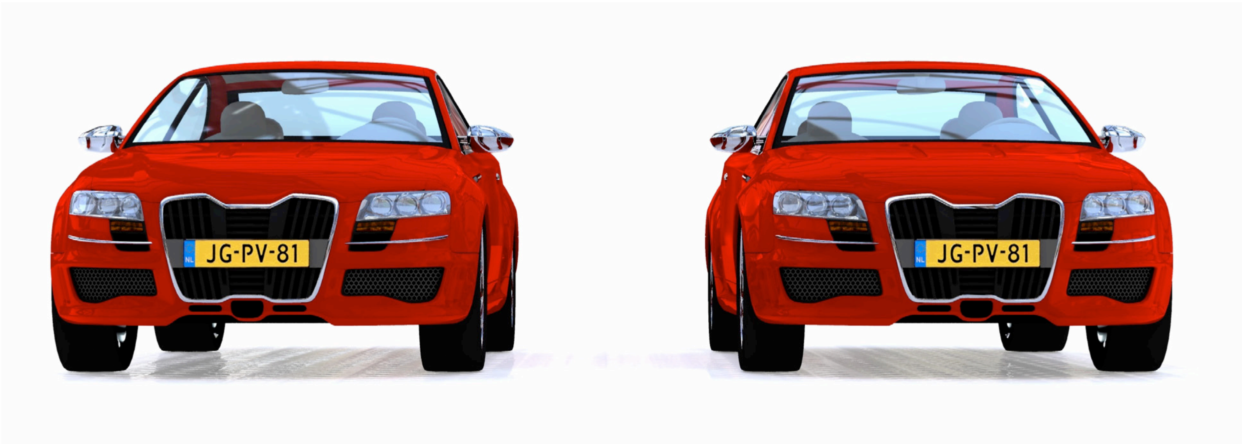
TWO CARS: SAME WEIGHT, SAME SIZE, SAME ENGINE, SAME TRACTION, SAME PERFORMANCE



CONVENTIONAL

HYDRAULIC SERIES HYBRID

HALF THE FUEL CONSUMPTION
HALF THE CO_2-EMISSION

THE HYDRID: A HYDRAULIC SERIES HYBRID

We want our cars to be strong and fast. This requires large and powerful engines. The maximum engine performance is, however, seldom needed. Most of the time –while driving in the city or cruising on the highway– the engine is running at low loads, often less than 20% of the maximum torque.

The high average fuel consumption of passenger cars is largely due to the low efficiency of internal combustion engines at these low loads. Would an engine be forced to run at high loads only, the fuel consumption of a vehicle would be more than halved.

This can be achieved with a series hydraulic hybrid drivetrain, called the ‘Hydrid’, which is developed by the Dutch company INNAS. In this new concept, the complete mechanical transmission of a car is replaced by a full hydrostatic transmission, allowing energy recuperation and an efficient engine operation. The concept requires extremely efficient hydrostatic pumps, motors and transformers, which have been developed recently.

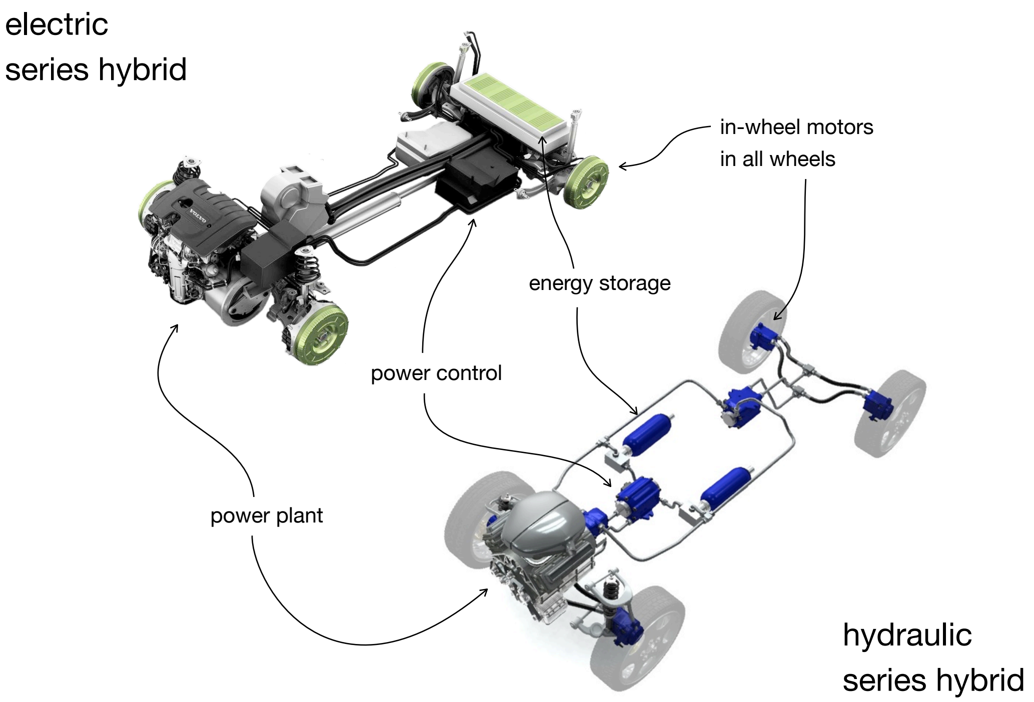
SERIES HYBRID
ELECTRIC OR HYDRAULIC?

Gear transmissions have the high efficiency, high power density and robustness that is required for automotive applications. But gear transmissions lack flexibility, and power management and energy storage is hardly possible.

Electric and hydraulic transmissions both offer power management, energy storage and flexibility. It is even possible to eliminate the mechanical drivetrain completely and have an in-wheel motor installed in the hub of each wheel.

These series systems are only feasible if all the transmission components have a high efficiency, also at part load and start-up conditions. Obviously, the new transmission components also need to fulfil all demands concerning traction, performance, durability, safety and cost.

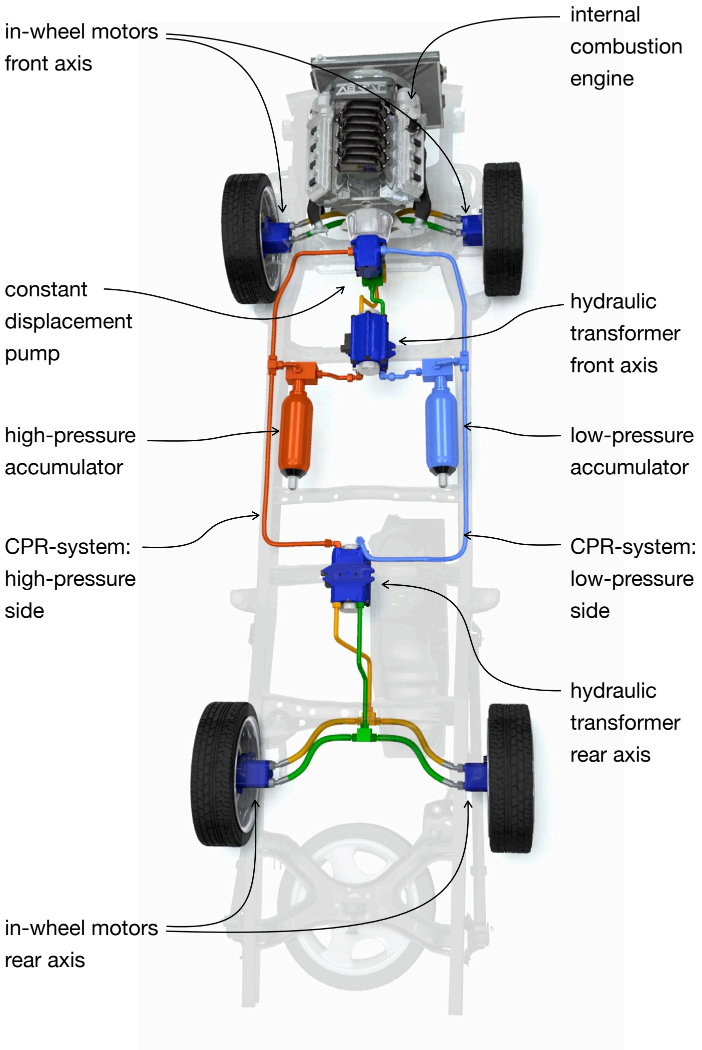
These requirements can only be met with modern hydraulic motors, pumps and transformers. The high power capacity of the hydraulic accumulators is an advantage over electric batteries. The energy capacity of the accumulators is not an issue: a 20 litre high pressure accumulator is sufficient for a mid-sized passenger car.



INDUSTRIAL APPLICATIONS
Hydraulic systems are applied in many stationary industrial applications, like hydraulic presses and injection moulding machines. Aside from the controllability, hydraulic systems are often used because of their robustness and durability.

MOBILE MACHINERY
Backhoe loaders, excavators and many other mobile machines are the main domain of hydraulic systems. These vehicles are production machines for which reliability is of greatest importance, even when working at -20°C or +40°C.

HYDRAULIC HYBRIDS
Hydraulic systems are also in development for light and heavy duty hybrid vehicle applications. An example is this delivery truck which has been developed by the US Environmental Protection Agency (EPA).



THE HYDRID
MAIN COMPONENTS

The backbone of the Hydrid is the common pressure rail or CPR-system. This system collects and distributes all the power inside the vehicle. The accumulators determine the pressure levels in the system. On the high pressure side, the pressure varies between 200 and 400 bar.

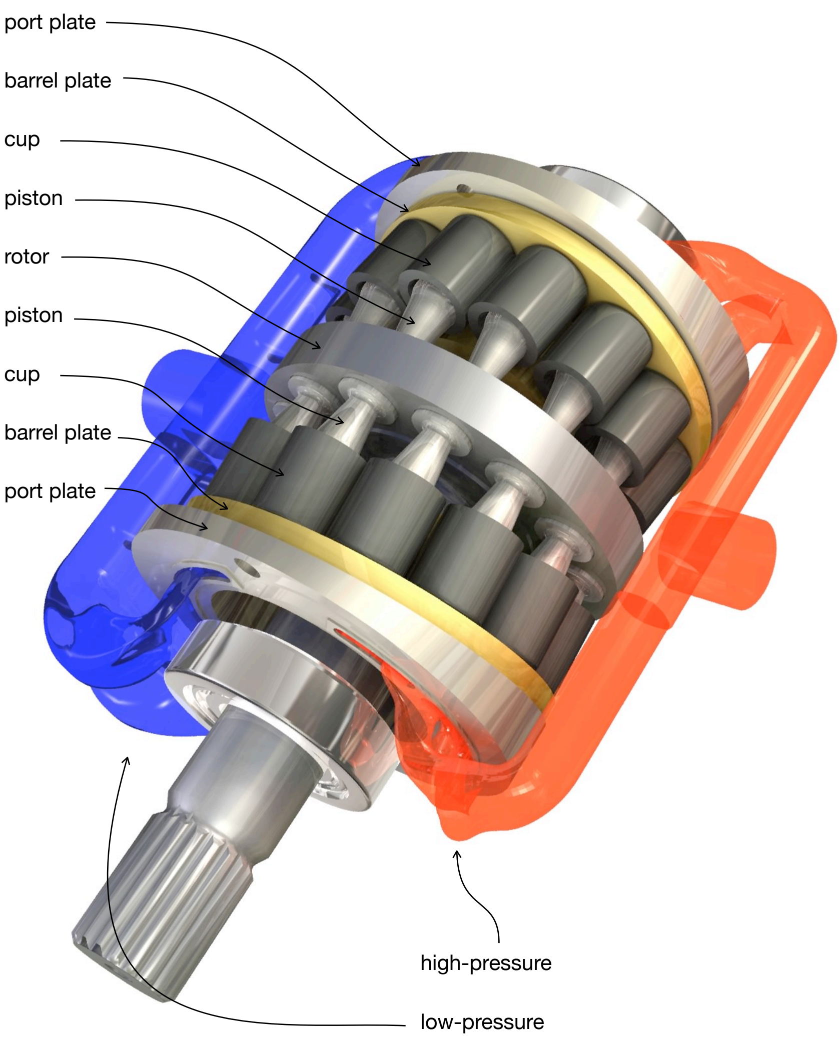
The internal combustion engine delivers all its energy to a constant displacement pump. The engine torque is directly related to the pressure in the high-pressure accumulator and can consequently only vary between 50% (at 200 bar) and 100% (at 400 bar) of the maximum torque. Operation of the engine at low loads is therefore completely avoided.

In the Hydrid, each wheel has its own hydraulic motor. These motors act as a pump when braking, thereby recuperating brake energy and storing it in the high-pressure accumulator. The torque of the in-wheel motors is controlled by means of the hydraulic transformers, one for each axis. The system has a variable traction control for the front and rear axis. The pumps, motors and transformers in the Hydrid are of the new ‘floating cup’ type.

CONVENTIONAL TRANSMISSION
In cars with a mechanical transmission, the engine mostly runs at very low loads. At these part load conditions, the engine has a very poor efficiency. This is the most important reason for the poor fuel economy of current vehicles.

PARALLEL HYBRID ELECTRIC VEHICLE
With the addition of an electric system, energy can be stored in a battery. This facilitates start-stop operation of the engine, which eliminates the idle losses. Moreover, during braking, some of the brake energy can be recuperated.

SERIES HYDRAULIC HYBRID VEHICLE
Series hybrid vehicles have all the advantages of parallel systems. In addition, they force the engine to run at medium to high loads where the engine has its highest efficiency. This system can only be realised with modern hydraulic components.

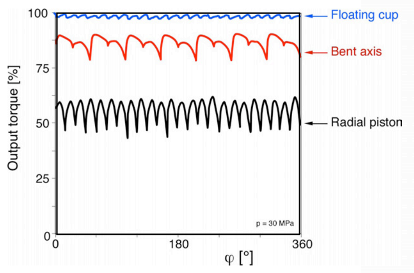


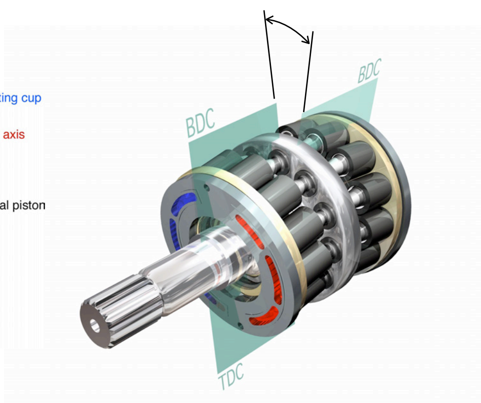
FLOATING CUP

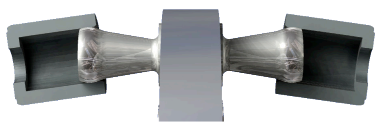
FOR PUMPS, MOTORS AND TRANSFORMERS

The new floating cup principle allows the design of extremely efficient pumps, motors and transformers. Floating cup machines typically have 24 pistons, much more than the 7 or 9 pistons of other axial piston pumps and motors. The pistons are pressed into a central rotor in a double, mirrored configuration. Each piston has its own, cup-like cylinder which is floating on a rotating barrel plate.

The floating cup principle has an extremely high efficiency, up to 98%. The principle has almost no torque losses at low-speed driving or during start-up when accelerating from standstill. The multi-piston design creates a smooth, almost constant torque output which is necessary for low noise, vibrations and harshness (NVH). The floating cup principle allows high pressure levels. Compared to electric machines, or even to other hydraulic pumps and motors, the floating cup principle has a very high power and torque density. This is especially important for the in-wheel motors in order to minimise the unsuspended weight of the wheels.







HIGH EFFICIENCY & SMOOTH TORQUE

Compared to other hydraulic motors, the floating cup principle has very low friction, losses, also at brake-away and at very low rotational speeds. Moreover, the high number of pistons creates an almost constant torque output.

OUT OF PHASE OPERATION

In floating cup machines a phase shift is created between the left and the right side. This not only minimises the torque variations created by the machine, but also strongly reduces the pulsation and noise levels of the pumps, motors and transformers.

AUTOMOTIVE PRODUCTION

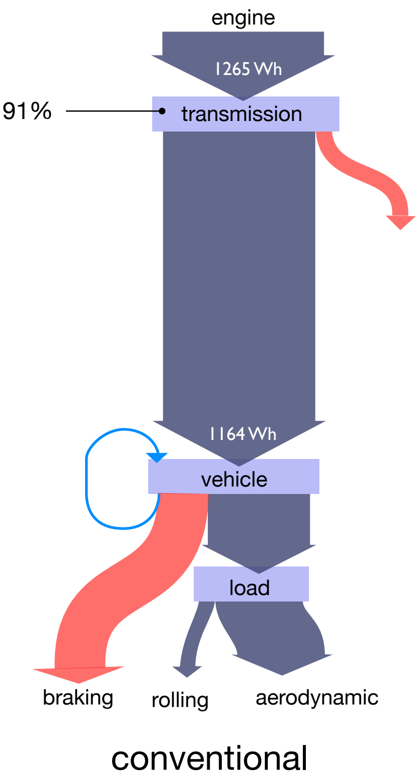
The floating cup principle is designed for deep drawing, sintering and other production technologies which are very familiar in the automotive world but relatively new for the production of hydrostatic machines.

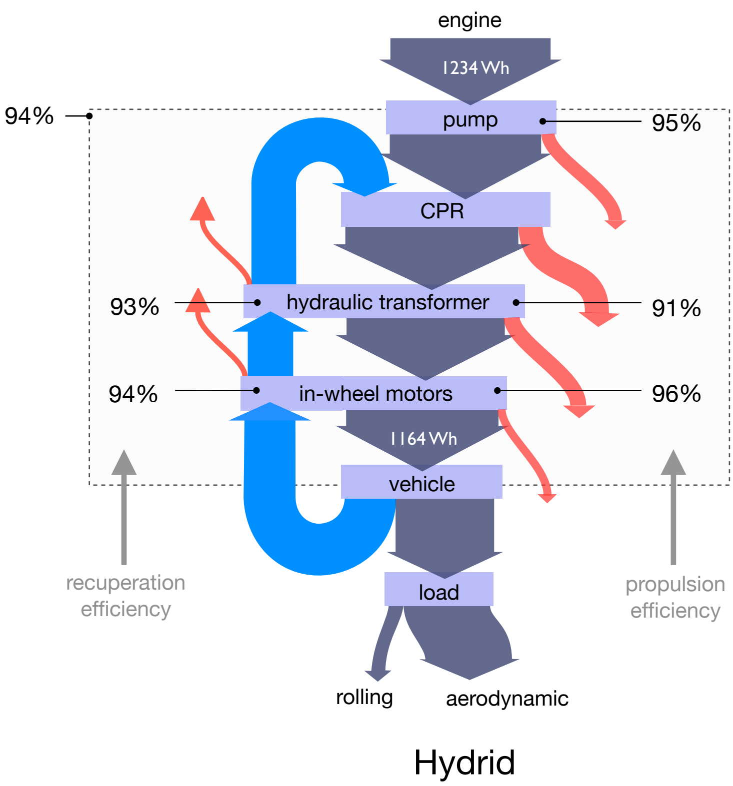
CYCLE ANALYSIS
TRANSMISSION EFFICIENCY

For driving a mid-sized sedan during the New European Driving Cycle (NEDC) an amount of 1164 Wh energy has to be supplied to the vehicle. The largest part of the energy amount is for overcoming the aerodynamic drag, especially when driving at high speed (the highway part of the NEDC). The same amount of energy is needed for the Hydrid transmission. Only now, the brake energy is not dissipated in the foundation brakes, but supplied back to the CPR-system.

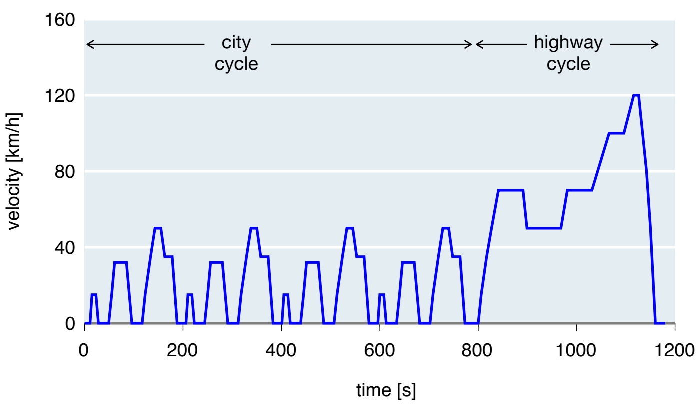
The German Institute for Fluid Power Drives and Controls (IFAS) at RWTH Aachen University has built a simulation model of the Hydrid. In this model, the efficiencies of the hydrostatic components are derived from measurements on existing floating cup machines.

The cycle analysis shows that the hydraulic components themselves create more losses than the mechanical transmission. But these losses are more than compensated by the energy which is recuperated during braking. Including the recuperated brake energy, the total efficiency of the Hydrid transmission is in the end somewhat better than the estimated efficiency of an all-wheel drive mechanical transmission.





NEW EUROPEAN DRIVING CYCLE
The New European Driving Cycle or NEDC is the regulated European cycle for defining the specific fuel consumption (in litres per 100 km) and emissions of passenger cars. The announced CO_2-emission limits are also defined on the basis of the NEDC. Moreover, a cycle analysis on the basis of the NEDC allows a direct comparison with the fuel consumption and CO_2-emissions of current cars as given by the car manufacturers.

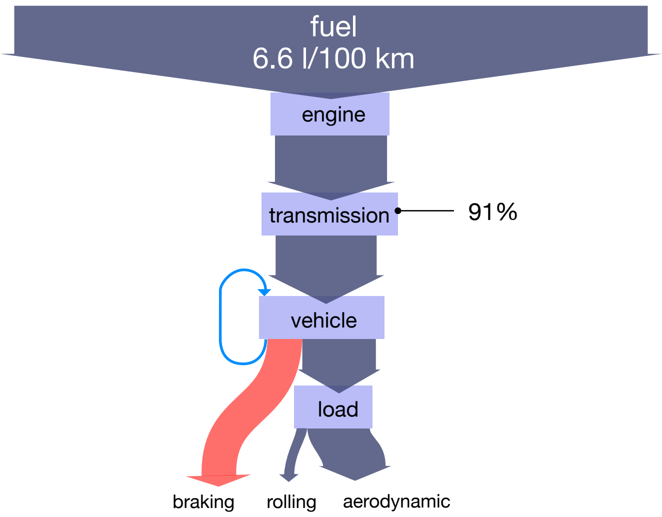


FUEL CONSUMPTION
ENGINE EFFICIENCY

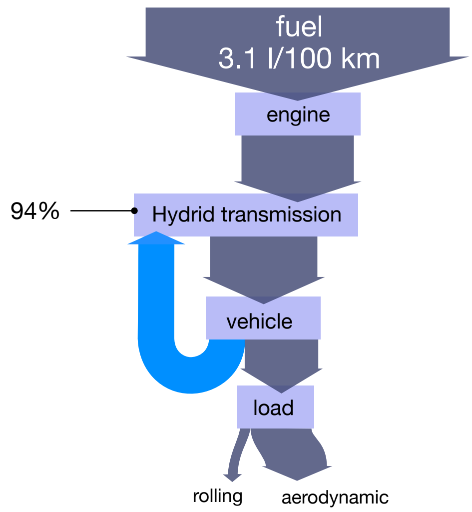
The effect of the Hydrid on the fuel consumption has also been calculated. Aside from the transmission, the Hydrid vehicle is identical to the conventional vehicle, having a diesel engine with a rated power of 100 kW. Both vehicles had the same weight (1450 kg) and both have an all-wheel drive transmission.

The cycle analysis of the Hydrid transmission has resulted in a specific fuel consumption of 3.1 litre per 100 km (or 77 MPG). This is less than half the fuel consumption of the conventional vehicle. The reason for the poor fuel economy of a vehicle with a mechanical drivetrain can be seen in the efficiency map of the engine: during 80% of the NEDC the power demand of the vehicle is less than 10 kW. At these low power conditions the engine can only run in an area with poor efficiency.

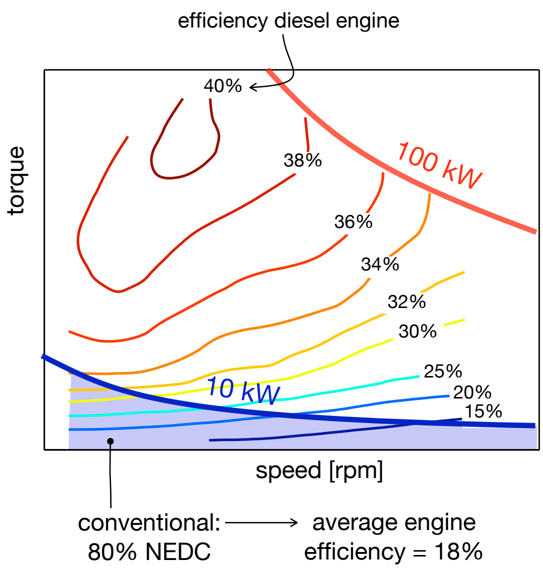
In the vehicle with the Hydrid transmission, the high-pressure accumulator forces the engine to run between the loads T_{min} and T_{max}. In this area the engine has the highest efficiency. The engine is now in on-off-operation and is only in operation during 11% of the cycle. The other 89%, the engine is switched off, thereby completely eliminating idle losses. The hydraulic pump can be used as a starter to enable the frequent on-off operation of the engine.

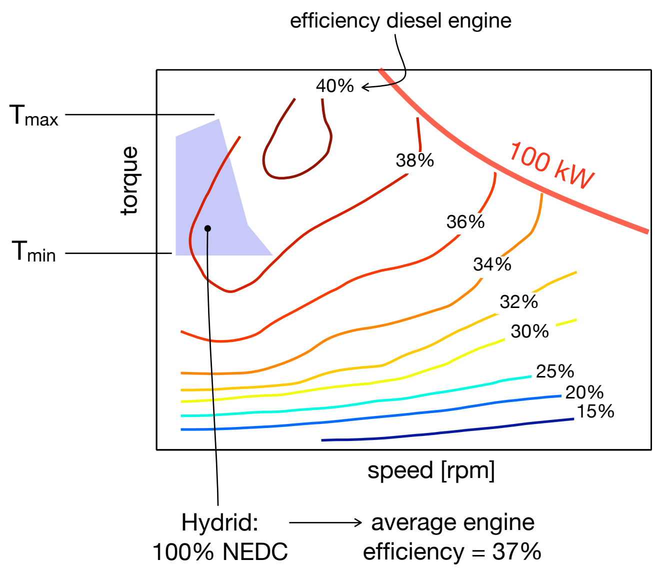


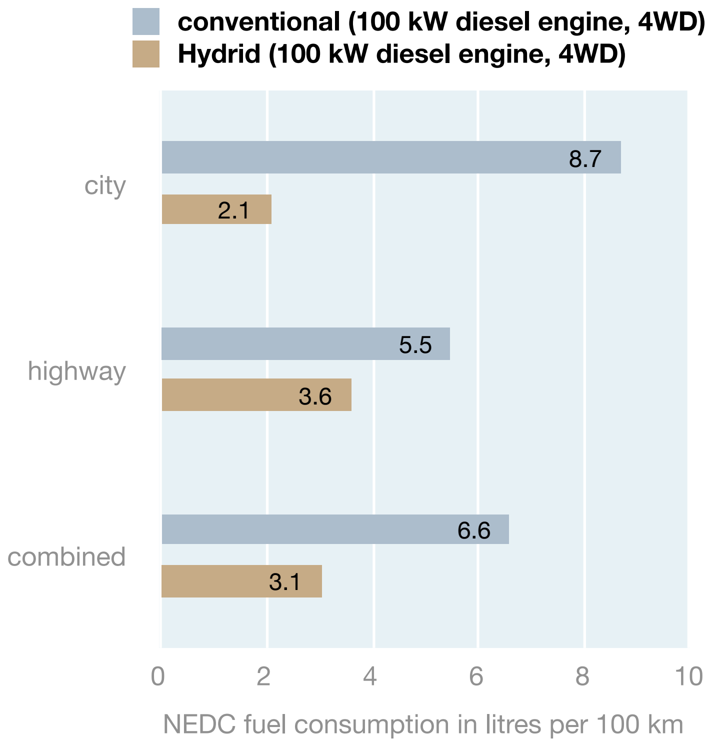
conventional

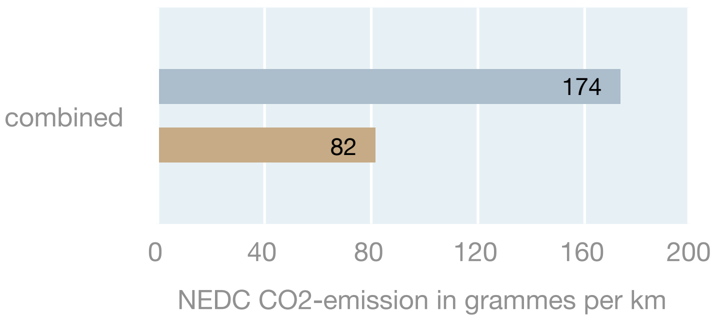


Hydrid









FUEL CONSUMPTION AND CO_2-EMISSION

CONCLUSIONS

While driving in the city, the energy needed for overcoming the rolling and aerodynamic resistance is (per kilometre travelled) about half the resistance during the highway part of the NEDC. Nevertheless the specific fuel consumption of a conventional vehicle is much higher when driving in the city. This is largely due to the strong part load operation of the engine. Also the lack of energy recuperation and the idle losses of the engine contribute to a high specific fuel consumption.

The Hydrid transmission strongly reduces the fuel consumption and the related CO_2-emission of a vehicle, especially during the city part of the NEDC. The Hydrid transmission does what any efficient drivetrain should do: to realise a high efficiency of the total drivetrain, independent of the vehicle speed. In the end, the fuel consumption of a vehicle should reflect the operation of the vehicle. Driving on the highway then results in a higher specific fuel consumption, simply because the drag increases at higher velocities of the vehicle.

NO COMPROMISES

It is to be expected that the European Commission will set CO_2-emission performance standards for passenger cars. Proposed is a limit of 130 grammes CO_2 per kilometre by the year 2012. With the proposed Hydrid transmission it is possible to achieve a much lower CO_2-emission. The transmission does not require any fundamentally new technologies to be developed but is based on state-of-the-art components.

The new Hydrid transmission will not increase the total weight of the vehicle, as is often the case with hybrid electric vehicles: the complete hydraulic drivetrain will have about the same weight as the all-wheel mechanical transmission it replaces.

Durability and safety are also no stumbling blocks for the Hydrid. Hydraulic transmissions have their domain in wheel loaders, excavators and other machines. These are production machines for which durability, reliability and safety are crucial. The Hydrid is in principle based on this field of experience.

Finally, unlike many other hybrid vehicle concepts, the Hydrid does not require any compromises regarding size, weight, or performance of the vehicle. It has the same acceleration performance, the same trailer load capacity and the same maximum speed as the equivalent vehicle with a mechanical drivetrain. In addition it offers a 4-wheel drive transmission with continuously variable traction control on the front and the rear axis.

INNAS

INNAS BV (Innovation Associates) is an independent engineering company specialised in innovative product development. INNAS gained an international reputation by innovative developments in the field of hydraulic components, hydraulic drives and combustion engines. Developing cleaner and energy efficient technologies has always been INNAS' point of special interest.

A substantial part of the innovations is developed on our own account and initiative. Research and development projects are also executed for, or in co-operation with medium-sized and larger industrial enterprises or technical universities in- and outside the Netherlands. Most of these organisations are active in the field of industrial vehicles, mobile equipment, combustion engines, and hydraulic drives and components.

NOAX

NOAX BV is responsible for the marketing and further development of the INNAS technology. On an exclusive basis NOAX exploits the industrial rights and know-how of the Chiron Free Piston Engine, the INNAS Hydraulic Transformer and the Floating Cup technology.

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