




**GT-SUITE Users Conference 2005**  
**Novotel Frankfurt Airport 1 – October 10, 2005**

**Layout of a power split hybrid powertrain using GT-Drive**


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Thank you John for the kind introduction.  
Good morning ladies and gentlemen!



Layout of a power split hybrid powertrain using GT-DRIVE



## Layout of a power split hybrid powertrain using GT-Drive

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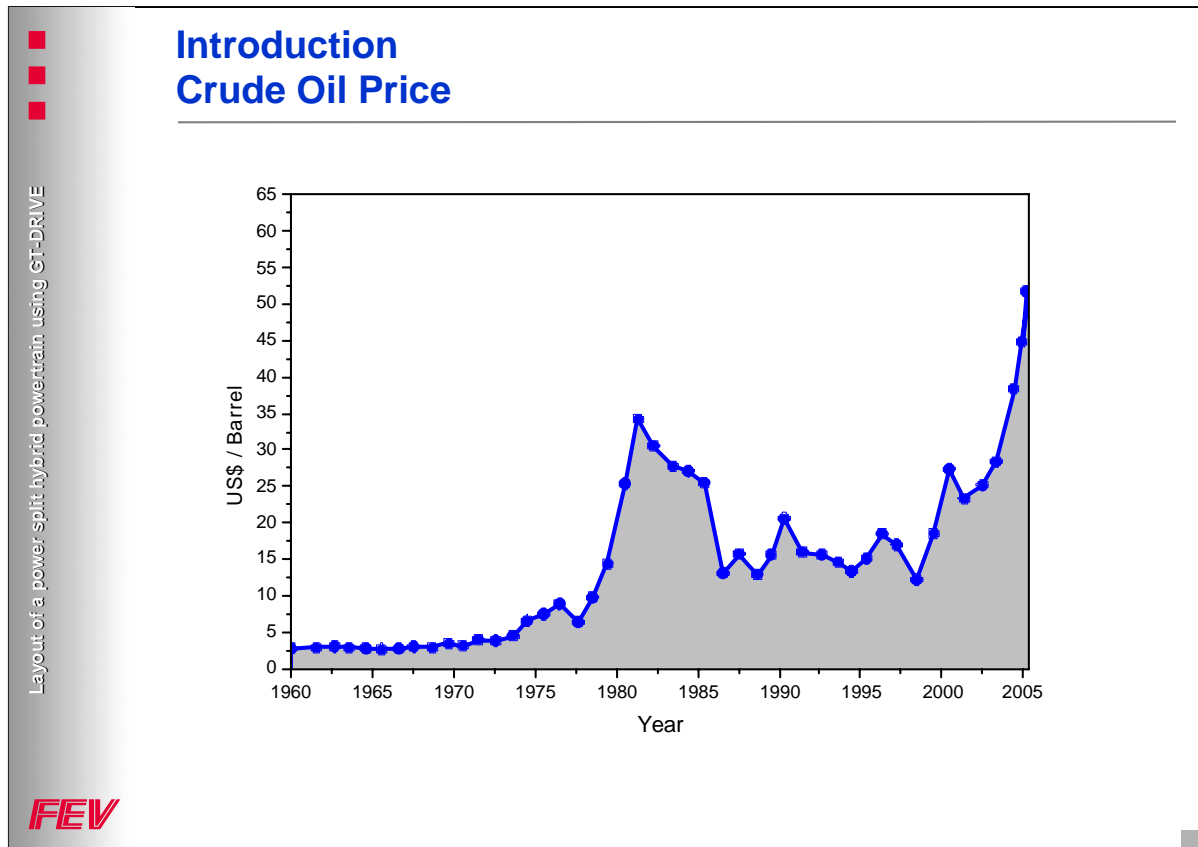
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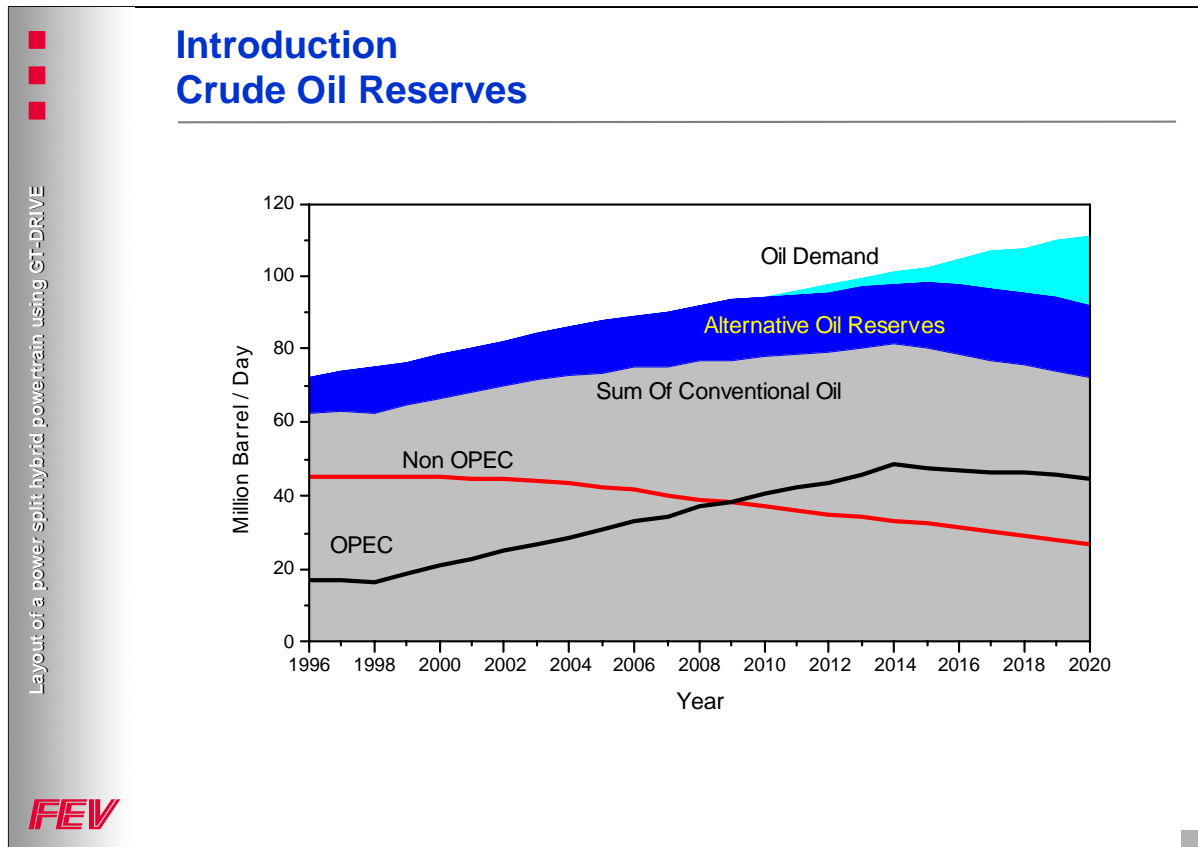
With this presentation I would like to give a short overview about the aim and potential of HEV vehicles.

I will introduce some different hybrid concepts with emphasis on the layout of a power split hybrid concept. I will point out the boundary conditions and limits for a power split hybrid vehicle and give an example for the layout and optimization of this concept.

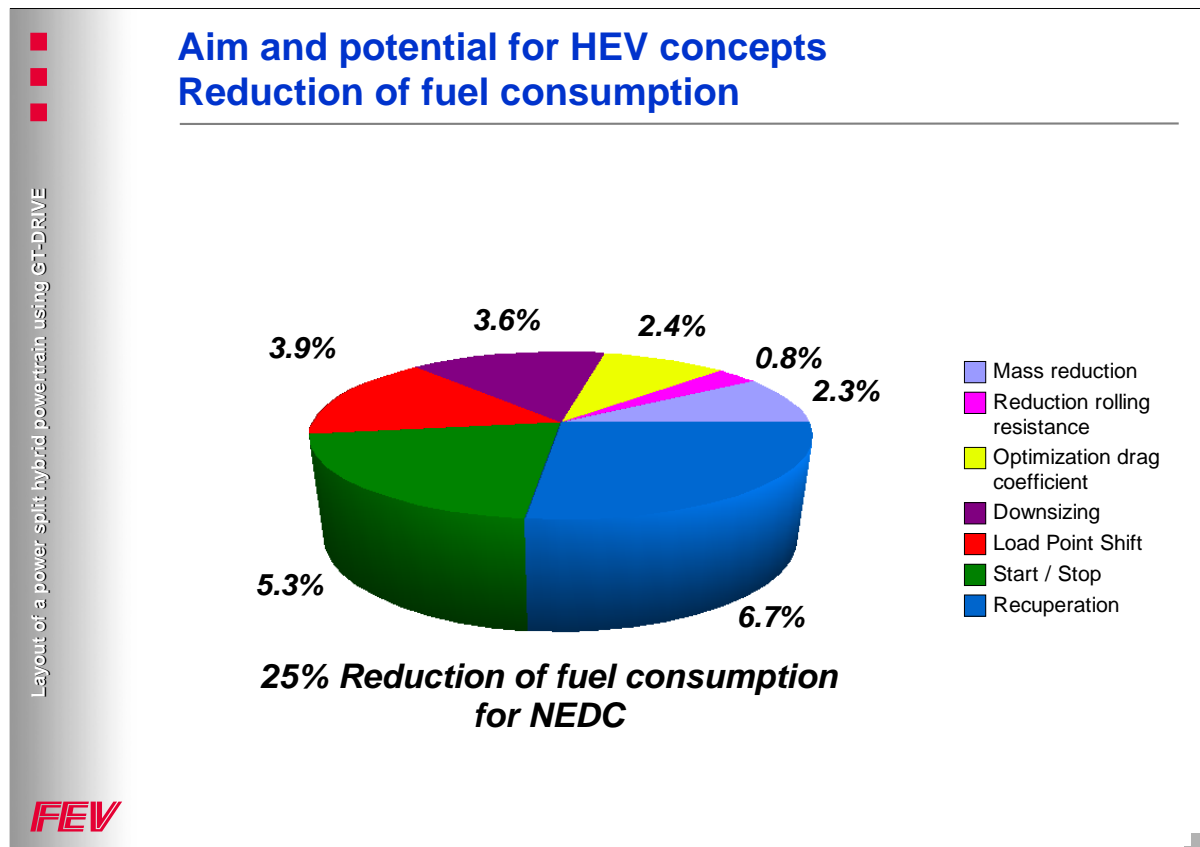
At the end, I will summarize the presentation and conclude.



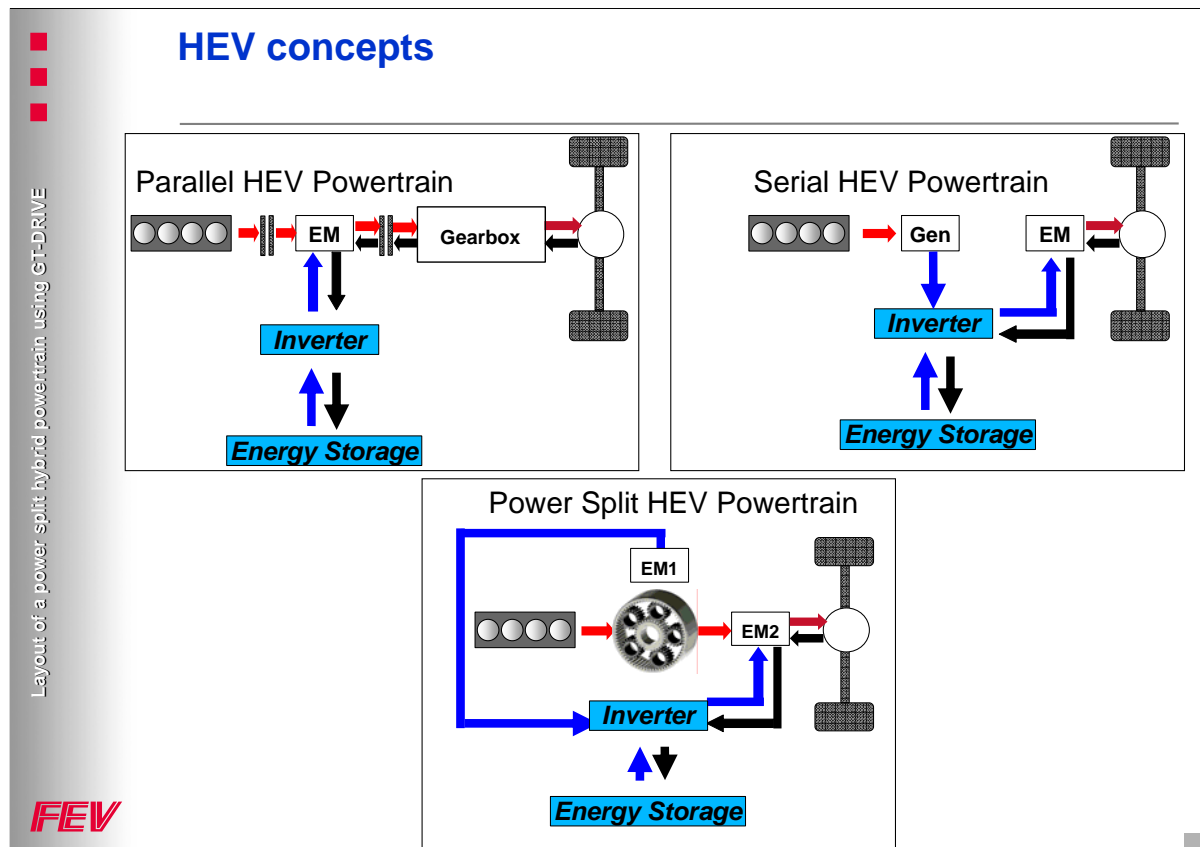
Looking at the trend of the crude oil price starting from 1960, it is visible that the increased demand coupled with the limited oil production and resources during the last 4 years lead to a sharp increase in price.



Regarding oil production and demand it can be seen that within a short period of time there will be a gap between demand and production. This fact and the emissions legislation lead to the demand for vehicle concepts with lower fuel consumption and emission output.

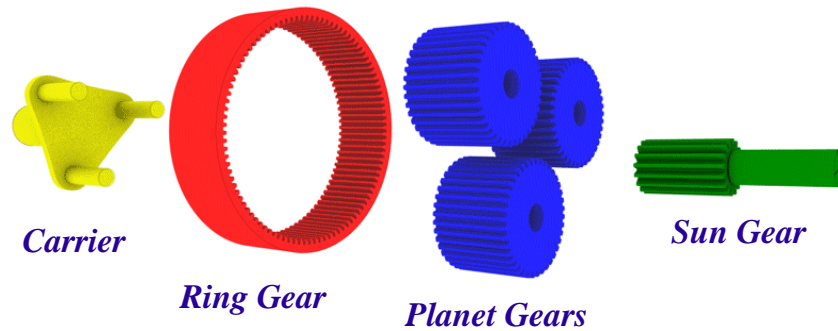


The overall potential for reducing the fuel consumption in NEDC driving cycle by using a HEV concept is about 25%. The main potential and the main aim for HEV concepts is load point shift, start / stop strategy and recuperation, which means storing the braking energy for its later use in acceleration mode.



The main HEV concepts are the parallel hybrid, the serial and the power split hybrid concept. For the serial concept, engine and powertrain are coupled only by wire. The parallel hybrid concept uses the electrical motor on the same driveshaft as the combustion engine. To enable start / stop and electrical driving, additional clutches have to be used. The power split powertrain is currently the only concept in volume production. Due to the fact that this is the most complex system and the variable factors are multifaceted, this system will be presented in more detail in the following.

## Power split HEV concept The Planetary Gear



$$i_0 = \frac{D_{\text{Sun}}}{D_{\text{Ring}}}$$

$$i_1 = \frac{i_0}{1 + i_0}$$

$$i_2 = \frac{1}{1 + i_0}$$

$$i_1 = \frac{|M_{\text{Sun}}|}{|M_{\text{Carrier}}|}$$

$$n_{\text{Carrier}} = i_1 \cdot n_{\text{Sun}} + i_2 \cdot n_{\text{Ring}}$$

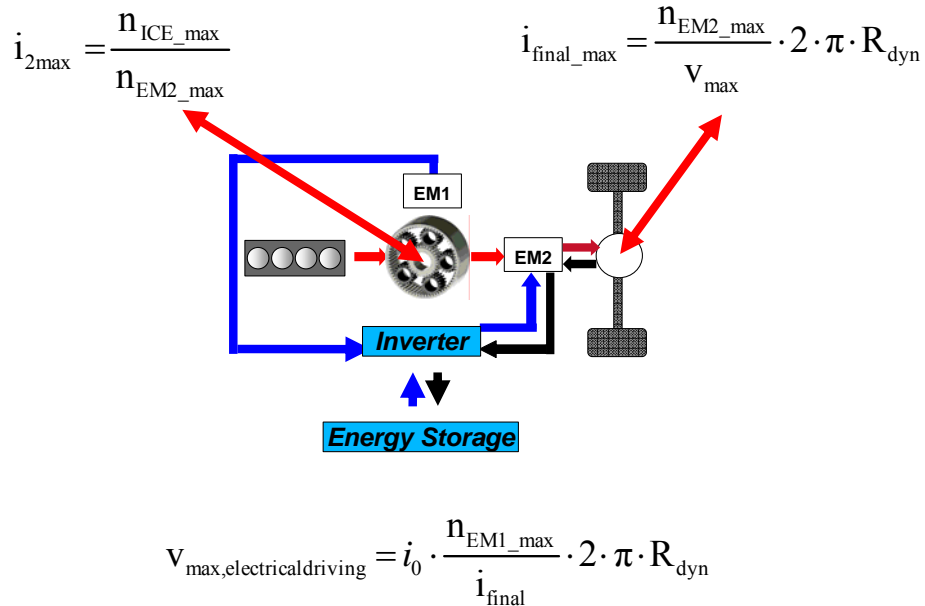
$$i_2 = \frac{|M_{\text{Ring}}|}{|M_{\text{Carrier}}|}$$

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The heart of the power split hybrid concept is a planetary gear set, which can be used as an electrical continuously variable transmission. The planetary gear consists of the ring gear, the planet gears, the planet carrier, which combines the planet gears and the central sun gear. Usually the sun gear is connected to the first electric motor, which is mainly used for controlling the speed ratio for the electrical CVT. The carrier and the combustion engine are linked together and the ring gear is coupled with the second electrical motor and the final drive.

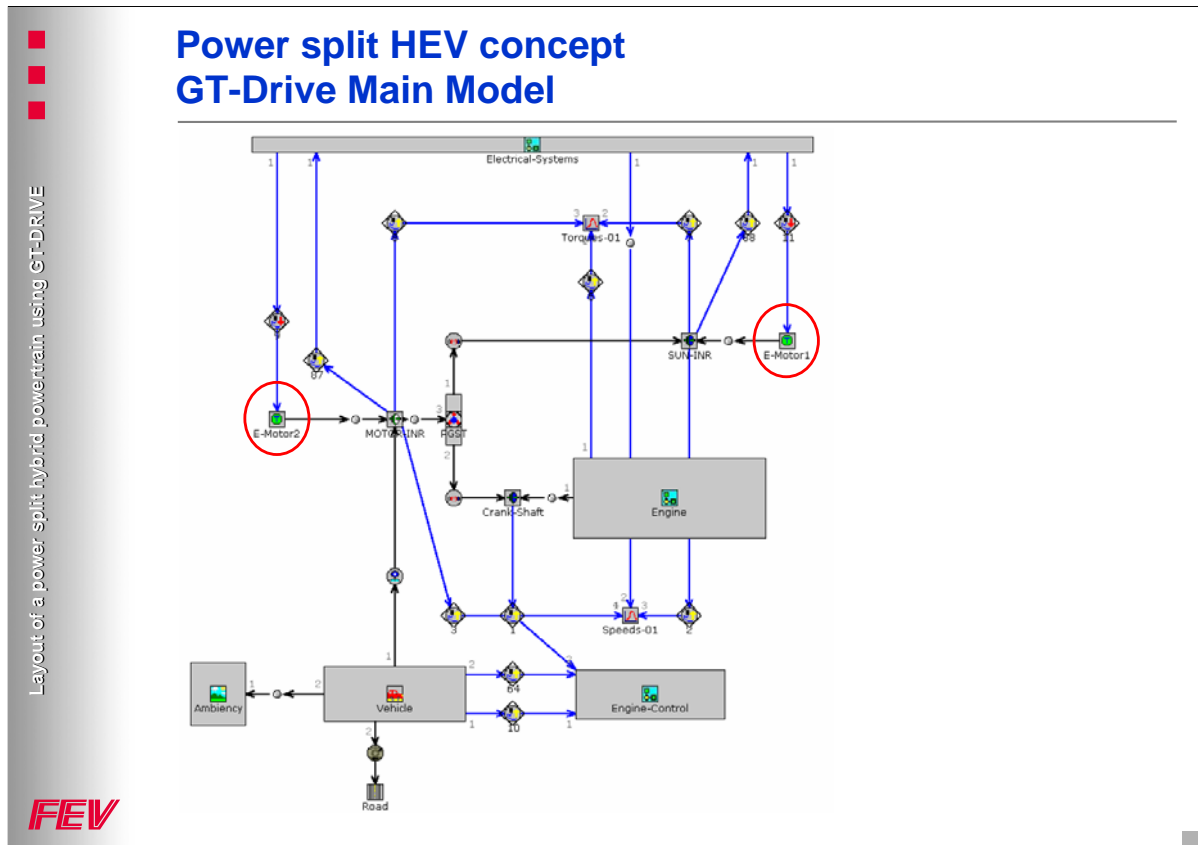
The kinematics of the planetary gear are defined with the ratio of sun and ring diameter or number of teeth. The speed ratios of the planetary gear can be divided in  $i_1$ , the ratio between sun and carrier and  $i_2$ , the ratio between ring and carrier. With a given ratio  $i_0$ , the speeds and torques for sun, carrier and ring are coupled with a fixed ratio.

## Power split HEV concept Limits for Layout



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The kinematic boundary conditions of the planetary gear define some boundary conditions for the layout of final drive and planetary gear. Additionally, the maximum vehicle speeds for electrical driving is defined by planetary gear layout and maximum speeds of the electrical motors.



Without simulating performance, the vehicle model for a power split HEV is quite simple. The possibility to simulate this concept with GT-Drive is given with the current version for the first time. In version 6.1 now a reliable model for the planetary gear set is available. The most complex task for the simulation of this concept is the electrical system and the operation strategy. Due to the fact that a complex control system for the operation strategy has to be implemented, the electrical motors are modeled with torque objects. This kind of modeling enables the user to get rid of the limitations of the electrical motor and battery objects.

## Power split HEV concept

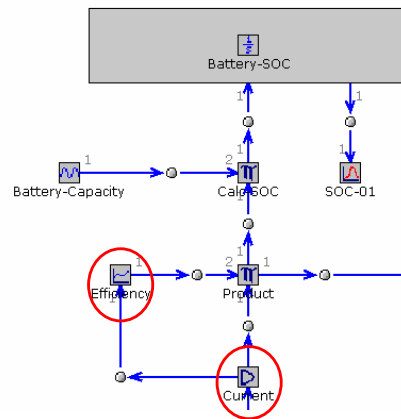
### Battery Model

Instantaneous electric charge  
of NiMH battery

$$Q_{ES} = Q_{ES\_0} + \int_{t_0}^t i_{NiMH}(t) \cdot dt$$

Instantaneous SOC of NiMH  
battery

$$SOC = \frac{Q_{ES}}{Q_{ES\_max}}$$



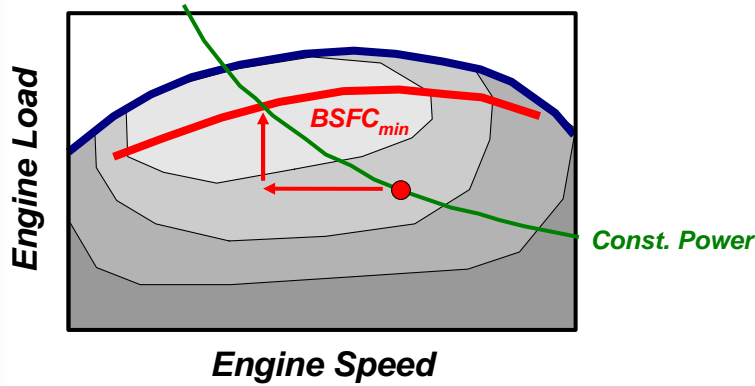
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The battery model can be set up simply by integrating the battery current. The efficiency for charging and discharging is defined using a map. This simple model does not yet include a model for battery temperature and voltage. However, investigations for several vehicle concepts have shown that this simple modeling is accurate enough for the layout of a HEV vehicle.



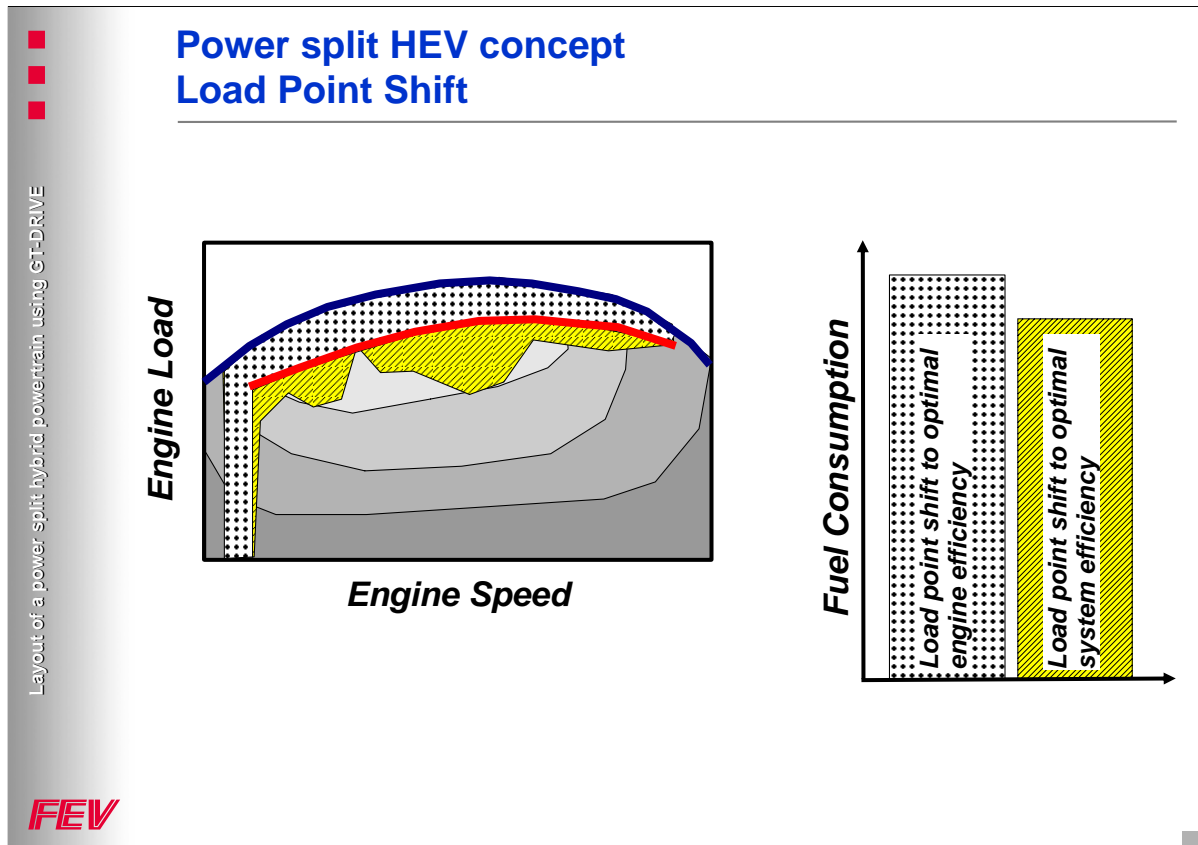
## Power split HEV concept Load Point Shift

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The main reason for using an electrical CVT is to enable load point shifting. For a specific vehicle speed and power demand the engine speed is decreased at constant ring speed by increasing the speed of the sun gear. Additionally the engine load is increased in order to meet the desired power. Controlled by the electrical engine at the sun gear, the ICE can be operated at optimal BSFC. The additional electric power generated at the sun gear is used by the electrical motor at the ring gear.



Unfortunately the usable power is reduced by the efficiencies of generator, inverter and motor. The product of these efficiencies can easily be lower than 70 %. Therefore, a load point shift to the line of minimal BSFC in a power split concept does not mean in every case to operate the system at best efficiency. The best system efficiency will be a compromise between best efficiency of the ICE and minimized power on the electrical path. For the optimized system efficiency the load point shift for every operating point during a cycle has to be calculated. This leads to a operation range which depends on the driving cycle and the layout of the HEV components.

## Summary and Conclusions

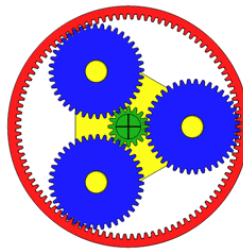
- With rising fuel prices even a cost intensive technology like the hybrid electrical vehicle may be economically reasonable.
- Additionally, future emission legislation will force the OEMs to equip diesel engines with cost intensive technology, too. These costs make HEVs with Gasoline engines increasingly attractive.
- HEV powertrains, especially the power split concept, are very complex.
- The layout of several components and the operation strategy directly influence the potential for improving fuel economy.
- Typically, the best layout is a trade-off between the efficiencies of several components.
- An efficient optimization work, sorting out the multitude of different combinations and strategies, is only possible by using simulation tools such as GT-DRIVE.

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