

With Electricity to ZEV? Potential and Limitations of Electric Mobility

2011-37-0011

Published
06/09/2011Christian Bacher and Günter Hohenberg
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doi:10.4271/2011-37-0011

ABSTRACT

“Zero Emission Vehicles” in the form of pure electric vehicles are quite feasible and useful for limited cruising ranges. However, market success depends on customer acceptance. Studies show, that customers expect electric vehicles with driving performance similar to conventional vehicles while comparable cruising ranges should be available at low additional cost. With currently available batteries using lithium ion technology a gravimetric energy density of only one percent of the energy density of gasoline or diesel can be reached. With respect to acceptable additional costs this effect leads to significant reduction of the cruising range. For various reasons such as battery aging, demand for heating, traffic jams, etc., this already decreased cruising range is further reduced. In such cases electrical energy can be generated with a demand oriented (down-) sized combustion engine, a so called “Range Extender”.

The presented paper describes the current state of development regarding electric mobility and demonstrates the potential and limitations of electric vehicles. In particular, the problem of limited cruising range will be discussed and a solution including a “Range Extender” will be presented, while considering economic and environmental aspects.

1. INTRODUCTION

By using renewable energy sources, Zero Emission Vehicles (ZEV) can be realized via electrically driven vehicles. However, discussions, whether Electric Vehicles (EV) have the potential to replace the internal combustion engine (ICE), are controversial. Comparison of the ICE with electric drive concepts typically shows the better efficiency of electrically driven vehicles.

However, this positive effect is faced by essential problem areas which are shown in [Figure 1](#).

The low energy density of currently available batteries compared to the energy density of liquid fuels leads to disadvantages which are discussed in the next chapters. In particular, the problem of limited cruising range will be addressed and a solution by using a so called “Range Extender” considering economic and environmental aspects will be discussed.

Incentives like time-limited tax exemption, no city toll, reserved parking places, etc. represents another important point. Particularly vehicle manufacturers are generally unsettled, because they don't know to what extent range extender concepts will be still accepted by the legislature as electric vehicles. Because of strategic reasons this aspect is very important for them.

2. CHALLENGES IN THE ESTABLISHMENT OF E-MOBILITY

Market success of electric vehicles depends on customer acceptance. Studies prove expectations, that electric vehicles with similar driving performance and low additional costs should reach cruising ranges comparable to conventional vehicles. Although it is known that about 50km are enough to cover about 70% of trips (See [\[1\]](#) and [Figure 16](#)), the remaining 30% will surpass the 50km. Thus, while maintaining current mobility patterns, EV's can only be used as a second or third vehicle.

If the EV should be commonly used in near future, we will be confronted with numerous challenges which are ultimately based on the limited capabilities of today's electrochemical energy storage systems (batteries).

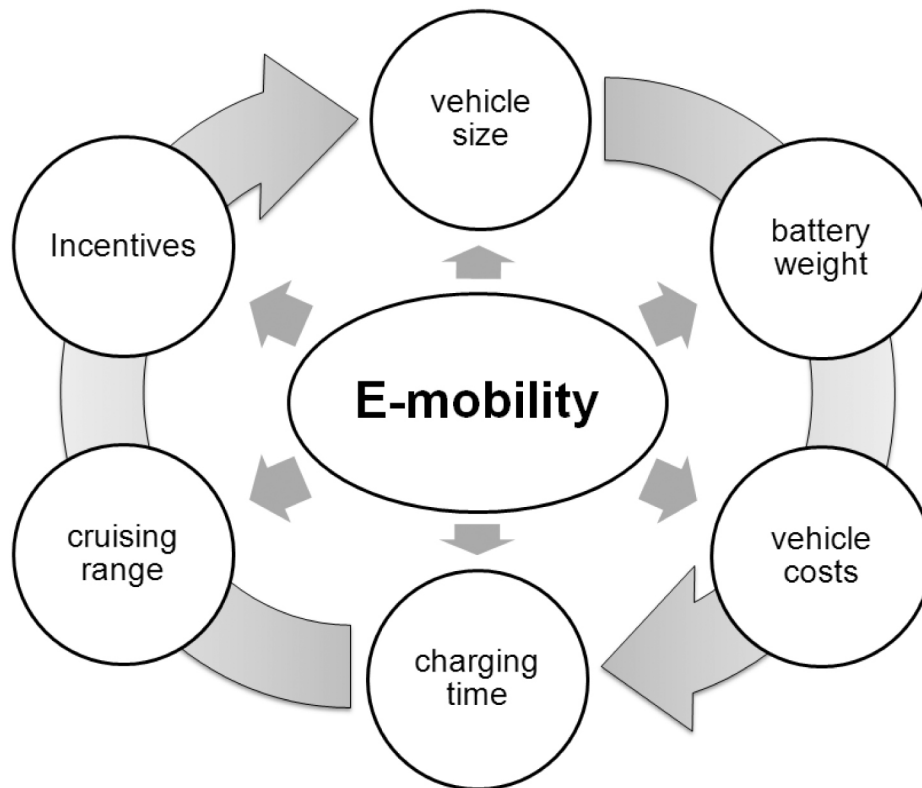


Figure 1. Challenges in the establishment of E-Mobility

The most significant issues are presented in the following chapters.

3. INFLUENCE OF VEHICLE SIZE

Vehicle weight and driving resistance (friction, aerodynamic resistance) affect the required driving power and therefore the required total driving energy over a designated route. To demonstrate this fact, the required energy in the New European Driving Cycle (NEDC) for three typical vehicle classes has been calculated by simulation (see [Figure 2](#); small city vehicle with 700 kg, C-segment vehicle with 1100 kg and Sports Utility Vehicle (SUV) with 1900 kg, each vehicle without battery weight). The assumed battery utilization (SOC-lift) was set to 65% and braking energy recuperation was set to 60% of available deceleration energy.

As shown above, the required battery capacity increases approximately linear with vehicle mass and proportional to the range. If, for cost reasons, the maximum battery size is set to 10-20kWh, the relationship between payload and gross weight will be more unfavourable with growing vehicle size. This is most apparent in the extreme case of the electric bike, which was added for reference purpose. From this it follows that it is not possible to introduce the new technology -as usually done- via premium class vehicles. At least for introduction, electric mobility is therefore limited to small and light vehicles. The few sport cars presented today are not

relevant for a noticeable breakthrough and have to be classified as show cars.

In daily based usage a shift to lower ranges happened but the general tendencies for possible cruising range remain the same.

4. COMPARISON OF VEHICLE WEIGHT, COSTS, CHARGING TIME AND RANGE BASED ON AN A-SEGMENT VEHICLE

Taking a conventional A-segment vehicle as basis and comparing it to the electrified counterpart, other aspects which counteract with the establishment of electric mobility will be shown.

WEIGHT OF THE ENERGY STORAGE DEVICE (BATTERY WEIGHT)

Chemical energy storage systems available are lower in energy density than gasoline or diesel. Modern lithium ion accumulators are reaching a gravimetric energy density of about 160Wh/kg. This means, that they can reach just about one percent compared to gasoline or diesel with energy densities of about 12,000Wh/kg [3]. Taking into account average efficiencies, a battery weighing of 870kg would be

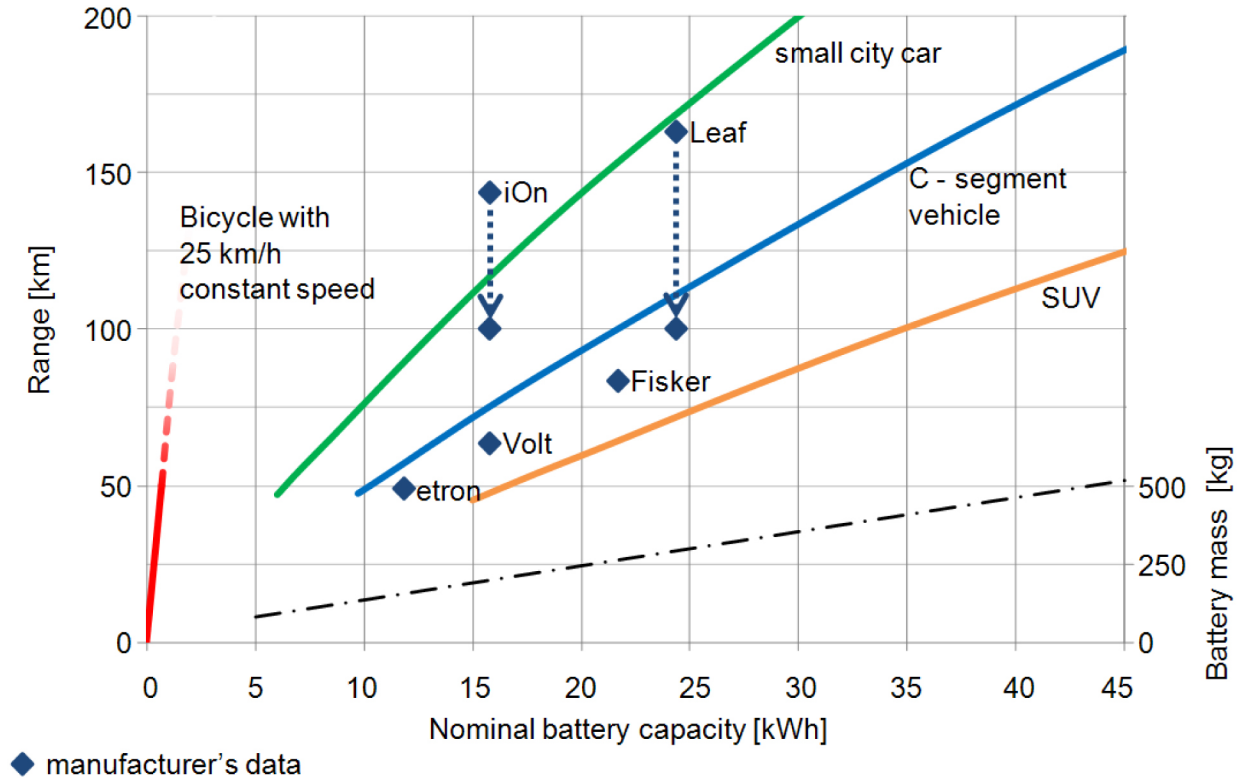


Figure 2. Influence of vehicle size on electric cruising range in the NEDC [2]

required to store the same amount of energy as 50l (equivalent to approximately 38kg) of gasoline for vehicle propulsion [4]. The vehicle which is used for the comparison has a battery capacity of about 27kWh. This results in a battery weight of 170kg. The gasoline vehicle has a fuel tank of 50l. Fuel and peripherals have a weight of about 45kg. Therefore the total weight of the energy storage system of the combustion engine driven vehicle is about 70% lower than the weight of energy storage system of the electric vehicle.

VEHICLE COSTS

In the opinion of experts, the costs of an electric vehicle will never reach the low level of ICE driven vehicles. According to publications of the Boston Consulting Group, the costs of modern lithium-ion (Li-Ion) accumulators are about 800USD/kWh which means that the battery costs of a vehicle with 10kWh to 20kWh are between 8000USD and 16000USD.

In addition, because of the cyclical and/or calendrical aging process also the residual value of the accumulator is problematic. Schwacke estimates that the residual value will be just 10% of the initial price after 5 years in operation [5]. A battery leasing concept moves the costs, but do not solve the problem. A marginal cost analysis conducted by Roland Berger says, that the current battery price of about 700USD/kWh shows a clear, on further cost reductions and via economics of scale exploitable cost reduction potential.

However, the study also mentions that costs may bottom out at 265USD/kWh. Also in future the total costs of the battery system will be a limiting factor in the dimensioning of the vehicle cruising range. The available cost reduction potential is shown in Figure 3. Related to the investigated vehicles there is an acquisition cost difference of about 40% in favour of the gasoline vehicle.

CHARGING TIME

An often underestimated aspect is the required charging time. While the refuelling time of a conventional ICE driven vehicle just takes few minutes, the charging time of electric vehicles normally takes hours. This fact leads to a relevant reduction of flexibility when using electric vehicles.

Fast charging strategies induce increased battery damage and the necessary infrastructure can be rarely found. Therefore they are just partially suitable to solve the problem.

In the current example, the electric vehicle requires a charging time of seven hours. If assumed that it takes maximum 5 minutes to fill up the conventional vehicle and that the battery could be charged by using a fast charging strategy up to 80% state of charge in just a quarter of the stated time, it follows, that for the electric vehicle the twentyfold charging time is needed. In other words: The

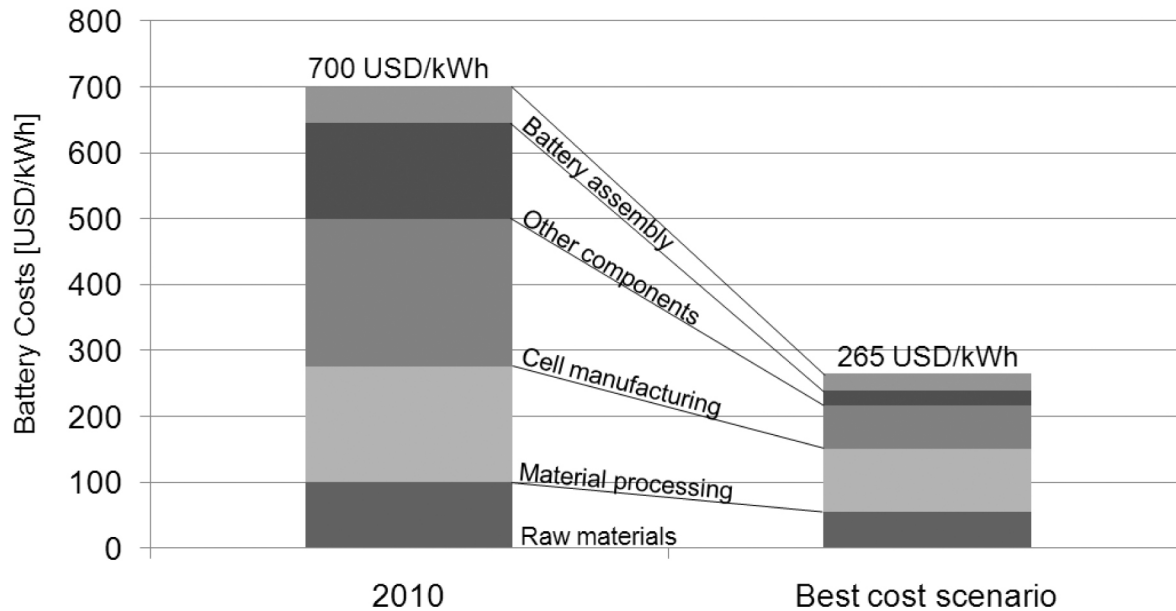


Figure 3. Cost reduction potential of batteries

gasoline driven vehicle requires only 5% of the charging time of the electric vehicle.

RANGE

Reasonable battery sizes and battery costs are the most discussed problem of electric mobility. Due to the high relevance, this point will be discussed in the following chapter more precisely.

In the current example the electric vehicle has a maximum range of 150km and the gasoline powered vehicle has a range up to 1000km.

Figure 4 shows the comparison results of the two vehicles. The crucial factor is that for the establishment of E-Mobility all four problems must be solved and not just one. Therefore it doesn't help to adapt the range of the electric vehicle by increasing the battery size to the range of the conventional vehicle, if a significant increase in cost, weight and charging time can be expected.

5. RANGE PROBLEM OF ELECTRIC DRIVEN VEHICLES

As already mentioned before, the electric cruising range, taking into account reasonable charges and battery sizes, is much smaller than the range of conventional vehicles. In Figure 5 the range of an electric vehicle with a nominal battery capacity of 10kWh and the range of a gasoline vehicle with a full tank (501) and with reserve (71) under ideal conditions and constant speed is shown. As shown, the electric cruising range at best only reaches the reserve range of the conventional vehicle at lower speeds. With higher

speeds, this decreases considerably. This effect, which can also be seen in Figure 7, is due to the rise in losses because of rolling resistance at nearly constant efficiency of the electric motor. With conventional vehicles this effect is smaller because the increasing losses will be partially compensated by the increasing efficiency of the combustion engine.

In Figure 6 this fact is shown graphically. Efficiency of the electric motor was calculated with a simulation model. The efficiency of the combustion engine was determined from measured consumption values. Both cases are assuming constant speed. While the efficiency of the electric motor from about 10km/h remains approximately constant at 80%, the efficiency of the combustion engine rises continuously from below 10% up to about 30%. Efficiencies may vary according to transmission design, but the general tendencies for possible cruising range remain the same.

This, strong speed dependent reduction of the cruising range, is contrary to the actual experiences of customers when using conventional vehicles. Therefore electric vehicles are more useful at lower speeds where longer ranges can be reached. In this area, improvements in battery technology also lead to a higher increase of range. To illustrate this effect again Figure 7 shows the range progression in percentage of the electric and conventional vehicle, based on the same maximum range. The electric cruising range reaches its maximum at about 18 km/h and drops down to about 25% at a speed of 130km/h, which represents a decline of 75%. The conventional vehicle reaches its maximum at about 70 km/h and drops down to about 65% at a speed of 130km/h, which represents a decline of 35%.

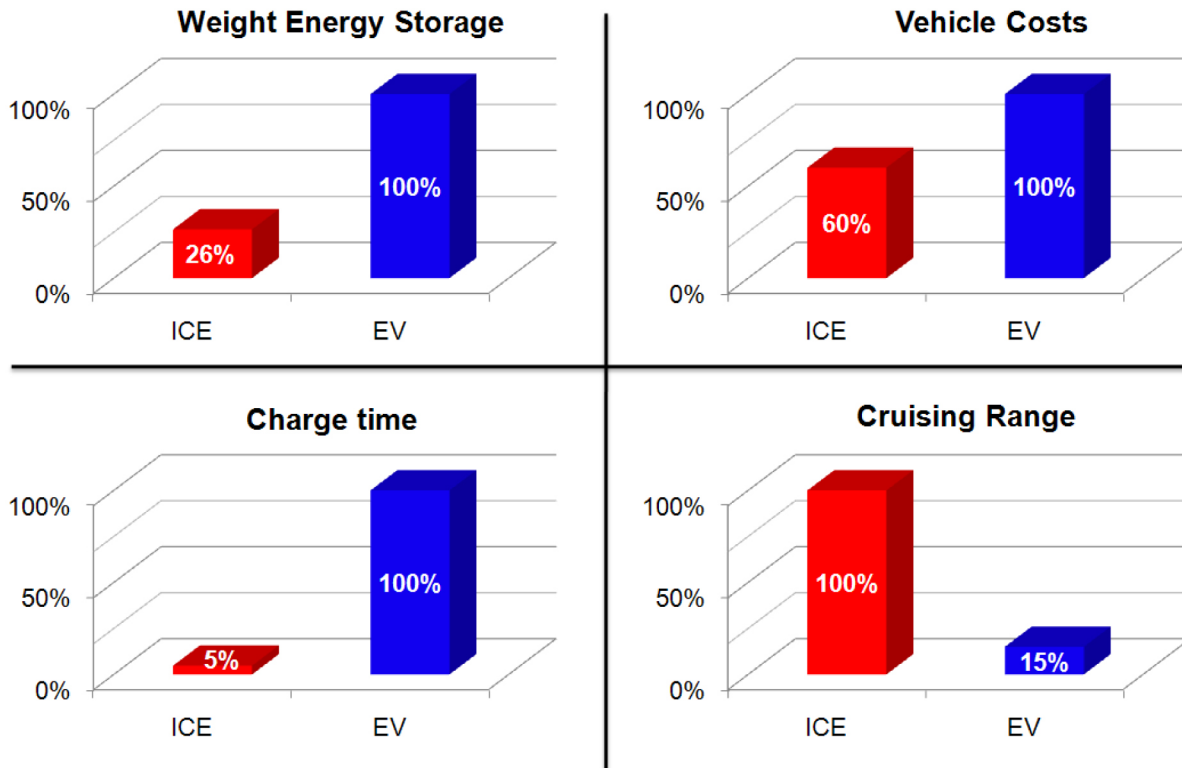


Figure 4. Combustion engine vs. electric propulsion

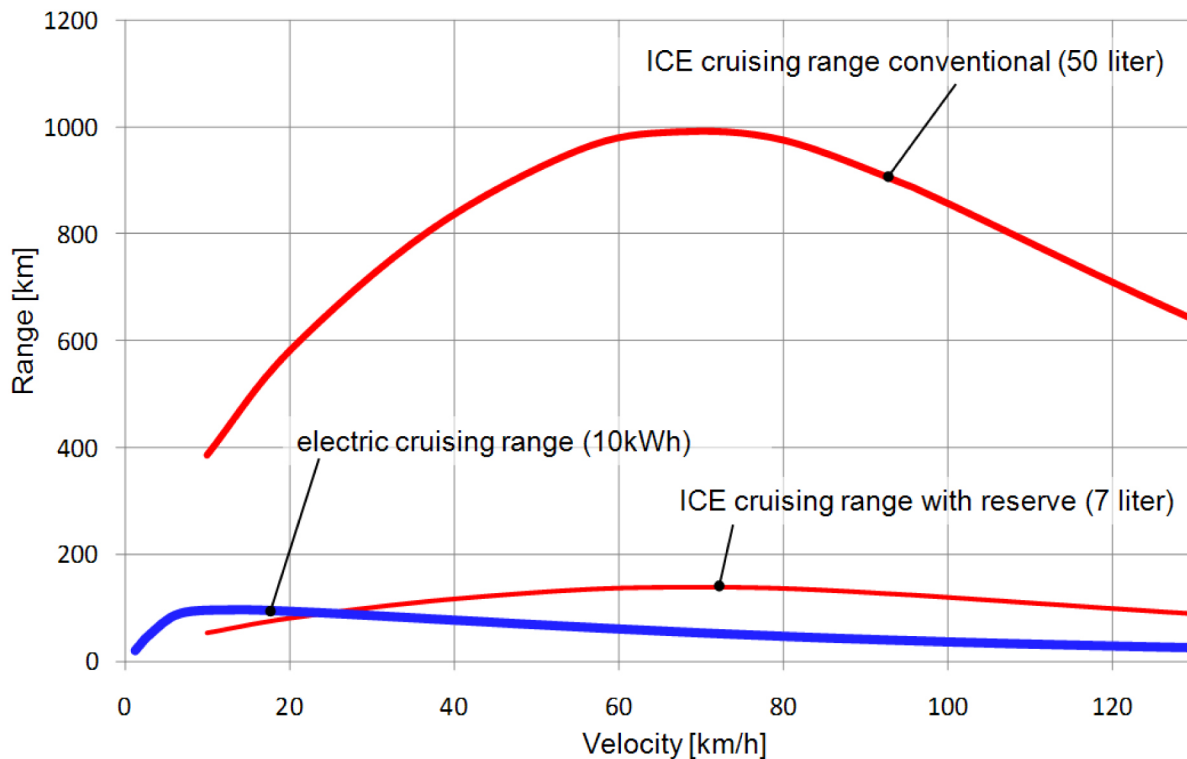


Figure 5. Range comparison (ICE vs. EV) at constant speed