Ex. 1 Efficiencies of power systems for a car

$$\varepsilon = \frac{\text{Energy output (useful)}}{\text{Energy input (necessary)}}$$

1. Internal combustion engines

The energy output is the mechanical energy at the wheel. In this particular case, a value per kilometer was given (specific energy): 150 Wh/km = 0.54 MJ/km. The energy input can be calculated with the given specific consumption in liters/kilometers.

a) Gasoline

$$\varepsilon = \frac{E'_{\text{mech-wheel}}}{V'\rho\,\Delta_{\mathrm{r}}h} = \frac{0.54\ \frac{\mathrm{MJ}}{\mathrm{km}}}{\frac{4}{100}\ \frac{\mathrm{L}}{\mathrm{km}} \cdot 0.74\ \frac{\mathrm{kg}}{\mathrm{L}} \cdot 44.2\ \frac{\mathrm{MJ}}{\mathrm{kg}}} \approx 41\%$$

b) Diesel

$$\varepsilon = \frac{E'_{\text{mech-wheel}}}{V'\rho\,\Delta_{\mathrm{r}}h} = \frac{0.54\ \frac{\mathrm{MJ}}{\mathrm{km}}}{\frac{4}{100}\ \frac{\mathrm{L}}{\mathrm{km}} \cdot 0.84\ \frac{\mathrm{kg}}{\mathrm{L}} \cdot 42.9\ \frac{\mathrm{MJ}}{\mathrm{kg}}} \approx 37\%$$

Remark:

This result appears questionable at first sight, since Diesel engines are typically more efficient than gasoline engines. In fact, it is correct *assuming the given identical specific consumptions* for the car (4L/100 km). By using this assumption, the efficiency is implicitly set (technological considerations not taken into account). In fact, the specific consumption of a diesel engine is typically lower than that of a gasoline engine.

2. Electric motor

In this exercise, the energy consumption of the electric car was not given. However, an overall efficiency is always the product of the partial efficiencies (of the chain) and these were given.

a) Battery charged with hydroelectricity

The power-chain is:

Mechanical → Electrical → Chemical → Electrical → Mechanical → Wheel
Turbine (hydro) Battery charge Discharge Motor Transmission

Each of the conversions (arrow) is operated by a system, with a particular efficiency (i.e., losses).

Hydroelectric conversion is about 88% efficient. Since it is renewable energy, it is however counted as 100% efficient in energy statistics.
The efficiency of a lithium-ion battery is around 80% for a complete cycle charge/discharge (i.e., two conversions: electricity → battery c /d → electricity).
The overall efficiency for the motor *and* for transmission to the wheel is around 80%.

The "well to wheel" efficiency is then:

$$\varepsilon_{\text{hydro-wheel}} = \varepsilon_{\text{turbine}}\, \varepsilon_{\text{battery}\frac{c}{d}}\, \varepsilon_{\text{motor \& transm.}} \approx 64\%$$

Assuming the specific energy at the wheel is the same as before (which should be for a sound comparison), then the electrical energy input is 234 Wh per km, and the hydrodynamic (mechanical) energy is 266 Wh per km (0.96 MJ/km).

b) PEFC, filled with H_2 generated with an electrolyser, itself fed with electricity coming from photovoltaic solar panels

The power-chain is:

Sun	→	Electricity	→	Hydrogen	→	Electricity	→	Torque	→	Wheel
	PV panels		Electrolysis		PEFC		Motor		Transmission	

PV panels are 18% efficient technically, but like for hydroelectricity, it is counted as 100% efficient (renewable) in energy statistics.
The efficiency for the production of hydrogen by electrolysis is typically 75%.
The electrical efficiency of the PEFC is assumed to be 65%.
Again, the overall efficiency for the motor *and* for transmission to the wheel is around 80%.

The "well to wheel" efficiency is then:

$$\varepsilon_{\text{sun-wheel}} = \varepsilon_{\text{PV}}\, \varepsilon_{\text{electrolysis}}\, \varepsilon_{\text{PEFC}}\, \varepsilon_{\text{motor \& transmission}} \approx 39\%$$

With the same assumption as before, the electrical energy input is 385 Wh per km, and the energy taken from the sun is 2.14 kWh per km (7.7 MJ/km).

Remark:

A current fuel-cell car appears similarly efficient (~39%) than the considered very efficient oil-based car (~37-41%). Yet, today the latter consume on average 7 L/km and thus are less efficient (~21-23%). Moreover, oil is going to end one day, whereas solar energy is not, on the human scale. Besides, it should be noted that the efficiency for the production and transport of diesel and gasoline was not accounted for (same as considering it 100% efficient; in reality it is about 90%).
Eventually, electric cars are the most efficient (~64%), but *only if the electricity is generated from a renewable source* and accounted for as 100% efficient. Their main drawback is their limited range with one battery charge.
Last but not least, a life cycle analysis of the whole chain would be necessary to assess the overall impact on the environment (e.g., taking into account the production of PV panels).

Thinking further:

- What other combinations can you imagine?

Purely in terms of efficiency, the best combination is one with as few conversions as possible and with as high efficiency as possible for each individual conversion. A constraint is of course the compatibility of the elements belonging to the chain (i.e., same type of energy at connections).