Market potential of Battery Electric Vehicles

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Abstract

The transition from internal combustion engines to electric vehicles is one of the most challenging tasks of our modern society. Electric vehicles offer significant advantages such as the potential to reduce greenhouse gas emissions, lower noise pollution and greater independency of oil. Although there is a lot of public attention to electric mobility and car manufacturers keep on presenting prototypes and show cars, the actual market share of electric vehicles is negligible in all passenger vehicle markets today.

This thesis analyses both the advantages and barriers for this new technology and investigates the market potential of electric vehicles. Success factors for the transition to electric mobility are put forward. Based on actual data, customers' total costs of ownership for current and future electric cars are compared with costs of conventional vehicles. In a scenario outlook to 2020, possible future developments of electric vehicles' cost competitiveness are discussed.

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List of abbreviations

BMBF	Bundesministerium für Bildung und Forschung
CARB	California Air Resources Board
CEO	Chief executive officer
CO2	Carbon dioxide
CTO	Chief technical officer
EU	European Union
EUR	Euro (1.3 USD = 1 EUR)
EV	Electric vehicle
FCEV	Fuel Cell Electric Vehicle
G2V	Grid-to-Vehicle
GBP	Pound sterling
GHG	Greenhouse gas
GM	General Motors
HEV	Hybrid Electric Vehicle
HFCV	Hydrogen fuel cell vehicle
ICE	Internal combustion engine
ICEV	Internal combustion engine Vehicle
Km	Kilometre
Km/h	Kilometres per hour
kWh	Kilowatt-hour
LPG	Liquefied petroleum gas
mpg	Miles per gallon
Mph	Miles per hour
NiMH	Nickel metal hydride battery
OEM	Original Equipment Manufacturer (an auto company)
PHEV	Plug-In Hybrid Electric Vehicle
SOC	State of Charge
TCO	Total costs of ownership
USD	US Dollar (1.3 USD = 1 EUR)
V2G	Vehicle-to-Grid
Wh	Watt-hour
WWF	World Wildlife Fund

1 Introduction

Most recently, there has been a lot of public attention to electric mobility on the one side and criticism about the petrol industry and oil dependency on the other side. Politicians like US president Barack Obama are speaking up for independency on fossil energy sources and global criticism of petrol powered societies has been reinforced by events such as the 2010 oil spill in the Gulf of Mexico. One of the biggest challenges in the 21st century will be to reduce our dependency on oil. It is this very topic that has increasing attention in modern society.

Another aspect that made electric mobility interesting recently is costs. In 2008, the price of oil reached an all-time high. People's interest in electric vehicles increased at that time. This is indicated by the increase of internet search requests for electric vehicles (Figure 1) parallel to rising petrol prices.

1.1 Ideas and objectives

The rising importance of the electric vehicle is also indicated by the number of prototype electric vehicles that were presented at 2009 and 2010 auto shows. One can say that there has been a real EV hype. However, electric vehicles are not completely new, but have played a role in passenger transportation in the early 20th century before becoming meaningless. The question is: Do electric vehicles now have a chance to become significant to the car industry and if so, what are the reasons for that?

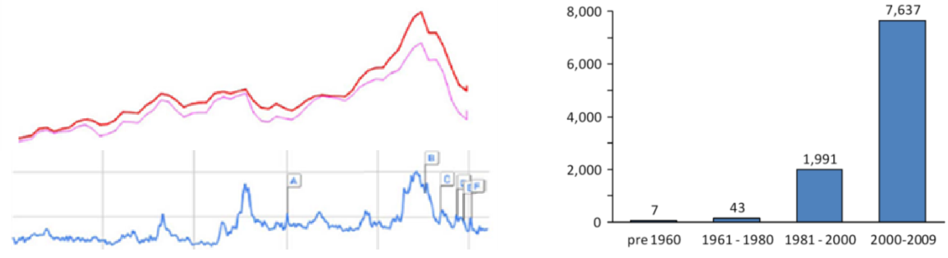

Figure 1 Left: Petrol prices in the UK 2004-2008 (red) and number of Google Search requests for electric vehicles (blue). Right: Number of published scientific papers on electric vehicles. Source: Urbancic 2010, Feller & Stephan 2009, p. 10.

This thesis investigates the market potential of battery electric vehicles. The central question is: How will the market for battery electric vehicles develop?

1.2 Structure and methods

This thesis conducts a broad market research to investigate the market potential of battery electric vehicles. Electric vehicles are highly technical and advanced products. Technical details are very important to be aware of in order to understand the potential of electric vehicles, therefore, some basic facts of the EV technology are researched and summarised in Chapter 2. Alternative concepts of vehicles and transportation are briefly introduced and discussed, in order to separate them from what is here referred to as *electric mobility*. Furthermore, a historic overview of electric vehicles is given and advantages of electric mobility as well as some critical theses about EVs are discussed in Chapter 3.

Chapter 4 investigates the market for electric vehicles and its most important component, the battery. In this section an ecoscopic market analysis for EVs and batteries is conducted.[1] Furthermore, the analysis includes the introduction and breakdown of announced products in the EV market.

The next Chapter 5 is about success factors of electric vehicles. Influencing factors on the market potential of electric vehicles are investigated from a political, technological and customer point of view. This is done with a market observation that includes research about business environment and the most important aspects of electric vehicle markets.

Chapter 6 analyses the market potential of electric vehicles in terms of cost competitiveness. Concrete market situations are introduced using scenario planning.

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[1] The term market analysis is used in the sense of Kreutle and refers to an investigation of the present situation only.

2 Concepts of alternatives vehicles and transportation

2.1 Hybrid vehicles

A hybrid vehicle is a vehicle that uses two or more distinct ways of energy storage and two or more energy converters (Blesl et al. 2009, p. 9). In the context of vehicles, the term hybrid refers to hybrid electric vehicles (HEV), which are vehicles that use an internal combustion engine (ICE) and an electric motor, together with a traction battery and fuel tank. The goal of combining these two is to take advantage of the strengths and reduce the weaknesses inherent in each individual system. There are many different ways to distinct HEVs, most commonly by the electric motor power, the energy content of the traction battery, the hybrid transmission, and the capability of all electric drive mode. In this thesis a classification by hybrid functionality is applied.

	Micro Hybrid	Mild Hybrid	Full Hybrid	Plug-In Hybrid
Features	Start/Stop	Start/Stop, recuperation, boost, load shift	Start/Stop, recuperation, boost, load shift, electric drive	Start/Stop, recuperation, boost, load shift, electric drive and external battery charging
Power Electric Motor in kW	< 6	< 15	20 – 100	> 40
Example	Smart mhd	Honda Civic, Mercedes S400 Hybrid	Toyota Prius, Lexus RX450h	Toyota Prius Plug-In (Concept)

Table 1 Comparison of different hybrid vehicle concepts. Source: (Blesl et al. 2009, p. 10).

The Micro Hybrid is often not equipped with a traction battery and does not have an electric motor that can support the powertrain while driving. It only has automatic start/stop functionality, meaning that the car will automatically turn off while waiting at red lights, for instance. The Mild Hybrid does have a high voltage traction battery and an electric motor, usually mounted onto the crank shaft allowing it to regain energy when decelerating (recuperation) and supporting the internal combustion engine when accelerating (boost). This also provides the possibility to shift the load between ICE and electric motor in order to optimise efficiency by operating the ICE in a better load point. The Full Hybrid provides electric drive, meaning the ability to move the car by electric power only. These hybrid vehicles charge the battery either with the ICE or with regaining brake energy. The Plug-In Hybrid vehicle in distinction to the Full Hybrid provides the ability to charge its battery externally. Therefore, depending on the battery size, it provides the possibility to use it in all electric modes. Furthermore, there are a lot of different concepts concerning the arrangement of the ICE and the electric motor, see Blesl et al. for further details.

Another concept is the so called range-extender. This concept is not always clear to distinguish from a Plug-In hybrid. It also combines an internal combustion engine with an electric motor and allows external charging and all electric drive. The difference to the Plug-In Hybrid is that a range extender uses the internal combustion engine only to generate electric energy for the electric propulsion motor. A range extender usually does not have the ability to drive with the ICE only, but rather also needs to use an electric motor.

2.2 Batteries and fuel cells

Electric Vehicles (EVs) are powered by an electric motor only and do not have an internal combustion engine. EVs can be classified by the type of the used energy storage. The most common concepts are Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEV). The FCEV has a fuel cell unit that provides electrical energy for the electric motor by combining hydrogen (stored either liquid or gaseous) and oxygen.[2]

The BEV uses a battery for energy storage and an electric motor for propulsion. By definition, a battery is an electrochemical cell, consisting of a pair of electrodes, electrolyte and casing. Originally the term battery referred to at least two of these cells, but the meaning of the term shifted. Today, the term battery can be used for a single battery cell. In this context, battery refers to a traction battery[3] that consist of rechargeable battery cells and additional components, like connectors of the cells, the battery case, cooling and heating components and monitoring electronics. It is important to differentiate between *battery, battery pack or battery system* and *battery cell* or *cell*. The first term refers to a system of several battery cells including case, components and electronics, whereas the latter refers to one battery cell that cannot be operated in a car without its peripherals.

In terms of the battery cells, several different chemistries need to be distinguished.

Cell chemistry	Energy Density Wh/kg	Power W/kg	Cost in EUR/kWh
Lead Acid	30-40	140-300	150
NiMH	60-80	1300	200-700
Lithium ion	100-200	300-3000	300-400

Table 2 Battery chemistries. Source: Derksen & Maitin 2009, p. 16.

Lead Acid batteries are as old as 1859 (Jossen & Weydanz 2006, p. 33) and are still being used in high volumes for starter batteries in ICE vehicles and for many stationary applications. Nickel-metal hydride batteries (NiMH) reached market maturity in the 1990s (Lave and MacLean 2003) and are used, for instance, for power tools, camcorders, phones, electric toys and home appliances. Also, NiMH batteries are still

[2] Usually a FCEV uses both a traction battery with high power capability but low energy content for spontaneous power demands and a fuel cell for continuous power. This makes it a hybrid by the definition given in section 2.1. FCEVs are most commonly classified as electric vehicles.

[3] The term traction battery refers to the fact that the battery energy is used to actually move the vehicle, not only for power supply to electronic devices.