

Market potential of Battery Electric Vehicles

Stefan Goede

Bibliografische Information der Deutschen Bibliothek

Die Deutsche Bibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über <http://dnb.ddb.de> abrufbar.

Goede, Stefan

Market potential of Battery Electric Vehicles

ISBN 978-3-941274-60-0

Alle Rechte vorbehalten

1. Edition 2010, Göttingen

© Optimus Verlag

URL: www.optimus-verlag.de

Printed in Germany

Paper is FSC certified (wood-free, chlorine free and acid-free,
and resistant to aging ANSI 3948 and ISO 9706)

Das Werk, einschließlich aller seiner Teile, ist urheberrechtlich geschützt. Jede Verwertung außerhalb der engen Grenzen des Urheberrechtsgesetzes in Deutschland ist ohne Zustimmung des Verlages unzulässig und strafbar. Dies gilt insbesondere für Vervielfältigungen, Übersetzungen, Mikroverfilmungen und die Einspeicherung und Verarbeitung in elektronischen Systemen.

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.

Table of Content

Table of Content	I
List of figures	III
List of tables	VII
List of abbreviations	IX
1 Introduction	1
1.1 Ideas and objectives	1
1.2 Structure and methods	2
2 Concepts of alternatives vehicles and transportation	3
2.1 Hybrid vehicles	3
2.2 Batteries and fuel cells	4
2.3 History of electric vehicles	7
3 Electric vehicles	13
3.1 Advantages of electric vehicles	13
3.2 Critical view of electric vehicles	20
3.3 Summary	28
4 Market situation	29
4.1 Electric Vehicles	29
4.2 Battery Market	40
5 Success factors for Electric Vehicles	43
5.1 Customer behavior	43
5.1.1 The electric vehicle is a system change	43
5.1.2 Range	44

5.1.3	Customer satisfaction	46
5.2	Costs	47
5.2.1	Fuelling costs	48
5.2.2	Investment costs	50
5.2.3	Estimation of total costs of ownership	51
5.3	Legal and political factors	57
5.4	Technology and infrastructure	60
6	Market potential	63
6.1	Studies about market potential	63
6.2	Scenarios	64
6.2.1	Scenario definition	64
6.2.2	Positive scenario	68
6.2.3	Negative scenario	73
7	Conclusion	75
	References	77
	Appendix	87
	Appendix A: Cost details for 2010 EV costs	88
	Appendix B: Cost details for 2020 EV costs	91
	Appendix C: Announced Electric Vehicle Data	95

List of figures

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.	1
Figure 2	Rangone Diagram: Specific energy and specific power of different battery types, fuel cells and ICE. Source: Aigle, Garche & Jossen 2009, p. 60.....	6
Figure 3	Left: Historical battery improvement rates. Right: Improvement of Lithium ion batteries. Sources: Feller & Stephan 2009, p. 23, Aigle, Garche & Jossen 2009, p. 42. ...	7
Figure 4	a) The Baker Electric was one of many successful electric vehicles in the 1900s. Source: Wong 2010. b) General Motor's EV-1 was built 1120 times – all of them were retracted in 2002. Source: Klauder 2009.	9
Figure 5	a) automobile and horse populations, US (1900-1950) b) Share of auto producers for each platform (ICE, steam, electric), with number of active producers. Source: Sterman & Struben 2006, p. 38.....	9
Figure 6	Gross electricity production (in TWh/yr) by fuel 1990-2006 in the EU Bennink et al. 2010, p. 33.	17
Figure 7	Do EVs emit less GHG than ICE vehicles?.....	21
Figure 8	Comparison of average well-to-wheel CO ₂ emissions of ICEs with those of EVs powered by the average EU electricity mix. Source: Bennink et al. 2010, p. 19.....	24
Figure 9	Well-to-wheel CO ₂ emissions for EV, Hybrid and Diesel.....	25
Figure 10	a) the REVAi electric car b) Tesla Roadster	30
Figure 11	Mitsubishi iMiEV and smart Electric Drive.....	31

Figure 12	Announced electric vehicles by length and estimated battery size	33
Figure 13	Worldwide production figures of cars and commercial vehicles. Source: OICA 2009).....	37
Figure 14	Worldwide market for Low Cost Cars in Mio units.Source: (Bechmann & Scherk 2009, p. 181).	37
Figure 15	Customer segmentation	38
Figure 16	Partnerships between car manufacturers and battery makers. Source: Lim 2010, p. 5.	41
Figure 17	Cost projection for Lithium batteries. Source: Blesl et al. 2009, p. 41.....	42
Figure 18	Analysis of mobility behavior in Germany. Source: (Kessler 2010, p. 11).	45
Figure 19	The Kano Model of customer satisfaction. Source: Rafinejad 2007, p. 77.	46
Figure 20	Annual Fuel Costs for 15,000 miles in USD	50
Figure 21	City cars' total costs of ownership in USD in dependency of annual mileage for Germany	54
Figure 22	City car total costs of ownership in USD in dependency of annual mileage for USA.....	55
Figure 23	TCO for medium size EVs over annual miles driven in the US including 7000 USD purchase incentives	56
Figure 24	TCO for medium size EVs over annual miles driven in Germany.....	57
Figure 25	Profitability of Different Charging Infrastructure Concepts. Source: Dallinger, Kley & Wietschel 2010.....	61
Figure 26	Predicted EV market penetration in Germany by 2020.	63
Figure 27	Positive scenario USA 2020: Total costs of ownership depending on annual mileage	69
Figure 28	Positive scenario Germany 2020: Total costs of ownership depending on annual mileage (see legend of Figure 27)	70

Figure 29	Positive scenario Germany 2020: Total costs of ownership per mile depending on annual mileage for different city EV battery sizes	71
Figure 30	Positive scenario Germany 2020: Total costs of ownership per mile depending on annual mileage for different medium size EV battery sizes	71
Figure 31	Positive scenario USA 2020: Total costs of ownership per mile depending on annual mileage for different medium size EV battery sizes	72
Figure 32	Positive scenario Germany 2020 with assumption that EV is completely depreciated within 5 years: Total costs of ownership depending on annual mileage	73
Figure 33	Negative scenario USA 2020: Total costs of ownership depending on annual mileage	74
Figure 34	Negative scenario Germany 2020: Total costs of ownership depending on annual mileage. Legend: Figure 33.	74
Figure 35	Technology maturity. Source: Matthies, Stricker & Traenckner 2010.	76

List of tables

Table 1	Comparison of different hybrid vehicle concepts. Source: (Blesl et al. 2009, p. 10).	3
Table 2	Battery chemistries. Source: Derksen & Maitin 2009, p. 16.....	5
Table 3	Efficiency of ICEV and EV. Source: (Bennink et al. 2010, p. 20).....	26
Table 4	Summary of arguments for and against electric mobility following Frey, Horst & Leprich 2009, p. 8.	28
Table 5	Market volume of electric vehicle market	35
Table 6	Definition of compared vehicles	48
Table 7	Energy Costs and fueling Costs in US Dollar for different vehicles	49
Table 8	Estimated sales prices in USD of compared vehicles in Germany and the US without state incentives	51
Table 9	Annual taxes for compared vehicles by country in USD	52
Table 10	Estimated salvage value, annual insurance and maintenance and repair costs in Germany in USD. Source: ADAC 2010a and ADAC 2010b	53
Table 11	Incentives for buying electric vehicles for customers in USD. Sources: Hawranked & Neubacher 2010, p. 80, Buller & Hanselka 2009, p. 7.	58
Table 12	Specific costs for mid-class vehicle components	66
Table 13	Estimated Energy prices in 2020 in positive and negative scenario	67
Table 14	TCO Estimation Germany 2010	88
Table 15	TCO Estimation US 2010.....	89
Table 16	TCO Estimation 2010 Factors.....	90
Table 17	2020Specific cost estimate for vehicle component	91

Table 18	2020 Annual vehicle cost estimation.....	92
Table 19	2020 Estimated investment costs	93
Table 20	2020 Estimated energy costs.....	94

List of abbreviations

BMBF	Bundesministerium für Bildung und Forschung
CARB	California Air Resources Board
CEO	Chief executive officer
CO ₂	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