

**Contesting range anxiety:  
The role of electric vehicle  
charging infrastructure in the  
transportation transition**

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in partial fulfilment of the requirements for the degree of

**Master of Science  
in Innovation Sciences**

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Agentschap NL  
Ministerie van Economische Zaken



# CONTESTING RANGE ANXIETY

*The Role of Electric Vehicle Charging Infrastructure  
in the Transportation Transition*

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May, 2011

Eindhoven University of Technology  
Netherlands Office for Science & Technology - Silicon Valley  
Eindhoven/San Francisco



Agentschap NL  
Ministerie van Economische Zaken

**TU/e** Technische Universiteit  
Eindhoven  
University of Technology

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**Eindhoven, May, 2011**

Eindhoven University of Technology, Netherlands Office for Science & Technology - Silicon Valley, 2011 | *Contesting Range Anxiety: The role of EV Charging Infrastructure in the Transportation Transition* | Eindhoven, San Francisco

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The Netherlands Office for Science & Technology (NOST) is part of the Economic Information Agency (EVD) division of Agentschap NL (NL Agency). NL Agency works for various ministries, focusing on sustainability, innovation and international business and cooperation.

Subject headings: electric vehicle, EV, charging infrastructure, sustainable development, sustainable transitions, transition management

*Cover photo:* Chevrolet Volt plug-in electric car at the North American International Auto Show in Detroit, Michigan, January 13, 2009. © Photo courtesy of Reuters/WFA.

*“The stone age did not end due to a lack of stones.”*

*- Unknown -*



## **Preface and acknowledgements**

Since my temporary job assignment at the Ministry of Transportation, I have been intrigued by major social issues in the transportation sector. I became fascinated by tackling contemporary challenges with implications that can affect large groups of people. This interest has led me to continue my studies in Innovation Sciences at the Eindhoven University of Technology. Through my professor in history of transportation and mobility, to whom I am still thankful for this, I found the ideal final project which seamlessly connected with my interests - the emergence of a new road transportation system.

Having become familiar with the Bay Area through a semester spent at the University of California in Berkeley, my path led me to the Netherlands Office for Science and Technology (NOST) in San Francisco. Having worked with NOST -in an extended stay- for over 8 months at the Consulate-General in San Francisco, I can say that this period has been one of the most vibrant and stimulating in my life. The hours researching at the office and various locations throughout the country have been very helpful in understanding current developments in the transportation sector.

I would like to take this opportunity to extend my gratitude to people who have been of great assistance in my research. First of all, I am grateful to my mentor and supervisor Bianca Oudshoff for her confidence in me and her help and advice in writing this report. I thank her for giving me the opportunity to discover and research throughout Silicon Valley and beyond. I also owe many thanks to Frederique Knoet for her help in making the connections for many interviews and appointments on electric vehicle development. Furthermore, I would like to thank Consul-General Bart van Bolhuis for his enthusiasm, confidence and the many ideas he proposed in making my work at the Consulate a wonderful experience.

Many others helped to make this project a big success; I thank my professor Gijs Mom for sharing his expertise and his counseling in this project, my second supervisors and experts on the topic Johan Schot from the Eindhoven University of Technology and Richard Smokers affiliated with Dutch research institute TNO. Furthermore I would like to thank Deputy Consul-General Jaap Veerman, my father, Marc Geller from Plug-in America for the many interesting conversations about EV development in California and insights on the topic, Jennifer Katell, especially for her editorial assistance, my colleagues at NOST and the Eindhoven University of Technology, and all my other colleagues at the Consulate for their assistance and great company.

Eindhoven, May, 2011.

## **Nomenclature**

AC	Alternating current
AFV	Alternative Fuel Vehicle
AVIP	Alternative Vehicle and Infrastructure Program
ARRA	American Recovery Reinvestment Act
BEV	Battery Electric Vehicle
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CEC	California Energy Commission
CPUC	California Public Utilities Commission
DC	Direct current
DOE	(US) Department of Energy
DOT	(US) Department of Transportation
EM	Electric Motor
EPA	Environmental Protection Agency
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
EREV	Extended Range Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FCHEV	Fuel Cell Hybrid Electric Vehicle
GHG	Greenhouse Gas
GIS	Geographic Information System
HEV	Hybrid Electric Vehicle
HOV	High Occupancy Vehicle
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
IT	Information Technology
kWh	kiloWatt hour
LDV	Light Duty Vehicle
MIT	Massachusetts Institute of Technology
NOST	Netherlands Office for Science & Technology
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicles
R&D	Research and development
SOC	State of charge
SULEV	Super low emission vehicle
TA	Technology Assessment
V2G	Vehicle-To-Grid
V2H	Vehicle-To-Home
ZEV	Zero Emissions Vehicle



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## **Executive Summary**

Environmental climate change and present consumption factors have alerted policy makers across the globe to implement more sustainable practices with respect to energy consumption and greenhouse gas emissions. Road transportation, which accounts for more than 30% of CO<sub>2</sub> emitted in the US, is a major contributor in climate change developments. Efforts to move away from a fossil fueled transportation system are gaining momentum; a transition seems imminent in the road transportation landscape. Governments, market players, utilities and standardization committees are taking part in preparing for the arrival of the electric vehicle.

Although there have been several attempts to introduce electric vehicles in the past, the current effort that is being made by policy makers and car manufacturers gives reason to believe that the electric vehicle is here to stay. An increasing number of hybrid electric vehicles on the road is the unquestionable result of these efforts, causing the transportation sector to move toward a more sustainable model. The question remains however how to build on this momentum and which factors will drive its success. In this study, central will be the role of EV charging infrastructure in the transition. Much is related to the so called ‘lock-in’ of the current technology (*i.e.* the internal combustion technology) in the transportation system, making it hard for competing technologies to win a new market share.

In literature, much has been written about technological change and regime transitions. Lock-in is a frequently used concept that accounts for technologies that have been deeply entrenched in societal systems making it hard for competing technologies to win a market share. Cowan & Hultén (1996) claim that, for the case of the electric vehicle, six conditions are required to escape the lock-in of internal combustion engine technology used in cars, including technical, regulatory, economic, social and scientific factors. The conditions they propose have largely been met today in the industrialized countries. However, a technology that is preferred above others would still require a system-scale infrastructure to support it.

The large scale introduction of plug-in electric vehicles in the near-term future will require the construction of a large EV charging infrastructure network. Both home and public charging infrastructure are to be deployed to support the new generation of plug-in electric vehicles. Home charging stations will be the prime source of power, with faster public charging providing an additional means of power supply. Securing home charging opportunities for electric vehicle owners in urban areas, where space and private garages are scarce, will be a challenging task. Policy makers and other stakeholders have to ensure that home charging will occur at off-peak hours, when energy is abundant and cheap.

There are two (2) elements in charging infrastructure that add to the lock-in of the current transportation system. The first element is the uncertainty surrounding the infrastructure (which relates to where, when, who, how and how much questions). Secondly, a lack of investment hampers infrastructure development. The existence of a gasoline refueling infrastructure *and* the lack of electric vehicle charging infrastructure are lock-in mechanisms which slow down the transition. These

two elements are inherently related to each other; uncertainty causes a lack of willingness to invest in infrastructure, and the lack of investment creates in turn more uncertainty.

Investment and deployment of public charging infrastructure will therefore prove indispensable especially in the early stages of the electric vehicle's introduction. Besides providing EV drivers with extra electricity when needed, public charging infrastructure will function as a psychological aid to adopters of electric vehicles. It will increase consumer confidence in the technology and encourage drivers to venture further out. Hence, public charging infrastructure reduces 'range anxiety', the fear of getting stranded with a discharged battery. Especially public fast charging infrastructure proves to be increasingly effective in reducing range anxiety and thus boosting electric vehicle usage patterns.

Public fast charging is a promising way to increase consumer confidence and electric vehicle adoption without substantially increasing the burden for electricity generation facilities. Based on the conclusions presented in this report, recommendations are made to the Netherlands agencies involved in the deployment of a national charging infrastructure in the Netherlands.



## **1 Introduction - The challenge of an unsustainable transportation system**

### **1.1 The electric vehicle**

A wary gaze points at me: “Researching *electric vehicles*?” It was not the first time that I sensed a slight touch of disbelief and skepticism when telling a lay person the subject of my final research project. Thinking about this, it came to mind that this reaction did not have to be surprising at all. Throughout most of automotive history, the electric vehicle had become largely underestimated as an equal competitor to its gasoline contender. After the gasoline car took over as dominant design in the early 1900s, the electric vehicle never again came quite close to reaching a critical mass or its desired ‘tipping point’ in prospect of a technology transition. Like my experience with lay persons on the topic illustrates, today’s fuel based transportation system has become so much the norm and part of daily life that alternatives are not perceived as truly obvious anymore, or even considered as viable alternatives. It shows how deep the current transportation system is rooted into many aspects of society.

Electric vehicles however have been among us for over a hundred years. Electric vehicles have a long history and have gone through a series of false starts in competition with its two main contenders; the gasoline car and the steam car. After losing its competition with the gasoline car in the early 1900’s, the electric car as a mainstream road transportation vehicle got lost in oblivion and only found application in some niche markets. It would never return as an equal competitor to the well established gasoline car. However, today, a number of global developments have brought the electric vehicle in the centre of interest again.

The following sections in this chapter will elaborate on these global developments that are bringing the electric vehicle to the front as a viable alternative for road-passenger transportation. The first sections aim to introduce the reader in the problems that are related to the current, fossil fueled transportation system. The prospected trend of electrification of automobiles is concisely discussed in this first chapter. Furthermore, several terms related to electric vehicles will be defined and a research question presented. The chapter concludes with an outline of the further chapters of the report.

### **1.2 Today’s global challenges**

Air pollution and its consequential climate change have become growing concerns of scientists, governments and citizens across the globe. The irreversible effects of the emissions of greenhouse gasses (GHGs) in the atmosphere are for many people reasons to worry about the short and long-term sustainability of life on planet Earth. Many different interest groups call for immediate action, however efforts to mitigate problems of climate change have resulted in few adequate policies. The UN Copenhagen Summit in December 2009 has been illustrative for the difficulty of putting in place a joint policy on climate change. Governments of several countries have therefore independently started to develop policies on climate change to reduce greenhouse gas emissions.

In the US, the transportation sector is the largest source of CO<sub>2</sub> emissions, producing over 30% of the nation’s total (EPA, 2006, p4). It is thereby also the fastest growing source of greenhouse gas (GHG) pollutions and the sector’s energy use is expected to increase even further between 2003 and 2025, despite projected technical improvements to limit pollution of transportation vehicles (EPA, 2006, p1). The transportation sector seems to have grown in equal pace with the cascade of technological developments over the past century. Personal mobility has become an indispensable element of modern society and has seen a tremendous increase over the years. Obviously, the diffusion of the automobile has played an important role in this development.

Automobile use is not without problems, ranging from congestion to its contribution to global warming. Some problems are specifically related to the use of internal combustion engines (ICEs). The emissions produced by these engines include CO<sub>2</sub> and other air pollutants, such as particulate

matter (PM), methane (CH<sub>4</sub>), hydrofluorocarbons, nitrous oxide (NO<sub>2</sub>) and volatile organic compounds (VOC) (Wallace, 1995, p138). There is a general understanding among policymakers and a growing general public that change towards a more sustainable road transportation system is needed. Several policy measures have been put in place to reduce the environmental impact of gasoline cars, like regulation on CO<sub>2</sub> emissions and smog tests.

### **1.3 The problems of oil; resources, dependency, potential energy conflicts**

Trends in global petroleum consumption are unsustainable for long-term human development, yet there seems to be little agreement as to what a more sustainable energy system would look like, even among energy experts. Meanwhile, energy consumption continues in a rapid pace; each day nearly 85 million barrels of petroleum are consumed, much of which is consumed relatively inefficiently in the form of gasoline for powering transportation.<sup>1</sup> Projections by the Institute for the Analysis of Global Security (2009) show that in the next 10 years, world oil consumption will rise with about 60% compared to today's level and transportation will thereby be the fastest growing oil consuming sector.<sup>2</sup>

The concentration of oil resources in the world brings along several other problems. The US imports, and this figure is still rising, more than half of its oil consumption of which 96% is used for fueling the transportation sector.<sup>3</sup> The distribution of imports and exports obviously indicates a high dependency on foreign oil production. Together with the acceleration of depletion of oil in the world, the situation incurs several social and political tensions (Friedman, 2008). Like with any geographically constrained resource, continued dependency on oil could facilitate tensions among nations (e.g. military action or resource exclusion). Oil provision security becomes a more important issue to governments as it contributes to economic stability and growth and becomes therefore a matter of national security.

### **1.4 The solution of electrified transportation**

A growing demand for mobility and energy in developing countries makes these problems even more critical. Primarily the automotive industry will be put to the challenge to find and realize sustainable solutions for the current challenges in personal mobility. As 97% of the vehicles worldwide burn petroleum fuels in internal combustion engines (Sperling & Gordon, 2009, p7), a transportation system that includes an increasing use of alternative fuels in vehicles could offer a number of solutions to global challenges such as climate change and oil dependency.

Electric vehicles, such as hybrid electric vehicles and fuel cell electric vehicles are proposed by many scientists and experts as one of the best solutions of the use of alternative fuels (Maggetto & Van Mierlo, 2001; Hoogma *et al.*, 2002, p115; Nagelhout & Ros, 2009; Offer *et al.*, 2010, p29). Electricity as a means of energy has several advantages above conventional energy bearers. As there is no combustion process, no exhaust gasses are emitted at the tailpipe. Electric motors also offer high efficiency ratios and contribute therefore in GHG emission reduction. However, the way the electricity is generated will eventually determine how environmentally friendly the vehicle really is. Still, vehicle miles fueled by electricity emit substantially less CO<sub>2</sub> than those fueled by gasoline – even with today's mix of generating sources (Kromer & Heywood, 2007).

### **1.5 The US, California, Bay Area as the field of study**

The United States offers an excellent field of study in researching automobile development. With its rich automotive history and being one of the most innovative countries in the world, many scholars have studied the development of the automotive industry in the US since the ending of the 19<sup>th</sup> century. From that period, automobiles and the US have become indissoluble from each other, making the car a nation-wide symbol of key American values, such as prosperity and individual autonomy (Rubin & Davidson, 2001). Up to today, the auto manufacturing industry directly and indirectly

<sup>1</sup> US Energy Information Agency. Data available online at <http://www.eia.doe.gov/emeu/aer/txt/ptb1110.html> Accessed 28 February, 2011.

<sup>2</sup> Institute for the Analysis of Global Security, Future of Oil. Available online at: <http://www.iags.org/futureofoil.html>. Accessed August 1, 2010.

<sup>3</sup> *Ibid.*

accounts for a major portion of the US economy. The US still remains among the three largest nations in car production, bringing roughly 5.7 million cars to the market in 2009.<sup>4</sup>

Historically, the state of California has always been both a testlab and frontrunner in automotive development (Sperling & Gordon, 2009). The state has a very high concentration of early adopters in terms of technology and environmentally friendly (auto) purchasers. With Los Angeles as its nation-wide car capital, the city is often held up as the prime example of urban development and car implementation. Much has been learned in this city about the impact of cars on public space and urban environment throughout the twentieth century, dealing with problems of congestion and air quality, safety, parking and urban and infrastructure development.

The metropolitan area around San Francisco known as the Bay Area, is an important region in the face of technology production and implementation. Especially in the area known as Silicon Valley, many new and innovative technologies are created by startups and next generation companies like Google, Facebook and Apple. Also in automotive development Silicon Valley breeds future technologies with electric car manufacturer Tesla as prime example, a company that has produced over a 1000 Roadsters of full electric vehicles successfully so far. The success of the Bay Area in terms of technology production is also ascribed to cultural aspects. The Area holds an extremely eco-friendly and progressive reputation, with people capable of embracing new technologies easily (Sperling & Gordon, 2009). It is then no surprise that the hybrid vehicle ownership rate is the highest in the state.<sup>5</sup> The Consulate-General in San Francisco, in the center of the Bay Area at about half an hour drive from Silicon Valley, is my point of departure for this study.

### **1.6 On definitions and terminology regarding vehicles**

Based on the current developments in road transportation and the technologies used in vehicles, a taxonomy can be distinguished on the types of technologies implemented in electric vehicles. To prevent the reader from confusions in terminology and abbreviations used in this thesis, a categorization of types of vehicles is laid out in the following section.

As with many definitions in emerging technologies, confusion arises on terminology used to define certain types of technology designs. The lack of agreement over terminology makes it harder for stakeholders to distinguish between them. Moreover, this confusion fosters misunderstanding among the general public which might create a certain impediment for the technology to be adopted. There are currently many different abbreviations that refer to the same breed of electric vehicles. For example, BEVs (battery electric vehicles), BVs (battery vehicles), BPEVs (battery powered electric vehicles), GEVs (Grid Enabled Vehicles), PEVs (Plug-in Electric Vehicles), EVs (electric vehicle) and FEVs (full electric vehicles) could all indicate the same type of vehicle design.

There are generally two types of propulsion designs to be found in passenger road vehicles today (Frenken *et al.*, 2004). The internal combustion engine (ICE) is the dominant design for propulsion. As we are moving towards an increased electrification of the road vehicles, an increased use of electric motors (EMs) is used within passenger road vehicles. Different designs have been developed to foster the transition, including the hybrid electric vehicle (HEV), plugin hybrid electric vehicle (PHEV), the extended range electric vehicle (EREV), the battery electric vehicle (BEV) and the fuel cell electric vehicle (FCEV). The HEV and the PHEV use both an ICE and EM for the propulsion of the vehicle. An EREV however uses the ICE only to charge the battery, which in turn propels the vehicle. One could argue that it is in essence a BEV, but uses additional means (*i.e.* a gasoline engine) to charge its batteries. The BEV makes fully use of an electric motor for its propulsion as well as the FCEV. An overview of the different propulsion and types of vehicles is given in figure 1.

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<sup>4</sup> Organisation Internationale des Constructeurs d'Automobiles (OICA), 2009 Production statistics, available online at: <http://oica.net/category/production-statistics/>. Accessed August 1, 2010.

<sup>5</sup> Los Angeles Times – March 20, 2009 Berkeley: hybrid capital of California - [http://latimesblogs.latimes.com/money\\_co/2009/03/berkeley-hybrid-capital-of-california.html](http://latimesblogs.latimes.com/money_co/2009/03/berkeley-hybrid-capital-of-california.html). Accessed August 2, 2010.

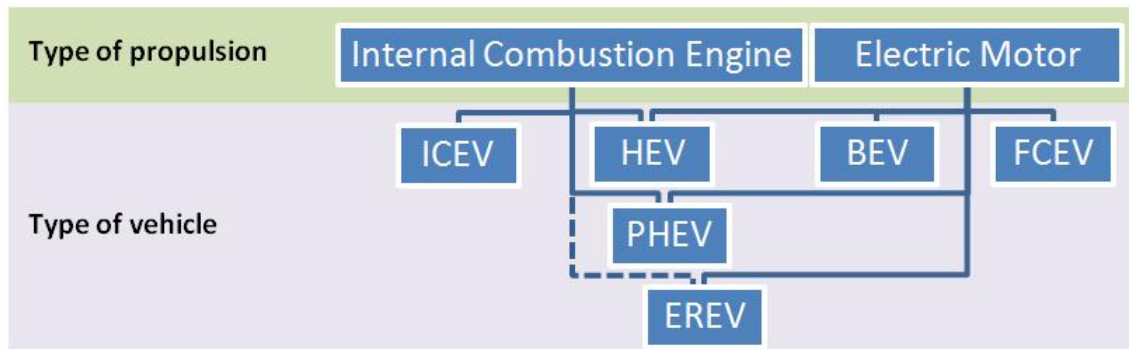


Figure 1 Types of propulsion designs used in modern vehicles.

In a parallel hybrid, the electric motor and the internal combustion engine are installed so that they can both individually or simultaneously power the vehicle. A series or a serial-hybrid, which have also been referred to as an Extended Range Electric Vehicle or Range-Extended Electric Vehicle (EREV/REEV), are vehicles that are driven only by the electric motor. When the battery runs out of energy, a gasoline generator starts recharging the battery, which in turn provides the electricity for the electric motor. Plug-in Electric Vehicles (PEVs) or Grid Enabled Vehicles (GEVs), is the category of BEVs, PHEVs and EREVs, distinguished by a plug to charge electricity onto onboard battery systems.

Electric vehicles is actually a very broad term. Any passenger vehicle with a battery component that provides the propulsion to the vehicle could be an electric vehicle, including wheelchairs. The Energy Independence and Security Act (2007)<sup>6</sup> defines a plug-in electric drive vehicle as a vehicle that:

- “draws motive power from a battery with a capacity of at least 4 kilowatt hours;
- can be recharged from an external source of electricity for motive power; and
- is a light-, medium-, or heavy-duty motor vehicle or non-road vehicle.”

In this thesis electric vehicles will be referred to as outlined above. However, all of the references regarding electric vehicles in this report will be inclined towards light duty vehicles (LDVs)<sup>7</sup>, vehicles that can be considered as substitutes for light duty passenger vehicles. These categories include the PHEV, the EREV and the BEV.

### 1.7 Research objective

The purpose of the research is to provide an insight in the current developments and trends in electric vehicle technology in and around California with the focus on EV charging infrastructure. The current change towards an electrified road transportation system is studied by an elaborate discussion on the state-of-the-art of the EV industry and recent technology developments in the US. In the research, there is a specific focus on the role of infrastructure of EV systems in the transition of the transportation sector. This is of particular interest as infrastructure companies and smart grid developers seek to integrate the electric vehicle within existing and future infrastructures. The main research question to the research is the following:

**“Which role does electric vehicle infrastructure play in the transportation transition?”**

The sub questions which support the main research question are:

- Is there imminence of a transition in the transportation system? (**chapter 2**)
  - What are the current developments in the transportation sector?
  - What are the challenges and barriers for a transition to occur?

<sup>6</sup> Energy Independence and Security Act 2007. Available online at: [http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110\\_cong\\_bills&docid=f:h6enr.txt.pdf](http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf). Accessed August 2, 2010.

<sup>7</sup> LDV is a US (EPA) classification for trucks or truck-based vehicles with a payload capacity of less than 4,000 pounds (1,815 kg).

- What are the conditions for a regime transition/change? (**chapter 3**)
  - Is the current transportation system subject to path dependency and lock-in?
  - In what way have EV technology and infrastructure developed, especially since the previous EV wave in the 90's?
- What is EV infrastructure? (**chapter 4**)
  - What are the important features and properties of EV infrastructure?
  - What factors/features of EV infrastructure play a role of importance in a technology transition/regime transformation?
- What role does electric vehicle infrastructure play in a transportation transition? (**chapter 5**)
  - How does this role relate to other factors in the transportation transition?
  - What can be concluded from this study?
- What could be recommendations to the Netherlands in deploying EV infrastructure? (**chapter 6**)

### **1.8 Research objective and methodology**

This thesis concentrates on a possible future transition in the mobility system. More specifically, it deals with some radical transformations in the (automotive) transportation system that have the aim of introducing more sustainable practices in the way cars are propelled. Transitions in the technological landscape like these have been a focus of many scholars in the field of science and technology studies. Especially literature in the realm of sustainable development has grown significantly over the last decades (Grin *et al.*, 2010).

This study will approach the transition from a socio-technical perspective. This means that technology is viewed in a contextual understanding and thus takes into account the many social factors that technology often is in interplay with. These social factors could be the mobilization of resources, social networks, the construction of new markets, regulatory frameworks and development of visions (Grin *et al.* 2010, p12). In this socio-technical approach on the transportation system, it will be studied how social and technological changes interact in a possible transition towards sustainable road transportation system.

A few disciplines in the field of transition studies will be mobilized to effectively determine the transition characteristics. To distinguish the actors related to the sustainable (EV) technology, a technology assessment (TA) practice (Smit & van Oost, 1999) will be applied. A concise actor analysis used from this method will be performed and will serve as an introduction into the most important developments in the automotive sector that we see today.

Another conceptual framework that will be applied to answer the research question is the concept of path dependency and technological lock-in in a socio-technical regime. Transitions do not occur easily, because these socio-technical systems are stabilized in many ways. This rigidity of the system is called lock-in, the result of the emergence of a technological regime (Rip & Kemp, 1998; Geels, 2002). For electric vehicles, we will determine the factors that play an important role in the lock-in of our current transportation system, and find possible alternative factors that could create an escape from this lock-in of the traditional technology.

### **1.9 Report outline and structure**

The first chapter, which you presumably just have read, entails the setup of the master thesis by an introduction to electric vehicles and the current road transportation system. As has been explained, the current transportation system is unsustainable due to the pollution caused and the dependency on finite fossil fuels. However, current market shares of electric-drive vehicles such as hybrid electric cars indicate a trend towards further electrification of personal transportation. In this introductory chapter, the starting points of the study are defined, the field of study, definitions and terminology, research objective and methodology.

Chapter 2 elaborates on the trend of electrification in the transportation sector. Efforts to move away from a fossil fueled transportation system are gaining momentum. An increased number of vehicles with electric propulsion components can be seen on the road. Today's car industry takes on an important role in introducing new types and more efficient vehicles, also forced by stringent legislation on efficiency and pollution. These developments in the legislative and market environment cause initiatives in other levels of governments, sectors and markets; cities, utility companies and standardization committees are taking part in the preparation for the electric vehicle. However, as the electric vehicle market evolves, many challenges and uncertainties lie ahead in making the transition successful. Experts see obstacles in battery technology, the electric power sector, consumer acceptance and a ubiquitous charging infrastructure that has to be deployed.

Chapter 3 approaches the current developments from a theoretical perspective and elaborates on three perspectives regarding technological change. Special focus goes to the lock-in of the current transportation regime. A concise historic analysis will show how this lock-in has emerged. After several failed attempts to escape the lock-in, with its most recent example in the mid 90's, scholars have debated the conditions that are necessary to achieve lock-out for technology systems. Amongst others, Cowan & Hultén (1996) claim that six conditions for the electric vehicle are required to escape from lock-in, including technical, regulatory, economic, social and scientific factors. The conditions they propose have largely been met in today's industrialized countries. However, a technology that is preferred above others (in terms of long term social costs), would still require a system-scale infrastructure to support it.

In chapter 4, this role of the EV charging infrastructure in creating the preconditions for a lock-out in the technological regime is studied. After an introduction of the general properties of EV charging infrastructure the most important features of EV charging infrastructure are elaborated upon. There will be shown that both home and public charging infrastructure are (equally) important to the success of new generation plug-in electric vehicles. Home charging stations will be used as the prime power supply equipment to the vehicle, with faster public charging stations providing an additional means of power supply. An important psychological factor arises in relation to the deployment of public charging infrastructure. Drivers gain confidence in venturing out with an electric vehicle as public stations are installed, but usage patterns remain very low. Two (2) elements are found in charging infrastructure that add to the lock-in of the current transportation system. The first element is the uncertainty surrounding the infrastructure and secondly, a lack of investment hampers infrastructure development.

Chapter 5 concludes with findings on the success of the electric vehicle and the role of EV charging stations in the transition. The charging infrastructure functions as a technological necessity to support the technology, but even so important as a catalyst in increasing consumer confidence in electric vehicle technology. Public fast charging especially thereby is a promising way to increase consumer confidence and electric vehicle adoption without substantially increasing the burden for electricity generation facilities. Based on the conclusions presented in chapter 5, chapter 6 discusses the implications for specific recommendations when it comes to deploying EV infrastructure in the Netherlands.

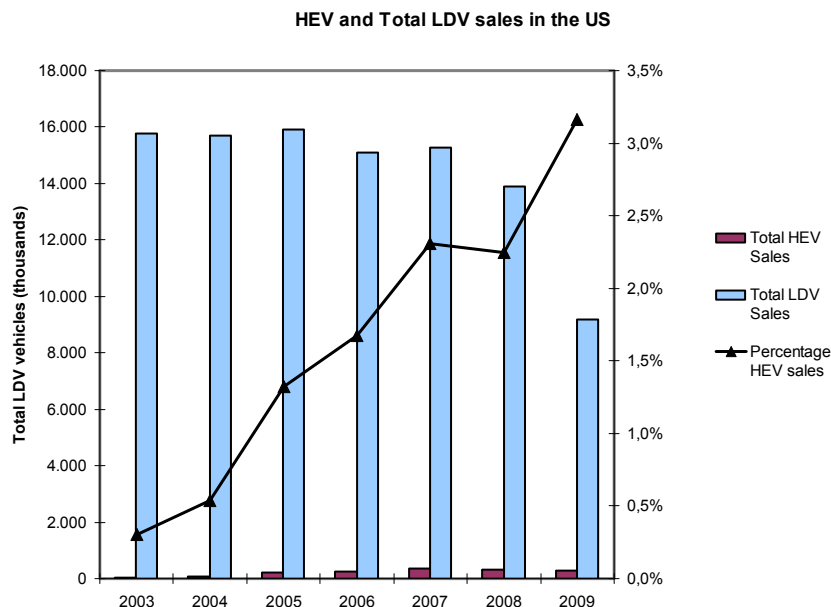
## 2 Transportation in transition - overview of electric vehicle developments and challenges

### 2.1 Introduction

This second chapter will elaborate on the current developments in the road transportation system in the US. This insight will be given by discussing the general market developments. Consequential developments comprise the emergence and preparation of stakeholders in the field. These stakeholders will be categorized and discussed by means of an actor analysis proposed in the technology assessment method by Smit & van Oost (1999). Through this ‘mapping of actors’, relations and current developments with respect to electrified transportation will become apparent. Along the way, also the key challenges seen by experts will be identified that will have to be dealt with by the industry and stakeholders in order to make the transition successful.

### 2.2 General market developments

Market developments are important gauges of transitional change. Market figures show that car manufacturers are putting an increased effort in the production of more sustainable (*i.e.* environmental friendlier) automobiles. Since the turn of the millennium, a rapid increase in sales of gasoline-electric hybrid vehicles has been recorded in Asian, European and Northern American markets. In the US alone, over 1.6 million gasoline-electric hybrid, or hybrid (electric) vehicles (HEVs) have been sold since 2000<sup>8</sup>, and sales are expected to increase in the years to come (Sperling & Gordon, 2009). This growing number of HEVs on the road seems to be largely due to stricter emission standards of federal governments, growing awareness of global warming impacts and increasing gasoline prices (Åhman, 2006, p434). It is obvious that the changes in the social, legal and political environment and the potentials in the emerging market have committed car manufacturers to develop cleaner and thriftier propulsion designs.



**Figure 2 New vehicle sales 2003-2009. Table composed from data of the AFDC.<sup>9</sup>**

In figure 2 it is shown that, despite the substantial decrease of new car sales since the collapse of the US car market in 2008, sales of HEVs have not decreased in relation to the total number of LDVs sold in the US. In five years, the market share of HEVs in new vehicle sales have increased from 0,2% to

<sup>8</sup> US Alternative Fuels & Advanced Vehicles Data Center – HEV Sales by model 1999 – 2009. Available online at: <http://www.afdc.energy.gov/afdc/data/vehicles.html>. Accessed May 27, 2010.

<sup>9</sup> *Ibid.*



3.1% in 6 years.<sup>10</sup> The downturn in the market in 2009 has had a major impact on the industry, but also offers new windows of opportunity.

In the automotive market today there is also a general consensus that profound change has come to the industry, as mature market segments have been thinned out significantly. At the SAE World Congress 2010 in Detroit this was evident by the historically low number of visitors,<sup>11</sup> a result of the severe impact on the industry by the economic crisis. The SAE World Congress 2010 with the theme 'Ecollaboration' had worked the need for sustainable development thoroughly in its conference program. The topics efficiency, environmental compatibility and sustainability were recurring in almost all of the sessions. It is clear as well, that not only HEVs are the result of the change in the industry and the new requirements for 21<sup>st</sup> century vehicles, full electric vehicles powered by battery-only stored energy are currently produced and released in several countries.<sup>12</sup>

The recent developments in the automotive sector have led to believe that a transition towards an increased electric propelled vehicle system is imminent (Sperling & Gordon, 2009, p22-23). The hybrid electric vehicle is viewed by Sperling & Gordon as the vanguard of these developments. Also other scientists and experts in the field of electric transportation expect that vehicles will become increasingly electrified, *i.e.* vehicles with electric-drive components. They believe that a probable transition could accour in several stages, from hybrid vehicles to the plug-in hybrid vehicle, to the full electric vehicle (Barkenbus, 2009, p399; CARB, 2009, p10). The linearity of this projected transition process is fairly debated, but the general belief remains that an increased use of electrical systems as central component in cars will be prevalent in the near and long term future (Pilkington *et al.*, 2002 p7; Sperling & Gordon, 2009, p23; Guille & Gross, 2009, p4379; Becker & Sidhu, 2009, p26). An often used expression to indicate the direction of the transition, is the *electrification of transportation*, to refer to this prospected change in the transportation system. The estimations on the speed of the transition vary significantly due to unpredictable events and impacts of federal policies and global developments. Hydrogen fuel cell electric vehicles are generally considered to be part of the final stage of the transition (Hoogma *et al.*, 2002, p41; Sperling & Gordon, 2009; G.J. Offer *et al.*, 2010, p29).

The main legislation body on air quality in California, the California Air Resources Board (CARB), has projected in a possible scenario (CARB, 2009, p10) a further increase in sales of HEVs up to 40% of gross total vehicle sales until the year 2020. According to their study, sales of PHEVs will increase in the following decade. Subsequently, BEVs and FCEVs will start to dominate new vehicle sales until total transition has been reached around the year 2040. Figure 3 depicts a scenario of the transition in terms of new vehicles sold, which has been forecasted by CARB (2009).

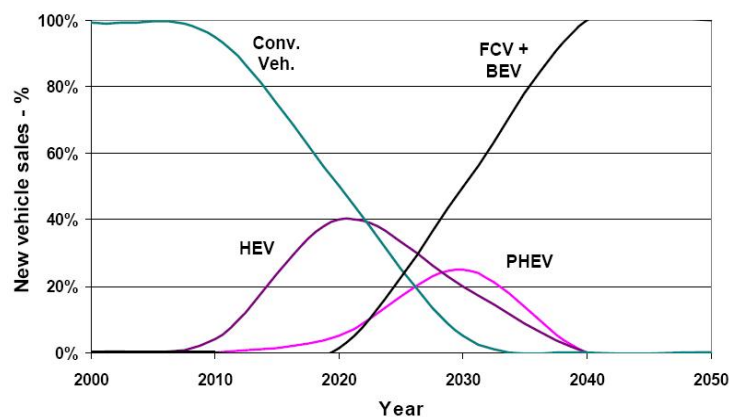


Figure 3 Projection of new vehicles sales 2000-2050. Source: CARB, 2009.

<sup>10</sup> *Ibid.*

<sup>11</sup> Keynote speech David L. Schutt, CEO SAE International. Grand opening ceremony at the 2010 SAE World Congress, Detroit. April 13, 2010.

<sup>12</sup> An overview of models scheduled to be introduced in the US market is given in *Appendix III, EV overview in California/US*.



Almost all of major car manufacturers<sup>13</sup>, introduced a product in their future plans with an electric propulsion design as a central component in their vehicle, such as HEVs. At least 75 of these models are expected to be introduced into the market by 2013 in mainly the USA, Europe and Japan (Tollefson, 2008, p438). Since the release of Tollefson's article, many more different designs with hybrid electric propulsion systems have been scheduled and taken into production by startups and established car manufacturers. As well, an increasing number of plug-in hybrid and full electric vehicles are developed by manufacturers, a trend that fits current projections of the electrification transition.

The change in the transportation technology landscape is expected to be largely promoted by policy measures by federal governments (Pilkington *et al.*, 2002 p7; Åhman, 2006, p434; Roland Berger, 2009, p9). The speed in which this transition will take place will be largely determined by the effectiveness of these institutional efforts. The policies could include efforts to promote EV ownership, deployment of infrastructure and creating a critical mass for a large scale uptake of electric vehicles. Next to factors such as social acceptance, technical factors will be determining the success of EVs such as developments in (costs of) battery technology and the progress in the development and the effectiveness of electric vehicle supply equipment.

### **2.3 Stakeholder categorization**

As a result of, or in symbioses with these developments, new actors emerged in the EV technology arena. To determine the actors that are in discourse with this technology, a technology assessment (TA) will be applied to assess the impacts of new technologies. A technology assessment therein functions as a tool for policy makers and in 'exploring the future in a systematic way' (Smit & van Oost, 1999, p13). Part of the method is the categorization of the social actors and network and stakeholders involved with the new technology. Four (4) different groups can be distinguished:

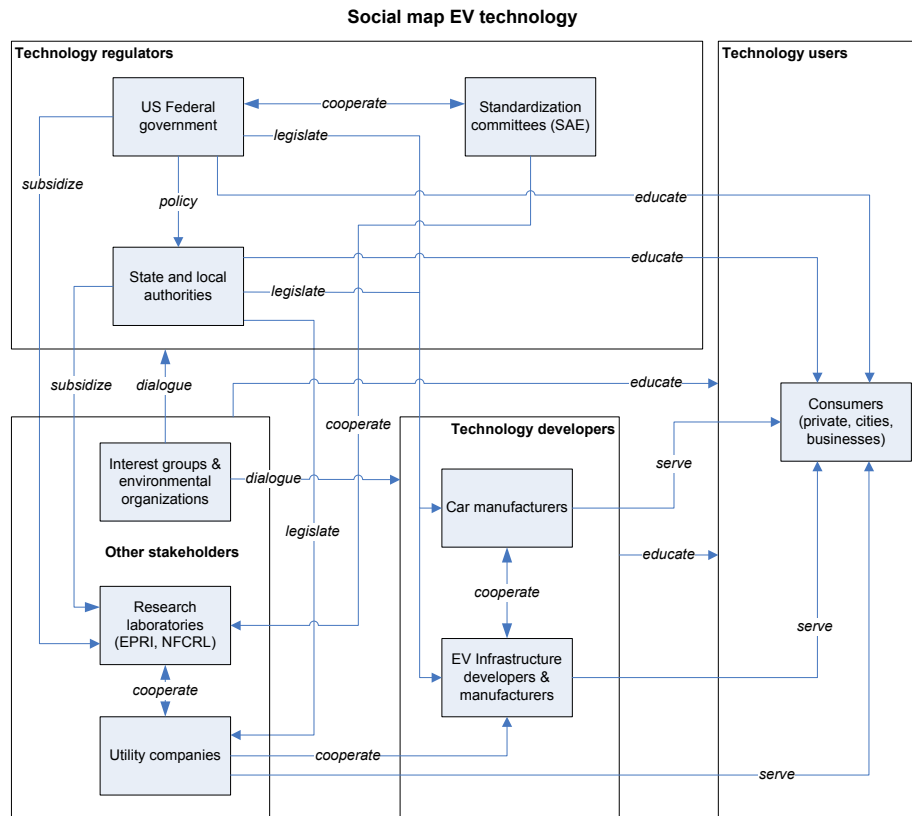
- Technology developers (section 2.4)
- Technology regulators (section 2.5)
- Technology users (section 2.6)
- Other stakeholders (section 2.7)

By classifying the different stakeholders in the above categories, an overview can be created of the different actors and their relationship among each other. As well, their aims and interests can be categorized that eventually will benefit or harm the development of a new technology.

Figure 4 depicts the different organizations and social actors that influence EV technology in the US. In this scheme the relations are represented between the different actors by the blue lines. It is important to understand how the different actors are connected and related to effectively determine the technology potentials and its embeddedness in society. The technology users have a direct impact on the development of EV technology by creating a 'market pull' demand on the EV technology (Smit & van Oost, 1999). The technology regulators are primarily responsible of fostering (*pushing*) and guiding the technology that is socially desired. Then, the technology developers are responsible for the development and commercialization of the technology by producing and offering it to the consumer. The other stakeholders in the figure are facilitators to the (development of the) technology, or have interests in moving the technology forward. An overview of the actual actors in the different categories is given in *Appendix III - EV overview CA/US*.

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<sup>13</sup> See: *Appendix III - EV overview in California/US*.



**Figure 4 Social map of EV technology in the US.**

As can be seen in the figure 4, the different stakeholders interact with almost all the actors in the field. It is interesting to see that at the conferences and conventions I have visited on EV development throughout the US, this interplay of actors can be easily distinguished. All of the actors from the different categories were always present in the meetings and are, as it seems, primarily concerned with knowledge exchange. This is primarily technological knowledge, however also exchange of knowledge on social factors of EV technology such as behavioral studies (charging, etc.) occurred. Lobbying is also an important part of actor interaction at these meetings, and is mostly done by the technology developers (*e.g.* standardization issues) and interest groups.

## 2.4 The technology developers

The technology developers are responsible for the design and production of the new technology. In the field of the development and employment of EV technology, car manufactures and EV infrastructure developers are the key players when it comes to introducing and offering the new technology to the market. The technology developers are subject to federal and state legislature, and have the goal of gaining the largest market share in their sector. In the following sections an elaboration the manufacturers of EVs and EV infrastructure.

### 2.4.1 Car manufacturers and strategies - market developments

Among car manufacturers and experts in the automobile industry, the general idea about further electrification of transportation is largely established (Sperling & Gordon, 2009). However, there are a host of different ideas about the exact pathway of development. Because of the different strands of ideas about further progress and integration of electrified vehicles into society and public space, management boards of car manufacturers have developed diverse strategies for their product development. For example, Toyota focuses primarily on enhancing their series of hybrid electric cars, Nissan, the Californian car manufacturers Tesla and Coda focus more on a full electric model, and Honda aims to develop of a fuel cell electric vehicle. A few manufacturers and their forefront EV product development are discussed in the following sections.

### Toyota - HEV – PHEV

Toyota has been the frontrunner in implementing HEV technology in passenger vehicles, being the world's largest producer of hybrid electric vehicles. Sales of its flagship the Prius have skyrocketed since its introduction in 2000; over 800,000 vehicles have been sold in the US and over 1.7 million worldwide.<sup>14</sup> Until recently, Toyota has been challenged by several technical issues with the Prius but plans on maintaining and exploiting its head start in hybrid vehicle technology. Toyota will bring several other models onto the market in the next months. Toyota has announced a plug-in version of the Prius to become available in 2012, and is working on an EV model to be introduced in that same year. Most other car manufacturers like Ford, Cadillac, Mercedes, BMW, Honda and many others have embarked in the hybrid market, by introducing a hybrid version of pre-existing models. Toyota has recently expressed their interest in the development of full electric vehicles by partnering with Tesla Motors Inc. on the development of a full electric vehicle.<sup>15</sup>



**Figure 5 Toyota Prius PHEV**

### General Motors – EREV

General Motors approaches the upcoming transition with another product development strategy. The scheduled introduction of the Chevrolet Volt seems to mark an important milestone in the history of the electric car. The Volt, which will be introduced in the market in the fourth quarter of 2010, is a different kind of hybrid than the highly successful (in sales at least) Toyota Prius. An extended range electric vehicle (EREV), also known as a series hybrid electric, has one single engine which directly propels the wheels. The batteries have capacity for 40 miles, and thereby meet the mobility needs of at least 78% of the cars in the US (Bureau of Transportation Statistics, 2003). A full tank of gasoline provides an added 300 miles in range and can be filled up in the conventional way. The single electric motor that achieves the propulsion in an EREV, brings the Volt a lot closer to the full electric car than a plug-in hybrid electric car.



**Figure 6 Chevrolet Volt EREV**

### Nissan – BEV

A company that moves directly towards the introduction of full electric cars is the Japanese car manufacturer Nissan. The LEAF is the first full electric car that will be for sale in the fourth quarter of 2010 (in California) and mass produced in 2012. By heading directly towards mass production, Nissan tries to achieve the advantages of economies of scale as soon as possible to lower the high purchase costs of a new vehicle. Also, Nissan considers the high residual value of the batteries, which are expected to outlive the car with ease, to be an important factor in order to create affordable electric driving.<sup>16</sup> Other manufacturers developing BEVs are Mitsubishi and Californian FEV developers Coda and Tesla.



**Figure 7 Nissan LEAF BEV**

<sup>14</sup> Alternative Fuels & Advanced Vehicles Data Center – HEV Sales by model 1999 – 2009. Available online at: <http://www.afdc.energy.gov/afdc/data/vehicles.html>. Accessed May 27, 2010.

<sup>15</sup> Press release Toyota Motor Corporation and Tesla Motors July 16<sup>th</sup>, 2010. Available online at: <http://pressroom.toyota.com/pr/tms/toyota/tesla-motors-and-toyota-motor-163915.aspx>. Accessed August 2, 2010.

<sup>16</sup> Based on statements in a panel discussion with Senior Vice President Minoru Shinohara of Nissan, at the 2010 SAE World Congress, Detroit. April 13, 2010

### Honda – FCEV

Honda has set itself ambitious goals in developing a fully hydrogen powered vehicle. Their fuel cell electric vehicle (FCEV) Honda FCX Clarity is already on the road in Southern California on a limited available lease base.<sup>17</sup> Fuel cell electric vehicles are generally believed to be one of the ultimate options for clean road passenger transportation in the long term future. However, today the technology still faces a number of considerable challenges, including cost and storage problems. FCEVs technology are currently trailing behind in comparison to EVs and will need substantial investments to win a competitive position in the AFV market (Hoogma *et al.*, 2002, p41; Sperling & Gordon, 2009; G.J. Offer *et al.*, 2010, p29).



**Figure 8 Honda FCX Clarity FCEV**

### 2.4.2 Infrastructure companies

Not only car manufacturers are anticipating the advent of an electric car era, also EV Infrastructure companies are planning the extensive rollout of charging infrastructure in the near future. Both developments in the emerging market of electric vehicles are pointed out in the sections below. Speculating on the transition, a number of EV infrastructure companies have emerged in the market place. The infrastructure they provide, also known as electric vehicle supply equipment (EVSE), can be divided into two categories. Home charging stations are generally believed to be very important in actual EV adoption and use. Then public charging infrastructure provides capacity for EV drivers at public parking spaces, lots and commercial/public facilities. An additional type of EV infrastructure comprises a battery swap solution to provide energy needs of the long range full electric vehicle drives. In the textbox 1 below, the four largest EVSE infrastructure developers in the US are concisely discussed.

#### **Textbox 1. Four major EVSE companies in the US**

##### AeroVironment - mainly home charging infrastructure

AeroVironment based in Monrovia, CA, develops home and public charging stations. Recently, it was selected by Nissan as the prime supplier of home EVSE for the Nissan LEAF which market introduction will be firstly in the states of California, Washington, Oregon, Arizona and Tennessee in the end of 2010.

##### Coulomb Technologies - mainly public charging infrastructure

Coulomb Technologies, Campbell, CA, leads the way in the deployment of public EVSE installations. The company has developed the densest EVSE infrastructure in the world in Amsterdam. and continues to expand its networks in the US, Netherlands, Norway, Italy, Belgium, Germany and Ireland.

##### ECOtality/ eTec (Electric Transportation Engineering Corporation) - home and public charging infrastructure

ECOtality, a company that was until recently known as eTec, announced their plan for 'The EV Project', the largest deployment of EVs and charging infrastructure in history. Plans include over 10.000 EV chargers, 260 fast chargers, 4700 Nissan LEAF cars in 11 cities and 5 states throughout the US.

##### Better Place – mainly battery swap stations infrastructure

Better Place, a Silicon Valley based company develops home and public EV infrastructure. The company is best known for its peculiar business model that includes quick battery replacement stations in order to get around the problem of range, charging times and the cost of electric cars. The most expensive part of the electric vehicles, the batteries, are owned by Better Place and the user 'pays by the mile' as if it were a phone plan.

### 2.4.3 Battery developers

Improvement of batteries is believed to be an important factor in further development of electric vehicle technology (ETC/ACC, 2009, p134). Batteries have never been able to compete with the high energy density of petroleum fuels and have therefore a major disadvantage when compared to ICEVs. Ongoing battery research is concentrated on developing new chemistries and assessing the performance of the batteries under different conditions. Battery improvements are focused on

<sup>17</sup> Honda FCX Clarity website. <http://automobiles.honda.com/fcx-clarity/> Accessed December 15, 2010.

basically five properties: i) power ii) energy iii) safety iv) life and v) cost. Finding the optimal combination of these very interrelated properties has been the goal of the industry since the beginning of battery development. The last years have seen significant strides in battery technology, substantially lowering cost and increasing range potential due to the improvements in lithium-ion batteries, primarily caused by the massive introduction of laptops and mobile phone devices (NRC, 2009, p17).

As the automotive battery has always been based on lead acid batteries, a transition occurred in type of battery used. The first battery that replaced the lead acid battery in automotive applications was the nickel-metal hydrid (NiMH) battery, with far better energy densities and superiority in almost all other properties (except cost). Currently mostly used in HEV applications, the production and implementation in automotive appliances is likely to change to lithium-ion battery chemistries (NRC, 2009, p17). As full electric vehicles arrive on the market, lithium-ion batteries seem to become the batteries of choice and will be prevalent in almost all storage designs in these type of electric vehicles (BERR, 2008, p28; ETC/ACC, 2009, p15). Lithium-ion batteries promise far better energy density and power density, allowing them to achieve a far better weight to performance ratio than predecessors.

Production cost reduction is a major challenge to the battery industry. Industry-wide estimates place the production costs in 2009 for lithium-ion batteries at roughly \$600-1500 per kWh (ETC/ACC, 2009, p19). To be competitive with average prices of ICEVs, the goal for battery manufacturers is to reach a \$100 to \$150 threshold per kWh, however this target seems extremely challenging and it is widely regarded unrealistic without a breakthrough in material cost (MIT, 2007). Considering the price difference between gasoline and electricity needed to power an EV, the consumer would not be able to recoup the price difference in the life of the vehicle with current price levels. Government incentives therefore have been highly instrumental in filling the gap between the affordability of electric vehicles and ICEVs to consumers.

A lack of economies of scale is seen as a main contributor to the high production cost of batteries. In a May 2009 DOE review (Barnett *et al.*, 2009), research was presented that indicated using current materials and current processing technology, scaling up to 500,000 units per year could drive the cost of PHEV packs down to \$364 per kWh, nearly achieving the goals outlined by the USABC.<sup>18</sup> Ongoing battery research will be focused on developing new chemistries and assessing the performance under different usage conditions.

## **2.5 The technology regulators**

Technology regulators have the responsibility of defining the framework in which the actors are interacting (Smit & van Oost, 1999, p240). The technology regulators thereby play also a role in fostering and guiding the socially desired technologies by means of policy implementation.

### 2.5.1 Regulation

Regulations are clearly seen as one of the principal forces in the construction of an electric vehicle industry (Calef & Goble, 2007; van Bree *et al.*, 2010). Environmental regulation has largely stimulated electrification efforts of auto manufacturers. CO2 emission reduction has been the main driver of the increased use of electric drive components within road passenger vehicles. The increased sales of hybrid electric vehicles is therefore the most important result of the regulatory changes. Besides the regulation on exhaust emissions, incentives are being granted to both owners and producers of (hybrid) electric vehicles.

### 2.5.2 Production regulation

Additional regulation for the production and use of electric vehicles is expected to be limited. Electric vehicles will be subdued to the same regulation as conventional gasoline engine vehicles. However,

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<sup>18</sup> United States Advanced Battery Consortium – “The USABC seeks to promote long-term R&D within the domestic electrochemical energy storage (EES) industry and to maintain a consortium that engages automobile manufacturers, EES manufacturers, the National Laboratories, universities, and other key stakeholders.” Source: [www.uscar.org](http://www.uscar.org)



recent research by the National Highway Traffic Safety Administration (NHTSA) concluded that an increased number of accidents was recorded with (hybrid) electric vehicles and (visually impaired) pedestrians and showed that additional legislation might be needed (NHTSA, 2009). Two major auto associations in cooperation with blind advocacy groups have announced in May 2010 to support the installation of sound emitting devices in new electric vehicles. It is likely that new legislation will be effective within three years requiring a sound base level for (hybrid) electric vehicles in slow speed (NHTSA, 2009).

### 2.5.3 Utility regulation

Electric vehicles do not require a whole new set of regulations. However, they are likely to have a substantial impact on the utility sector which provides the electricity to charge electric vehicles. The California Public Utility Commission (CPUC) is the main regulating body in California and is tasked to set up the (new) regulation to prepare for a large scale introduction of electric vehicles in the grid. The CPUC has divided the decisions to be made on the regulation in three phases. In the first phase decisions will be made on whether charging installation streamlining will be regulated and a review of capital costs for EV related infrastructure is expected to be announced. One of the most important decisions the agency has announced recently is the judgment that electric-car charging services are not considered utilities and therefore not subject to Commission rules.<sup>19</sup> Now, the market will dictate prices and business conditions. The decisions made over these regulations conclude phase 1 and start the phase 2, a consideration of rate design policies and direct charging management, separate metering for electric vehicles and utility costs recovery policy. The third phase entails issues the commission may not have decided upon until then, such as the need for separate residential meters, billing system upgrades, and any other matters.

### 2.5.4 Policy and emission regulations

The first policy measures to promote electric vehicle drive in the US date back to the 1970's. Successive oil shocks alerted most Americans to the vulnerabilities of oil dependence. Together with the pressure from the environmental movements, a first serious attempt at the federal level to increase the number of HEVs and EVs on the road was by means of the Electric and Hybrid Vehicle Research Development and Demonstration Act in 1976. By most accounts, the program failed due to design errors in the policy program (EC, 2009). Almost two decades later, the electric vehicle gained renewed interest by CARB's Zero Emissions Vehicle Mandate in which vehicle manufacturers were required to sell a certain percentage of vehicles with zero emissions by 1998 if they wished to sell any cars in California. Again, the program unambiguously failed and the reasons for this failure remain subject of much controversy (an elaboration on this is given in section 3.4).

The Energy Independence and Security Act (EISA) of 2007 is an important piece of legislation with respect to promoting plug-in electric vehicles. A Near-term Transportation Sector Electrification Program authorized \$95 billion per year in grants between 2008 and 2013, with an emphasis on large-scale electrification projects (EISA, at §131(b)). A second program, the Plug-in Electric Drive Vehicle Program, further authorized the Department of Energy (DOE) to disperse \$90 million per year between 2008 and 2012 in grants to states and localities to encourage the use of plug-in electric vehicles or other emerging electric vehicle technologies. In 2008, President Obama set an ambitious goal: sales of plug-in hybrid and electric vehicles would have to reach 1 billion in 2015. In May 2009, he substantiated his intent by sharpening fuel economy standards, requiring overall fleet fuel efficiency for all domestically sold passenger cars to reach 39 miles per gallon by 2016, up from 27,5 miles per gallon today. According to the Electrification Roadmap prepared by the EC (2009), it is likely that some form of increased hybridization and electrification will be needed to meet such standards, however, the standards alone are not sufficient to drive significant production of (plug-in) electric vehicles.

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<sup>19</sup> California Public Utilities Commission, Proposed decision of commissioner Ryan, May 2010. Available online at: <http://docs.cpuc.ca.gov/efile/PD/118345.pdf>. Accessed, 22 January, 2011.

In direct response to the recent economic recession, the Obama administration enacted the American Recovery and Reinvestment Act (ARRA) of 2009 to mitigate the effects of loss of jobs, investments and consumer spending on the economy. Among the many reinvestments of a \$787 billion total, the act ensures additional funding for advanced energy projects, including electric drive vehicles. President Obama announced in August 2009 that 48 new advanced battery and electric drive projects will receive \$2.4 billion in funding under the ARRA. The investments include:

- \$1.5 billion in grants to US based manufacturers to produce batteries and their components and to expand battery recycling capacity;
- \$500 million in grants to US based manufacturers to produce electric drive components for vehicles, including electric motors, power electronics, and other drive train components; and
- \$400 million in grants to purchase thousands of plug-in hybrid and all-electric vehicles for test demonstrations in several dozen locations; to deploy them and evaluate their performance; to install electric charging infrastructure; and to provide education and workforce training to support the transition to advanced electric transportation systems.

More grants and loans (partly) in relation to the advancement of electric vehicle developments are provided through the ARRA of 2009, namely:

- \$300 million for federal vehicle fleets, to cover the cost of acquiring electric vehicles, including plug-in hybrid vehicles.
- \$11 billion funding for an electric smart grid,
- \$4.5 billion for the Office of Electricity and Energy Reliability to modernize the nation's electrical grid and smart grid.

#### 2.5.4.1 State policies

At the state level, several policy measures have been implemented to encourage the electrification of the transportation system. The efforts exist of incentives and investments to encourage EV-ownership such as a rebate on vehicle purchase and several other advantages. In California, rebates on EV purchases are an important part of electric vehicle development stimulation. The rebates offered can reach up to \$5,000 for light-duty zero emission and plug-in hybrid vehicles, and up to \$20,000 for zero emission commercial vehicles that are approved or certified by the California Air Resources Board (CARB) on a first-come, first-served basis.<sup>20</sup>

Another policy that impacts emission regulation substantially is the the Global Warming Solutions Act of 2006, Assembly Bill 32 or AB 32, is a California State Law that fights climate change by establishing a program to reduce greenhouse gas missions from all sources throughout the state. AB 32 requires CARB to develop regulations and market mechanisms to reduce California's greenhouse gas emissions to 1990 levels by 2020, representing a 25% reduction statewide, with mandatory caps beginning in 2012 for significant emissions sources.<sup>21</sup>

#### 2.5.5 Standardization

In many emerging markets, standardization is a delicate matter in terms of the influence on technology development and the (political and commercial) interests involved (Van den Bossche & Gaston, 2002; Brown *et al.*, 2010a). To be implemented in the Northern American market, the SAE has succeeded to take on a standard for electric vehicle connectors. Adopted January 14<sup>th</sup>, 2010 by the SAE Motor Vehicle Council, the SAE J1772 standard will cover “the general physical, electrical, communication protocol and performance requirements for the electric vehicle conductive charge

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<sup>20</sup> Alternative Fuels & Vehicles Data Center State Incentives and laws. <http://www.afdc.energy.gov/afdc/laws/law/CA/8161>. Accessed August 23, 2010.

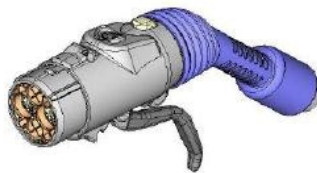
<sup>21</sup> California Air Resources Board Fact Sheet Assembly Bill 32 (AB32) Available online at: <http://www.arb.ca.gov/cc/factsheets/ab32factsheet.pdf> <http://www.arb.ca.gov/cc/docs/ab32text.pdf>. Accessed 14 February, 2011.

system and coupler.”<sup>22</sup> The current revision of SAE J1772 (as of October 2009), also referred to as SAE J1772-2009, allows for a power delivery of up to 16.8 kW delivered via single phase 120–240 V alternating current (AC) at up to 80A. The connector is designed for both level I and level II AC charging<sup>23</sup> and includes several safety features, such as shock protection and the ability to charge in wet conditions. Much more work lies ahead for the standardization committee, as the general standard on the communication protocol (SAE J2847/J2836) for power transmission on the SAE J1772 connector has to be defined yet.

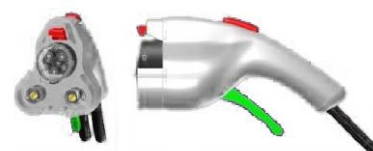
Furthermore, an enhancement of the SAE J1772-2009 coupler is under consideration, making it possible to fast charge with DC electricity on the connector as well. Figure 5 depicts the SAE 1772-2009 connector which will be used in the Northern American continent. For fast charging, the TEPCO connector (figure 6) developed by the Japanese standardization committee ‘CHAdeMO’ is used in North America. Figure 7 represents the enhanced version of the SAE J1772-2009 which will be appropriate for fast charging and is currently in phases of development. A key advantage of the J1772 combo connector proposal is that a single connector can support both AC and DC, and this reduces confusion for the driver.<sup>24</sup> Electric vehicles with a fast charge option, such as the Nissan LEAF, are currently equipped with the standardized SAE J1772-2009 inlet and the TEPCO fast charge inlet.



**Figure 9** SAE J1772-2009 charge coupler appropriate for AC Level I & II (and DC level I) charging.



**Figure 10** TEPCO DC level II (fast charge) coupler standardized by CHAdeMO.



**Figure 11** Enhancement of the SAE J1772-2009 proposed as the ‘Combo Charging Connector’ which enables DC level II fast charging (under development).

## 2.6 The technology user

The technology users are the actors that will ultimately determine the failure or success of the technology by buying or ignoring the new product. Many concerns are currently related to how EV technology will be received at the consumer level. Surveys among potential consumers suggest that demand will be more than sufficient in the early stages of the introduction. Ernst & Young released a survey result in June 2010 that over 25% of drivers across the US, Europe, Japan and China are favorable towards plug-in hybrid and electric vehicles as soon as they come to the market.<sup>25</sup> According to the researchers, it is a significant number for a propulsion technology which is not yet widely available. Electric vehicles therefore have an opportunity to make a significant entrance to the market especially in these early stages. However, there are more factors that will determine the eventual adoption at the consumer side. As can be concluded in the social map (figure 4), education, pricing and experience with the new technology seem important success factors. An elaboration on these factors will be given in the following section.

### 2.6.1 Consumer acceptance

New innovations often require many years to become widely adopted, and hybrid and electric cars have been no exception so far. For a technology design that has been commercially available for more than ten years (Sperling & Gordon, 2009), sales of hybrid vehicles accounted for only 3.1% of new

<sup>22</sup> Society of Automotive Engineers; Craig B. Toepfer (2001-09-27) (DOC). *SAE Electric Vehicle Conductive Charge Coupler, SAE J1772, REV. MONTH01*. California Air Resources Board. <http://www.arb.ca.gov/msprog/zevprog/stakeholders/infrastructure/finalsaej1772.doc>. Accessed 23-10-2009.

<sup>23</sup> For more information on level charging, see section: 4.3 Level charging, page 41.

<sup>24</sup> Presentation by SAE J1772 task force leader Gery J. Kissel (GM), at the Plug-in 2010 conference, San Jose, CA.

<sup>25</sup> Ernst & Young Global Automotive Center, *Gauging interest for plug-in hybrid and electric vehicles in select markets. Compared results*. 2010. Available online at: [http://www.ey.com/Publication/vwLUAssets/Gauging-interest-for-plug-in-hybrid-and-electric-vehicles/\\$FILE/Gauging-interest-for-plug-in-hybrid-and-electric-vehicles.pdf](http://www.ey.com/Publication/vwLUAssets/Gauging-interest-for-plug-in-hybrid-and-electric-vehicles/$FILE/Gauging-interest-for-plug-in-hybrid-and-electric-vehicles.pdf). Accessed 14 February, 2011



LDV vehicle sales in 2009 (see section 2.2). Consumer acceptance of electric drive vehicles is dependent on certain aspects. One of these aspects involves the price factor compared to conventional vehicles. The total cost of ownership may be lower by the reduced fuel and maintenance cost in comparison to ICEVs, the current price of batteries makes the value proposition difficult to the consumer. Without federal tax incentives, the payback period for electric vehicles is beyond the life of the vehicle (EC, 2009). It is therefore important to investigate alternative methods of battery financing and study the residual value of used automotive batteries.

Another factor involved in consumer acceptance is change of habits. People have gained experience with certain technologies and have become habituated to them. An important implication of this is that new technologies are evaluated in terms of the characteristics and services of the old technologies (Kemp, 1994). For example, drivers have been accustomed to filling up their tanks using a ubiquitous gasoline infrastructure that has been developed over the last 100 years. Charging at home can be a considerable change in the usual routine.

Similar factors influencing the consumer acceptance are vehicle performances, first experiences and the expectations and preferences consumers have considering vehicle range and refueling. The Department of Energy (DOE) estimates that EVs on average will travel between 100 and 200 miles before recharging.<sup>26</sup> In comparison to some conventional ICEVs with a range of 500 miles and even more on a single tank, a change to electric vehicle driving entails a considerable surrender of mobility for the consumer. In combination with the increased amount of time needed to refuel the car, these factors could play an important role in technology adoption.

Driver concerns over electric vehicles are thus limited to longer distance trips, especially in countries with vast geographical dimensions as the United States. Refueling here becomes an important issue, in the current situation of a largely absent public charging infrastructure. Even if recharging infrastructure would be ubiquitous, charging an electric vehicle at a fast charger on 220 Volt (level II), takes several hours. Addressing this issue would require the deployment of fast chargers (up to 450 Volt), which could charge a vehicle in minutes rather than hours, or battery swapping networks.

On the face of consumer acceptance, much lies in public awareness and education on the possibilities, constraints and misunderstandings related to electric vehicles. However, the threshold to buying an electric car includes previously shaped conceptions, expectations and desires. Nevertheless, the most common notion about the weaknesses around the electric vehicle by the consumer remains the storage component of the car, the battery; its capacity, time to charge and costs.

## **2.7 The other stakeholders**

The other stakeholders that have significant impact on the development of the technology are the utility companies, the research laboratories, and the several interest groups. The other stakeholders are facilitators to the (development of the) technology, or have interests in moving the technology forward.

### **2.7.1 Utility companies**

The utility companies are the facilitators of the electricity that will be used by the next generation of electric vehicles. The utility will eventually provide almost all of the energy used by electric vehicles (with the exception of some self-sustaining home configurations with solar or wind energy). The electric power sector in the US is by law responsible for providing safe and reliable electricity to the consumer. Utility companies are legislated by the federal and state government on their service and quality.

Currently, the electricity grid, especially in the US, was not designed and does not operate as an aspect of the transportation system (EC, 2009). A number of vehicles scattered over a large area will have a low impact on the grid, however a small number in a specific area, or thousands densely concentrated in a single city will certainly have implications in terms of necessary grid infrastructure

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<sup>26</sup> Electric Vehicles (EVs), Fueleconomy.gov. Online available at: [www.fueleconomy.gov/feg/evtech.shtml](http://www.fueleconomy.gov/feg/evtech.shtml). Accessed June 4, 2010.

upgrades. The role of the energy sector in managing this change will be of relevance to the success of the electric vehicle. In order to prepare for the connectivity of EVs onto the grid, utilities will have to upgrade their infrastructure by replacing transformers and seek innovative regulation to serve these new customers.

### 2.7.2 Research laboratories

An important institution that is involved in scientific research on electric vehicle development is the Electric Power Research Institute (EPRI) in California. EPRI conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. In this respect, they are currently investigating the impact that electric vehicles will have on the electric power grid system when early adopters will start using them. An important task of the research laboratories as independent organizations, is bringing together the scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies.

### 2.7.3 Interest groups

There are many interest groups in California focusing on environmental issues. As well on sustainable transportation there are several interest groups active throughout the US (see *Appendix III - EV overview CA/US*). Plug-In America is probably one of the most well known in this respect. Plug-In America is a coalition of Toyota RAV4-EV drivers, former lessees of Honda EV+, GM EV1, Ford Ranger and Ford Th!nk City electric cars, and advocates of energy independence and clean air. Prior to 2008, they functioned as a loose network of individuals organized around various websites like donterush.com and saveEV1.com. They then coalesced into a chapter of the Electric Auto Association. The prime mission to interest groups like Plug-in America and other environmental interest group is to accelerate the shift to plug-in vehicles (which are clean, affordable, and powered by domestic electricity) to reduce our nation's dependence on petroleum and improve the global environment (Plug-In America, 2010). Interest groups like Plug-in America use various forms of advocacy to influence public opinion or policy, by lobbying and educating other stakeholders in the system to increase the adoption of electric vehicles.

## **2.8 Conclusion**

The increased electrification of vehicles is visible in the growing market shares of hybrid electric vehicles in the market place. It is regarded entirely possible that this trend will persist and result in a system-scale uptake of electric and fuel cell vehicles in the system. In combination with these developments it has been shown that many stakeholders are anticipating the emergence of new transportation technologies in the system. Serious efforts are currently being undertaken by car manufacturers to capitalize on these developments and gain early mover advantages in the market. Also infrastructure companies are emerging and growing. Regulatory efforts have been, and are being designed by California's clean air agency CARB and federal authorities to promote electric drive vehicles even further. Furthermore, consumer demand for electric vehicles is expected to be sufficient in the early stages, although consumer acceptance could eventually pose some challenges in the further development of the market.

The challenges that have been identified in this chapter include not only technological and engineering obstacles, but also cultural, social, political and economic impediments. The most essential of these challenges are however of a technical nature, and related to the energy storage component of the vehicle, the batteries. The other major challenges are the preparations that have to be taken by the electric power sector, the installation of a ubiquitous charging infrastructure and consumer acceptance. Now that we have identified the overall developments and challenges in the transportation system, in the following chapter, transition theory is discussed and this change is analysed from a theoretical perspective.

### 3 A concise historic analysis of lock-in and transition theory

#### 3.1 Introduction

In this chapter, the developments, changes and challenges in the transportation system are viewed from a theoretical perspective. In literature, useful concepts such as technological regimes and technological lock-in have been used to account for the different phenomena in technological development. In this chapter, three approaches will be presented on technological change that may be helpful in explaining the current transition in the transportation sector. There will be a special focus on the so called lock-in of internal combustion engine technology in the automobile of today. Several scholars have debated the factors that are necessary to escape from this lock-in in order to create opportunities for alternative (sustainable) technologies to evolve. These factors will be discussed and combined with the actual developments that have been identified in chapter 2. A special focus in these elaborations will be on the infrastructural aspect of electric vehicle technology. A conclusion based on the findings will lead to the introduction of chapter 4, the role of electric vehicle infrastructure in a possible regime-shift.

#### 3.2 Technological regimes

The current transportation system as we know it today includes a technology (*i.e.* internal combustion technology) that is sustained by a so called ‘technological regime’. The concept of a technological regime was first coined in 1977 by Nelson and Winter. Rip & Kemp (1998) have further developed the concept to what Hoogma *et al.* (2002) have used as a similar definition:

”...the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures.” (Hoogma *et al.*, 2002, p19)

The concept thus of a technological regime relates to the belief of technicians about what is feasible or at least worth attempting. Technological regimes thus result in *technological trajectories*, because the community of engineers searches in the same direction (Geels, 2002, p1259). Kemp (1994, p1025) has already applied the concept of technological regimes within the transportation system by the example of an electrically powered car being part of a new technological regime, as “the material properties of plastics [plastic bodies were regarded a viable option for EVs at that time], the functioning of electric motors and the manufacturing of such a car require a different knowledge base, different types of engineering skills, linkages with information networks and interactions with different supply industries.” It remains clear that shifting the regime towards alternative propulsion technologies will be difficult due to the many interests which exist in the sector that will defend the *status quo*. In the following sections, we will focus on the perspectives on technological transitions and the sustaining elements of technological regimes, which all of them have resulted in the so-called ‘technological lock-in’ of internal combustion technology.

#### 3.3 Technological transitions

In order to understand socio-technical transitions, scholars have developed several models on transitions. Summarized by Grin *et al.* (2010, p11-12), transitions are co-evolutionary, multi-actor, long-term processes resulting in ‘radical shifts from one [socio-technical] system or configuration to another’. These radical shifts involve the development of new technological innovations and their use in society. The impact of the innovations will have such an influence on societal domains (such as food, communication, health care, etc) that the systems are transformed in systems that involve the new innovations. Throughout the last decades, several perspectives have been developed to view technological regimes and socio-technical transitions. In the following sections three useful and therefore frequently used approaches in transition studies will be discussed. In particular there will be looked at the stabilizing factors of the regimes in the different perspectives.

### 3.3.1 The Multi-Level Perspective (MLP)

One of the most useful frameworks in respect of technological transitions is the Multi-Level Perspective (MLP), provided by Geels (2002). The MLP starts from three levels: 1) technological niches, 2) socio-technical regimes and 3) socio-technical landscape. The relationship between the three levels can be understood as a hierarchy, as the regimes are embedded within the landscapes, and the niches within the technological regime (see figure 12). The landscape level represents the ‘wider exogenous environment’ (Geels, 2004, p. 913) and puts pressure on the socio-technical regime level. On the other side, technological niches act as ‘incubation rooms’ for new technologies (Schot, 1998), protecting them from mainstream market selection. When niche-innovations have sufficiently stabilized they will lead to increased competition and also create pressures on the existing regime.

The middle level of socio-technical regimes institutes several rules (cognitive, normative and regulative) account for the stability and lock-in of socio-technical systems. Examples of cognitive rules are belief systems, guiding principles, goals, innovation agendas, problem definitions and search heuristics. Cognitive rules for example, make engineers and designers look to particular directions blinding them to developments outside their focus (Nelson & Winter, 1982). Examples of regulative rules are regulations, standards and laws; contracts, technical standards and existing regulation may favor existing technologies. Examples of normative rules are such as values and behavioral norms.

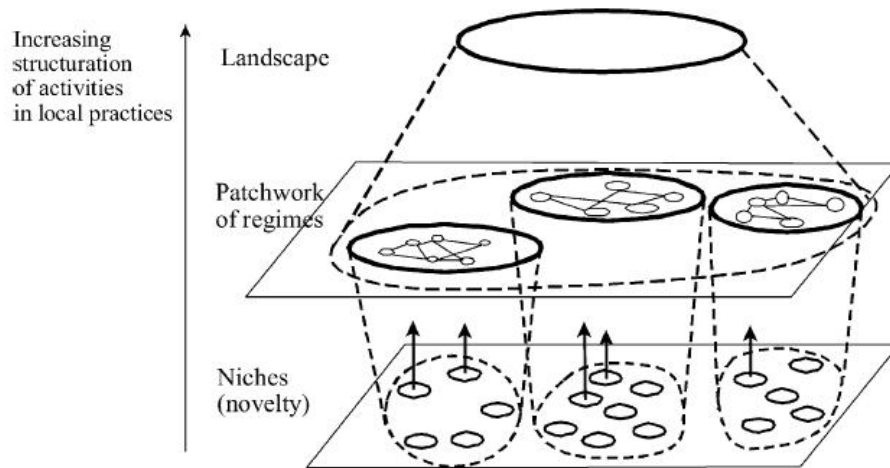


Figure 12 The three layers of the MLP. Source: Geels, 2002

While regimes usually generate incremental innovations, radical innovations are generated at the niche-level. Niches are crucial for technological transitions because they provide the seeds for change (Geels, 2002, p1261). At the niche level, new innovations are protected because the selection criteria are different from the regime. These innovations are important as they provide locations for learning processes (e.g. by learning by doing, learning by using and learning by interacting.) Niches also provide space to build the networks which support innovations, like supply-chains, and user-producer relationships.

As a result of the rules (and actors) governing a technology regime, existing socio-technical systems are stable: innovation still occurs but is of incremental nature, leading to cumulative technical trajectories. This is the main cause of lock-in in the perspective of the MLP model. Changes in trajectories, however, are sometimes so powerful that they result in tensions in the regime. These tensions create ‘windows of opportunity’ for transitions (Geels, 2002, p1262).

### 3.3.2 Technological Innovation systems (TIS)

Another strand of research in innovation systems and technological transitions is the TIS (Technological Innovation System) literature. The TIS approach includes a system perspective, just as the MLP, including societal factors, but not so much on the macro level. Instead, it derives from the

idea that the core of a transition process lies in technological innovation (Carlson and Stankiewicz, 1991). These technological innovations are supported by a TIS, defined as:

‘A dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilisation of technology.’  
(Carlson and Stankiewicz, 1991, p31)

The literature suggests that emerging technologies will pass through a so-called formative stage, before they can be introduced in a market environment (Jacobsson & Bergek, 2004). As the formative stage matures, networks are created and institutions are designed and fine-tuned. Ultimately, these networks and institutions will become increasingly aligned with the emerging technology. The central idea behind this approach is that technological change is not only to be found in individual firms or in research institutes, but also in the broad societal structure.

In the TIS approach, technological change is regarded as ‘a recombination of knowledge’ rather than material development and hinges therefore more on the development of networks and structures and their internal knowledge and competence flows. Institutions are to play an important role in exchanging knowledge and competences. Suurs (2009) states that institutions are so important that they can be regarded the rules, regulations, and routines that shape the ‘possibility space’ of actors. Obvious remains, that TIS stresses the relations between actors and institutions that create technological change.

The most basic structures of TIS represents the elements that are stable over time, meaning the actors, the institutions and the technologies. These have been defined in the literature by Carlson & Stankiewicz (1991) and Jacobsson and Johnson (2000). The actors involve all organizations that contribute to the emerging technology, either directly or indirectly. The development of a TIS depends on the presence, the skills and the willingness of the actors to take action. The institutions are in TIS the core of the innovation system concept. As mentioned earlier, they contribute to the rules and routine of the system. The technological factors consist of artefacts and the technological infrastructures in which they are integrated (Suurs, 2009, p45). The techno-economic functioning of these artifacts -such as cost structures, safety, reliability effects of up-scaling etc.- are of crucial importance to understand the process of technological change.

The relationships between the structural factors determine the eventual success of technological change. These relationships involve relations between actors, relations between institutions and relations between technologies, but also between actors and institutions, actors and technologies and technologies and institutions. If these structural factors form a dense configuration, they may be called a network structure, or a network (Suurs, 2009). It is thus the network that is important in bringing about change but as well the failure factor to bring about change. This particularly stresses the endogenous character of the perspective on technological change.

### 3.3.3 Strategic Niche Management (SNM)

Strategic Niche Management (SNM) is another perspective on transitional change, although in recent literature it has been integrated within the Multi-Level Perspective. According to (Kemp *et al.*, 1998) Strategic Niche Management is:

*‘the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of (1) learning about the desirability of the new technology and (2) enhancing the further development and the rate of application of the new technology’.*

Strategic Niche Management constitutes an effort to develop protected spaces for new technologies. The creation and development of new technologies is fostered by experimentation and learning processes. The focus thereby is mainly on learning. The aim of strategic niche management is to focus on the changes in the technology and in the institutional framework which are deemed necessary.

Although SNM is more of a tool or a governance methodology, the theory reclines on a strong focus and relevance of niches in transitions.

The proposition of SNM lies in two fundamental processes (Hoogma *et al.* 2002, p4): the first assumption is that the introduction of new technologies is a social process that is not a result of a scientific and technological logic, or a simple outcome the market. Therefore the term co-evolutionary and co-production are frequently connected to the SNM approach. The second assumption is that experiments are a useful practice to understand, develop and commercialize new technologies. Experiments make it possible to establish learning processes and also to work towards societal embedding and adoption of new technology.

#### 3.3.4 The three perspectives and sustainable development

The approaches of MLP, SNM and TIS explain three perspectives to look on transitions. There are many similarities between the MLP, TIS and SNM approaches. The relevance of concepts as niches and evolutionary economics are present in all perspectives. All the approaches are also taking the innovation process as the heart of a transition. Most significant, the approaches of MLP, SNM and TIS stress the relevance of technological change as a learning and build-up process.

There are also differences; as MLP focuses more on macroscopic dynamics, the TIS focuses more on mesoscopic dynamics, and SNM more on microscopic dynamics. The disadvantage of MLP is that it is too aggregated and long-term oriented to offer a strategic value. On the other hand, SNM offers a strong strategic proposition, just as TIS has been found effective as a policy design model. Hence, as MLP is more a descriptive model, TIS and SNM become more prescriptive models, that is, that they can be used as policy design tools to improve and accelerate technological change.

In the perspective of sustainable development and a changing transportation regime, it is important to note that in especially the MLP, the stabilizing factors are well described (by cognitive, normative and regulative rules and the actors that rule the regime). In the TIS approach these stabilizing factors are somewhat underexposed. In TIS, the rules and routines of the institutions are the shaping factor of technological change (Suurs, 2009) including the economy's productive structure, rate of capital investment and technical infrastructure. Extending this perspective, these factors can be understood as the stabilizing factor in technological regimes, rather than the actors. The structures of institutions are the barriers and the drivers of technological change in the TIS approach.

In the SNM approach, a whole set of interrelated factors is the cause of hampered technological change. These include technological, governmental and regulatory, cultural, psychological, market and production, and infrastructural factors (Hoogma *et al.*, 2002). SNM focuses more on the learning processes and opportunities that are aimed at eventually overcoming these barriers.

For electric vehicle development, it is important to understand the stabilizing factors of technological regimes which hinder technological change as policy makers are looking for different ways to promote sustainable means of transportation. In the literature, the term technological lock-in is often used to describe these stabilizing factors in technological regimes. In the following sections this lock-in will be further elaborated upon and will be sought after the specific barriers in electric vehicle development.

### **3.4 Technological lock-in**

Transitions such as those envisaged in the transportation system do not come about easily because the existing system is stabilized in many ways. This is where we speak of 'lock-in' of a certain technology, in our case the lock-in of the internal combustion engine (ICE) technology in the transportation system. This lock-in of the fossil fueled based energy system has also been termed as a *carbon lock-in* (Unruh, 2000, p817) which created persistent failures on the promotion of use sustainable technologies in the transportation sector. In recent years, a renewed interest on this particular lock-in of the internal combustion technology has been added to the literature (e.g. Kemp, 1994; Cowan & Hultén, 1996; Hoogma *et al.*, 2002; Ball & Wietschel, 2009; van Bree *et al.*, 2010).

Like with internal combustion technology in automobiles, many established technologies do not meet the demands of the modern knowledge that is available. The problem can be that they do not represent the best known technology design. The established technologies often have created unforeseen -and often unwanted- side-effects. A famous example of a technology not representing the latest knowledge is that of the QWERTY keyboard, a technology design that could be remodeled to a more efficient, ergonomic and intuitive design, but became 'locked-in' due to dominance of available keyboards and training (David, 1985).<sup>27</sup> Many other technologies are known for their locked-in position as they initially became very well-entrenched in the technological system.

The path that leads to a lock-in of a technology often starts with a small historical event or a sequence of events. This historical event could be an accident, a random marketing gadget or a problem demanding immediate action. An initial advantage that is created by a certain technology can "create a snowballing-effect based on learning by doing, learning by using and learning about pay-offs, which quickly makes the technology preferred above others" (Cowan & Hultén, 1996). This process is often denoted as the path-dependency model, in which competing technologies already exist and the most of the decisive technology is produced within the industry. In the following sections, the lock-in of gasoline cars in the market is described, resulting in the overall dominance of gasoline cars in the road transportation system.

Hence, as a result of these lock-in mechanisms, existing technical regimes are stable: innovation still occurs but is of an incremental nature, leading to cumulative technical trajectories; just as we have seen in the history of automobile development until now (see section 3.4). One of the key reasons why technological progress often proceeds along certain trajectories (defined by a technological regime) is that the prevailing technology and design has already benefited from all kinds of evolutionary improvements. These improvements can be in terms of costs and performance characteristics, from a better understanding at the user side, accumulated knowledge, capital outlays, infrastructure, available skills, production routines, social norms, regulations and lifestyles (Kemp, 1994, p1027).

At times, however, changes in trajectories are so powerful that they result in tensions which create windows of opportunity for transitions (Grin *et al.*, 2010). For the case of electric vehicles, we will determine the factors that play an important role in creating such windows of opportunity that allow an escape of the lock-in of our current transportation system. It is important to understand how the internal combustion engine technology became 'locked-in' the technological regime; hence, in the further sections of this chapter we will discuss the developments from an historical perspective.

### **3.5 The lock-in of gasoline technology**

As said, the establishment of the gasoline car as the dominant design in the early 1900s has much likeness with that of a locked-in technology. Over the decades, after the gasoline car had won the competition over the steam and electric car, the internal combustion engine vehicle entrenched itself very well into society. From the 1900s onwards, an entire network of petrol stations was constructed and the petroleum and refining industry grew intensively. In addition, mechanics specialized in the repair of gasoline engines and started new businesses. The different stakeholders around the gasoline car became intimately linked and created a strong, stable and extensive network, making the position of the gasoline car very difficult to assail.

Hence, how did the internal combustion engine prevail in the market as the solution for automobile propulsion? The automobile industry began to develop rapidly in the 1890's. From the beginning of the new industry, electric, steam and gasoline cars competed for the market. The causes why the electric vehicle eventually lost the competition on the car market have been debated extensively by scientists (see *e.g.*: Rae, 1984; Flink, 1988; Volti, 1995; Mom & van der Vinne, 1995; Kirsch, 2000; Mom, 2004). The technical solutions found in the car industry is such a factor that played an important role in the outcome of the battle for the market. It seemed that gasoline engine producers

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<sup>27</sup> David (1985) suggests that time savings of 20% to 30% of using the Dvorak keyboards rather than QWERTY keyboards are not enough to spur the users and producers to change keyboard.

found solutions in a much quicker pace than the electric vehicle industry (Rae, 1984; Volti, 1995). Battery technology did also improve in the beginning of the century, but very slow; it took 10 years to fulfill the expectations of 1900 (Flink, 1988). In 1910 the battery performance was still uncompetitive, because of the many advances in the gasoline car industry. According to Flink, the arrival of the starting-lightning-ignition (SLI) in 1912 was the conclusive disaster for the electric car. Additionally, electric vehicle producers were more interested in selling their cars to the right customers at a high price than they were in developing a mass market.

Although many believe, even today, that internal combustion had become the prevailing standard mainly because of its technological superiority, the outcome also was dependent on other factors (e.g.: Flink, 1988; Kirsch, 2000; Mom, 2004). The impression that electric vehicle technology was an inferior technology at that time, is challenged by these historians who believe that also the social context of the EV, marketing/consumer feedback and cultural ideas about electric vehicles in particular were the cause of an emerging gasoline based transportation system. To them, it is evident that a combination of economic, cultural, social and technical factors eventually resulted in the decisive advantage of the gasoline car between 1900 and 1905. These factors included cultural factors such as the feminine connotation of electric vehicles at a time when most buyers were men, the trend of touring (for the wealthy mainly) in the early years of the automobile, the appeal of adventurousness of ICEVs, the popularity of speed and endurance races, and low cost mass production opening up the an enormous economic opportunity on which gasoline vehicle producers heavily embarked upon.

Focusing on the infrastructural problems that gave an advantage to the internal combustion engine, the much heavier infrastructure the electric vehicle required was an impending factor (Mom, 2004). Due to the range of electric vehicle, (again closely connected to the battery's low energy density) a network of charging stations would have to be much denser than a network gasoline fuel stations. Also, the difficulty of changing large numbers of batteries played an unfavorable factor to the electric vehicle (Mom, 2004). Volti (1995) argues that the practicality of electric cars could have been considerably increased by the development of a network of battery charging stations. Even battery-swapping stations could have been set up to make electric vehicles useful for long-distance travel. The technical and economic problems were difficult but far from impossible (Volti, 1995). Flink (1970, p241) questions whether a system of charging systems would have changed history, unless the cost of electric power could also have been reduced substantially in the short run to make it competitive with gasoline.

As the manufacturers of electric autos failed to construct such a network, electric-utility companies also did not help the car manufacturers out. Thomas Edison suggested that power stations had to go into the garage business to stimulate the demand for electric vehicles; his advice was not followed (Volti, 1995). It would have been a solution to a problem of power generation and making optimal use of installed capacity with regard to the fluctuating demand over twenty-four hours of a day, an argument that is often mentioned in today's discussions. Meanwhile, oil companies aggressively set up stations to fuel internal-combustion cars. According to Volti (1995), the small size of the electric-car market was partly to blame for the failure of constructing an electric vehicle infrastructure. Electric-company officials argued that they would get more involved only when the manufacturers reduced the price of the cars. Hence, a vicious circle emerged. The small market kept the power companies from building more charging facilities, and the lack of charging facilities helped keep the market small. Furthermore, there was little promise of economic benefit for the power companies; one power-station manager estimated that keeping the batteries of one electric truck charged would produce no more revenue over a year than powering eighteen electric irons (Volti, 1995).

Resulting from these early years of automotive development, the gasoline car industry began to grow to an unprecedented magnitude. Gasoline cars gained an enormous influence on the way people lived, how far they could commute, and how they spent their leisure time. The fossil fueled car became the undebated solution for personal mobility and a part of every day life more intensely.



### **3.6 Previous attempts to escape the lock-in**

It was only in the 1970s that the gasoline car was firstly called into question by the problems of congestion in large cities, car accidents and the growing awareness of air pollution. In addition to the growing concerns over these issues, the oil crisis of 1973-1974 made people rethink the way of continuing their mobility needs that had developed over the decades (Rubin & Davidson, 2001). It was in those years, that many early electric vehicle programs were initiated. Several research institutes and firms in Europe and the US started projects on battery electric vehicles and conducted a number of field tests (Hoogma *et al.*, 2002). The results of these were not very satisfying as the vehicles had poor technological performance and were relatively expensive compared to the standards set by the gasoline car. It quickly became obvious that the demands on electric vehicles to compete with gasoline cars were impossible to meet with the then existing battery technology. During the years that followed alternatives modes of transport gained attention due to the growing environmental movement, the worsening air pollution problems in urban areas and, later, the issue of global climate change. The increased attention resulted in calls for the development of more environmentally friendly cars, of which among them, electric vehicles.

These developments resulted in a serious effort to implement electric drive vehicles on the road in California in 1990. The attempt was policy-driven by regulation from the California Air Resources Board (CARB) in order to promote the use and further development of Zero Emission Vehicles (ZEVs). In southern California the atmosphere in the region had become one of the most polluted in the world. Especially the health problems in the Los Angeles area incited the agency to implement regulation that would require automakers to manufacture zero emission cars for 2% of their new car sales by 1998 (Sperling & Gordon, 2009, p187). For 2001, the requirements would be 5% of total sales and for 2003, 10%. Any manufacturer failing to meet the CARB requirements would be fined up to \$5,000 for each vehicle falling short on the quota (Sovacool & Hirsh, 2009). The legislation implemented in California generated considerable interest from other states, and 10 additional states applied for the same regulation.

The ZEV mandate of 1990, under which name it became well-known, created the promise of a market for electric vehicles. The regulatory changes led to a series of developments and initiatives within electric utility companies, car companies, governments and research laboratories. At the federal level, the Department of Energy (DoE) founded the US Advanced Battery Consortium with participation of the major car manufacturers, battery industry and electric utilities who targeted the development of a high-performance battery (Hoogma *et al.*, 2002). Auto makers General Motors and Honda responded at CARB's mandate by starting to develop full electric vehicles, of which respectively the EV1 and the EV Plus are the most famous models of that period.

Other car manufacturers together with the American Automobile Manufacturers Association (AAMA), a trade group of automobile manufacturers in the US, started to resist the CARB mandate by claiming that EVs would not provide a significant environmental benefit. Car manufacturers also alleged that alternative fueled vehicles (AFVs) would be too costly for consumers, adding in some cases \$2,823 to the price of each vehicle (Sovacool & Hirsh, 2009, p1101). A consortium of major oil companies contributed more than \$1.1 million to legislative candidates in California in an attempt to weaken the state's push towards electric vehicles. Among other initiatives to discredit the use of AFVs, the Mobil Oil Corporation spent \$3.5 million in advertisements aimed at discrediting AFVs (Calef & Goble, 2007).

These efforts resulted for the CARB to roll back the electric vehicle mandate by five years. Further reviews by CARB delayed the introduction of the EV even more, and put emphasis on the development of other clean vehicle technologies such as hybrids and fuel-cell vehicles instead (Sperling & Gordon, 2009, p189). Also, CARB started discussions about including the pollution caused by the generation of electricity used for electric cars. In 1998, CARB decided to allow auto manufacturers to meet a portion of their ZEV requirements with gasoline-powered vehicles or hybrid vehicles that produced emissions in the so called super low emission vehicle (SULEV) (Hoogma *et al.*, 2002).

During this period, electric vehicle public charging stations were deployed all around in California. According to Plug-In America Director Marc Geller, more than 1500 charging stations in California were deployed during the 90's to support the full electric vehicles that arrived on the market.<sup>28</sup> However, not much literature has been written on the public charging infrastructure deployment in this period. It remains clear nonetheless, that public charging infrastructure was regarded limited but sufficient as experienced by first time users, and their limited deployment not a failure factor, largely because charging mainly occurred at home at that time.<sup>29</sup>

All of these developments described above, resulted in a return of the electric vehicle into niche markets. It is evident from this history that the institutional efforts done to promote AFV use were not sufficient to cause a technology transition towards electric vehicles. The question remains on what other factors (next to regulatory efforts) the success of the EV is dependent on, *i.e.* what additional conditions are necessary to establish a lock-out for combustion technology?

### **3.7 Conditions to achieve a regime-shift**

Hoogma *et al.* (2002) have studied the barriers that can exist in introducing more sustainable technologies in the transportation system. They have identified several interrelated factors which account for the slow change in the transportation regime and the under-utilization of sustainable technologies. According to them, technological factors constitute a barrier as the introduction of a new technology does often not fit well with existing transportation systems. The introduction of electric vehicles will for example require the development of an infrastructure for charging batteries. It may also be the case that the technology needs to be further developed before it can be introduced in the market (Hoogma *et al.*, 2002, p13).

Furthermore, governmental and regulatory factors may be barriers. Even though governments are committed to environmental protection and other social goals, often they are not putting out a clear message that there is a need for specific new technologies (Hoogma *et al.*, 2002, p14). Other factors include cultural, psychological and demand factors, such as preferences and expectations, which are barriers that could hamper the adoption of environmentally friendly cars. The technology may not yet have proved its value and the consumers are not sure what to expect. Then production factors are playing an important role too, as auto manufacturers are hesitant to embark on new technologies with uncertainties on large investments. Infrastructural and maintenance investments are also accounting for potential barriers in a system transition. New distribution systems (*i.e.* charging infrastructure) needs to be established and mechanics in garages must be introduced to new technologies in order to be able to check and repair the new vehicles.

An earlier study by Cowan & Hultén (1996) also suggest that there are several possible avenues of escape from lock-in for the electric vehicle, ranging from technical, regulatory, economical, social and scientific origins. To escape lock-in, it is not enough for a competing technology to perform better, but it is also necessary that some additional events occur. Cowan & Hultén (1996) propose six factors that could help the automobile market escape the lock-in of the gasoline car technology. These six factors are:

1. Crisis in the existing technology;
2. Regulation;
3. Technological breakthrough producing a (real or imagined) cost breakthrough;
4. Changes in taste;
5. Growth of niche markets; and
6. Scientific results creating new knowledge.

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<sup>28</sup> An overview (incl. map) of public charging stations that are currently available (and still in operation) from this period in and around California can be viewed at: <http://www.evchargernews.com/#regions>. Accessed 4 March, 2011.

<sup>29</sup> Interview with Plug-In America Director Marc Geller, San Francisco. March 8, 2010.

In the next sections, the different factors will be reviewed in the light of the recent developments in the electric vehicle industry.

### **3.8 Escaping lock-in for electric vehicle technology**

#### **3.8.1 Crisis of the existing technology**

Gasoline cars are today clearly dominantly existent as the means of personal mobility for most consumers. Although today's gasoline car technology still performs as people expect it to at predictable costs, the automotive industry recently has faced substantial difficulties due to the global economic crisis, causing the industry to fundamentally reorganize (see also section 2.2). General Motors, as of 2010 the second largest car manufacturer in the world, had to file bankruptcy in 2009 due to dropping sales in 2008 and 2009 of respectively 22% and 30%.<sup>30</sup> The financial aid that was required to help sustain major car manufacturers in the market, brought the companies into considerable discredit. With a growing concern about GHG emissions, oil dependency, price volatility and environmental issues, gasoline car technology has become much more debated in recent years. These recent developments in the car manufacturing industry could indicate the turmoil in the sector, causing it to change and aim at new and long-term opportunities.

#### **3.8.2 Regulation**

Regulations are seen as one of the principal forces in the construction of an electric vehicle industry (Åhman, 2006, p434; Roland Berger, 2009; Cowan & Hultén, 1996, p75). Throughout the 90s, it has become clear that regulation had accelerated electric vehicle technology going forward (Calef & Goble, 2007). A study by Kalhammer *et al.* (1995) concluded that the battery manufacturers and researchers interviewed in their research were unanimously convinced that the ZEV mandate of CARB had accelerated investment and progress in developing advanced batteries for electric vehicles. Strong policy efforts are currently undertaken to promote electric vehicle development through emission standards, production quota and incentives to buyers. In the US, emission standards are managed by the Environmental Protection Agency (EPA), by means of CAFE<sup>31</sup> regulations, but the state of California has special dispensation to promulgate more stringent vehicle emissions standards, and other states may choose to follow either the national or California standards. In May 2009, president Obama drastically sharpened fuel economy standards, requiring overall fleet fuel efficiency for all domestically sold passenger cars to reach 39 miles per gallon by 2016, up from 27,5 miles per gallon today.<sup>32</sup>

#### **3.8.3 Real or imagined technological (cost) breakthroughs**

The arrival of lithium-ion batteries to the market has created a new opportunity for the electric vehicle to challenge the position of gasoline fueled cars (ECN, 2009, p50). The intense use of lithium-ion batteries in laptops and mobile phones has created a series of improvements in battery technology. Lithium-ion batteries currently represent the most promising technology for energy storage purposes and 'there is a widespread feeling that lithium-ion batteries will become the dominant chemistry for electrically-driven vehicles in the future' (MIT, 2007). However, the cost of lithium-ion batteries is still very high compared to the cost of gasoline (NRC, 2010, p31). Future battery pack cost estimations are also quite uncertain. A literature review on the cost reduction estimates for batteries in the near, medium and long term future shows that it is unlikely that the price will fall below \$300 in the near term future (BERR, 2008). According to an unpublished paper of the International Energy Agency, the coming years will be decisive for moving towards mass production of batteries for electric vehicles (ETC/ACC, 2009, p20). However, car manufacturers which heavily embark on electric vehicle technology like Nissan<sup>33</sup>, demonstrate confidence in future price reduction and competitive pricing potentials.

<sup>30</sup> PR Newswire United Business Media - <http://www.prnewswire.com/news-releases/chevrolet-buick-gmc-and-cadillac-post-sales-gains-80720277.html>. Accessed 11 August, 2010.

<sup>31</sup> Corporate Average Fuel Economy (CAFE) standards (enacted 1975) are to improve the average fuel economy of cars and light trucks (trucks, vans and sport utility vehicles) sold in the US.

<sup>32</sup> Politico.com – A living diary of the Obama Presidency - <http://www.politico.com/news/stories/0509/22650.html>. Accessed 17 February, 2011

<sup>33</sup> Nissan plans FEV LEAF production to reach 500.000 annually in 2012.

#### 3.8.4 Changes in taste

New ideas about social behavior and different values may be needed for new technologies to be adopted and used (Kemp, 1994, p1032). As we have seen in recent years, growing awareness and concerns over environmental and resource problems has created markets for environmentally friendly products (Bloom, 1995). In the process of consumer taste formation there are social aspects involved such as status, appeal, social acceptance etc. These social aspects are still not well understood, but they may have important implications for the ultimate choice of technologies (Kemp, 1994, p1032).

However, use of oil as source of energy has become increasingly discredited by environmental problems of fossil fuels and impacts consumer taste formation. A poll by WorldPublicOpinion.org finds that majorities in 15 of 16 nations surveyed around the world think that oil is running out and governments should make a major effort to find new sources of energy.<sup>34</sup> Air pollution and disasters, such as the recent oil spill in the Gulf of Mexico and dependency on unstable regimes in middle-east countries have contributed to the changes in public opinion. The consumer willingness to buy AFVs on the market place is evidenced of these changes in taste at the customer side. Research by Ernst & Young showed that over 25% of drivers across the US, Europe, Japan and China are favorable towards plug-in hybrid and electric vehicles as soon as they come to the market.<sup>35</sup> According to the researchers, this is a significant number for a propulsion technology which is not yet widely available. Electric vehicles therefore have an opportunity to make a significant entrance to the market especially in these early stages (Ernst & Young Global Automotive Center, 2010).

#### 3.8.5 Enough niche markets

The existence of a large set of early adopters is very beneficial to any technology trying to create a market share. Early adopters form the foundation for a new technology to take off and provide the experience needed by doing and learning and learning by using (Cowan & Hultén, 1996, p76). If a technology succeeds in a particular niche in the market and becomes valuable to a certain group of customers, early adoption will be accomplished. Hoogma *et al.* (2002) have also stressed the importance of niches for promising new technologies through experimentation in their book on Strategic Niche Management. According to them, niches can offer opportunities for experimenting with new technologies, establishing an “open-ended search and learning process” which would allow for working on both technical and social side of introducing new technologies (Hoogma *et al.*, 2002, p4). Eventually, the technology might compete head-on with the dominant technological option in a part of its market or markets.

Well known examples of niches in the case of the electric vehicle have been golf carts, forklift trucks and electric milk floats (primarily in the UK), indoor-transport vehicles at airports and train stations, but also lightweight electric vehicles in Switzerland and delivery carts in France. (Hoogma *et al.*, 2002, p41) In more recent years, electric vehicles have been adopted as a quiet and nonpolluting means of transport in holiday resorts such as car-free mountain villages in Switzerland and in the US retirement communities (Hoogma *et al.*, 2002, p57). The large number of different applications shows that there are many niche markets for electric vehicles, hence an increased variety of uses and reasons for adoption have been generated. It is likely that the threshold of sufficient niche markets might have been reached, as high end consumers recently have been engaged in buying electric sport cars such as the Tesla and more mainstream models are lining up for production in the coming months.

#### 3.8.6 Scientific results

The electric vehicle industry has largely been thriving on scientific results due to available knowledge on the effects of GHG emissions to the environment (Cowan & Hultén, 1996, p77). There are fears that irreparable damage has been done to the environment due to the use of gasoline cars, among other technologies. Without the scientists measuring the pollution and estimating the future effects of the pollution, the electric vehicle would be far less interesting. Scientific results also help in

<sup>34</sup> WorldPublicOpinion.org Report - *World Publics Say Oil Needs to Be Replaced as Energy Source*, April, 2008. Report available online: [http://www.worldpublicopinion.org/pipa/pdf/apr08/WPO\\_Oil\\_Apr08\\_pr.pdf](http://www.worldpublicopinion.org/pipa/pdf/apr08/WPO_Oil_Apr08_pr.pdf). Accessed 25 February, 2011

<sup>35</sup> Ernst & Young Global Automotive Center, *Gauging interest for plug-in hybrid and electric vehicles in select markets. Compared results*. 2010. Available online at: [http://www.ey.com/Publication/vwLUAssets/Gauging-interest-for-plug-in-hybrid-and-electric-vehicles/\\$FILE/Gauging-interest-for-plug-in-hybrid-and-electric-vehicles.pdf](http://www.ey.com/Publication/vwLUAssets/Gauging-interest-for-plug-in-hybrid-and-electric-vehicles/$FILE/Gauging-interest-for-plug-in-hybrid-and-electric-vehicles.pdf). Accessed 14 February, 2011

approximating future capabilities of technologies, such as the theoretical energy density that can be stored in lithium batteries. It is also frequently stated that radical innovations depend on new scientific insights which open up new technological and economic opportunities (Kemp, 1994). The rise of lithium-ion batteries in the industry could become apparent as such an event that makes the industry believe that electric vehicles could be successful.

### **3.9 Conclusion**

In this chapter, the developments, changes and challenges in the transportation system have been viewed from a theoretical perspective. Three different approaches have been discussed to view sustainable technology transitions in the light of electric vehicle development. From the historical analysis it can be concluded that electric vehicle applications have remained at the niche-level (of the Multi-Level Perspective) ever since they have lost the initial competition with gasoline cars in the early 1900s. However in the recent years, landscape pressures, such as global climate awareness and increasing oil prices, are putting intensified pressures on the technological regime and create opportunities for niche technologies.

Geels & Schot (2007) have proposed different transformation pathways based on empirical research. Van Bree *et al.* (2010) have consequently indicated these possible transformation pathways for hydrogen and battery-powered electric vehicles leading to two (2) different sets of scenarios. In one set of scenarios tightening emissions regulation stimulates carmakers to scale up experiments with alternative vehicles, moving them into the commercialization phase. In the other set, rising fuel prices prompt carmakers to first extend their current product line-up with plug-in versions, and later with battery-electric and fuel cell vehicles.

Landscape pressures and the performance of regime actors are therefore determining factors of technological change when it comes to electric vehicle development. Radical breakthroughs at the niche-level are unlikely to happen (see section 2.4.3 on battery technology), however with the increased R&D and capital investment in sustainable transportation different scenarios are possible. Electric vehicle technology so far has not experienced radical innovations, although there have been serious improvements in battery technology. The electric vehicle therefore remained at the niche-level and experts still doubt the readiness of the technology for mass market introduction.

The TIS approach describes the current increased interest for electric vehicles less well. The structures of the TIS that form the network do not explain for the macroscopic developments in the transportation landscape. However, through TIS, certain hubs of innovation systems can be distinguished in which electric vehicle development is taking a rapid course. Examples are the Californian institutional efforts aimed at promoting electric vehicle development. In its own ways, Strategic Niche Management is currently successfully employed in Californian cities as San Diego, Los Angeles, Tokyo, Berlin, London and San Francisco (see section 2.4 and section 4.8).

Through historical analysis, it has become clear that the technological regime of internal combustion technology has become deeply rooted into the road transportation system during the last century due to a combination of economic, cultural, social and technical factors. Several efforts, mainly in the 70s and 90s, have failed to assail the dominant position of the gasoline car. Scholars have studied this lock-in of the internal combustion technology identified the barriers that hinder a regime shift and possible avenues to escape from this lock-in.

Since the release of Cowan & Hultén's (1996) article on the possible routes to escape from the lock-in, several developments have taken place in technological, regulatory, social and economic systems. We can conclude that a crisis has taken place in the existing technology and market (*i.e.* the ICE-technology). This crisis had been absent at the time of Cowan & Hultén's article release. Also major changes in regulatory frameworks have taken place in the recent past regarding road transportation. Although the ZEV mandate in California has been considerably delayed and partly revoked, emission standard regulations have drastically increased recently, and will probably again prove to be very instrumental in the construction of a sustainable automotive sector.

The existence of technological breakthroughs within the technology is another factor that is described by Cowan & Hultén as a prerequisite for a successful regime shift. Despite the significant rise of lithium-ion batteries in electronic products, and consequential cost reductions, it remains a debated issue whether prices will become competitive to gasoline automobiles despite projected economies of scale advantages. However, a growing change is evident in consumer demand factors due to a change in taste which is noticed in the general public as people are willing to buy more sustainable products and belief that this change is needed. Scientific results on global warming and climate change are the last factor described by Cowan & Hultén that are backing the beliefs for sustainable development in the transportation sector.

#### 3.9.1 The 7<sup>th</sup> factor in escaping lock-in: charging infrastructure

The factors proposed by Cowan & Hultén that determine a successful escape of lock-in are mostly met in the current state of electric vehicle technology. Nevertheless, having met all the factors proposed by Cowan & Hultén, the technology would still have to overcome another important technological impediment. As claimed in this thesis, the infrastructure in which it is to be received would be this essential investment in the case of the electric vehicle. Technological infrastructure development involves important organizational and investment efforts. Standardization and interconnectivity of electric vehicle equipment are all closely related to interoperability and the eventual functionality of the vehicle. In the following chapter, an effort will be done by studying what exactly the role of electric vehicle infrastructure is in creating escape opportunities from the lock-in of gasoline vehicle technology in the transportation system.

## **4 Escaping lock-in – The role of electric vehicle charging infrastructure**

### **4.1 Introduction**

As proposed in the conclusion of chapter 3, infrastructural development around electric vehicles is of major importance in challenging the internal combustion regime in the transportation system. This idea will be the main topic of this chapter, hence, the role of electric vehicle charging infrastructure in a possible transition is studied. To begin with, it is important to understand the general properties and functionality of electric vehicle charging infrastructure so a thorough introduction is given on the general characteristics and state of the art of electric vehicle charging infrastructure. It will remain clear that besides the functional property of charging infrastructure, it offers consumers psychological support. Consequently in the conclusion, an analysis is performed on the role of the development of electric vehicle charging infrastructure in the transition.

### **4.2 Electric Vehicle Supply Equipment**

The infrastructure needed to charge electric vehicles is referred to in technical literature as electric vehicle supply equipment (EVSE).<sup>36</sup> The term ‘charger’ is often misused in reference to the charge equipment, as the charger is located on the vehicle itself.<sup>37</sup> EVSE consists of a device that (which is sometimes only a cord with a safety feature) integrates the vehicle with an electricity circuit. Several safety issues require the use of EVSE instead of simple cords that connect an outlet to a vehicle.

EVSE ensures that electric vehicles are connected properly and grounded before transmission of power begins, such as preventing a driver from pulling away while the vehicle is still plugged in. EVSE will, depending on the level of intelligence, ease integration of plug-in electric vehicles into the grid. They are expected to control charging starts and stops in the future, enable variable charge control based on pricing or grid loading, process user identification and payment, handle vehicle specific metering enable vehicle diagnostic reporting; and in the future control vehicle to grid capacity, and possibly many other novel functions (NREL, 2010).

### **4.3 Level charging**

There are several different levels of charging based on the power available. Some of these charging levels have been specified by the Society of Automotive Engineers (SAE), the main organization in the US that has the responsibility of developing automotive standards. The specification SAE J1772 defines level I and level II charging as well as the interface between the vehicle and the charging infrastructure. Level I charging is specified for the NEMA<sup>38</sup> outlet, the outlet that most Americans use, which is the traditional home plug. The speed of charging on this outlet is relatively slow, with a maximum of 120V and 12A of respectively electrical force and current. Charging a full electric vehicle with a 30kWh battery takes over 8 hours to charge, depending on the initial state of charge (SOC) and capacity of the battery (INL, 2008, p14). Level I is therefore currently used by many PHEV owners, mostly converted hybrid cars with an increased battery pack and a plug.

The lengthy charging on a level I outlet will likely convince most consumers to choose for higher voltage charging with full electric vehicles; a level II charge. Level II charging is specified by SAE up to 240V and a current of 12A to 80A, and is expected to charge cars fully in about 4 to 8 hours. The higher voltage ratios are already widely applied in many homes in the US for electric clothes driers, electric ovens, or well pumps. Level I and level II charging are standardized by the SAE, but a level III charging standard is yet to be announced. Many refer incorrectly to the fast chargers as level III chargers, as the type of current that is used will be different from level I and level II charging. Direct current will be the preferred type of current for fast charging in the future (Botsford & Szczepanek,

<sup>36</sup> California Energy Commission - Electric Vehicle Charging Equipment Design And Health and Safety Codes. Available online at: [http://www.energy.ca.gov/papers/98-09-23\\_KATELEY.PDF](http://www.energy.ca.gov/papers/98-09-23_KATELEY.PDF). Accessed 26 February, 2011.

<sup>37</sup> Only for level I and level II charging. See section 4.3 for an elaboration on level charging.

<sup>38</sup> National Electrical Manufacturers Association



2009, p2), which is divided in another confusing three levels.<sup>39</sup> Designed for commercial applications, these chargers range from 30kW to 90kW. Even faster chargers are under development, making charges possible in less than 10 minutes. An overview of the charging levels is shown in table 1.

Types of charging AC/DC	
AC (alternating current) charging	DC (direct current) charging
<i>Level I *</i> <i>120 V – single phase – 12; 16Amp – 1.44; 1.92kW</i>	Level I 200-450V – ≤80 Amp – ≤19.2kW
<i>Level II *</i> <i>240 V – single phase – ≤80Amp – ≤19.2 kW</i>	<i>Level II (fast charge)</i> <i>200-450V – ≤200 Amp – ≤90kW</i>
Level III TBD ** - single/three phase	Level III 200-600V – ≤400 Amp - ≤240kW

**Table 1 Overview of charging levels for AC and DC charging. The charging levels in italics represent the most suitable charging levels for commercial use in the near-term future. Source: Presentation by SAE J1772 task force leader Gery J. Kissel (GM), at the Plug-in 2010 conference, San Jose, CA. (\*standardized by SAE; \*\* to be denounced).**

#### 4.4 Types of charging infrastructure

Several types of EVSE exist to charge electric vehicles. Electric vehicles are, due to current battery technology, dependent on more frequent use of charging/refueling infrastructure than gasoline cars. Making the introduction of electric vehicles successful requires therefore an increased effort in the development of charging infrastructure. To analyze how EV infrastructure exactly relates to the electric vehicle and expected use patterns, different types of charging scenarios are discussed in the sections below.

##### 4.4.1 Home charging

Especially in the early stages of introduction, charging electric vehicles is generally believed to occur at owners' homes. (DoT, 2010; EPRI, 2010, p5) Most vehicles are parked overnight at homes, which provides plenty opportunity to charge the battery pack of the vehicle with charge levels required. Although level I charging is the most economic option for EVSE installation, most consumers will prefer the convenience of a level II charger in their homes (EC, 2009). For US citizens, the installation of level II charging equipment means the requirement of a 220V outlet in their garages or shelters. This installation is an additional cost to the electric vehicle. Estimates on charging station installation at home suggest an average of \$878,- for a level I installation and \$2,146,- for a level II installation (INL, 2008). A great concern related to home charging is the fact that every household is required to have access to a dedicated parking space. According to many experts in the field, this could mean a significant impediment to electric vehicle adoption in urban and other densely populated areas (PlaNYC, 2010).

##### 4.4.2 Public charging

Public charging infrastructure entails the EVSE in public spaces, which could be available to anyone owning an electric vehicle and optionally free of charge. The Electrification Coalition (2009, p94) identifies two reasons why public charging is evenly and arguably even more important than home charging infrastructure for moving past the early stages of electric vehicle development. The first factor of importance is that drivers are used to the ubiquitous network of gasoline fueling infrastructure which has been set up over the last 100 years. By lack of an electric vehicle charging infrastructure, the inability to 'fuel up' the vehicle virtually anywhere creates hesitancy for most consumers in venturing out with an EV and even acquiring an EV. This hesitancy was referred to by some of the EV1 drivers as 'range anxiety'. Range anxiety entails the 'continual concern and fear of becoming stranded with a discharged battery.' (Tate *et al.*, 2008).

<sup>39</sup> Presentation by SAE J1772 task force leader Gery J. Kissel (GM), at the Plug-in 2010 conference, San Jose, CA.



The other factor is that the absence of the public infrastructure will lead to an increased charging load on the electricity network in the evening. Testing by the Idaho National Laboratory largely confirms that charging tends to increase in the hours between 6pm and 10pm (INL, 2008). Concentrating charging in a few hours will put an increased strain on the network, particularly at the local distribution (transformer) level.

#### 4.4.3 Battery swapping infrastructure

Battery swapping stations offer an option for electric vehicle recharging in which the owner does not own the battery. Consumers drive to swapping stations where the depleted battery is exchanged for a fully charged battery in less than a minute.<sup>40</sup> The Silicon Valley based Better Place company is the well-known example of this model. Although Better Place has generated substantial interest from venture capital companies, its business model is fairly debated among critics in the field of electric vehicles. Electric vehicle interest group Plug-in America for example does not regard the battery swap stations a viable solution for the short term future.<sup>41</sup> The company however has been fairly successful in drawing over \$700 million in investment capital, and ordered over a 100,000 Renault Fluences for their projects.<sup>42</sup> Despite these vast investments, it seems that much more investment is needed to facilitate a country as vast as the US.

Battery swapping may be a successful in longer term future scenario, but consumers now are likely to be reluctant to switch batteries with strangers because they do not have full knowledge about the history and current condition of the battery (Brown *et al.*, 2010b). Most importantly according to the critics on battery swapping is that there would not exist a large need for this type of service. Instead, consumers might choose to charge their vehicle at home with a level I or a level II charging system. Auto manufacturers have expressed their concerns about battery safety, warranty and design homogenization/standardization (Brown *et al.*, 2010b). Nissan will not include a battery swap option in their new LEAF as they currently do not regard it a viable option for recharging.<sup>43</sup> As well, battery compatibility is fundamental to the concept and there is no industry-wide standard yet for battery type, make or model.

### **4.5 Advanced charging scenario's**

#### 4.5.1 V2G and V2H technology

Vehicle-to-grid (V2G) technology allows electric vehicles to both draw electricity from and return electricity to the grid. Ideally, owners of electric vehicles would recharge their vehicles during off-peak hours and in case the vehicle is not used during peak hours, the electricity stored in the battery would be send back into the grid. This technology could provide a broad array of advantages and opportunities to both electric vehicle owners as well as utilities (Guille & Gross, 2009). Vehicle owners may save money on their electricity bill by buying electricity off-peak and returning it when price levels are high. Utility companies are eager to implement V2G technology as it may reinforce grid stability and lower power generation during peak hours.

Furthermore, V2G technology may allow utility companies to increase their use of intermittent renewable energies, such as wind and solar. However, V2G technology is in its very early stages of development and needs extensive testing and piloting before it can be applied on a large scale. Furthermore, it is uncertain how the technology will be accepted by the general public and how actual use patterns will evolve. According to some experts, vehicle-to-home (V2H) technology is therefore likely to be successful in a shorter term, as the technology operates independently from the utility company and can already manage energy flows within the home effectively.<sup>44</sup>

#### 4.5.2 Inductive charging

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<sup>40</sup> According to Shai Agassi, CEO of Better Place, latest developments make it possible to swap a battery in 59.1 seconds. Opening speech Open House Better Place, Palo Alto, July 13, 2010.

<sup>41</sup> Interview with Plug-In America Director Marc Geller, San Francisco, March 8, 2010.

<sup>42</sup> Better Place runs several projects around the world in countries including Australia, Japan, Israel, Denmark China and North America.

<sup>43</sup> Based on statements in panel discussion with Senior Vice President Minoru Shinohara of Nissan, at the 2010 SAE World Congress, Detroit. April 13, 2010.

<sup>44</sup> Interview with Pacific Gas & Electric (PG&E) Manager Clean Air Transportation Dan Bowermaster, San Francisco, June 29, 2010.

Inductive charging uses magnetic fields to transport electricity to recharge electric vehicles. The plug and receptor do not have to make physical contact, making it possible to recharge through pavement based charging systems along roads or designated highways and in public and private parking spaces. However, costs and practicality currently make inductive electricity charging at this moment somewhat unrealistic (Brown *et al.*, 2010b).

#### 4.6 Home vs public charging

Electric vehicle owners will have the option to charge their electric vehicle at home or at a public charging infrastructure. The actual proportion of the charging events that will occur at home is uncertain and currently subject of extensive research efforts. The charging preferences of consumers will determine the actual use of home EVSE versus public EVSE. The Electric Power Research Institute (EPRI) has recently finalized a study to determine the expected charging behavior and preferences among consumers. The findings of a survey employed under residential customers of the Southern California Edison (SCE) utility company indicate that almost all (95%) consumers expect to charge their PHEV at home. Charging at home during the night is preferred by the majority of consumers, as they feel it is most conducive to their lifestyle and they expect the electricity to be cheaper (EPRI, 2010, p2-10).

However, there are concerns about the availability of public infrastructure when EV-owners will venture out with an electric vehicle. Particularly when consumers are planning a long trip, they want to be assured that there will be fully operational charging stations along the way when they want to charge their vehicle (EPRI, 2010, p2-15). Most of the respondents surveyed in the study by EPRI are expecting to charging stations will have to be available along the freeway as frequently as gas station locations. Therefore, installation of public charging EVSE will be needed, although it will be likely that the service will be used as an extra resource to EV owners if an extra charge is needed along the way or during stopovers, thus, as an addition to home charging.

Public charging will differ significantly from home charging in terms of speed of charge. For private and office use, slower charge EVSE will be preferred as time allow ample charging possibility and cost will be an important factor in acquisition of the charge equipment. Figure 8 shows the relation between the location and the speed of charging. Public charging infrastructure is likely to charge batteries faster, especially in locations where consumers do not have or want to wait.<sup>45</sup>

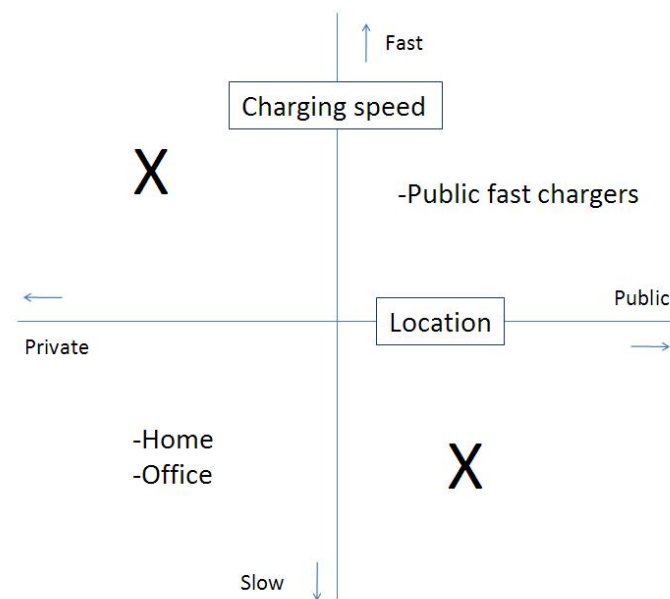


Figure 13 Charge speed and related type of EVSE. From: TEPCO presentation Takafumi Anegawa.

<sup>45</sup> Presentation Takafumi Anegawa Tokyo Electric Power Company (TEPCO Aoki at the at the Plug-in 2010 conference, San Jose, CA.

Due to the longer charging times than conventional vehicles and the lack of a pervasive electric vehicle infrastructure, consumers will be more aware of the battery status in their vehicle while driving an electric car. Since charging an electric car also takes longer than refueling a gasoline car, consumers have to adapt to a new fueling/charging behavior. Driving an electric car will therefore involve more upfront planning as drivers do not want to run out of electricity or wait for charging along the road.

#### 4.6.1 Choosing locations for public charging infrastructure

Public charging infrastructure will offer consumers to charge their electric vehicles away from home. Conventional fuel stations such as gasoline stations, are not considered good locations for charging points as charging will take longer than most people want to wait.<sup>46</sup> However, commercial locations and areas where people linger, such as restaurants, hotels, shopping malls, churches and entertainment venues - are considered more promising locations for installation of EVSE. For many businesses, installation of an EVSE at their venue could constitute an interesting business case in order to attract customers and increase profits. For example, while charging their electric vehicle at the parking lot, customers could be tempted to shop or dine (such as an extra cup of coffee after dinner) a little bit longer just to top off their batteries.

#### 4.6.2 Market models

Many pioneering EV infrastructure companies in cooperation with utilities are offering power to charge electric vehicles free of charge at public EVSE, either because they want to encourage early adopters or because they simply have not yet figured out how to collect payments from consumers. Regulating authorities are investigating a regulation framework in which utilities are able to provide electricity to infrastructure companies and their related business models. In prospect of the regulation prepared by these authorities, several business models are currently under study by infrastructure companies to find the best possible way to fund the installation of the public charging network. Until now, a profitable business model has not been reliably demonstrated that would encourage anyone in the private sector to invest in the installation of a public charging infrastructure network. In order for electric vehicles to be economic, the charging of their vehicles should be inexpensive. The availability of home charging stations to EV owners places an upper limit on what consumers will be willing to pay – so what private entities could charge – for public charging on a regular basis. Until now, public EV infrastructure projects executed by companies such as Coulomb Technologies, ECOtality and AeroVironment are funded largely by government investments.

#### 4.6.3 Charging in urban areas

The deployment of electric vehicle infrastructure in urban areas is a challenging task for federal and local authorities. The planning, permitting and installation of public charging infrastructure requires extensive coordination efforts and financial investments. These investments are crucial to the large scale adoption of electric vehicles in urban areas. Public charging infrastructure becomes even more important in urban areas as many new EV-owners are dependent on public charging poles because they do often not have access to a dedicated (private) parking space. Research by New York City (2010) on EV adoption showed that early adopters did not express a strong need for public charging infrastructure throughout the city but do have a strong requirement for dedicated charging where they park their vehicle for the longest duration - at home, whether that is in a personal garage or driveway, or at a commercial garage.

Residents in urban areas are more dependent on charging stations in public spaces due to space and price constraints. Two types of EV parking places in public spaces can be distinguished in urban areas. The first sort of parking assignment is a public charging infrastructure parking spot dedicated to any electric vehicle. Any EV-owner can park and charge his electric vehicle, until now often free of charge and up to a limited amount of time. A less conventional parking assignment is a private EV parking spot in public space. As indicated by the New York City study (PlaNYC, 2010), the need for these dedicated EV parking spaces is high; early adopters desire a guaranty on availability of charging

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<sup>46</sup> The Wall Street Journal, June 16, 2010 – California's costly Electric Car push - <http://online.wsj.com/article/SB10001424052748703513604575310702985839306.html>. Accessed August 6, 2010.

equipment when arriving home from work. If not available, the car will not be charged for the following workday and this will likely imply unacceptable consequences to potential EV-owners. Until now, local authorities in the US and the Netherlands have not engaged in assigning private parking places to new EV-owners in public spaces in the city.

Furthermore, for a large part of the early adopters of the New York City study, the ability to avoid refueling at public stations will be one of the reasons to shift to an electric vehicle. Facilitating ‘home’ charging in urban areas remains a considerable challenge put to policy makers on EV development. Solutions include IT implementations, such as online reservation systems, multi-dwelling charging stations which increase availability per charging pole and assigning (paid per term or not) dedicated private parking spots. The other critical potential barriers that early adopters pointed out in relation to ‘home’ charging are the cost and complexity of the installation process: difficulties negotiating with garage operators in commercial and apartment garages to provide charging, and an overall lack of standardization in commercially-available charging equipment and plugs (New York City, 2010).

#### 4.7 Amount of public chargers

It is widely assumed that a vast network of public charging infrastructure is needed to satisfy consumer demand for refueling (Fontaine, 2008; EC, 2009). The network would mitigate the problem of range anxiety and make consumers more comfortable buying plug-in electric vehicles. Based on research performed by consultancy firm PRTM, the Electrification Coalition (2009, p127) claims that in early stages of adoption investment in public charging equipment will need to be more intense. Table 2 contains the assumed public charger ratios needed for electric vehicles over various scenarios. PRTM estimates that as consumers gain experience and comfort with vehicle reliability and state of charge, deployment of public charging infrastructure can be more targeted. As can be seen in the diagram, the number of public charging stations is expected to decrease in the decades after introduction.

Public charger ratios			
	2010	2020	2030
Expected Public Chargers per vehicle	2.0	1.5	1.0
Maximum Public Chargers per vehicle	2.5	2.0	1.5
Minimum Public Chargers per vehicle	1.5	1.0	0.5

Table 2 Expected public charger ratios. Source: EC (2009).

#### 4.8 The functional and psychological components of charging infrastructure

##### 4.8.1 The TEPCO/Aerovironment experiment

Recently, there have however been promising study results on the account of the deployment of public charging infrastructure. During the conferences and visits on electric vehicle topics, I came across a presentation on an interesting study conducted by the Tokyo Electric Power Company (TEPCO) in Japan. The study showed that the effects of public charging infrastructure are not such of practical matter but merely of psychological importance to consumers. In a following interview I had with the Group Head of Mobility Technology of TEPCO and head of the CHAdeMO association, Mr Takafumi Anegawa explained me more on the study. In the following sections this peculiar study on deployment of public fast charging infrastructure will be discussed.

In October 2007, TEPCO in cooperation with American infrastructure developer AeroVironment, started to record driving and charging behavior of a small group of TEPCO employees, driving a small fleet of electric vehicles.<sup>47</sup> The electric vehicles TEPCO used in their commercial business fleet were mainly used by technicians to attend meetings and service appointments within a TEPCO

<sup>47</sup> This experiment has been mentioned in literature (see Botsford & Szczepanek, 2009, p7), but for unclear reasons the research has never been published by TEPCO or AeroVironment.

service area (approx. 120 km<sup>2</sup>), demarcated by the orange line in the figures 9 and 10.<sup>48</sup> The employees were left free to take either a gasoline car or an EV to attend appointments. In the beginning of the experiment, TEPCO's commercial fleet of EVs charged primarily at the central facility of the company (the TEPCO-company logo at the right side in figure 9). These EVs traveled constrained routes and stops (the red arrows and dots) and returned typically with a very high SOC (State of Charge); often with more than half the available distance in the batteries. According to the study, the drivers stated that they were confident with the range listed by the vehicle, but always wanted a considerable amount of energy to be left in the batteries.



**Figure 14 Driving behavior before installation of the charger.** Source: TEPCO presentation Hiroyuki Aoki. Courtesy of the TEPCO company.

AeroVironment then installed a single fast charging station at the TEPCO facility (see the pink edged TEPCO logo in figure 10). The EVs in use, ten (10) Subaru's (R1e), had a range of 93 miles, but the drivers of the vehicles still rarely left the closest area of the charging station. Some of the drivers stayed within a ten mile range only. The cumulative driving mileage by October 2007 for the electric vehicles was 126 miles only. A second charger then was placed in March 2008 in the center of the service area (see the pink edged fast charger picture in figure 10) and this changed driving behavior significantly. Drivers ventured out much further over the whole service area and chose to take the electric vehicle instead of the gasoline car much more. The cumulative driving distance increased in 4 months to a staggering 915 miles; an increase of over seven times.

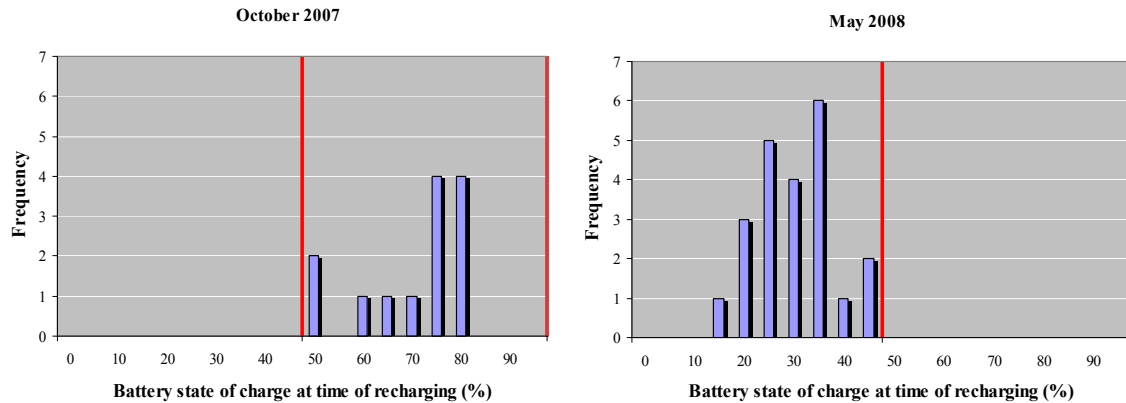


**Figure 15 Driving behavior after fast charger was installed.** Source: TEPCO presentation Hiroyuki Aoki. Courtesy of the TEPCO company.

<sup>48</sup> Interview with Mr Takafumi Anegawa, Tokyo Electric Power Company (TEPCO), Group Head of Mobility Technology, San Francisco/Tokyo, 24 June, 2010.



Most surprisingly to the researchers, the fast charger installed in the center of the service area did not attract drivers to charge their vehicles more. The fast charging station was only used 2 to 3 times a month but just knowing that the chargers were available made the drivers more comfortable driving further out. Figure 11 shows the differences in SOC of the electric vehicle before and after the installation of the fast charger in the service area.



**Figure 16 Battery state of charge (SOC) before and after fast charger installation. From: TEPCO presentation Hiroyuki Aoki.**

#### 4.8.2 The BMW mini E project (2009-2011) confirms TEPCO study results

Another experiment that has been initiated more recently on the implementation of electric cars confirmed the need and effects of deployment of public charging infrastructure. In a research project of car manufacturer BMW, over 500 Mini E cars were leased to the public. Sven Beiker, Executive Director of the Center for Automotive Research (CARS) at Stanford University has summarized the preliminary results of the BMW Mini E project (2009-2011) in a presentation at the PHEV research center at UC Davis University. The project, that is currently in progress in the three cities of Los Angeles, Berlin and London is monitoring the early experiences of new electric vehicle drivers.<sup>49</sup> Online surveys, (phone) interviews, blogs and facebook were used to collect data on driving behavior and customer response. Most households say they have completed 90-100% of trips in their Mini E. In Berlin, where public fast chargers were installed, the chargers were again, just as in Japan, seldom used, however, 80% of the interviewees in the survey alleged that they consider public charging infrastructure 'absolutely necessary'. Over 85% thereby agreed that they wished they could have a second charger at a different location.

The results of these studies become increasingly important as new EVs are currently entering the market. It confirms the notion that is already accepted among scientists and experts on infrastructure development; although charging will occur primarily at home, public charging stations confirm buying behavior and alleviate range anxiety for EV-drivers. It is even more interesting that usage patterns of public charging stations remain very low and electric vehicle drivers opt to charge at home instead. Hence, a developed public fast charging infrastructure is needed, especially in the early stages of electric vehicle development, in order to satisfy customer needs. While driving alternative fuel vehicles, such as EVs, drivers will continuously look out for refueling and charging options, to be sure

#### 4.9 Conclusion

As has been shown in this chapter, charging infrastructure is developing fast and definitive designs and standards are currently becoming dominant in the market. The challenges for policy makers now lie ahead in the deployment of a pervasive charging infrastructure. Especially securing home charging opportunities for electric vehicle owners in urban areas, where space and private garages are scarce, will be a challenging task for concerned authorities. Deploying public charging infrastructure

<sup>49</sup> Presentation available online at: [http://www.stanford.edu/class/me302/PreviousTerms/2011-02-15\\_CustomersMarkets\\_Turrentine.pdf](http://www.stanford.edu/class/me302/PreviousTerms/2011-02-15_CustomersMarkets_Turrentine.pdf). Accessed 13 May, 2011

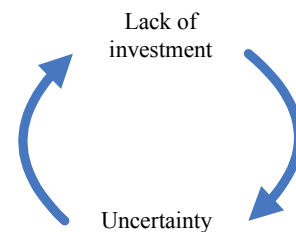
constitutes also a peculiar task as the costs, the set-up and the extra burden for electricity generation facilities are potential problem-makers. Battery swapping seems a viable solution for the long term future, but an expensive one, and not an instant solution for all markets.

#### 4.9.1 Lock-in factors of electric vehicle charging infrastructure: lack of investment & uncertainty

It is important to understand the role that electric vehicle charging infrastructure plays in the transition. The sunk investments of the existent infrastructure are often denoted as an important lock-in mechanism that hinder technological change (Grin *et al.*, 2010, p20). The stakeholders defend their businesses and their network of relationships with buyers, suppliers, and financial backers. However, the lack of investments in the competing infrastructure is also to be seen as an important lock-in factor that hinders technological change. From the analysis above (section 4.7), it remains clear that infrastructure investment in the early stages is vital to the success of EV adoption. This is especially important since gasoline fueling stations are not yet in direct competition with electric vehicle charging.

Also can be concluded from this chapter, is that another lock-in mechanism plays a significant role in the transition. This factor is the uncertainty -of course in general- but also specifically around EV infrastructure. As shown in this chapter, in current infrastructure development, there are still many uncertainties. These uncertainties entail standardization issues (in the US, but especially in Europe), the different charging scenarios (V2G, V2H, home charging, public charging, battery swapping and even inductive charging), the amount of charging facilities, the market model (payment methods) and the location where the infrastructure is to be deployed. These uncertainties hinder the progressive development of electric vehicles in the market, due to skipped investments and a lack of consumer confidence.

The two factors of costs and uncertainty are also interrelated. Uncertainty causes a lack of willingness to invest in infrastructure, and the lack of investment causes in turn more uncertainty (see figure 17). The vicious circle has much alike with the often denoted *chicken-and-egg problem* related with AFV infrastructure. This problem describes the reluctance of car manufacturers to introduce alternative fuel vehicles in the absence of supporting infrastructure and -similarly- the reluctance of fuel providers to invest in infrastructure when no such vehicles are available (van Bree *et al.*, 2010, p534). It has to be mentioned here as well that uncertainty and the question who the actual investor should be, also hampers the investment in infrastructure.



**Figure 17 Interrelation between the lock-in factors lack of investment and uncertainty**

It is obvious therefore that a progressive mentality towards deployment of both home and public charging infrastructure is needed to support the new generation of plug-in electric vehicles. Home charging stations remain essential as it will be used as the prime source of power to charge the battery pack. Faster public charging will thereby function as an additional means of power supply in case of emergency or during stop overs. It is now therefore of essential importance to invest in the deployment of charging infrastructure, to take away the uncertainties, -such as range anxiety- that surrounds electric vehicle charging infrastructure, as the new generation of contemporary electric vehicles are entering the market.

The TEPCO and BMW Mini E experiments have shown that public charging infrastructure relieves the electric vehicle driver from this range anxiety. Electric vehicle drivers are less hesitant in venturing out with their electric vehicle and drive further out. In addition, the use patterns of public charging infrastructure remain very low. Besides providing consumers extra electricity when needed, public charging infrastructure will function as a psychological aid to the early adopters of electric vehicles. If fast charging can affect the psychology of a set of fleet drivers (as in the TEPCO and BMW Mini E experiments), a system-scale EV fast charge infrastructure could enable the further wide adoption of

EVs. The existence of a fast charging infrastructure could be the key in creating consumer confidence and gain a large set of early adopters.



## 5 Conclusion

In chapter 1 and 2, it has been explained that the current transportation system is unsustainable due to the pollution caused and the dependency on finite fossil fuels. Current market shares of electric-drive vehicles such as hybrid electric cars indicate a trend towards electrification of personal transportation. Today's car industry takes on an important role in introducing new types and more efficient vehicles, also forced by stringent legislation on efficiency and pollution. These developments in the legislative and market environment cause initiatives in other levels of governments, sectors and markets; cities, utility companies and standardization committees are taking part in the preparation for the electric vehicle. However, as the electric vehicle market evolves, many challenges and uncertainties lie ahead in making the transition successful. Experts see obstacles in battery technology, the electric power sector (especially in the US), consumer acceptance and a ubiquitous charging infrastructure that has to be deployed.

In chapter 3, theoretical perspectives on transitions have been employed to account for the changes in the transportation system. Landscape pressures and some regime actors (which in fact have responded on landscape developments) have opened up 'windows of opportunity' for alternative fuel transportation modes. From a concise historic analysis we have learned how the *status quo* and lock-in of the transportation sector came to be by technological path dependency due to technical, socio-technical, cultural, and marketing factors. After several failed attempts to escape this lock-in, with its most recent example in the mid 90's, scholars have debated the conditions that are necessary to achieve lock-out for technology systems. Amongst others, Cowan & Hultén (1996) claim that six conditions for the electric vehicle are required to escape from lock-in, including technical, regulatory, economic, social and scientific factors. The conditions they propose have largely been met in today's industrialized countries. However, a technology that is preferred above others (in terms of long term social costs), would still require a system-scale charging infrastructure to support it.

In chapter 4, this role of the EV charging infrastructure in creating the preconditions for escaping the lock-in of the technological regime has been studied. The general (functional) properties of charging infrastructure show how the technology is currently embedded and envisioned by the experts in the transportation system. As the TEPCO and BMW Mini E experiments show, an important psychological factor is related to the deployment of public charging infrastructure. Drivers gain confidence in opting to drive and venturing out with an electric vehicle as public fast charging stations are installed, but usage patterns remain very low. Home charging stations will be used as the prime power supply equipment to the vehicle, with faster public charging stations providing an additional means of power supply. Concluding from the analysis done in this chapter, there are two (2) elements in charging infrastructure that add to the lock-in of the current transportation system. The first element is the uncertainty surrounding the infrastructure (which relates to where, when, who, how and how much questions). Secondly, a lack of investment hampers infrastructure development. These two elements are inherently related to each other; uncertainty causes a lack of willingness to invest in infrastructure, and the lack of investment creates in turn more uncertainty.

### 5.1 Functional and psychological features of public charging infrastructure

On the account of public EV charging infrastructure, we can distinguish two purposes of public charging infrastructure, namely one of functional and one of psychological importance. The functional component is of utilitarian nature; the infrastructure serves to charge and allows the consumer to drive the vehicle. It is thereby crucially important, as we have learned from the TEPCO/Mini E research projects, that the psychological purpose of deployed charging infrastructure should not be underestimated. The psychological component contributes to the conviction of the consumer in EV technology, as well as confirming the buying behavior and as a catalyst to venture more and further out with an EV. Hence, it reduces range anxiety, one of the most inhibiting factors in EV adoption.

As public charging infrastructure was not frequently used in the experiments after deployment, but *did* constitute a catalyzing factor in EV adoption and use, it should therefore not be worrying that installed infrastructure will not be used as frequently as home charging infrastructure. Hence, based on the previous assumptions the following conclusions are drawn, as below:

1. public EV infrastructure serves two purposes; one of functional and one of psychological importance;
2. public charging infrastructure increases consumer confidence and reduces range anxiety; it makes EV drivers venture more and further out with their vehicles
3. the psychological importance of EV charging infrastructure should not be underestimated; charging infrastructure primarily serves psychological rather than functional ends.

Hence:

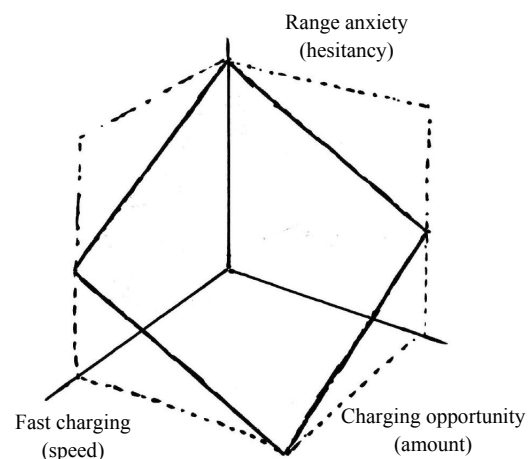
4. underutilization of public charging infrastructure should not be considered an 'adoption failure'.

### 5.2 Fast charging and range anxiety

As shown in chapter 4, the availability of charging infrastructure (*i.e. charging opportunity*) is closely interrelated with range anxiety. It is however possible to add another dimension to these posterior inductions.

A major difference with the EV wave during in the 90s, is the recent development of fast charging infrastructure. This type of charging has become commercially available in the last years to charge an electric vehicle within half an hour. The TEPCO and BMW Mini E projects have shown that fast charging increasingly reduced range anxiety and that it encouraged drivers to drive further and more often with their electric vehicle.

Range anxiety is therefore related to both the amount and the speed of charging infrastructure. This relation can be visualized by a surface in a three dimensional field (see figure 17). As charging opportunity and the speed of charging increases, so does range anxiety at the consumer level. This depiction is not intended to be an exact representation of the interrelations; quantitative analysis will learn us this, rather it shows how speed and amount of infrastructure work on range anxiety in principle.



**Figure 17. Overview of interrelations between range anxiety, charging opportunity and fast charging.**

Concluded can be the following:

5. range anxiety is related both to amount and speed of charging infrastructure; fast charging infrastructure accelerates consumer confidence, as charging opportunity increases

### 5.3 Transition vehicles

For places where public charging infrastructure is still absent, in vast countries as the US, the introduction of PHEVs and EREVs in the market attempts to address these issues. Also, they provide an alternative that is less removed from the norm. *Transition vehicles*, as I will propose them (plug-in

hybrids, and especially serial hybrids) can herein be key-players in closing the gap in confidence at the consumer level. Transition vehicles will presumably have more importance in areas where people travel longer distances, as in the US, as users will not be constrained by the range limitations of full electric vehicles. Transition vehicles, especially EREVs will make the EV user become familiar with electric drive technology, without fearing to suffer from range anxiety and independently from public charging infrastructure.

6. where EV infrastructure is still absent, transition vehicles will close the gap in consumer confidence, and win the market share

#### 5.4 Role of charging infrastructure

Hence, can the electric vehicle be successful due to the deployment of charging infrastructure? Yes, the charging infrastructure functions as a technological necessity to support EV technology, but is even so important as a catalyst in increasing consumer confidence in electric vehicle technology. Its success will not be dependent alone on infrastructure deployment; there are many other (e.g. regulatory, technological) issues that will have to be addressed also. However, besides its functionality, it seems plausible that current charging infrastructure could effectively stand in for other factors that have not been satisfied yet. Fast charging infrastructure could replace the perceived discomfort of the low and costly energy capacity of batteries.

Much has to be done and decided, and the options are numerous. Electric driving is an emerging domain and therefore new infrastructure technologies and opportunities are still developing and many possibilities are open. This situation restrains the transition speed. However, with the EV infrastructure opening up an escape possibility from the lock-in of the gasoline technology used in road passenger vehicles, indeed, a paradoxical new situation of lock-in could arise: the establishment of a battery-powered electric vehicle era.

## **6 Recommendations regarding the deployment of charging infrastructure in the Netherlands**

Building on the conclusion presented in chapter 5, a range of recommendations can be made with regard to the deployment of charging infrastructure in the Netherlands. This chapter will start of with an introduction on the efforts to promote electric vehicle development in the Netherlands. Consequently, the current situation will be concisely discussed on which further recommendations for a national fast charging infrastructure will be done.

### **6.1 Governmental efforts in the Netherlands**

In the Netherlands, considerable governmental efforts are made when it comes to promoting EV development. The central government's contribution to this ambition will mount up to €65 million. The central government supports all efforts by market parties, social organisations and local and regional authorities. That means that the national investment in this ambition will likely be larger. The government expects that the contribution will stimulate around €500 million in expenditures from others for electric driving (The Chairman of the Dutch House of Representatives, 2009). The central government's contribution consists of three main efforts:

- The establishment of a Formula E team, with robust and authoritative chairperson and members from all industries indispensable for the successful introduction and roll-out of electric driving. The team's primary task is to spur market development and remove obstacles.
- The central government will take practical measures in 2009-2011 on the following fronts: (a) Practical testing and demonstration projects, (b) launching customership, (c) recharging, energy and other infrastructure, (d) research, development and production of electric vehicles and/or parts for them, (e) formation of consortiums and coalitions and (f) ancillary policy.
- A market introduction facilitated, coordinated and phased in by the formula E team. That means programmatic work, based on the central government's action plan and that of other pertinent studies and action plans.

### **6.2 EV charging infrastructure development in the Netherlands**

In the Netherlands, one of the main coordinating bodies that are dedicated to the deployment of EV charging infrastructure is the foundation of E-laad.nl. E-laad.nl is an initiative of the collaborating network operators in Netherlands who are responsible for managing the electricity and gas network in the Netherlands. In order to determine how the electricity grid will be affected by large-scale electric vehicle implementation, it is important to understand what electrical drive for the Dutch electricity network is going to mean. Therefore e-laad.nl will put effort in recording charging behavior of early electric vehicle drivers. E-laad.nl places and maintains charging infrastructure at the request of local authorities and private entities. Figure 12 shows the 102 installed EV charging stations since October 2009 in the Netherlands. Their goal is to coordinate the installation of 10.000 charging stations.



Figure 19 EV charging stations installed in the Netherlands. As of 26 January, 2011. Source: E-laad.nl.

### 6.3 Developing a national network of fast charging infrastructure

Connecting the conclusions of this thesis to the current situation in the Netherlands, the efforts of e-laad.nl are certainly favorable to the development of EV adoption. However, a great deal of the charging infrastructure that e-laad.nl installs is public charging infrastructure, in use by a private electric vehicle owner. This means, that an electric vehicle owner will have to depend on a *de facto* public charging infrastructure equipment. Theoretically, an EV owner could return from work at the end of the day and find the station – that was installed upon his request – occupied by another vehicle. This scenario will not be very likely, as the charging speed of these stations will be still relatively low and the visiting driver would need to wait a substantial period to recharge the vehicle. (Charging the vehicle could take between up to 8 hours.)

However, the above scenario could lead to hesitancy for potential buyers to acquire an electric vehicle. Therefore, public charging infrastructure would be needed that charges the vehicle fast, and will be readily accessible to the public; *i.e.* independent from a vehicle owner. A national network of fast charging infrastructure could solve this problem. As the TEPCO/AeroVironment experiment in Japan showed, the installation of fast chargers will make EV drivers more comfortable in venturing out with an electric vehicle. A suggestion for a network of fast chargers in the Netherlands is depicted in figure 13.





**Figure 20 Suggestion for a national network of public fast charging infrastructure.**

Installation of public fast charging stations could increase the burden for electricity generation companies during peak hours and consequently cause additional GHG emissions. However, the TEPCO experiment also showed that use patterns of these fast charge stations are expected to remain very low. For potential EV buyers and EV owners just knowing that public fast chargers will be available could make a substantial difference in the proposition of buying or driving an EV. Just by knowing that throughout the Netherlands charging opportunities are always 50km away, could make the electric vehicle a lot more attractive.

#### **6.4 Further recommendations on infrastructure development**

Based on the knowledge and experiences on electric vehicle development in California, I hereby propose several further recommendations for deploying infrastructure in the Netherlands. The following measures could be proposed for implementation analysis:

- Prepare for necessary proceedings after the release of the EU standardized plug
- Increase competition (within governmental capabilities) in home and public infrastructure market
- Concerning home charging infrastructure:
  - o Develop a fully integrated national home charging installation framework
    - Develop a simple, fast and uniform national permitting process
    - Foster a fast installation process
  - o Prepare peak and off-peak tariff options for EVs
  - o Provide 'green' electricity options at installation (such as roof-top solar panel installation)
  - o Tackle the problem (on a national level) of no-garage owners (see: Urban charging Ch. 4)
  - o Tackle the problem (on a national level) of renters (see: Urban charging Ch. 4)
  - o Provide and incentivize home/building charging installation electrical service (*i.e.* provide no/low cost installation financed thru monthly utility bill)
- Concerning public charging infrastructure:
  - o Develop a national ubiquitous public fast charging infrastructure
    - Only a handful are needed for a big impact (see: TEPCO/AeroVironment example Ch. 4)
  - o Strategic placement of EVSE
    - Make use of information where HEVs are currently sold
    - Strategic locations for EVSE could be: shopping malls: IKEA/restaurants: McDonalds/Van der Valk/AC restaurants/Congested highways: A4/universities/libraries
  - o Place effort in uniformity and ease of use of public charging infrastructure
  - o Use internet for EVSE requests (*e.g.* eTec/EVproject<sup>50</sup> (see *Appendix I - Additional recommendations to the Netherlands*, section A.4.1))
  - o Advert to businesses, or set up incentives for businesses to buy fast chargers at their premises
  - o Establish free/discounted parking for EV at EVSE
  - o Request cooperation at the EU level in setting up a European EV charging infrastructure and GIS (Geographic Information System)

#### **IT/GIS (Geographic Information System) for public charging infrastructure**

- Encourage integration of IT and GISs into EV systems
- Foster the development of one single national/European GIS
- Foster the integration of the GIS in navigation devices and smartphone apps,
  - o Make registration of a public charger within the national GIS mandatory
- Set requirements to EVSE manufacturers about charge information communication to the EV owner
- Make EVSE location requests possible through GIS

<sup>50</sup> The Geographical Information System (GIS) of The EV Project offers a possibility to request EV charging infrastructure installation by submitting a location through the internet. See: <http://theevproject.com/charging-maps.php>. Accessed May 21, 2010.





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## Appendix I - Additional recommendations to the Netherlands

### A.1 Introduction

Studying electric vehicle development in the US has been instrumental in developing specific additional recommendations to the Netherlands in aiming focal interest. The recommendations that can be done on the basis of insights of the case in California are twofold: i) learning from best practices in the US and ii) focusing on opportunities for the Netherlands. Best practices are important sources of information regarding effectiveness of policies and infrastructure deployment and deserve system-scale attention. Important best practices that can be instructive to the Netherlands are: policies & regulations, exchanging EV experiences, infrastructure development and grid impact. The opportunities for the Netherlands consist of both opportunities to Dutch industries such as the supplier industry for electric vehicles as well as exploiting the achieved head start in electric vehicle development. It is recommended to keep track of the progress in specific industries in the US and California when it comes to electric vehicles: the US is most likely to lead the emergence of electric cars as a means of mass transportation according to research by McKinsey.<sup>51</sup> Closely following the developments in especially California is recommended, as the state is the initial market area of many electric vehicle car manufacturers. Much can be learned here from the impact of a few thousands car on the road and grid in the coming months.

### A.2 Learning from best practices – policies & regulation

A host of different policy measures exists to be implemented when it comes to stimulating electric drive vehicles (see *Appendix II – Policy options to be considered for the Netherlands*). The different policy measures range from incentives, regulations, requirements, tax alterations and many more. The effectiveness of these different policies may vary significantly, and offers therefore an extensive research site for public policy makers. There is much to learn from policies which have been effectively implemented by national and regional initiatives in the past. Therefore, exchanging experiences and learning from policy implementations undertaken in California is highly advisable. In the sections below, important stakeholders and their work in the field of policy and regulation will be discussed that could be of specific interest to the Netherlands.

#### A.2.1 California Public Utilities Commission (CPUC) - setting the rules of the game for EVs

The California Public Utilities Commission (CPUC) is the main regulating body for the public utility companies in California. The CPUC sets up and provides the regulation for utility companies which supply public services like water, gas and electricity. With regard to electric vehicle development they are expected to play an important role in setting up the framework in which electric vehicles are to be conceived. They are held responsible for essentially leading the process of establishing ‘the rules of the game’ for EVs, and, since this has never been done before, the results will likely serve as a template for other states and countries going forward.

The CPUC has divided the decisions to be made on the regulation in three phases. In the first phase decisions will be made on whether charging installation streamlining will be regulated and a review of capital costs for EV related infrastructure is expected to be announced. The decisions made over these regulations conclude phase 1 and start the phase 2, a consideration of rate design policies and direct charging management, separate metering for electric vehicles and utility costs recovery policy. The third phase entails issues the commission may not have decided upon until then, such as the need for separate residential meters, billing system upgrades, and any other matters.

The framework for EVs to be put in place by the CPUC is now in phases of development. The rulemaking that is being considered for electric vehicles by the CPUC entail:

- rate design options, including the potential for a statewide electricity rate for EVs;

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<sup>51</sup> Financial Times, August 9, 2010 - *US tops electric vehicle index*. Available online at: <http://www.ft.com/cms/s/0/4be512c0-a345-11df-8cf4-00144feabdc0.html>. Accessed August 12, 2010 (requires free subscription).

- vehicle incentives to encourage Californians to buy and operate EVs, including ratepayer funded incentive programs;
- options for development of metering and charging infrastructure for EVs;
- options to streamline permitting requirements and contractor installation of residential EV charging equipment; and
- options to incorporate EV charging with renewable energy supply, including, but not limited to, PV arrays over charging stations or off-peak charging that takes advantage of overnight wind resources expected in the utility resource portfolio(CPUC, 2009).

The chosen policy options on regulation decisions prepared by the CPUC could be educational in designing Dutch EV policies and regulation. Preparatory visits for knowledge exchange between the CPUC and Dutch policy makers & executives of utility companies are therefore highly advisable.

#### A.2.2 California Air Resources Board (CARB) - electrification through regulation

Regulations are clearly seen as one of the principal forces in the construction of an electric vehicle industry. The California Air Resources Board designs and implements regulation for the improvement of air quality such as green house gas emissions standards by the transportation sector. Their regulation on ZEV car manufacturers' sales quota is an important example of stimulation of electric transportation. Maintaining its original ZEV programs in the 1990s has been unsuccessful but its remainder, a moderate version, still remains an important impetus for an increasing number of (H)EVs on the road. Much can be learned about the effects of their progressive policies in the field of electric vehicle development.

### **A.3 Learning from best practices – exchanging EV implementation experiences**

#### A.3.1 US Department of Energy - Alternative Fuels & Advanced Vehicles Data Center and Clean Cities

Many local programs for the encouragement of electric drive transportation have been initiated in California and other states in the US. These initiatives often culminate in valuable best practices for other local (and national) authorities to be followed. The US Department of Energy (DOE) underscored the value of exchanging these experiences in the field of AFV implementation. The DOE has therefore put effort in setting up a data center on the use of alternative fueled transportation. The Alternative Fuels and Advanced Vehicles Data Center (AFDC) offers a comprehensive collection of data publications, tools and information related to advanced transportation technologies. Also, a collection of the different incentives and regulation on both federal and state level have been brought together and are available to anyone interested in AFV stimulus packages.<sup>52</sup>

A part of the effort by the DOE is the Clean Cities initiative. The program provides tools and resources as a government-industry partnership to government agencies and private companies to reduce petroleum consumption in the transportation sector. Almost 90 coalitions nation-wide have joined the Clean Cities initiative so far and build up an extensive knowledge base on AFV implementation and EV implementations.<sup>53</sup> Clean Cities offers assistance with setting up a coalition, funding of programs and providing experienced coalition contacts and coordinators. Clean Cities is more than willing to cooperate on an international level<sup>54</sup>, as they do already, and it would therefore be of great interest to the Netherlands to set up similar initiatives or exchange AFV (EV) experiences with US coalitions.

#### **A.4 Learning from best practices – infrastructure development & grid impact**

Infrastructure development will become one of the major focuses of interest around electric vehicle development in the near-term future. Much more is to be learned about the relationship between

<sup>52</sup> An overview of all current federal and state regulation on AFV stimulation can be viewed online at <http://www.afdc.energy.gov/afdc/laws/>. Accessed May 19, 2010.

<sup>53</sup> An overview of AFV experiences of over 90 - and counting – coalitions (city and corporate fleet managements) can be obtained through the Clean Cities website: <http://www1.eere.energy.gov/cleancities/>. Accessed May 19, 2010. For AFV fleet experiences: [http://www.afdc.energy.gov/afdc/fleets/fleet\\_experiences.html](http://www.afdc.energy.gov/afdc/fleets/fleet_experiences.html). Accessed May 19, 2010.

<sup>54</sup> According to Andrew P. Hudgins, project leader and Clean Cities representative at the National Renewable Energy Laboratory (NREL).

infrastructure and EV acquisition of potential EV buyers. Questions that will have to be answered involve matters like:

- How will charging occur at home? (Time/load)
- In what way do infrastructure development and the uptake of electric vehicles interrelate on a large scale?
- How many public charging stations suffice to alleviate range anxiety for the potential EV driver?
- How many people and how often will people charge at public charging stations?

Questions that will be raised are as well of a more practical matter, such as:

- How do utility companies cooperate at best with EVSE companies?
- Which processes are suitable for streamlining EVSE installation?
- How will the grid exactly be impacted and what metering possibilities work best?

Definitive answers to these questions are likely to be given only in learning-by-doing experiences. As not to invent the wheel twice, learning from the experiences and results of frontrunners in the field is highly recommended. The frontrunners in infrastructure development and grid preparation in California in this field are discussed in the sections below.

#### A.4.1 The EV Project

‘The EV Project’ is clearly a front running initiative in the field of electric vehicle development. According to the coordinating organization ECOTality, formerly known as eTec (Electric Transportation Engineering Corporation), it would be the largest deployment of electric vehicles and charge infrastructure in history.<sup>55</sup> The project was awarded \$99.8 million from the US Department of Energy to deploy up to 4,700 zero-emission electric vehicles (Nissan LEAF’s) and 11,210 charging systems throughout 5 states in the US. The EV Project was launched on October 1, 2009 and is expected to be completed on December 2012.

Besides coordinating the extensive rollout of EVs and EVSEs, The EV Project will collect and analyze data on vehicle use in diverse topographic and climatic conditions, evaluate the effectiveness of installed charge infrastructure and conduct trials of different revenue systems for commercial and public charge infrastructure. As indicated on their project goals overview, the ultimate objective of the EV Project is to take the lessons learned from the deployment of these first 4,700 EVs and the charging infrastructure supporting them, to enable the streamlined deployment of EVs nationwide. The expertise that is likely to be build up in this project will be extensive: the deployment of charging stations and vehicles, but also the coordination of these efforts. Some of the questions that will be answered in this project could be:

##### Charging stations

- Location – how are the correct locations chosen?
- Utilization - when and how long are they being used?
- Electric Utility impact – what will be the impact on the grid of home and/ vs. public charging EVSE?

##### Vehicles

- Utilization - how did vehicle use change over time?
- Behavior change - how did the behavior of drivers change?
- PHEV vs BEV - what differences were noted between the types of vehicles?

##### Planning

- Effectiveness - how did the process work in diverse locations?
- Structure - did the program differ significantly between sites?

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<sup>55</sup> ECOTality Press release - *ECOTality’s eTec awarded \$100 million for transportation electrification*. August 5, 2009.



- Transferability - how transferable is the process to other markets?

#### A.4.2 The City of San Diego and the San Diego Gas & Electric company

One of the five regions where the EV Project is initiated is San Diego, CA, home to the largest of the five regional projects.<sup>56</sup> eTec has announced it will work with the City of San Diego and San Diego Gas & Electric (SDG&E) and other partners on the roll-out of 1,500 public and commercial and 1000 home charging points across the county, starting in the second quarter of 2010. The goal is to prepare the charging infrastructure for the Nissan LEAF which will be sold in the city as one of the first areas in the US. The California Energy Commission (CEC) has awarded the city with an additional \$8 million in the aim to ensure that the region will be the first in the nation to become a 'plug-in' ready green area.

The San Diego Gas & Electric Company (SDG&E) will be the coordinator for the San Diego area for the EV Project to help pull together regional EV fleets that municipalities, universities, the military, the private fleets and others use daily. In their experience setting up this effort, SDG&E will assemble an extensive amount of information on charging infrastructure installation, metering, promotion of off-peak charging and making the vehicles compatible with smart meters and the smart grid which could be useful to similar agencies pursuing the same goals.

The output that the EV project will create by stimulating electrification of transportation will contain an extensive amount of information on EV deployment. Much can be learned from the large base of study material generated. Interesting study topics entail the private-public collaboration in setting up a large network of charging infrastructure, developing the script for application, the permitting processes and installation of home charge infrastructure. Therefore, advisable is a cooperation or knowledge exchange with the collaborative partners of the EV project such as eTec, the City of San Diego and the San Diego Gas & Electric Company with national and local stakeholders in the Netherlands. Parties that could participate in these exchanges could be utilities like Nuon or Essent, local institutions such as the City of Amsterdam or Den Bosch, or national similar initiatives.

The topics that could be included in the discussion with these organization are the following:

- set up of customer support (call center, dynamic website etc.)
- customer outreach (EV events, PR/Media preparedness, program specific areas)
- internal support (EV team, multi-sectors of company, smart grid, rates, commercial and industrial, etc.)
- regional coordination/outreach (permitting, municipalities, public access site selection process)
- mechanics (field support personnel training, meters, etc.)

#### **A.5 Opportunities for the Netherlands**

Several opportunities for the Netherlands exist when it comes to electric vehicle development in the future. As the Netherlands goes driven on electric vehicle development, it should utilize the expertise that is being build up. Also for the supplier automotive industry there are several opportunities to take advantage from.

##### A.5.1 Exploiting the headstart in EV development

The Netherlands currently build extensive experiences and knowledge in charging infrastructure deployment, and should stay ahead in electric vehicle development, continuing to learn from encountered dead-ends and successes. The Netherlands has an advantage for nationwide EV deployment due to its favorable geographical dimensions. The relative short distances within and between cities, relatively short commutes to work (average aprox. 20 miles) in combination with a

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<sup>56</sup> Other regions include Seattle, Portland, Phoenix/Tucson, and Chattanooga/Knoxville, Tennessee.

robust power supply network are considered important factors for successful in EV introduction (Federal Action Plan for Electric Driving, 2009). Exploiting the head start which has been achieved through expertise in the last years on EV incentives and EV infrastructure deployment, the emerging electric vehicle (infrastructure) market could offer interesting business opportunities to the Netherlands.

#### A.5.2 Netherlands supplier industry, battery and charging technology

Although the Netherlands does not have a large automobile industry, it does have a major components industry and a large supplier potential. With regard to the electric vehicle this could mean the infrastructure, battery and electromotor industry. With regard to business opportunities with the US, it should be noted that California offers a large research & development industry in electric vehicle technology.

#### **A.6 Conclusion**

Learning from best practices in California and focusing on opportunities for the Netherlands are the key recommendations to the Netherlands. Important best practices that can be instructive to the Netherlands are in the following fields: policies & regulations, EV experiences exchanges and infrastructure & grid development. Several organizations in California can be visited that could provide invaluable expertise knowledge on fostering electric vehicle developments. These organizations include regulating authorities, governmental organizations, infrastructure and utility companies, and many others. The opportunities for the Netherlands consist of both opportunities to Dutch industries such as the supplier industry for electric vehicles as well as exploiting the achieved head start in electric vehicle development. The US is most likely to lead the emergence of electric cars as a means of mass transportation<sup>57</sup>. It is therefore recommended to keep track of the progress in electric vehicle developments in the US and California. Since California is the initial market area of many electric vehicle car manufacturers, much can be learned there from the impact of the few thousand cars that will arrive on the road and the electricity grid in the coming months.

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<sup>57</sup> Financial Times, August 9, 2010 - *US tops electric vehicle index*. Available online at: <http://www.ft.com/cms/s/0/4be512c0-a345-11df-8cf4-00144feabdc0.html>. Accessed August 12, 2010 (requires free subscription).

## **Appendix II - Policy options to be considered for the Netherlands**

A broad array of different policy measures have been opted and/or implemented by federal, state and local authorities to stimulate the electrification of transportation in the US. Some of these measures could be specifically suitable for implementation in the Netherlands as well. In the following section a collection of these measures is given for analyses to implementation in the Netherlands. In some cases the measures have been transcribed for implementation in the Netherlands.

The measures, which are recommended for *implementation analysis*, are divided in 5 different groups. The general measures are limited to mostly federal level decisions, preparing nationwide adoption of electric vehicles. The EV ownership-measures are to promote the uptake and increased acquisition of EVs while infrastructure-measures entails the increased effort in EV charging infrastructure development. As Information Technology (IT) is becoming increasingly important and entrenched in almost every aspect of today's society, policy measure recommendations are focused on a geographical information system (GIS) to provide location and usage information of charging infrastructure. Education increases awareness and understanding of EV technology which are fundamental to a broad scale adoption.

### General

- Confirm roles & responsibilities stakeholders
  - o Enforce pro-active role utilities
  - o Enforce pro-active role cities
  - o Regulate by law the EV preparations to be done by utilities and regional authorities
- Implement long term predictable policies
  - o Stricter emission regulations
    - Towards HEV baseline emission regulations
  - o Increase tax on gasoline car fuel, ownership and purchase; consider 'feebates'<sup>58</sup>
  - o ZEV sales quota for car manufacturers
  - o ZEV quota for governmental organization fleets
- Investigate residual value of used large format automotive batteries
  - o Establish a guaranteed residual value
  - o Review existing regulations on vehicle warranties
- Commit /fund governmental organization fleet purchases
- Incentivize university/business/city fleet purchases
- Prepare/adapt building codes for fast/eased installation

### EV ownership

- Establish free/discount parking for EVs (independent of EVSE)
- Relief tax on purchase and ownership of EV and EVSE
- Discount on electricity for EVs
- Tackle the problem of metering (at the vehicle, EVSE or utility meter)
- Consider alternative incentives for EV ownership
  - o HOV lanes
  - o Favorable grants or loans for EV purchase
  - o Stimulate discount on car insurance
- Prepare for necessary proceedings after the release of the EU standardized plug

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<sup>58</sup> For more information see: Gordon, D., Levenson, L., 1989. Drive +: A Proposal for California to Use Consumer Fees and Rebates to Reduce New Motor Vehicle Emissions and Fuel Consumption. Applied Science Division, Lawrence Berkeley Laboratory, Berkeley, CA, July, p. 131.

- Increase competition (within governmental capabilities) in home and public infrastructure market
- Concerning home charging infrastructure:
  - o Develop a fully integrated national home charging installation framework
    - Develop a simple, fast and uniform national permitting process
    - Foster a fast installation process
  - o Prepare peak and off-peak tariff options for EVs
  - o Provide 'green' electricity options at installation (such as roof-top solar panel installation)
  - o Tackle the problem (on a national level) of no-garage owners (see: Urban charging Ch. 4)
  - o Tackle the problem (on a national level) of renters (see: Urban charging Ch. 4)
  - o Provide and incentivize home/building charging installation electrical service (*i.e.* provide no/low cost installation financed thru monthly utility bill)
- Concerning public charging infrastructure:
  - o Develop a national ubiquitous public fast charging infrastructure
    - Only a handful are needed for a big impact (see: TEPCO/AeroVironment example Ch. 4)
  - o Strategic placement of EVSE
    - Make use of information where HEVs are currently sold
    - Strategic locations for EVSE could be: shopping malls: IKEA/restaurants: McDonalds/Van der Valk/AC restaurants/Congested highways: A4/universities/libraries
  - o Place effort in uniformity and ease of use of public charging infrastructure
  - o Use internet for EVSE requests (*e.g.* eTec/EVproject<sup>59</sup> (see *Appendix I - Additional recommendations to the Netherlands*, section A.4.1))
  - o Advert to businesses, or set up incentives for businesses to buy chargers at their premises
  - o Establish free/discounted parking for EV at EVSE
  - o Request cooperation at the EU level in setting up a European EV charging infrastructure and GIS (Geographic Information System)

#### IT/GIS (Geographic Information System) for public charging infrastructure

- Encourage integration of IT and GISs into EV systems
- Foster the development of one single national/European GIS
- Foster the integration of the GIS in navigation devices and mobile phone applications,
- Set requirements to EVSE manufacturers about charge information communication to the EV owner
- Make EVSE location requests possible through GIS

#### Public awareness & education

- Take away confusion about general misunderstandings on EVs
- Develop commercials and advertisements to promote electric driving
- Accentuate the healthy clean city air aspect of EVs
- Place signs directing to public chargers

<sup>59</sup> The Geographical Information System (GIS) of The EV Project offers a possibility to request EV charging infrastructure installation by submitting a location through the internet. See: <http://theevproject.com/charging-maps.php>. Accessed May 21, 2010.

- Improve recognizability of EVSE
- Set up demonstration projects and EV-events

### Appendix III – EV overview in CA/US as of 10/2010

#### FEVs by established manufacturers (to be launched in the US)

Brand	Model	More information:
Audi	e-tron	<a href="http://www.audiusanews.com/newsrelease.do;jsessionid=30018BF2C1A63DFB5A64C5EFEB19CC05?id=1517">www.audiusanews.com/newsrelease.do;jsessionid=30018BF2C1A63DFB5A64C5EFEB19CC05?id=1517</a>
BMW	Mini E	<a href="http://www.miniusa.com/minie-usa">www.miniusa.com/minie-usa</a>
BYD	e6	<a href="http://www.byd.com/showroom.php?car=e6">www.byd.com/showroom.php?car=e6</a>
Chrysler	Dodge Circuit	<a href="http://www.chryslergroupllc.com/?redir=cllc">www.chryslergroupllc.com/?redir=cllc</a>
Citroen	C-Zero	<a href="http://www.electric.citroen.com">www.electric.citroen.com</a>
Daimler	Smart ED	<a href="http://www.daimler.com/dccom/0-5-1189740-1-1194078-1-0-0-1193782-0-0-135-876574-0-0-0-0-0-0-0.html">www.daimler.com/dccom/0-5-1189740-1-1194078-1-0-0-1193782-0-0-135-876574-0-0-0-0-0-0-0.html</a>
Ford	Focus EV	<a href="http://www.thefordstory.com/green/ford-focus-electric-coming-soon">www.thefordstory.com/green/ford-focus-electric-coming-soon</a>
Honda	EV-N	<a href="http://world.honda.com/design/designers-talk/tms2009/ev-nl">http://world.honda.com/design/designers-talk/tms2009/ev-nl</a>
Hyundai	i10 Electric	<a href="http://gm-volt.com/2009/09/04/hyundai-i10-electric-car-unveiled/">http://gm-volt.com/2009/09/04/hyundai-i10-electric-car-unveiled/</a>
Mitsubishi	iMEV	<a href="http://www.mitsubishi-motors.com/special/ev">www.mitsubishi-motors.com/special/ev</a>
Nissan	LEAF	<a href="http://www.nissan-zeroemission.com/EN/LEAF">www.nissan-zeroemission.com/EN/LEAF</a>
Peugeot	iOn	<a href="http://www.peugeot.co.uk/about-peugeot/news/jul09-sep09/peugeot-electric-vehicle">www.peugeot.co.uk/about-peugeot/news/jul09-sep09/peugeot-electric-vehicle</a>
Renault	Fluence ZE, Kangoo, ZE, Zoe, ZE	<a href="http://www.renault-ze.com">www.renault-ze.com</a>
Rolls Royce	Electric Phantom	<a href="http://www.rolls-roycemotorcars.com">www.rolls-roycemotorcars.com</a>
Subaru	Stella EV, R1e	<a href="http://drive.subaru.com/Sum08/Sum08_News_R1e.htm">http://drive.subaru.com/Sum08/Sum08_News_R1e.htm</a>
Tata Motors	Indica EV	<a href="http://www.tata.com/media/releases/inside.aspx?artid=D8J398/KAjI=">www.tata.com/media/releases/inside.aspx?artid=D8J398/KAjI=</a>
Toyota	FT-EV, FT-EVII	<a href="http://www.toyota.com/concept-ftev.html">www.toyota.com/concept-ftev.html</a>
Volkswagen	E-Up!	<a href="http://www.volkswagen.com/vwcms/master_public/virtualmaster/en2/experience/messe0.html">www.volkswagen.com/vwcms/master_public/virtualmaster/en2/experience/messe0.html</a>
Volvo	C-30	<a href="http://www.volvocars.com/Pages/default.aspx">www.volvocars.com/Pages/default.aspx</a>

#### New-to-market FEV developers (worldwide)

BAIC	BE701	<a href="http://www.baihc.com/en/site/index.php">www.baihc.com/en/site/index.php</a>
Chery Automobile Co.	S18	<a href="http://www.cheryinternational.com/node/121">www.cheryinternational.com/node/121</a>
Coda Automotive	Santa Monica	<a href="http://www.codaautomotive.com">www.codaautomotive.com</a>
Commuter Cars	T600	<a href="http://www.commutercars.com">www.commutercars.com</a>
Detroit Electric	e63	<a href="http://www.detroit-electric.com">www.detroit-electric.com</a>
Ginetta Cars	G50	<a href="http://www.ginettacars.com/roadcar_range_details.php?id=1">www.ginettacars.com/roadcar_range_details.php?id=1</a>
Herpa Miniaturomodelle GmbH	Trabant nT	<a href="http://www.trabant-nt.de/367/en/home.aspx">www.trabant-nt.de/367/en/home.aspx</a>
Heuliez	WILL	<a href="http://www.heuliez.com/heuliez-electric/will.php">www.heuliez.com/heuliez-electric/will.php</a>
Lightning Car Company	GT	<a href="http://www.lightningcarcompany.co.uk">www.lightningcarcompany.co.uk</a>
Loremo	Loremo EV	<a href="http://www.loremo.com/englisch/index.htm">www.loremo.com/englisch/index.htm</a>

Myers Motors	DUO	<a href="http://myersmotors.com">http://myersmotors.com</a>
NICE & Fiat	Micro-Vett, e500	<a href="http://www.nicecarcompany.co.uk/e500.html">www.nicecarcompany.co.uk/e500.html</a>
Phoenix Motorcars	SUT, SUV	<a href="http://www.phoenixmotorcars.com">www.phoenixmotorcars.com</a>
Pininfarina Bollore	BLEUCAR aka B0	<a href="http://www.pininfarina.com/index/storiaModelli/Pininfarina-BlueCar.html">www.pininfarina.com/index/storiaModelli/Pininfarina-BlueCar.html</a>
REVA	NXG, NXR	<a href="http://revaglobal.com/">http://revaglobal.com/</a>
SABA	Carbon Zero	<a href="http://www.sabamotors.com">www.sabamotors.com</a>
SAIC	Roewe 750	<a href="http://www.saicmotor.com/english/xwzx/xwk/11568.shtml">www.saicmotor.com/english/xwzx/xwk/11568.shtml</a>
Tesla	Roadster Model S	<a href="http://www.teslamotors.com">www.teslamotors.com</a>
Think	O	<a href="http://thinkev.com/content/view/full/885">http://thinkev.com/content/view/full/885</a>
Venturi	Volage	<a href="http://www.venturi.fr/-Home-page-.html">www.venturi.fr/-Home-page-.html</a>
Wheego	Whip LiFe	<a href="http://www.wheego.net">www.wheego.net</a>
ATT R&D	Parade	<a href="http://www.attrd.com">www.attrd.com</a>
Green Vehicles	Triac, Moose	<a href="http://www.greenvehicles.com">www.greenvehicles.com</a>

#### **PHEV (to be launched in the US)**

AFS Trinity	Saturn Vue, XH-150	
Audi	Metroproject Quattro	<a href="http://www.automotoportal.com/article/audi-unveils-metroproject-quattro">www.automotoportal.com/article/audi-unveils-metroproject-quattro</a>
BYD	F3DM	
Jeep	Patriot	
Daimler/Mercedes	BlueZERO E-cell Plus	
Ford	Escape	
Hyundai	Hybrid Sonata, Blue Will	
Jaguar	SJ Sedan, SE roadster	
Suzuki	Swift	
Toyota	Prius PHEV	<a href="http://www.toyota.com/esq/">www.toyota.com/esq/</a>
Volkswagen	Golf	

#### **EREV (to be launched in the US)**

Fisker	Karma	<a href="http://karma.fiskerautomotive.com/">http://karma.fiskerautomotive.com/</a>
Chevrolet	Volt	<a href="http://www.chevrolet.com/pages/open/default/future/volt.do">www.chevrolet.com/pages/open/default/future/volt.do</a>
Jeep	Patriot	<a href="http://www.worldcarfans.com/109011116083/jeep-patriot-ev-revealed">www.worldcarfans.com/109011116083/jeep-patriot-ev-revealed</a>

#### **FCEV (to be launched in the US)**

Honda	FCX Clarity	<a href="http://automobiles.honda.com/fcx-clarity/">http://automobiles.honda.com/fcx-clarity/</a>
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#### **Specialized EV Companies, US**

AC Propulsion (eBox)	San Dimas	<a href="http://www.acpropulsion.com">www.acpropulsion.com</a>
Azure Dynamics Corporation	Oak Park,	<a href="http://www.azuredynamics.com">www.azuredynamics.com</a>

	Michigan	
Synergy EV Inc.	Monte Sereno	<a href="http://www.synergyev.com">www.synergyev.com</a>
EV of America Inc.	New Hampshire	<a href="http://www.evamerica.com">www.evamerica.com</a>
<b>Conversions, CA</b>		
3Prong Power	Berkeley	<a href="http://www.3prongpower.com">www.3prongpower.com</a>
eeVee Motors (Honda Civic)	Silicon Valley	<a href="http://eeveemotors.com/car.php">http://eeveemotors.com/car.php</a>
ElectraDrive	San Francisco	<a href="http://www.electradrive.net">www.electradrive.net</a>
Jungle Motors	San Juan Capistrano	<a href="http://www.junglemotors.com">www.junglemotors.com</a>
Luscious Garage (Toyota Prius)	San Francisco	<a href="http://www.lusciousgarage.com">www.lusciousgarage.com</a>
Operation Z	Northridge	<a href="http://www.operationz.biz">www.operationz.biz</a>
<b>Interest Groups</b>		
California Cars Initiative	Palo Alto	<a href="http://www.calcars.org">www.calcars.org</a>
Calstart	Richmond, Pasadena	<a href="http://www.calstart.org">www.calstart.org</a>
Plug-in America	San Francisco	<a href="http://www.pluginamerica.org">www.pluginamerica.org</a>
Plug-in Bay Area	San Francisco	<a href="http://www.pluginbayarea.org">www.pluginbayarea.org</a>
Utah EV Interest Group	Utah	<a href="http://groups.google.com/group/utah-ev-interest">http://groups.google.com/group/utah-ev-interest</a>
<b>Infrastructure</b>		
AeroVironment	Monrovia	<a href="http://www.avinc.com/ev_charging">www.avinc.com/ev_charging</a>
AVCON Corporation	Franklin, Wisconsin	<a href="http://www.avconev.com">www.avconev.com</a>
Better Place	Palo Alto	<a href="http://www.betterplace.com">www.betterplace.com</a>
ClipperCreek	Auburn	<a href="http://www.clippercreek.net/">www.clippercreek.net/</a>
Coulomb Technologies	Campbell	<a href="http://www.coulombtech.com">www.coulombtech.com</a>
Ecotality	Scottsdale, Arizona	<a href="http://www.ecotality.com">www.ecotality.com</a>
ETEC	Phoenix, Texas	<a href="http://www.etecevs.com">www.etecevs.com</a>
EVI (Electric Vehicle Infrastructure)	Auburn	<a href="http://www.bowzerbird.com/eviweb/index.html">www.bowzerbird.com/eviweb/index.html</a>
OpConnect	Beaverton, Oregon	<a href="http://www.opconnect.com">www.opconnect.com</a>
SolarCity	Foster City	<a href="http://www.solarcity.com">www.solarcity.com</a>
<b>Incubators</b>		



San Jose Redevelopment Center	San Jose	<a href="http://www.sjredevelopment.org">www.sjredevelopment.org</a>
San Jose Entrepreneur Center	San Jose	<a href="http://www.ecenteronline.org/home.htm">www.ecenteronline.org/home.htm</a>
Environmental Business Cluster	San Jose	<a href="http://www.environmentalcluster.org">www.environmentalcluster.org</a>
Electronic Transportation Development Center	San Jose	<a href="http://www.synergyev.com/synergy/autoshow/index.html">www.synergyev.com/synergy/autoshow/index.html</a>
San Jose State University Research Foundation	San Jose	<a href="http://www.sjsufoundation.org">www.sjsufoundation.org</a>
Cleantech Group	San Francisco	<a href="http://cleantech.com">cleantech.com</a>

### **Governmental Institutions**

California Air Resources Board	<a href="http://www.arb.ca.gov">www.arb.ca.gov</a>
California Energy Commission	<a href="http://www.energy.ca.gov">www.energy.ca.gov</a>
Department of Energy California	<a href="http://www.energy.gov/california.htm">www.energy.gov/california.htm</a>
Alternative Fuels and Advanced Vehicles Data Center	<a href="http://www.afdc.energy.gov">www.afdc.energy.gov</a>
Department of Transportation California	<a href="http://www.dot.gov">www.dot.gov</a>
Environmental Protection Agency California	<a href="http://www.epa.gov">www.epa.gov</a>

### **Local/public-private institutions**

Economic Development Center San Jose	San Jose	<a href="http://www.sjeconomy.com">www.sjeconomy.com</a>
Silicon Valley Clean City Association	Silicon Valley	<a href="http://www.svcleancities.org">www.svcleancities.org</a>

### **EV Weblogs/Media**

Coda Clearing the air weblog	<a href="http://blog.codaautomotive.com">blog.codaautomotive.com</a>
EV Weblog	<a href="http://www.evweblog.com">www.evweblog.com</a>
EV World	<a href="http://evworld.com">evworld.com</a>
Planet Better Place weblog	<a href="http://planet.betterplace.com">planet.betterplace.com</a>

### **Programs**

Air Quality Investment Program	South Coast Air Quality Management District
Alternative and Renewable Fuel & Vehicle Technology Program	California Energy Commission
Assembly Bill (AB) 2766 Motor Vehicle Registration Fee Program	California Air Resources Board
California Transportation Plan	California Department of Transportation (Caltrans)
Clean Air Vehicle Parking Program	City of San Jose, City of Santa Monica, Hermosa Beach, Sacramento, LAX
Clean Fuels Program	South Coast Air Quality Management District
Innovative Clean Air Technologies (ICAT) Program	California Air Resources Board
Mobile Sources Program	California Air Resources Board
REMOVE II Program	San Joaquin Valley Air Pollution Control District
Southern California Regional Plug-in Electric Vehicle Plan	Los Angeles

