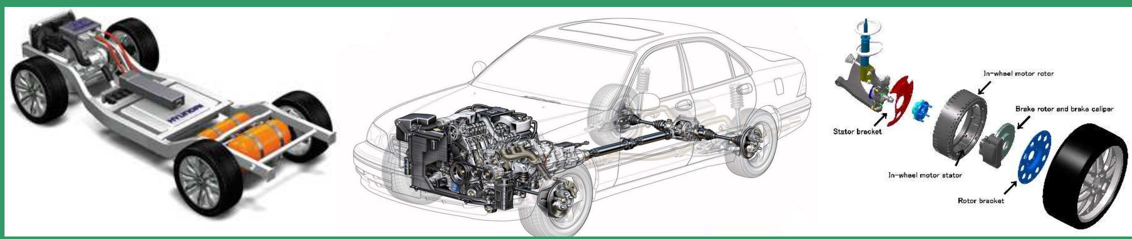
A cost- and benefit analysis of combustion cars, electric cars and hydrogen cars in the Netherlands

The development of the costs and benefits of cars powered by gasoline, electricity and hydrogen in the Netherlands in the period 2008 – 2030



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Preface

I would like to thank all the people that contributed to this study. I am especially thankful to Rembrandt, Peter and Pieter from Peakoil Netherlands. Your feedback and the provided information contributed a lot to the quality of the study.
I also would like to thank Jan Heetebrij and Emil Möller from HeeCon Business Development for assisting me with the research by providing valuable feedback and data. Other people that I would like to thank are Douwe Beerda and Rob Winkel from Ecofys, Daan Nap from Epyon and Willem van der Kooi from ECEcars. Finally I want to thank my supervisor, Dr. Lars Hein, for the feedback that kept me focussed and structured during the research. It was a really positive experience to work together.

Summary

The attention for electric and hydrogen vehicles is growing worldwide because of oil price fluctuations, uncertainties in the future oil security and increased attention for environmental issues. Recently Israel, Denmark, Portugal and California announced the large scale implementation of electric cars in the near future. In California hydrogen refuelling stations are being established and hydrogen cars introduced.
For a country like the Netherlands it is interesting to consider a transition to electric- or hydrogen cars. The Netherlands are densely populated which offers cost advantages over the construction of an energy infrastructure for electric or hydrogen cars. Electric- and hydrogen cars offer advantages such as a reduced dependency on oil, the reduction of CO_2 and PM_{10} emissions and the lower price of electricity compared to oil.

The goal of this research is to compare the costs of driving an electric- and hydrogen car to the costs of driving a car with an internal combustion engine for the Dutch situation.
The prices of the cars are compared to each other by calculating the depreciation costs, fuel costs, fixed costs and costs related to repair, maintenance and wheels for the different car types. Scenarios are developed in which the annual driving distance, the period of car ownership, the energy price development and the specific traffic conditions are described. In a benchmark the costs per kilometre of the electric- and hydrogen car are compared to the costs of the car with an internal combustion engine for the years 2008, 2020 and 2030. Scenarios are developed to estimate the cost developments until 2020 and 2030.

According to the benchmark which is performed in this study the costs per kilometre of the electric car are lower then the costs of the hydrogen car and the car with an internal combustion engine for all the calculated years. The total costs per kilometre of the electric car are lower for the situation in 2008 and are estimated to remain lower for the situation in 2020 and 2030. Especially the lower fuel-, tax and maintenance costs of the electric car offer cost advantages compared to the car with an internal combustion engine.

Besides economic benefits the electric car offers other advantages such as a reduced oil dependency, a better environmental performance and reduced environmental costs. Electricity can be produced from a variety of sources which makes it less vulnerable for large price fluctuations. A transition to electric cars makes the Netherlands less dependent on oil from political unstable regions. Compared to cars with an internal combustion engine the drive-train of electric cars is much more efficient which results in environmental benefits such as a reduced energy use and a reduced CO_2 and PM_{10} production.

The performances of the electric car with an advanced Lithium-ion polymer battery are sufficient for most consumers, the major electricity infrastructure is already in place, the production costs of electric cars are decreasing, electric cars require little maintenance and production facilities are realized to produce large numbers of electric cars in the near future.
The government could stimulate the large scale implementation of electric cars by: subsidizing R&D projects related to improvement of electric cars and the necessary electricity infrastructure; switching to electric vehicles themselves and stimulating companies and organisations to do the same; offering fiscal advantages to electric car drivers; covering the initial battery costs and leasing the batteries to electric car drivers; stimulate electricity companies to develop an infrastructure for electric cars.

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1. Introduction

The past decade the global oil price per barrel showed large fluctuations. Despite the fluctuations the price of oil increased significantly from an average price of less then $15 per barrel in 1998 to an average price of over $75 in 2007. During 2008 the oil price showed extreme price fluctuations with daily oil prices ranging from $70 to $140 per barrel. The main reasons for the increasing oil price are the growing global demand for oil and the limitations in the production capacity to supply the growing demand. In the near future the demand for oil will increase further because fast growing economies such as India and China demand increasing amounts of oil.
At some point the global commercially available oil reserves will reach a maximum and start to decline. This moment is called 'peak oil'. It is not certain when this situation will be reached but experts in the oil sector expect that it will take place between 2010 and 2020 (*Hirsch, 2005*). Major investments are necessary to increase the production capacity of unconventional oil resources sufficiently to meet the growing global demand for oil.
Between 1997 and 2007 the average global oil production increased from 70 million to 80 million barrels per day. It is estimated that the global oil demand will increase further to almost 120 million barrels per day by 2030 (*EIA 2006 and NPC 2007*)
Of all the sectors in an economy, the transportation sector is most dependent on oil. In the United states for example the transportation sector accounts for 68% of the overall oil demand (*IEA, 2005*). Measures need to be taken to anticipate on possible future oil related problems in the transportation sector such as: 1. oil shortages 2. rising oil prices 3. fluctuating oil prices and oil availability 4. dependency on oil from political unstable regions.
In this study I will focus on electric and hydrogen vehicles as a possible method to decrease the oil dependency of the Dutch transportation sector.

Electric- and hydrogen cars
Despite the continuous technical improvements the internal combustion engine (ICE) that powers the majority of the cars is still very energy inefficient. In the combustion process in which the energy stored in the oil is converted to mechanical energy only 15 % is left for the actual movement of the car and powering the accessories. The majority of the energy is converted to heat and leaves the car through the exhaust or by the cooling water *(USDOE 2008)*.
A solution for both the dependency on oil and the inefficient combustion engines is the electromotor. Compared to the internal combustion engine the electromotor is more efficient and it is powered by electricity which can be produced from a big variety of sources. The energy efficiency of an electric vehicle (EV) is about 75% (*Bossel 2003 and IEA 2005*). An other alternative for the ICE car is the hydrogen car (H_2 car) in which hydrogen is used to power an electromotor.
Several pilot projects are realized in which EVs and H_2 cars and the related infrastructure are realised in practice. In Israel the company Project Better Place is working together with the Israeli government and car manufacturers Nissan/Renault to build EVs and realize an energy infrastructure for EVs. In Denmark and Portugal similar developments are taking place *(Project Better Place 2008)*. In California H_2 refuelling stations are realized and Honda started the production of a H_2 car for the Californian market.

Purpose of the study
For a country like the Netherlands it is interesting to consider a transition to EVs or H_2 cars. The Netherlands is highly dependent on oil and no good alternatives for oil are available (*Appendix 1*). A transition to EVs and H_2 cars can offer advantages such as a reduced dependency on oil, the reduction of CO_2 emissions a better vehicle efficiency and related economic benefits.

The goal of this research is to compare the costs of driving an EV and H_2 car to the costs of driving an ICE car for the Dutch situation. The research consists of the following research questions:

- How will the average Dutch price of gasoline, H_2 and electricity develop in the periods 2008-2020 and 2020-2030 by multiple scenarios?
- What are the price differences between an EV, H_2 car and ICE car, which developments will influence the price of EVs, H_2 and ICE cars in the period 2008-2030 and what are the costs for the realization of an infrastructure for EVs and H_2 cars?
- What are the current cost implications for car users if a transition to EV and H_2 cars is made and how will these cost implications develop in the periods 2008-2020 and 2020-2030?

2. Methodology

2.1 Approach

In this study the total costs of an ICE car are compared to the total costs of an EV and H_2 car for the Dutch situation. The current costs per kilometre of ICE-, electric- and H_2 cars are described and the expected development of these costs by 2020 and 2030. Scenarios are developed which describe the driving behaviour of the car owner. A benchmark is performed in which the costs and benefits of the different cars are compared to each other by combining the costs of the different cars with the driving behaviour scenarios. The values of the parameters are based on literature review and expert interviews.

2.2 Model

The total costs of driving an ICE-, EV and H_2 car are calculated by a model which is based on cost related aspects of the different cars (*ANWB 2008*). The aspects on which the model is based are: 1. fuel costs per km 2. depreciation costs per km 3. fixed costs per km (road tax, insurance and membership AA patrol) 4. maintenance and repair costs per km. In my research I added a fifth aspect which includes the costs related to the km tax which I expect to be implemented by 2020. The data on which the model is based are described in chapter 2.3 and is gathered by literature research and expert interviews. The model is the basis of the final benchmark in which the total costs of ICE car, EV and H_2 cars are compared with each other for the current situation and the situation in 2020 and 2030.

2.3 Data gathering

In this study a description of the developments in the global oil market is given which is based on literature research and personal communication with experts. Literature research is performed to identify the current and expected future price developments in the Dutch oil, electricity and hydrogen sector. Data from literature research and expert interviews are combined to develop scenarios for the price development of oil, electricity and hydrogen in the Netherlands in the periods 2008-2020 and 2020-2030.
The literature sources that will be used in this chapter are recent reports from the IEA (International energy agency), NPC (National Petroleum Council), EC (European Commission), CBS (Centraal Bureau voor de Statistiek), ECN (Energie Centrum Nederland) and others. Experts in the international and Dutch energy sector are interviewed as well as stakeholders in the electric car and hydrogen car sector.
The expected developments in the ICE-, electric and H_2 car industry are described until 2030. Both the technological developments in the design of ICE-, electric and H_2 cars are described as the developments in the energy infrastructure of EVs and H_2 cars in the Netherlands. The expected costs and benefits related to the technical developments in the design of the cars and the energy infrastructure are described. A variety of energy infrastructure options for EVs and H_2 cars and their related costs are described because there are multiple technologies to realize such an infrastructure.
Scenarios for the current and expected future price developments in the Dutch oil, electricity and hydrogen sector are combined with expected data concerning the price developments in the design of the different cars and the related energy infrastructure. Based on literature research and expert interviews assumptions are made concerning the chosen energy infrastructure that will be implemented for EVs and H_2 cars. A benchmark is created in which the total costs per km for the different cars can be calculated for a selected scenario. The selected scenario depends on aspects such as the oil-, electricity and hydrogen price development, the amount and kind of driven km's and the development of taxes for cars. In the benchmark the costs per km for ICE-, electric and H_2 cars are

compared with each other for the current situation in the Netherlands and the situation in 2020 and in 2030.
In the discussion the results of the research are described and critically analyzed and in the conclusion the research questions will be answered. Finally policy recommendations will be given.

Borders of the research
All the future price scenarios are adapted for the expected inflation level of 2% per year

The timeframe of the model is from 2008 until 2030. The costs and benefits of driving EVs and H_2 cars compared to ICE cars will be calculated for the current situation and the situation in 2030.

The study refers specifically to the situation in the Netherlands. The cost and benefit analysis is based on current Dutch data and the expected situation in the Netherlands in 2030.

In the cost and benefit analysis that is made in this study the costs refer to the costs per km for the car owner. The costs of EVs and H_2 cars are compared to the costs of an ICE car. The benefits refer to the possible cost advantages per km of EVs and H_2 cars over ICE cars. The costs per km are based on the depreciation costs, fuel costs, maintenance costs, fixed costs and taxes.

The additional costs per km for the energy infrastructure of EVs and H_2 cars are expected to be implemented in the fuel price of the specific fuel. For the current situation EV drivers do not need an additional energy infrastructure because they can simply plug in their EV at home. By 2030 the EV energy infrastructure consists out of charging poles at parking lots and additional fast charging facilities. H_2 cars demand an refuelling infrastructure from their introduction on because there is no possibility yet to refuel hydrogen. The costs for this hydrogen infrastructure is implemented in the fuel costs of H_2 cars from 2008 on.

The cars that are compared with each other correspond in size, have a range of over 300 km on a charge and a maximum speed of over 130 km/h. The price, weight, power output, range and other aspects may differ but this is related to the differences in car technology. In general basic subcompact models of an EV, H_2 car and ICE car are selected.

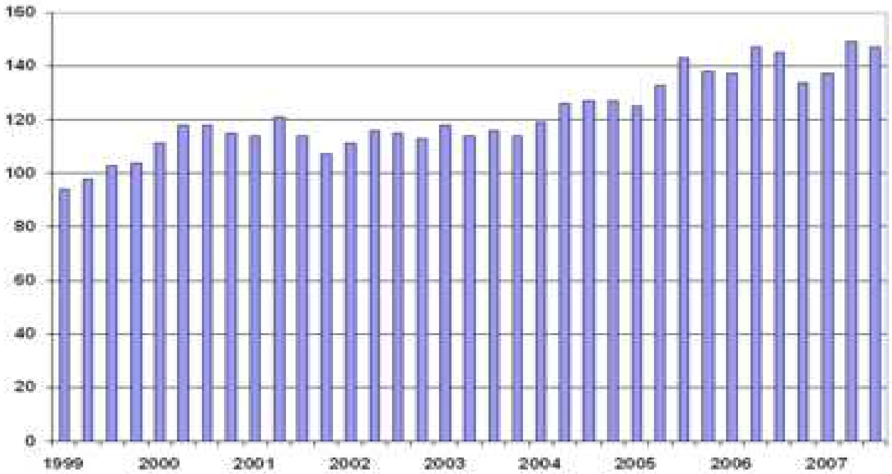
The values of the parameters of the cost and benefit analysis are based on scenarios and projections of organizations, institutions and experts.

3. Development of Dutch oil, electricity and H_2 price

3.1 Oil price development in the Netherlands

The global oil price has risen significantly over the past decades. From the high oil price during the second energy crisis (1979 – 1980) the oil price dropped to an average price of $25 per barrel in 1986 and to less than $20 per barrel 1998.
In 1999 the oil price started to increase again. Despite several price fluctuations the oil price increased gradually to an average price of $66.40 per barrel in 2007 (*Inflationdata 2008*).
The global oil price rise caused significant effects on the petrol price in the Netherlands because they are coupled (*table 1*). In the period 2000 – 2007 the average price of a litre of petrol (Euro 95) at a fuel station increased with more then 40%.

Table 1: Average Dutch petrol price in €/ct per litre Euro 95 (CBS)



In the Netherlands the oil price projections of the IEA are the basis of current policy development. The oil price predictions until 2030 of the IEA have not been consistent over the years (*Figure 1*). Just as the oil price predictions of other agencies and organisations the oil price predictions of the IEA have been adjusted continuously over the past decade. The rising global oil price forced a continuous adjustment of the predicted oil price by 2030.

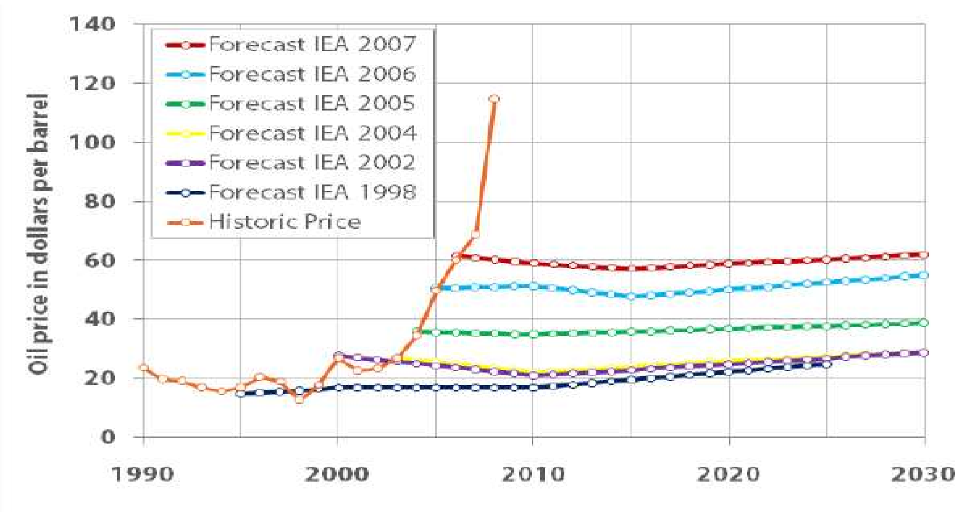


Figure 1: Global oil price forecasts from several years (IEA)

The prediction of the global oil price is complicated because it depends on different aspects. In the period 1998 – 2007 the global oil price increased significantly. In June and July 2008 the global oil price reached a peak of over $140 for a few days after which it started to decrease rapidly again. No model is able to predict the development of the oil price exactly because aspects such as the global demand for oil, the economic situation, technical developments and geopolitical tensions are unpredictable.

Dutch petrol price scenarios
In this study 2 scenarios are created for the petrol price development in the Netherlands.
The first scenario is based on IEA assumptions from 2008 which assume an average global oil price of over $100 per barrel between 2010 and 2030 (*Figure 2*)

Figure 2: Average IEA crude oil import price (annual data) (IEA 2008)

In this scenario the Dutch petrol price increases from the 2007 average of €1.40 per litre (Euro 95) to €1.50 per litre in 2020 and €1.60 per litre in 2030. The energy content of gasoline is 34.3 MJ/l which results in a price of €0.15 kWh in 2008, €0.16 kWh in 2020 and €0.17 kWh in 2030.
In the second petrol price scenario it is assumed that the predicted oil reserves are insufficient to meet the growing global oil demand which will cause a global oil scarcity. At the same time the predicted global oil reserves are smaller then expected, the production costs increase because more energy is necessary to produce the less quality oil. Compared to the first scenario the global oil price is expected to increase to a higher level in the second scenario. In this scenario the Dutch petrol price is expected to increase gradually to €2.00 by 2030 which is equal to an annual inflation corrected gasoline price increase of 1.56%. In this scenario the Dutch petrol price will be €1.7 per litre (Euro 95) by 2020. The price of gasoline increases to €0.18 kWh by 2020 and to €0.21 kWh by 2030 in this scenario (*Goldman Sachs 2008 and personal communication with R. Koppelaar 2008*).

3.2 Electricity price development in the Netherlands

The Dutch electricity market is part of the North-Western European electricity market in which also countries such as Germany, Belgium and France are integrated. Possibly Norway and England will become part of this North-Western European electricity market after 2008.
The Dutch electricity price for small consumers has risen significantly over the past decade (*Figure 3*). The electricity price of households (100 kWh) increased from €14.21 in January 2000 to €23.00 in Januari 2008 (*CBS 2008*). Since 1991 the household price of electricity is more then doubled in the Netherlands. The electricity price in the Netherlands is one of the highest in Europe and the coming years it is expected to increase further (*ECN 2004 and European commission 2007*).

The Dutch electricity price is linked to the price of natural gas which is the main source of electricity in the Netherlands (*Figure 4*). Natural gas is also the energy source which is used to produce the additional electricity during peak-demand because the power-plants powered by natural gas can be easily switched on and off.

The past decade the price of natural gas increased gradually which resulted in a higher electricity price (*Personal communication with R. Koppelaar 2008*). On the other hand the prices of sustainable produced electricity are decreasing every year and it is expected that this will have an effect on the electricity price the coming decade (*Appendix 2*).

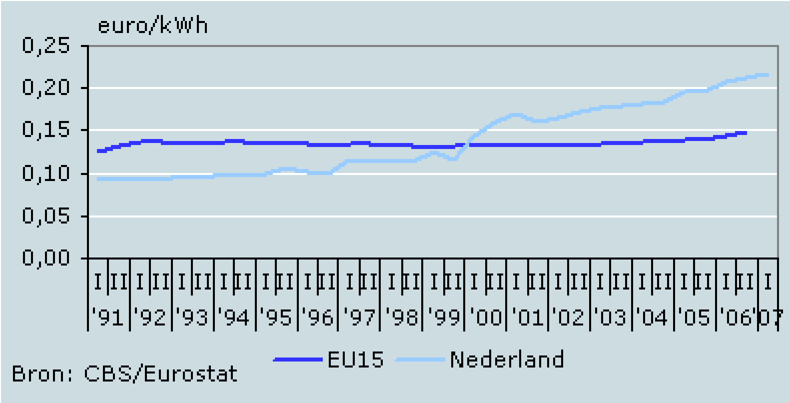


Figure 3: Electricity price development EU15 and the Netherlands (CBS 2007)

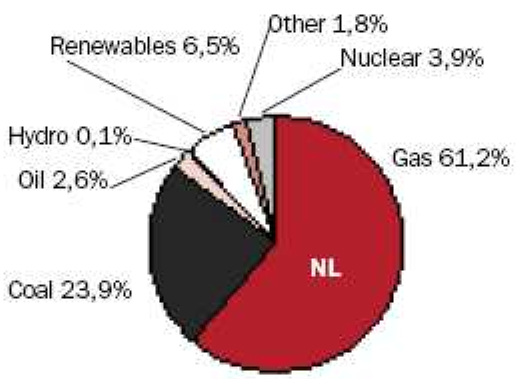


Figure 4: Fuel mix for electricity production in the Netherlands (Energieraad 2008)

Dutch electricity price scenarios

In this study the development of the Dutch electricity price until 2030 is based on two scenarios. The two scenarios that are created in this study are based on assumptions concerning the future state of the parameters that influence the Dutch household electricity price.

In the first scenario it is expected that during the period 2008 – 2013 the Dutch electricity price will increase at the same rate as it did in the period 2000 – 2008. Corrected for the expected level of inflation this means an average price increase of 4,5% per year for the Dutch households. After 2013 the electricity price is expected to decrease gradually to the price level of 2004 with an inflation corrected percentage of 1,5% a year. This price decrease is caused by investments in smart electricity grids and the realization of a more efficient energy infrastructure. By 2020 this scenario would result in a household electricity price of €0.26 kWh and €0.22 kWh by 2030 (*Personal communication with R. Koppelaar 2008).*

In the second scenario it is also expected that in the period 2008 – 2013 the Dutch electricity price will increase at the same rate as it did in the period 2000 – 2007. After 2013 it is expected that the rate of increase will be reduced to 1,5% per year. In this scenario the continuous price increase is caused by a scarcity on the electricity market. Too less money is invested in an improved electricity grid while the price of natural gas increases gradually. In this scenario the current household electricity price of €0.23 per kWh is expected to increase to €0.32 kWh by 2020 and to €0.37 kWh by 2030 (*Personal communication with R. Koppelaar 2008) (Appendix 3*).

3.3 H_2 price development in the Netherlands

H_2 can be produced by different processes such as reforming natural gas and the electrolysis of water. In a fuel-cell H_2 car the H_2 is converted to electricity which is used to power the electromotor of the car. H_2 can be stored either liquefied or compressed in a fuel-cell H_2 car. At the moment no infrastructure is available in the Netherlands to fuel a H_2 car because the development of a H_2 car infrastructure demands large investments. A H_2 infrastructure consists out of centralised or decentralised H_2 production facilities, a H_2 distribution system (only with centralised H_2 production) and H_2 refuelling stations. The H_2 can be produced by multiple processes but the centralised electrolysis of water or reforming natural gas seems to be the most economical. H_2 can be distributed either by pipeline or by truck. The construction of a H_2 pipeline demands big initial investments and relative high transportation costs because of the low energy density of H_2. The distribution of liquid H_2 by truck is expensive because of the energy which is necessary to liquefy the H_2. The H_2 refuelling stations are complex because the cooled or compressed H_2 needs to be stored before they are transported to H_2 cars.
There are few examples of the realization of a H_2 infrastructure but in Amsterdam (Netherlands) a pilot project is running where H_2 is produced decentralised to power 4 city buses. The H_2 is produced by the electrolyse of water. The capacity of the H_2 fuelling station is 60m3 of H_2 per hour which is equal to 120 kg H_2 per day. The H_2 production facility costs €750,000. With a price of €0.23 kWh the 4.8 kWh of electricity which is necessary to produce 1m3 of H_2 costs €1.1. The depreciation costs over the installation are €0.31 m3/ H_2 if calculated with an installation lifetime of 5 years. In this project the total production costs for a m3 of H_2 are €1.41 (*Duurzame Energie Thuis 2008*).
The physical density of H_2 is 84 g/m3, the specific energy content of H_2 gas is 142 MJ/kg which results in an energy content of 11.8 MJ or 3.3 kWh per m3 of H_2. In the project in Amsterdam 1.5 kWh electricity is necessary to produce 1 kWh of H_2 which results in energy costs of €0.35 kWh H_2. The depreciation costs of the installation are €0.31 / 3.3 kWh H_2 = €0.09 kWh H_2 which brings the total H_2 production costs on €0.44 kWh. In this cost price no taxes and profits are included.

Dutch H_2 price scenarios

In this study the development of the Dutch H_2 price until 2030 is based on scenarios. Two different scenarios are created which are based on assumptions concerning the future state of the parameters that influence the Dutch H_2 price. In the 2 scenarios it is expected that the H_2 will be produced decentralised at H_2 refuelling stations because it is not expected that centralised H_2 production plants and the necessary distribution infrastructure will be realized within the next 2 decades. The H_2 will be produced by reforming natural gas because this is the cheapest method to produce H_2 (*Tesla 2007 and Smit et al. 2006*).
In the first scenario the price of H_2 decreases by producing it on a larger scale in decentralised H_2 production plants which are located next to H_2 refuelling stations. Not much data is available concerning the construction costs of H_2 production facilities and a H_2 infrastructure but in an ECN study it is estimated that the total H_2 production costs of a small scale reformer installation that produces 631 kg of H_2 per day are €2.2 kg/ H_2 (*Smit et al. 2006*).
With an energy content of 39.4 kWh/kg the production costs of H_2 are €0.056 kWh which includes the depreciation costs over the natural gas reformer. The ECN study assumes tax costs of €0.076 kWh over H_2. The ECN study contains a lot of uncertainties and assumptions because a large scale H_2 production and distribution infrastructure has never been realized and because it models the situation until 2050. By including a profit percentage for the refuelling stations the price of H_2 is estimated to be at least €0.15 kWh by 2020 and €0.18 kWh by 2030.
In the second scenario the H_2 is also produced decentralised at the refuelling stations. In this scenario the construction costs of the reforming stations are expected to be higher and the natural gas price is expected to increase at a higher rate. In this scenario the costs of H_2 are expected to reach €0.18 kWh by 2020 and €0.22 by 2030.

3.4 Oil, electricity and H_2 price scenarios

In chapter 3.1 the price development of gasoline in the Netherlands is described by 2 scenarios. In the first scenario the price of petrol (Euro 95) is expected to increase to €0.16 by 2020 and €0.17 kWh by 2030. In the second scenario the price of petrol is expected to increase to €0.18 kWh by 2020 and €0.21 kWh by 2030 (*Table 2*). In chapter 3.2 the price development of a kWh electricity in the Netherlands is described by 2 scenarios. In the first scenario the price of a kWh of electricity is expected to increase to €0.26 kWh by 2020 and decrease to €0.22 by 2030. In the second scenario the electricity price is expected to increase to €0.32 kWh in 2020 and €0.37 kWh by 2030.

In chapter 3.3 the price development of H_2 in the Netherlands is described by 2 scenarios. In the first scenario the price of a kWh of $H_2$is assumed to be €0.15 kWh by 2020 and €0.18 kWh by 2030. In the second scenario the price of a kWh of H_2 is expected to increase to €0.18 kWh by 2020 and €0.22 kWh by 2030 (*Figure 5*)..

Table 2: Price scenarios for gasoline, electricity and H_2 in the Netherlands

Year	gasoline price (kWh Euro 95) Scenario 1	gasoline price (kWh Euro 95) Scenario 2	electricity price (kWh) Scenario 1	electricity price (kWh) Scenario 2	H_2 price (kWh) Scenario 1	H_2 price (kWh) Scenario 2
2008	€0.15		€0.23		€0.44	
2020	€0.16	€0.18	€0.26	€0.32	€0.15	€0.18
2030	€0.17	€0.21	€0.22	€0.37	€0.18	€0.22

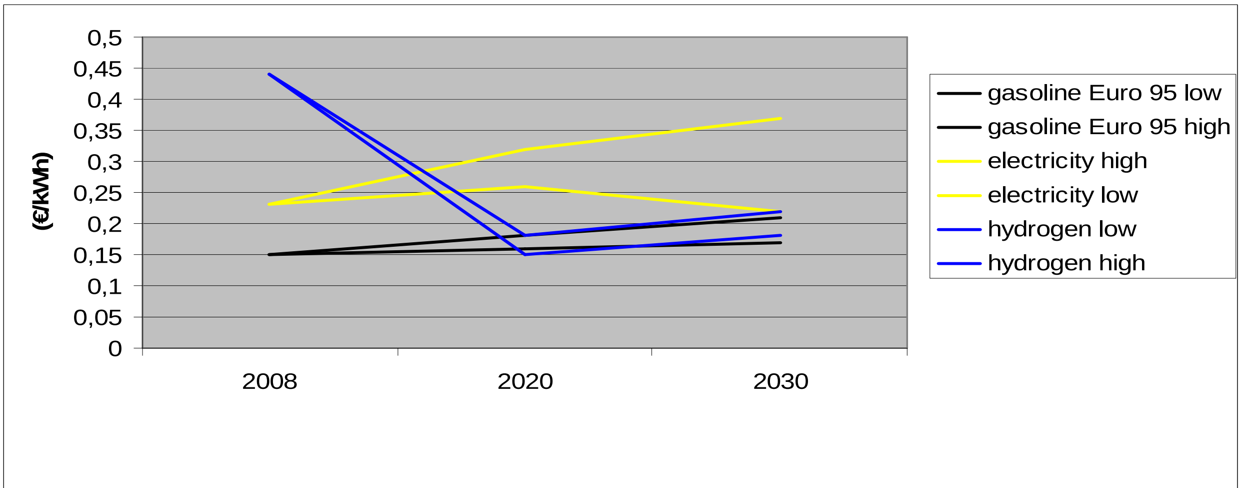


Figure 5: Gasoline, electricity and hydrogen price scenarios

4. Developments in ICE, EV and H_2 car industry and infrastructure

4.1 EVs

4.1.1 EV history

The EV1 (*Table 3*), produced by General Motors (GM), is the best example of an EV that has been produced on a relatively large scale. As a reaction on the Californian Zero Emission Act, that forced car manufacturers to produce 2% of zero emission cars by 1998, GM started the production of the EV1 in 1996. At the same time an infrastructure for charging the EVs was realized in California.
GM spend 1.3 billion US$ for the production of 1057 EV1's and the state of California .
It was not possible to buy the EV1, it had to be leased for 250 – 500 US$ per month, depending on the model.
The production of the EV1 continued until 2000 and in 2003 all the EV1 drivers were ordered to return their cars. Besides GM also Ford and Toyota introduced an EV in California in the same period(*Table 3*) but not in such large numbers.
The EV1, Toyota RAV-4 EV and Ford Ranger EV had some major disadvantages compared to an ICE car such as the relative small range (50 – 100 mile) and the heavy pack of lead-acid (PbAc) batteries.

Table 3: Examples of EVs which have been in production (EVADC 2008)

	GM EV1	**Ford Ranger EV**	**Toyota RAV-4 EV**
Voltage	312-volt system	312-volt system	288-volt system
Range	75 to 130 miles	73 miles	125 miles
Top speed	80 mph (governed)	75 mph (governed)	78 mph (governed)
Weight	2,900 pounds / 1320 kg	5,400 pounds	3,480 pounds
Motor	3-phase AC, 137 hp	3-phase AC, 90 hp	56kW perm. magnet
Drive train	Front-wheel drive	Rear-wheel drive	Rear-wheel drive
Batteries	26 12-volt NiMH or PbA	39 8-volt VRLA	24 12-volt VRLA NiMH
Charger	220 volts/30 amp	240 volts/30 amp	220 volts/30 amp
Cost	Lease, $250+ /month	Lease, $350 /month	Lease, $477 /month

4.1.2 Technical developments in EV industry

Drivetrain of EVs

EVs are powered by an electromotor which is situated either in the front or back of the car. EVs can also be powered directly in the wheels by small electromotors which are located in the wheels according to the Direct-Drive-In-Wheel principle (DDIW). The electromotor is powered directly by electricity from a battery which is located in the front, back or middle part of the car (*Figure 6*).

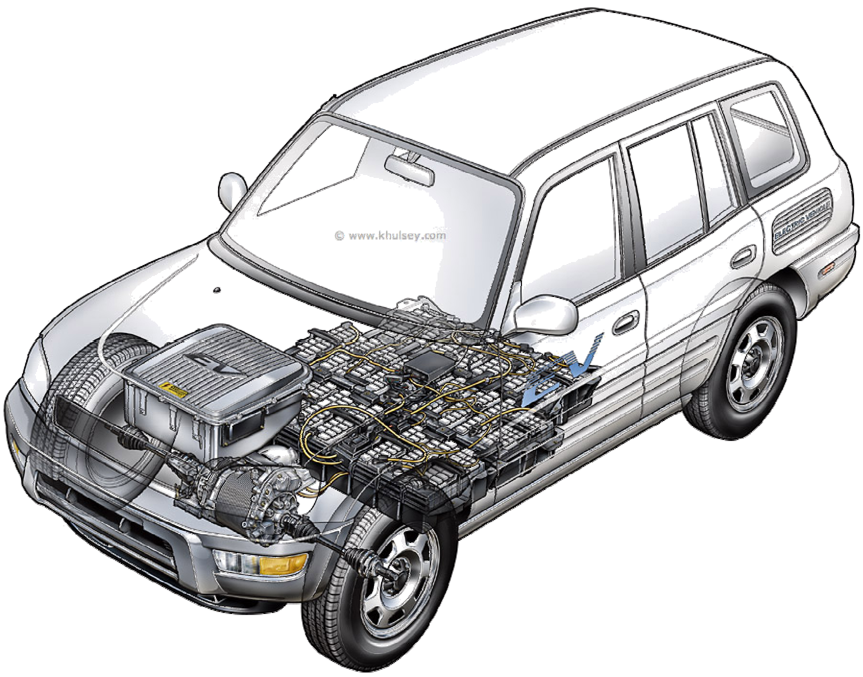


Figure 6: EV drive-train (*Khulsey 2008*)

Developments in EV design

At the moment technical innovations are in progress to improve the design of the EV. The major EV innovations are related to the battery because it is the most important part of the EV. Innovations are necessary to increase the range of the EV, enable fast charging of the battery, reduce the cost, reduce the weight and assure a longer lifetime of the battery.

Compared to an ICE car the battery is the limiting factor of the EV because the range of the EV is limited, it has a relatively high weight, a limited lifetime and is relatively costly. In the past not much EV battery related research and development projects were performed because of the limited interest of the market. Recently the development of improved batteries has been triggered by the growing interest in EVs.

The Li-ion polymer batteries ($LiFePO_4$) that are used nowadays in EVs provide significant power density advantages over the Pb-Ac and Ni-MH batteries which were used in EVs until now (*Table 4*). At the moment research facilities are set up by car manufacturers especially to construct better batteries for their EVs (*Appendix 4*). Car manufacturers such as Nissan, Renault and Toyota start partnerships with other companies to construct EV batteries with an increased energy density, cycle life, power output and which are able to resist fast charging. Despite innovations and an increased battery production which resulted in lighter, more durable and cost efficient batteries they are still expensive and heavy. Bigger batteries result in higher vehicle costs and vehicle weight (*Essent 2008) (Appendix 15)*. Battery technology for EVs is developing quick and an improved battery efficiency and reduced battery costs could cause an increasing EV range (*Appendix 14*).

Table 4: Comparison of battery technologies (Photon International 2008)

	Lead	**NiCd**	**NiMH**	**Li-ion**	**Li-ion polymer**	**Na-NiCl -Zebra**
Specific energy (Wh/kg)	25-45	50-70	50-70	100-140	110-150	90-120
Theoretically possible energy (Wh/kg)	175	240	300	> 450	> 450	788
Power density (W/kg)	50-100	150-200	100-200	100-200	120-200	200

Until an infrastructure for the fast charging of EVs has been established the range of the EV can be extended by an onboard, plug-in, range extender. The range extender is a small generator that produces additional electricity which is transported directly to the car battery if it is necessary to drive longer distances. The PEEC POWER generator that is developed in the Netherlands by Carver uses a new generator technology to construct a small, energy efficient onboard generator for electricity production (*Groenopweg 2008*). The range extender works on ethanol, bio-fuel or gasoline and provides electricity to the battery. Because the range extender is connected to the efficient electric drive-train it is estimated that the EV can drive 40 km on 1 litre of gasoline. The range extender is not in production yet but it is estimated that it has a power output of 30kW/h and a weight of 60kg (*Personal communication with J. C. G. Heetebrij from HeeCon 2008*).
Other improvements can still be made in the transmission of the EV. At the moment most EVs are powered by a central electromotor that transports the motive energy indirectly to the wheels. Electro motors for EVs are improved continuously by decreasing their weight, size and increasing their power. It is also possible to power the wheels of an EV directly by using the electricity from the battery to power small electro motors which are located in the wheels. The concept of powering the wheels directly is called 'Direct Drive In-Wheel (DDIW)' configuration. Disadvantages of this system are the higher costs, weight issues and legislative problems (*Appendix 14*).

Developments in EV energy infrastructure

The main infrastructure for the power supply of EVs is already established because the EV can be plugged in any power-point if the battery is empty. The EV charges in several hours if connected to a standard 230 V power-point and has a range of 200 - 300 km on a full battery. If the EV is used mainly for short distances the EV can be plugged in at households at night to be fully charged in the morning. Depending on the size of the battery and the power output the charging time varies from 2 – 7 hours. Charging the Detroit Electric Subcompact with 16A takes at maximum 7 hours (*Appendix 14*).
The large scale implementation of EVs demands a more advanced charging infrastructure capable of charging the EVs at parking lots and in a relatively short period of time. Charging poles (230V, 16-25A) and an automatic payment system need to be constructed at parking lots. The costs of such an infrastructure are not expected to be high because the main electricity infrastructure already exists. If EV owners want to travel longer distances an alternative for petrol stations should be developed where EVs can be charged in several minutes (*Appendix 5*). An EV can be charged in several minutes (15 minutes) at high voltage charging points (380V, +100A). Just like petrol stations these high voltage charging points should be evenly distributed over the Netherlands and have sufficient capacity (*Appendix 15*). In the Netherlands advanced ultra fast charging systems are already used to decrease the charging time of electric vehicles, such as forklift fleets, in warehouses (*Appendix 15*). Especially for electric vehicles that need to be continuously available ultra fast charging offers economic advantages. Forklift fleets, delivery vehicles and taxi fleets are suited for these systems. Future electric vehicles need to be adapted for ultra fast charging (*Appendix 15*). The energy efficiency of ultra fast charging systems is over 90%.
An other option is to construct fully automatic battery swapping stations where the empty batteries can be changed for a full one. These stations would be similar to a car-wash as far as that the

consumer drives the car in a tunnel and a robotic arm changes the battery instead of cleaning the car (*Project Better Place 2008*).

The charging of EVs provides opportunities for both car driver and electricity producer/distributor. Systems are being developed where the owner of the EV has the opportunity to charge the car at the lowest electricity tariff. If the EV is connected to a power-point the car owner can decide that it starts charging in the night when the electricity tariff is low. In the Netherlands the energy company Essent and the company 'EVs Europe' developed the Mobile Smart Grid (MSG) which enables EV drivers to charge more easy. If a car is plugged in to the electricity grid it is recognised by the system and the bill will be sent automatically to the car owner. The system also enables the car owner to charge the car at the lowest electricity tariff (*Essent 2008*).
EVs can be an interesting development for electricity companies because the charging of the EVs will generate additional income. EVs increase the flexibility of the electricity grid because they will be mainly charged in the night when the electricity price and the demand for electricity is low. In this way the peak electricity demand during the day is flattened because of the higher electricity consumption at night. During the day when the demand for electricity is high the plugged in EVs can serve as an electricity buffer by providing their stored electricity at a relative high price to the electricity grid (*Essent 2008*). The EV can contribute to the development of a smart electricity grid in the Netherlands in which a more diverse, sustainable and flexible electricity production are integrated (*Appendix 6*). Compared to conventional electricity grid, the High-Voltage Direct Current power lines enable a much more efficient electricity transport. Electricity companies, car lease companies and the government could be the suited parties to set up a battery lease contract with the EV car owners according to the Project Better Place model (*Project Better Place 2008*). Car owners lease the battery from the electricity company and do not have to pay the costs for the battery when they buy a new car. The car owners pay a monthly fee for the battery and the used electricity (*Appendix 15*).

4.1.3 Price developments in EV design and energy infrastructure

Price developments in the design of EVs
The costs which are related to the EV can be divided in: 1. Depreciation costs over the new price of the car 2. Fuel costs 3. Fixed costs 4. Costs related to repair, maintenance and wheels. The fixed costs include road tax, insurance costs, membership of AA patrol and costs for washing the car.

Price of EV
Not much car manufacturers are building EVs but multiple important producers recently announced programs to construct an EV the coming years.
It is expected that several EVs from the company Detroit Electric will be imported to the Benelux from 2009/2010 on. Models from the compact and middle class will be available for a price of €22,491 to €30,000. The price of the Detroit Electric subcompact will be €22,491 (*ECEcars 2008*).
Because of the relative high battery costs the depreciation over the EV largely depends on the lifetime of the battery. Compared to ICE cars the life expectancy of the drive-train of EVs is expected to be longer because of the smaller amount of moving components which are vulnerable for wearing out. In this report the depreciation factor over an EV is chosen to be equal to the depreciation factor over an ICE car. The monthly depreciation factor over a Peugeot 207 1.4 5d XR with a new price of €14,950 and a rest value of €6,790 after 4 years is approximately 0.98369. Over a period of 4 years the average depreciation costs per month are €170 (*ANWB 2008* and *personal communication with ANWB 18-11-2008*). The monthly depreciation costs are different by assuming that the car owner will sell the car after 6 or 8 years instead of 4. By assuming an equal monthly depreciation factor the value of the Peugeot is reduced to €4575.5 in 6 years and €3083.4 in 8 years. The average monthly depreciation costs are €144.1 in the 6 year scenario and €123.6 in the 8 year scenario.
The monthly depreciation factor over a Detroit Electric Subcompact is estimated to be equal to the depreciation factor over the Peugeot 207 1.4 5d XR. The new price of the Detroit Electric subcompact is

€22,491. After 4 years the value of the EV decreased 55% to €10,121. The average depreciation costs per month during these 4 years are €257.7. Per kilometre the depreciation costs are €0.20. By assuming the same depreciation factor as the Peugeot the monthly depreciation costs over the EV in the 6 year scenario are €216.8 which results in depreciation costs of €0.17 per kilometre. In the 8 year scenario the monthly depreciation costs are €186 which results in depreciation costs of €0.15 per kilometre.
The battery is one of the most expensive components of the EV. Compared to older Lead-Acid, Nickel-Cadmium and Nickel metal hydrate batteries the Li-ion polymer batteries that are used nowadays have advantages such as a higher energy density and a lot of charging cycles. The disadvantage of Li-ion batteries are the relative high costs (*Figure 7*).

Energy Density	Cost	Charge Cycles
Lead Acid 30-40 wh/kg*	Eur/wh 0.15	500-1000
NiCd 40+*	Eur/wh 0.20	1000-2000
NiMH 71 WH/kg*	Eur/wh 0.60	1000-2000
Li Ion 105-170 wh/kg**	Eur/wh 0.3-0.4	7000+

Figure 7: Battery energy density and cost comparison (Deutsche Bank 2008)

The past decade the demand for Li-ion polymer batteries increased significantly because of their use in laptops and mobile phones. The bigger demand stimulated the development of the Li-ion polymer battery which made them both more efficient and cheaper (*Figure 8). The costs of a 22kWh battery pack are estimated to reach €8,500 in the near future (€386 per kWh) (*Deutsche Bank 2008)* (*Appendix 15*) (*Appendix 7*) With a life expectancy of 240,000 km the battery costs per km are equal to €0.035 (*Deutsche Bank 2008*). The current price of Li-ion polymer batteries is in the range of €220 – €2,500 kWh depending on the quality of the battery. The Li-ion polymer batteries that are used by ECEcars cost €750 kWh (*Appendix 14*) and the high quality Li-ion polymer batteries capable of ultra fast charging cost €800 kWh (*Appendix 15*). The high performance and high energy Li-ion polymer batteries that are developed at the moment are increasingly efficient and durable but still very expensive. The price of high performance Li-ion polymer batteries is €1,500 – €2,000 kWh depending on the quality of the battery and the price of high energy batteries is €1,000 – €2,500 kWh depending on the quality of the battery (*Photon International 2008*). The mass production of Li-ion polymer batteries will cause a decrease of battery costs which will result in a lower price per kWh. The target is to construct high energy Li-ion polymer batteries for €300 kWh (*Photon International 2008*).

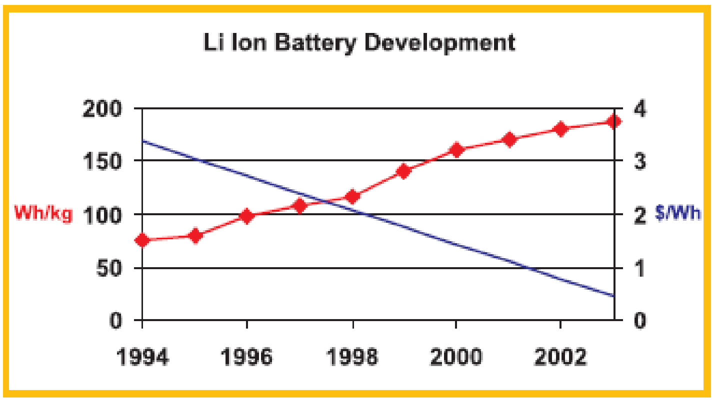


Figure 8: Efficiency and price of Li-ion batteries (Ridley 2007)

The market for Li-ion polymer batteries is growing rapidly and recent researches estimate that this grow will continue in the future. A global grow from €5 billion to €7 – €10.5 billion by 2015 is projected. Stimulated by the development of the EV and other electronic equipment a further grow to €21 – €28 billion is predicted by 2020 (*Deutsche Bank 2008*).

According to experts 6 -7 million tons of lithium can be mined for a reasonably price which is sufficient for 2.4 – 4 billion car batteries (140 - 200g lithium / kWh). At the moment there are less then 1 billion cars globally (*Photon International 2008*).
At the moment research is performed to create more efficient, durable and more cost efficient batteries. The Zn-air, Vanadium redox and Zinc-bromine flow batteries are not produced on a large scale yet but seem to offer possibilities to improve the battery technology further (*Appendices 8 and 12*).
The price of the Subcompact Detroit Electric that enters the Dutch market in 2009 will be €22,491. The most expensive component of the EV is the Li-ion polymer battery which cost €750 kWh in 2008. The price of Li-ion polymer batteries is expected to decrease to €300 kWh which will cause a significant EV price decrease. The mass production of EVs and an increased production efficiency will cause a further price reduction. Including BPM and taxes the net consumer price of a subcompact EV is estimated to converge to the price of an ICE car. The absence of expensive ICE car components such as the combustion engine and transmission system results in cost benefits but battery costs are expected to result in an higher overall price of EVs compared to ICE cars. By 2020 and 2030 the price of a subcompact EV with a power output of 30 kWh is expected to be €20,000.

Fuel costs
The well-to-wheel fuel efficiency of an EV can be defined by identifying both the well-to-tank and tank-to-wheel efficiency. The well-to-tank efficiency of electricity is over 35% for electricity produced by a combination of natural gas and coal powered power-plants in the Netherlands. Both the natural gas recovery process as the processing process are 97.5% efficient (*Tesla 2007)*, producing electricity in a gas fired power-plant is 43% efficient (Seebregts et al., *2005*) and transporting the electricity over the Dutch electricity grid is over 92% efficient (*Personal communication with J. C. G. Heetebrij from HeeCon 2008*). The efficiency of coal powered power plants in the Netherlands is about 39% (Seebregts et al., *2005*).
The cycle of charging and discharging the battery of modern EVs is 86% efficient (*Appendix 15*) (*Tesla Motors 2007*). The electromotor, that directly powers the wheels, has an efficiency of over 90% which results in an overall EV energy efficiency of 75% to 77% (*Bossel 2003 and IEA 2005*). To calculate the overall vehicle efficiency of the EV the amount of electricity which is consumed from the vehicles battery is multiplied with the efficiency of the battery cycle (*Figure 9*). To drive a kilometre the Tesla Roadster consumes 110 watt-hours from the battery which is equal to an efficiency of 2.53 km/MJ or 9.11 km/kWh (*Tesla Motors 2007*). The overall efficiency of the Tesla Roadster is calculated by multiplying the EV efficiency with the cycle of charging and discharging the battery which results in 0.86 * 2.53 km/MJ is 2.18 km/MJ or 7.83km/kWh (*Appendix 10*). Older EVs with a less advanced battery show already a high energy efficiency. The GM-EV1, with lead-acid (Pb-Ac) battery, which was introduced in California in 1996 drove 6.2 km/kWh (*Insightcentral 2008*).
The overall well-to-wheel efficiency of the EV is 0.35 * 2.18 km/MJ is 0.76 km/MJ. Producing the electricity with a 60% efficient high–efficiency gas turbine results in a well-to-wheel efficiency of 1.21 km/MJ. Sustainable produced electricity results in a well-to-wheel efficiency of 2.11 km/MJ because of the electricity losses during transportation.
In this study it is assumed that the efficiency of the Detroit Electric Subcompact is similar to the efficiency of the Tesla Roadster. It is expected that the efficiency of the Detroit Electric Subcompact is even better then the efficiency of the Tesla Roadster because of the smaller power output of the motor and the lower weight. Because of battery improvement and other technological developments the efficiency of the EV is expected to increase to 8.5 km/kWh by 2020 and 9 km/kWh by 2030.

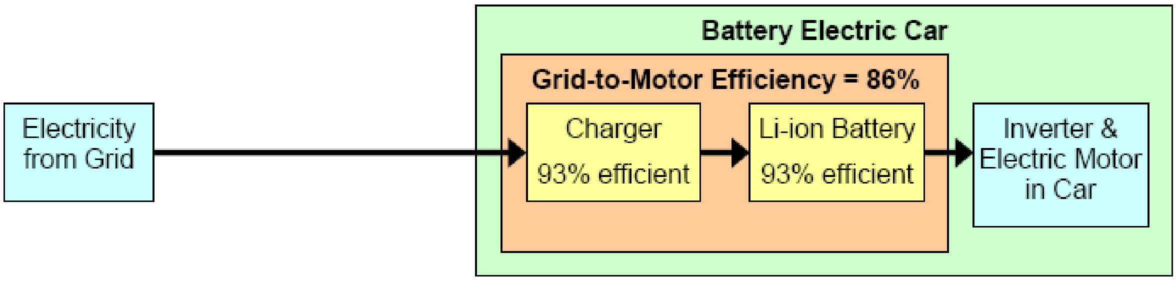


Figure 9: Grid to motor effiency EV (Tesla 2007)

EVs drive on electricity from the grid. The current household price of electricity in the Netherlands is €0.23 kWh. On average a distance of 7.83 km can be driven on a kWh in mixed traffic which results in fuel costs of €0.029 / km (*Tesla 2007*).
Charging EVs at home provides the opportunity to charge at night when the electricity costs are lower but in this study it is estimated that EV owners buy the electricity for the average household price.
Compared to ICE cars modern EVs are especially more efficient in city traffic because they recover energy with regenerative breaking and a more efficient drive-train at low speed (*Appendix 12*). In this report it is estimated that the efficiency of the Detroit Electric Subcompact is 7.83 km/kWh in both city and highway traffic.
In this report an average yearly driving distance of 15,000 km is used for a Dutch car. With an electricity price of € 0.029 km the yearly fuel costs for the Detroit Electric Subcompact will be €435 by assuming the same energy efficiency as a Tesla Roadster.

Costs related to repair, maintenance and wheels
Compared to an ICE car the average maintenance costs of the EV are low because the drive-train of an EV contains not much moving components which are vulnerable for wearing out. Compared to an ICE motor the electro motor of an EV has few moving components and the drive-train of an EV contains no gearbox, transmission and other moving components.
Regular ICE car maintenance such as the replacement of oil and filters is not necessary in EVs. The necessary maintenance of EVs can be reduced to once per 40,000 km. With a yearly driving distance of 15,000 km the maintenance costs of the EV are expected to be €180 a year or €0.012 km (*Appendix 12*).

Fixed costs
The fixed costs of a compact EV consist of insurance costs, the costs for the membership of the AA patrol and costs for cleaning the exterior of the car. Currently Dutch EV drivers of do not have to pay road tax. The fixed costs of the Detroit Electric are estimated to be €90 per month which is equal to the fixed costs of a Peugeot 207 1.4 5d XR without road tax (*ANWB 2008*).
In the Netherlands owners of EVs have to pay less car related taxes then owners of ICE cars at the moment. The owners of EVs do not have to pay 'BPM' and 'road tax'. An average EV driver does not have to pay 42.3% BPM tax over the net price of the car and EVs are free from road tax which results in a yearly reduction of over €400 compared to an ICE car.
For car leasing companies EVs are interesting because of the low tax scale of 14% on the catalogue price and the possibility to receive money back by the VAMIL-, EIA- and MIA regulations (*Appendices 12 and 14*).
There is no certainty concerning the development of the fiscal situation of the EV in the Netherlands. If the EV will not be implemented on a large scale (< 15% of car park) it is affordable for the government to continue the current low tax costs over EVs (*Appendix 12*). On the other hand a growing number of EVs (and a decreasing number of ICE cars) results in lower tax income for the government. A kilometre tax which is coupled with a CO_2 tax could be an appropriate method to force ICE car drivers to drive EVs while ensuring the tax income of the state (*Appendix 12*). There is no certainty about the development of the car related taxes but in this study it is assumed that the

kilometre tax will be realized by 2020. The CPB estimates that the fixed tariff per kilometre will be €0.038 when the kilometre tax is implemented (*CPB 2008*). Besides a kilometre tax the Dutch government recently decided to implement a CO_2 tax for cars from 2018 on (*Energieraad 2008*). The price of CO_2 emissions are rising and it is expected that this price will continue to rise until 2030 (*Appendix 11*). No exact tariffs are agreed upon yet but in this study it is assumed that the CO_2 tax will be €0.01 for EVs and H_2 cars and €0.04 for ICE cars. By adding a CO_2 emission tax it is estimated in this study that the average km tax will be €0.05 km for EVs and €0.08 km for ICE cars.
Another method to ensure the tax income of the government is to gradually increase the EV and ICE taxes. In Israel for example the tax over an ICE car is 72%, while the tax over a hybrid car is 30% and over an EV 10% (*Businessweek 2008*). These taxes will gradually increase to 110% for ICE cars and 50% for EVs (*Project Better Place 2008*). In this report it is assumed that by 2020 a km tax will be implemented. When the Mobile Smart Grid system is implemented the EV is identified when it is plugged in and an additional electricity tax can be calculated directly over the used electricity

Price developments in the energy infrastructure of EVs
Charging points
The majority of the EV charging infrastructure already exists because the EV can be plugged in the conventional electricity grid to charge. A network of EV charging points (230V, 25A) located at parking lots of companies, hotels, train stations and shopping centres will improve the flexibility of the EV (*Appendix 5*). The costs per charging point (230V, 16-25A) are expected to be in the range of a few hundred to a maximum of thousand Euros (*Appendices 12 and 15*). In this study the costs of the EV charging infrastructure will be paid by electricity companies because it will increase their market share. Car owners that plug their car in a charging pole pay a price per kWh in which the additional costs for the EV charging poles are included.

Fast charging stations
For longer distance trips with EVs a network of stations needs to be developed where EVs can be completely charged in several minutes. Several options are considered but all of them have their limitations and there is no data available concerning the costs of the different fast charging options. A network of high voltage charging stations (380V, +100A) which are located next to highways and on other strategic positions is necessary if EVs are implemented on a large scale. These high voltage charging stations allow car owners to charge their car completely in 5 - 15 minutes (*Personal communication with Willem v.d. Kooi from ECEcars 2008 and J. C. G. Heetebrij from HeeCon 2008*). The Dutch company Epyon produces ultra fast charging systems capable of charging EVs in 6 to 30 minutes. Ultra fast charging systems capable of charging EVs in 15 – 30 minutes are already used but the costs of ultra fast charging in 6 minutes are still high. The costs of ultra fast charging systems are expected to decrease in the near future. The costs of ultra fast charging stations for EVs are expected to be cost competitive with conventional petrol stations (*Personal communication with Daan Nap from Epyon 2008*). Car owners that fuel their car at these ultra fast charging stations pay an additional price per kWh for the provided service.

Battery swapping stations
The price of battery swapping stations is not known because they have not been realized yet. The costs of the battery swapping stations are estimated to be integrated in the costs for the battery swapping service. Battery swapping stations can benefit from the low electricity costs during the night by charging the batteries when the demand for electricity is low.

4.2 H_2 cars

4.2.1 H_2 car history

The technology to use H_2 in vehicles is already known for a long time. In the Second World War the Germans considered to fuel the combustion engines of their army vehicles with H_2 because there was a shortage of oil. The production of H_2 powered fuel cells started in the early 1990s when the first fuel cell vehicles were developed. Since the early 1990s car manufacturers have produced a small amount of H_2 powered fuel cell vehicles but until now they are not commercially available. The few H_2 cars on the market can be leased but not be bought. The price of fuel cell vehicles is still high because of the high costs of the fuel cells and onboard H_2 storage systems. At the moment a lot of research is performed to reduce the price and improve the durability of fuel cells and onboard H_2 storage systems. The other bottleneck for the H_2 car are the high costs and the complexity of the H_2 production, distribution and refuelling system. The centralised production of H_2 is energy and price efficient but the distribution of the H_2 by pipeline or truck is difficult and expensive. The decentralised production of H_2 is expensive and energy inefficient.

4.2.2 Technical developments in the H_2 car industry and energy infrastructure

Drivetrain of H_2 cars

The H_2 car is powered by an electromotor which is generated by electricity from a fuel cell. The electromotor can be located either central in the car or directly in the wheels according to the Direct-Drive-In-Wheel principle (DDIW) (*Figure 10*). The H_2 car is in fact an EV but a fuel cell is integrated to provide the electricity for the car. The H_2 car is often abbreviated to Fuel Cell Electric Vehicle (FCEV) (*WWF 2008*). Besides a fuel cell a H_2 storage system and DC converter are necessary. In the H_2 storage system the compressed or cooled H_2 is stored until it is used in the fuel cell. The DC converter is necessary to adapt the voltage of the fuel cell to the voltage of the battery.

Figure 10: H_2 drivetrain (Hyunday 2008)

Developments in H_2 car design

The fuel cell is the most important part of the H_2 car. The fuel cell type which is used most often in H_2 cars at the moment is the proton exchange membrane (PEM) fuel cell. The PEM fuel cells are capable of functioning at a relatively low temperature of 80˚C other fuel cell types such as the molten carbonate (MC) and solid oxide (SO) fuel cells need higher temperatures. The fuel efficiency of PEM fuel cells is estimated to be 64% (*IEA 2005*). The fuel cells which are used nowadays are still expensive and relatively inefficient. Research is performed to design more durable, energy efficient and economic fuel cells. At the moment there is no onboard storage system for H_2 available that meets the technical and economic requirements necessary for large scale commercialization. The available technologies such as compression to 350 – 700 bar and the liquid storage at low temperature (-253 ˚C) are both expensive and complex technologies.

Developments in H_2 car energy infrastructure
Hydrogen can be produced in multiple ways but the most common methods are the electrolysis of water or the reforming of natural gas. The most efficient way to produce hydrogen in large quantities is by reforming natural gas (CH_4). The well-to-tank efficiency of H_2 production is estimated to be in the range of 52 – 61% (*GM corp., Argonne National Laboratory, BP, ExxonMobil, Shell, 2001*). The H_2 gas can be transported either by pipeline or compressed or cooled in trucks to the H_2 refuelling station.
In the current situation with a low implementation level of H_2 cars the small scale decentralised production of H_2 by electrolysis or reforming natural gas is the most economic option. Decentralised H_2 production systems do not demand an expensive H_2 distribution system because the H_2 is produced on-site and investments in large scale H_2 production plants are not necessary. When H_2 cars are implemented on a larger scale the switch to larger and more energy- and cost efficient large scale H_2 production methods can be made.

4.2.3 Price developments in the H_2 car design and energy infrastructure

Price developments in the design of H_2 cars

The costs of a H_2 car can be divided in: 1. Depreciation costs over the new price of the car 2. Fuel costs 3. Fixed costs 4. Costs related to repair, maintenance and wheels. The fixed costs include road tax, insurance costs, membership of AA patrol and costs for washing the car.

Price of the H_2 car
H_2 cars are not yet available on the market. The H_2 cars that are on the road nowadays are the property of the car manufacturers and can only be leased. At the moment the production costs of H_2 cars are still too high to be commercially competitive with ICE cars. The current price of a H_2 car is over a million Euro because of the costs related to the construction of a new production line and the high costs of fuel cells and onboard storage systems. The Honda FCX Clarity which is produced at the moment on a small scale cost a few million Dollar each. Honda expects that the price of H_2 powered fuel cell cars such as the Honda Clarity will decrease to $100,000 the coming decade by producing them in series. The large scale production of H_2 cars will cause a significant price reduction but is not estimated to be realized in the near future because a H_2 refuelling infrastructure needs to be constructed before H_2 cars will be produced on a large scale. In a recent ECN study it is estimated that H_2 cars will not be implemented on a large scale in the Netherlands before 2030 (*Figure 11*) (*Smit et al. 2006*). In this study it is estimated that H_2 cars will be produced on a large scale by 2030.

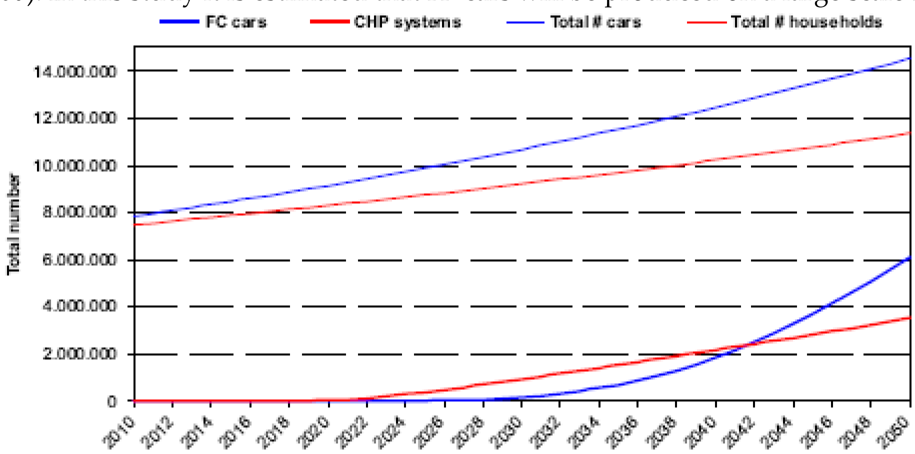


Figure 11: Estimated development of the number of CHP systems and FC-cars in the Netherlands (Smit et al. 2006)

Including BPM and taxes the net consumer price of a subcompact H_2 car is estimated to converge to the price of an ICE car. The absence of expensive ICE car components such as the combustion engine and transmission system results in cost benefits but costs related to the fuel-cell, H_2 storage system and other components of the H_2 car drive-train are expected to result in an higher overall price of H_2 cars compared to ICE cars. By 2020 the price of a subcompact H_2 car is expected to be €100,000. By 2030 the large scale production of H_2 cars results in a price of €20,000 for a subcompact H_2 car.

In this study the depreciation factor over a H_2 car is estimated to be equal to the depreciation factor over a Peugeot 207 1.4 5d XR. In 2008 H_2 cars were not commercially available yet but the price of a subcompact H_2 car is estimated on €1,000,000 in this study. After 4 years the value of the EV decreased 55% to €450,000. The average depreciation costs per month during these 4 years are more then €11,000 which results in depreciation costs per kilometre of €9.2.
The price of Proton Exchange Membrane Fuel Cells (PEMFC) which are most common at the moment exceeds \$2,000 kWh. The Dutch company Nedstack produces a 10 kWh fuel cell with a price of is €20,000 which indicates a fuel cell price of €100,000 for a 50 kW H_2 car. The production of fuel cells is still in its niche phase and it is expected that the large scale production will cause a significant price decrease. The price of PEM fuel cells is expected to decrease to €250 kWh by 2009 and further to \$100 kWh by producing them in large quantities (*IEA 2005*). Fuel cells are expensive because they contain costly components such as a membrane, electrode, bipolar plates, platinum catalyst and peripheral materials. Besides these components there are also the costs associated with assembly. Especially the costs for the manually produced bipolar plates and the electrodes contribute to the total costs of the fuel cell (*Figure 12*).

	Cost (USD/m^2)	Cost (USD/kW)	Share (%)
Membrane	500	250	14
Electrode	1 423	712	39
Bipolar plates	1 650	825	45
Platinum catalyst	48	24	1
Peripherals	15	8	0
Assembly		8	0
Total		1 826	100

Source: Tsuchiya and Kobayashi, 2004.

Figure 12: Estimates of current costs of manually produced PEM fuel cells (IEA 2005)

The large scale industrial production of fuel cells could lead to a significant price decrease. According to the IEA the large scale production of fuel cells (sufficient for 500,000 vehicles) should lead to a fuel cell price of \$100 kWh (*Figure 13*) (*IEA 2005*). A fuel cell price of less then \$100 kWh can only be realized by shifting to cheaper electrodes and bipolar plates. In practice new membrane technologies, new electrode production technologies and a new method for bipolar plates production are necessary.

	Cost (USD/m^2)	Cost (USD/kW)	Share (%)
Membrane	50	17	16
Electrode	150	50	49
Bipolar plates	91	30	29
Platinum catalyst	8	3	3
Peripherals	4	1	1
Assembly		2	2
Total		103	100

Figure 13: Estimated future cost of a PEM fuel cell stack (based on the identified cost reduction potential) (IEA 2005)

Besides the fuel cell the H_2 fuel cell car contains other expensive components such as the onboard H_2 storage system. The onboard storage of the H_2 gas is costly. The available technologies such as compression to 350 – 700 bar and the liquid storage at low temperature (-253 ˚C) are both expensive. The costs of the storage tank for compressed H_2 are in the range of \$600 – \$800 kg/ H_2. The onboard gaseous storage at 700 bar is the technology which is expected to be implemented in H_2 cars.

Fuel costs

The well-to-tank efficiency of large scale H_2 production by natural gas reforming is estimated to be in the range of 52% to 61% (*GM corp. et al. 2001*). The well-to-tank efficiency of decentralized H_2 production by reforming natural gas is estimated to be 67%. Both the natural gas recovery process as the processing process are 97.5% efficient, decentralized H_2 production by natural gas reforming is estimated to be 70% efficient (*Smit et al. 2006).*

The maximum energy efficiency of a fuel cell is 50% but this has not been realized in H_2 cars yet (*Bossel 2003*). By considering a maximum fuel cell efficiency and losses due to the compression of hydrogen, parasitic losses for the hydrogen fuel cell system and energy losses in the drive train a maximum vehicle efficiency of 40% is estimated (*Bossel 2003*).

The energy density of hydrogen (142 MJ/kg HHV) can be used to calculate the efficiency of the H_2 car. The vehicle efficiency of the Honda FCX H_2 car which has been tested by the American Environmental Protection Agency (*EPA*) in 2008 was 0.82 km/MJ or 2.96 km/kWh considering 55% highway traffic and 45% city traffic (*Fueleconomy 2008).* The maximum overall well-to-wheel efficiency of the Honda FCX is 0.67x0.82 km/MJ = 0.55 km/MJ which is lower then the efficiency of an EV and higher then the efficiency of an ICE car (*Appendix 10*).

At the moment the fuel costs of H_2 are €0.44 kWh. With a vehicle efficiency of 2.96 km/kWh the current H_2 car fuel costs are €0.15 per kilometre. Because of battery improvement and other technological developments the efficiency of the H_2 car is expected to increase to 3.5 km/kWh by 2020 and 4 km/kWh by 2030.

Costs related to repair, maintenance and wheels

In this report it is assumed that the average maintenance costs of the H_2 car are equal to the maintenance costs of the EV because their drive trains are similar except for the fuel cell, DC-converter and the H_2 storage system. Compared to an ICE car the drive-train of a H_2 car has few moving components which are vulnerable for wearing out. With a yearly driving distance of 15,000 km the maintenance costs of the H_2 are expected to be €180 a year or €0.012 km.

Fixed costs

The fixed costs of a compact H_2 car consist of insurance costs, the costs for the membership of the AA patrol and costs for cleaning the exterior of the car. Drivers of H_2 cars do not have to pay road tax. The fixed costs of a compact H_2 car are estimated to be €90 per month which is equal to the fixed costs of a Peugeot 207 1.4 5d XR without road tax (*ANWB 2008*).

At the moment Dutch H_2 car owners have to pay less car related taxes then owners of ICE cars. The owners of H_2 cars do not have to pay 'BPM' and 'road tax'. A H_2 car driver does not have to pay the average 42.3% BPM (Belasting personenauto's en motorrijwielen) over the net price of the car and H_2 cars are free from road tax which results in a yearly reduction of over €400 compared to an ICE car.

For companies that lease cars H_2 cars are interesting because of the low tax scale of 14% on the catalogue price and possibility to receive money back by the VAMIL-, EIA- and MIA regulations (*Appendices 12 and 14*).

There is no certainty concerning the development of the fiscal situation of the H_2 car in the Netherlands. In this study it is assumed that a combined km and CO_2 tax will be implemented in the Netherlands. A kilometre tax which is combined with the CO_2 emission of a car could be a method to force ICE car drivers to drive H_2 cars while ensuring the tax income of the state (*Appendix 12*). There is no certainty about the development of the kilometre tax but in this study it is assumed to be realized by 2020. For H_2 cars an average km tax of €0.05 km is estimated while for ICE cars the average km tax is estimated to be €0.08 km.

Price developments in the energy infrastructure of H_2 cars

The majority of the H_2 which is used nowadays in industrial purposes is produced on-site because the distribution of H_2 is problematic. In this study it is estimated that by 2030 the H_2 to power H_2 fuel cell cars is produced onsite at the H_2 refuelling station by reforming natural gas. The expected Dutch production costs and minimum price of H_2 by 2020 and 2030 are described in chapter 3.3.

H_2 gas can be produced centralised and transported either by pipeline or by truck to H_2 refuelling stations but expensive and complex bottlenecks exist. H_2 gas, which is the lightest gas in the universe, exists out of small H molecules that will penetrate a conventional natural gas pipeline because they are too porous. The natural gas pipelines need to be coated or special stainless steel pipelines need to be constructed for the transport of the H_2 gas. The costs of these stainless steel pipelines are twice the costs of a natural gas pipeline. The physical density of H_2 gas is 84 g/m3 which is low compared to the physical density of natural gas which has a density of 714 g/m3. Although the specific energy content of H_2 gas is high (142 MJ/kg HHV) compared to the specific energy content of natural gas (54 MJ/kg) H_2 gas still demands six times more space for the same energy content. Because of the low physical density of H_2 gas the costs of a H_2 gas pipeline with the same energy content of a natural gas pipeline are six times higher.

Another transport option of H_2 gas is to compress it to 200 atm or cool it to -253 degrees and transport it by truck. The processes to cool or compress H_2 gas are energy intensive and because of the lower energy density of H_2 compared to gasoline much more trucks are necessary to transport the same amount of energy (*WWF 2008*).

4.3 ICE cars

4.3.1 Technical developments in ICE car design and energy infrastructure

Drivetrain of ICE cars

The ICE car is powered by an internal combustion engine (ICE) which is located in the front, back or middle part of the car. The ICE is powered by gasoline or diesel and generates kinetic energy from a combustion process. The kinetic energy is transported by axles and a transmission system to two or four wheels (*Figure 14*)

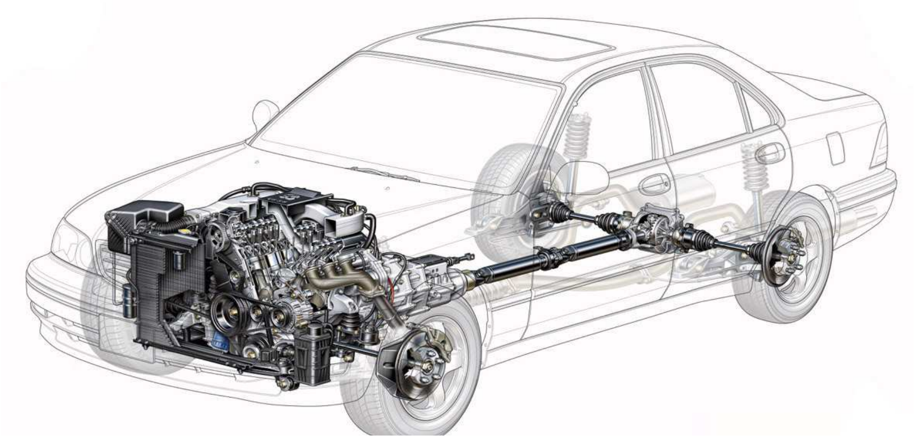


Figure 14: Drivetrain ICE car (Kevin Hulsey Illustration 2007)

During the past decades European cars with internal combustion engines became more energy efficient and less polluting by the implementation of more efficient engines, better aerodynamics and soot filters. On the other hand the cars became bigger, more powerful, heavier and more comfortable (air-conditioning and other electronic systems) which had negative effects on the energy efficiency of the cars. The overall energy efficiency of European cars with internal combustion engines improved not much between 1990 and 2000. Between 2000 and 2005 the energy efficiency increased more because of an increasing fuel price, a more environmental friendly driving behaviour and the development of more efficient combustion engines. (*European Commission 2007*)

The main bottleneck in the improvement of the energy efficiency of the ICE car is the internal combustion engine that powers the ICE car. The internal combustion engine has a low energy efficiency because most of the energy that is stored in the gasoline is converted to heat during the combustion process. Only a relative small amount of energy (15 – 20%) is converted to motive energy to power the car and its accessories (*Fueleconomy 2008 and USDOE 2008)*. During the transportation from the engine to the wheels the produced motive energy is partly turned to heat by friction between the moving components. In city traffic the efficiency of the internal combustion car is further reduced because of the continuous accelerating and braking cycle.

Cars that are powered by an internal combustion engine will become more efficient during the coming years but big improvements are not possible without changing the drive-train of the car.

4.3.2 Price developments in ICE car industry and energy infrastructure

The costs which are related to the ICE car can be divided in: 1. Depreciation costs over the new price of the car 2. Fuel costs 3. Fixed costs 4. Costs related to repair, maintenance and wheels. The fixed costs include road tax, insurance costs, membership of AA patrol and costs for washing the car. There are no costs related to the ICE car energy infrastructure because this infrastructure is already realized

Price of the ICE car

The monthly depreciation factor over a Peugeot 207 1.4 5d XR with a new price of €14,950 and a rest value of €6,790 after 4 years is 0.98369. Over a period of 4 years the average depreciation costs per month are €170 (*ANWB 2008 and Personal communication with ANWB 18-11-2008*). The monthly depreciation costs are different by assuming that the car owner will sell the car after 6 or 8 years instead of 4. With a monthly depreciation factor of 0.98369 the value of the Peugeot is reduced to €4575.5 in 6 years and €3083.4 in 8 years. The average monthly depreciation costs are €144.1 in the 6 year scenario and €123.6 in the 8 year scenario. The depreciation cost in the 4 year ownership scenario are €0.136 per kilometre (*ANWB 2008*).

Fuel costs

Because of the high fuel costs and EU regulations ICE cars will become a more energy efficient in the future but the efficiency of the ICE drive-train can not be improved much further (*Appendix 12*). A lot of components of the drive train can be improved further but these improvements are costly and the biggest efficiency loss is caused by the ICE process (*Figure 15*). The Peugeot 207 1.4 5d XR uses 6.2 l /100 km in combined traffic (7.9 in city traffic and 5.2 on the highway with 90 km/h). The average Dutch fuel price in 2007 was €1.4 for a litre of Euro 95 gasoline. Considering a fuel use of 6.2 l /100 km the fuel costs are €8.68 / 100 km or €0.0868 / km. In city traffic the fuel costs of the Peugeot 207 1.4 5d XR are €11.06 / 100 km or €0.11 / km and on highways the fuel costs are €7.28 / 100 km or €0.0728 / km. The well-to-tank efficiency of gasoline production is 83% (*USDOE 2000*). The energy efficiency of the Peugeot can be calculated by multiplying the energy content of gasoline (34.3 MJ/l) with the fuel consumption in mixed traffic (6.2 litre/100 km). The Peugeot drives 0.47 km/MJ or 1,7 km/kWh. The overall well-to-wheel efficiency of the Peugeot is 0.83 * 0.47 km/MJ is 0,39 km/MJ (*Appendix 10*). The EU wants to reach an average fuel efficiency of 5,0 l/100km by 2012 for gasoline fuelled cars. By assuming that ICE cars will become increasingly energy efficient the energy efficiency of a subcompact car is estimated to be 4.5 litre/100 km in combined traffic by 2020 and 4.0 litre/100 km by 2030.

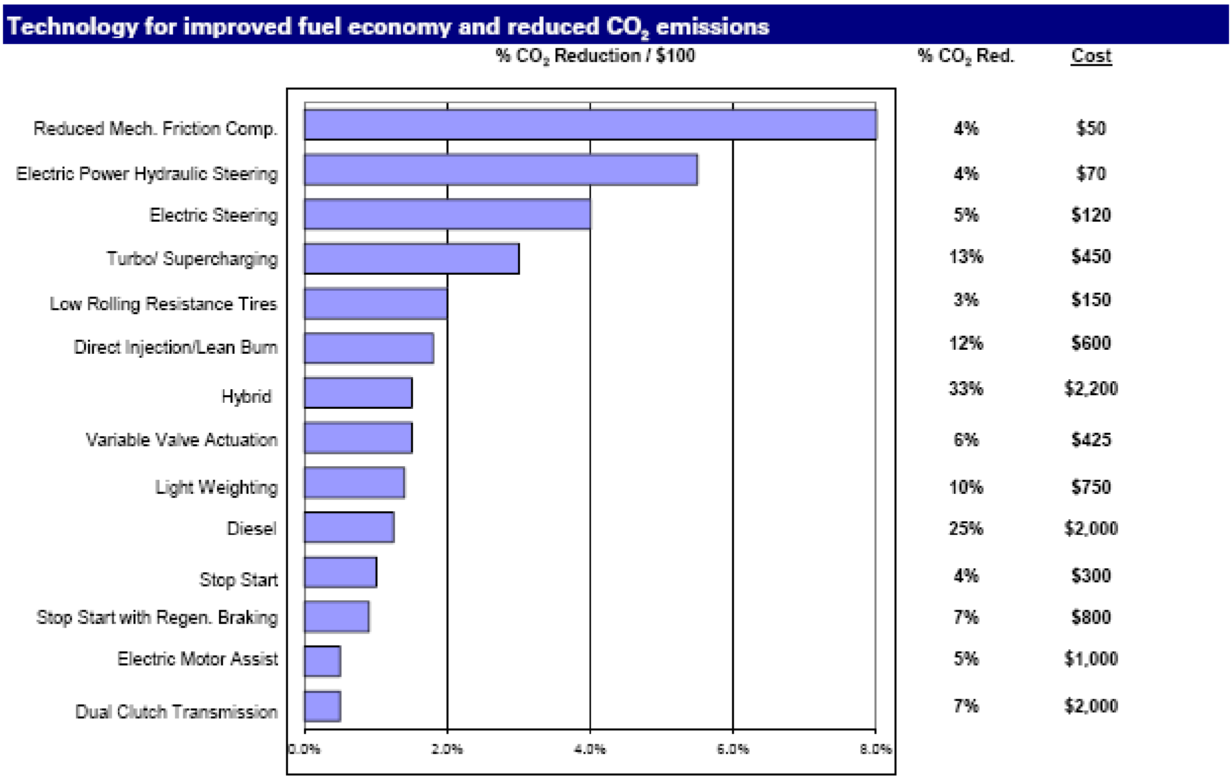


Figure 15: Technology for improved fuel economy and reduced CO_2 emissions (Deutsche Bank, 2008)

Maintenance costs
The maintenance costs of a car consist of maintenance work, the replacement of tyres and the repair costs. The maintenance costs per month for a Peugeot 207 1.4 5d XR with 55 kW (15,000 km) are € 37 per month or €444 per year (*ANWB 2008*). Common maintenance costs on an ICE car are related to oil changes, spark plugs, brake pads, gear belt and the exhaust.

Fixed costs
Fixed costs have to be paid for the insurance of the car, road tax and additional costs for the membership of the AA patrol and maintenance of the chassis (car washing). The insurance whish is used in this study is 'all risk' and has a no claim percentage of 55%, the road tax is based on the road tax tariff of the province 'Zuid Holland', one of the most expensive provinces for road tax in the Netherlands. The total fixed costs for the Peugeot 207 1.4 5d XR are €131 per month or €1,572 per year (*ANWB 2008*).
By 2020 it is expected that a CO_2 emission coupled km tax is implemented in the Netherlands. In this study the costs per km for a compact ICE car are estimated to be €0.08 km.

4.4 Synthesis

Scenario 2008

In this chapter the development of the new price of the ICE car, EV and H_2 car, the fixed costs and the costs related to repair, maintenance and wheels are described for 2008 (*Table 5*). These costs are used in chapter 5 to compare the total costs of the ICE car, EV and H_2 car per kilometre.

Table 5: Price of EV, H_2 car and ICE car in 2008

2008	Peugeot 207 1.4 5d XR	Detroit Electric Subcompact	Subcompact H_2 car
New price (€)	14,950	22,491	1,000,000
Fixed costs (€ month)	141	90	90
Repair, maintenance, wheels (€ month)	37	15	15

Scenario 2020

In this chapter the development of the new price of the ICE car, EV and H_2 car, the fixed costs and the costs related to repair, maintenance and wheels are described for 2020 (*Table 6*). These costs are used in chapter 5 to compare the total costs of the ICE car, EV and H_2 car per kilometre

Table 6: Price of EV, H_2 car and ICE car in 2020

2020	ICE car	Subcompact electric car	Subcompact H_2 car
New price (€)	14,950	20,000	€100,000
Fixed costs (€ month)	90	90	90
Repair, maintenance, wheels (€ month)	37	15	15
Km tax (€/km)	0.08	0.05	0.05

Scenario 2030

In this chapter the development of the new price of the ICE car, EV and H_2 car, the fixed costs and the costs related to repair, maintenance and wheels are described for 2030 (*Table 7*). These costs are used in chapter 5 to compare the total costs of the ICE car, EV and H_2 car per kilometre

Table 7: Price of EV, H_2 car and ICE car in 2030

2030	Subcompact ICE car	Subcompact electric car	Subcompact H_2 car
New price (€)	14,950	20.000	20.000
Fixed costs (€ month)	90	90	90
Repair, maintenance, wheels (€ month)	37	15	15
Km tax	0.08	0.05	0.05

5. Cost comparison of EVs, H_2 cars and ICE cars

5.1 Introduction

In this chapter the development of the yearly total costs of a compact the ICE car, EV and the H_2 car will be calculated for the years 2008, 2020 and 2030. In chapter 5.2 assumptions are made concerning the indirect parameters that attribute to the overall costs of the car: 1. The amount of driven kilometres 2. The difference between city and highway traffic 3. Depreciation cost scenarios.
The different parameters that attribute to the total costs of the ICE car, EV and the H_2 car are implemented in a model which is described in chapter 5.3. In the model the fuel price scenarios, the price developments in the car design and infrastructure and the indirect parameters from chapter 5.2 are implemented. The total costs of the ICE car, EV and the H_2 car in different scenarios are described by a benchmark in chapter 5.4.

5.2 Assumptions

The parameters related to the amount of driven kilometres, the difference between city and highway traffic, the fuel price development and the costs related to a variable period of ownership will be used in specific scenarios concerning the driving behaviour of the consumer. These scenarios are used to calculate the yearly total costs of a compact ICE car, EV and the H_2 car in different scenarios.

The amount of driven kilometres
In this report the average amount of yearly driven kilometres per car in 2008 is 15,000 which is based on data from the ANWB who use the same number. In this study the average amount of yearly driven kilometres is projected to increase to 16,500 by 2020 and 18,000 by 2030.

The difference between city and highway traffic
A difference between city-, highway- and mixed traffic is made because the fuel efficiency of cars in city traffic differs from the fuel efficiency of cars in highway traffic. In this study it is assumed that the ICE car, EV and the H_2 car drive 45% city traffic and 55% highway traffic but they are also compared to each other for driving solemnly city- or highway traffic.

Period of car ownership
In this study the depreciation costs over the different cars are calculated by assuming that the consumer will sell the car after 4 years. The difference between the new price of the car and the value of the car after 4 years is calculated as a monthly depreciation factor over the car. Because no data concerning the depreciation rate over EVs and H_2 cars is available their depreciation rate is estimated to be equal to ICE cars. The life time of EVs and H_2 cars is estimated to be at least equal to the lifetime of ICE cars because their drive-train is less vulnerable for wearing-out. In this study the depreciation costs of the cars are also compared to each other by assuming that the car owner sells the car after 6 and 8 years.

5.3 Model description

The model to calculate the overall costs of the ICE car, EV and the H_2 car in the Netherlands by 2008, 2020 and 2030 integrates the fuel price scenarios which are described in chapter 3, the price developments in the car designs and energy infrastructures which are described in chapter 4 and the indirect parameters from chapter 5.2.

The overall consumer costs of the ICE car, H_2 car and EV are calculated in a spreadsheet in which the values for the parameters are included for the years 2008, 2020 and 2030.

Scenario 2008

In the 2008 scenario the total yearly costs of the ICE car, H_2 car and EV are calculated by assuming a yearly driving distance of 15,000 km, a variable period of car ownership (4, 6 or 8 years) and city-, highway- or mixed traffic. The new price of the ICE car is €14,950 and the new price of the EV car and H_2 car are estimated to be respectively €22,491 and €1,000,000 (*Table 8*).

Table 8: parameters to calculate overall consumer costs of ICE car, H_2 car and EV in 2008

	ICE car	**H_2 car**	**EV**
New price (€)	14,950	1,000,000	22,491
Yearly driven km	15,000	15,000	15,000
Traffic	City , highway and mixed traffic (45%city, 55% highway)	City , highway and mixed traffic (45%city, 55% highway)	City , highway and mixed traffic (45%city, 55% highway)
Fuel price (€/kWh)	0.15	0.44	0.23
Fixed costs (€/month)	90	90	90
Road tax (€/month)	41	-	-
Maintenance costs (€/year)	444	180	180
Efficiency (km/kWh)	Mixed: 1.69 City: 1.33 Highway: 2.02	Mixed: 2.96 City: 3.13 Highway: 2.74	Mixed: 7.83 City: 7.83 Highway: 7.83
Period of car ownership	4,6 or 8 years	4,6 or 8 years	4,6 or 8 years

Scenario 2020

In the 2020 scenario the total yearly costs of the ICE car, H_2 car and EV are calculated by assuming a yearly driving distance of 16,500 km, a variable period of car ownership (4, 6 or 8 years) and city-, highway- or mixed traffic. The new price of the ICE car is €14,950 and the new price of the EV car and H_2 car are estimated to be respectively €20,000 and €100,000 (*Table 9*).

Table 9: parameters to calculate overall consumer costs of ICE car, H_2 car and EV in 2020

	ICE car	**H_2 car**	**EV**
New price (€)	14,950	100,000	20,000
Yearly driven km	16,500	16,500	16,500
Traffic	City , highway and mixed traffic (45%city, 55% highway)	City , highway and mixed traffic (45%city, 55% highway)	City , highway and mixed traffic (45%city, 55% highway)
Fuel price (€/kWh)	Low: 0.16 High: 0.18	Low: 0.15 High: 0.18	Low: 0.26 High: 0.32
Fixed costs (€/month)	90	90	90
Km tax (€/km)	0.08	0.05	0.05
Maintenance costs (€/year)	444	180	180
Efficiency (km/kWh)	Mixed: 2.33 City: 1.83 Highway: 2.78	Mixed: 3.5 City: 3.5 Highway: 3.5	Mixed:8.5 City: 8.5 Highway: 8.5
Period of car ownership	4,6 or 8 years	4,6 or 8 years	4,6 or 8 years

Scenario 2030

In the 2030 scenario the total yearly costs of the ICE car, H_2 car and EV are calculated by assuming a yearly driving distance of 18,000 km, a variable period of car ownership (4, 6 or 8 years) and city-, highway- or mixed traffic. The new price of the ICE car is €14,950 and the new price of the EV car and H_2 car are estimated to be respectively €20,000 and €100,000 (*Table 10*).

Table 10: parameters to calculate overall consumer costs of ICE car, H_2 car and EV in 2030

	ICE car	**H_2 car**	**EV**
New price (€)	14,950	20,000	20,000
Yearly driven km	18,000	18,000	18,000
Traffic	City , highway and mixed traffic (45%city, 55% highway)	City , highway and mixed traffic (45%city, 55% highway)	City , highway and mixed traffic (45%city, 55% highway)
Fuel price (€/kWh)	Low: 0.17 High: 0.21	Low: 0.18 High: 0.22	Low: 0.22 High: 0.37
Fixed costs (€/month)	90	90	90
Road tax (€/month)	0.08	0.05	0.05
Maintenance costs (€/year)	444	180	180
Efficiency (km/kWh)	Mixed: 2.62 City: 2.06 Highway: 3.13	Mixed: 4.00 City: 4.00 Highway: 4.00	Mixed: 9.00 City: 9.00 Highway: 9.00
Period of car ownership	4,6 or 8 years	4,6 or 8 years	4,6 or 8 years

5.4 Benchmark

Benchmark 2008

The data from table 8 are used in a spreadsheet to calculate the total costs per kilometre of the cars. The total cost per kilometre of an ICE car are €0.36, for an EV these costs are €0.32 and for a H_2 car €9.33 in 2008 by assuming mixed traffic and a 4 year car ownership (*Table 11*). By assuming an average yearly driving distance of 15,000 km this results in overall yearly costs of €5387 for an ICE car, €4769 for an EV, and €139,953 for a H_2 car.

Period of ownership

The average monthly depreciation costs depend on the amount of years that the owner uses the car. By assuming a 6 year car ownership instead of a 4 year ownership the total costs per kilometre are reduced to €0.34 for an ICE car, €0.29 for an EV and €7.94 for a H_2 car (*Figure 16*). By assuming an average yearly driving distance of 15.000 km this results in overall costs of €5076 for an ICE car, €4301 for an EV, and €119,148 for a H_2 car.

By assuming an 8 year car ownership instead of a 4 year ownership the total costs per kilometre are reduced to €0.32 for an ICE car, €0.26 for an EV and €6.85 km for a H_2 car. By assuming an average yearly driving distance of 15.000 km this results in overall costs of €4831 for an ICE car, €3931 for an EV, and €102709 for a H_2 car.

Variable traffic scenario

By assuming city traffic instead of mixed traffic the total costs per kilometre of an ICE car increase to €0.38 and the total costs per kilometre of a H_2 car decrease to €9.32. The total costs per kilometre of an EV remain equal because of a similar efficiency in city and highway traffic.

By assuming highway traffic instead of mixed traffic the total costs per kilometre of an ICE car decrease to €0.34 and the total costs per kilometre of a H_2 car increase €9.34.

Benchmark 2020

Low energy price scenario

The data from table 9 are used in a spreadsheet to calculate the total costs per kilometre of the different cars. The total cost per kilometre of an ICE car in the low energy price scenario are €0.36, for an EV these costs are €0.32 and for a H_2 car €1.00 in 2020 by assuming mixed traffic and a 4 year car ownership. By assuming an average yearly driving distance of 16,500 km this results in overall costs of €6017 for an ICE car, €5319 for an EV, and €16,438 for a H_2 car.

High energy price scenario

The total cost per kilometre of an ICE car in the high energy price scenario are €0.37, for an EV these costs are €0.33 and for a H_2 car €1.00 in 2020 by assuming mixed traffic and a 4 year car ownership. By assuming an average yearly driving distance of 16,500 km this results in overall costs of €6159 for an ICE car, €5435 for an EV, and €16,579 for a H_2 car.

Variable Period of ownership

The average monthly depreciation costs depend on the amount of years that the owner uses the car. By assuming a 6 year ownership instead of a 4 year ownership the total costs per kilometre in the low energy price scenario are reduced to €0.35 for an ICE car, €0.30 for an EV and €0.87 for a H_2 car. By assuming an average yearly driving distance of 16.500 km this results in overall yearly costs of €5706 for an ICE car, €4903 for an EV, and €14358 for a H_2 car.

By assuming an 8 year ownership instead of a 4 year ownership the total costs per kilometre are reduced to €0.33 for an ICE car, €0.28 for an EV and €0.77 km for a H_2 car. By assuming an average yearly driving distance of 16,500 km this results in overall yearly costs of €5460 for an ICE car, €4574 for an EV, and €12714 for a H_2 car.

Variable traffic scenario

By assuming city traffic instead of mixed traffic the total costs per kilometre of an ICE car increase to €0.38 and the yearly overall costs of the ICE car increase to €6327 for the low energy price scenario and a 4 year car ownership. The total costs per kilometre of an EV and H_2 car remain the same.

By assuming highway traffic instead of mixed traffic the total costs per kilometre of an ICE car decrease to €0.35 and the yearly overall costs of the ICE car decrease to €5834. The total costs per kilometre of an EV and H_2 car remain equal because of a similar efficiency in city and highway traffic

Benchmark 2030

Low energy price scenario

The data from table 10 are used in a spreadsheet to calculate the total costs per kilometre of the different cars. The total cost per kilometre of an ICE car in the low energy price scenario are €0.34, for an EV these costs are €0.30 and for a H_2 car €0.32 in 2030 by assuming mixed traffic and a 4 year car ownership. By assuming an average yearly driving distance of 18,000 km this results in overall costs of €6172 for an ICE car, €5329 for an EV and €5699 for a H_2 car.

High energy price scenario

The total cost per kilometre of an ICE car in the low energy price scenario are €0.36, for an EV these costs are €0.31 and for a H_2 car €0.33 in 2030 by assuming mixed traffic and a 4 year car ownership. By assuming an average yearly driving distance of 18,000 km this results in overall costs of €6447 for an ICE car, €5629 for an EV and €5879 for a H_2 car.

Period of ownership

The average monthly depreciation costs depend on the amount of years that the owner uses the car. By assuming a 6 year ownership instead of a 4 year ownership the total costs per kilometre in the low energy price scenario are reduced to €0.33 for an ICE car, €0.27 for an EV and €0.29 for a H_2 car. By assuming an average yearly driving distance of 18,000 km this results in overall yearly costs of €5861 for an ICE car, €4913 for an EV, and €5283 for a H_2 car.

By assuming an 8 year ownership instead of a 4 year ownership the total costs per kilometre are reduced to €0.31 for an ICE car, €0.25 for an EV and €0.28 km for a H_2 car. By assuming an average yearly driving distance of 18,000 km this results in overall yearly costs of €5615 for an ICE car, €4584 for an EV, and €4954 for a H_2 car.

Variable traffic scenario

By assuming city traffic instead of mixed traffic the total costs per kilometre of an ICE car increase to €0.36 and the yearly overall costs of the ICE car increase to €6490 for the low energy price scenario and a 4 year car ownership. The total costs per km of an EV and H_2 car remain the same.

By assuming highway traffic instead of mixed traffic the total costs per km of an ICE car decrease to €0.33 and the yearly overall costs of the ICE car decrease to €5982. The total costs per kilometre of an EV and H_2 car remain equal because of a similar efficiency in city and highway traffic

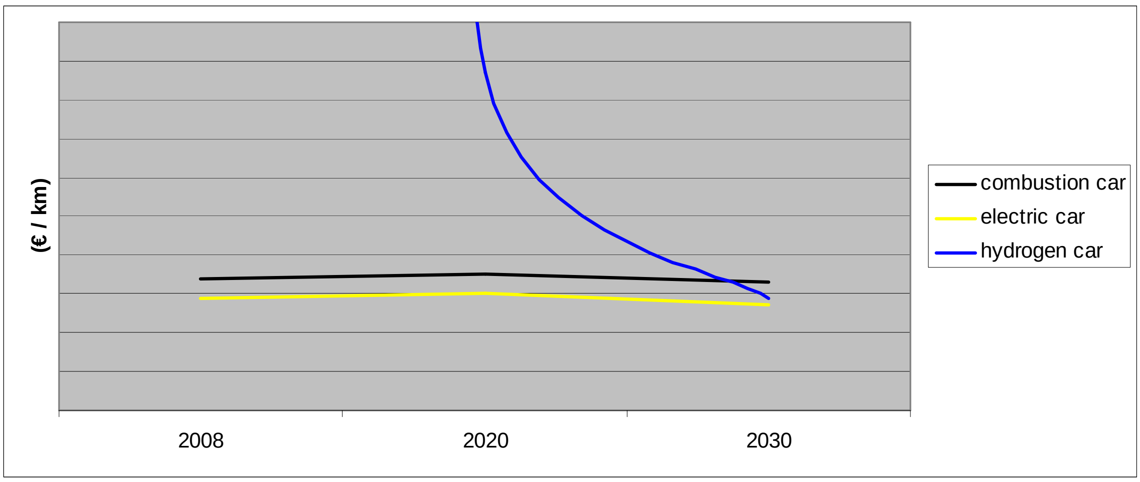


Figure 16: km price comparison of ICE car, EV and H_2 car

Table 11: Total annual costs of ICE cars, EVs and H_2 cars in different scenarios

	ICE car costs/km (€)	EV costs/km (€)	H_2 car costs/km (€)
2008			
Scenario 15,000 km yearly Mixed traffic 4 year car ownership	0.36	0.32	9.33
6 year car ownership 8 year car ownership	0.34 0.32	0.29 0.26	7.94 6.85
City traffic Highway traffic	0.38 0.34	0.32 0.32	9.32 9.34
2020			
Scenario 16,500 km yearly Low energy price Mixed traffic 4 year car ownership	0.36	0.32	1.00
High energy price	0.37	0.33	1.00
6 year car ownership 8 year car ownership	0.35 0.33	0.30 0.28	0.87 0.77
City traffic Highway traffic	0.38 0.35	0.32 0.32	1.00 1.00
2030			
Scenario 18,000 km yearly Low energy price Mixed traffic 4 year car ownership	0.34	0.30	0.32
High energy price	0.36	0.31	0.33
6 year car ownership 8 year car ownership	0.33 0.31	0.27 0.25	0.29 0.28
City traffic Highway traffic	0.36 0.33	0.30 0.30	0.32 0.32

6. Discussion

6.1 Sensitivity analysis

In this study the development of the ICE car, EV and H_2 car costs depends on the development of the depreciation costs, fuel costs, fixed costs, costs related to repair, maintenance and wheels and km tax. The expected development of the costs is based on literature review and expert interviews. A sensitivity analysis is performed to analyze the sensitivity of the total costs per kilometre to changing depreciation costs, costs related to repair, maintenance and wheels and fuel costs. The fixed costs are stable because they consist of stable costs such as insurance costs, costs for the AA patrol and cleaning costs. The development of the car taxes can not be predicted but according to European policy developments the taxes will depend on the car emissions. The calculations in the sensitivity analysis are based on the low electricity price scenario, mixed traffic conditions and a 4 year car ownership.

Fuel costs

The oil price scenarios in this report are based on IEA assumptions and personal communication with energy experts. In this study a bottom price of €1.40 per litre of gasoline (Euro 95) is used which was the average price in 2007. The current price of gasoline is €1.20 per litre (Euro 95) which would result in a km price of €0.35 instead of €0.36 in 2008, a slightly lower km price in 2020 and a km price of €0.33 instead of €0.34 in 2030.

There is not much literature available about the price of H_2 at refuelling stations. The current cost price is €0.44 but according to a recent ECN study the price will be reduced to €0.056 kWh for decentralized H_2 production by reforming natural gas *(Smit et al. 2006*). The ECN study contains a lot of uncertainties because the H_2 price development is based on assumptions concerning the production costs of H_2 and the future development of the Dutch H_2 market. A H_2 price of €0.12 kWh instead of €0.18 kWh results in a km price of €0.31 instead of €0.33 by 2030 and a H_2 price of €0.24 kWh instead of €0.18 kWh results in a km price of €0.35 by 2030.

In this study the development of the electricity price already shows a large variation which ranges from €0.22 kWh to €0.37 kWh by 2030.

Costs of the EV and H_2 car

The development of the price of the EV and H_2 car is hard to estimate because they are not produced on a large scale yet and no estimations can be made about their future production numbers. In this report a large scale production of EVs is estimated by 2020 and a large scale production of H_2 cars by 2030. When produced at a large scale the price of EVs and H_2 cars is estimated to converge to the price of ICE cars. Because of the expensive battery, fuel-cell, and more complex H_2 drive-train the price of EVs and H_2 cars are estimated to be higher then the price of ICE cars. In this study both EVs and H_2 cars are estimated to reach a stable price of €20,000 once produced on a large scale. The effect of a stable EV price of €25,000 instead of €20,000 would result in an EV km price of €0.34 instead of €0.32 by 2008, €0.36 instead of €0.32 by 2020 and €0.33 instead of €0.30 by 2030. For H_2 cars a price of €25,000 would result in a km price of €0.35 instead of €0.32 by 2030.

Costs related to repair maintenance and wheels

Compared to the drive-train of ICE cars the drive-train of EVs and H_2 cars is assumed to be less vulnerable for wearing-out because they contain only a small amount of moving components. Unforeseen problems with EV and H_2 car drive-trains may cause increasing costs related to repair, maintenance and wheels.

By assuming equal costs related to repair, maintenance and wheels for EVs and ICE cars the EV km costs increase to of €0.34 instead of €0.32 by 2008, €0.34 instead of €0.32 by 2020 and €0.31 instead of €0.30 by 2030. By assuming equal costs related to repair, maintenance and wheels for H_2 cars and ICE cars the H_2 km costs increase to of €9.34 instead of €9.33 by 2008, €1.01 instead of €1.00 by 2020 and €0.33 instead of €0.32 by 2030.

6.2 Drivers and barriers to implementation

The large scale implementation of the EV and the H_2 car in the Netherlands depends on a variety of aspects. Besides costs and benefits specific drivers and barriers related to car design, fuel infrastructure, policy and safety aspects can be identified for ICE cars, EVs and H_2 cars. In this study a driver is considered an aspect that enables the large scale implementation and a barrier is an aspect that blocks a large scale implementation.

Car design

Comapared to EVs and H_2 cars the ICE car is relatively cheap because it is produced in large numbers all over the world. The infrastructure to construct, fuel and maintain ICE cars is well established which makes the ICE car practical to drive. The main disadvantages of the ICE car are the inefficiency of the drive-train and its dependency on gasoline (*Table 12*).

Compared to ICE cars not much EVs are produced at the moment but their number is growing as well as the companies that manufacture them. The price of EVs is expected to decrease when the number of produced EVs increases. Recent EVs are still limited by a relative short range and expensive batteries but these aspects are expected to improve in the near future. The maintenance of an EV is not expected to be problematic because of the small amount of moving components in the EV drive-train.

Currently H_2 cars are only produced in small numbers which makes them very expensive. Research in fuel-cell technology is necessary to reduce costs and improve their fuel efficiency and durability. The fuel-cell technology of a H_2 car is complex and scaling-up the process is necessary to achieve cost reductions. Investments are necessary to realize large scale fuel-cell and H_2 car production facilities. The maintenance on a H_2 car could be complicated because of the complexity of the fuel cell and H_2 drive-train but in general the drive-train of the H_2 car is not expected to be vulnerable for wearing out because of the small amount of moving components.

Fuel production and infrastructure

The infrastructure to refuel an ICE car is established which makes it easy to refuel all over the world. Disadvantages of gasoline are the dependency on the oil producing countries which makes the energy security uncertain and the expected price increase of oil (*IEA 2008*).

The basic infrastructure to refuel EVs already exists because it is possible to plug the EV directly in the socket at home. The electricity refuelling infrastructure can be extended relatively easy and cost efficient by building charging poles at parking lots. An infrastructure to charge EVs quick by constructing fast charging- or battery swap stations is more complex to realize but fast charging facilities are already available. An alternative could be to integrate an onboard range extender in the EV that produces additional electricity on longer trips.

An infrastructure to refuel H_2 cars is not realized. With a low penetration level of H_2 cars decentralised H_2 production at the H_2 refuelling stations is the best option because the transportation of H_2 by pipeline is complex and big H_2 production plants need to be constructed. A centralised H_2 production and distribution infrastructure requires large investments because of the necessary adaptations to the natural gas pipelines which are used for the transport of H_2 and the construction costs of the H_2 production plants.

Policy

Currently consumers are stimulated financially to buy EVs and H_2 cars because of their exemption from road tax and BPM. If EVs and H_2 cars are implemented on a larger scale it is expected that an increased amount of taxes needs to be paid over these cars to guarantee the tax incomes of the state. The government is an important actor in the future implementation of the EV and H_2 car in the Netherlands because EVs and H_2 cars need to be financially competitive with ICE cars before consumers will consider to buy them. Besides a financial impulse the large scale implementation of EVs and H_2 cars can be forced by introducing quotas for a specific type of car.

Safety

In this study the safety of ICE cars, EVs and H_2 cars is not expected to differ because all cars on the Dutch roads need to meet strict safety regulations. Past safety issues about the onboard storage of compressed or liquefied H_2 are expected to be solved by technological developments. The production and distribution process of gasoline, electricity and H_2 is not expected to cause any safety issues.

Table 12: drivers and barriers of ICE car, H_2 car and EV

	ICE car	**H_2 car**	**EV**
Car design			
Technological barriers	+	-	0
Service and maintenance	++	-	+
Production capacity	++	-	0/+
Fuel production and infrastructure			
Production	-	-	+
Distribution	++	-	++
Refuelling	++	-	0
Policy			
Current policy	-	+	+
Future policy expectation	-	+	+
Safety			
Vehicle	+	+	+
Energy infrastructure	+	+	+
Energy production	+	+	+

6.3 Fuel dependency and environment

Fuel dependency

Compared to an ICE car and H_2 car the necessary electricity to fuel an EV can be produced from a variety of (sustainable) sources. ICE cars depend on gasoline which can not easily be replaced for another fuel. Bio-fuels are an alternative but there is not enough space to produce sufficient bio-fuels in the Netherlands. H_2 is preferably produced from natural gas which is an ending resource. At the moment there is still a big natural gas resource in the Netherlands but it will start to decrease in the near future. H_2 can also be produced by the electrolysis of water but this is a very energy inefficient process. EVs are less affected by rising oil and gas prices, scarcities of oil and gas, a dependency on oil and gas from unstable regions and tensions on the international market then ICE cars and H_2 cars because of the local produced electricity.

Environment

Besides economic benefits the EV shows environmental benefits over ICE cars and H_2 cars. The overall well-to-wheel efficiency of the EV is 0.76 km/kWh. Producing the electricity with a 60% efficient high–efficiency gas turbine results in a well-to-wheel efficiency of 1.21 km/MJ. Sustainable electricity results in a well-to-wheel efficiency of 2.11 km/MJ. The overall well-to-wheel efficiency of the Honda FCX H_2 car is 0.55 km/MJ which is much lower than the efficiency of an EV that uses electricity from a gas powered power-plant with a 40% efficiency. The EV provides even more environmental benefits if sustainable produced electricity is used. The overall well-to-wheel efficiency of the Peugeot ICE car is 0,39 km/kWh which is a factor two lower then the efficiency of the electric car (*Appendix 10*).

The environmental impacts of the ICE car, EV and H_2 car differ because of their differences in drive-train efficiency and fuel types. Because of their high well-to-wheel energy efficiency the EV emits a relatively small amount of CO_2 and PM_{10}. Other environmental advantage of EVs are the opportunities of power plants to treat their emissions while ICE cars directly emit their emissions in the atmosphere without much treatment.

6.4 Policy recommendations

By considering financial-, energy security- and environmental issues the EV offers advantages over both ICE- and H_2 cars. In this study EVs prove to be cost competitive with ICE cars by considering their costs per kilometre in 2008. In this study it is estimated that the cost advantages of EVs over ICE cars will increase further in 2020 and 2030. It is also estimated that H_2 cars have no cost advantages over ICE cars until 2030 (*Smit et al. 2008*). EVs and H_2 cars offer opportunities to reduce the fuel dependency of the Netherlands because they do not depend on gasoline as a fuel. EVs drive on electricity which can be produced by a variety of sources. Compared to ICE and H_2 cars the well-to-wheel energy efficiency of EVs is much better, especially if the electricity is produced sustainable. Compared to ICE- and H_2 cars the EV has a much lower CO_2 production per driven kilometre.

The implementation of the EV in the Netherlands is in its niche phase (*Figure 17*). Not much EVs are driving around and no additional electricity infrastructure has been realized yet. Israel, Denmark, Portugal and America have set targets to stimulate the large scale implementation of EVs. By taking sufficient measures the Dutch government is capable of starting the large scale implementation of EVs in the Netherlands.

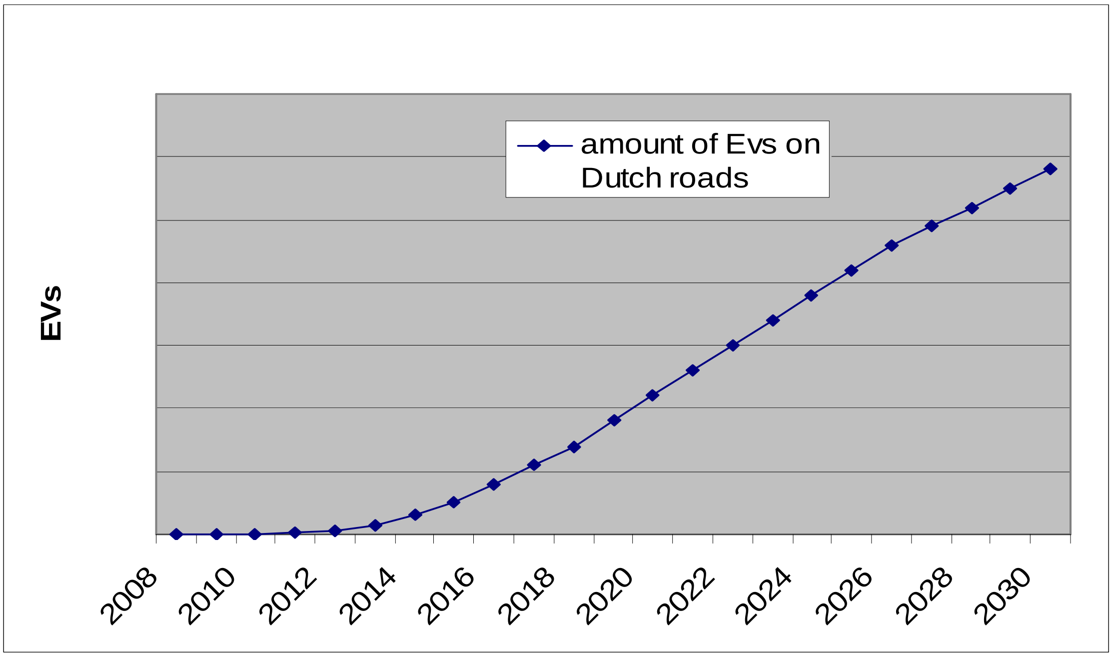


Figure 17: Scenario for the large scale introduction of EVs in the Netherlands

Measures

The large scale implementation of EVs can be stimulated by:

- Providing research and development funds for programs focussed on the technical improvement of EVs. Universities, companies and other institutions should receive funding for EV related research topics such as technical developments in EV car design and fast charging infrastructure
- The car park of the government should become electric for a certain percentage and initiatives of companies and organisations to develop a partly electric car parc should be stimulated. Efforts are necessary to improve the availability of the currently produced EVs on the Dutch market. A method to increase the amount of EVs on the Dutch roads would be to force (public transport) companies to make their car park partly electric by setting quota.

- In the current situation law and regulations stimulate consumers financially to drive EVs because of their exemption from road tax and BPM. In the near future EV drivers should be stimulated financially to make EVs competitive with ICE cars which can be done by developing a kilometre tax which is related to the CO_2 emission of a car
- The high initial investments related to the battery costs of the EV can be covered by the government or electricity companies. The car users lease the battery from the organisation that owns the battery which also covers the risks if a battery may get broken
- To realize a large scale implementation of EVs and ensure tax incomes the road tax on EVs and ICE cars can be increased gradually. In the initial situation the road tax on EVs is lower than the road tax on ICE cars. Both taxes increase at certain rate which causes a gradual phasing out of the ICE car because of the rising consumer costs
- To stimulate the EV sales in the niche phase the exemption of BPM on the net price of EVs should be continued in the near future until mass production causes a reduced EV price
- The integration of EVs in a smart electricity grid should be stimulated. EVs which are charged at night act as an electricity buffer during peak electricity demand if they are connected to the electricity grid. Electricity companies need to develop an electricity infrastructure which enables EV drivers to easily charge their EV and sell their electricity to the grid if necessary
- Pilot projects where EVs and the related energy infrastructure are realized need to be analyzed to learn lessons for the implementation of the EV in the Netherlands. In Israel, Denmark and Portugal the large scale implementation of the EV has already started (*Koppelaar R, Meerkerk B van, Polder P, Bulk J van den, Kamphorst F 2008*)

7. Conclusion

The goal of this research is to compare the costs of driving an EV and H_2 car to the costs of driving an ICE car for the Dutch situation. The total annual costs of the ICE car, EV and H_2 car are calculated for the years 2008, 2020 and 2030 by defining the fuel costs, depreciation costs, fixed costs and maintenance costs of the different cars. Scenarios are developed in this study to compare the total car costs for different driving behaviours in 2008, 2020 and 2030.

In this study a subcompact ICE car, EV and H_2 car are compared to each other. The compared cars differ in price, power output, weight and other aspects because of technology related aspects such as expensive fuel cell technology and heavy batteries.
In 2008 the total costs per kilometre of an EV are lower then the total costs per kilometre of an ICE car and H_2 car. With a yearly driving distance of 15,000 km, a 4 year car ownership and a mixed traffic (45% city, 55% highway) the costs per kilometre of an EV are €0.32 against to €0.36 for an ICE car and €9.33 for a H_2 car.
By 2020 the total costs per kilometre of an EV are lower then the total costs per kilometre of an ICE car and H_2 car. With a yearly driving distance of 16,500 km, a 4 year car ownership and a mixed traffic (45% city, 55% highway) the costs per kilometre of an EV are €0.32 against €0.36 for an ICE car and €1.00 for a H_2 car.
By 2030 the total annual costs per kilometre of an EV are lower then the total annual costs per kilometre of an ICE car and H_2 car. With a yearly driving distance of 18,000 km, a 4 year car ownership and a mixed traffic (45% city, 55% highway) the costs per kilometre of an EV are €0.30 against €0.34 for an ICE car and €0.32 for a H_2 car.
The total annual depreciation costs over ICE cars, EVs and H_2 cars are reduced by assuming a 6 or 8 year period of ownership instead of 4. Especially for H_2 cars and EVs the depreciation costs per kilometre decrease because of their relative high new price compared to ICE cars. The fuel efficiency of ICE cars in city traffic is lower then the fuel efficiency of ICE cars in highway traffic which results in higher fuel costs in city traffic and lower fuel costs in highway traffic. The fuel efficiency of EVs and H_2 cars in city- and highway traffic is assumed to be equal.

Besides the financial picture the possible implementation of EVs and H_2 cars in the Netherlands depends on a variety of drivers and barriers. Compared to the ICE car, major drivers of the EV and H_2 car are the independency of oil and the reduced CO_2 emissions. Compared to the ICE car and H2 car a major driver of the EV car is its energy efficiency.
The battery price and the range of the EV used to be a barrier for the large scale implementation of EVs but these problems are expected to be solved on the short term by mass production of batteries and improved battery design. On the short term H_2 cars are not ready for mass production because the fuel cell is too expensive and energy inefficient. The complex drive-train of H_2 cars causes a further price increase. The production capacity of EVs will increase significantly in the near future because multiple companies are building EV production facilities at the moment. The complex drive-train of the H_2 car requires large investments in production facilities which is a barrier for H_2 car manufacturers. Not much EV maintenance barriers are expected because the drive-train of the EV is easy to understand and it is not expected to require much maintenance. The drive-train of the H_2 car requires more expertise.
The majority of the refuelling infrastructure of EVs already exists because the EV can be plugged in to the electricity grid directly. Charging poles at parking lots and fast charging facilities are necessary to increase the practical use of EVs. For H_2 cars no energy refuelling infrastructure has been realized yet and large investments are necessary to realize it. On the short term no large scale H_2 production and distribution infrastructure is expected to be realized.

According to this study the EV offers some important advantages over ICE- and H_2 cars. The government can encourage the implementation of EVs by:

- Investing in research and development projects to improve the EV and the necessary electricity infrastructure
- Switching to EVs and stimulate companies and organizations to do the same
- Provide fiscal advantages for EV drivers during the EV implementation phase (exemption from BPM and road tax)
- Covering initial battery investments by the government or electricity companies and leasing the battery to car users
- Develop a future vehicle tax system which stimulates cars with a low CO_2 emission and cars that are independent from oil
- Stimulate electricity companies to develop an electricity infrastructure for EVs
- Analyze countries where EVs are introduced at the moment and use the information to implement EVs in the Netherlands

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Appendices

Appendix 1: Description Dutch energy and transport sector

General
The gross energy consumption of the Netherlands in 2005 was 81.0 Mtoe. Natural gas provided 43.6 % of the gross energy demand followed by oil (39.5%), solid fuels such as coal (10.1%), renewables (3.5%), nuclear (1.2%) and other (2%) (*Table 1*).
In the same year the Netherlands was a net exporter of gas (59.3%) and a net importer of oil (97.1%) and solid fuels (101.5%)*.
The final Dutch energy consumption in 2005 was 51.6 Mtoe. Natural gas provided 39.3% of the final energy consumption followed by oil (33.7%), electricity (17.4%), derived heat & industrial waste (5.8%), solid fuels (2.9%) and renewables (0.8%)**. In 2005 the transport sector consumed 29% of the total Dutch energy consumption, industry 29% and other sectors such as households and services 42%. In the transport sector the transport by road consumes 73% of the energy, followed by air transport (25%), railway (1%) and inland navigation (1%).

Electricity
The Dutch electricity production capacity in 2005 was 21,667 MW. The biggest part (92%) was produced conventional thermal, 6% by wind and 2% nuclear.
The gross Dutch electricity production in TWh was generated for 87% conventional thermal, for 9% by renewables and for 4% by nuclear facilities. The conventional thermal electricity was produced for 70% by natural gas, 27% by coal and for 3% by oil and other power stations.
(*European commission 2007*).

Number of cars
In the period 1990-2005 the amount of passenger cars in the Netherlands increased with 29% from 5.5 million in 1990 to 7.1 million by 2005. There were 434 cars per 1000 inhabitants in the Netherlands by 2005.
The amount of road goods vehicles increased in the period 1990-2004 with 58% from 553,000 in 1990 to 1,035,600 by 2004.
The number of buses and coaches on the Dutch roads declined with 7% in the period 1990-2004. In 1990 there were 12,100 buses and coaches on the roads instead of 11,200 in 2004. (*Eurostat 2007*)

Infrastructure
The total length of roads (excluding motorways) in the Netherlands was over 125,000 km in 2000. The Dutch main roads increased during the period 1990-2003. The length of the motorways increased with 21% from 2,092 km in 1990 to 2,541 km by 2003.
The length of the Dutch oil pipeline network is 418 km (2004).
(*Eurostat 2007*)

Energy consumption road transport
The Dutch transportation sector consumes 29% of the total Dutch energy consumption. In Europe as a whole the transportation sector is responsible for 31% of the total energy consumption. The Dutch consumption per capita (5,056 kgoe/cap in 2004) is higher than the average energy use per capita in the rest of the European union (3,689 kgoe/cap in 2004).
The Dutch CO_2 production per capita (10,902 kg/cap in 2004) is higher then the average European CO_2 production per capita (8,180 kg/cap in 2004).

In the period 1990-2004 the Dutch transportation sector has shown a large growth. The energy use of the transport by road increased with 37% from 8,040 Ttoe to 11,004 Ttoe, the transport by air increased with 121% from 1,614 Ttoe to 3,563 Ttoe and the transport by rail increased with 28% from 147 Ttoe to 188 Ttoe.

In the period 1996-2006 the share of diesel in the road transport sector increased. The petrol/diesel balance in 1996 showed a 48% petrol use against a 52% diesel use. In 2006 the petrol/diesel balance showed a 39.6% petrol use against a 60.4% diesel use.
(*Eurostat 2007*)
The final Dutch energy consumption in 2005 was 51.6 Mtoe. The road transport sector accounted with 11.0 Mtoe for 21% of the total energy consumption. (*European commission 2007*).
The average amount of km driven by a car in the Netherlands was almost 14,000 km in 2006 (CBS, 2008). Privately owned cars drive on average 12,000 km while cars that belong to companies drive on average 26,000 km annually. The average diesel car drives on overage 26,000 km annually which is twice the amount of a gasoline car.
The greenhouse gas emissions from the Dutch transport sector increased with 34% between 1990 and 2004. The emission increased from 26.4 million tons in 1990 to 35.4 million tons in 2004. (*Eurostat 2007*)

* *changes in stocks cause values over 100%*
** excluding consumption of renewables for electricity and derived heat

Table 1: Energy statistics for the Netherlands (European commission, 2007)

Mtoe	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Production	60.48	67.32	67.28	68.52	66.39	66.24	74.06	66.02	63.20	59.67	57.37	61.10	60.60	58.37	67.60	61.84
Solid fuels																
Oil	4.03	3.76	3.40	3.32	4.38	3.56	3.23	3.06	2.76	2.60	2.42	2.28	3.15	3.10	2.93	2.30
Gas	54.61	61.74	62.01	63.12	59.88	60.46	68.34	60.59	57.61	54.12	51.90	55.71	54.27	52.21	61.58	56.27
Nuclear	0.88	0.84	0.87	0.99	1.02	1.04	1.04	0.59	0.94	0.99	1.01	1.03	1.01	1.04	0.99	1.03
Renewables	0.96	0.98	1.01	1.10	1.11	1.15	1.39	1.55	1.65	1.71	1.82	1.87	1.96	2.02	2.11	2.25
Industrial waste						0.03	0.07	0.23	0.25	0.25	0.21	0.21	0.21			
Net Imports	17.45	14.47	14.65	13.37	17.18	16.36	14.06	22.72	23.49	25.93	34.34	31.53	31.50	35.47	30.05	36.91
Solid fuels	9.57	8.34	8.39	8.57	8.93	8.92	8.91	10.42	8.69	7.24	8.22	8.48	8.23	9.23	9.14	8.31
Oil	30.88	32.62	34.14	32.75	33.86	32.83	35.12	36.46	36.47	36.65	41.67	41.69	40.19	40.92	44.11	47.39
Gas	-23.80	-27.29	-28.63	-28.84	-26.51	-26.37	-30.89	-25.25	-22.69	-19.54	-17.19	-20.17	-18.45	-16.20	-24.86	-20.94
Electricity	0.79	0.79	0.75	0.89	0.91	0.98	0.91	1.09	1.02	1.59	1.63	1.49	1.41	1.46	1.39	1.57
Renewables	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.12	0.07	0.27	0.56
Derived heat																
Gross Inland Consumption	67.07	70.11	70.26	71.07	70.86	73.63	76.47	75.31	75.23	74.68	75.92	77.96	78.62	80.59	82.37	80.97
Solid fuels	9.21	8.10	8.49	8.78	8.86	9.10	9.15	9.14	9.27	7.52	8.03	8.42	8.47	8.82	9.26	8.19
Oil	24.42	24.96	25.76	25.04	25.59	27.24	26.46	27.38	27.16	28.03	28.50	29.37	29.60	31.19	31.62	32.03
Gas	30.81	34.45	33.38	34.27	33.36	34.09	37.46	35.33	34.95	34.58	34.71	35.55	35.84	36.00	36.74	35.32
Nuclear	0.88	0.84	0.87	0.99	1.02	1.04	1.04	0.59	0.94	0.99	1.01	1.03	1.01	1.04	0.99	1.03
Renewables	0.96	0.98	1.01	1.11	1.11	1.15	1.39	1.55	1.65	1.72	1.83	1.90	2.08	2.09	2.37	2.82
Other (****)	0.79	0.79	0.75	0.89	0.91	1.01	0.98	1.32	1.27	1.84	1.84	1.70	1.62	1.46	1.39	1.57
Elec. Generation (TWh)	71.97	74.39	77.19	76.99	79.65	81.07	85.33	86.66	91.12	86.68	89.62	93.75	95.97	96.78	100.77	100.22
Coal (TWh)	25.05	22.66	22.63	21.41	24.46	26.08	24.05	22.98	24.17	19.00	22.60	23.72	23.94	24.34	23.50	23.50
Oil (TWh)	3.09	3.38	3.25	3.07	3.08	3.87	3.91	3.62	3.53	6.57	3.13	3.11	2.82	2.86	2.82	2.26
Gas (TWh)	39.14	43.71	45.99	46.92	46.32	44.83	50.09	53.53	55.09	52.66	54.56	58.28	59.95	60.01	63.75	61.28
Nuclear (TWh)	3.50	3.33	3.80	3.95	3.97	4.02	4.16	2.41	3.81	3.83	3.93	3.98	3.92	4.02	3.82	4.00
Renewables (TWh) (*)	1.19	1.31	1.37	1.57	1.71	1.96	2.67	3.48	3.88	3.56	4.23	4.41	4.04	5.33	6.67	8.92
Other (TWh) (***)			0.15	0.08	0.11	0.32	0.45	0.65	0.64	1.06	1.17	0.24	1.31	0.22	0.20	0.26
Final Energy Consumption	42.87	45.91	45.22	46.89	46.14	47.75	51.76	49.54	49.72	48.87	50.19	50.94	50.78	51.63	52.55	51.59
by fuel/product																
Solid fuels	1.70	1.45	1.46	1.57	1.23	1.46	1.45	1.62	1.53	1.49	1.35	1.43	1.46	1.42	1.63	1.51
Oil	12.79	13.48	13.91	14.38	14.51	14.68	15.55	15.85	16.07	16.03	16.47	16.51	16.91	17.16	17.43	17.37
Gas	21.24	23.57	22.16	23.12	21.78	22.52	25.06	21.93	21.48	20.39	21.01	21.55	20.99	21.69	21.65	20.34
Electricity	6.32	6.50	6.69	6.77	6.99	7.14	7.41	7.70	7.97	8.14	8.42	8.55	8.58	8.64	8.87	8.99
Renewables	0.38	0.39	0.42	0.42	0.43	0.37	0.38	0.38	0.37	0.36	0.38	0.38	0.38	0.38	0.41	0.41
Derived heat & industrial waste	0.44	0.50	0.59	0.63	1.19	1.57	1.90	2.07	2.29	2.46	2.56	2.53	2.47	2.33	2.56	2.98
by sector																
Industry	12.58	12.77	12.63	13.31	12.55	12.75	13.26	13.26	13.22	12.85	13.83	13.80	13.80	14.35	14.88	14.95
Transport	10.36	10.55	11.20	11.57	11.81	12.40	13.12	13.49	13.61	13.77	13.82	14.23	14.58	14.67	15.04	15.07
Households	9.94	11.06	10.21	10.78	10.63	11.15	12.38	10.75	10.38	10.33	10.33	10.65	10.25	10.50	10.44	10.10
Commerce, etc.	9.99	11.53	11.17	11.23	11.14	11.44	13.00	12.04	12.52	11.92	12.21	12.25	12.16	12.11	12.19	11.47
Non-Energy Uses	9.49	9.71	9.42	8.08	8.71	9.41	7.87	8.67	8.36	8.94	9.58	9.47	9.66	10.69	10.96	12.30
CO_2 Emissions (Mt) (**)	198	205	204	210	208	214	222	218	222	218	222	232	232	233	239	241
Energy Intensity (toe/M€ '00)	219	224	220	220	213	215	216	204	196	186	182	183	184	188	188	182
CO_2 Intensity (tCO_2/toe)	2.96	2.92	2.90	2.95	2.94	2.90	2.90	2.90	2.95	2.92	2.92	2.97	2.95	2.89	2.90	2.97
Import dependency, %	22.4	17.8	18.0	16.2	21.0	19.3	16.0	26.0	26.9	29.7	38.5	34.1	33.9	37.7	31.0	37.8
Energy per capita (kgoe/cap)	4487	4653	4628	4648	4607	4763	4926	4825	4790	4724	4768	4860	4869	4968	5061	4962
CO_2 per capita (kg/cap)	13266	13576	13416	13730	13540	13819	14299	13965	14115	13774	13946	14444	14377	14355	14662	14761

Source: Eurostat, December 2007 (*) not including pumping (**) Source: European Environment Agency, December 2007; Including Bunkers (***) Pumped Storage Plants and Other Power Stations (****) Electical Energy and Industrial Waste

60(81)

Appendix 2: The Price of sustainable energy

The recent price of on-shore and off-shore wind energy is respectively €0.088 and €0.137 kWh and is expected to decrease to respectively €0.064 kWh for on-shore and €0.082 kWh for off-shore by 2020. The ECN Powers model projects a base-load electricity price of €0.05 by 2020. The expected market price of electricity by 2020 is €0.068 and €0.084 kWh which makes wind energy economically competitive (*NWEA 2008*).
The price of PV-electricity has decreased rapidly the past decade and is expected to decrease further the coming future. The price of home produced PV electricity in Germany is expected to decrease to €0.24 kWh by 2013 (*Photon International 2008*). Despite the market chances for sustainable produced electricity it is expected that the Dutch electricity price will gradually increase because the majority of the electricity in the Netherlands is produced in power plants that are powered by coal and natural gas. The prices for natural gas and coal have been rising the past years and are expected to do so in the future.

Appendix 3: Generation costs of electricity in Europe

	€'2005/MWh					Change in %	
	2000	2005	2010	2020	2030	00-05	05-30
Generation Costs	53.3	59.5	59.4	63.1	65.1	2.2	0.4
Annual capital costs	17.5	18.9	20.7	22.2	24.2	1.5	1.0
Non-Fuel Gener. Costs	13.3	13.2	13.1	12.4	11.5	-0.2	-0.5
Fuel costs	22.5	27.4	25.5	28.6	29.4	4.1	0.3
Grid and Supply Costs	16.4	17.5	17.8	18.5	19.1	1.3	0.3
Profit mark-up	14.7	6.4	5.6	5.0	5.7	-15.4	-0.5
Avg. Pre-tax Price of Electricity	84.4	83.4	82.7	86.7	89.8	-0.2	0.3
Electricity Taxes	11.2	14.6	14.7	15.1	15.2	5.5	0.2
Avg. End-user Price of Electricity	95.6	98.0	97.5	101.8	105.0	0.5	0.3

Figure: Power system costs and prices (EC 2007)

Appendix 4: EV battery production facilities

Nissan Motor and NEC joint venture Automotive Energy Supply Corp.
Recently it was announced that Nissan Motor is planning to become a world leader in zero emission EVs. Nissan Motor will work together with the company NEC to produce advanced lithium-ion batteries which are necessary for EVs.
Together Nissan Motor and NEC have set up the joint venture company Automotive Energy Supply Corporation which wants to start the production of advanced Lithium-ion batteries by 2009. An amount of $114,6 million is spend by the Automotive Energy Supply Corporation to realize production facilities. The Automotive Energy Supply Corporation plans a production capacity of 13,000 batteries which can be expanded to 65,000.
The designed batteries are claimed to produce twice the power of a conventional Nickel-metal hydride battery with only half the size. The designed batteries will have a lifetime of over 100,000 km. The Automotive Energy Supply Corporation plans to launch EVs in US and Japan by 2010, In Israel and Denmark as a part of the Project Better Place initiative in 2011 and start the mass marketing of EVs by 2012.

Appendix 5: EV energy infrastructure

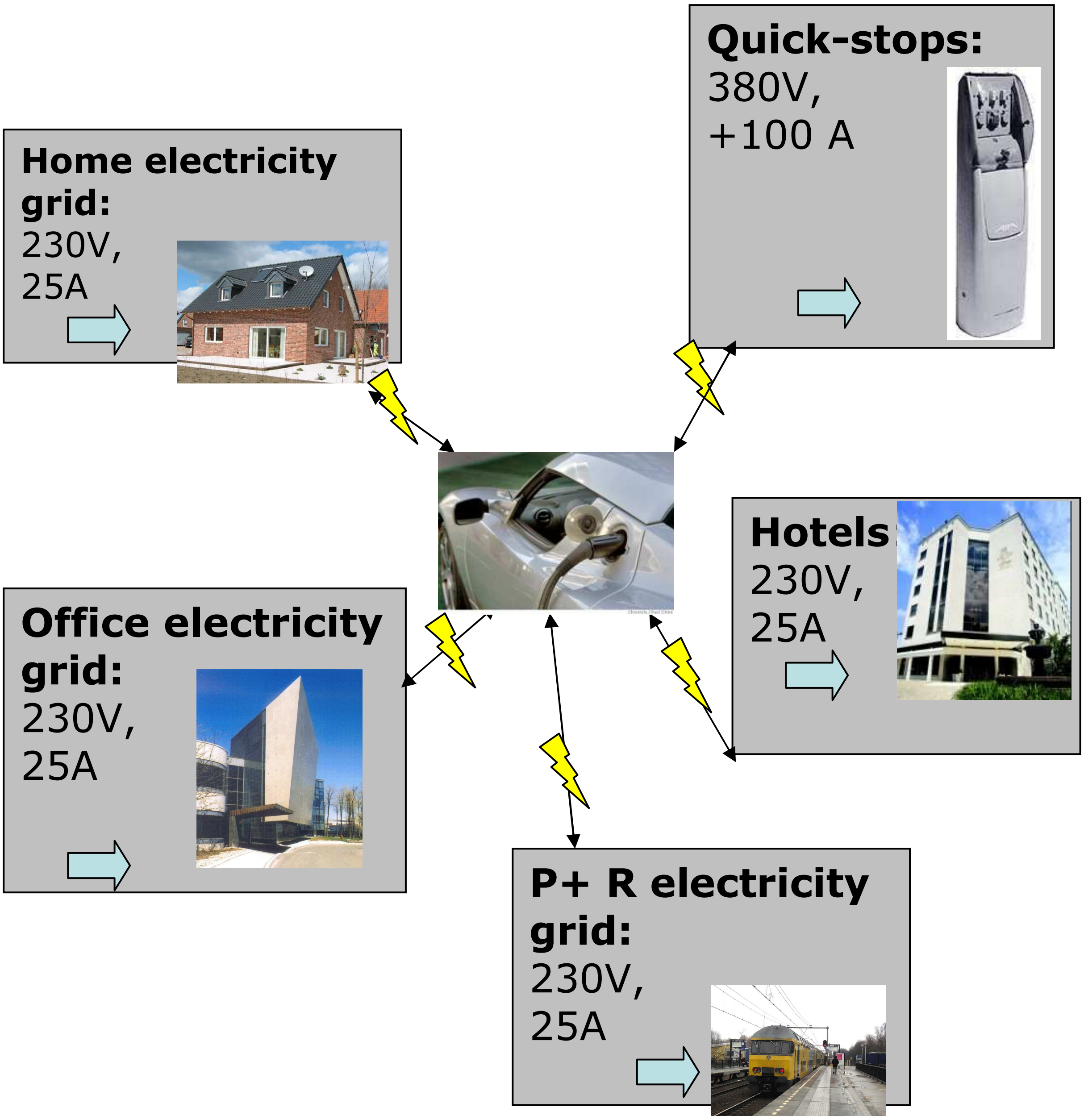


Figure: Possible charging infrastructure for electric cars

Appendix 6: Smart Electricity Grids

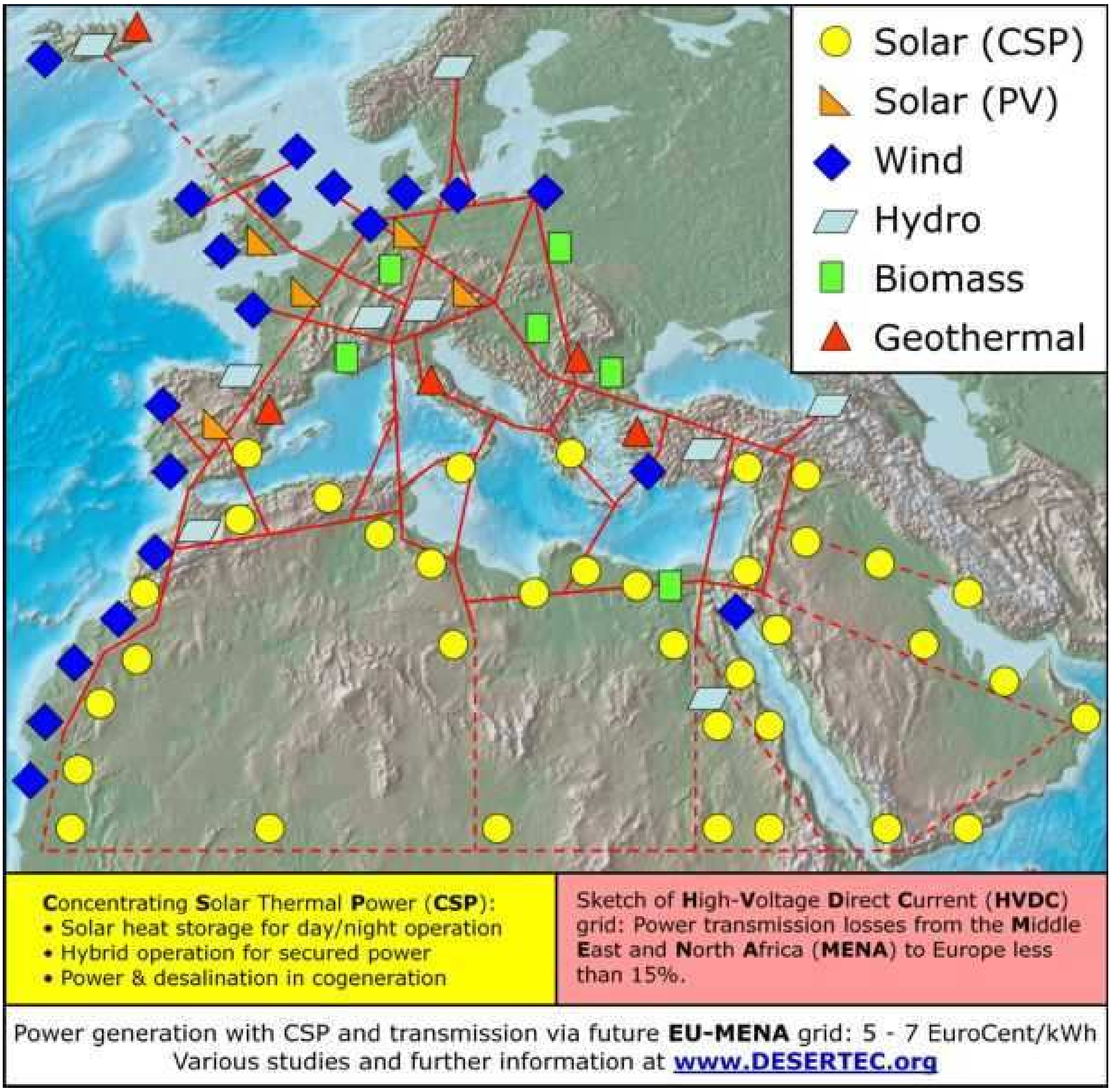
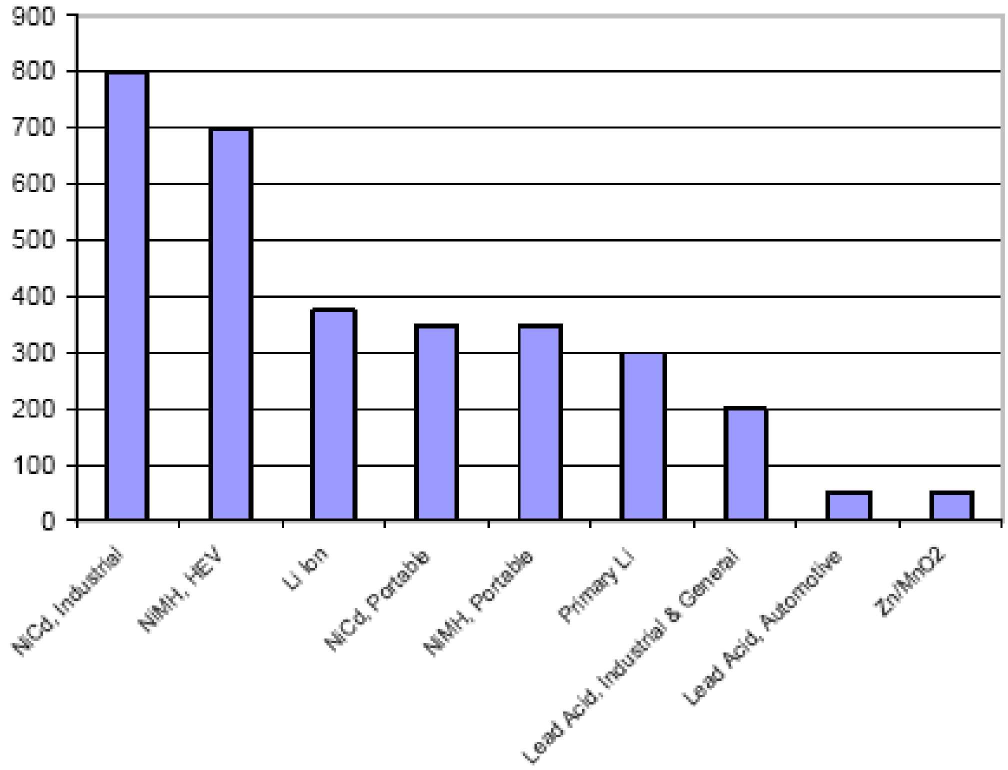


Figure: Example of a smart electricity grid (Desertec 2008)

Appendix 7: Battery costs



Average battery costs at cell manufacturing level in $/kWh (electronics and connections to form the battery not included) (Deutsche Bank 2008)

Appendix 8: Rechargable Zn-air battery

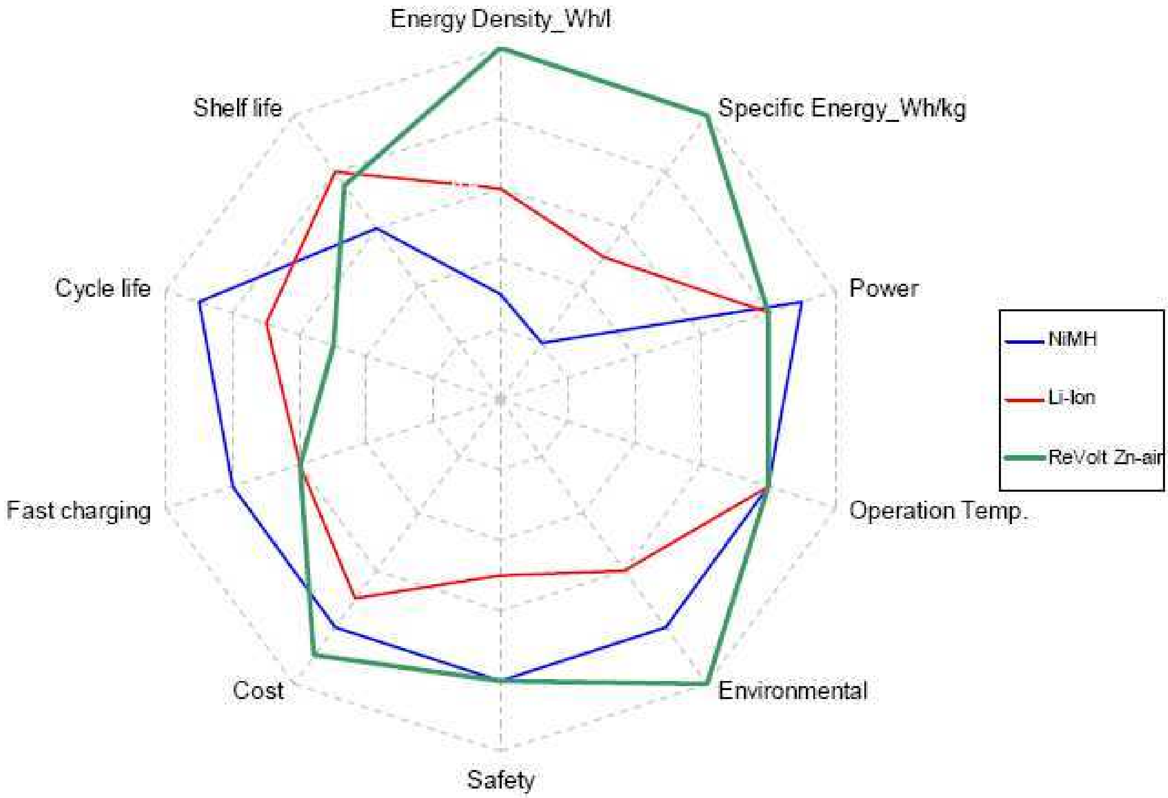


Figure: Characteristics of ReVolt Zn-air battery (ReVolt technology 2008)

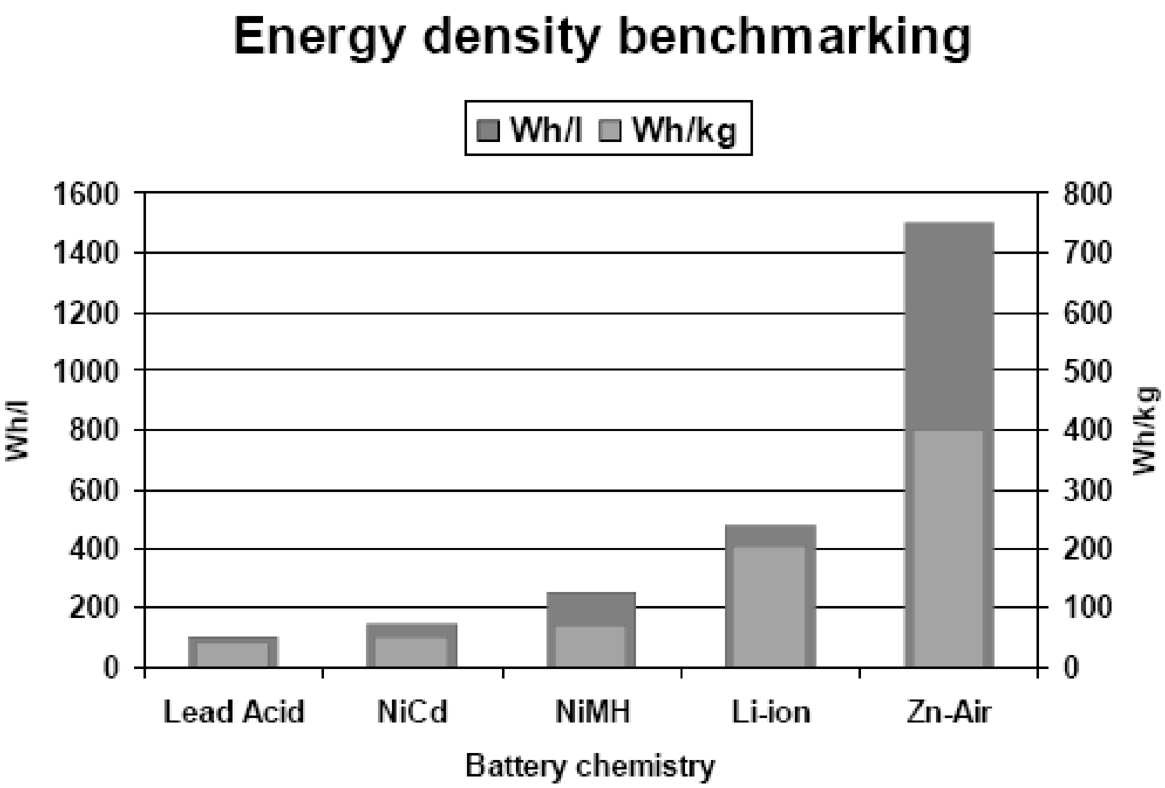
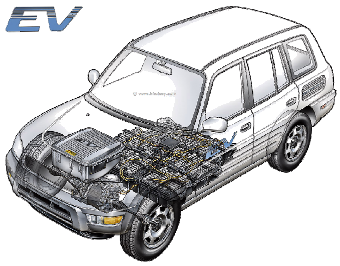


Figure: Energy density of ReVolt Zn-air battery (ReVolt technology 2008)

Appendix 9: Energy efficiency of ICE, EV and H_2 car

Internal combustion car

Combustion engine efficiency: 20%
Overall ICE car efficiency: 15%



Electric car

Efficiency of charging and discharging battery: 85%
Overall EV efficiency: 75%

Hydrogen car

Fuel cell efficiency: 50%
Overall H_2 car efficiency: 40%

Figure: Efficiency of ICE car, EV and H_2 car

Data	Value	Source
Tank-to-wheel efficiency ICE car (%)	15%	USDOE 2008
Tank-to-wheel efficiency EV (%)	75%	IEA 2005
Tank-to-wheel efficiency H_2 car (%)	40%	Bossel 2003

Appendix 10: Well-to-Wheel energy Efficiency

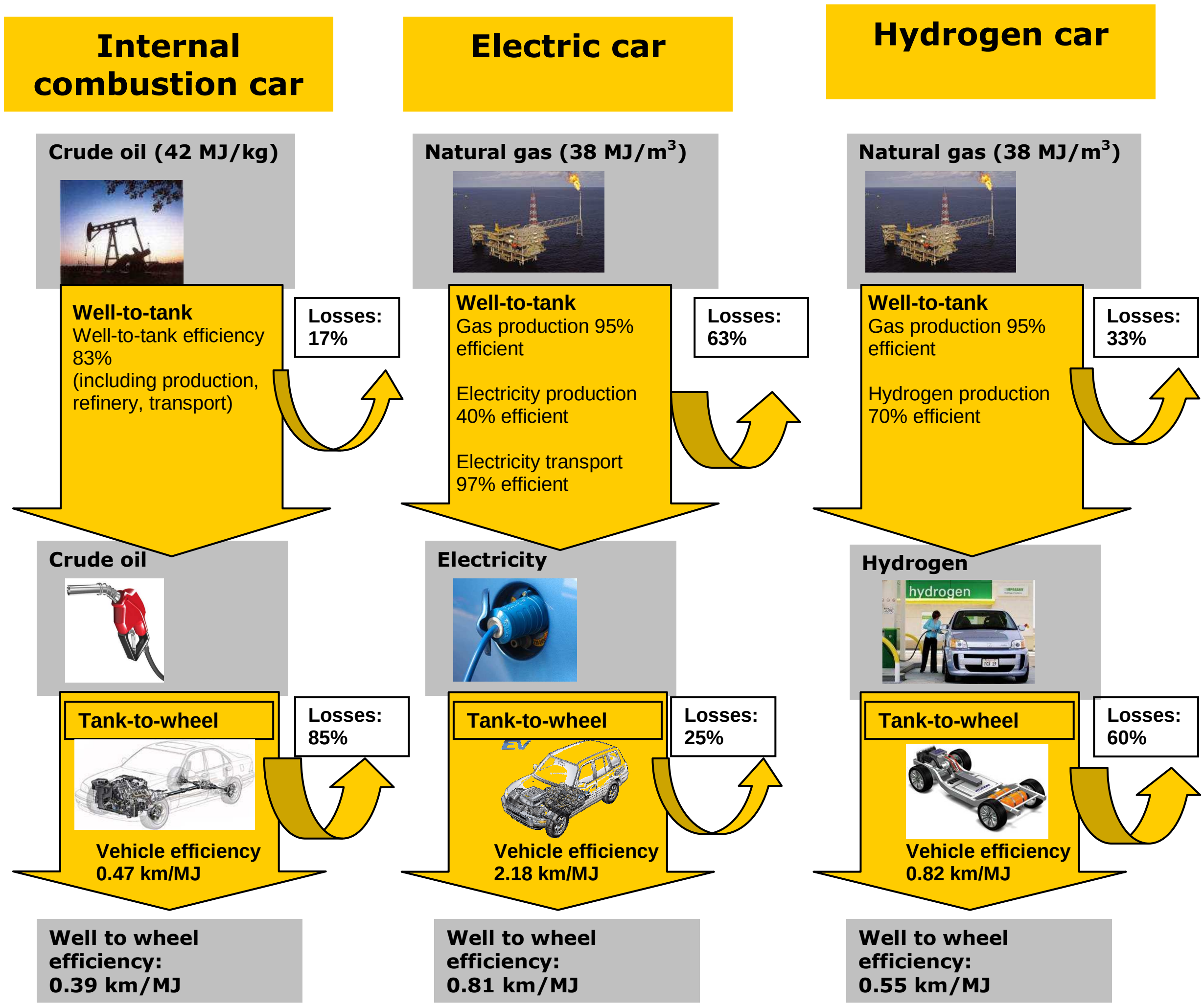


Figure: Well-to-wheel efficiency of ICE car, EV and H_2 car

Data	Value	Source
Well-to-tank efficiency of oil production	83%	USDOE 2000
Natural gas production efficiency	95%	Tesla Motors 2007
Electricity production from natural gas	+40%	Seebregts et al., 2005
Electricity transportation efficiency over the grid	+92%	Tesla Motors 2007
Efficiency of decentralized H_2 production by natural gas reforming	70%	Smit et al., 2006
Tank-to-wheel efficiency ICE car (%)	15%	USDOE 2008
Tank-to-wheel efficiency EV (%)	75%	IEA 2005
Tank-to-wheel efficiency H_2 car (%)	40%	Bossel 2003
ICE car energy use (km/MJ)	0.47	ANWB 2008
EV energy use (km/MJ)	2.18	Tesla Motors 2007
H_2 car energy use (km/MJ)	0.82	Fueleconomy 2008

In the Netherlands the majority of the electricity is produced in natural gas powered power plants. In the current situation H_2 is produced most economically in a decentralized natural gas reforming process. The well-to-wheel efficiency of the ICE car, EV and H_2 car are calculated by multiplying the well-to-tank efficiency of the specific fuel with the energy use of the vehicle in km/MJ.

Appendix 11: CO_2 price development

Table: Estimated CO_2 price development in the Netherlands (ECN2004)

		2005	2010	2015	2020
CO_2-prijs	€/ton	2	7	11	11
Doortikfactor		0,5	0,54	0,69	0,85
Netto CO_2-prijs	€/ton	1	4,3	7,6	9,3

Appendix 12: Interview Jan Heetebrij (HeeCon Business Development)

Jan Heetebrij (HeeCon business development)
Date: 30-09-2008
Place: Zoetermeer (NL)

Introductionn:
Think is one of the few companies that really builds EVs in relatively large numbers and the Ox model which will be available soon is bigger and more powerful than the previous models. Zapp is another company that builds relatively large numbers of EVs. Renault, Nissan, Toyota, Chevrolet, Ford and other big car manufacturers are busy to construct an assembly line of EVs but they will not construct them the coming 1 to 2 years.
Background
Jan Heetebrij is working as Maniging Partner at HeeCon Business Development for 7 years. He became an expert in the EV topic in the Netherlands because of his involvement in different projects. Despite the limited production capacity of Lithium the opinion of Jan Heetebrij is that Li-ion polymer batteries have the best chance to be used in EVs on the short term (< 5 year). Jan Heetebrij expects that advanced Zn-air batteries can be a good alternative because of their lower weight and possible reduced price. Zn batteries and their production facilities exist for a long time already and Jan Heetebrij expects that this will simplify the production of advanced Zn-air batteries on the longer term (<20 year).
EV energy infrastructure
According to Jan Heetebrij an onboard range extender can be implemented to increase the range of EVs by charging the battery. The range extender is powered by a liquid fuel (i.e. gasoline or ethanol) and produces electricity which is delivered directly to the battery of the car. Because the vehicle is still powered by the efficient electric drive train a fuel use of 1 litre in 40 km should be possible according to Jan Heetebrij. The power output of the range extender will be 30 kW and it weights about 60 kg. The costs of EV charging poles (230 V) are estimated to be in the range of a few hundred euros each but there is not much initiative from the electricity companies to realize such an infrastructure. Essent is the most active party. The charging poles are not more than a socket with an implemented pay system.
Batteries
According to Jan Heetebrij the maximum range of EVs is 300 km. To increase the range bigger batteries are necessary which cause increased battery costs and battery weight.
According to Jan Heetebrij the costs of Li-ion batteries will decrease to €100 - €150 kWh within the next 8 years. Jan Heetebrij estimates that the costs of advanced Zn-air batteries could decrease to €80 - €100 kWh. In the literature a lifetime of 20 years and 7000 charging cycles is mentioned for the new generation Li-ion batteries. According to Jan Heetebrij more improvements in battery efficiency can be made by improvements in the efficiency of the battery itself and improved battery management systems. The efficiency of the charging and discharging cycle of the batteries can still be improved.
Buying or leasing
Acoording to Jan Heetebrij battery leasing is a proper construction to stimulate the EV car sales in the Netherlands because it reduces the risks for the consumer and increases the opportunities for electricity companies to implement the batteries in their electricity grid.
Electricity grid
According to Jan Heetebrij the maximum Dutch electricity production is 20,000 MWh. During peak demand only 13,000 MWh is used. The average Dutch demand is 10.000 MWh and during the night 6,000 MWh. There is sufficient capacity to charge EVs. The Dutch electricity price is not expected to increase much further because of the development of a smart electricity grid which results in cost reductions.
Taxes

According to Jan Heetebrij the current profitable tax system for EVs will last until they represent 10% to 15% of the Dutch car fleet. New policy should be developed to gradually increase the costs for ICE and EV driving while maintaining a more advantageous tax system for the EV. This can be realized by introducing a CO_2 coupled km tax.

ICE cars

ICE cars are becoming more energy efficient but it is a slow process. According to Jan Heetebrij the yearly maintenance costs of ICE cars are €500 and the insurance costs for EVs and ICE cars are comparable.

Appendix 13: Interview Douwe Beerda (Master student RUG)

Date: 30-09-2008
Place: Utrecht

Background
Douwe Beerda is a Master student at the RUG (Rijks Universiteit Groningen) who works on his thesis for the company Ecofys in Utrecht. The subject of the thesis on which Douwe Beerda is working for 2 months is electric driving.
Batteries
On the short term (<5 year) Douwe Beerda expects that Li-ion batteries will be used in EVs because these batteries are used in cars that are currently entering the market. On the longer term (<20 year) Douwe Beerda expects that also Li-ion batteries will be used in EVs because he does not know any better alternatives. Important aspects are a high energy density, long lifecycle and a low weight.
The current range of EVs is 150 – 300 km but it can be increased to 400 to 500 km by implementing a bigger battery. A bigger range is possible but not plausible because of the high price and weight of the battery. The battery costs can be reduced significantly by mass production and improved battery design. There are no large scale production facilities yet for Li-ion batteries that are used in EVs and scaling up this process will cause a significant price decrease.
According to literature the life time of advanced Li-ion batteries is 10 years. It is the question whether a longer life time is necessary because it is not necessary that the battery life exceeds the life of the car. Douwe Beerda does not expect that much more efficient batteries will be developed because battery technology is already available for a long time. The construction of large scale production facilities for Li-ion batteries is most important.
EV energy infrastructure
According to Douwe Beerda both fast charging and battery swap stations are a possibility but swapping stations are quicker and more easy. With both options problems with standardization occur. An option could be to construct swapping stations for people that lease their battery and fast charging stations for people that own the battery themselves. Douwe Beerda expects that battery leasing constructions develop by itself in the Netherlands if business opportunities occur.
According to Essent the electricity production capacity is sufficient to add 1 million EVs to the Dutch car fleet. More EVs can be added if decentralized energy production
Oil and electricity price
According to Douwe Beerda the global oil price could increase to over $300 in the long term. The price of electricity is not expected to increase much further then €0.40 kWh because then solar energy becomes competitive and consumers will start to produce their own electricity.
Douwe Beerda expects that the current profitable EV tax system continues on the short term. On the long term there is the possibility to gradually increase the BPM taxes on ICE cars and EVs to force people to drive EVs. If EVs become a significant part of the Dutch car fleet tax incomes need to be guaranted.
ICE cars
The current efficiency of an ICE motor is about 20%, not much improvements are possible to increase this efficiency much further.

Appendix 14: Interview Willem van der Kooi (ECEcars)

Date: 01-11-2008
Place: Lochem (NL)

Introduction:
Together with Hjalmar Engel, Willem van der Kooi is director of Electric Cars Europe (ECEcars) which was founded in June 2008. Currently ECEcars revises ICE cars (Volkswagens and Lotus) to EV's by stripping the ICE drive-train and replacing it for an electric one. The revised EVs are sold for €60,000 to both companies or private users.
Background
The goal of ECEcars is the drastic reduction of CO_2 emissions by replacing ICE cars for EVs. At the moment ECEcars and PROTON are realizing an EV production plant in Malaysia capable of producing 30.000 EVs by 2009, 120.000 by 2010 and 270.000 by 2011. The EVs will be sold under the name Detroit Electric in Europe and America.
EV energy infrastructure
According to Willem the future energy infrastructure to charge EVs contains a smart electricity grid, charging poles and fast charging facilities (+100 A). The realization of such an energy infrastructure can be realized because the smart electricity grid is developed at the moment (Essent, 2008) and (fast) charging facilities are an extension of the current electricity infrastructure. The smart electricity grid enables EV drivers to easily sell and buy electricity from the grid. The Mobile Smart Grid which is already developed recognises an EV when it is plugged in the electricity grid and enables EV drivers to charge their car at the lowest electricity price. At peak electricity demand electricity can be drawn from EVs that are connected to the electricity grid. The public (fast) charging facilities need to be robust to prevent abuse. According to Willem the development of an EV energy infrastructure will start when 100,000 EVs are in operation in the Netherlands.
Batteries
According to Willem the efficiency of Li-ion polymer batteries is expected to increase largely in the near future. Willem estimates that the energy density of Li-ion polymer batteries for EVs will increase with a factor 5 the coming 5 years. According to Willem a lot of improvements in battery efficiency have been realized in research projects all over the world.
According to Willem the battery costs for ECEcars are expected to decrease with almost a factor 2 in the near future because they will start with their own battery production facility in Malaysia. At the moment ECEcars pays €750 kWh and in the near future this price is expected to decrease to €400 kWh. The battery production facility in Malaysia enables a yearly production of 200,000 batteries. According to Willem the current range of a 37 kW EV is 300 km. Because of improved battery efficiency the range of EVs is expected to increase to 1500 km in the near future. The lifetime of a Li-ion polymer battery is 200,000 km (from 100% to 80% capacity) after which the batteries can be used for onsite electricity storage.
Willem assumes that alternatives for Li-ion polymer batteries will be developed if necessary.
EVs
According to Willem the current range of a 37 kW EV is 300 km. Because of improved battery efficiency the range of EVs is expected to increase to 1500 km in the near future. The lifetime of a Li-ion polymer battery is 200,000 km (from 100% to 80% capacity) after which the batteries can be used for onsite electricity storage. The price of the Detroit Electric subcompact will be around €23,000 once it is imported in the Netherlands by 2009. The larger and more powerful Detroit Electric Persona will cost €32,000.
The costs related to repair, maintenance and wheels are not known yet because not much EVs are driving around. The EVs from Detroit Electric are powered by a small and powerful electromotor which is located centrally in the car. To Willems opinion the Direct Drive In Wheel (DDIW) principle

provides not much advantages compared to a central electromotor; separate motors are more expensive, the weight distribution of the car is different, synchronisation of the wheels is complicated and policy barriers in the European law need to be solved.

Taxes

There is no certainty concerning the future development of EV related taxes. Willem estimates that km related taxes will be realized in the future. The Mobile Smart Grid (MSG) recognises an EV when it is plugged in the electricity grid. The MSG enables the government to implement a certain tax percentage in the electricity that is sold to an EV.

ICE cars

Willem estimates that multiple car manufacturers will focus on hybrid cars in the near future because of the larger range of hybrid cars compared to EVs. According to Willem the range of EVs increases largely in the coming years which makes the EV even more attractive.

Lease companies

Several large lease companies ordered an EV from ECEcars.

Appendix 15: Interview Daan Nap (Epyon)

Date: 03-11-2008
Place: Rijswijk (NL)

Introduction:
Daan Nap started half a year ago as Sales Engineer at Epyon. As a Sales Engineer he identifies commercial chances and proposes technical solutions to prospects for Epyon.
The company Epyon started three and a half year ago as a spin-off from the University Delft. The company was set up based on the business opportunities for Lithium polymer battery technology and super capacitors that enable the breakthrough of environmental friendly electric vehicles. At the moment Epyon develops (ultra fast) charging systems for electric vehicles. Epyons (ultra fast) charging systems are currently being implemented in pilot projects with forklift fleets, a plug-in Prius, hybrid car, delivery vehicles and cleaning machines.
According to Daan the Epyon (ultra fast) charging systems are especially suited for forklift fleets, cleaning machines, taxi fleets and delivery fleets because these vehicles need to drive many kilometres and need to be highly available. For the owner of a forklift fleet for example a long charging time results in higher costs because additional vehicles or battery packs are necessary during the charging cycle of the forklifts with an empty battery.
In warehouses electric vehicles are used because they are free from emissions and result in lower Total Costs of Ownership (TOC). Ultra fast charging systems enable a more intensive use of the electric vehicles because significant less time is necessary for the entire charging cycle and opportunity charging is a possibility.

Batteries
The battery development on the long term is never certain but on the short and medium term various types of Lithium-ion batteries will be used. At the moment Li-ion batteries are expensive but in the near future cost reductions are expected.
According to Daan Nap high quality Lithium-ion batteries are currently available for a minimum price of €800 kWh. These batteries are suited for ultra fast charging in 15 – 30 minutes. Daan assumes that the price of high quality Lithium-ion batteries could decrease to €400 kWh in the near future.
The efficiency of Lithium-ion batteries can increase significantly and a lot of battery related research projects are being performed at the moment. Bottlenecks in the battery development are the chemical processes inside the battery, charge and discharge capacity and battery management systems. The battery life depends largely on the percentage of the battery that is used (battery capacity) which makes it difficult to define the battery life.
Ultra fast charging in 6 minutes is already possible but demands high costs. In the future the costs for ultra fast charging are expected to decrease.
The energy efficiency of the ultra fast charging system of Epyon is over 90%.

EVs
According to Daan Nap the range of EVs is not expected to become more than 300 km in medium term. Batteries are expensive and currently require more space than a conventional gasoline reservoir with the same energy content. The battery capacity of EVs in the near future is expected to be 20 – 30 kWh. Larger batteries will be used in heavy vehicles such as city buses and garbage trucks. EVs need to be prepared for the ultra fast charging process in order to ensure safety, which is first priority at Epyon. Because of high battery costs Daan assumes that the price of EVs will initially remain higher than the price of ICE cars in the conventional car cost model which is usually focussed on the initial investment. Currently the costs of a 20 kWh battery are €16,000 and in the near future this price is not assumed to become less then €8,000.

Energy infrastructure
Daan Nap estimates that the future EV charging infrastructure contains households, charging poles and fast charging facilities. Currently the costs of a charging pole are high but these costs are expected to decrease when they are produced on a larger scale.
The smart electricity grid is a promising development which provides opportunities for both EVs and electricity companies. Battery lease contracts are a promising method to make EVs available for consumers. The batteries can be owned by electricity companies, the government or car lease companies.
According to Daan Nap EV charging stations are significantly cheaper then H_2 refuelling stations because they are less complex and the necessary parts are already developed and often readily available for the conventional electricity infrastructure.