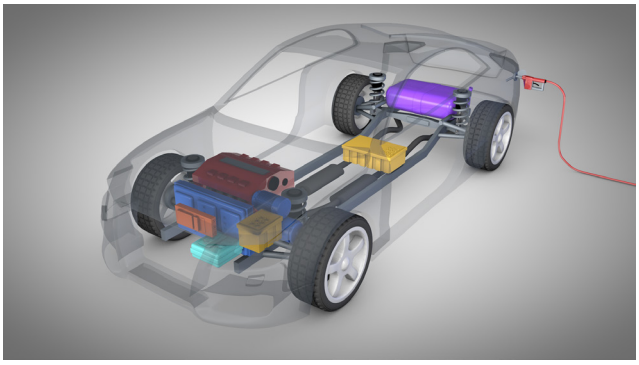
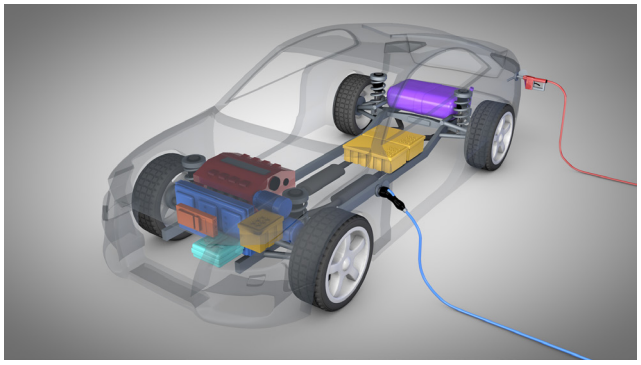
Hybrid and plug-in hybrid electric vehicles (HEVs & PHEVs)





There are two steps towards to EVs: hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs). There are many different potential HEV and PHEV configurations, but in general, an (P)HEV has an electric drivetrain like an EV, plus a fuel-burning engine of some type that can recharge the batteries periodically. HEVs and PHEVs are quite popular because:

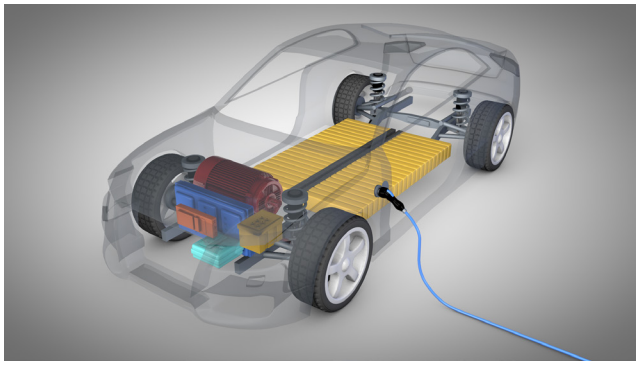
- Their range is not limited by the battery
- They save a lot of fuel compared to ICE vehicles
- They require less maintenance on the powertrain and brakes. This is due to the fact that the fuel engine is supported by the electric motor.

The advantage of an HEV is that the fuel-burning engine, in general, is most efficient in only a small range of operating conditions (speed and load). Also, at this most efficient operating point, the fuel-burning engine usually produces its lowest levels of emissions. Unfortunately, while driving, the engine in the car has

to run under a wide range of speeds and loads, and thus it is far less efficient and produces much greater emissions than it would if it could run at its most efficient point all the time. Electric drivetrains are also most efficient at only one point, but the reduction in efficiency for other speeds and loads is far less. Therefore, an HEV can run the fuel-burning engine at its most efficient point for battery charging and can use the electric drivetrain to take up all the slack under other conditions.

This way, emissions are much less than for the fuel-burning engine driving the car by itself, and fuel economy can be significantly improved. Hybrid technologies extend the usable range of EVs beyond what an all-electric vehicle can achieve with batteries only. Being a hybrid or plug-in hybrid would allow the vehicle to operate on only batteries within an urban/polluted area, and then switch to its engine outside the urban area.

Battery electric vehicles (BEVs)



Some of the main advantages of the BEV are that it runs fully on a cheap and relatively sustainable energy source, it requires little maintenance due to the reduction in moving parts, and the possibility to employ one pedal driving makes

it possible to make very efficient use of the energy. A disadvantage is that a large battery is needed for a long range. But as Auke states, according to his research, a range of 400 - 500 km should be enough, so there is no use in making batteries larger than that. Another disadvantage is that fast charging is needed in order to compete with ICE vehicles. It is expected that within five year, fast charging capabilities will be so far that a range of 250 km can be attained within 15 minutes.

Take a moment to study this table which shows a total cost of ownership comparison between gasoline vehicles and FEVs:

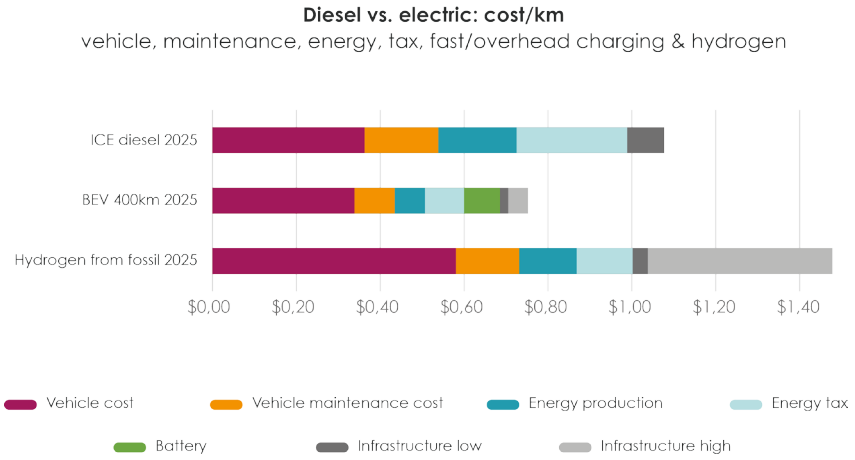
Battery electric vehicles: Total cost of ownership

Cost type	Gasoline	BEV 2000	BEV 2030
Drivetrain	$15k	$20	$5
Battery	$0	$100k	$10k
Fuel	$17k - 40k	$6k - 10k	$6k - 10k
Maintenance	$18k	$12k	$6k
X	$50k - 73k	Disadvantage: $65k - 92k	Advantage: $ 19k - 46k

Full electric trucks

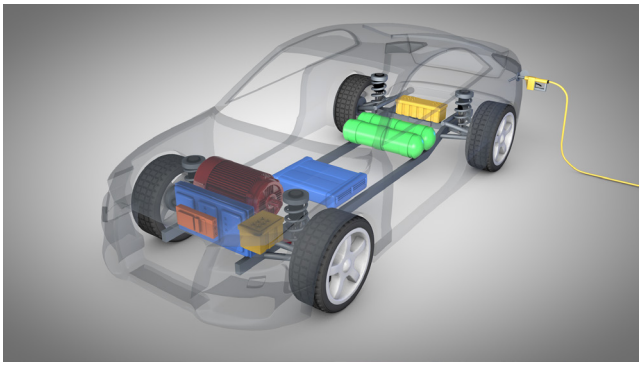
There is a great future for electric trucks, because looking at the total cost of ownership, EVs get cheaper once they are used more. As heavy trucks spend a lot of time on the road, they are an excellent candidate for electrification, if fast charging infrastructure is provided.

The figure below shows the components of total cost of ownership of different types of trucks by 2025. The middle bar is the full electric truck.



Fuel cell electric vehicles

Despite the benefits, there are few disadvantages associated with EVs. The major one is the low energy and power density of the batteries compared with liquid fuels (gasoline and diesel). Another common concern is the battery recharging time. Charging times range between 4 to 8 hours. However, charging electric batteries is significantly cheaper compared to filling a fuel tank.



A fuel cell vehicle has the advantage of a short refilling times compared with the batteries, way less maintenance requirements and a relatively longer lifetime. Additionally, another advantage of fuel cell cars is the extended driving range, which is also more similar to a vehicle based on a traditional ICE. This is because the energy available is inside a hydrogen tank which can store more energy than batteries.

The graph from the preceding paragraph about full electric trucks also includes a bar for fuel cell electric vehicles. Auke is less enthusiastic about FCEVs: they are a great solution for electric driving in remote areas, because you only need hydrogen and no charging infrastructure, but it is still (just like biofuel) a very inefficient way to make use of the energy of the sun.