

# Future mobility based on renewable energies

## Fraunhofer ISE

Dr. Günther Ebert  
 guenther.ebert@ise.fraunhofer.de

## ZSW

Prof. Werner Tillmetz  
 werner.tillmetz@zsw-bw.de

Dr. Michael Specht  
 michael.specht@zsw-bw.de

## Fraunhofer IWES

Dr. Michael Sterner  
 michael.sterner@iwes.fraunhofer.de

Dr. Bernd Krautkremer

Bernd.Krautkremer@iwes.fraunhofer.de

## DLR

Dr. Thomas Pregger  
 thomas.pregger@dlr.de

## Jülich

Dr. Wilhelm Kuckshinrichs  
 w.kuckshinrichs@fz-juelich.de

In Germany, traffic accounts for about 20% of all CO<sub>2</sub> emissions. The main pollutant is individual traffic, i.e. cars and lorries, with about 80%. The average consumption of fossil fuel per vehicle has fallen in recent years but worldwide the total number of vehicles is continuing to increase beyond the current 900 million and therefore also the consumption of fossil energies and CO<sub>2</sub> emissions along with it. High CO<sub>2</sub> emissions that acutely threaten our environment and the finite reserves of fossil fuels such as oil and gas are therefore, in addition to the increasing air pollution in urban areas, the main reasons almost all major vehicle manufacturers are working intensively on alternative vehicle concepts.

The German federal government has recognised the problem and supports the development of technologies for **battery** and **fuel-cell** assisted electric vehicles with its „National Electromobility Development Plan“. Both share the extremely energy-efficient electric drives and the option of using renewable sources such as solar or wind energy for their energy supply. Another promising approach is supply based on **biofuels**. The ecological potential and the characteristics of all three vehicle concepts will hereinafter be briefly described and compared (Figure 1).

## Battery electric vehicles (BEV)

Vehicles powered by electricity alone have an electric motor that draws its power from an on-board battery, in contrast to conventional combustion engines that are powered by petrol or diesel. The battery is regularly recharged with power from the stationary grid. Electric motors are very efficient with energy. Petrol or diesel vehicles convert the bulk of the chemically bound energy within the fuel into heat. Electric drive systems, on the other hand, use the electrical energy stored in the battery almost entirely for the drive system. Therefore, they only need about ¼ of the energy that a combustion engine needs (Figure 2).

However, there is still a significant disadvantage: Batteries can store only a relatively small amount of energy per volume or weight, which is more than an order of magnitude lower than that of liquid fuels. The result is that the range of these electric vehicles is still limited to around 150-200 km. However, these vehicles still suffice for many tasks because most of our daily journeys are relatively short, such as the drive to work or to the supermarket. They are therefore suitable as vehicles for commuters, as second family cars or as an urban vehicle.

Figure 1  
 Vehicle concepts based on renewable energies

Drive system	(Mobile) energy carrier	Energy source
Electric motor	Battery	Electricity from renewable energy sources
Electric motor	Fuel cell	H <sub>2</sub> from renewable energy sources
Combustion engine	Biofuels	Biomass

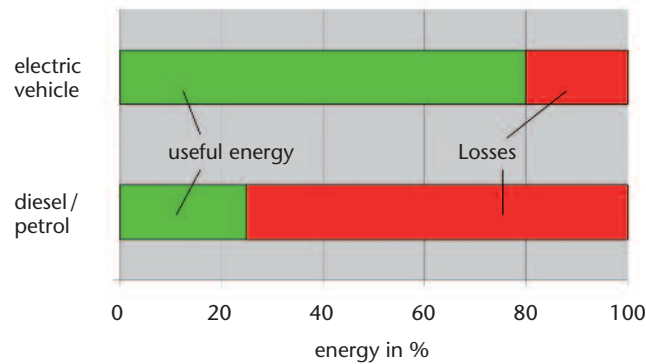


Figure 2  
Electric vehicles are highly efficient.

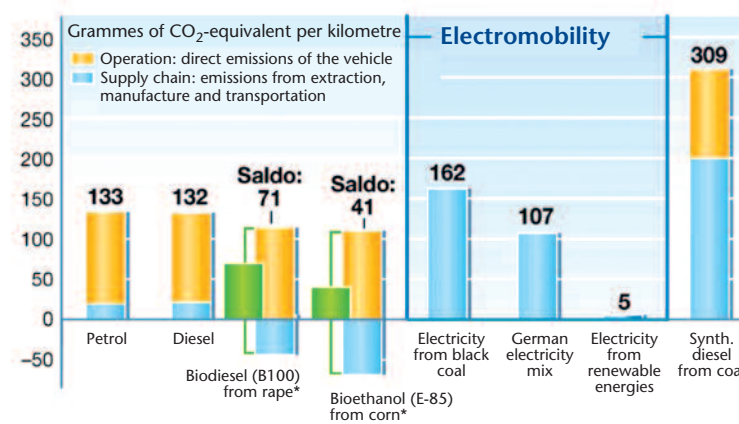


Figure 3  
Electric vehicles require electricity from renewables.  
(Source BMU)

Drivers who have to travel longer distances sometimes should opt for a so-called plug-in hybrid electric vehicle (PHEV). In addition to an electric drive, these vehicles also have a combustion engine that is used when the battery is empty. In extreme cases, the combustion engine only serves to generate electricity for charging the battery. This allows for very simple vehicle designs without any kind of mechanical connection between combustion engine and wheels. Such plug-in hybrid electric vehicles are ideal for the transitional phase from conventional combustion-driven vehicles to electric vehicles. They are mostly electrically driven but since they do not abruptly stop when the battery is empty, which is what drivers might fear, they have great market potential as universal vehicles. Electric vehicles show virtually no local CO<sub>2</sub> emissions. For the total balance, however, the source of the electricity is crucial. If it is from a coal-fired power plant, which also

transforms a high proportion of primary energy into heat instead of electricity, the emissions turn out to be about 160 g of CO<sub>2</sub>-equivalent for a small car – more than petrol and diesel vehicles. In this case, nothing would be gained.

With the current German electricity mix, things are already looking better. With just under 110 g, there is already a modest improvement over conventional vehicles.

However, electric vehicles only really make sense if the electricity is largely generated with renewable energy sources, in which case negligible CO<sub>2</sub> emissions are achievable. Therefore, the introduction of electric vehicles has to be inextricably bound to rapid increases in the share of renewables in our electricity generation (Figure 3).

Figure 4  
Electric vehicles require infrastructures.

→ **Always charge electric vehicles when they are stationary**

**Charging options at home need to be supplemented by public charging infrastructures**

**Billing and communication system**

- **Universal**
- **Cost-effective**
- **Intelligent**
- **User friendly**



They account for about 16% of electricity generation today. According to the pilot study of the federal government, this percentage should increase to 30% by 2020, 50% by 2030 and 80% by 2050. As the change-over to an electric vehicle fleet should take place in similar time frames, the supply of electric vehicles with renewable energies would be guaranteed in the medium term.

Electric vehicles primarily draw their energy from the electricity grid. Thanks to the economical electric drive, this kind of supply can be managed without any further problems. If, following the objective of the federal government, one million electric cars were driving on German roads by 2020, our total electricity consumption would increase by less than 0.5% and even if in a few decades all 45 million cars were to be electrically powered, electricity consumption would increase by only 20-25%. However, temporal concentrations of recharging processes could lead to undesirable load peaks. If all vehicle owners were to recharge their cars at night, it could very well lead to grid overload assuming a strong market penetration of electric vehicles. These effects can be avoided with modern control technologies and flexible tariffs, made possible with the introduction of electronic meters: Battery electric vehicles still

have to be recharged at regular intervals but the exact timing is somewhat flexible.

This will often make it possible to recharge the vehicles selectively during favourable generation and consumption periods (Figure 4).

Imbalances in energy generation and consumption can be offset within certain limits by choosing the time for recharging the vehicle. In addition to these temporal load shifts, it is even possible to feed back the electrical energy from the vehicle batteries into the electricity grid and thus compensate, or at least mitigate, deficits caused by a high consumption or a momentary lull in the output of wind power plants. This is possible because the vehicles are stationary more than 90% of the time and are available to be connected to the grid. With a high proportion of electrical vehicles, a huge electrical energy storage can be realised that can effectively dampen the fluctuations of wind and solar energy, thus facilitating the further expansion of renewable energy.

**R&D requirements:**

In addition to the further development in light-weight vehicle construction, which is especially important for electric vehicles, battery technology in particular needs to be advanced.

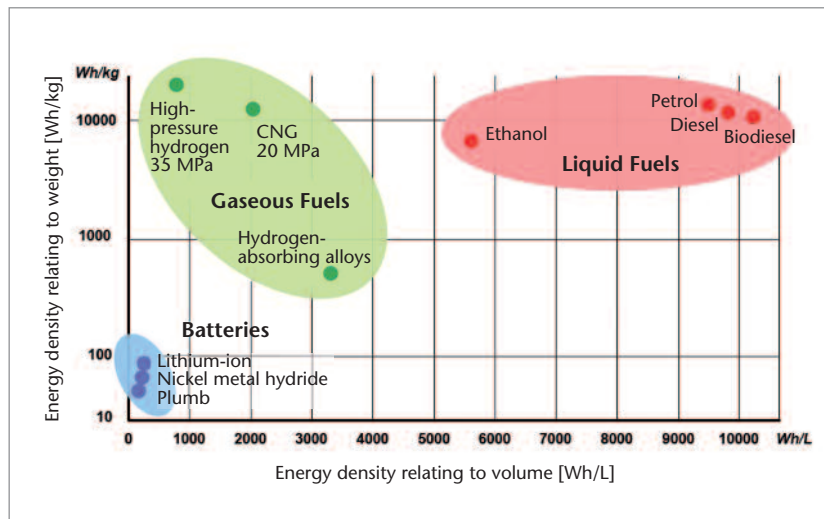


Figure 5  
Energy density of various storage media  
(Source: Toyota)

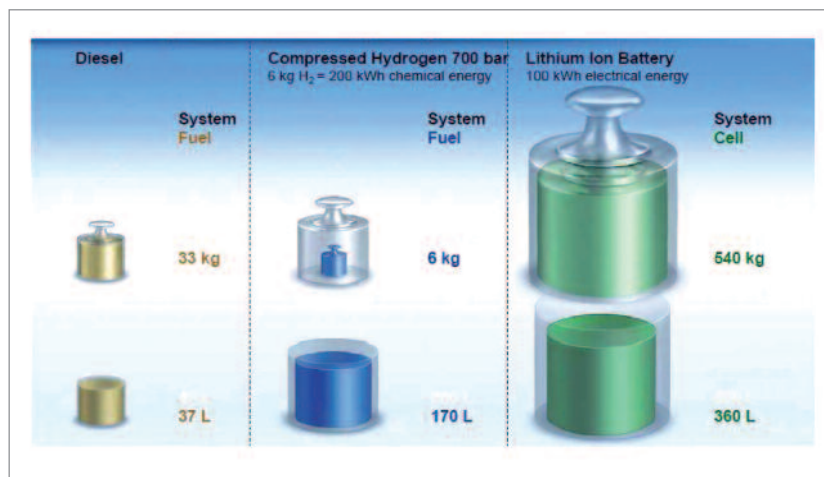


Figure 6  
Comparison of diesel, hydrogen and battery-powered vehicles: volume and weight for a range of 500 km

Storage capacity, durability, cost, safety and recharging times are all still not really sufficient for a wide acceptance of electric vehicles.

The introduction of electric vehicles also requires the creation of a recharging infrastructure. As electric vehicles only have a limited range, they should always be connected to the grid while stationary. In addition to domestic sockets that can be used for basic requirements, recharging possibilities at work, in front of supermarkets, in car parks or public parking areas have to be implemented in the future. Individual charging stations as they are already installed today on hand-selected sites are not sufficient and above all, too expensive in order to achieve a sufficient density. A universal, affordable, user-friendly charging and billing process is required that allays the consumer's fear of searching for recharging options.

## Fuel cell vehicles

For many years, a number of major vehicle manufacturers have been working on electric vehicles with fuel cells as an energy source. Worldwide, there is a lot of practical experience with cars, lorries and buses. Currently, the vehicles on the road are in their second and third generation. In 2010, Daimler are planning a further development of their B-Class fuel cell technology during test operation. For 2015, a general market launch is planned. Compared to the previous versions, improvements in the lifetime of the fuel cell stack (> 2000 h), its performance (65 kW to 100 kW), range (from 160 km to over 400 km), reliability and cold start ability were achieved.

Fuel cell vehicles also have an electric motor that draws its energy from a fuel cell. The fuel cell runs on pure hydrogen, which is usually stored compressed in a tank. As is the case with battery electric vehicles, virtually no CO<sub>2</sub> is emitted while driving. Of greater importance to the environment, however, are the total emissions of the system. These depend on how the hydrogen was produced and processed. Conventional production from natural gas leads to emission values similar to those of battery electric vehicles that run on the current German electricity mix, which means they are only moderately more favourable than conventional diesel and petrol vehicles. CO<sub>2</sub> emissions can only be reduced to very low levels if the hydrogen is produced using renewable energy, such as via electrolysis (*Figure 9*). The prerequisite here is that the electricity is to be supplied from renewable energy sources as well.

One difference to battery electric vehicles still remains: Compared to battery electric vehicles, the energy loss in the entire process from supplying power for electrolysis up to filling the pressure tank is several times as high, leading to a significant cost disadvantage for fuel cell vehicles in the future.

The higher energy density (*Figure 5*) of hydrogen allows for perfectly acceptable ranges of 400 km and more (*Figure 6*).

That means that the application of fuel cells in buses and lorries remains viable. There is still much room for improvement of fuel cell technology, however. Above all, this includes the high costs, which are expected to be significantly reduced along with further technical progress but above all, by the start of mass production.

Further improvements in the durability, robustness and in the storage capacity of hydrogen are desirable. Another major hurdle to market introduction of fuel cell vehicles is the lack of a hydrogen supply infrastructure. A sufficiently dense network of hydrogen filling stations is a prerequisite for consumer acceptance but it also requires large investments. Nevertheless, an industrial consortium consisting of car manufacturers and energy suppliers have recently declared they want to establish a dense filling station network by 2015.

## Biofuels

In addition to battery electric and fuel cell vehicles, vehicles running on biofuels also offer a high ecological potential. Biofuels either are a part of a closed cycle and the related plants absorb similar amounts of CO<sub>2</sub> during their growth phases as are emitted by the vehicles during operation or they are produced with already existing biomass. CO<sub>2</sub> emissions range from low to significant when compared to fossil fuels and depend both on the method and the individual design.

First-generation biofuels such as biodiesel from rape or ethanol from sugar cane that only use a certain part of the plant are considered moderately ecologically effective. In contrast, second-generation biofuels use the whole plant, resulting in a significantly higher CO<sub>2</sub> reduction.

Today, biofuel has found widespread use in some countries as diesel additive or as ethanol. Worldwide however, only about 2.4% of fossil fuels are substituted by this. In general, biofuel is a limited resource. If one were to use the entire potential area of 3.2 million hectares for cultivating biofuel crops in Germany, a maximum of 20% of today's fuel requirements could be covered.

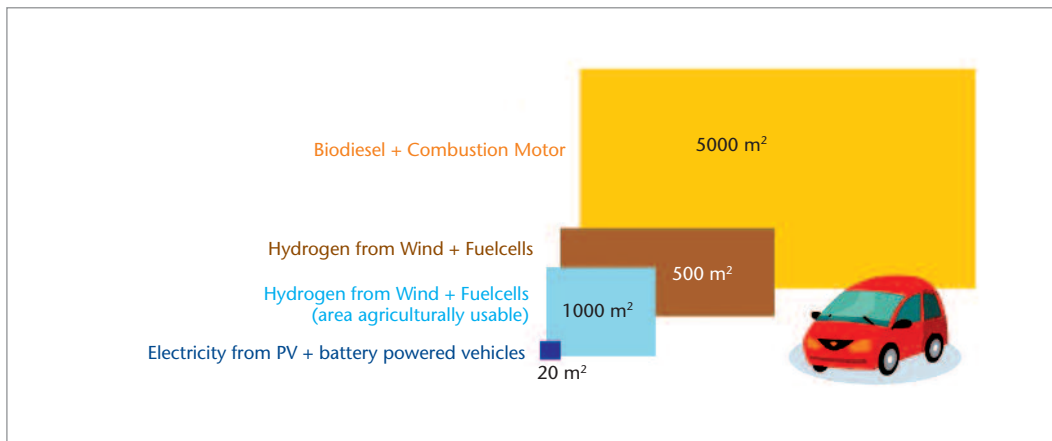


Figure 7  
Space requirements in  
comparison

However, competing alongside normal traffic, there is also air traffic for which biofuels possibly represent the only viable alternative to fossil fuels, as well as the stationary sector with combined heat and power plants in which biofuel can be used to an even greater advantage. For example, 6 t of wood is enough to produce 1 t of diesel but it can also substitute 2 t of heating oil. The application of biofuel should therefore mainly take place where its advantages are fully realised. One such an area of application is the plug-in hybrid vehicle or vehicles for which an electrification will be much more difficult to realise.

A disadvantage is the high demand for land that biofuels have when compared to wind or solar energy. In order to generate the annual electricity demand of a small car running on biofuel, an area of about 5000 m<sup>2</sup> of arable land is required. For an electric vehicle with the same annual mileage, the roof of a single-family house with about 20 m<sup>2</sup> would suffice (Figure 7).

A relatively new approach relies on the production of substitute natural gas called SNG. Hydrogen, produced via electrolysis powered either by wind or solar energy, is methanated in the presence of CO<sub>2</sub> (see Figure 6 on p. 118). This methane can then be distributed via conventional natural gas pipelines and used for

local electricity and heat generation and for the operation of natural gas cars. The advantage of this approach is basing the vehicle's supply on renewable energies, the uncomplicated long-term storage, the presence of a distribution infrastructure and the universal useability of the energy carrier methane. In addition, methane produced from biomass can be included. A disadvantage, however, are the high energy losses in the process chain.

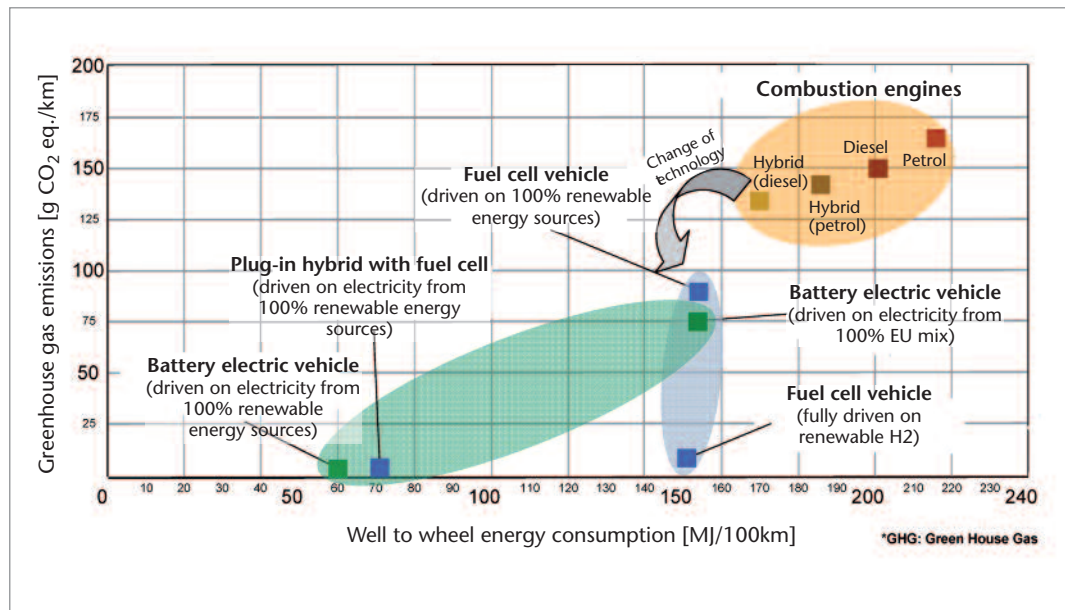
## Summary

It is safe to assume that vehicles with battery and/or fuel cell aided electric drives will successively replace our conventional, primarily fossil-powered, vehicles in the private transport sector in the decades to come because of their potential environmental advantages.

Prerequisite, however, is a consistent focus on research and development to improve on the still existing weaknesses such as insufficient energy density, durability, safety, road capability and cost-effectiveness. Furthermore, the rapid creation of a corresponding filling or recharging infrastructure is called for.

**Figure 8**  
Well to wheel balances of the various types of vehicles, showing their energy consumption and greenhouse gas emissions

(Source: Daimler)



Regarding biofuel technology, especially the CO<sub>2</sub> emissions from production have to be reduced. The current processes for producing bio-diesel can only be a beginning. In general, biofuels will remain a limited resource and should therefore mainly be used in those niches that do not offer any other solutions.

Luckily, the federal government is supporting all target areas with subsidy funds. This responsibility is shared by five ministries responsible for research and development, economy, the environment, transport and agriculture.