicle as a deliverable in the project. This generation will also incorporate Li-ion batteries and parallel power-split device. The main hardware difference compared to the early-second generation hybrids is the inclusion of electrified auxiliary components (IVECO-ALTRA) combined with lightweight vehicle chassis and body (VOLVO). Unlike earlier generations, and due to the electrification of these components, electric driving in combination with stop-start functionality of the engine is possible. This is intended to enhance the fuel efficiency for hybrid commercial vehicles.

2.2 Scope of Components

Part of the advanced second generation vehicles is the incorporation of electrified auxiliary components in the vehicles which were developed in SP2000 of the project. Information of the electrifiable components identified in the HCV project [4][5] is listed below.

- E-A/C
- E-compressor
- E-heating
- E-powered steering servo
- E-actuated mechanical brakes

A technology evaluation, detailed information collection and documentation of controls are made for each of the components in the project. Eventually these electrified components are validated further in SP4000 and SP5000.

2.3 Scope of Vehicle Classes

In close cooperation with DAF and with the review and confirmation of all other partners in the HCV project, the vehicle classifications proposed by ACEA's heavy-duty CO_2 Working Group, are accepted. This means that the hybrid vehicles will fit in the classes that were proposed by ACEA for heavy duty trucks and buses.

ACEA proposed in 2010 a HDV classification based on a combination of truck-axle configuration and Gross Vehicle Weight (GVW) to be used in a simulation tool for calculating CO_2 emissions. In addition, ACEA proposed mission profiles which described the type of use [2]. This proposal of ACEA is described in the LOT1 report [1]. At the end of 2011, this classification was updated by ACEA [2]. The different Heavy Duty Vehicle (HDV) categories following ACEA classification of trucks that have been considered in the report are summarized in

Table 1. Trucks were classified according to their axle configuration, chassis configuration, and their GVW. Moreover, trucks were also classified into five broad mission/vehicle cycle categories based on their mission as shown in Table 2.

Table 1: ACEA classification of HDV trucks – GVW ≥ 7.5 t (October 2011)

Axle Configuration		Chassis Configuration	GVW (t)
Truck	4x2	Rigid	3.5-7.5t
Truck 2 Axles	4x2	Rigid + (Tractor)	7.5-10t
		Rigid + (Tractor)	10-12t
		Rigid + (Tractor)	12-16t
		Rigid	>16t
		Tractor	>16t
	4x4	Rigid	7.5-16t
		Rigid	>16t
		Tractor	>16t
Truck 3 Axles	6x2/2-4	Rigid	All Weights
		Tractor	All Weights
	6x4	Rigid	All Weights
		Tractor	All Weights
	6x6	Rigid	All Weights
		Tractor	All Weights
Truck 4 Axles	8x2	Rigid	All Weights
	8x4	Rigid	All Weights
	8x6/8x8	Rigid	All Weights

Table 2: Mission types of HDV trucks – GVW ≥ 7.5 t – according to ACEA (October 2011).

No.	Vehicle Cycle /Mission	Mission / Vehicle Cycle Description
1	Urban Delivery	Urban delivery of consumer goods from a central store to selling points (inner-city and partly suburban roads).
2	Municipal Delivery	Urban truck operation like refuse collection (many stops, partly low vehicle speed operation, driving to and back to central base point).
3	Regional Delivery	Regional delivery of consumer goods from a central warehouse to local stores (inner-city, suburban, regional and also mountain roads).
4	Long Haul	Delivery to national and international sites (mainly highway operation and a small share of regional roads).
5	Construction	Construction site vehicles with delivery from central store to very few local customers (inner-city, suburban and regional roads; only small share of off-road driving).

Buses and coaches with GVW ≥ 7.5 t were categorized according to ACEA (October 2011) into five different mission/vehicle cycles: City Class I, which includes heavy urban, urban and suburban categories, Interurban Class II and Coach Class III (Table 3). For buses and coaches there are only three main vehicle cycles. In total there are eight different mission types considered for HDV.

Table 3: Mission types of HDV buses and coaches – GVW ≥ 7.5 t – by ACEA (October 2011)

No.	Vehicle Cycle /Mission	Sub-categories
1	City Class I	Heavy Urban
2		Urban
3		Suburban
4	Interurban Class II	-
5	Coach Class III	-

2.4 Scope of Drive Cycles

For defining fuel consumption and corresponding CO_2 emission results each mission profile will have its own drive cycle. In the LOT 2 report [3] there are eleven drive cycles proposed and listed in Table 4.

Table 4: HDV-CO_2 test cycles - *Actual cycles in velocity time, velocity distance or other were not yet derived and are future work-*

Mission	Cycle Acronym
Heavy goods vehicles	
Long haul	LH
Regional delivery	RD
Urban delivery	UD
Municipal Utility	MU
Construction	CS
Heavy passenger vehicles	
Heavy Urban	HU
Urban	UR
Suburban	SU
Interurban	IU
Coach	CO
All HDV	
Common Short Test Cycle	CST

As agreed that hybrid vehicles could fit in the defined vehicle classes, so could the drive cycles defined for each mission profile fit to the hybrid vehicles. Apart from these drive cycles, special drive cycles were developed (task 6110) based on heavy duty hybrid vehicle data from the HCV project. These three cycles are depicted in Figure 3.

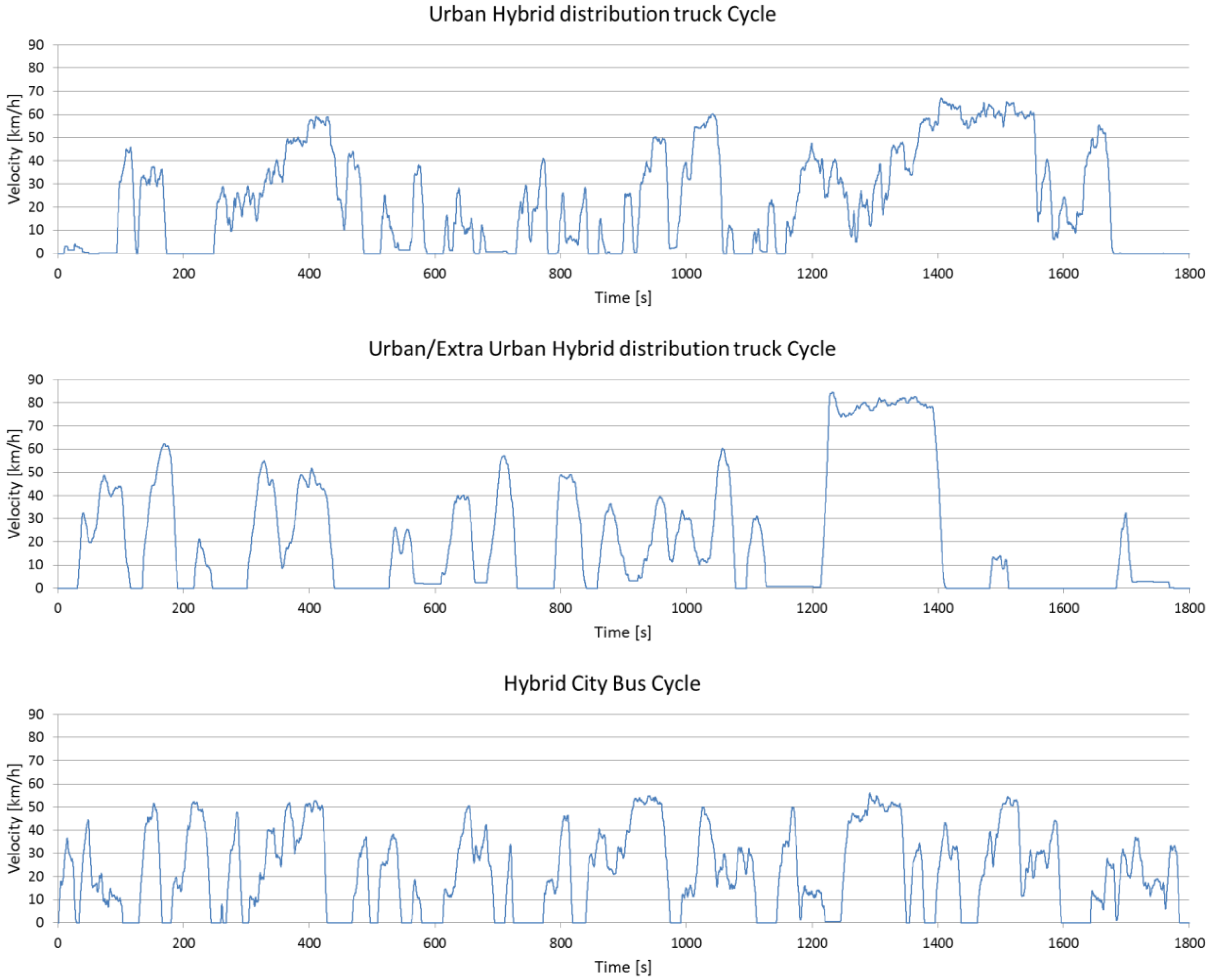

Figure 3: Developed drive cycles by TNO in the HCV project

More information about the development of the drive cycles and testing can be found in report D.6100.1 - Report concerning drive cycles and D.6100.4 - Report concerning test results and test procedure validation.

3 Drive Cycle Performance

To be able to give some conclusions on commonality of auxiliary components, an analysis of the required performance for the different drive cycles is completed. This is performed using a simulation approach, taking the hybrid performance set-up into account.

3.1 Approach

The drive cycles are defined by a speed profile against time. For a given vehicle, the power demand at the wheels can be calculated for a drive cycle. This calculation is done by a Power Consumption Model (PCM). It takes the drive cycle as input and using the vehicle parameters. The power demand at the wheels is given as output. The schematic of the PCM is depicted in Figure 4.

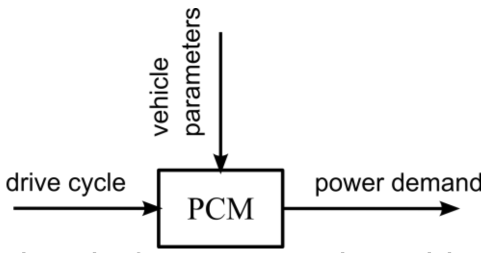

Figure 4 Schematic of power consumption model

In the calculations from here on, it is assumed that all negative power demands at the wheels can be put at the driven axle, such that it is possible to convert longitudinal vehicle kinetic energy into electric energy that can be fed to the battery, such as via regenerative braking. Vehicle stability is not taken into account, as this is also the case for brake and weight distribution. In that sense the amount of energy that can be regenerated is purely theoretical, because vehicle stability may prevent the hybrid system from recuperating kinetic energy in a number of cases.

3.2 Analysis HCV Vehicles

3.2.1 DAF LF

The output of the PCM for the DAF LF on the Urban/Extra Urban Hybrid distribution truck cycle is depicted in Figure 5, including the speed profile of the cycle. The vehicle payload is set to 55% of the maximum payload mass.

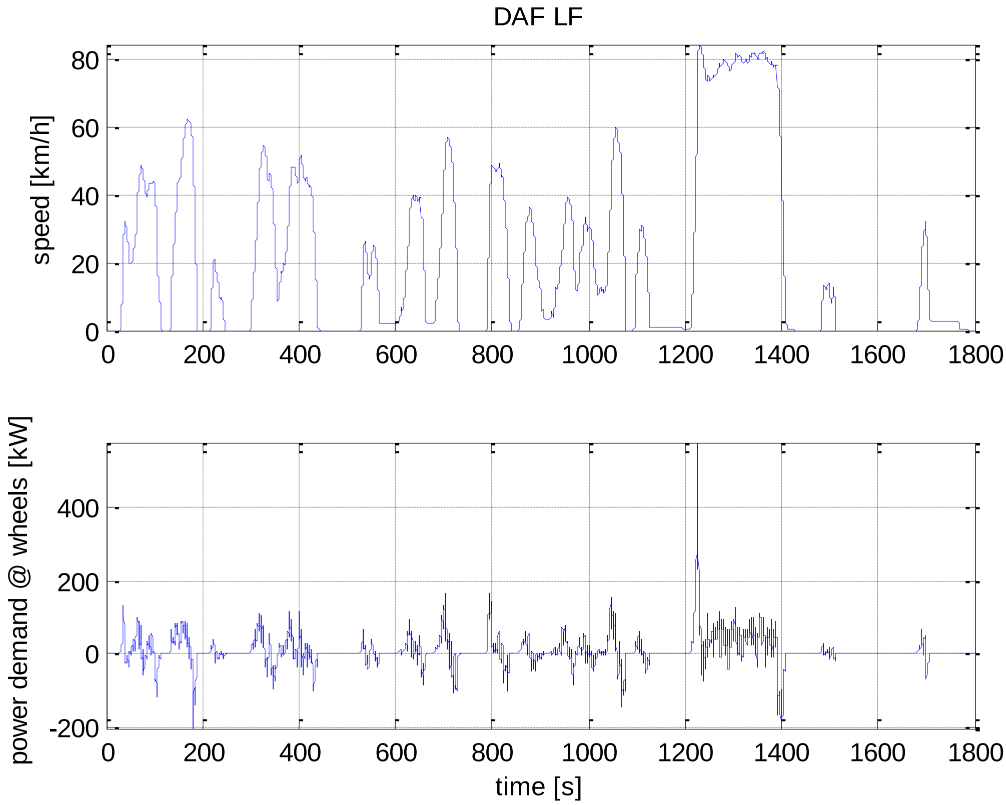

Figure 5 DAF cycle and corresponding power demand at the wheels

An extreme of power demand is visible when the truck is required to accelerate to 80 km/h. Other power demand values are within a range of approximately -200 kW and 200 kW as can be seen in Figure 5.

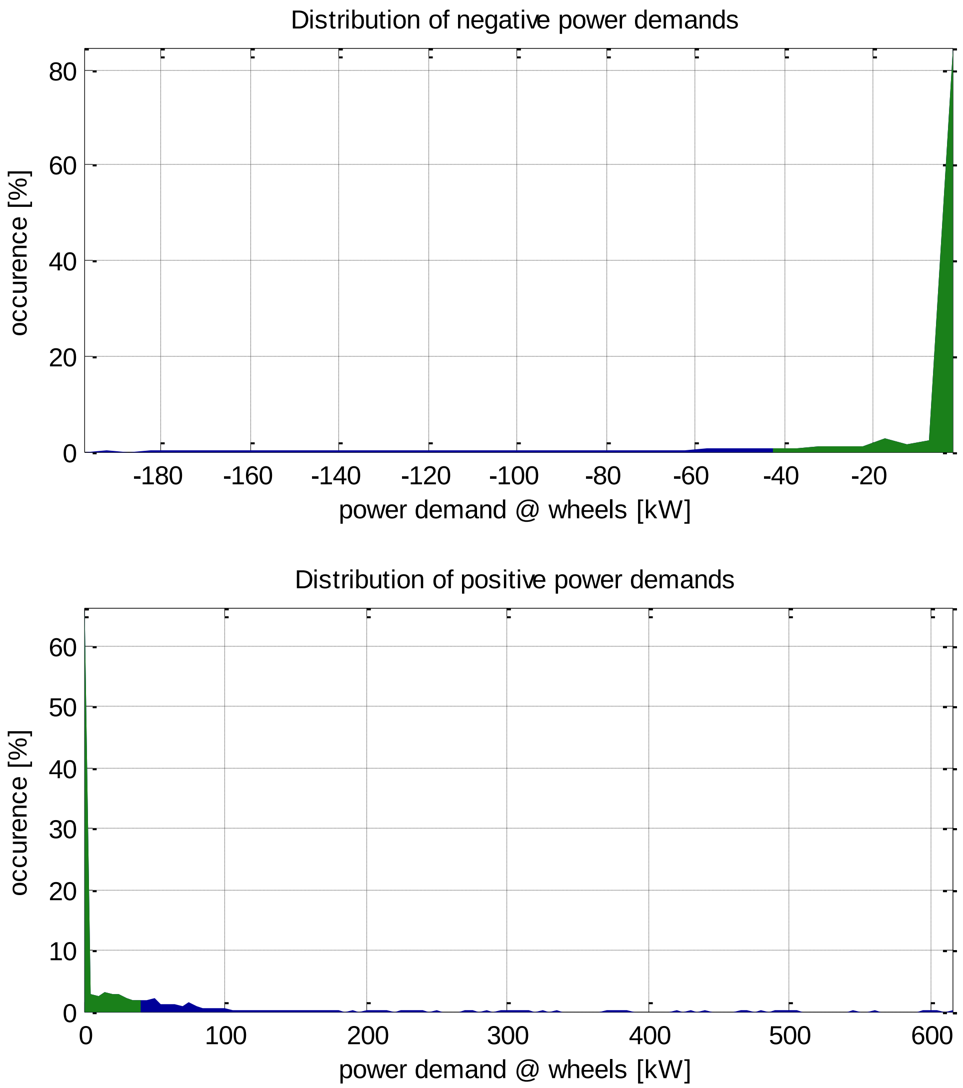

Figure 6 Distribution of negative power demand at the wheels. The part indicated in green visualizes the capability of the electric machine in the DAF LF.

Distribution of power demands at the wheels is depicted in Figure 6. It appears that the electric machine is power-wise capable of recuperating kinetic energy in 95.6 % of the time during the DAF cycle, i.e. negative power demands smaller than -44 kW, at which the electric motor power is rated, do occur only a few times. The amount of energy that can be recuperated during the complete cycle is 2.9 kWh. The battery mounted in the DAF LF hybrid truck is rated at a capacity of 1.9 kWh. The battery capacity is thus too small to store the complete amount of kinetic energy that can be recovered during the cycle. However, the amount of energy that may be recuperated during a single slow-down does not exceed 0.3 kWh, which means that if the stored energy in the battery is used when accelerating, the battery is sufficiently large.

When considering the positive power demands, it becomes clear that power demands up to 100 kW occur regularly. The electric motor can provide up to approximately half the required traction power, offering plenty degrees of freedom for changing the operating point of the internal combustion engine.

3.2.2 Volvo 7700

The output of the PCM for the Volvo 7700 on the Hybrid city bus cycle is depicted in Figure 7, including the speed profile of the cycle. The vehicle payload is set to 55% of the maximum payload mass.

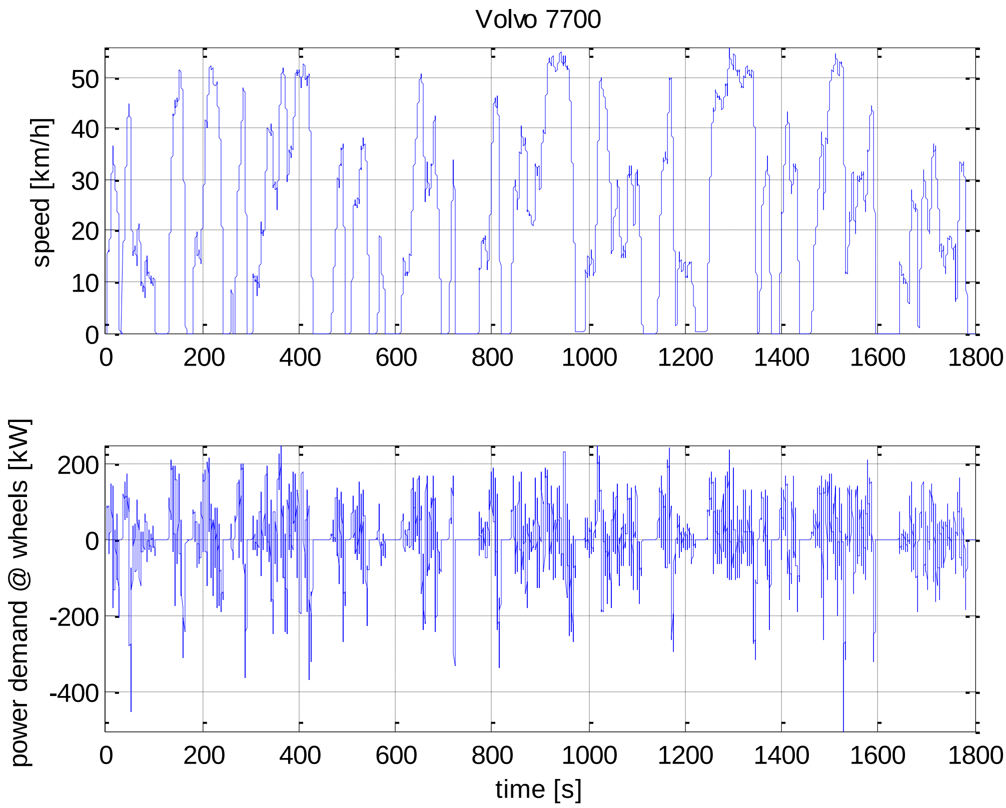

Figure 7 Volvo cycle and corresponding power demand at the wheels

Multiple negative power demand peaks are visible during some deceleration phases. This is caused by relative high decelerations in combination with a relative high vehicle weight.

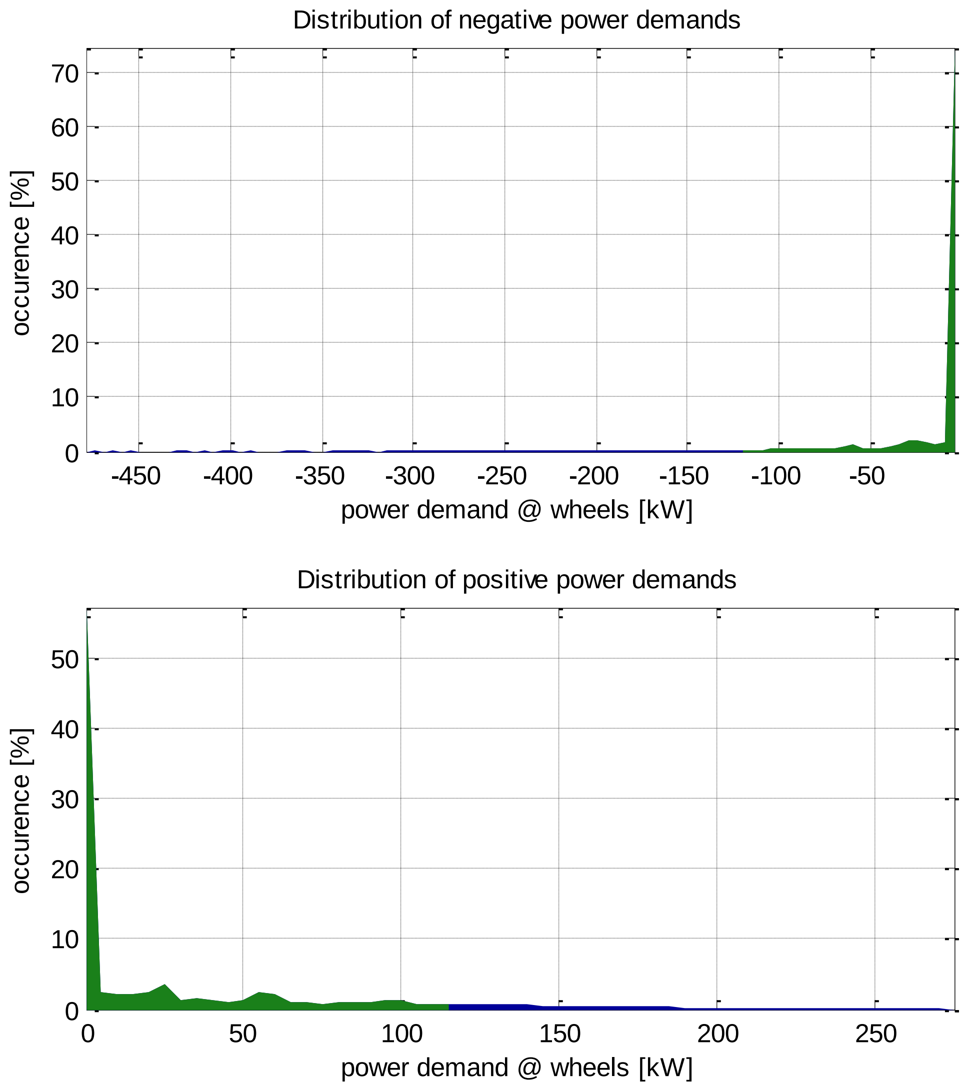

Figure 8 Distribution of negative power demand at the wheels. The part indicated in green visualizes the capability of the electric machine in the Volvo 7700.

Distribution of power demands at the wheels is depicted in Figure 8. It appears that the electric machine is power-wise capable of recuperating kinetic energy in 94.6 % of the time during the Hybrid City Bus cycle, i.e. negative power demands smaller than -120 kW, at which the electro motor power is rated, do occur only a few times. The amount of energy that can be recuperated during the complete cycle is 10.0 kWh. The battery mounted in the Volvo 7700 hybrid bus is rated at a capacity of 4.2 kWh. The battery is again not capable of storing all energy that can be regenerated during the cycle. The possible energy recuperation of individual slow-down periods does not exceed 0.5 kWh, meaning the battery capacity is sufficiently large if the stored energy in the battery is reused when accelerating.

The distribution of the positive power demand shows that most power demands are beneath 180 kW. The electric motor rated at 120 kW allows for a fair amount of freedom when choosing the operating point of the internal combustion engine during accelerations.

3.2.3 Iveco Daily

The output of the PCM for the Iveco Daily on the Urban Hybrid distribution truck cycle is depicted in Figure 9, including the speed profile of the cycle. The vehicle payload is set to 55% of the maximum payload mass.

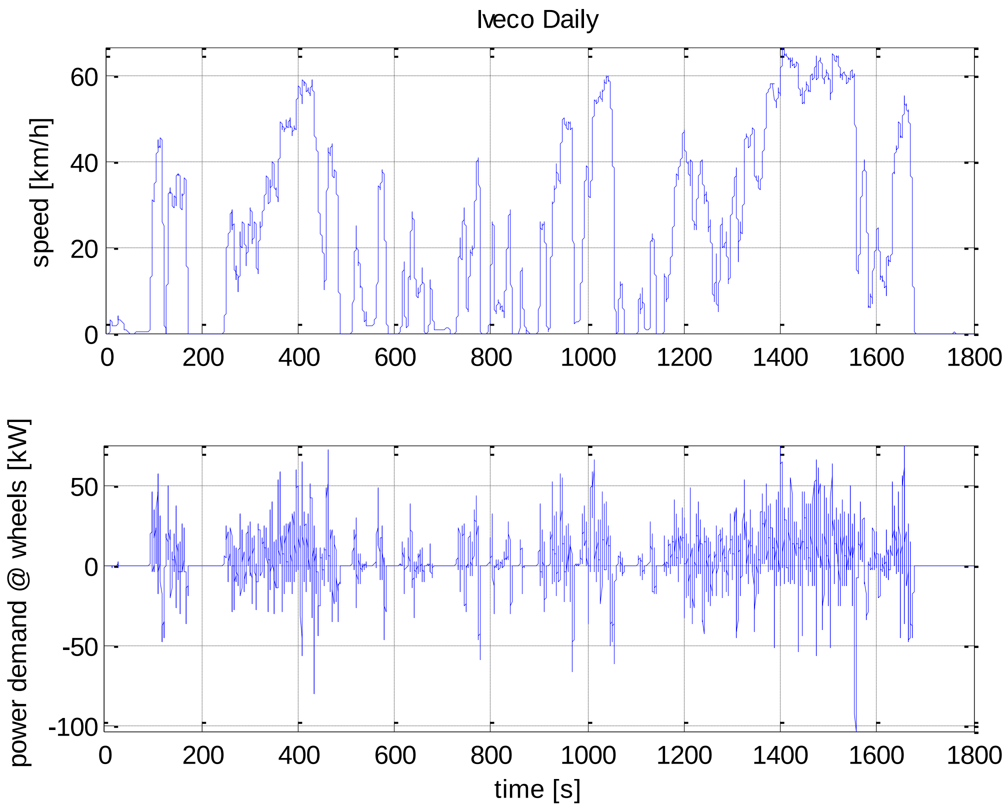

Figure 9 Iveco cycle and corresponding power demand at the wheels

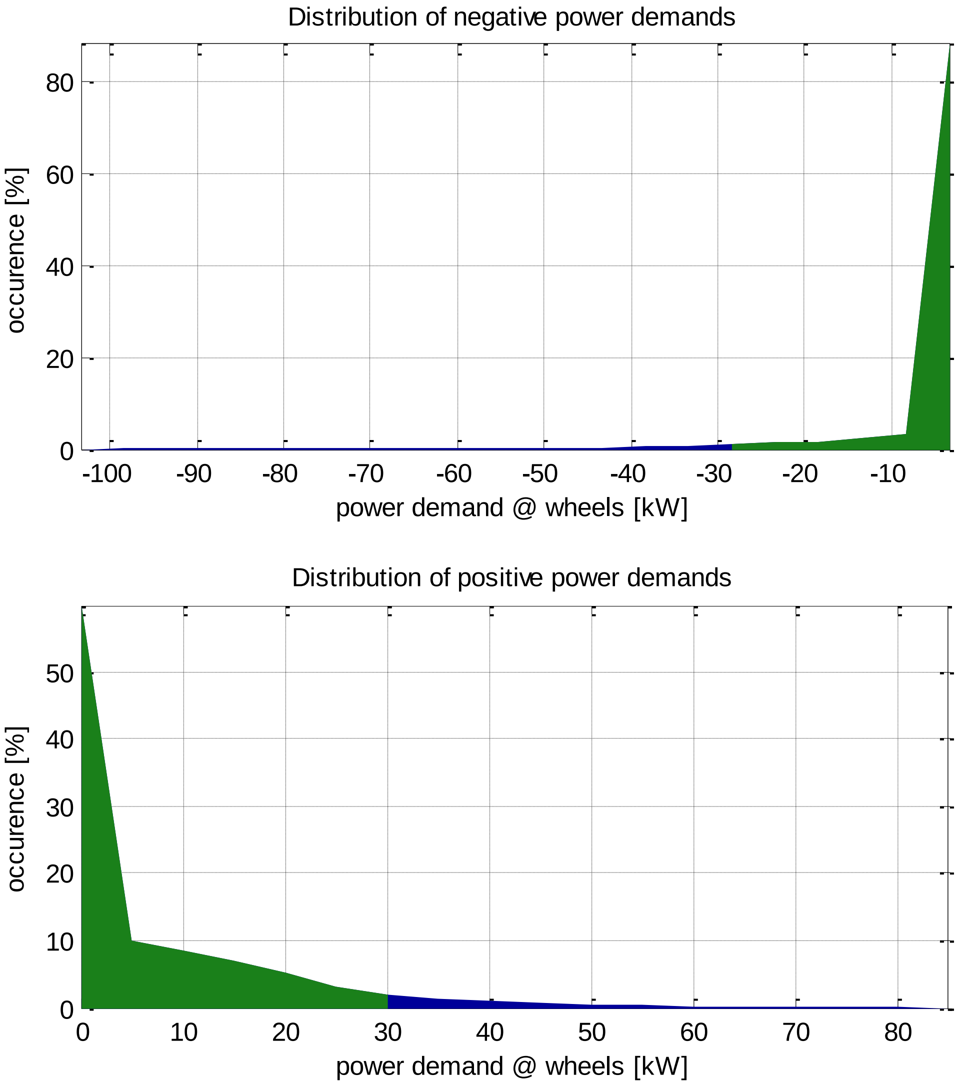

Figure 10 Distribution of negative power demand at the wheels. The part indicated in green visualizes the capability of the electric machine in the Iveco Daily.

Distribution of power demands at the wheels is depicted in Figure 10. It appears that the electric machine is power-wise capable of recuperating kinetic energy in 97.9 % of the time during the Urban Hybrid Distribution truck cycle, i.e. negative power demands smaller than -32 kW, at which the maximum power of the electro motor is rated, do occur only very few times. The amount of energy that can be recuperated during the complete cycle is 1.33 kWh. The battery mounted in the Iveco Daily hybrid van is rated at a capacity of 2.38 kWh. The conclusion can be drawn that the battery in the Iveco Daily hybrid is more than capable of storing all energy that can be recuperated during the cycle.

During accelerations and driving at constant speed the electric motor of the Iveco Daily is sufficiently powerful to create a substantial amount of freedom in those situations.

3.3 Performance Comparison

The study examined how the power rating of the electric machine affects the ability of recuperating kinetic energy during the presented drive cycles. Figure 11 depicts the percentage of energy that can be regenerated as a function of the power rating of the electric machine. The lines represent the percentage of energy that could be regenerated at different installed power ratings. The power ratings of the electric machines currently installed in the hybrid vehicles are indicated by the dot on the line.

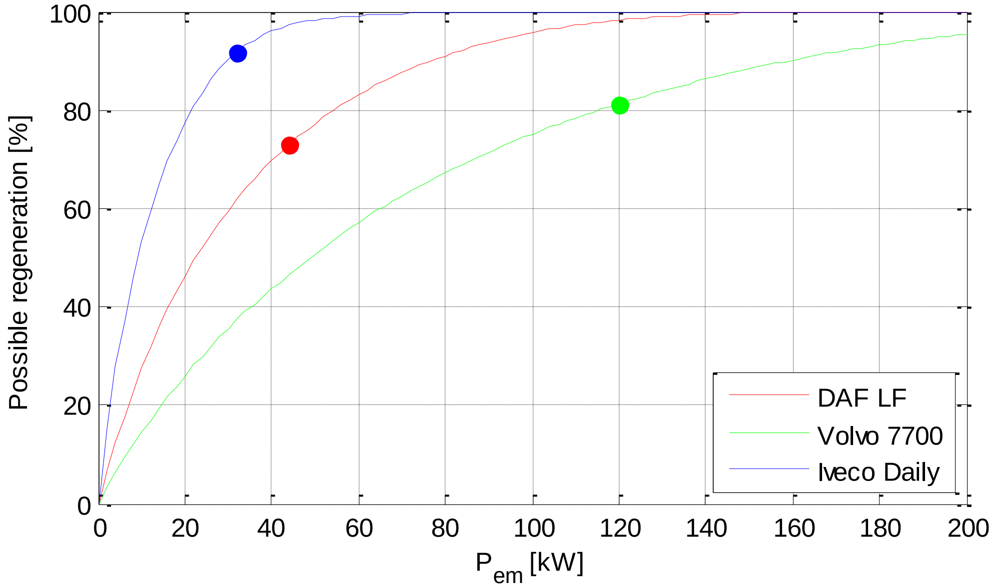

Figure 11 Electric machine power rating versus energy recuperation capability

It appears that for the different vehicles, the same level of possible regeneration of kinetic energy is reached for different power ratings of the electric machine. By increasing the power rating, more energy could be regenerated. Naturally, the differences between the vehicles are mostly the result of the differences in vehicle weight. If the result is normalized for vehicle weight, the outcome is as displayed in Figure 12.

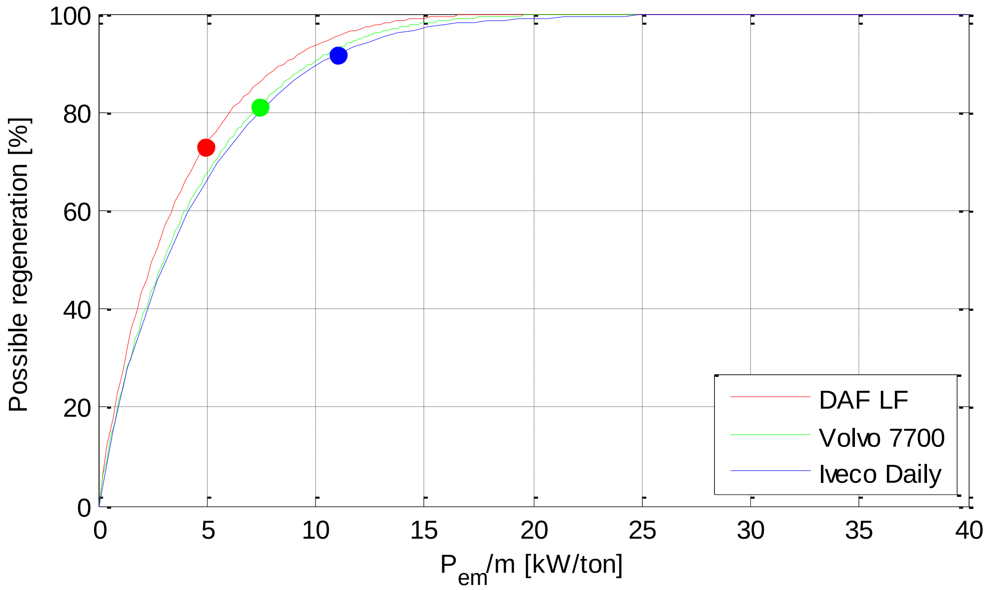

Figure 12 Electric machine power rating normalized by vehicle mass versus energy recuperation capability

From Figure 12 it becomes clear that when normalizing with respect to vehicle mass, the energy recuperation capability curves are very similar. This makes sense, because the remaining differences between the vehicles are the factors concerning air drag, the rolling resistance and the differing drive cycles. Note that also the brake and (dynamic) weight distribution will also influence the results, but these aspects are not taken into account as mentioned in the approach.

4 Component Functionality

Based on the results of SP2000 in which research and development is done for heavy duty hybrid e-auxiliaries, concepts in [4] and [5] will be described in this chapter. In general, the maturity and availability of e-auxiliaries for heavy duty vehicles is low, compared to passenger vehicle e-auxiliaries, where electric hybrid vehicles are already introduced to the market on a large scale. Electrified auxiliaries are common good due to the greenhouse gas emission targets that were introduced. It introduced a challenge to get the least amount of CO_2 emissions. In European member states, nationwide incentives were offered to vehicles with the lowest CO_2 labels. The heavy duty industry could make a benefit out of this developed CO_2 saving technologies and strategies for their hybrid electrical vehicles, but also for conventional vehicles. Advantages and challenges will be described per auxiliary across the vehicle classes in the HCV project and which effect the auxiliaries have on the drive cycles.

4.1 *Across Vehicle Classes*

The four types of vehicles in the HCV project, fit in the classes defined in Section 2.3 ‘Scope of Vehicle ’, as stated in Table 5. The vehicles in the HCV project fit in heavy duty classes truck and bus. The components used for those classes will be compared with the components identified in [4] and [5]. If appropriate, components already present in passenger cars will be involved. The components are air-conditioning, air-compressor, power steering, heating, braking. For each of the auxiliary components a simulation approach on the components functionality per class is given.

Table 5: Vehicles in the HCV project and the corresponding class and sub classes

Vehicle	Class	Sub classes
DAF LF	Truck, 4x2, Rigid, GVW 3.5-7.5 ton	-
Volvo 7700	Bus, City Class I	Heavy Urban, Urban, Suburban
Iveco-Altra	Truck, 4x2, Rigid, GVW 3.5-7.5 ton	-
Solaris Urbino	Bus, City Class I	Heavy Urban, Urban, Suburban

Air-Conditioning

Electrification of the air-conditioning system will mean that the main component, the compressor, is electrically driven. A third option instead of the compressor being solely electrically or mechanically driven is a compressor that could be driven both mechanically and electrically.

The air-conditioning system layout and performance is dependent on the cooling capacity requirements and can vary a lot when using it for cooling a truck cab, van, bus driver compartment or a complete bus. For small compartments which require less cooling capacity, electrified air-conditioning systems used in passenger vehicles today could be used on a hybridized HD vehicle. Advantages are that the maturity of the product is already high and it complies with automotive standards (passenger cars). For sure there are also practical challenges to overcome like voltage levels, control, packaging, communication, etc.
Looking at larger cooling capacities than covered in passenger vehicles, only project specific solutions were found. In these solutions, industrial electric motors were selected and were engineered into a frame or construction to drive a standard compressor. Advantages would be that for each requirement there will be a specific solution that would fulfill the requirements. Challenges to overcome for usability in heavy duty hybrid trucks are for

example costs, engineering effort, complying to automotive standards, reliability and efficiency.

Air Compressor

An air compressor is not used in passenger cars as much as in the heavy duty vehicle industry, since heavy duty vehicles use compressed air for suspension and braking systems, whereas passenger cars use compressed air systems only for suspension on luxury cars or cars with special comfort needs. An electrified air compressor is not directly needed for stop-start operation when stopping for example at a traffic light, but could be required during only electric driving without using the engine for safety reasons (i.e. braking).

An electrified air compressor for automotive has not been found in [4]. Disregarding the type of the air compressor (vane, screw, piston) a solution was given to make use of existing electrically driven industrial air compressors. Advantages are the availability of different sizes, types and brands. Challenges to overcome are for example costs, engineering effort, complying to automotive standards, packaging, sizing, control, reliability and efficiency.

Power steering

Power steering applications for heavy duty vehicles are commonly a hydraulic pump driven by the engine, which provide hydraulic pressure to assist steering. For full electric driving, electrification of the power steering system could be realized with an electric motor driving the hydraulic pump (electric-hydraulic) or direct electrical assist (full electric). Main difference between electric-hydraulic and full electric is that the first one uses pressurized fluid (hydraulics) to assist the driver during steering and the full electric system only assists with an electric motor when a steering action is required. The electric-hydraulic system always uses some energy for the electric motor to drive the hydraulic pump to keep the system pressurized, unlike the full electric system which only uses energy when the driver is actually steering.

Both electro-hydraulic and full electric power steering systems are commonly present in passenger cars. System requirements and performance of such systems could not be interchanged directly with heavy duty vehicles. However, the technology and techniques could be used to design a designated heavy duty vehicle power steering system. Hydraulic only systems are especially problematic in buses, where hydraulic lines need to be routed from the back of the vehicle where the engine is located, to the front where the steering system is placed. An electrified power steering system is not directly needed for stop-start operation, but is essential during electric drive only with the engine shut off.

Advantages of the electro-hydraulic power steering system are the minor adjustments that have to be made to the existing hydraulic system and the flexibility of pump location. Challenges to overcome are for example costs, engineering effort, complying to automotive standards, packaging, sizing, control, reliability and efficiency.

Advantages of the full electric power steering system is the lack of hydraulic components, hydraulic oil, amount of components, energy saving (uses only energy when steering action is required). Challenges to overcome are for example costs, engineering effort, packaging and sizing.

Heating

The heating systems of vans, buses and trucks can vary a lot. Where van and truck cabins are often heated by the engine cooling system only, the heating system in buses is extended with a combustion heating device to heat up passenger and driver compartments.

Electrification of the extra heating capacity for buses or extra heating capacity for a van or truck can be done by heating up the coolant with a device that is similar to an electrical boiler.

Sizing can vary a lot between an extra heater for a van or bus. For small capacities, there are already special electrical heaters on the market for automotive applications. These heaters are often used in fully electrical vehicles, where there is no other heat source to heat up the driver and passengers. This kind of heaters can be necessary when the frequency and duration of stop-start and electric driving is increased, and the engine coolant is not sufficient anymore for heating the cabin space of a truck or van. Electrical heaters with the capacity of heating the passenger compartment of a bus are available on a small scale [4].

Electrical heating may be needed in hybrid trucks or vans where the engine cooling is not sufficient, however a combustion heating device could also be used. Advantages of electrified heaters compared to combustion heating devices are noise reduction and eliminating the heating specific emissions. Challenges to overcome are electric power capability of the battery pack, control, routing, reliability and efficiency.

Braking

One of the biggest energy and fuel saving advantages of hybrid electrical vehicles is the fact that the vehicle deceleration energy can be recuperated with the electric motor acting as a generator and storing the energy back in the traction battery. Theoretically there is a lot of deceleration energy present in real world driving that could be recuperated. However, there are a lot of limitations like the maximum braking force on the driven wheels, the capacity of the electric motor (see also chapter 3), the non-driven wheels braking forces, acceptance of the driver and last mentioned but not least drivability. Electrifying the brake system will mean that the brake pedal movement is partly decoupled (not fully because of safety reasons) from the actual hydraulic/pneumatic brake system. This decoupled part is covered with a ‘pedal feel simulator’ providing a normal brake pedal feel to the driver. A first movement of the brake pedal can in this case be used for ‘electrical braking’ (recuperating brake energy).

In present passenger cars, not necessarily hybrid electric or full electric vehicles, special brake pedal and brake servo systems are developed to utilize deceleration movements as much as possible and recuperating the energy with an electric motor, without actually using the friction brakes. For hydraulic brake systems used in passenger cars, LCV’s and some small trucks, there are several techniques and systems ready to use which are able to maximize the required drivers deceleration demand with electrical braking.

In [5] there were no systems identified that were available for pneumatic brake systems commonly found on HDV’s. Development of these systems could be beneficial because there is always a difference between the maximum theoretical recuperated energy and the actual recuperated energy. Minimizing this difference will maximize the fuel-efficiency of hybrid electric HDV’s.

Advantages of the electric braking system for hydraulic brake systems is that there is a lot of choice in existing systems which results in low costs and in some cases the relative large brake servo is not needed and saves space. Challenges to overcome are for example control, calibration and engineering effort.

For pneumatic operated brake systems, which enables recuperation of energy by the electric motor, challenges to overcome are for example costs, designing effort, engineering effort, packaging, sizing, control, reliability and complying to automotive specific standards.

4.2 Influence on drive cycle results

A theoretical approach, based on the working principle description in [4] and [5] is used to describe the effects that (electrified) components will have on the fuel economy of a vehicle driving a defined drive cycle (only longitudinal movement) like the designed drive cycles from chapter 2.4 Scope of Drive Cycles.

Air-conditioning
In typical vehicle drive cycle simulations and tests, the energy usage of the air-conditioning system is not always taken into account. In new, still under development, CO_2 certification procedures, the effect the system has on fuel economy is under consideration. Especially for systems with a large cooling capacity, the fuel economy with the system on or off will make a difference on CO_2 emissions and thus fuel economy. Hard numbers on the effect which an electrified air conditioning will have on fuel economy compared to the conventional mechanically driven version cannot be given. An electrified air conditioning system is more a kind of enabler to maintain functioning during stop-start and fully electrical driving with the engine shut-off (the actual fuel saving measures besides recuperating energy during deceleration). The system not working properly is affecting the driver convenience.

Air compressor
In typical vehicle drive cycle simulations the energy usage of the compressor is assumed to be constant (average consumption). During actual driving on the road or drive cycle tests with the complete vehicle, the energy consumption of the air compressor is included in the total fuel consumption of the vehicle. During driving, the energy needed to pressurize air and maintain a certain pressure has a typical on-off behavior. By electrifying the air-compressor, electric driving with the engine shut-off could be realized. Little is known on what the energy usage differences are between an electrically driven compressor and one that is driven directly by the combustion engine.

Power steering
After the introduction of the power steering system, a lot of effort has been spend in the past to minimize the energy usage needed to pressurize the power steering fluid. This resulted in a minimized energy consumption when no steering action is required. However, still the engine needs to operate to enable power steering. Looking at electric-hydraulic steering systems, the efficiency of the pump is not dependent anymore on the rpm range of the combustion engine. The electric motor efficiency can then be matched with the optimal pump efficiency.

Electric power steering systems where only electric power is used to help steering will only be activated when a steering action is needed. Electric steering assist is only using energy during steering, where the hydraulic system still uses some energy that goes to pump losses, and rotational losses (e.g. from the engine or electric motor driving the pump wheel continuously). An electric power steering system will consume less energy compared to a conventional hydraulic power steering system in a drive cycle as no steering action is required.

Same as for the e-compressor, the electric-hydraulic and electric power steering system is more a kind of enabler to maintain functioning during stop-start and driving fully electrical with the engine shut-off.

Heating
In typical vehicle drive cycle simulations and tests, the energy usage of an extra heating system is not always taken into account. In new, still under development, CO_2 certification procedures, the effect the system has on fuel economy is under consideration.

Normally, the heat losses of the engine are used to warm up the driver and passenger spaces in a truck or van without using extra fuel. Adding an extra electrical heating device or combustion heating device will result in more fuel consumption because this heat energy must be generated on top of the available engine cooling heat. With electrically powered heating devices, extra pollutants from emissions and noise are prevented and will make these systems from that point of view more beneficial than combustion heating devices.

Same as for the e-A/C, e-compressor and e-power steering an e-heater system is also a kind of enabler to maintain functioning during stop-start and driving fully electrical with the engine shut-off.

Braking
As said before, maximizing the amount of electrically recuperated energy from vehicle deceleration will maximize fuel economy in a drive cycle. As stated in chapter 3 and this chapter the size of the electromotor, battery specs, an optimized electrically actuated brake system and the control, often referred to as energy management, will eventually define the maximum fuel savings on a drive cycle or in real world driving. Because fuel savings rely on several systems together and affects the drive characteristics, effort is needed to maximize the efficiency, prevent unexpected brake pedal feeling and unreliable or unexpected vehicle behavior.

Apart from the other electrified auxiliaries, which are more enablers for stop-start and electric driving operation, this electrification optimization will directly save energy and thus fuel on a drive cycle.

5 Conclusions and recommendations

5.1 Component commonality

Commonality is described as the fact of being common to more than one individual. For the components discussed in this report, this will mean the interchangeability of different components in the vehicle classes or currently available products from the passenger car and light commercial vehicle industry. This is graphically depicted in Table 6 and explained further on.

Table 6: Usability of electrified auxiliaries from passenger cars and LCV's. Dark green means that e-components are used already on production models. Light green, high usability in the class, yellow is possible usability, orange is usability not possible, blank is not (yet) available

Electrification of…		Passenger cars and LCV's	Truck		Bus	
			Light	Heavy	Driver compartment	Passenger compartment
A/C		from EV, HEV				
Air-compressor						
Power steering	electric-hydraulic					
	full electric					
Heating		from EV, HEV				
Braking (recuperating energy)			Hydraulic systems	Pneumatic systems		

Apart from the air-conditioning system (for cooling capacities covered in passenger cars and LCV's), the air-compressor, hydraulic steering pump and air-conditioning system (for cooling capacities not covered in passenger cars and LCV's), the current used parts could be electrified by adding an electric motor to drive those components individually or together by using a mechanical connection (belt, chain, etc) at a defined electric motor speed. By using existing components the interchangeability of the currently available components will remain. For the vehicle classes trucks and vans it is easier to couple different components to one electric drive compared to a bus, where engine and air compressor, steering system, A/C and heating system are spread around in the available space as modules. In Table 6 this is indicated by the thick borders.

Electrified air-conditioning systems and electrical heater systems (for cooling and heating capacities covered in passenger cars and LCV's) are already in use with a wide range of dimensioning classes, both for hybrid electric and full electric vehicles. These components could be used in heavy duty hybrid vehicles with less effort compared to designing the components from scratch.

Full electric power steering systems are commonly used in passenger cars and LCV's but are not yet capable of dealing with the high steering forces present in HDV's [5].

Braking systems for hydraulic actuated brakes, which have the capability of maximizing the recuperation of kinetic and potential energy when operating the brake pedal, are already available from the passenger and LCV industry. These systems could be used on HDV's (with hydraulic actuated brakes). Such systems were not yet found for pneumatic actuated brake systems which could maximize the recuperation of energy and thus increasing the fuel efficiency. Actual potential of the maximum amount of energy that could be recuperated with the given specs of the hybrid vehicles in the HCV project, is projected in chapter 3.

Electrification of the components (individually or as a set) will enable stop-start operation and electric driving with the engine shut off, without a lack of comfort (A/C and heating) and safety (steering and braking). Apart from efficient recuperation of energy (electrical actuated braking) during deceleration, stop-start and electric driving operations will also enhance fuel consumption reduction in CO_2 certification drive cycles as well as in real world driving.

5.2 Component standardization

Standardization is described as the process of establishing a technical standard. This can be a test method, process, procedure, specification, etc. For the components discussed to this point, this will mean the challenges that must be faced when using the proposed electrified components of the technology evaluation done in SP2000 [4], [5] on hybrid electric heavy duty vehicles. To give an indication on the weight of the challenges and thus effort to standardize, see Table 7.

Table 7: Weight of effort to standardize the e-auxiliaries. Green indicates little effort, yellow medium effort, orange much effort

Standardization of electrified…		Truck		Bus	
		Light	Heavy	Driver compartment	Passenger compartment
A/C					
Air-compressor					
Power steering	electric-hydraulic				
	full electric				
Heating					
Braking (recuperating energy)		hydraulic	pneumatic		

Looking at the actual electrification of components (individually or group) challenges to overcome are for example packaging, routing, engineering, control, reliability, durability, efficiency, safety aspects, fault handling, communication protocols and complying to the desired automotive standards. If these challenges are picked up with the goal of designing a modular electrified powertrain and auxiliaries system, a lot of effort can be saved when the system is interchangeable between different vehicle classes and types and can cope with different system set-up and component sizes.

E-A/C, electro-hydraulic power steering, e-heating and e-braking systems that are already present on the passenger and LCV's industry offer a good possibility for usage in hybrid electric heavy duty vehicles. Condition for usage are overlapping specifications and requirements. In many cases the specifications and requirement will differ much (A/C, heating, steering and braking for buses and steering and braking for trucks). Vans and small trucks could benefit the most due to comparable or close to comparable specifications and requirements of passenger car and LCV's.

Where possible, existing standards, processes, methods, engineering, specifications and functionality of the 'under' designed components could be used as a basis to adapt the systems to heavy duty vehicle standards.

Annex

Annex A: HCV project vehicle specs

Hybrid generation	Early 2e generation	Early 2e generation	Early 2e generation	1e generation
Brand	**Iveco-Altra**	**DAF**	**Volvo**	**Solaris**
Type	**Daily Ecodriver 35S12**	**LF45**	**7700 hybrid**	**Urbino 18 hybrid**
Additional	#4, 6	#10, 11, 12	#2, 3	#7, 8, 9
				
Class	truck	distribution truck	bus	bus
GVW [kg]	3,5 ton and 5 ton	12 ton	18900	28 ton
Curb weight [kg]			12700	
Dimensions LxWxH [m]	6m x 1,8m x 3,3m		12m x 2,55m x 3,2m	
Passenger/load capacity [-]/[kg]			95 persons	51-161 persons
Hybrid type	parallel	parallel	parallel	serie-parallel
date of presentation			series prod. April 2010	
General specifications				
maximum speed [km/h]				
max speed electric [km/h]			15km/h	
range [km]				
full electric range [km]		2km	1km	
ICE	2,3l F1A HPI	4,5l Cummins ISBe5	Deutz 5l Euro 5	6,7l Cummins ISBe5 250B
#cilinders [-]	4, line	4, line	4,line	
Fuel	diesel	diesel	diesel	diesel
Max power @ rpm kW@rpm	85kW @ 3600rpm	118kW @ 1900rpm	160kW	180,5 kW
Max torque @ rpm Nm@rpm	270Nm @ 1800rpm	600Nm @ 1200-1800rpm	800Nm	1008Nm @1200-1600rpm
Meets regulation	EURO 4	EURO 5, EEV		EURO 5, EEV
Additional				
EM1	Bosch	EATON, UQM Technologies	Danahere	Allison transmissions
EM1 type	AC synchronous	C permanent magnet synchronous, 3phas	AC permanent magnet synchronous	concentric AC induction 3-phase
EM1 nominal power [kW]	32kW	26kW	70kW	
EM1 peak power [kW]	60kW	44kW /2600rpm	120	100hp
EM1 nom torque [Nm]			400	
EM1 max. torque [Nm]	280Nm	420Nm	800	
EM1 specific power [kW/kg]				
EM1 efficiency [%]				
EM2				concentric AC induction
EM2 type				
EM2 nominal power [kW]				
EM2 peak power [kW]				100hp
EM2 max. torque [Nm]				
EM2 specific power [kW/kg]				
EM2 efficiency [%]				
Battery	Johnson Controls		Magna	
technology	NiMH/ Ni-cadmio	Li-ion/Li-Mn	Li-ion / Fe phosphate	NiMH, gel-based
capacity [kWh]	1,4kWh	1,9kWh	4	
[Ah]	4 Ah	5,5Ah	7,6	
Nominal voltage [V]	340V	340V	630	400V
energy density [Wh/kg				
total weight [kg]		100 kg	350kg	437kg
battery life [years]				6 years
			water cooled	
			active temp. controlled	
		100x3,4V / nominal 340V	indiv. Cell charge control	40x6x…V
Transmission	ZF 6as400	EATON	Volvo I-shift AT2412C	Allison Transmission Ev-drive
Auto/manual	Auto	Auto	Automatic splitter	EVT/power-split
Amount of gears	6	6	12, close-ratio	3 planetarian gearings
Clutch	Dual-clutch	Single-clutch		two synchronic
Weight	70kg (dry without aux)		369kg (with retarder, no oil)	428kg (wet)
Additional	ZF control unit			Allison Transmission Ep50
Inverter/Converter			Danahere/Danahere	Allison Transmission
DC-AC			280A max current	430-900V/150kW AC
DC-DC			max 11 A high voltage side	
Converter specific power [kW/kg]				
Converter efficiency [%]				
Converter specifications			Energy converter DC/DC 600V/24V 7,5kW	Dual power inverter module DPIM, oil cooled, combined with Ev-drive, AC-DC rectifier, DC-AC inverter, 75kg, 430-900VDC, 150kWcontinuous 3 phase AC, CAN/ J1939 communication All locks have High Voltage Interlock Loop
Electronic control unit	FPT & Magneti Marelli			Allison Transmission
Hybrid system				1000/2000/2400 series
ICE	Bosch EDC16C39			
Transmission	ZF transmissions			
Options				
Brake energy recovery	yes	yes	yes	yes
electrified steering pump	yes	no	yes	
electrified cooling fan	yes	no	yes	
electrified air compressor		no	yes	
electrified doors				
electrified airco		no airco	yes	
electrified waterpump	yes	no		
stop & start	yes	yes	yes	
EV launch capability	yes	yes	yes	

Annex B: List of sources

1. **Hill, N. et al.** *Reduction and Testing of Greenhouse Gas (GHG) Emissions from Heavy Duty Vehicles Lot 1: Strategy.* Didcot : AEA, 22 Feb 2011.

2. **ACEA Workgroup CO2-HDV.** *White Book CO2 declaration procedure HDV, Status October 2011. Bruxelles : Association des Constructeurs Européens d'Automobiles (ACEA)*, 3 Nov 2011.

3. **Hausberger, S. et al.** *Reduction and testing of Greenhouse Gas Emissions from Heavy Duty Vehicles – Lot 2: Development and testing of a certification procedure for CO2 emissions and fuel consumption of HDV*, 21 Nov 2011.

4. **Ferraris, W. et al.** *Technology evaluation report for auxiliaries for e-A/C, e-compressor and e-heating – D2200.1*, Nov 2011.

5. **Szkucik, D. et al.** *Technology evaluation report for electrically powered steering servo and electrical actuated mechanical brakes* – D2300.1, March 2012.

Annex C: List of abbreviations

HCV	Hybrid Commercial Vehicle
ACEA	European Automobile Manufacturers Association
HDV	Heavy Duty Vehicle
LCV	Light Commercial Vehicle
A/C	air-conditioning system