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The Electric Car Controversy

A social-constructivist interpretation of the California zero-emission vehicle mandate

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Göteborg, Sweden 1998

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Abstract

This study focuses the socio-technical dynamics of the attempted re-introduction of electric cars in California. The underlying question is whether or not it is possible to open up an entrenched technological area as car technology, and achieve a radical change. With the perspectives of social constructivist approaches to technological change, this study examines how a large technological controversy was initiated by regulatory action of the air agency in California, the California Air Resources Board, how this controversy developed and stabilized, and how it was ended by the air agency and the auto industry.

Based on mainly secondary sources, the definitions that were established on electric cars and gasoline cars at the turn of the 20'th century are highlighted, thus showing the existence of two types of automobiles: the city car and the endurance car. The city car did not survive, and was not defined as being real car. Based on mainly primary sources, the recent electric car controversy is examined, suggesting that the air agency could not force the car industry to re-introduce the city car, and consequently the efforts were directed towards the development of more advanced batteries that could give the electric car a performance close to that of the gasoline car. It also display that electric car technology was enhanced due to the mandate. In ending the controversy, the agency, due to political forces, changed from 'command-and-control' to a 'partnership' strategy. The California Air Resources Board postponed the mandate (from 1998 to 2003), due to the fact that large volume production of advanced batteries was not expected to be in place by 1998. This regulatory relief removed the principal obstacle on behalf of auto manufacturers of not to accept mandated markets, and led General Motors to start to market their purpose built electric sports car by late 1996, and Toyota to promote electric- and electric hybrid car technologies. Thus car technology was re-opened.

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Göteborg, January, 1998
Hans Fogelberg

I. STUDY AND PERSPECTIVES

Introduction

In September 1990 California adopted a regulation that would force car manufacturers to sell zero-emission vehicles in the state by the year of 1998, and in subsequent years to follow, thus initiating a paradigmatic change in car technology by an attempt to revive the battery-only electric car. The impulse behind this rather radical move came from an awareness of the problems created by the use of cars, and of the important historical role of cars in American society, in combination with the projected increase of cars and miles driven in California; or in the words of automotive historian, James Flink:

> A lifestyle based on mass personal automobility first developed in Southern California, and nowhere in the world has mass motorization been more pervasive in its impacts.[1]

Problems with automotive air pollution were not expected by air agencies to be solvable in the long run within the realm of main-stream car technology. Something radical had to be done, or at least had to be started, and a zero-emission vehicle regulation was adopted. The regulation would have an impact on car technology, car use, and even on the very notion of what a "car" is — aspects and areas that have become entrenched due to the long history of integration of cars with society. The regulation started a large technological controversy over electric cars involving both public and private interests, and can thus be seen as a social experiment, with society as a full scale laboratory, for attempts to open up and achieve changes in areas which have been closed for a long time. At the conclusion of the controversy, the automotive industry was given additional lead time (until 2003) for the required introduction, whereas several manufacturers were to enter the market with electric cars even before 1998.

Using an historical account of the electric car, car-society relationships, and the technological controversy over the zero-emission vehicle mandate, this study attempts to address the following three issues: (1) how "open/closed" is car technology for societally induced changes

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[1]Flink 1990, p. 140.

and the *implementation of technology* that is radically new, and (2) what role do our notions and *definitions of technology* play? These aspects will be addressed through studying the zero-emission vehicle regulation in California as (3) a *controversy of technology*, approached through the perspectives of the history and the sociology of technology.

Below, the theoretical basis of this study and the three areas of focus will be briefly discussed.

The key concept of interpretative flexibility

With the perspectives of relationships of society and technology, we can explain changes in society with reference to technological factors and we can explain changes in technology with reference to social factors, or both at the same time as a process. But we cannot explain changes in technology with reference to technological factors only, i.e. the object under study does not explain itself, or expressed somewhat more abstractly; we should view the "working" or "non-working" of artefacts as explanandum and not as explanans.[2] That is a point of departure of this study, and it is one cornerstone of the social-constructivist approach to technological change. This means that the explanation of the success of the gasoline car and the failures of the steam and electric car, respectively, at the beginning of the 20'th century should be sought in the socio-historical circumstances that created (or did not create) these technologies, rather than within some internal logic of technology.[3]

Interpretative flexibility refers to the variety of views and claims actors articulate about a certain technology. For the artefacts of our daily life, we will usually find a very low degree of interpretative flexibility. We just use them without having to think much about what we are doing. And certainly this stability is needed for these artefacts to be produced in larger volumes. It would be hard to sell artefacts that consumers would not know how to use. To the extent that we can detect a low degree of interpretative flexibility we can also argue for technology having become 'socially constructed'. We 'know' what it is, what it should do; i.e. a

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[2]Bijker 1995, p. 75.

[3]The theoretical basis for this will be further elaborated below. Steam cars will not be a focus of this study.

stable, common-sense view has been established. This state is also called 'closed' or 'black-boxed'. However, common-sense views are not God-given, but have emerged from a situation with a much higher degree of interpretative flexibility, where technology has been much more 'open' for changes. Thus, for the purpose of this study, the concept of interpretative flexibility will be used to pinpoint and reveal how 'open' or how 'closed' technologies are for changes, and also for tracing the dynamics of these shifts from open to closed, and vice-versa.

Definitions of technology — why is the electric car so controversial?

As will be shown, views and expectations of the electric car have been rather constant over their one hundred-year history. At the turn of the century it was fairly evident to contemporaries that the gasoline car was to be preferred to steam and electric cars. All three technologies (gasoline, steam, electric) had been developed into functionally working devices, thus they had been successfully 'technologically constructed' (albeit they had very different technological properties). But what is also obvious is that they early on became 'socially constructed' in the sense that people's attitudes of appropriate car technology converged towards a multi-purpose vehicle, capable of both high-speed and long-range travel. The two decades before the turn of the century were characterized by a car technology in flux, with no established common use of cars, and even with a very different perception of street space as such. The first two decades of the century were, on the other hand, characterized by converging technology and converging views on what a car was, what it should be able to do, and where and when it should be driven. Thus the range of interpretations (i.e. the degree of interpretative flexibility) of the technology and the use of that technology decreased drastically during a short time period. Simultaneously, the opinions about the 'losers', the failed alternatives of steam and electric propulsion, were also cemented, and have since then been fairly constant. We "know" that lead-acid battery cars do not fulfil the requirements of a "car", since the notion of the car was integrated and constructed along with gasoline car technology. This is not only of academic interest. These notions of the inferiority of the electric car have accompanied battery-electric propulsion for a long time, being carried along within our car culture as 'ghosts' of the past. When the market for electric cars began to vanish, some manufacturers of electric cars attempted to establish it as a 'womens car'. This failed, but the notion of electric cars as being a somewhat less masculine became associated with the artefact. Today when we start to reconsider electric propulsion, we simultaneously have to reinterpret electric cars, and perhaps even reconstruct the notion of what a car is, what it should and should not do.

High volume production industries, such as car manufacturing, require a fairly stable market with different market niches. Within the perspective of this study, these niches must be considered to be very similar to each other. Therefore, the large car manufacturers probably either would, or could, fiddle with our notion of "the car" without being forced or encouraged. And, as will be shown in this study, the regulation that is to force car manufacturers to start manufacturing a vehicle that many do not regard as a "real" car, has definitely created some resistance. Car manufacturers try hard to build cars based on their market traditions and will therefore attempt to make electric cars as similar to gasoline cars as possible, whereas "new" car concepts are mostly found within the realm of the so-called start-up firms. However, these small firms which develop new types of vehicles and work on alternative vehicle technology usually lack the resources to implement large volume production.

Implementation of technology — a renaissance of the electric car?

In essence, a renaissance of the electric car requires a re-opening of the 'black-boxed' and closed technological area of automotive propulsion, followed by an at least partial closure including electric propulsion as a means of propelling a car. In this study of electric cars, the actor-world of electric cars in California and the rest of the U.S, as well as in Europe and Japan, seems to be quantitatively and qualitatively different from that of earlier attempts to introduce electric cars. The number of powerful social actors involved is larger than ever before, and the scope of activities is more fundamental and interrelated, thus creating a field of electric vehicle related activities that gives momentum to developments in electric car technology.

The question of whether or not the California initiative to introduce zero-emission vehicles will eventually succeed in re-opening the black box of automotive propulsion technology and establish a major and growing market for electric cars in California and elsewhere still remains and will not be made an explicit topic of this study. But what can be analysed are the ongoing processes that aim for this change in car technology. These processes relate to the role of the car in society, the degree of integration of car technology with society, and the possibility of influencing such technologies more than marginally and incrementally. In order to capture some of this complexity, the methodological approach to studying implementation will be twofold.

First, to focus on the specifics of the ongoing dynamics of the introduction of electric cars in California in order to enhance our understanding of how such processes can be initiated and influenced. It is evident that any technology needs the support of strong actors pursuing a future for that alternative, in order to be developed and to survive on the market. But very few of the theoretically possible technological options will find this support by social actors, regardless of how desirable or potentially feasible some might argue them to be. Here, one underlying assumption about technology is that we can never know anything for sure about the potentials of the 'un-tried' routes of technology, and that we therefore should avoid using judgements as *ex post* explanations of the success or failure of a technology. Instead, what must be explained is why actors tends to 'cluster' around certain technologies, while avoiding others. This clustering sometimes even happens before a technology has reached an early market, and in this sense, choices by actors have to be made on a rather weak knowledge base. This is especially problematic since technological alternatives are not something that we can store on a shelf, to be used whenever we think appropriate. Different alternatives have different properties, and therefore cannot be compared on equal grounds. But choices still have to be made by actors in order to make anything happen. So the question is therefore how we can understand the dynamics of these choices, an issue that will be briefly discussed in this study as a part of the outline of the processes that took place immediately before the zero-emission regulation was adopted. In that process choices on fuels resulted in a further consolidation of gasoline as the un-challenged liquid fuel for cars (at the cost of other liquid fuels and compressed natural gas), and left electricity as the only competitor to gasoline.

Second, to ask questions about the historical context of technological change, with the assumption that there might be "windows for change" under certain circumstances (i.e. situations when the rules of the game are temporarily altered due to macro-social changes that, by and large, are external to the discussion of electric cars). Earlier attempts to introduce electric cars have been undertaken during periods of warfare or other circumstances of oil shortage and concerns about energy conservation. During these periods, the electric car seems to have gained in relative strength in relation to the gasoline car. Domestic fuels tend to be investigated and reconsidered as an option for cars, thus car technology is in this way reopened for changes in areas that earlier were closed. In the case of California there are several salient societal concerns at hand. On the federal level (as well as at state level), energy supply for the transport sector (i.e. oil) is an increasing concern since the availability of oil within the U.S. does not seem to be sufficient for the projected future demands of that sector. Electric car technology, perhaps in combination with combustion engines, so-called hybrid electric vehicles, is being pursued as a key area of technology for reducing oil-consumption by cars in the U.S. of the future.

Environmental concerns and health related issues are two other areas that have at times incited increased interest in electric cars. In the recent controversy over electric cars in California, health concerns served as the main driving force. The agencies responsible for maintaining federal standards of air quality do not consider it possible to meet these standards with gasoline car technology in the long run. Air emission regulations in California are the world's toughest, and draw on both a public and a political discussion where health and environmental issues are high on the political agenda,[4] but also on the strong regulatory framework of the federal Clean Air Act, which has its roots back in the 1970's.

In this way, concerns about public health, environment and energy conservation have served as the background for what was to be a technological controversy over electric cars. But as soon as the pressure on society is relieved, the electric car tends to be abandoned by societal actors, and the direct support of these vehicles by subsidies and other encouragement is redirected mostly towards basic research in battery

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[4]According to the California Air Resources Board member, Lynn Edgerton, air pollution is the fourth-highest ranking public concern (California Air Resources Board 1996c, p. 166.).

technology. When there are no longer any significant pressures on the gasoline car, the strength of vested interests, traditions, perceptions and physical structures is very hard to overcome for those who pursue alternatives. In such situations these alternatives are left to compete according to rules 'set' by the gasoline car. Thus it requires little imagination to realize why it has been so hard for alternative propulsion technologies to gain any momentum.

Controversy of technology — the case of the electric car

The electric car controversy over 'appropriate' means of solving air pollution problems was initiated by the zero-emission vehicle regulation in 1990. The controversy developed along certain lines, dealing with different issues, of which some developed to be what can be regarded as 'sub'-controversies of the 'main' controversy. These sub-controversies were to merge and bring about an ending of the main controversy.

A technological controversy is a widespread dispute, large enough to have societal consequences, with opposing claims about the features and prospects of different technologies.[5] A technological controversy usually involves opposing interests (political, economical, authoritative), different ethical positions (right, wrong, bad, good), as well as varying theoretical assumptions about forces behind technological change ('internal' versus 'external'). In essence, we might say that technological controversies involve all sorts of things in a mix.

Thus to be able to analyse these messy situations we need some analytical tools. First of all, we must acknowledge that a technological controversy does not come about randomly and does not exist in a vacuum. Therefore it is important to analyse the controversy in relation

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[5]Brante et al 1995, p. 10 ff. Authors talk about mixed scientific/technological controversies. A technological controversy is also a scientific controversy, but in order to declare my focus on technology, I speak about technological controversies (with elements of scientific claims) rather than scientific controversies (with elements of technological claims). As with the authors, my use of the concept of *technological controversy* therefore refers to what we 'know' about electric cars, while my use of the concept of *technology* refers to technical knowledge, as well as practices and artefacts.

to its socio-historical setting and contextual factors. Furthermore, technological controversies can be seen as having three distinguishable phases: *origin, stabilization, ending*.[6] The *origin* of a technological controversy can be explained by socio-political factors of conflicting interests. Essentially this means that the tensions on which a controversy can evolve may be in place, albeit not visible to the same extent as after a controversy has broken out. Usually it is also possible to argue that one particular event has triggered the controversy. During the *stabilization* of a technological controversy the participants and arguments become polarized, strategic alliances are formed and basic notions and perceptions of technology and technological change become illuminated. Actors seek allies among those 'experts' that happen to hold views in line with their particular interests. By following the participants 'on the battlefield', it may be possible to identify different interpretations of the same technology (i.e. the presence of interpretative flexibility), and to the extent this is the case, the technology can be said to be 'open'. The *ending* of a technological controversy can take different forms, but can hardly be expected to rest on epistemic grounds only, due to the presence of mixed interests and different perceptions of technology. Rather, we might expect different *modes* of ending the controversy to be working simultaneously.

The story: The technological controversy over electric cars was initiated by a decision of the state agency, California Air Resources Board (CARB) in 1990. Beginning in 1998, seven of the largest car manufacturers in the world would be forced to market two percent of their fleet in California as zero-emission vehicles (i.e. battery-only powered electric cars).[7] From 2001 the figure would rise to five percent, and in 2003 even smaller car manufacturers would be required (mandated) to see to it that ten percent of their sales in California were zero-emission vehicles.[8] Along with the regulation a mechanism of bi-annual revision on the technological and economic feasibility of these cars was adopted. The first revision did not stir up any great turbulence, but at the second revisory meeting (1994) the fight over the regulations was

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[6]Brante 1990. Please note that stabilization is used also in the social constructivist approach to describe the stabilization of an artefact. Being theoretically different, they still deal with similar aspects.

[7]Formally it was 'model year 1998' which in practise meant that these cars was to be on market in early 1997.

[8]"Small manufacturers" thus also include companies like Volvo.

more harsh, thus at this point the controversy had taken its basic form. Still, no changes of the regulations were made. But in early 1996, before the formal revision date, major changes were made that can be seen as an important step towards ending this controversy. Due to a variety of factors (political, strategic, battery technology, and changes in regulatory 'paradigm' — from 'command and control' to 'partnership') the requirement of marketing electric cars was postponed to the year 2003, with the ten percent requirement for that year unchanged. Incorporated with, and at the core of this decision was an agreement with car manufacturers requiring them to deliver a smaller number of electric vehicles with more advanced batteries between 1998 and 2003. These cars were to be equipped with batteries that were not expected to be available in larger volumes before the first years of the 21'st century. The major car manufacturers have prepared to produce these cars, but General Motors and Toyota have been going beyond this agreement. GM entered the California market with a electric sports car in late 1996, and Toyota started to sell electric cars equipped with an advanced battery in Japan the same year. Thus the outcome was threefold. Firstly, the mandated introduction of electric cars was postponed to the year of 2003, with the requirement that ten percent of cars sold by medium and large manufacturers be zero-emission vehicles. Secondly, an agreement between car industry and air-quality agencies was established to enhance the development of so-called advanced batteries. Thirdly, the two largest manufacturers, General Motors and Toyota, entered the private car market in California and Japan, respectively, in late 1996 with so-called purpose-built electric cars.[9]

The actors: The controversy attracted public and private interest on both sides; with the agency responsible for regulating emissions from mobile sources in California, the California Air Resources Board (CARB) as the main proponent, with support from health and environmental organizations, electric utility industry and academia. As the main opponents we find the car industry, oil companies, and tax-payers' organizations. Consequently, due to the variety of interests involved, the controversy exhibits a rich mix of knowledge claims, economic interests,

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[9]A vehicle can be more or less adapted for electric propulsion. A 'purpose-built' car is designed for electric propulsion from the beginning. Due to the low amount of energy carried, an electric car must be rather different from a gasoline car. The car from GM was fully adapted for electric propulsion, whereas Toyota's car was a 'semi-conversion'.

various political standpoints and basically different (i.e. incommensurable) perceptions of technology and technological change.

The controversy: The 1990 decision reveals these very different perceptions and expectations of battery-only electric car technology, which at the time was the major interpretation of the zero-emission vehicle requirement.

At the core of the controversy was the appropriateness of the zero-emission vehicle regulation; whether the technology could be developed within the required time-frame, whether there would be any market for the cars, whether zero-emission vehicles (i.e. battery-only electric cars) would solve emission problems at all, and whether or not society should intervene in car technology.

One might expect anything to be a potential topic for dispute in a technological controversy such as this one. However, as will also be shown, not all potentially controversial topics became issues of dispute. The controversy displayed and developed 'rules of the game' for what was to become an issue and what was not, and to a large degree these were formed by the already established relations between air quality agencies in California and the car industry.

In tracking down these socio-technical processes we see that actors, as is usual under similar circumstances, take very different and opposing standpoints, which, as has earlier been mentioned, can be derived from different interpretations of the features and feasibility of the technology at stake. The zero-emission vehicle controversy is no exemption to this polarization of standpoints, and the discussion of electric cars as a technological controversy will be focused on the different interpretations made by different actors of zero-emission vehicle technology, as a measure of how open or closed car technology is for radical change. Thus our perceptions of a certain technology and our possibilities to achieve changes in that technology are two interrelated aspects that can be analysed through the focus on the technological controversy as briefly outlined above.

Also, a technological controversy offers a strategic research site for analysing science-technology-society dynamics, since it brings out in the open many usually hidden processes as well as offering a 'simplified' (and thus more researchable) picture of these highly complex processes.[10]

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[10] About this aspect, see for example Bijker et al 1987 p. 191., and Nelkin 1995, pp. 444-445.

Without being able to focus on the controversy as a field of actors, arguments and activities, the available empirical material would have been more sparse and disperse. The participants in a controversy make explicit their views on both the dominant car technology as well as on the alternative technologies. They build artefacts to prove their standpoints. They make computer simulations to support their arguments. A wealth of literature emerges that follows each step in technology development in industry and in public research institutions. There are periodicals that follow legislative twists and turns in every detail, but perhaps most importantly, statements and arguments are documented in hearing protocols.

The situation that has emerged from the controversy can be described in terms of the 'black-boxed' (or closed) technology of car propulsion having been opened, whereas the concept of a black-box refers to something that we take for granted and do not fundamentally question. Thus it does not refer directly to technology "itself", it refers to how actors view and perceive technology. Whether technology is seen as open or closed is therefore a question of what analytical level and what perspectives we choose. Automotive propulsion is, within the perspective of this study, a closed technology, since the basic concept of the car being propelled by an internal combustion (Otto) engine with gasoline as fuel has not been fundamentally questioned during the hundred year history of the automobile. Thus the interpretations of a "car" have been stable.

Aim, outline and material used

Aim

This study touches upon three different but interrelated areas: (1) interpretation of technology, (2) implementation of technology, (3) controversy over technology. The socio-technical processes pertinent to electric cars can be followed and analysed through the interpretations and notions expressed by different actors. Thus, the three areas are tied together through the concept of interpretative flexibility.

Interpretation of technology: The first aim is to analyse what role notions and interpretations of electric car technology play in the discussion of technological alternatives. In order to discuss issues of change, we must first understand how society as a whole defines different technologies, and how these interpretations have emerged and influenced technology. The 'appropriate' or 'best' technologies have to be explained, as well as the corresponding technological 'failures'. Here, historical and social-constructivist perspectives on technology are useful for understanding how we have come to interpret, perceive and define different technologies. These aspects will be dealt with in the historical background part of the study (chapter II), and are mainly based on secondary text sources or contemporary automotive textbooks. The results of this historical survey are then used in order to put the recent zero-emission vehicle controversy in California into a socio-historical context, and thus emphasize that the views actors express today often have historical precedents.

Implementation of technology: The second aim of this study is to address the relations between society and technology, with an emphasis on the ability of societal (public) actors to influence the rate and direction of technological change. The California zero-emission vehicle regulation is an attempt to initiate a paradigmatic change in car technology. Therefore California can be seen as a full scale "laboratory" for analysing the prospects of whether, when, and how such radical change might be achieved. This is essentially to ask questions about the degree of flexibility of car technology. Issues of implementation will not be treated in separate chapters, but are implicit (and sometimes explicit) in the study as a whole.

Controversy over technology: Finally (and mainly), the aim of this study is to understand the dynamics of the zero-emission vehicle controversy in California. In a controversy different interpretations will be made. This flexibility of interpretation (or lack of flexibility) calls for explanation since it serves as a basis for actions made by actors in relation to the technology at stake. The controversy will be described in more detail in chapter III.

Outline of study and material used

For the purpose of this study, the articulation made by actors on technology serves as the empirical material, i.e. textual sources and interviews. Obviously, not all sources are equally relevant for answering the questions of this study, and in the following, the material used will be discussed in relation to the study.

Chapter II starts with a presentation of the technical features of the early electric car in order to give an understanding of how these vehicles were designed. This is followed by an attempt to address important features of the process at the turn of the century that led to the emergence of a gasoline car society, and not one based on electric cars. The relatively small, but yet existing, market for electric propulsion in commercial electric vehicles that survived until the 1940's is described. This chapter ends by focusing on factors that, at times, have induced renewed interest in electric cars.

This chapter (II) employs a social constructivist (re)interpretation of material presented in recent automobile and electric car literature, coming from the history of technology and from the domain of cultural studies. The two main types of material used in this chapter are as follows. Firstly, sources consisting of contemporary and often rather comprehensive textbooks that present detailed insight into the technical aspects of the three different main propulsion alternatives discussed at the turn of the century: steam, electric, and gasoline cars. In these textbooks, insights and facts about early automobiles are presented that lead me to the conclusion that these authors must have been located within the mainstream discourse of automobiles at that time. Early automobile literature employed includes: *Motor Vehicles and Motors: Their Design Construction and Working by Steam Oil and Electricity; Horseless Vehicles: Automobiles, Motor Cycles: Operated By Steam, Hydro-Carbon, Electric and Pneumatic Motors; Self-Propelled Vehicles: A Practical Treatise On The Theory, Construction, Operation, Care And Management of All Forms of Automobiles,* and two text books from the late 1930's and early 1940's, *Automobilens historia*; *Battery-Electric Vehicles: Dealing with the Construction and Operation of all types of Battery-operated Electric Vehicles and Accessory Equipment.* Secondary sources consisting of recent automotive literature on the (American) history of the automobile and electric cars, as presented in the "previous studies" chapter below, are also used. Important sources upon which this literature is built are, for example, periodicals from the turn of the century such as, *Horseless Age* and *Scientific American*, and more specifically electric car related sources from the same period, as for example, *Electrical World*.

Chapter III deals with the controversy over the introduction of electric cars in California, i.e. the question whether or not air quality problems should be solved within the dominant gasoline car technology or with a radical solution as represented by the zero-emission vehicle. Also, the dispute about the appropriateness of mandated regulations *vis-à-vis* market based regulatory approaches is addressed.

The basic methodology of this part is *to follow the actors* of the controversy. Starting in 1992 with newspaper articles and so-called newsletters related to transportation, it was possible to identify some major actors and arenas of the electric car discourse. Early on, the electric car conferences comprised one such arena that I studied, but the issues discussed at these conferences were to a large extent purely technical, or, the presentations made by actors were only the *outcome* of a process. It did not say much about what was really going on. Other sources studied were, for example, official (i.e. final draft) documents from air agencies. However, all parts of the processes cannot be revealed by such documents when studied as a single piece of empirical material. It soon became clear that in order to answer questions about the processes, the actions and statements made by the actors had to be understood *in relation* to each other, i.e. as a discourse. Therefore, a research trip was made to California in early 1995 to track down both how and where such material could be found and understood. Also, by that time, many of the main actors had already been identified (by one actor leading to another, etc.). Still, some new information was found and my assumptions as to the relative importance of each actor in the process were also adjusted somewhat. What was found was that many of the reports made and cited in media, play a certain role in the discourse, being, for example, counter arguments to assertions made by the 'other side' of the controversy. Usually nothing of these processes is made explicit in the reports. That type of information could only be collected by communicating directly with the actors, and by trying to closely follow the dynamics of the controversy, i.e. by being as close to the controversy as the actors themselves.

Chapter III is based mainly on primary sources from the actors in this controversy, with *transcripts* from the hearing processes on the ZEV mandate at the California Air Resources Board (CARB), being the central material. All the major actors have participated in the hearings, where they articulate their view about the technology and the regulations at stake. Also, interviews were conducted in early 1995. At these interviews, argument text sources from both the interviewed actor as well as key documents from actors of the other 'side' could be collected. This was possible precisely because these actors were heavily involved in the controversy. They had access to the key documents from the other side of the controversy. The interviewed actors include: officials from the California Air Resources Board and the South Coast Quality Management District, the California Energy Commission, start-ups, electric utility industry, academia, and the environmental community.

Thus there is an obvious unbalance with respect to the range of actors being interviewed. Representatives of car and oil industry were not visited. However, for example, the views of the car industry in Detroit on these issues have been stable, and been studied through their responses to air agency reports and in hearing transcripts. Secondary material can be found in a variety of sources. Examples include the interview book *Building the E-motive Industry: Essays and Conversations About Strategies for Creating an Electric Vehicle Industry*, and interviews and articles in the periodical *Electric Vehicle Progress.*

In the concluding chapter (IV), attempts are made to argue for the importance of the role of definitions of technology when an attempt is made to introduce a radically new technology, and the usefulness of approaching these processes through understanding them as a controversy of technology.

Previous studies

The automobile related literature is rather comprehensive, involving many different foci and time periods. Interest in studying the automobile is found in many different academic disciplines (e.g. history, policy, planning, engineering), which can also be traced in the fairly rough thematic division employed below. The main body of this literature is, not surprisingly, focused on gasoline cars since that alternative has become "the machine that changed the world", as captured in the title of a study of car production and competitiveness by James P. Womak *et al.* Still, several studies on the failed alternatives of the electric and the steam car do exist, and some of those pertinent to this study will be outlined below. One common feature of most studies in the history of cars is that they deal with the American automobile scene. For the purpose of this study, however, this can be argued to be a strength. If dividing this body of literature into 'general automobile' studies and 'electric car' studies, the following thematic division can be useful.

Automobile literature

Cars and the city:[11] The interesting relation between the emergence of the modern city and the automobile has been addressed by several authors based on the perspectives of city planning and geography. Here, the explicit focus is on the interaction between development of the city and the use of vehicles within the city. From the perspective of cultural analysis, Clay McShane focuses on the social factors behind the emerging use of vehicles, as an integrated part of the processes of suburbanization of the very early American (automobile) city. With a focus more set on the physical structure of the city in relation to the commercial use of vehicles for freight purposes, Robert Raburn analyses the impact that the use of steam, electric and gasoline propelled freight vehicles had on city morphology in California and the West. With a focus on transportation and city planning of the city of Los Angeles, and the battle of transportation systems (public transportation *vis-à-vis* automobiles), Scott L. Bottles, follows a similar track as McShane in starting the analysis of automobility by looking into processes that preceded the car.

Cars and technology policy:[12] The literature on regulation of cars is also rich, which may not come as a surprise, due to the long tradition of emission regulations and the great complexity of regulatory frameworks for environmental protection. From the viewpoints of economics, Paul R. Portney (ed) focuses on the history of environmental regulation with an emphasis on the cost-effectiveness of different regulatory approaches, with preference for more market oriented approaches to allow for greater flexibility. In a study from the domain of political science, Gary C. Bryner, narrows the scope and outlines the developments of the Clean Air Act, to assess its effectiveness in relation to the political system. In both of these studies, the history of gasoline car emission regulations is outlined. Even more focused on car regulations is a study from 1977 by James E. Krier and Edmund Ursin on California car regulatory activities between the years of 1940 and 1975. Yet another study, that even employs

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[11] McShane 1994, Raburn 1988, Bottles 1987.

[12] Portney 1990, Bryner 1993, Krier *et al* 1977, Lundqvist 1980.

comparisons between Sweden and U.S. regulatory traditions is one in political science by Lennart J. Lundqvist, also from the late 1970's, that compares the relative merits of two very different regulatory traditions with an emphasis on the different political-institutional contexts.

Cars and society:[13] Several historical studies on cars and American society and culture have been produced. In his first book on the history of the automobile, James J. Flink, focuses on the early developments, and the social setting in which this artefact emerged. Examining the same processes of early automobility, but with a focus on gender issues and studies of culture, Virginia Scharff, argues for the electric car having become a gendered artefact. The further development of the car, its production system, and the American automobile based society is the focus of a second book by Flink. If one tradition can be seen as mainly historical, the other may be seen as focused more on culture. One example of such literature is the anthology edited by David L. Lewis and Laurence Goldstein, in which, for example, the automobile in arts is investigated.

Electric car literature

'Alternative car' literature:[14] This type of writing takes its departure from energy and/or air pollution concerns, but perhaps above all, the attempt to achieve long-term 'sustainability' in the transport sector. In many cases, electric propulsion is argued to be an appropriate long-term solution to many of the problems that the use of cars has created. Many books of this type have been written in the 1990's, dealing with (mainly) the present and the future. One example of a study on electric cars is a book by the head of the Institute of Transportation Studies in Davis, California, Daniel Sperling, who summarizes the fairly large work conducted at ITS Davis on electric propulsion related research in a book on electric car technology and market, but also gives some insight into the recent politics of electric cars in California. Like Sperling, James J. MacKenzie, also covers a wide range of topics on technology, energy, pollution, politics, and policy and emphasizes long term solutions. With a stronger focus on technology, Robert Q. Riley, gives a comprehensive overview of the technology and physics of vehicles, and the state of the art in electric

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[13]Flink 1970, Scharff 1991, Flink 1990, Lewis et al 1983.

[14]Sperling 1995, MacKenzie 1994, Riley 1994, Moore *et al* 1994, Maruo 1996.

propulsion as of the mid 1990's. With a strong support of electric propulsion, Curtis Moore and Alan Miller argue for the inevitable (and commercially profitable) development of zero-emitting technologies. Kanehira Maruo, argues in a study (in Swedish) of global processes that will lead towards electric propulsion.

History:[15] Insights into the technical history of electric cars are presented by Ernest H. Wakefield, in an overview of the American makes from the very beginnings to the early 1990's. However, a lot of facts are presented without much analysis and context. A more contextual approach is put forward by Michael Brian Schiffer in his historical and cultural study of the early electric car in America. Schiffer stresses that it may have been a much more open-ended race between alternatives of propulsion than it appears using the same sources as gasoline car historians. From the perspectives of history of technology, evolutionary economics, David A. Kirsch also argues in his dissertation for the situation being more open ended than earlier studies in the history of the automobile have suggested, but concludes that this 'window' closed by 1903. Another body of literature focuses on the present situation of the gasoline car society and the (im)possibilities for change. One example is the focus on the car based society as a large technological system, as put forward by, for example, Reiner Grundmann, who emphasizes the need for political and technical support networks and the creation of niches in order to 'un-lock' the existing system. The Dutch scholars, Boelie Elzen and Johan Schot, also stress the importance of the creation and managing of niches in combination with regulations and the creation of alliances, in order to allow radical alternatives (such as the electric car) to gain momentum in relation to an existing technological 'paradigm'.

[15] Wakefield 1993, Schiffer 1994, Kirsch 1996, Grundmann 1992, Schot *et al* 1994.

Theoretical framework

Knowledge and belief as social construct

The basis of the so-called *strong programme*[16] is to analyse all forms of knowledge claims and beliefs in the same way, and thus not make a priori distinctions and value judgements about these claims based on how they were generated or what degree of consensus they enjoy. Thus the same types of explanations should be used on all types of knowledge claims irrespective of whether these claims are considered as "true" or "false".[17] In this sense, the strong programme serves well for both the de-constructive ambitions of this study (to reveal hidden processes and aspects of technological change) and as a tool for the constructive ambitions (to explain how facts and artefacts emerge). Four interrelated basic methodological principles are central to the strong programme:

(1) Claims and beliefs emerge under certain circumstances and are *caused* by a variety of different factors. The task then becomes to analyse these circumstances.

(2) When analysing statements we should be *impartial* to that which actors say about the technology at stake, for example what actors consider to be: true or false, success or failure, possible or impossible, and expected or unexpected developments.

(3) Also, when trying to explain why technology is viewed as false or true, or when explaining a technological success or failure, we should make use of the same types of causes. Thus explanations should be *symmetric*. What is regarded as being a relevant type of explanation for a technological success must also be relevant for analysing a technological failure.

(4) Explanations made within the conceptual framework of the strong programme are obviously also in themselves claims to knowledge. It

[16] As outlined in Sundqvist 1991, pp. 56-64., and discussed in relation to technology in, Pinch et al 1987, pp. 17ff.

[17] It may be appropriate to note that this social epistemology conflicts with philosophical claims that accord 'science' and 'nature' the ability to make absolute judgements in such matters; and that on these issues the theoretical basis of this study may conflict with the assumptions underlying engineering science.

should therefore be possible to perform (self) analysis even on texts produced by the researcher. This is what is called being *reflexive.* Reflexivity is therefore a special case of the common sense notion of being reflective — of being self conscious.

To focus in this way on what experts, stakeholders and other actors articulate about technology is a strategy for understanding technological change. It builds on the assumption that it is impossible to gain absolute and everlasting knowledge (here in matters of technology and science). The problem of trying to decide *who* is "right" or "wrong" becomes instead a problem of showing *how* and *why* right and wrong become generally accepted, consolidated and upheld. Thus the theories and practices of engineering science, as well as the artefacts themselves will here be regarded as social constructs, and consequently the 'technical' cannot (or rather should not) be separated from the social. To be able to answer these how and why questions, it is necessary to be impartial towards the claims made by actors, and not make judgements or impose *à priori* distinctions on the analysis. Instead this will be an open empirical question that needs to be answered. To be symmetrical, all statements about technology, concerning for example both functional and non-functional technology, should be analysed. While doing this, the functionality or non-functionality cannot be used as causal explanations of the success or failure of a technology, since these properties themselves are the result of a social process.[18] The goal of being symmetrical does not, however, imply that all actors should be treated as equally powerful and effective, since that would be an *à priori* distinction, and thus violate the premise of the programme to *not* make such distinctions.

Technology as a social construct

In its simplest (and perhaps trivial) form, this is to say that technology is a result of social activity. The extension of the strong programme to a *sociology of technology* and the realm of technical artefacts, is to say that the converging attitudes towards artefacts as functional or non-functional, also lead to a *physical stabilization* of their form and technical content. We all *know*, for example, how a bicycle works and what it looks like,

[18]Bijker 1995, p. 15.

thus both the *appearance* and the *'internal' technical design* are stabilized. And as emphasized earlier, this stabilization is not a result of finding the best design in some absolute sense, but of the actors viewing it as being the best design. This means that *perceptions* and *expectations* on the part of social actors in the field of electric vehicles help to explain what these actors will try and not try to do. In the process of the stabilization of perceptions and expectations, the artefacts themselves play a part. How we, for example, perceive a car, and what we can expect it to be able to do in the future, will, at least to some extent, be determined by that existing artefact.

Three different approaches to technology have emerged (and diverged): the social construction of technology, large technological systems, and actor-networks.[19] All three build on the ambition of being open towards many different factors and avoiding the use of distinctions that prescribe what type of factors are engaged in the making of technology. The main approach used here is the social constructivist approach, but since all three approaches have inspired my thinking, they will be outlined below.

Social Construction of Technology

The social-constructivist approach to technological change builds on an extension of the strong programme, and thus requires us to look for the circumstances behind the creation of a technology.[20] At the core of this approach is the earlier discussed concept of *interpretative flexibility*. This refers to the variety of perceptions that different actors, or "relevant social groups", articulate in relation to a technology.[21] The concept of *closure* is closely related to interpretative flexibility, and refers to the process of a decreasing degree of interpretative flexibility on the part of the actors. Thus, in this way, closure captures the basic features of the artefact in a very fundamental way, what it should be able to do and thus

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[19] Bijker 1995, p. 6.

[20] Bijker *et al* 1987.

[21] In the following, "actors" or "social groups" will be used in the same sense as Bijker uses "*relevant* social groups".

in some sense what 'it is'.[22] As a consequence of decreasing interpretative flexibility, the variety of possible basic features of the artefact will be narrowed by the closure mechanism and one dominant design will emerge.[23]

Still, closure does not cover the many technical problems (details) that remain to be solved in order to adapt the artefact for production. The concept of *stabilization* captures these processes of an emerging dominant set of technical solutions for the artefact. Through an analysis of the step-by-step exclusion of technical details in descriptions made of technology within a social group, it will be possible to trace the black-boxing on the level of components of the artefact. Thus, in this way the process of stabilization tells us something about future technological trajectories and it shows how certain designs become entrenched. The stabilization of an artefact could in theory go in many different directions, however not all possible directions will be considered in the technical design of an artefact. Taking an automobile company as an example, people can share (among other things): theoretical knowledge, tacit knowledge, firm history, goals, and solutions to problems. All these factors will have an influence on how this firm will act when designing a new product. This phenomenon is captured by the concept of *technological frame*, which has two implications for technological developments. On the one hand it puts constraints on possible developments, since:

> Technological frames specify...the way in which members of a relevant social group interact, and the way they think and act...[and thus]...constrain freedom of choice in designing new technologies.[24]

On the other hand it allows for faster, and more successful developments within these boundaries, since:

> it enables its members by providing problem-solving strategies, theories, and testing practices.[25]

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[22]Bijker 1995, p. 77.
[23]Bijker 1995, pp. 86-87.
[24]Bijker 1995, p. 264.
[25]Bijker 1995, p. 264.

By making use of a Darwinian system metaphor, the American historian, Thomas P. Hughes, argues that technology can be analysed as large (socio) technical systems, which are orchestrated by an (intentional) system builder.[26] These systems are made up of components from both the social and the physical worlds, being functionally related in a way that supports the "life" of the system. This means that the boundary between inside/outside of a socio-technical system is the locus where a given component is no longer fulfilling a function in the system.

The focus of Hughes' theory is on technological change rather than on a steady-state condition, thus Hughes makes use of metaphors such as *technological momentum* and *reverse salient*. Both metaphors are utilized as concepts in this theory. 'Technological momentum' implies that the system has inertia based on well-developed practices or organizational structures and the like. 'Reverse salient' is a military concept, referring to a war-time situation where the expanding front line is held up by a small enemy group, and to continue the advance, this reverse salient has to be eliminated. Therefore, it refers to any hindrance to the further expansion of the boundary of a socio-technical system. It must be coped with and solved in some way by the system, which means that the system must have the ability to display some degree of intentionality, for example on the part of an entrepreneurial *system builder*, or some agent able to identify such a hindrance, and carry out strategies for its elimination. Any successful change of the system that solves the problem of a reverse salient is called a *conservative change*, because its purpose is to preserve the further life of a system already in place. If the system fails to do so, it may die, and a *radical change* may come about. A radical change means a total rearrangement of components and the functional relations between them. In such a case, the system is very open for new technologies and social entities to arise, and old ones may find themselves displaced.

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[26]Hughes 1987, pp. 51-82. In the case of car traffic, it have been argued that it is impossible to identify a single system builder (of person(s) or organizations), in Hughes' sense. See, (Grundmann 1992, p. 41.). Thus, in using Hughes' theory of large technological system it may be wise to not emphasize the intentionality and rationality of the dynamics at the system level too much.

Actor-networks

The actor-network theory put forward by the French sociologist Michel Callon takes this strategy of analysing forces behind a certain technology much further, in linking *enrolment* of a *networking agent* with a concept of power.[27] However, it must be noted that Callon's notion of power may be somewhat different from that of a more common sense perception of the concept. Economic or political strength, for example, is no guarantee of being powerful all the time and in all aspects of a technological controversy. Power can instead be viewed as the ability of what Callon calls *actor-networks* to achieve their goals.[28] The actor-network is held together by the strength of these (interrelated) relationships of a set of factors, artefacts and social groups. Even non-human entities come into consideration, since artefacts and nature-facts also have to be enrolled to play their part. Both human and non-human entities have to behave as the networking agent wants them to do.[29] If this fails, or if the (hostile) surroundings of the actor-network become too strong, the network will fall apart and lose its power and thereby its ability to impose its will.[30]

For a company or an organization that wants to do something, the key question then becomes whether it can enrol other actors to see the world in the same way it does, and get them to support a common purpose. One merit of this approach is that network theories are open for all sorts of factors to be taken into consideration as a part of an explanation. The requirement for any entity to be considered as an agent is for it to have, at some point, an established relation to other agents of the network,

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[27]Callon 1980. On actor network theories, See also Akrich 1992, Law 1987, Law 1994, and Latour 1987.

[28]This concept of power is similar to what Bijker terms as "micro politics of power" (Bijker 1995, pp. 260 ff.).

[29]This is of course not the same thing as to say that 'wants' can change nature. The roles are given in accordance with the existing knowledge and expectations of the networking agent.

[30]Callon 1987, pp. 83-103. This controversial step to argue that even non-social entities should be treated as acting entities in explanations, and the total denial of structure as having anything to do with the development of technology has created some anger and turbulence among social scientists. I have neither the ambition, nor the ability, to cover the rather theoretical controversy pertinent to sociological theories of actor-networks.

whereas theories of technological systems are somewhat more constrained in this respect, and try to uphold distinctions between inside and outside.

Technological Controversies

From the viewpoint of studies of scientific controversies, Ernan McMullin has described "mixed controversies" as follows:

> [it]...involves disagreement on both the scientific and the nonscientific aspects...involve an application of science to some human purpose — that is, a technology of some sort. It is from this application that the moral or political issue derives...[and that]...decisions have to be made in the absence of a consensus.[31]

But even if controversies are mixed and messy they can still be analysed. After having given a more broad description of the historical background and the context of the controversy, we can often pinpoint an initial period of events that can be seen as leading up to and triggering the controversy. The second period is where the actors take their different positions and the arguments becomes more refined. The third and last period is when the controversy in one way or another reaches an ending. McMullin talks about ending a controversy without reaching consensus. In the interpretative framework developed here, a technological controversy can be concluded by other means than consensus. Here I will argue that the ending of a controversy can incorporate different closure mechanisms at different points of the closure. For example, a controversy over technological issues that deal with uncertain knowledge can end in other ways than by consensus — but in order for a technological artefact to become a consumer product, a rather high level of consensus has to be established about its features.

Also, as a part of this establishment of consensus, actors tend to rewrite history so that mainstream perceptions of the technology become further consolidated. The chosen technology will be regarded as the best technology, and the perceptions of the technology will be regarded as the only possible way to see it.

A technological controversy offers a methodological opportunity to study complex processes. In the controversy, experts and stakeholders see

[31] McMullin 1987, p. 76.

their statements about the technology deconstructed by their opponents, who often are experts eager to analyse every small aspect of the technological issues at question. We cannot do this on our own. In this way a controversy offers what is called a strategic research site.

In this paper I emphasize the historical background and context as being important in order to understand the dynamics of the zero-emission vehicle (ZEV) controversy. When does a technological controversy start? As indicated above there is some initial event that can be regarded as triggering the controversy. This choice, albeit not entirely arbitrary, is essentially an act of the researcher who has to show that at least one event eventually triggered the conflict. In the case of the ZEV controversy, this is easily argued to be the decision by CARB in September 1990 to mandate the introduction of ZEV's in California. The decision came as a surprise to many people, but that does not mean that we cannot explain its origin. However, in focusing on the period of the emerging scene of the controversy, we are much more on our own; if one methodological merit of following a controversy is that it reveals many hidden aspects, the pre-controversy period might be more problematic to analyse because socio-technical dynamics are hidden, and inscriptions in history may be difficult to trace.[32] Thus there is the obvious risk of over-emphasizing those few events and related factors one comes across, and thus erroneously proposing sequential casual relationships between these events.

After a controversy has been triggered, it can develop in different ways, but it seems plausible to suggest that this phase generally follows certain patterns. Some actors will be regarded as having the right to speak out and some will not. Some will have, take, or be given, the ability to set the agenda and influence which topics will and will not be discussed. Some actors will be regarded as experts, 'independent' or 'aligned'. Some will be regarded as major stakeholders and others as minor stakeholders. Thus there develops a basic set of rules of each controversy, that structure it in some sense. As the temperature rises, the different roles and positions will be increasingly visible and explicit. The conclusion of a controversy can take different forms. A controversy, even if it is described as a single issue, can often also be seen as several sub-controversies that end differently.

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32 Latour 1987, p. 4.

The ZEV debate has been carried out in a variety of places (for example, in the media: newspapers, journals, Internet, and television, and in political arenas: the California State Assembly, the California Air Resources Board, the Public Utility Commission, the Ozone Transport Commission). Not all of this will be covered at length or in depth in this study, but still, several important aspects of the controversy will be studied. The main scene for the ZEV controversy has been the California Air Resources Board. In this respect some of the dynamics of the controversy have political and structural explanations. Not all actions are freely and consciously taken by the actors. Some actions and measures adopted can be derived from, for example, federal legislation. However the outcome of these measures and actions have to a large extent been much more dynamic than one might expect by just focusing on structures. Structures have not orchestrated the controversy.

II. SOCIO-HISTORICAL BACKGROUND

The artefact

The earliest electric automobile that can be traced in the literature, as far as I know, was developed in Edinburg in 1842. A man named A. Davidson is reported by the local newspaper "Edinburg Evening Journal" to have built an electric automobile, and other early electrically propelled vehicles were made in England, Italy, and somewhat later, also in Germany and France.[33] This vehicle must have been one of the first electric vehicles, since a practically working electric motor is not considered to have been available for more than a few years at this time, and the lead-acid battery was yet to be invented.

Both the steam automobile and the electric automobile had an initial advantage over the gasoline automobile, in that they used propulsion systems which were already developed.[34] For steam, the historical predecessor is evident, but even the electric automobile could make use of

[33] Referred to in Nerén 1937, p. 73.

[34] Schallenberg 1982, p. 254.

developments already made. Components suitable for making an electric automobile came from the earlier developed electric trolley: batteries (albeit for stationary applications in trolley powerhouse or for lightning), battery chargers, electric motors, and controllers.[35] These technologies were produced commercially before they were put in automobiles. Common to all types of propulsive technologies in automobiles was that the mechanical design had its origin in either the *horse carriage* or the *bicycle*.[36] Later on, these two streams merged somewhat, in combining the enclosed body of the horse carriage with the lightweight structure developed by bicycle manufacturers. Many of the early manufacturers of electric cars had worked with bicycles before starting to build automobiles.[37] These technological 'ancestors' of the electric car are summarized in figure 1. The pleasure electric was a vehicle intended for city use only, and, as will be shown below, was never successfully established. The street delivery vehicle survived somewhat longer, but eventually also vanished. Battery-electric propulsion was from that point on, by and large, disconnected from use on streets.

One example of electric car design by bicycle manufacturers is the series of electric vehicles from Columbia Electric (see fig. 2). The Columbia Electric Stanhope Carriage of 1900 had a weight of 1,150 kg, of which 43 percent, or 500 kg, was battery weight. It had a range of about 55 km on level roads. The energy consumption ("expenditure of current") was given as 90 Watt-hours per km with three people riding the vehicle, and the needed recharge ("recuperation current") was given as 136 Wh per km, thus giving a battery cycle efficiency of about 65 percent.[38]

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[35] Schiffer 1994, p. 33., and Schallenberg 1982, p. 250.

[36] This is a consensus among most automobile historians. Flink argues that the tradition of bicycle manufacturing was the most influential in early automobile manufacturing, (Flink 1990, p. 9.).

[37] Raburn 1988, p. 74.

[38] Beaumont 1900, p. 435-436. Interestingly, for lead acid battery vehicles, a battery weight of 40 percent of total vehicle weight is still viewed as the 'appropriate' value. The speed at which energy consumption was measured was probably 16 km per hour.

Figure 1. Development lines of the early electric car

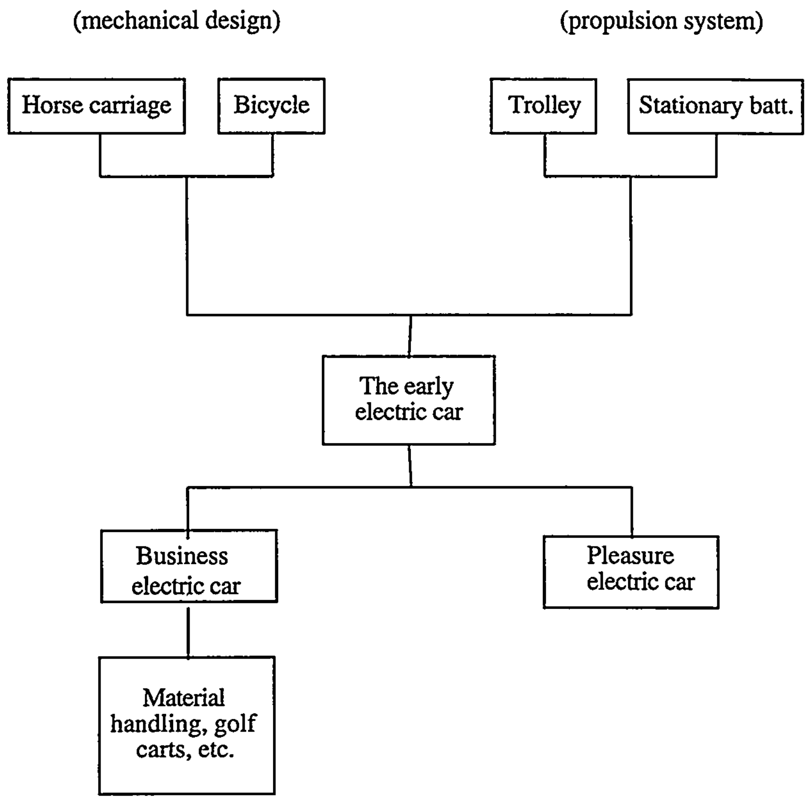
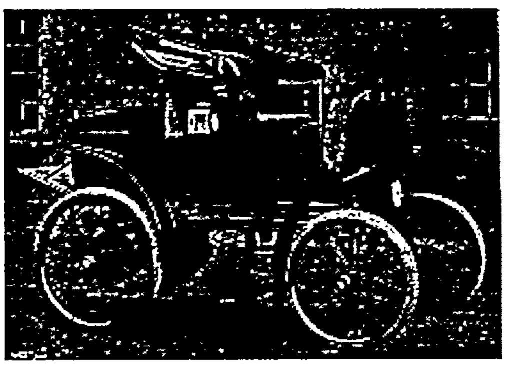


Figure 2. Columbia Electric Stanhope Carriage from 1900



Source: From; Beaumont, W. Worby. 1900. *Motor Vehicles and Motors: Their Design Construction and Working by Steam Oil and Electricity.* Westminister: Archibald Constable & Company Ltd., p. 434.

A simple calculation[39] suggests that the specific energy of the battery was probably about 10 Wh/kg at a 3.5 hour discharge rate. This specific energy is approximately 3 or 4 times less than that of commercially available lead acid batteries of the mid 1990's. The energy consumed by early electrics was mainly due to rolling friction, which in essence was due to roughness of the road surface. Air resistance at such low speeds as 16 km per hour is negligible. Of course hill climbing required extra energy, but the electric car never really established itself in areas with extensive hill climbing. One reason for this was probably problems with battery life under high loading conditions during hill climbing. Today, roads are very smooth compared with a hundred years ago, but the higher speeds and frequent accelerations of urban and highway driving seem to have consumed what gains have been made in battery development. Thus a lead-acid battery powered vehicle has about the same range today as one hundred years ago.

The cost of the electric car was also, at least to some extent, influenced by the line of developments. Apart from batteries being one expensive component, electric automobiles were usually more exclusive, and several times more expensive than their gasoline powered counterparts.[40] Producers of electric automobiles enclosed the vehicles at a much earlier stage than did producers of gasoline automobiles, and seem, to a larger extent than the steam and the gasoline car, to have competed with the traditional horse carriage. Flink argues that manufacturers of electric cars copied fashionable (and exclusive) carriage forms in order to tap into the already established market for the horse carriage:

> The electric car was the most conservative form of the automobile, in that it bore the closest resemblance to the horse-drawn vehicle in both appearance and performance.[41]

In 1898 the Automobile Club of France conducted a test of electric vehicles by Jenatzy and Kriéger and compared them with a Peugeot Petrol Coupé from the point of view of operating costs. The results were in

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[39] Specific energy = (55 km * 90 Wh/km) / 500 kg = approx. 10 Wh/kg.

Discharge rate = 55 km / 16 km/h = 3.4 h.

[40] Schallenberg 1982, p. 253.

[41] Flink 1990, p. 10.

favour of the electric vehicles, but a contemporary treatise described this test as having large bias towards electric propulsion.[42]

Generally speaking, there was little consensus this early in the history of the automobile as to how cost comparisons should be made. This situation would eventually change, but the gasoline car had by that time already gained enough momentum as to not be threatened by the electric vehicle. Still it should also be pointed out that this conservative marketing strategy by manufacturers of electric cars, building upon the already established market of the horse drawn carriage, was fairly rational. These manufacturers can hardly be blamed for not realizing that the personal transportation market had no stability at this time.

Complete figures on automobile ownership in America at the turn of the century are not easily found, a common picture of automobile history literature. There were few publicly held files, and most data available come from estimates made by people engaged in the development of automobiles at that time. In a treatise on automobile development and maintenance from the year 1900, it is indicated that France was initially the leading nation in the development of automobiles. Of a total of 7,000 owners of automobiles in Europe, about 5,600 of them were to be found in France. Furthermore, France was reported to have had as many as:

> 619 manufacturers of automobiles, not including makers of detail parts, 998 of them,. 1,095 repair shops, 3,939 stores for oil, gas, etc., and 265 electric charging plants.[43]

Some of the first cars in the United States were imported from Europe.[44] There was also initially an extensive technology transfer from Europe to the United States via technical literature, research trips, importation of technical personnel, lessons learned from automobile races and finally, competition in the marketplace.[45] But the French leadership did not last very long. Already by 1904, the production of automobiles in the United States was larger than in France.[46]

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[42]Beaumont 1900, p. 396.

[43]Hiscox 1900, p. 14.

[44]McShane 1994, p. 104.

[45]McShane 1994, p. 106.

[46]Flink 1990, p. 25.

Social preferences

As will be shown below, the social preferences as to what a car should be able to do, what it should be used for, and how it should look were established rather early in the history of the automobile. And it was the gasoline car that came to be preferred to automobiles propelled by steam or electricity. But even if electric cars were early on viewed as inappropriate for longer trips, they were perceived as perfect for use within cities, or in the words of one contemporary:

> Anyone who is familiar with the condition of the art and with the character of the product of the various types of motor vehicles [i.e. steam, petrol, electric], cannot doubt the wide field [i.e. use in cities] that the electric motor vehicle will cover.[47]

However, this "wide field" for the electric car was never established, because the prevailing 'winner', the gasoline car, was soon to be the *one and only* alternative.

The automobile and the American city

During the last decades of the 19'th century, cities became increasingly crowded, which made decentralization of the city a social goal for planners at that time; and the entrance of the electric streetcar (trolley) encouraged and initiated the growth of suburbs.[48] The use of automobiles would initially follow these travel patterns already established by the electric streetcar.[49]

In *Down The Asphalt Path*[50] McShane starts his historical review well before the car had any impact on urban life, either in real-life situations or in people's minds. In doing so, he fills a gap in automotive history, in that many historians, more or less take the internal combustion car as their point of departure. McShane focuses instead on processes of

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[47]Hiscox 1900, p. 354.

[48]Foster 1980, pp. 26, 29. In, for example the City of Los Angeles, the population increased from about 10,000 in 1880 to about 100,000 in 1900, Bottles 1987, p. 32.

[49]Bottles 1987, p. 13.

[50]McShane 1994.

urbanization that were initiated before any self-propelled vehicle entered the scene. The diffusion of automobiles in the United States is described as only one, albeit important, technology that began to occupy the street space. With this focus McShane can also explain why the car managed to establish itself so quickly when it did appear. Social processes that began to establish a need for travelling appeared simultaneously with the emergence of the car. Thus some of these processes were boosted by the development of the automobile.

McShane shows that before suburbanization started in the U.S. in the 1890's, workplace and housing were not separated to any larger extent, and people did not use the streets only for transport. The street was an open space for communication, buying food, for children to play on, and, of course, also for walking to the workplace.

This perception of the street is highly different from ours today, and to allow automobiles to enter the street space, a social reinterpretation of the *meaning* of the streets had to take place, as well as a shift in power relations from those already occupying the streets to those who wanted to drive fast vehicles. Fortunately for the car, these reinterpretation processes had already started, and were only boosted by the (gasoline) car — not initiated.

Beginning with the trolley, city planners had begun to look upon the street as mainly a place for transportation. Earlier, the paving of roads was motivated to a large extent as a health issue (or, as in France, a military concern). The steam powered automobile was an early (pre 1890's) form of self-propulsion to enter the streets, but met heavy resistance. Steam propulsion vehicles were in general considered to be dangerous because of the (perceived) risk of exploding boilers, and were therefore regulated and banned in many cities in the U.S. In general, all kinds of fast moving vehicles were considered to be dangerous, and were thus not a welcome novelty. This would however change very rapidly, and in a few years the diffusion of automobiles would instead be encouraged by city planners, and automobiles became increasingly accepted.[51]

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[51] Still, there was opposition from several social groups, as, for example: *horse-drawn interests* (horse breeders, stable owners, horse-drawn vehicle drivers' associations), and *antispeed organisations* (Flink 1970, pp. 64-65.).

Racing for power and endurance

Automobile endurance races were an important social activity in forming the perception of what an automobile should be able to do.[52] Several famous races were conducted in Europe and the U.S. These races proved the feasibility of self-propelled vehicles in relation to the horse drawn carriage, and clearly showed the public that (steam and gasoline) automobiles could do things out of reach of the horse-drawn wagon, as well as the electric car.[53]

One example of such a race was the Paris-Bordeaux-Paris race in 1895, which received a lot of publicity in the U.S.[54] The course was about 1,200 km long, and was completed by the Panhard et Levassor gasoline car at an average speed of 24 km/h, which is extremely fast considering the roads and vehicles available.[55] A typical electric car of 1895 might, at this speed at best manage to complete about 40 km (or 3% of course length). Another example of a race, the Times-Herald race in Chicago the same year, told the public the same story; the electric car could not compete. Only two out of six entries were electric cars, and they never finished the 90 km long race.[56]

These two races are chosen rather arbitrarily, from a large number of similar events during the early years of the automobile. Still, they display the general features of what became an *à priori* disqualification of the electric car. It simply had no chance. The important thing here, in relation to social preferences, is that it was the long-range and high-speed vehicle that became the preferred one; in contrast with how people of that time actually used the automobile, and definitely in contrast with how the automobile has been used throughout the history of automobility. Thus, the striving for high peak-performance capability of cars has historical accounts.[57]

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[52] Hård et al 1993, p. 144., Flink 1970, p. 243, Flink 1990, p. 17., Schiffer 1994, pp. 74-75.

[53] Flink 1990, p. 17.

[54] Flink 1970, p. 12.

[55] Flink 1990, p. 17.

[56] Schiffer 1994, p. 46.

[57] See also (Hård et al 1993, p. 142.) for a similar conclusion.

A gendered artefact

The starting point here is that technical artefacts can carry symbolic meaning in a similar way as words or symbols, and that these symbolic meanings can be reproduced by our culture. Few scholars disagree that the gasoline car became gendered towards the 'male'; both in the sense that the vehicles to a large extent were owned and driven by men, and in the sense that it carries some kind of symbolic meaning that is gendered towards the 'male'. The gasoline car was viewed as powerful, with few limitations set upon the driver, and even as a dangerous artefact, which certainly was not seen as appropriate for women. The electric car was generally viewed as having restrictions set upon the driver, only good for short trips, and with features that posed no real 'manly challenge' because it was so simple to drive and maintain.[58] In this way the gasoline car became an image of the common sense notion of the 'male' in relation to the 'female' electric car.

The way I see the gendering of the electric car is that it took place in two different ways (and steps). Firstly, the social construction of "the car" (as being gasoline propelled and 'male') made the electric car *relatively* gendered towards the female, parts of which process are here suggested to have taken place in the U.S. before the year of 1900. Secondly, the advertisements in the first two decades made by producers of electrics attempted to forge a link between women and the electric car, and thus worked towards a rhetorical closure of the view of the electric car as a feminine artefact.[59] Other publicity-related activities making this link between the electric car and women were articles in magazines for upper class women, and a rather special event in Boston in 1913. This was a large three day 'electric-pleasure-car-salon' with 10,000 people invited of which about 2,500 people attended.[60]

Still, the attempts to make the electric car a women's car was only a final attempt to capture a market at a point where the gasoline car had already established itself as the main alternative.[61] Faced with the threat of

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[58] This aspect of 'manly challenge' is put forward by the Dutch automotive historian Gilbert Mom (Mom 1996). The view of electrics as being 'restricted' is often put forward in contemporary, turn of the century, writings.

[59] Scharff 1991, pp. 35-50.

[60] Schiffer 1994, pp.138-139.

[61] McShane 1994, p. 140.

declining sales, manufacturers of electric cars tried to establish a separate market sphere for electric vehicles, making it a vehicle for short trips and for urban, upper-class women. Virginia Scharff describes in *Taking the Wheel*[62] that this "...identification with women took hold early and tenaciously"[63] and that electric car manufacturers actively sought through advertisements to establish a positive link between the electric car and women. Scharff argues that this link already existed, culturally speaking. Victorian notions of gender differences represented a view of female and male as two separate spheres with the female sphere representing the passive and the private, while the male sphere represented the opposite values. The way manufacturers transformed these values into a market strategy was to:

> associate the qualities of comfort, convenience and aesthetic appeal with women, while linking power, range, economy and thrift with men.[64]

This move was based on the rationality of the electric automobile manufacturers of that time. In relation to gasoline cars, electric cars had qualities (or rather notions of qualities) that accorded with the idea of women's nature and abilities. It should, however, once again be emphasized that this perceived 'fitness' of a simple and low performance vehicle for women, originated in relation to the already existing gasoline car, and existing notions of gender.

The market strategy of these early electric vehicle manufacturers obviously failed, but it still succeeded in attaching symbolic meaning to 'the electric car' as a somewhat less male artefact. Thus to say that the electric car is a feminine artefact does not necessarily mean that women need to have liked electric cars more than men, or that women need to have been common drivers of electric cars.[65] The gendering aspects of the social construction of artefacts can still be in place, and in the case of the electric car, it is here argued to be one important and underestimated component in understanding recent activities in the field of electric vehicles.

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[62] Scharff 1991.

[63] Scharff 1991, p. 37.

[64] Scharff 1991, p. 36.

[65] For a critique of the view that mostly women drove electric cars, see Mom 1996.

Closure

As early as the year 1900 there is fairly reliable evidence of emerging closure. Gardner D. Hiscox writes:

> Already the tendency at this stage in the progress of manufacture of automobiles of all kinds of motive power is to meet the desire of owners and operators of these vehicles for great power and fast speed.[66]

Another textbook from the same year tells us about how electric propulsion was viewed in relation to this goal of power and range:

> comparatively with other methods of propulsion, electricity has met with little favour, even for short-distance work, either for private or commercial purposes.[67]

This suggests that closure, by and large, was established by the late 1890's, which is a few years before this closure can be validated by production figures. The limitations on batteries' abilities to meet these goals were also recognized early. Electric vehicles with a range of up to 100 miles were available, however contemporary engineers knew that this long range shortened battery lifespan.[68] Heavy load, from for example hill climbing, was also detrimental to the battery.[69] But this knowledge was not passed on by the battery manufacturers to the early consumers of electrics.[70] Already with the ancestor of electric cars, the electric streetcar (trolley), heavy weight and load were recognized as creating problems with battery lifespan. There seemed to soon be established a consensus that heavy electric automobiles did not work very well.[71] The solution was lightweight design, thus giving the battery a lighter load to handle. The

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66 Hiscox 1900, p. 23.

67 Beaumont 1900, p. 394.

68 See for example, Hiscox 1900, pp. 343-344. Hiscox states that a "storage battery" could propel the electric car 300 km on one charge, but will result in a "consequent short life".

69 See for example Homans 1907, p. 469., or, Schallenberg 1982, p. 251. Homans gives a strong recommendation not to exceed a 3 hours discharge rate. An "average high-speed riding" resulted according to Homans in a 4 hours discharge rate, whereas heavy-load conditions leading to a 1 hour discharge rate were regarded as detrimental to the lifespan of the battery.

70 Nerén 1937, p. 70.

71 Schallenberg 1982, pp. 251-252. Beaumont 1900, p. 394. Nerén 1937, p. 71.

'cost' of doing this was shortened range since the total battery weight also had to be reduced.

In following the discussion of contemporaries it is clear that none expected short range to be a problem. They did not see it as a risky market strategy, since they expected a demand for luxurious short-range vehicles to arise in urban milieus. The relative merits of the electric automobile in such settings were obvious, and few seemed to argue about that. It was even seen as the ideal power for vehicles in general — as soon as the "battery problem" was solved.

Later on, the developments would be further consolidated, and by 1907 the technical design of vehicles is commented upon in an engineering textbook, saying that there is a steady tendency:

> towards a greater uniformity of design, rather than toward any eccentric or novel constructions [and] toward a perfecting of a standard constructions already recognised, rather than toward anything entirely new and peculiar.[72]

So, by 1907 there is evidence that the closure was finished, as neatly summarized by this rather prophetic automotive engineer who a few years earlier (in 1900) had stated that:

> We may expect progress in the development of the automobile in several directions at once. We may build the highest types of pleasure vehicles first, for wealth and leisure to enjoy, the racer for the sporting community and from that we may meet the larger service of the more numerous classes, with the motor bicycle and tricycle; while, on the other hand, we may speed up and lighten the traction engine, transforming it successively into the autotruck and the delivery wagon, until **the developing types shall meet and fully cover all requirements.**[73] (emphasis added)

Generally speaking, in the history of technology there is a strong tendency towards a "winner take all" situation, i.e. *technological lock-in effects* reinforcing the emerging dominance of one alternative and consequently serving as a hindrance to attempts to alter this dominance.[74]

There was basically only one type of artefact and set of symbolic meaning that were to go to mass production — the gasoline car with the (internal combustion) Otto motor. Consequently, one obvious effect of this dominance of the gasoline car was that 'electric propulsion' no longer

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[72]Homans 1907, p. 132.

[73]Hiscox 1900, p. 29.

[74]For a discussion of this aspect in relation to the electric car, see (Cowan *et al* 1994). The beginning of a technological lock-in process is similar to the processes closure.

had the symbolic meaning of a technology for propulsion of cars. After closure, electric propulsion could only be established on markets far away from the mainstream alternative, for example material handling, milk deliveries, bath chairs, and more recently, golf carts. These applications were to become areas where electric propulsion was able to be established and sustained, since it did not 'attach' to cars.[75]

Commercial vehicles as a niche market

So, the city-use-only vehicle could not be established. But did not electric propulsion still have a chance to survive as a niche vehicle for short range urban delivery service? Early manufacturers of commercial electric vehicles in the U.S. were found in urban areas in the eastern states, which had fairly good roads, relatively many electric stations and a dense urban milieu. Commercial electric vehicles were used by department stores, breweries, bakeries, ice houses, newspapers and florists, but also by express companies and the cotton manufacturing industry.[76] In some large cities, such as New York, Chicago and Washington D.C., commercial electric vehicles were in fairly widespread use. New York City was perhaps the world's leading centre for electric trucks, in that 40 percent of the commercial vehicles were electric in 1913.[77] However, as shown by Raburn, these electric vehicles were essentially a replacement for the horse-drawn delivery wagon, and did not have the sort of impact on the city morphology as did their gasoline powered counterparts. Instead, the limited range of battery powered vehicles made them less interesting as the radii of commercial activities in urban areas exceeded the range of

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[75] Drawing on the history of the failed alternative of steam, and the successful alternative of diesel engines, Mikael Hård and Andrew Jamison argue that any technological alternative needs to cope simultaneously with three areas of the dominant alternative in order to compete: the *symbolic power*, the embedded *organizational structures*, and the *behavioural patterns* of users (Hård et al 1996). Hård and Jamison argue that the electric car requires too many changes on these three levels, and thus may not be able to compete.

[76] Raburn 1988, pp. 83, 89, 101.

[77] Raburn 1988, p. 86.

these electric vehicles. This problem increased as the distant suburban areas began to also host commercial activities.[78]

The commercial electric vehicle, as well as the 'pleasure' electrics, were generally discussed in terms of competition with the horse drawn wagon — as opposed to the gasoline car which established patterns of use which were totally new and different.

Cost comparisons at the turn of the century were problematic due to lack of data. A decade later, in the 1910s, the situation was somewhat more reliable. Schallenberg shows that the price of electricity sank rapidly during the first two decades of the century. At the same time the price of gasoline increased. Between the years of 1903 and 1913 the price of gasoline in the United States went up from 10 to 24 cents per gallon, while the cost of electricity went down from 23 to 7 cents per kWh. The relative merits of the electric vehicle over gasoline powered vehicles for light delivery in urban or suburban stop-and-go schedules then became evident. In 1913 a report was prepared at MIT that compared the relative costs of commercial vehicles propelled by electricity, gasoline and horses. On a cost per day basis, the horse was somewhat cheaper, but for cost per mile driven, or cost per delivery made, the electric vehicle was 75 to 85 percent cheaper than the gasoline car and the horse driven vehicle.[79]

Thus, for the purpose of this study, it seems wise to separate this interest in electric vehicles into two areas of vehicle markets; *commercial* vehicles, and *private* cars. Commercial users make use of economic rationality to a larger extent than do private persons, and they sometimes also have a rather predictable transportation pattern, which allows them to perform 'range-budgets' in a way that private car owners usually are not familiar with.[80] The high *initial cost* of an electric automobile need not therefore be a barrier for operators of commercial vehicles, as long as the *overall costs* are competitive. Also, the limited vehicle range could be handled by using these vehicles in driving patterns where this range is not a problem. Many such firms do exist (and have existed). This is one important reason that electric propulsion survived longer in the market of commercial vehicles, than in the market of private cars.

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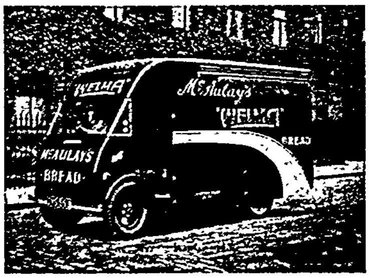
[78] Raburn 1988, pp. 74-86.

[79] Schallenberg 1982, pp. 275-279.

[80] On people's ability to learn how to make range budgets instead of only time budgets, see Turrentine et al 1995.

England is also an example of a country in which the electric vehicle had a fairly widespread use in commercial applications. Hills describes how these vehicles were used for municipal service and delivery work, and had a short but distinct renaissance between 1934 and 1939 in which the number of electric vehicles in England increased by a factor of 3.5, to a total of 5,000 (not including trucks). These electrics were used by municipalities for refuse collection, by the electric utility industry as a service vehicle and by firms for the delivery of milk and bread.[81]

Figure 3. A lightweight delivery vehicle of early 1940's



Source: From; Hills, Stanley M. 1943. *Battery-Electric Vehicles: Dealing with the Construction and Operation of all types of Battery-operated Electric Vehicles and Accessory Equipment.* London: George Newnes Limited, p. 10.

For the delivery of food, the cleanliness of this type of vehicle was used as a sales argument.[82] In the early 1940's a lightweight electric delivery wagon had range of 80 km on roads with good surfaces and moderate gradients. The maximum speed was about 40 km/h. The corresponding performance for a 5 ton truck was 56 km at a maximum speed of 20 km/h.[83] The speed of these vehicles was of course lower than that of a gasoline powered vehicle of the same type, but in frequent stop-and-go service the electric vehicles were able to achieve higher average speeds. This was mainly due to the higher torque of electric motors and that the electric vehicles did not use multiple-gears, that required the

[81] Hills 1943, pp. 5, 7, 75. Also Germany had quite a few electric vehicles. The German Reichspost, for example, had about 2,500 electric vehicles in use by mid 1930's (Electrical Review 1934).

[82] Hills 1943, p. 12.

[83] Hills 1943, p. 10.

disengagement of motor torque every time the gear was changed.[84] The effect of this is shown in the table below.

Table 1. Time tests for three types of vehicle over a measured mile

	Time in minutes	
Vehicle	Stopping every 10 yards	Stopping every 20 yards
Horse-drawn	33	32
Petrol (2-tonner)	15	11
Electric (2-tonner)	11	9

Source: Hills, Stanley M. 1943. *Battery-Electric Vehicles: Dealing with the Construction and Operation of all types of Battery-operated Electric Vehicles and Accessory Equipment.* London: George Newnes Limited, p. 10.

After the outbreak of W.W.II there were government plans in England to develop and produce 1,000 units of a 1-ton electric delivery wagon. On the suggestion of the Ministry of Supply, the Electric Vehicle Association formed a sub-committee for working out standards for a 1-ton payload delivery vehicle. It was designed with a 8 hp G.E.C. manufactured motor, a Wilson four-speed controller and a 48 V lead-acid battery arrangement. The rationale for this action was the fact that electricity was produced in England (from coal), while oil was not. However, the war also had negative impacts on the supply of materials, and the proposed production of the vehicles was cancelled.[85]

Renewed interest in electric propulsion

There are three important causes of renewed societal interest in electric vehicle propulsion. Taken in order of appearance during the history of the automobile, they are; *oil shortage* and the consequent emphasis on energy conservation, *air pollution* and environmental and health concerns, and finally, the establishment of a *new industry* (and thus also the rescuing of an old one). Oil shortages during the wars developed interest in electric propulsion in many countries that did not possess domestic oil. Beginning with the oil crisis of the 1970's, even the U.S. started to consider electric propulsion for reasons of oil security. Environmental concern established

[84] Hills 1943, p. 150.

[85] Hills 1943, p. 203.

itself on the political agenda from the late 1960's. These two societal concerns (energy, and health) merged in the more recent discussion of the possibility of establishing an advanced transportation industry in California, which could counteract the recession that began in the late 1980's in the high-tech industry in California due to declining federal funding from the Department of Defense.[86] The techno-politics of air pollution and this new industry will be covered in chapter III.

Oil conservation was the rationale in the U.S. for the introduction of the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976. The U.S. was becoming increasingly dependent upon foreign oil, an issue raised after the oil crisis in 1973. The field of transportation being the single largest consumer of oil, Congress perceived that dependence on foreign oil for this sector:

> jeopardizes national security, inhibits foreign policy, and undermines economic well-being.[87]

Electric cars, as opposed to gasoline cars, would be propelled by electricity, generated from coal and nuclear plants. The program, a six year, three phase, 160 million dollar effort was described by Congressman McCormack in the following way:

> The Members of Congress have clearly understood that in order for electric vehicles to gain acceptance by the consumer public, the present state of the art must be greatly improved and, in addition, there must be a concerted effort to place these new cars in service on the American scene where people can drive and evaluate them [pointing out that what has to improve is] the extension of battery operation between charges[88]

Battery research had been carried out by the administrating organ, the Energy Research and Development Administration, even before the passage of the 1976 electric car act, but the act was perceived as having boosted this development.[89] Phase one of this program aimed at establishing standard criteria, using state of the art technology. Phase two was to be a technology procurement of 2,500 electrically converted cars which were to be leased out throughout the nation and evaluated. Based on this evaluation, new criteria would be set for a phase three purchase

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[86]Scott 1993, p. 16.

[87]15 U.S.C. 2501.

[88]Reprinted article from 1976 by Congressman McCormack, in Wakefield 1993, p. 496.

[89]Wakefield 1993, p. 154.

program of up to 5,000 electric vehicles.[90] These vehicles were to a large extent to be used by the federal agencies of the Postal Service, General Services Administration and the Secretary of Defence, who were to:

> arrange for the introduction of electric and hybrid vehicles into their fleets as soon as possible.[91]

Even though this act did not result in a long range 'super battery' or any other significantly new EV technology, it did create a fairly large fleet of electric cars. An example of a company that this program helped to put vehicles on the road is Jet Industries, a family company in Austin, Texas. This company started to manufacture electric cars in the early 1980's, and over a period of two years converted 1,400 cars based on gliders (i.e. cars without complete drive lines) from Chrysler and Ford.[92]

In 1981 they sold electric cars with air conditioning, remote control mirrors and a four-speaker stereo system which was claimed to be "extra enjoyable" due to the quiet operation of these vehicles. They were equipped with a 20 horsepower series-wound 96 volt DC motor, weighing about 50 kg, controlled by a transistor operated controller. The battery pack consisted of lead-acid batteries totalling 450 kg, giving the cars an 80 to 120 km range in freeway driving. The acceleration was fairly modest, at least for on-ramp acceleration: about 8 seconds to reach 50 km/h and 23 seconds to reach 80 km/h.[93]

Approximately half of the cars were sold to government fleets, and the other half were sold to individuals to serve commuting needs. The vehicles were subsidized by the 1976 Electric Car Act, and rebates were offered to the consumers. However, this federal program was suspended in 1982, which was unfortunate for Jet Industries. They went out of business in 1984.[94]

To cope with the range problem of electrically converted gasoline cars with commercially available components, another technological strategy than simply converting gasoline cars to electric propulsion was tried. The simple, small, slow and low-acceleration electric vehicle has been tried as a possible way to go — drawing on the strategy that if electric propulsion technology is hard to improve, a shift of focus from

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[90] Wakefield 1993, p. 496.

[91] 15 U.S.C. 2510.

[92] Skokan 1995.

[93] Technical data are from a Jet Industry fact sheet, dated 1981.

[94] Skokan 1995.

the drive train to the vehicle itself might be a way out. People in the electric vehicle 'culture' perceived, and to some extent still perceive, that the electric vehicle should be rather small, making use of lightweight design — even if such a vehicle would have to diverge from what a car usually looks like.

An example of a vehicle of this type is the CitiCar, which was sold in fairly large numbers in the U.S. by the mid 1970's. The company Sebring Vanguard Inc. had sold over 2,250 of these vehicles, and according to the man behind this car, Robert G. Beaumont, several hundred CitiCars are still in use and have accumulated over 30,000,000 km without fatal accidents or any serious injuries (which was a major concern in the 1970's). The CitiCar was a simple vehicle, based on golf-cart technology (both as to the technical content and to vehicle form) and Beaumont himself did not think of it as a "real car".[95]

Still, consumer expectations measured this vehicle according to the standards of real cars, which in turn created a low public acceptance.[96] Today this technical point of view is giving way to a more market sensitive approach, saying that the electric car has to look, feel, and behave exactly the same as the gasoline car.[97] The basic view that lightweight design is desirable seems still persistent, but the proponents of the mid 1990's are also aware of the huge marketing effort needed to launch a totally new vehicle for commuting purposes, especially in a situation where automakers are projecting a small market size for such restricted vehicles.

While looking into the background of the periods of renewed interest for the electric car, it should be acknowledged that electric car enthusiasts (few as they may be) have been important developers and sustainers of 'electric-car-culture'. One mainstay of this culture is the Electric Auto Association, which was formed in 1967 in San José.[98] The organization has at present about 1,700 members (mainly engineers) with an estimated electric car ownership of about 800 cars. The idea behind the creation of this organization was to educate the public in how to convert their own

[95] Letter to author from Robert G. Beamont, (Beaumont 1993).

[96] Skokan 1995.

[97] Skokan 1995.

[98] Skokan 1995. Kirsch argues that the formation of this organization was one important step towards a challenge of the gasoline car (Kirsch 1994).

cars to electric propulsion, since: "at that time, no automaker was interested in building electric cars."[99]

This social movement was expected to *start an initial market*, thus encouraging the automakers to build electric cars themselves. This initial market never arose, but still, since the start the organization had a tradition of fighting the big automakers. This has recently changed due to the processes pertinent to the mandated introduction of electric cars:

> Right now it does not make any sense to fight them, because the electric car is not going to happen until they [the automakers] do it[100]

III. THE ELECTRIC CAR CONTROVERSY

Social actors

The electric car controversy was initiated by the zero-emission vehicle mandate in 1990, and is about the question whether or not standards of air quality as defined in federal legislation can be reached within the dominant gasoline car technology, or if a zero-emission car is needed. The controversy can be seen as consisting of many *sub*-controversies, of which several will be outlined in subsequent chapters. All these sub-controversies were initiated by the 1990 mandate, and were to affect the outcome of the controversy.

The central actor of this controversy is the state air agency, the *California Air Resources Board* (CARB) of the California Environmental Protection Agency. The Air Resources Board has the authority (and responsibility) to make regulations that meet federal and state standards of air quality. The regulation triggering the controversy under study, the zero-emission vehicle mandate, is argued by the Air Resources Board to be a necessary measure in order to meet the requirements set by the federal Clean Air Act.

[99]Skokan 1995.

[100]Skokan 1995.

The *automobile manufacturers* of interest here are those affected by this 1990 zero-emission vehicle mandate: three U.S. companies, General Motors, Ford, and Chrysler, and four Japanese, Toyota, Honda, Nissan, and Mazda. Within the scope of this study, it would be impossible to cover the whole industry. Therefore, the main focus will be on the most important automaker in this controversy, General Motors, and the activities of the lobbying organization of the U.S. automakers, the American Automobile Manufacturers Association.

Oil companies have been very active in activities against the mandate. The lobbying organization of many oil companies in the U.S., the Western States Petroleum Association, and the oil company Mobile Oil have launched several public campaigns in the media.

Health and environmental organizations, so-called non-governmental organizations (NGO's), have been very active in countering these attacks on the mandate, and have strongly supported CARB and their zero-emission vehicle mandate. These NGO's have links to academia and are well prepared to enter into scientific controversies on air emissions. Organisations that have been active are, for example, the American Lung Association, the Coalition for Clean Air, the Natural Resources Defense Council, the Environmental Defense Fund, and the Union of Concerned Scientists.

The *electric utility industry* is an important social actor, with a long history of interest in electric cars. Active in preparing the electric infrastructure needed for a large scale introduction have been: the research body of this industry, the Electric Power Research Institute (EPRI), and also individual electric utility actors: Southern California Edison, the L.A. Department of Water and Power, the Pacific Gas and Electric Company, and finally the Sacramento Municipal Utility District. Active in supporting the mandate has been the lobby organization, the California Electric Transportation Coalition (Cal ETC).

New industry, so-called *start-up companies,* has played an important role in supporting CARB in maintaining the mandate, in that these commercial activities are described as a direct cause of the mandate. This support of the mandate has consisted in their presence at hearings at CARB as well as their playing an important role in the debate on the side of the actors who have supported the mandate. Different types of start-ups have emerged. First, the high-tech industry in California started to take an interest in this new market and has joined the umbrella organization

Calstart.[101] Other types of firms are making converted electric cars, for example U.S. Electricar, or trying to create new designs, such as the Michigan firm Solectria, or specializing in developing new technology, for example AC Propulsion.

The following chapters on the actors, activities, and arguments of the electric car controversy, will not be outlined in a strict chronological presentation, but through focusing on the controversy from different angles.

Origin

The U.S. have a long tradition of technology forcing activities. The Federal Environmental Protection Agency established so-called national ambient air quality standards for six criteria pollutants: carbon monoxide, ozone, particulate matter, sulphur dioxide, nitrogen dioxide, and lead. The states are given the responsibility to develop plans to meet these standards, and they are given the authority to force industry to follow these standards. This is the regulatory authority which California has used to take the lead in national air regulations.[102] The basis of this regulatory framework was established in 1970, when major changes in the overall air policy strategies of the U.S. took place and were embodied in the 1970 Amendments to the Clean Air Act.[103] The Clean Air Act initiated a new era in automotive emission regulation, both enabling the introduction of the three-way catalytic converter, as well as serving as the basis for California's initiative to introduce electric vehicles 20 years later.

The major shift in air policy issues in the 1970's was from an earlier focus on the technical and economic feasibility of control measures, to a focus more guided by the protection of public health, and also a shift towards an increased federal role in setting standards, and in enforcing

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[101] Calstart have (as by spring 1995) over 120 members, ranging from small entrepreneur firms to large high-tech companies. Its mission is to recreate high skilled jobs, clean the state air, and restore global competitiveness. The strategy is to enhance knowledge sharing across borders of firms, and to help to establish relationships between these firms (Gage 1995).

[102] Bryner 1993, pp. 42, 83, 150.

[103] Lundqvist 1980, p. 61.

these standards.[104] This was carried out through national air quality and auto emission standards with strict timetables for meeting these new requirements.[105] Public pressure for cleaner air was very strong in 1970. In a 1970 Gallup Poll, 58 percent answered that the presidential candidates' stands regarding pollution control were extremely important in their decision in the upcoming election.[106]

The 1977 amendments to the federal Clean Air Act called for the whole nation to have achieved clean air by 1987, but California could not meet this requirement:

> California, indeed, did its [state implementation] plans [1979, 1982]; probably, I believe, the most comprehensive in the world. But, at that time, we still could not forecast clear air in all of California's areas by the mandatory deadline of 1987.[107]

Thus by the late 1980's it was clear to air agencies in California that the state would not be able to achieve air quality goals. The projections of immigration into the state, leading to more cars being bought and driven, together with the trend of an increase in miles driven by each car, indicated the need for a more radical control measure. This was made explicit in the plan presented by the air agency of the Los Angeles area, the South Coast Air Quality Management District.[108] In 1988 the district presented a plan which asked for more radical technical changes that would lead to the implementation of:

> passenger vehicles operating on clean fuels such as electricity or methanol within the next twenty years.[109]

At the state level, this goal was embodied in the California Code of Regulation of 1990, with the explicit requirement that a larger number of electric cars be introduced in California.[110]

In retrospect, it can be seen that the late 1980's was a period of converging actions that finally were embodied in this 1990 decision of the California Air Resources Board. It is always difficult to argue for causal

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[104]Lundqvist 1980, p. 61.

[105]Lundqvist 1980, p. 61.

[106]Lundqvist 1980, p. 117.

[107]California Air Resources Board 1995f, p. 106. Statement by CARB Staff Executive Officer, Jim Boyd.

[108]South Coast Air Quality Management District 1988.

[109]South Coast Air Quality Management District 1988, p. 7-2.

[110]California Air Resources Board 1990a.

relationships between events, because one has to extract a few things out of historically intertwined processes. Still, the following chapters are here suggested to be one possible and relevant description of the events that led to the introduction of the zero-emission vehicle mandate.

Alternative Fuels

The AB234 Commission

In the late 1980's there were attempts in California to introduce alternative fuels (i.e. methanol) that would reduce emissions of criteria pollutants and, to the extent that they were produced from domestic natural gas, reduce dependency on foreign oil. In 1987, a state assemblyman (Lennard) introduced a bill, AB234 that would mandate oil companies to start marketing methanol as an alternative fuel, and car companies to start building methanol cars.[111] The bill passed the assembly but not the state senate. Instead the senate appointed a commission that was to look into alternative fuels in general, and not only methanol. Chaired by Jannane Sharpless, who a few years later was to play a key role in the creation of the ZEV mandate, this commission laid the basis for a systematic approach to regarding fuels and vehicles as a system.[112] The bill:

> gave rise to a competition between methanol and reformulated gasoline, and [the oil company] ARCO was asserting for years that reformulated gasoline could be as clean as methanol.[113]

Industries that are to a large extent entrenched, often try to handle external pressure by employing conservative changes, and the oil industry is no exception.

Bryner shows how the threat of requirements for cleaner fuels was handled by the oil industry on a federal level. Before the 1990 Amendment of the federal Clean Air Act, there was a hard fight over fuels, with the oil industry standing in the middle. In 1989, the oil company, Atlantic Richfield (ARCO), stated that they were able to produce a cleaner gasoline variant that would reduce ozone and air toxins

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[111] Wuebben 1995.

[112] Wuebben 1995.

[113] Wuebben 1995.

from automobiles without having to change anything in the vehicles. This fuel was called 'reformulated gasoline'. This move by ARCO made it easy for Congress to impose this requirement on all oil companies. Reformulated gasoline was also supported by the environmental community, but above all, it was supported by economically strong Midwestern agricultural interests who expected new markets to arise from the use of additives which were to be produced from grain. Methanol did not at that time enjoy any powerful economic or political support, and consequently, few requirements were explicitly made for the use of methanol.[114] But as will be shown below, electricity as a fuel did find such support.

CARB and alternative fuels

In December 1989, the CARB staff delivered a "progress report" to the Board which outlined the vehicle-fuel systemic approach.[115] In this proposal there were only three categories of vehicles: transitional low-emission vehicles (TLEV), low-emission vehicles (LEV), and ultra low-emission vehicles (ULEV). Both TLEV and LEV were regarded as gasoline vehicle categories. The most stringent category, the ULEV, however, was at this time said to be an *alternatively fuelled* vehicle. In discussing ULEV's, the staff noted that:

> The standards for ULEVs are based on the capabilities of electric- and compressed natural gas powered vehicles, and the projected emission capabilities of vehicles equipped with an electrically heated catalyst, fuelled with methanol, ethanol, liquefied petroleum gas, or, possibly, reformulated gasoline.[116]

Note the order of precedence of fuels. Still, looking at the promising measurements made of a gasoline powered vehicle with an electrically heated catalyst in the report, it must have been obvious to staff and board in 1989, that the automakers would prefer to achieve ULEV emissions using a gasoline car, and would probably succeed. This interpretation is also supported by statements made by one of the engineers who worked

[114]Bryner 1993, pp. 134-140.

[115]California Air Resources Board 1989, p. 1.

[116]California Air Resources Board 1989, p. 24.

on these measurements of a gasoline car with an electrically heated catalyst:

> we then knew, through SAE conferences, that an electrically heated catalyst was possible...we were able to achieve, successfully, ULEV levels before the regulation was set.[117]

Consequently in the staff report released in August 1990, that preceded the regulation in September the same year, this was made explicit, stating that:

> The standards for ULEVs...are based on the capabilities of vehicles powered by gasoline and equipped with an electrically heated catalyst.[118]

Still, the intentions of the staff concerning electric vehicles were also clear, at least as early as 1989, and electricity did have some support, as opposed to the other non-gasoline fuels.[119] This meant that only reformulated gasoline and electricity had support when CARB outlined its new program.

In addition there was the promise of an electric sports car from General Motors, the Impact. But before taking a closer look at the status of electric car technology at that time, there are more events in the late 1980's that paved the way for the ZEV mandate.

The City of Los Angeles Initiative

In the late 1980's, the Los Angeles basin area was far from living up to federal standards for clean air. The Environmental Protection Agency then threatened California with a moratorium on business expansion in the Los Angeles area, so this time air pollution was actually threatening business.[120] Councilman Marvin Braude started to look for ways to stimulate electric vehicle business, which led to the L.A. Initiative.[121]

The basic idea that Braude had in the L.A Initiative was to make use of the power that a City Council has over its own city. Local business,

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117Osborn 1995.

118California Air Resources Board 1990b, p. 32.

119Paul Wuebben argues that: "the staff [of CARB] recognized that the [electric] utilities were in a strong political position to help them adopt this EV mandate" (Wuebben 1995).

120Braude 1989.

121Skokan 1995.

industry, governmental organizations as well as private citizens were to be persuaded to buy electric cars, which in turn would persuade the car manufacturers to start to build these cars in quantity, since according to Braude, the auto industry was:

> so tied to internal-combustion engines that it has been unwilling to show the initiative that would have been required.[122]

Braude's plan was to change this situation by the creation of an 'initial market', essentially the same idea as the Electric Auto Association attempted in the late 1960's. The plan was introduced on May 6, 1989, after discussions with the large electric utility company, Southern California Edison and America's largest municipally-owned utility, the L.A. Department of Water and Power. In the hearings preceding this proposal, Braude argued that enthusiasm was even to be found among representatives from the major auto manufacturers.[123]

The GM Sunracer[124]

A car propelled solely by what is delivered from solar cells on the roof is, of course, the ultimate vision for a future sustainable transportation mode; and to some extent it has been shown to be at least partly feasible, for smaller urban vehicles in sunny areas of the earth. This is the so-called Asian Car concept. The GM Sunracer was developed mainly by three very diverse actors: the car manufacturer GM, the Hughes Aircraft subsidiary of GM, and by AeroVironment. Also, as we will see later on in the description of the GM electric sportscar, several of the actors in the GM Sunracer project are to be found as key actors in the Impact project. The World Solar Challenge contest in Australia was a 3,000 km cross-country race, from Darwin in the north to Adelaide in the south. The invitation to this contest was mailed directly to the Chairman of General Motors at that time, Roger Smith. The Office of the Chairman passed it on to Howard Wilson, vice-president of Hughes Aircraft (a GM subsidiary). For Wilson, this offered an opportunity to demonstrate

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[122]Braude 1989.

[123]Braude 1989.

[124]This section builds largely on one book, (Tuckey 1989), but according to one of the key persons in the Sunracer project, Dr. Paul MacCready, this book gives an adequate picture of the history of the Sunracer (MacCready 1995).

synergy between automotive and aircraft technology. Also, Bob Stempel, who was later to become the head of GM, recognized this opportunity to bridge the gap between the automotive side of GM and the high-technology side by supporting the Sunracer. Still, the car to be built did not represent any of the mainstream activities of either GM or Hughes Aircraft, thus they needed someone to actually put this vehicle together. AeroVironment, a small and highly specialized firm in California was asked by Wilson to join. Money was to come from GM, Hughes had extensive experience in solar panels, Delco Remy had knowledge about electric motors and AeroVironment knew how to build extremely light-weight structures. The first step was to prepare, within three weeks, a proposal to be presented to GM executives (on resources allocated by Stempel). The GM Executive committee approved the proposal to build a solar powered car for entry in the World Solar Race in Australia in 1987. The car, of course, looked peculiar, more or less like a very big wood-louse, since it had been designed to minimize air and rolling resistance, while at the same time offering as much exposure to the sun as possible.

It turned out that the Sunracer travelled the 3,000 km at an average speed of 67 km/h without any competition at all from the other vehicles. Of course, this was due to the amount of resources that were poured into this project, where AeroVironment played a key role as a program manager. However, AeroVironment was once more to play an important role for GM. AeroVironment made a proposal to GM that they collaborate on a 'real' electric car.

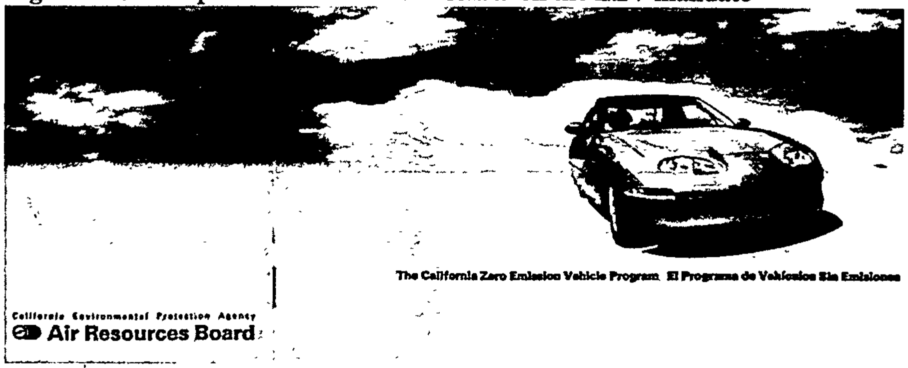
The GM electric sports car

The basic nodes and relations of a working network were already established by the work on the Sunracer. Thus when AeroVironment proposed to GM a project aimed at building a full sized high performance electric car, this could be done in a short time period.[125] AeroVironment, having a very low degree of inclusion in the technological frame of traditional automotive engineering, proposed to GM that they could build

[125] According to Paul McCready, Chairman of AeroVironment, and Alan Cocconi, who built the controller, the Impact project was initiated by AeroVironment and not GM (MacCready 1995, Cocconi 1995).

a full-sized battery-only electric sports car. The idea was supported by the chairman of GM, Roger Smith, and AeroVironment worked together with GM's design people and electrical engineers at Hughes to develop the car that was finally introduced by Smith at the Los Angeles Auto Show in January 1990.[126]

Figure 4. GM Impact on a folder from CARB on the ZEV mandate



Source: California Air Resources Board.

The first Impact was designed in moulded fibreglass with two 57 hp AC induction motors, one at each of the front wheels. This made the car very light, about 1,000 kg, even though it was carrying a 395 kg lead acid battery pack with an energy capacity of 13.5 kWh at a 2 hour discharge rate.[127] This car can be seen as embodying the "doing more with less" philosophy of Paul McCready at AeroVironment. Very low losses in the electrical components of the drive line allow for high power output without overheating, and the extremely good streamlining of the light vehicle body and the minimizing of rolling resistance enable this car to travel about 200 km in highway or urban driving.

[126]Fichetti 1992, pp. 34-43.

[127]Wakefield 1993, pp. 288-295.

Stabilization

The Automobile Industry and the Mandate

The automobile industry is, to say the least, a problematic actor to give a simple and comprehensive description of. Sometimes they have worked together in support of electric cars (as for example in battery development), whereas in other cases this collaboration has instead been directed towards fighting electric cars (as with the American Automobile Manufacturers Association lobbying activities). But above all, these companies are tough competitors, and it is unlikely that they have been collaborating on many aspects of electric car development. Also, a single company such as GM can be treated as a single actor in one focus of a study (e.g. as regards their official position), while at the same time being regarded as several actors when looking closer (e.g. at electric vehicle development units versus other units).

Generally speaking, the automotive industry in the United States seems unwilling to let legislative officials know about technological progress made within the industry, because legislative authorities tend to set requirements as soon as they think a certain technology is available. In a way, of course, the technologies may become available just because they are required by regulations. But for industry, it is undesirable to have requirements imposed on them every time they reveal something new. Based on the above argument and based upon the fact that General Motors must have been aware of the discussions on electric cars at CARB, the presentation of the GM Impact at the L.A Auto Show in January 1990 must have been a conscious action. GM knew that regulations were to be adopted by CARB in September 1990 and that electric cars were being discussed.[128] Obviously the regulation would be affected by this unveiling. What GM obviously did not expect, however, was a "sales mandate" of electric cars that would affect not only GM, but also their main competitors.[129] Through this move by CARB the market niche GM

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[128]Here referring to public documents available from CARB that must have been seen by GM, which was to be influenced by the regulations. See also (Wallace 1995, p. 163.).

[129]By 1995, GM talks about the mandate as being caused by the GM Impact (California Air Resources Board 1995g). Technically, CARB cannot require auto makers to sell electric cars, but they can set requirement for the cars to be certified for the California car market. Therefore auto makers under the ZEV mandate are required to certify zero

planned on having to themselves was with divided among seven different companies, thus making it hard to exploit profitably. As put by an official from GM:

> The CARB ZEV requirements that would force six major competitors into the EV market made a shamble of our business case for the Impact vehicle.[130]

The regulation that was adopted in September 1990 by the CARB was called the Low Emission Vehicle Program, and contained *four* emissions categories for cars; 1/ Transitional Low Emission Vehicles, 2/ Low Emission Vehicles, 3/ Ultra Low Emission Vehicles, and 4/ Zero Emission Vehicles. The ZEV category was soon to become very controversial, which also led to ZEV being treated as a separate program, even though it formally was given legislative authority within the adopted Low Emission Vehicle program of 1990. As of the actual adoption date (in 1990) and at the hearings preceding this adoption, there had been very little discussion, about the ZEV requirement even though the auto industry made it clear that they did not like a mandate.[131] The discussions focused instead on the other (gasoline car) low emission categories.[132]

For GM, we already know that they anticipated having an electric car on the market by the mid 1990's (a not confirmed but widely discussed date was the year 1994), but they never expected this car to actually take a major market share from gasoline cars. They perceived the electric car to be a very nice niche-vehicle that: "will meet limited customer demands".[133] CARB, on the other hand, had much larger expectations. They actually wanted to replace gasoline cars in California with electric cars, and they wanted that process to start.[134]

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emission vehicles, which in practice means that they have to be produced, and if they are not to just be stored on a big parking lot, they have to be sold. This is why industry talks about a "sales mandate".

130California Air Resources Board 1996c, p. 320.

131California Air Resources Board 1990c.

132Evashenk 1995.

133California Air Resources Board 1995g, p. 195. Another example is a statement of former Chairman Robert Stempel, saying that: "We sell passenger cars, sports cars, vans, light-duty trucks—a vehicle for each life style...so why not an electric car for your commuting needs?" (Fichetti 1992, p. 42-43.).

134See for example the 1989 South Coast Air Quality Management Plan, which proposes that: "...virtually all the passenger cars in the region should be electric (or other "ultra-low emission" fuel, if any emerge) by the year of 2010.", as referred to in (The California

The increasing percentage figures in the ZEV regulations reveal this. The 10 percent figure set for 2003, was not conceived as an upper limit to the size the market for electrics eventually could attain, such as it has been interpreted by automakers. And even as of late 1996, it seems that the automakers have not yet fully understood this underlying message — that after 2003, the gasoline car is meant to be phased out. And indeed, the rather stabilized notions of the pros and cons of electric versus gasoline propulsion, prescribe that electric propulsion is by definition not competitive with gasoline. Thus it is not very surprising that auto manufacturers have not fully understood this message. For the CARB people, having a very low degree of inclusion in the technological frame of automotive engineering, this step may have seemed radical, but at least conceivable.

Initially, GM was to market the Impact in the mid 1990's but by December 1992 production plans were halted due to low expected sales, technological uncertainties and economic problems within GM as a whole, but also due to the mandate itself. GM thought that they would need two or three different electric cars to be sure to meet the required percentages of the mandate (2% in 1998-2000, 5% in 2001-2002, and 10 % in 2003). This was considered too costly, and at the first bi-annual revision (1992) of the ZEV mandate, General Motors joined the rest of the Big Seven automakers in staunch opposition to the ZEV mandate.[135] Before this date GM had not taken a strong stand against the mandate. In the 1992 revision, six years before the mandate was to take effect, CARB determined that the ZEV mandate was still technologically and economically feasible, on the basis of which they assured that no changes in the regulations were to be made.[136]

Electric Vehicle Task Force 1989, p. 7.) or statement by CARB: "...ZEVs is an important step toward the ultimate goal of achieving a vehicle fleet largely composed of vehicles which have emissions that approach zero.", in (California Air Resources Board 1990b, p. 17), or statements by CARB chairman John Dunlap at Eco Expo in Los Angeles in Aril 1995, saying that: "just as the motor vehicle replaced horses, the vehicles that are being pioneered today will replace combustion engines.", in (Electric Vehicle Progress 1995), or similar statements by Jim Boyd, (Boyd 1992).

[135]Schweibold 1995, p. 103-107.

[136]California Air Resources Board 1994a, p. 1.

Even though GM could have managed to do what was required by the mandate and still survive, the two smaller brothers within the big three could probably not have managed to develop a mass production electric car from scratch, at least not by the 1998 start-up year. As in earlier cases in American automotive history, Big Brother does not severely hurt the smaller brothers, even if he can. From 1992, until the mandate was dropped by CARB in late 1995, GM, Ford and Chrysler stood unified against CARB, at least rhetorically.[137]

GM have since 1992 argued that they are "...not against EV's, they're against the mandate", and they have acted rather consistently during this process.[138] And at this point, too much prestige had been poured into the GM Impact, so GM could not really back out of it. To preserve its competitive advantage and the faith of the public, GM launched the PrEView Drive program, which is described by a GM official as being:

> the industry's most far-flung, most aggressive, most expensive [$32 million] customer and technology research project ever conceived.[139]

In September, 1993, production began of 30 GM Impact cars that over a two year period were to be placed in the hands of about 1,000 drivers participating in this program, each driving the car for a couple of weeks.[140] Drivers would also have a generic infrastructure accompanying the cars, thus simulating a real market situation where the needed infrastructure had already been developed. The responses from drivers were extremely positive, and again GM was oriented towards actually putting these cars on the market. The initial name of the program, "Proto-Demo" program, encourages this interpretation. This "market survey" by GM was not meant to be anonymous, and it was meant to be a success. The cars was meant to be seen, to be talked about.

By the bi-annual revision of 1994, the automakers had geared up their opposition since it was now clear that CARB was really going to require these electric cars to be on the market by 1998. And even this revision was ended by CARB concluding that they did not see any major technical

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137On GM's shift in 1992, see California Air Resources Board 1992.

138Citation from statement of Robert Stempel, GM, at the plenar discussion of the 12th Electric Vehicle Symposium in Anaheim, California, 1994.

139Schweibold 1995, p. 107.

140Schweibold 1995, p. 107.

or economical reasons that would make the introduction of electric cars impossible.[141]

In 1995, GM made it relatively clear that once CARB dropped the mandate, they would put their electric sports car on the market, a message that had been implicit for a while.[142] And as soon as CARB announced its intention to alter the mandate, GM started to move again and announced that they would produce the electric sports car (the GM Impact, version-5) under the name "GM EV-1". In practice, they had been preparing for this during the several years of the battle over the ZEV mandate, just waiting for the right moment to come.

Still, there were two other strong forces acting on CARB in late 1995. One was Governor Pete Wilson, who urged for more market oriented regulatory approaches (i.e. doing away with the mandate), and the other was a report on the commercial availability of advanced batteries (a report used by CARB to close the controversy). Both these acting forces will be described in more detail in subsequent chapters. Another important dynamic of this controversy was the attempt by other states to follow Californias' lead, and regulate an electric car market.

Diffusion of Electric Car Requirements to the North-Eastern States

Ever since the enactment of the federal Clean Air Act Amendment of 1970, California has been allowed to adopt its own vehicle emission standards,[143] and from 1977 on, Congress has also allowed other states to choose between federal standards *or* the more stringent California standards.[144] The amendment of 1970 directs the federal Environmental Protection Agency (EPA) to establish national standards with which all states have to comply, the so-called National Ambient Air Quality Standards (NAAQS). The responsibility for attaining these standards,

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[141]California Air Resources Board 1994c.

[142]This is of course never made explicit by GM, but it is the underlying message from statements by GM at the June 28, 1995 CARB workshop (Purcell 1995) and at the concluding hearings in December, 1995 (California Air Resources Board 1995g).

[143]Lundqvist 1980, p. 74.

[144]Belden 1993.

however, was placed at the state level, together with instruments for enforcement. In order to fulfil this, states are to submit plans to the EPA that show how they will comply with the standards in a 'State Implementation Plan'.[145]

The LEV program adopted in California with the ZEV component is one part of such a plan. If these plans are not made, or if the plans submitted to the EPA do not make it probable that the standards will be met, the EPA may come in and take over the state's role and implement a "Federal Implementation Plan".[146] California, having the most difficulties in attaining these standards, has set increasingly stringent vehicle emission standards in order to comply with the federal NAAQS. But until the early 1990's no other state had chosen the California standards instead of the federal ones for motor vehicles, and consequently there has been a "49-state" auto market with federal regulations, and a "1-state" (California) market.

In September, 1991, the Northeast States for Co-ordinated Air Use Management (NESCAUM), presented a study which outlined the benefits of adopting the California LEV program, and one of the key findings was that after 2005 the air quality benefits of the California program would be significantly better than those of the federal regulations.[147] It was shortly after the release of this report from NESCAUM, that nine eastern states New York, New Jersey, Pennsylvania, Massachusetts, Virginia, Maryland, Delaware, New Hampshire, Maine, and the District of Columbia, announced that they would seek to adopt a program similar to the California LEV.[148] The first states to actually do this were New York and Massachusetts in 1992, followed by Maine, Maryland and New Jersey in 1993, thus making a total of five states.[149]

For the automakers, this situation was starting to get out of hand. If the ZEV requirement were to spread to most of the regions that had problems with attaining air quality standards, the required number of ZEV's to be produced might be several times higher than if only California were to have the ZEV requirement.

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[145]Bryner 1993, p. 83.

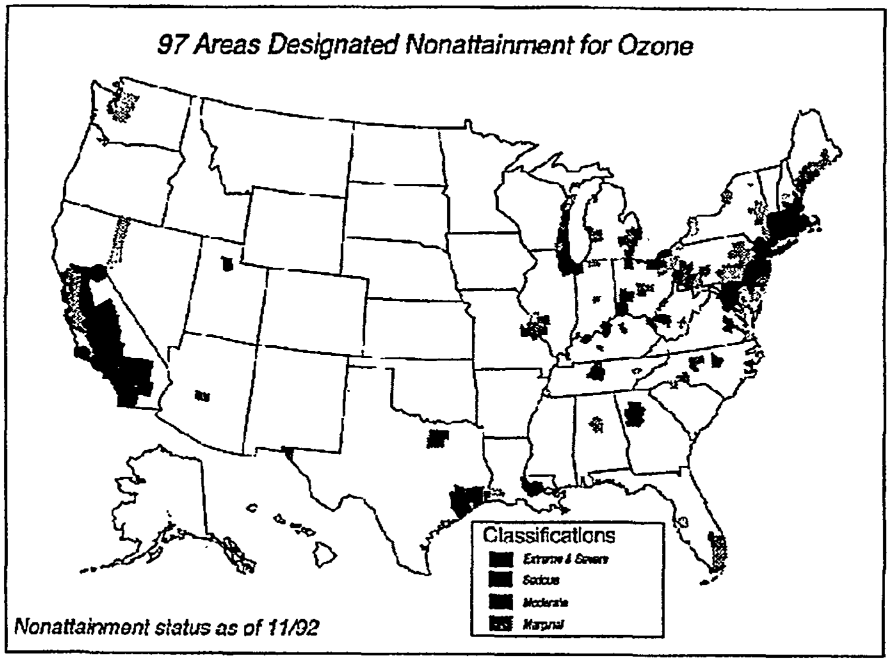
[146]Wallace 1995, p. 122.

[147]Electric Transportation Coalition 1992.

[148]Electric Transportation Coalition 1992.

[149]Electric Transportation Coalition 1993.

Figure 5. Non-attainment areas for ozone in U.S. in 1992



Source: From Office of Mobile Sources, Environmental Protection Agency. *Automobiles and Ozone.* Fact sheet OMS-4 (EPA 400-F-92-006), dated January 1993.

The lobbying organization of the U.S auto industry, the American Automobile Manufacturers Association, tried to stop this diffusion process of the ZEV requirement to other states by starting a legal process against the states of New York and Massachusetts, questioning whether these states' action was supported by the Clean Air Act or not.[150] On trial was the fact that the states tried to adopt the "clean car" part of the California LEV program, without adopting the "clean fuels" part, and it was not clear at the time whether or not this separation was legally supported by the Clean Air Act. The Clean Air Act allows states to adopt the California rulings, but it does not allow them to create a situation where there would be a third type of car required, besides the federal and California vehicles. The automakers' lobbying organization initially blocked New York by court decision using the "third car argument".[151] Having to fight

[150]Electric Vehicle Progress 1992.

[151]See for example, (Electric Vehicle Progress 1992), or (Belden 1993). The legal twists and turns of this story will not be further outlined here.

the 'Big three' U.S. automakers, these states sought allies.

These were to be found in the Northeast, in states that have problems meeting ozone standards. These states are defined by the Clean Air Act (as amended in 1990) as the Ozone Transport Region (OTR).[152] The creation of such a region was due to the fact that air pollution is no respecter of state borders. Both ozone and its precursors are transported by the wind, causing air pollution problems and non-attainment in other states than those where they are emitted, which affects a state's possibility to meet federal requirements.

Following the statutory requirements of the Act, a commission was established in 1991 consisting of the Governors (or representatives appointed by the Governor) and EPA officials.[153] This commission, called the Ozone Transport Commission (OTC), became enmeshed in the ZEV controversy in 1993, when the head of New York State's EPA, Tom Jorling, turned to them for support.[154]

This was a natural step for the five states which had already adopted the California LEV program, since they were also members of the OTC, and since NESCAUM states, which announced their interest in the California LEV, were now also members of the OTC. The OTC proposed an "11-state plus one district LEV program" in November 1993, in which regions could decide whether or not ZEV's were needed.[155]

By early 1994, the OTC further refined this position by noting in a recommendation to EPA that OTC wanted ZEV's to be a required component of the OTC Low Emission Vehicle Program only if this was coupled to their right to adopt the California program, i.e. if ZEV requirements could not be separated from the program without violation of the Clean Air Act. The OTC wanted to give each state the possibility to require a ZEV production mandate if this was needed for attainment.[156] In the "final rule" document from the EPA in January 1995, it is stated that:

> EPA...does not require states in the OTR to adopt California's Zero Emission Vehicle (ZEV) production mandate, but leaves this choice to each state's

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[152]Environmental Protection Agency 1994b.

[153]Environmental Protection Agency 1994b.

[154]Sperling 1995, pp. 39-40.

[155]Ozone Transport Commission 1993.

[156]Environmental Protection Agency 1994a, Volume 3, p. 30.

> discretion. EPA has determined that section 177 of the Act allows states to adopt the California LEV program without adopting the ZEV mandate.[157]

Also, in this final ruling, the EPA made it very clear that it did not want the OTC states to go through with their LEV program. Rather, the EPA has urged, from the start of this process, that stakeholders (OTC states and the Big three) seek to agree on a *nation-wide LEV program*, something that the EPA does not have the authority to force them to do under the Clean Air Act before the year 2004. But as for the OTC Low Emission Vehicle Program, the EPA had no other choice than to give approval, since the Clean Air Act required them to do so. But they really did not want it to actually be implemented.

The benefits of the OTC LEV for the EPA were, however, of another kind. In a proposed ruling, the EPA states that:

> The OTC States and environmentalists provided the opportunity for this cooperative effort by pushing for adoption of the California LEV program throughout the Ozone Transport Region (OTR).[158]

By giving the OTC states the right to implement the OTC LEV program, much more pressure was put on automakers to agree with the OTC states on a voluntary 49-state program instead of the OTC LEV program, which was a much too California-like program to suit the automakers.

However, to understand this process we have to go back a step and see what happened after the OTC states revealed their intentions in the OTC LEV program.

The automakers had to do something to regain the initiative in this process, so as not to just be running behind having to fight ever more ZEV initiatives across the nation.[159] For the automakers, the OTC activities, and especially those related to the potential increase of ZEV requirements, seemed threatening, and in late 1993 the AAMA announced

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[157]Environmental Protection Agency 1995b, p. 4716.

[158]Environmental Protection Agency 1995a, p. 52735.

[159]This interpretation is also supported in a statement made by Bob Doyle, attorney advisor at the EPA in Washington, saying that "The Fed LEV is a reaction to the Ozone Transport Commission's decision, as well as the other state air quality programs...//...The automakers want all these states to drop their plans to adopt the California standards.". Cited in (Electric Vehicle Progress 1994b). A similar interpretation is made by Janet Hathway from the Natural Resources Defence Council in her testimony at the CARB hearing on changes in the California ZEV requirements, California Air Resources Board 1996c, pp. 97-98.

a 49-state proposal for a new auto emissions program called "Fed LEV". For the EPA, the Fed LEV was at least a step in the right direction, because it was aiming at a 49-state-wide agreement on cleaner vehicles for the U.S. The automakers were willing to accept somewhat more stringent emissions regulations nation-wide in exchange for stopping diffusion of the California LEV requirements, and especially the ZEV mandate.[160] The Fed LEV was seemingly not supported by the Act and therefore it can also be seen more as a positioning and a first negotiation bid from the automakers side.[161] An intensive policymaking process followed.

The U.S. automakers and OTC member states embarked on a regulatory process aiming at adopting a 49-state program that would be acceptable to all parties. The ZEV component had been an important part of the earlier OTC LEV, but in the 49-state program now being discussed this was not to the same extent meant to foster a major change in automotive propulsion technology, and certainly not meant to mandate ZEV's.

One important forum for these discussions of a 49-state program was the 'Subcommittee on Mobile Source Emissions and Air Quality' in the North-eastern States (established by the EPA in August, 1994) in which different parties discussed both issues related to the OTC LEV, as well as an alternative 49-state program. Participants included health and environmental groups, automobile manufacturers and dealers, utilities, fuel providers and proponents of alternative fuel vehicles.[162] This activity was heavily supported by the EPA, in their quest for an alternative nation-wide LEV program, which they termed the 'National' LEV program.

California was still to have a separate position in the U.S., but the EPA wanted to tie together the National LEV and the California LEV program in as many respects as possible. And that actually happened. Between late 1995 and early 1996, the regulatory processes of the north-eastern states were to *converge* with those of the ZEV controversy in California. A 49-state program for automobile emissions standards was agreed upon and signed by automakers in California at the March 28-29, 1996, meeting on changes of the ZEV requirement. Thus, the circle was

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[160] Electric Vehicle Progress 1994a.

[161] On the Fed LEV and CAA, see for example, Electric Vehicle Progress 1994a.

[162] Environmental Protection Agency 1995a, p. 52740.

closed and the auto industry had regained control of ZEV-related activities in other states.[163]

The United States Advanced Battery Consortium

Even though, as described above, automakers did a fairly good job in fighting the mandate, they showed a more positive attitude towards battery developments. The U.S. Advanced Battery Consortium (USABC) is evaluated in a report from the U.S. General Accounting Office. In early 1991, the three big automakers established the United States Advanced Battery Consortium (USABC), with the ultimate goal of developing batteries that would enable the electric car to compete with the gasoline car in terms of cost and performance.[164] The reason for the automakers doing this was that the ZEV mandate was interpreted as requiring, not an incremental step, but a "leap" in automotive technology, which encouraged the automakers to do new things, as argued by GM:

> The ZEV mandates are forcing co-operation where previously we would have competed.[165]

The Electric Power Research Institute (EPRI) and several utility companies joined in mid 1991, and finally in late 1991, the Department of Energy (DOE) joined, by a co-operative agreement, with the consortium.[166] DOE's involvement was actually legislated by the earlier mentioned Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976, and from 1992 on, reaffirmed by the Energy Policy Act. Through this act, DOE is mandated to:

> enter cooperative agreements with industry to develop advanced batteries for EV applications.[167]

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[163]Several states have, however, announced that they will continue to adopt their own ZEV regulation, irrespective of what happens in California. Still, it is hard to see how these states will manage to do what CARB, the strongest air agency in the U.S., could not do.

[164]United States General Accounting Office 1995, p. 1.

[165]Schweibold 1995, p. 112.

[166]United States General Accounting Office 1995, p. 3.

[167]United States General Accounting Office 1995, p. 3.

USABC was meant to disband in 1995, with a total funding of 262 million dollars on a cost share basis of 50/50 between public and private interests. In the original budget proposal for the USABC, battery developers were to provide 28 percent and automakers 17 percent of the total funding.[168] During the establishment phase of USABC, the DOE pointed out that there was a considerable uncertainty as to whether it was possible to meet the long-term battery goals in such a short period of time, especially when the California mandate in practice demanded high-volume production of batteries even before 1998. Eventually this led to the establishment of an intermediate goal, the so called "mid-term battery", which was perceived to be good enough for fleet applications and to strengthen the domestic battery industry, and also to provide real-world data to rely on for the development of a long-term battery.[169]

Table 2. USABC Advanced Battery Technology Goals

Criteria	Mid-term goals	Long-term goals
Specific power	150-200 W/kg	400 W/kg
Specific energy	80-100 Wh/kg	200 Wh/kg
Calendar life	5 years	10 years
Cycle life	600 cycles	1,000 cycles
Ultimate price	<$150/kWh	<$100/kWh

Source: United States General Accounting Office, GAO. 1995. *Electric Vehicles: Efforts to Complete Advanced Battery Development Will Require More Time and Funding*. Report to the Ranking Minority Members, Committee on Governmental Affairs, United States Senate. GAO/RCED-95-234, Appendix V.

The relative funding between long-term and mid term research is outlined in the GAO-report. In mid-term battery research and development, the nickel-metal Hydride battery has gained most funding. Ovonic Battery Company, together with Saft America, has signed contracts of over 45 million dollars. The lithium-ion battery has been classified as a mid-term battery, even though it is perceived to have the potential to reach above this goal. This is simply because it is not expected to be able to reach the long term goals. The Duracell/Varta joint venture has been contracted at about 18 million dollars for conducting research on the lithium-ion battery. For the long term option, other lithium based systems are being pursued. Great expectations lie with the lithium-solid-polymer battery which has been contracted at about 60 million dollars. Companies

[168]United States General Accounting Office 1995. pp 3-4.

[169]United States General Accounting Office 1995, pp. 4-5.

working on this battery are W.R Grace and 3M. Saft America also has a 17 million dollar contract for developing a high-temperature lithium-iron-disulphide battery.[170]

A battery pack of a total of 30 kWh, yielding a battery weight of between 300-375 kg at mid-term battery levels is expected by the consortia to give an adequate range for most purposes.[171] Still, the automakers do not expect mid-term batteries to propel any larger market.

A range test conducted at CARB's test facility in El Monte in Southern California on an electrically converted sub-compact, the Solectria Geo Metro, with a nickel metal hydride battery pack with a total of 19 kWh yielded a range of about 200 km in urban driving and 250 km in highway driving.[172] This example would indicate that "the perceived adequate range" for the consortia would be about 300 km in city driving and about 400 km in highway driving. Given a long-term battery, with twice the specific energy, these range figures would be about 600 km and 800 km, respectively.

The cost level for the mid-term battery, however, is not expected to be favourable in the near future. The price of a 30 kWh mid-term battery pack is expected to be about $9,000-15,000 in pilot plant production, and about $7,000 in large scale production. This is above the price goal of the consortia for a 30 kWh battery, which corresponds to $4,500.[173] At the March 1996 hearing at CARB, it was concluded that the price of a battery pack in pilot production is essentially a political or industrial-political issue, in that the price will inherently be tied to the ongoing regulatory processes and the marketing strategies of the major auto manufacturers.[174]

The expectations of the performance of the Ovonic nickel-metal-hydride battery are very high. This battery is regarded as "The" mid-term battery of the late 1990's, with a specific energy expected to reach about 95 Wh/kg. One reason for the high expectations of this battery is the potentially high cycle-life for batteries that are being cycled "at the top". On the cell level, this battery is reported to have achieved 10,000 cycles at

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[170]United States General Accounting Office 1995, pp. 28-29.

[171]United States General Accounting Office 1995, p. 6. The battery weight is derived by author from the specific energy of a mid-term battery (as specified in table 2).

[172]California Air Resources Board 1994d.

[173]United States General Accounting Office 1995, p. 6.

[174]California Air Resources Board 1996c, p. 287.

a discharge level of 30%.[175] This corresponds to 70 km of commuter driving per day, for about 30 years, still leaving the option of an occasional 300 km drive before recharging.[176]

The USABC differs from earlier battery research efforts in the U.S. Here the main actor in the automotive arena, the automakers, is given control over research activities that earlier had been publicly operated and controlled.[177] Also, the power relations in USABC do not correspond to the funding given. Automakers only contribute 17 percent of the money, but have full control of the program. However, pointing this out here is not meant to be considered as an overall critique. In practice, DOE has had a de-facto veto, in that they could choose not to support what the auto executives had decided upon. In addition it must be noted that the goal of getting full sized advanced electric vehicle batteries on the road has been rather successfully met, compared to earlier achievements in the field of batteries for electric cars.

As shown by the GAO-report, the work of the USABC has not, however, been entirely free from problems. The diverse characters and the different institutional practices of the actors in the consortia seem to have created large start-up problems, for example delays in the program. Many of these problems seem to have been related to differences in organizational culture (ways of doing things) and in ownership (what is considered as private, and what is considered as publicly owned developments). In addition there were also problems related to purely technical matters.[178]

The negotiation of contracts with battery developers, as discussed in the report, created problems when the DOE demanded to be able to take control of the developed product if the battery developer decided not to commercialize within the required time frame. The industry criticized the DOE for not taking part in the negotiation processes, being able to overturn a long negotiation process by not giving final approvement of contracts. By March 1995, there were 139 million unused dollars and the

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[175]Riley 1994, p. 237. Also, Professor John Ross, a consultant to Ovonics, reported at a CalStart meeting in Oakland on April 7, 1995, that the future nickel-metal battery from Ovonic will eventually outlast the vehicle itself.

[176]Derived by the author from an extrapolation of data of the Geo Metro, as tested by CARB.

[177]McLarnon 1995.

[178]United States General Accounting Office 1995.

consortium has requested a 4-year extension of the program through 1997, to use the remaining funds mainly for completing the development of the mid-term battery, and during 1998 and 1999, working on the long-term battery. This last phase would need a total extra funding of $81 million, of which $38 million would be provided by the DOE.[179]

The USABC may not have been able to achieve its goals within the anticipated time frame, but nevertheless, the state of the art in advanced electric vehicle batteries has taken a big step forward during the years of the program. Even though this is basically a research effort, the USABC has become a strong supporter of these technologies, paying attention to their further development and final application in real life situations.

The Vain Search for a 'Swift' Battery[180]

But why have automakers continuously been asking that "super-batteries" be developed before electric propulsion can be perceived to be feasible and marketable? The "super-battery", making the battery electric car fully competitive with the gasoline car, was an explicit long-term demand from automakers, and originally they did not want anything less from the USABC.[181] The background of this position has a long history but can perhaps be summarized by the two following statements. 1/ since the closure processes at the turn of the century batteries have been perceived as an inferior technology, unable to propel a car, thus needing to be radically improved. 2/ automakers did not want to socially (re)-construct a new artefact, a new "Car" (e.g. the short range city car) because they were concerned about the size of the market for such a vehicle. Thus, the fully competitive battery had to be their long-term goal.

Long-range requirements on cars, using a social constructivist interpretation, emerged along with the development of the automobile as a new artefact. What people came to perceive as being 'short range' and

179United States General Accounting Office 1995.

180In a fiction story from 1910, the young adventurer Tom Swift succeeded in developing a battery with which he could win a 500 mile race over his rival who was driving a fast gasoline car (McShane 1994, p. 145.), thus indicating that the idea of having an electric car winning over an gasoline car was by 1910 perceived as being a fiction.

181See for example Schweibold 1995, p. 113.

'long range' are therefore not absolute categories, but relative. The definition of 'long range' was developed along with the improvements of the gasoline car, and as soon as the gasoline car established itself as the winning alternative, 'long range' become the range that a 'car' should have. Even if the developers of the early electric car became aware that electric cars would not be able to compete with gasoline cars in range, top-speed and hill climbing, they still wanted to reach as far as possible on the range criteria. An example of both the desire for long range and high power vehicles, as well as the awareness of the limitations of the lead-acid battery to meet these desired goals can be exemplified by W. Worby Beamount, who in 1900 argued that:

> The past two years have considerably lowered the weight of battery made for vehicle purposes, but even if a battery of theoretically least weight could be used, that weight would still hopelessly handicap the electric vehicle for long journey work over average country. It is not invention alone that is required to provide for the successful electricity accumulator. Discovery must be made of means of employing materials other than lead and its oxides and salts.[182]

In 1908 an electric car proponent asks the public not to hope for a 100 mile range battery any longer, a hope which had at that time lowered sales for the batteries actually available.[183] The history of electric cars can in one way be seen as the search for this "discovery" of a radically new battery technology. But at the same time, it should be noted, developers did think that the electric car still would be able to establish itself as a city vehicle, and they expected the automobile market to host different kinds of vehicles. As of 1907 it is argued that:

> The electric vehicle has taken its logical position as a means of freight and passenger traffic in cities and for short tours out of town; while the gasoline machine is rapidly gaining recognition as the automobile *par excellence.*[184]

Thus the "problem" of electric cars has since then been described as a problem of scientific research and technical development (and not as a regulatory, market, organizational, or system optimization problem). There are numerous statements in the history of EV's where batteries are described as the "Achilles heel" of electric cars. The problem of achieving longer range is reduced to the problem of energy storage only, whereas range, of course, is a result of two factors: the *access to energy*, on the

[182]Beaumont 1900, p. 394.

[183]Scharff 1991, p. 39.

[184]Homans 1907, p.132.

one hand, and the vehicle's *use of energy,* on the other hand. But radical changes in vehicle design philosophy seem not so easy to achieve.

Also, that the long-term battery can make the electric vehicle fully competitive with the gasoline car has not been totally accepted by all automotive manufacturers and by all automotive engineers. The background for this argument is that if one does not take into account any other changes to the car, in for example the thermal management of the compartment or the materials used in the vehicle, then the available energy would probably not give the same performance, even if a long-term battery was used. In a gasoline car, energy for propulsion, electricity, and heating or cooling, has never been a problem. For example, the heat dissipation during driving is so extensive that there has not been any major work done to significantly improve the energy efficiency of the thermal management of the compartment, and the generated mechanical energy has been so large that no significant efficiency improvements have been needed in components such as the generator or power steering. This is not of course to say that there have been no advances in these areas. The point here, is that these advances have not been aimed at reducing energy consumption.

Constructing "zero"

The end result of the process of defining the ZEV is important as setting the emissions levels which will be regarded as 'cleanest', and setting a goal for the future technological trajectory in automotive propulsion development. As will be shown, the concept of 'zero-emission' is successively filled with content and meaning through a regulatory process, and the following chapter aims at revealing some of the socio-technical dynamics of that process. The resulting definition in this matter will probably, and at least to some extent, determine the types of cars that will be driven in California in the future. In the history of automotive emission technology, there has typically been a diffusion of technologies, and to some extent also regulations, to other parts of the Western world. Thus, both the problem definitions and their corresponding socio-technical solutions tend to end up elsewhere, regardless of their 'appropriateness' for solving problems under other local conditions than those where they originated (in this case the south coast air basin in California).

From the discussions among air officials in late 1980 regarding electric vehicles, it is a fairly safe interpretation that the ZEV category in LEV of 1990 was just another way to say "electric cars". Even when deciding what a ZEV really is, the electric car driven in southern California serves as the basis for definition.

When the concept of 'ZEV' was launched it was a 'black-boxed' concept in the sense that it was defined only through the interpretative frame of one actor, CARB, with the regulatory language heavily tilted towards the conceptual framework of gasoline car regulation. These concepts were not capable of framing a radically different technology, such as the electric car demanded. During the regulatory process that followed, the concept of 'ZEV' was opened up for additions and changes. In that situation there was a high degree of interpretative flexibility and also an openness on the part of CARB towards having this flexibility.

The part of the text in the regulatory document of 1990 that directly refers to the ZEV mandate was so short compared to other parts in the LEV program, that a plausible interpretation seems to be that CARB 'invited' or at least expected the interested parties to start a regulatory process for determining what a 'zero emission vehicle' should be. In 1990 a zero-emission vehicle was one that had:

> no exhaust or evaporative emissions of any regulated pollutant...[and that should do so]...under any and all possible operational modes and conditions.[185]

Obviously if interpreted literally, this is a very strong language. It is obvious that CARB did not want gasoline engines on board the vehicles, thus excluding hybrids even if they could, in theory, be driven in a pure battery mode. The main reason for this standpoint had to do with the fear that in the course of the vehicle life, the battery in the hybrid car will detoriate and lose the capacity for the pure electric driving mode. At the same time, the gasoline engine would naturally detoriate leading to a situation where the hybrid may not be any cleaner than an ordinary gasoline car. This would be because they would in practice be driven in ICE mode, carrying dead-weight batteries. By referring to operational "conditions" it is also clear that CARB did not want a fuel powered compartment heater on board. On these two points, however, there were to be some major changes. The black box of 'zero' was to be opened. Both liquid fuelled heaters and combustion engine vehicles were to be accepted

[185]California Air Resources Board 1990b, pp. 32, A2.

within the frame of 'zero-emission' vehicles. In the case of the latter, the semantic move of saying 'equivalent ZEV' is used.

Departure #1 — Allowing fuel fired heaters

In August, 1990, the staff of CARB argued that "...only battery-powered electric vehicles without combustion heaters are expected to qualify as ZEV's"[186]. This would soon be altered by arguments from manufacturers against the feasibility of electric cars in cold weather. CARB explains their way of reasoning as follows:

> We did that because [the auto manufacturer in] Detroit was complaining and saying "we're losing too much range on cold weather". But we said, well we're in California, you will not have cold weather but we'll let you have fuel fired heaters.[187]

The already short range of these cars would be reduced severely if the batteries also had to heat the compartment. In order to save the mandate, CARB made the first major departure from the original text in that they allowed fuel heaters to be used, but only during driving and only under an ambient temperature of about 5 degrees Celsius or less.[188] The strategy of CARB was to avoid points of controversy that could threaten the mandate.

Departure #2 — Acknowledging the "elsewhere emission" argument and adding an equivalent ZEV

The second major departure was also due to arguments from the car manufacturers' side, who, together with oil companies and natural gas vehicle proponents, argued that the upstream emissions of electricity generation should be incorporated in the concept of 'zero' since the electric car essentially was just moving emissions from one area to another. This is what has been coined as the Elsewhere-Emission Vehicle argument. This argument can be interesting for future regulatory work,

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[186]California Air Resources Board 1990b, p. 32.

[187]Osborn 1995.

[188]Electric Vehicle Progress 1993.

since the car manufacturer is actually asking for regulatory connections to be made between upstream emissions and cars. They ask that the electric car be responsible for emissions outside the vehicle, while at the same time, its not really plausible that the car manufacturers would like the same connections be made between upstream emissions from gasoline production and the use of gasoline cars. However, since the incorporation of upstream emissions from the generation of electricity would not, in CARB's view, thwart the introduction of electric cars, they did not really oppose this change. If a vehicle would achieve the same very low levels of emissions as electric cars, it would, in a sense, deserve to be credited as belonging in the 'ZEV' category.

In CARB's proposed requirements for the equivalent ZEV, however, not all of the upstream emissions caused by the use of a combustion engine in the equivalent zero-emission vehicle are taken into account, even if the staff at CARB initially wanted them to be.[189] Emissions associated with the production, transportation and distribution of fuel were not incorporated into the requirements of the equivalent ZEV category.[190] This can be explained by the regulatory connection between the negative environmental effects caused by cars, and which of these negative effects that car industry can control, especially when these emissions are difficult to quantify. Therefore only exhaust, evaporative and refuelling emissions are used in the comparison with emissions from the generation of electricity. The equivalent ZEV vehicle was defined in February, 1996, as:

> vehicles having exhaust, evaporative and refueling emissions equivalent to the power plant emissions [of oxides of nitrogen and reactive organic gases in the California south coast air basin] associated with EVs.[191]

The vehicles are required to maintain the equivalent ZEV levels of emissions over the entire vehicle life, and will need an infrastructure of new refuelling equipment to be able to achieve equivalent ZEV levels.

California in general, and the south coastal parts of California in particular, have a very 'clean' electricity generation mix compared to other states as well as compared to many European countries.

189California Air Resources Board 1995d, p. 13.

190California Air Resources Board 1996a, p. 5.

191California Air Resources Board 1996b, p. 21.

Table 3. Fuel mix to produce Electricity in California

	Source	*[%]*
In California	Natural gas	31
	Nuclear	15
	Hydroelectric	10
	Coal	10
	Geothermal	6
	Wind & Solar	1.5
Imports:	Hydroelectric, coal, Natural gas, others	23

Comments: Figures refer to actual consumption in 1991.
Source: California Energy Commission, *Calfuels Plan September 1994.*

Electric cars in California are argued by proponents to make sense from a regulated emissions point of view since they will reduce and remove emissions from where people live and work.

But how was one to define what the actual emissions would be? Obviously many assumptions as to technological characteristics, consumer behaviour, market dynamics of electricity production and future emission levels of electrical power plants had to be made. All these parts could be points of controversy, but they were not contested. Two important reasons for this were that the actors and expertise related to these issues were very much on CARB's side, and that in the eyes of car manufacturers the ZEV credit system was of more importance. The calculations were made by the California Energy Commission, which in turn used a computer program from the Environmental Defense Fund to simulate the marginal power production. The energy efficiency ('plug to wheel') was set at 2.2 kWh/10 km based on testing of the purpose-built Solectria Sunrise and the converted U.S. Electricar Prism. Furthermore, it was assumed that 55 percent of the EV's in California would be driven in the south coast air basin, and that 16 percent of the battery charging would be during so-called on-peak hours.[192] The emission levels turned out to be about 10 percent of that of ULEV levels. The ULEV level is regarded to be very tough emission standards for gasoline cars.

[192]California Air Resources Board 1996a. Also, as with Calstart, officials at the California Energy Commission sees themselves as being a catalyst for the introduction of electric cars, and a "marriage broker" between different parties (de Witt 1995, Fong 1995).

Instead of delivering the required ZEV's or Equivalent ZEV's, manufacturers can choose to deliver a larger number of hybrid electric vehicles with ULEV standard engines according to a specific *credit system*. The hybrid electric vehicle classes are proposed to be connected to the ZEV requirement through a credit system based on all-electric range capability and level of battery management. The partial ZEV credit system starts at a 50 km all-electric range capability giving 68 percent ZEV credit, with a fairly slow increase up to 88 percent ZEV credit for an all-electric range of at least 145 km. Hybrids with less range capability than 50 km receive no credits at all.[193] The control measures required of battery versus auxiliary power unit operation are fairly simple to set. Since it is just a matter of choosing the right algorithm in the microcontrollers, car manufacturers will probably achieve the maximum credits. This means that for each ZEV required, manufacturers can choose to deliver 1.47 hybrids with a 50 km all-electric range.

This concept of equivalent zero-emission vehicles was discussed in detail by concerned parties in 1995 and is outlined in a 'staff report'[194], where it is described as appropriate for:

> extremely low-emitting HEV's to receive at least partial credit toward the zero-emission requirement.[195]

By means of a partial ZEV credit, a car manufacturer could choose not to deliver any (battery-only) zero-emission vehicles at all, given that the partial ZEV credited vehicles were delivered in somewhat larger numbers. Initially CARB perceived this to be a safe move, since it was expected that only very good electric hybrids would be given any usable partial ZEV credits, thus still inducing radical changes into the field of

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[193]The credit given for a certain all-electric range in miles per day is statistically derived as the percentage of the 'statistical' travel distance within this range (i.e. 68 percent of cars drives less than 50 km per day). Values are valid if the system disables the driver from manual control of on/of-mode of the combustion engine and if the vehicle cannot be driven after the batteries have detoriated to 80 percent of nominal capacity. For hybrids that do not fulfil this, only half the credits are given (California Air Resources Board 1995d).

[194]California Air Resources Board 1995d.

[195]California Air Resources Board 1995d, p. i.

car propulsion technology, and the possibility of many cars being driven in pure electric mode within cities. But what CARB might not expect is that car manufacturers may try to achieve levels well below the ULEV levels with combustion engines only. The rationale for requiring a significant "all-electric" range is by CARB officially motivated by emissions only; the vision of inducing such a radically new technology as pure electric propulsion cannot be made explicit and used as an argument. The HEV requirements are that the gasoline engine must achieve ULEV levels, and the vehicle must be capable of running on "all-electric" mode for a practical commuting distance. This means, using CARB's own estimates, that vehicles would emit at the level of ULEV/10 in daily commuting, and at ULEV levels for longer "in-basin" distances.

Table 4. Light-Duty Low-Emission Vehicle 50,000-Mile Exhaust Emission Standards

Vehicle Class	NMOG (g/mile)	CO (g/mile)	NOx (g/mile)
TLEV	0.125	3.4	0.4
LEV	0.075	3.4	0.2
ULEV	0.040	1.7	0.2
ZEV	zero	zero	zero
Equivalent ZEV	0.004	0.17	0.02

Comments: NMOG (non-methane organic gasses). TLEV (corresponds to a Swedish "Miljöklass 1" car.
Source: California Air Resources Board, CARB. 1996. *Proposed Amendments to the Low-Emission Vehicle Regulations to Add An Equivalent Zero-Emission Vehicle Standard.* Preliminary Draft Staff Report

But if car manufacturers manage to make, for example, ULEV/5 with combustion engines only, it is obvious that the emission gap between the two is narrowed and may not be enough to support the costly requirement of the electric drive-line with batteries of an HEV.[196]

CARB did not really try to keep the ZEV concept closed, and there were several reasons for that. First, the context of regulatory authority and the regulatory history of CARB are very much about gasoline powered internal combustion engine cars, and in that context electric cars are certainly a novelty. Secondly, and perhaps most importantly, changing the definition of the ZEV was not perceived by CARB as an overall threat towards the introduction of electric cars, since auto manufacturers were

[196]Volvo has indicated that they might reach emission levels with ICE corresponding to ULEV divided by five (Rosengren 1996).

not expected to reach these very low levels with gasoline cars. In mid 1995 CARB argued that:

> The amendments would have no effect on...the unique benefits that battery-electric technology offers.[197]

But if auto manufacturers may achieve emission levels well below the ULEV level with the ICE, this is much closer to the levels of the ZEV than originally anticipated by CARB, and some of the future ZEV classified cars might not even be propelled by an electric motor. Also, the rather generous credit mechanism allowing manufacturers to meet ZEV requirements with HEV's will lower the possibility of a paradigmatic change in automotive propulsion technology.

During the controversy over the ZEV mandate of 1990, the interpretative flexibility of how to define the ZEV concept was narrowed and by mid 1996 it was clear that, by and large, 'ZEV' had been redefined and that a consensus had been reached on how to interpret this emission class. Since in this case, the definition of the concept is also incorporated in a regulation, a bridge and a connection are made between the cognitive level of the interpretative flexibility, the following closure, and its consequences on the physical level.

Generally speaking, both the regulating agencies and the regulated industry perceive technology forcing regulations as something that should be 'neutral' towards the choice of technology that will fulfil the requirements. The underlying idea is that it should be up to the dynamics of the 'market forces' to develop the most cost efficient technology to solve a certain problem. In that context, any regulatory measure that interferes with the market and mandates or 'picks' a certain technological solution will be perceived as bad or flawed. This is the general view of both 'sides' in the ZEV controversy. This is also an implicit rule of conflict resolution in U.S. policymaking.[198] By getting an initial requirement of zero vehicle-bound emissions, industry felt that CARB violated this principle of 'technology neutral' regulations. Industry regarded this regulation as being "qualitatively different from other mobile source regulations"[199] The only technology that in practice could be used by car manufacturers to fulfil the requirement of 'zero emission' was the battery electric car. Therefore, car manufacturers argued, in

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[197]California Air Resources Board 1995d, p. 2.

[198]Rich 1987, p. 155.

[199]California Air Resources Board 1996b, p. 2.

reality this regulation was mandating a certain technology. This was of course true, but could nevertheless not be made explicit in the regulations, since CARB does not have authority to mandate a technology. The whole idea of the ZEV requirement is to induce radical change within the long term perspective in car technology. When the program was launched in 1990 all the relevant actors knew that CARB was pushing battery-electric cars, and of course, this strong desire for "neutrality" stems from the prevalent and generally accepted market-oriented world-view of technological development. Technologies should, according to this *theory*, be chosen through market competition only. With this as a background it made sense for CARB to add and allow for an equivalent ZEV technology. Such a move would undermine the "neutrality" critique by opponents of the ZEV mandate, or in the word of CARB:

> The proposed EZEV standard would be an optional standard that would add flexibility to the existing regulations by making the ZEV requirement more "technology neutral"[200]

One other aspect which has not yet been addressed within this controversy refers to a more general ethical discussion having to do with equality. By moving the emissions to less populated areas, the people who drive the cars will be better off, relieved from the negative health impacts of their way of life, while other (albeit fewer) people will be paying the price by being forced to breath pollution originally generated elsewhere. CARB, however, argued that even if these effects exist, the extra pollution from EV's will be marginal.

The lead-acid battery dispute

In following the electric vehicle controversy it can be difficult to understand why the rather obvious problem of the toxic material in batteries did not create more turbulence than it did. A closer look, however, at this short but intensive dispute shows us something interesting about the nature of the electric vehicle controversy. The mere fact that it did not become a major issue that could affect the ZEV mandate calls for explanation.

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[200]California Air Resources Board 1996a, p. 1.

The dispute was initiated by an article in *Science* in May 1995.[201] In this article, "Environmental Implications of Electric Cars", the authors argued using life cycle analyses that the negative environmental effects of emissions from production and recycling of lead acid batteries would be a threat to the public health, and the benefits of reducing the regulated emissions would be low compared to these negative effects. The article, often called "the Carnegie-Mellon Report" was cited in many automotive and electric car journals and in newspapers, where it even was argued to be the "...kiss of death for electric vehicles"[202]. The people of the Electric Vehicle Association were of course unhappy with this and argued that:

> The Science magazine article was widely promoted in the American press and seriously undermined popular support for EVs by spreading confusion.[203]

CARB argued that the Carnegie-Mellon researchers "...used questionable assumptions and outdated data..."[204] In order to allow the authors of the article a possibility to defend themselves, they were invited to the workshop on infrastructure in July, but they did not attend. Instead they sent a letter that was presented at the work-shop.

This letter was a response to critique from CARB (in a June 5, 1995 letter) to the CMU researchers. The response from the CMU researchers to CARB was that CARB had failed to take into account all the environmental effects of mandating the introduction of electric cars by 1998. The researchers felt that CARB was too focused on air emissions in California, and thus neglected the environmental impact on air, water and land in California as well as out of state. Also they emphasized the qualitative difference between ozone and the indefinitely persistent pollutant lead.[205]

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[201]Lave et al 1995b.

[202]Passell 1995.

[203]Garlow 1996, pp. 405-415.

[204]California Air Resources Board 1995a.

[205]Letter to Mr. Tom Cackette of Air Resources Board, dated July 11, 1995. The letter was included in the mail-out for the EV Infrastructure Forum at CARB on July 12, 1995 (California Air Resources Board 1995c).

In CARB's review of the study it was clear that CMU and CARB were not speaking the same language as regards lead pollution associated with EV's. The difference was huge.

Table 5. Lead emissions from stationary sources (Pb emissions/Pb processed)

Source	CMU	ARB	Difference
Primary Smelting	4%	0.09%	44
Secondary Smelting	2%	0.002%	1000
Battery Manuf.	1%	0.0025%	400

Source: Table adopted from material presented by the CARB staff at the EV Infrastructure Forum, July 12, 1995.

As in several cases in the zero-emission vehicle controversy, the evaluation of the relevance of a study is made with reference to who funded it, which is used as an argument to undermine the validity of the results presented. To counteract this critique, the researchers from Carnegie Mellon University ended their letter, saying:

> In closing, we [the CMU researchers] assure you that, contrary to some accusations, this study was not supported by "oil or automobile company sponsorship." The study is based on our desire to enhance environmental quality and to help you to avoid achieving the opposite of what you intend. We look forward to working with you and your staff on this important matter.[206]

In a follow-up article in *Science*, the CMU report was again heavily attacked by EV-proponents, mainly from academia and well known in the electric vehicle discourse, who criticized the calculations along similar lines as CARB. Life-cycle analysis, in general, offers many potential points of disagreement, especially if the object of study has not been discussed earlier and, thus, no consensus has been established. The Carnegie-Mellon researchers were probably not aware of the heated nature of the electric car controversy at the time of their entry into it earlier in 1995, but after the Infrastructure Forum at CARB and the Letter response in Science they found it:

> astonishing in terms of the level of attention, venom, and desire to defend EVs.[207]

Eventually they withdrew from the dispute, and in October 1995, Bob Cross, Assistant Chief from Mobile Source Division at CARB concluded that:

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[206]Letter from Lave to Cackette, in California Air Resources Board 1995c.

[207]Lave 1995a, p. 744.

> There have been several subsequent exchanges of written comments between CMU and ARB staff. I don't think that we'll ever fully agree with CMU. They haven't entirely moved off their position, and we're confident we're right. So I don't think that the debate is going anywhere.[208]

From the point of view of CMU there was really no point in continuing this debate. Nor did CARB have any interest in continuing. CARB was using the mandate to initiate a new technological paradigm and did not expect lead-acid batteries to be of importance for the future EV's. Therefore, an interpretation of this dispute's position within the electric vehicle controversy, is that it was closed by the *exit* of the Carnegie-Mellon research group, which, together with CARB's power of having the 'final word' in the process, stopped this dispute. CARB used its relative strength in relation to the other actors, given by the regulatory power, to achieve a *closure by external force* (i.e. external to arguments). Also we might conclude that a question that did not fit into the structure of the EV controversy (i.e. air emission of regulated pollutants) had a problem establishing itself since it was regarded as somewhat external to the framework of the EV controversy. This interpretation is also supported by the general type of EV discursive texts produced during the controversy. Very few of these texts touch upon the types of issues raised by CMU. CARB's reasoning for not going any further with this is obvious, the ZEV controversy was complicated enough as it was.

But why did not car manufacturers pick it up and make it a strong argument against the mandate. One reason is that the manufacturers would have been attacking themselves with this argument, since every gasoline car sold has a 10-20 kg starter-lighting-ignition lead-acid battery, and these batteries are not being recycled to the same degree as EV batteries probably would. By pushing the lead-acid battery arguments against EV's, there was a risk of not only putting pressure on the ZEV mandate but starting a debate on the use of lead-acid batteries altogether, even in gasoline cars. But what about the environmental community? In this dispute they were represented mainly by EV-proponents, who gave very little credit to the environmental and health concerns raised by the Carnegie-Mellon researchers. Of course, while reading the *Science* article, it is obvious that the authors do attack the electric car and the mandate as such, but the basic environmental concern could still be an appropriate topic to discuss. Instead of taking up the positive side of the

[208]California Air Resources Board 1995e, p. 128.

argument on the question of how to deal with EV batteries, the environmental community chose to close the debate. Why? Just like CARB, these people in general perceive the electric car as being needed for the future and they have been working hard under the years of the ZEV mandate controversy to help CARB maintain the mandate.[209] It seems that keeping the technology forcing mechanism in place was at this particular phase of the ZEV controversy more important to the EV proponents in the environmental community than raising new health concerns. Especially when the discussion about batteries in the EV discourse asserts in general that 'green' batteries are just around the corner, and that it does not really matter what type of batteries are used in the first electric cars.[210] However, having once entered a technological trajectory with advanced lead-acid batteries in electric cars, the switch over to so-called green batteries might be harder and take longer to achieve than anticipated. Even though lead-acid batteries have other drawbacks than limited specific energy, positive features such as economics of scale and the possibility for battery manufacturers to take advantage of further development of an already well-known technology can be very competitive during a shorter or longer period. This phenomenon is well known in the history of technology. Forced by competitive pressure, the existing main technological alternative can sometimes be advanced considerably and offer resistance to a new technology. But in the long run, in many cases, these new technologies eventually win the race.

A final remark to make here is that there is indeed enough power residing within the issues raised by CMU to feed a larger controversy. This means that the lead-acid battery dispute that was closed at the end of 1995 might not stay closed. If electric car sales do take off, the CMU issues might very well develop to be a major concern.

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[209]One example is the Zero Emission Vehicle Alliance, an informal group of environmentalists that was formed in 1994, including influential organizations as for example the Natural Resources Defense Council, Sierra Club, American Lung Association and Union of Concerned Scientists, where UCS alone has about 100,000 members. The strategy of EV Alliance was to "...solidify the support [of the ZEV mandate] among the environmental community..." (Hwang 1995).

[210]See for example the responses in *Science* by several authors in the Letters to the editor page (Vol. 269, pp. 741-744, August 11, 1995) to the Carnegie-Mellon article (Lave *et al* 1995b).

Ending

At the ending of this controversy it was clear that changes had to be made due to the pressure put on this regulation, and due to the uncertainty as to what would happen if CARB stood by its original proposal, especially with respect to the risk of losing future regulatory credibility, in pushing for a regulation that could fail.[211] Three major revisions to the original mandate were discussed in 1995.

The first proposal was supported by the oil industry and was meant to kill the zero-emission vehicle mandate in California and stop any further diffusion of the mandate to the north-eastern states. The oil industry wanted market forces only to determine the future of the electric car. The second proposal was favoured by both auto industry and CARB, and was based on an agreement between these two actors to combine market forces with regulatory requirements. This was also the alternative used to end the controversy, which in addition, will have consequences for the north-eastern states. The third proposal was favoured by environmental groups and the electric utility industry. This proposal was a softer version of the existing regulatory requirement of electric cars, but with a slower phase-in.[212]

Between 1990 and 1994 the controversy was a mainly a process of positioning and opposition, whereas the processes of 1995 were intensive and more constructive in the sense that all the actors knew that the upcoming biannual revision was to determine the future of the regulation. In the hearings in late 1995, it became obvious that CARB and automakers just wanted to end the controversy. Parallel to the intensive *public* regulatory process, CARB and automakers entered a *closed* regulatory negotiation. The outcome of this negotiation was a contract, in which CARB abandoned the technology forcing strategy in exchange for a partnership strategy. The environmental groups, lead-acid battery manufacturers, and small start-up firms, urged CARB to stay on course and not allow any changes, but the relative power of these actors was not as strong as before. They had helped CARB to maintain the mandate for five years and thus forced developments, which most actors agree would probably not have taken place without it. CARB wanted to slip out of the stalemate, and auto industry wanted to do away with the mandate. But

[211]Wuebben 1995.

[212]California Air Resources Board 1995h.

there was another strong actor entering the scene. Strong political force exerted from the 'outside', from Governor Pete Wilson, pushed CARB and car industry to end this controversy.

The Role of Politics

Governor Wilson sent a letter to the chairman of CARB, John Dunlap, dated June 1, 1995, where he outlined the three basic principles to be considered by the Board in setting the vehicle emission standards in the forthcoming work to redefine their State Implementation Plan:

> 1) The Board will adopt regulations or substitutes in a timely manner to avoid legal recourses for failure to demonstrate attainment. 2) Any substitute measure should meet or exceed the emissions reductions benefits of the original measure. 3) The Board must make maximum use of competitive forces and market based strategies that advance technology development in a cost-effective manner.[213]

Pertinent to the first principle, CARB made two important considerations.

First, the report of the Battery Panel, said that only lead-acid batteries would be available by the start-up year 1998 of the program, thus decreasing the perceived probability that electric cars would achieve a big enough market.

Second, automakers have continuously claimed that they would need (very) long range batteries to manage to sell electric cars in the required numbers in the 'ramp-up' phase of the ZEV mandate. CARB's assertion of having achieved the second principle is by some actors regarded as a juridical twist, since it would have been politically impossible for CARB to change from a command and control strategy in their policymaking to a partnership strategy if the air quality had been worse. CARB had to show that they were not selling out the air quality, as argued strongly by health and environmental NGO's.[214]

The third principle set out by governor Wilson had perhaps the most powerful political force. In American society, few statements are seen as so rational as saying that government should make use of the dynamics of "the market" to the largest extent possible. All the statements by

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[213]California Environmental Protection Agency 1995. see also California Air Resources Board 1994b, p. 15. In addition, CARB had just completed a regulatory process with oil companies that was carried out by this new regulatory philosophy of partnership.

[214]See statements in California Air Resources Board 1995g.

politicians at the important hearing in December 14 and 21, 1995, give the same message — take away the mandate.[215] The statement by Wilson might not be considered as a direct order to CARB to alter the ZEV mandate, but it was at least a definite weakening of CARB's possibility to maintain it.

The role of battery technology

CARB tried to re-open not only the propulsion system of cars, but also the vehicle technology as a whole, by an emphasis on the overall *energy efficiency* of the vehicle and inspired by the promise of future car technology, as visualized by GM in the Impact car.[216] Such a focus would require not only the re-opening of means of propulsion, but also a re-opening of almost every aspect of vehicle technology. Soon it was to become evident that car industry was not prepared to do this total revision of vehicle technology. Instead the discussion was to be on battery technology. The battery that auto industry argued be needed to start a market for electric cars (i.e. "conversions"), was the so-called "mid-term" battery, having about 3 times the specific energy of the conventional lead-acid battery of the mid 1990's:

> The automakers believe that USABC mid-term battery criteria represent minimum goals for a battery that will allow the electric vehicle to break out of small market niches.[217]

Battery capacity became directly associated with market size. Obviously, this requires taking a lot of things for granted in order to say that battery capacity determines market size (i.e. keeping most aspects of the vehicle closed). Still, this was what happened. In de-constructing this history, we find that behind this requirement for a mid-term battery there seems originally to have been a 100-plus miles (>160 km) range criterion for

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[215]For example a statement by Senator Ray Haynes, saying that: "Mandates are based on socialist economic policy and in the end will fail.", California Air Resources Board 1995g, p. 128.

[216]California Air Resources Board 1990b, p. 38. Obviously the GM Impact was the type of vehicle CARB people were aiming at.

[217]Kalhammer et al 1995, p. IV-1. On the range issue, see for example, Schweibold 1995, p. 113.

electrically converted gasoline cars.[218] But consensus was established on specific energy in batteries and not on range. This closure of a minimum requirement of a "mid-term" battery stayed closed even when the energy efficiency of conversions and semi-conversions made it possible to give the electric car a "mid-term range" with advanced lead-acid battery technology, even if these batteries did not fulfil the mid-term battery requirements.[219] This was made possible not only due to the batteries, but also the developments made during the 1990-1995 time frame in energy efficiency in motor and controller technology. Also, the advanced lead-acid battery was expected by CARB to be available by the 1998 start-up year. This was expressed as an *expectation* in 1994, and was further reinforced by the Battery Panel in late 1995 as being a *fact.*[220]

But lead-acid batteries were never a favourite of CARB, who argued that they did not:

> believe it prudent to rely upon a large scale introduction of lead-acid battery EVs to launch the consumer ZEV market.[221]

Similar statements have been common. In 1992, for example, Jim Boyd, executive officer of CARB, stated that:

> The heart of the electric car, the battery, is still its weakest point and the biggest obstacle to its development[222]

CARB Staff in 1994 stated that:

> The biggest technological challenge of electric vehicles is the development of an effective energy storage system[223]

With this type of argument, CARB early on closed the door for a larger market introduction using lead-acid batteries. Something else was needed.

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[218]Kalhammer et al 1995, pp. II-2 - II-3. See also an article based on an interview with Kalhammer in Moore 1996. This range corresponds to range achieved with an electrically converted gasoline car, thus not a purpose built electric car.

[219]California Air Resources Board 1994a, pp. 3, 7, 21. In a hearing from late 1995 the Advanced Lead Acid Battery Consortium (ALABC) argues that the lead-acid battery powered EV of 1998 will have a 100-plus mile range, 3 year life, and be capable of recharging in a few minutes. ALABC also said that this information had been communicated to CARB (California Air Resources Board 1995f, pp. 221-222.).

[220]This was also one of the conclusions from forums at CARB held in late 1995, (California Air Resources Board 1995e, p. 133.).

[221]California Air Resources Board 1996b, p. 22.

[222]Boyd 1992.

[223]California Air Resources Board 1994a, p. 3.

CARB's argument that electric propulsion was technologically feasible had to be supported by making it probable that improvements in battery technology would happen. Based on information given by battery manufacturers, the CARB staff argues in 1994 that at least two battery technologies were "extremely promising for the 1998 time frame."[224]. By early 1995, expectations were still high, and the person responsible for evaluating electric vehicles and monitoring battery activities at CARB's test lab in El Monte expressed both this expectation, and the genesis of CARB's strategy:

> In talking with foreign manufacturers we have extreme confidence that within the next five years, very conservative, you will have available on the market a 250 mile plus EV [>400 km], that the battery will last you a minimum of 10 years, closer to 20 years...We know it, the auto industry starts to be more and more aware of it. Now, the question is, why don't we just delay the mandate until that technology is ready to go. **We say, if we delay the mandate, that technology may not be around.**[225] (emphasis added).

Thus in the 'perceptual frame' of this regulatory tradition of technology forcing, keeping the regulations in place would create an early market with EV's having lead-acid batteries, which in turn would spur and encourage investments in more advanced batteries. Changes, on the other hand could discourage further developments and investments from battery manufacturers.

By 1995 it was argued in a report on the status of commercialization of advanced batteries, the so-called, Battery Panel report, that mid-term capable batteries were probably not to be commercially available in the 1998-2001 time frame.

The Battery Panel

In early 1995 it was known by CARB that the development of advanced batteries might be behind schedule in relation to the 1998 mandate and the years to follow, and that automakers wanted more lead-time:

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[224]California Air Resources Board 1994b, pp. 14-15.

[225]Osborn 1995. Note that this engineer is expressing a theory of technological change, that the developments are caused by action, whereas automakers are referring to change as something immanent in technology thus cannot be pushed. These two type of explanations can be seen as incommensurable.

we [CARB] realize the ramp-up phase is going to be longer than thought in 1990. Basically, we have more information now than we had then...The automakers have been talking to us for a while about lead time, and they're already beginning to be concerned because they're talking about having to look into vehicle designs soon.[226,227]

An independent battery panel was established to look into these issues of advanced battery commercialization, and it was clear from the start that the report from the panel was to be an important piece.

The battery panel was a typical "expert panel", playing the role of being independent from the processes of politics and interests. Robert F. Rich has described the role of such experts in controversies:

On highly technological and scientific issues, expert opinion is often sought to help influence the resolution of the controversy or even dictate a "solution". Experts are often used as part of formal advisory committees. The advisory committees are given special status, and it is often assured that their views will play a major role in formulating public policy.[228]

That the results from this battery panel was to be important for ending the controversy was clear from the start. By late 1995, CARB Chairman Dunlap, makes an explicit connection between the report of the Battery Panel and the fate of the 1998 ZEV mandate, saying that:

I do not believe that this Board can ignore the panel's findings, because the heart of the ZEV program is its reliance on battery technology for the foreseeable future.[229]

The Battery Panel (unwillingly) played the role of delivering a report that allowed CARB to arrange an agreement with the car industry to establish a *closure* of the ZEV regulations.[230] The Panel was not, however, prepared to play the role of a mandate-killer without opposition. In the final report they added a post-script, where they tried to counteract the way the preliminary results had been interpreted and the way it was used for making changes in the original ZEV mandate. This post-script was given a prominent place, ending the conclusions of the final report and

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[226]Chang 1995.

[227]Evashenk 1995.

[228]Rich 1987, p. 160.

[229]California Air Resources Board 1995b, p. 3.

[230]Maruo 1996.

pointing out the high risks of stopping investments in advanced battery technology by making larger changes in the mandate.[231]

IV. DISCUSSION

The social construction of the electric car

By de-constructing *the automobile* there was evidence, before the closure at the turn of the 20'th century, of two different ideas of vehicles: the 'pleasure' vehicle for use in cities, and the 'endurance' vehicle for multi-purpose use. The combined processes of urbanization and suburbanization of late 19'th century America, created travel patterns which structurally (physically and mentally) favoured vehicles with a longer range than that of the electric car.

In the beginning, it was not clear that only one type of automobile was to survive. The processes of closure did not allow for two vehicles with similar form but different properties to co-exist. This emergence of one dominant design is a fundamental aspect of closure processes. Thus the "functional" gasoline car and the "non-functional" electric car were established, which in turn created the notion of the inferiority of batteries as a means of propulsion.

The notion of the electric car as a woman's car was established by advertisements made by electric car manufacturers early in the century. Even so, no such (gendered) market sphere was established. Thus the artefact never stabilized.

The notions of the electric car have had an impact on the expectations on electric car technology, and have been carried by the technological frame of automotive engineering (among other actors), thus influencing the actions undertaken by these actors. For example, to re-establish a "city-car" would have been a marketing effort, not a technology development effort. A 50 to 70 km range battery electric city-car has been technologically available since the mid 1890's. But cars are so

[231] Kalhammer et al 1995, p. IV-7.

integrated with our society that up to now no actor has succeeded at reestablishing a "city car" of any type.

Still, this establishment of city cars on the car market is what many proponents of the zero-emission vehicle mandate have urged CARB to do, through forcing the automakers to market electric conversions by 1998. However, the long technological, cultural, institutional and organizational history of car production made it difficult for automakers to change their views of the car. The route car manufacturers pursued was to try to make the electric car a "real car" (i.e. long range car). Thus the view of the problem of electric propulsion as a problem of battery capacity made it necessary for automakers to focus on battery development.

This is also why we can identify two types of electric car concepts today, as well as earlier in the history of automobility; the traditional car (endurance) and the city car. Entrepreneurs and small start-up firms have a low degree of inclusion in the technological frame of automotive manufacturing, thus not being as restricted in vehicle design as the large manufacturers, and these small firms are the ones that have built electric "city cars". One example is the CitiCar described in Chapter II. Still, some recent electric "city cars" (albeit not earlier discussed in this study) have also been proposed by European and Japanese automakers as 'showcase' vehicles, but these cars are not meant to be produced. The electric cars actually put on the streets by most automakers are instead *interpretative hybrids*, a combination of the basic technology and form of the traditional car, but having the range of a "city car". And consequently, as argued above, vehicle range is a major issue for these cars which, due to this keeping of vehicle design a closed technological area, need more advanced batteries.

Since the closure early in this century, gasoline cars have played an important role in society, with infrastructure, commercial activities, and lifestyles to some extent based on this artefact. Car manufacturing, roads, service stations, gasoline stations, motels, taxes, traffic legislations, etc., are all factors that make up this large technological system. Due to the expansion of the system, it has occasionally come under pressure. Oil crises, car safety, and air pollution are examples of reverse salients that the system has managed to solve with conservative change, thus allowing further expansion of the system and the use of more cars. Fuel efficiency was enhanced in the U.S. by the so-called CAFE-standards, air-bags helped to make driving more safe, and the catalytic converter 'solved' emission problems.[232]

The catalytic converter allowed the gasoline car system to continue to grow, but this expansion has once again led to new pressures being put on the system. Air quality is still high on the agenda, and the electric car is proposed as a solution. The electric car may lead to a conservative change of the existing technological system. To the extent that car manufacturers incorporate this technology within the system, only minor changes in relation to other entities of the system may occur, which will just enforce further expansion. If on the other hand, new relations and functions are established during the emergence of electric cars, this may eventually lead to a radical change at the system level. A more strict interpretation of a radical change in Hughes' sense, such as a total failure of the gasoline car system to cope with the reverse salient of air pollution, at the same time as a new system based on electric car technology emerges, is not here considered as plausible near term outcome. This is because a solution need not solve the problem in some absolute sense. A reverse salient, in the way I have outlined it, can very well be 'solved' with, for example, media campaigns that establish a closure on the subject. This means that one actor can enrol others, in Callon's sense, to see the world in the way they do. This was, for example, what oil companies tried to do when launching media campaigns that argued for reformulated gasoline as being the best solution to the problem of air pollution.

The pressure on this large technological system was increased even more in California in late 1980's, when the California Air Resources Board began to discuss alternative fuels as one solution, and adopted a zero-emission vehicle regulation, which was argued to be a necessary measure to meet future air emission goals. That regulation was the origin of the electric car controversy. This controversy was about the problem of reaching attainment of federal air quality standards in California.

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[232]Here it should be noted that these reverse salients were solved, in the sense of being considered to be solved. This means that my use of reverse salient and conservative change differs from that of Hughes. Hughes talks about reverse salient in terms of technical properties that need to be enhanced in some absolute sense. My use is however not to say that these solutions were false, it is to say that the important thing is the acceptance of them as being regarded as real solutions, and that this is what allowed further expansion of the system. Thus there is, in this particular case, a relationship between Hughes' concept of conservative change and Bijkers' concept of closure.

CARB and other electric car proponents argued that *ZEV* was needed, and the opponents argued that the problems could be solved with *gasoline car* technology.

Another feature of this controversy was the more general (and political) question about how a radical change in technology should be managed; through *markets* or through *mandates*. For the time frame of 1996 to 2002, the car industry won the battle over appropriate means of influencing technology (the market approach), but lost the battle over future car technology (the ZEV). Electric cars are now being introduced in California without being pushed by a mandate at the time of market introduction.[233] Of course, there still is the 10 percent mandate in 2003 to live up to, but the first round of the battle over the principle not to accept 'mandated markets' has been postponed until 2003.

The 1990 mandate initiated a range of sub-controversies and technology development activities, of which several have been examined more closely in this study. These sub-controversies and related activities have been chosen in order to capture what can be seen as important aspects of the processes that led to the stabilization of the controversy. This regards what made things happen (or not happen) in the field of electric car development, and factors that worked towards ending the controversy.

By early 1994, the actor world of this controversy can be seen as basically stabilized, and from this point on, it was very difficult for new issues to enter the controversy. For example the argument of the potential health risk of lead-batteries was to a large extent rejected by the actors in the controversy. It did not fit the 'rules of the game' that had been stabilized within the controversy. These 'rules of the game' have a longer history than that of the 1990 to 1996 electric car controversy. Air quality problems were defined in California in the 1970's in the process of regulating emissions from gasoline cars. Thus the problems that the electric car is to solve are prescribed by that process, as regards air emissions from (gasoline) cars. Other environmental effects of the use of the car were not included in the processes in the 1970's and early 1980's, and were not included in the recent electric car controversy either. When

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233GM EV-1 will be available to customers in Los Angeles, San Diego, Phoenix and Tuscon from 5 December, 1996. The three year (48,000 km) lease price is between $480 and $640 per month, plus $55 per month for the charger. Fuel cost will typically be $546 per year (Automotive Environment Analyst 1996).

the controversy was to be ended, the two main actors, CARB and the auto industry established closure to a large extent on their own.

Thus some areas of technology could be re-opened, whereas, as argued above, some are much harder to open up. The processes of the electric car controversy were able to re-open car technology *partially* (propulsion system), and were able to create a car market *regionally* (California). One reason for why this could take place is beacuse cars in California have since the late 1940's, when the emission problem was discovered, carried the notion of being polluters. However, this refers to the propulsion system; not the vehicle itself, and not the use of the vehicles. These areas were closed and could not be re-opened by the mandate.

A strong regulatory technology forcing framework was in place, as well as a well-developed institutional setting for handling these issues, in combination with a large car market in a region having rather few people economically dependent on automotive manufacturing. Yet another factor was that the strength of the already established relations between major actors (CARB and car industry) could not be altered by the environmental community, start-up companies, battery manufacturers, or the electric utility industry. These actors helped to support the mandate, and in that way helped to push electric vehicle developments forward. A general consensus among all actors is that electric vehicle technology has advanced significantly since 1990, and that this would not have happened without the mandate.

Oil industry acted aggressively against both the mandate and the electric car. General Motors worked against the mandate only, and has been fairly enthusiastic about having an advanced electric car for sale. Ford and Chrysler have not to the same degree been enthusiastic about electric cars, and certainly not about the mandate. The Japanese automakers were worried about what they regarded to be some sort of alliance between American interests versus foreign (Japanese) competitors.[234] Toyota is taking a similar and a more active role in Japan, as GM is doing in the United States. The Chairman of Toyota, Shoichiro Toyoda, stated at the 13th Electric Vehicle Symposium, in Osaka, Japan, that:

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[234]Maruo 1996, p. 67.

> Our mission on behalf of society should be to promote electric vehicles throughout the world as we move towards the 21st century. And I think we should proceed with that task.[235]

The electric utility industry, which historically has been a supporter of electric cars, never started to mass-produce electric cars itself. In the controversy under study, the ability of the electric utility industry to support the introduction of electric cars was negatively affected because the electric utility companies are not allowed by the Public Utilities Commission (PUC) to raise their rates in order to fund such activities.[236] For example, in the San Francisco bay area, this has led to a decreasing support for the electric charging infrastructure of Pacific Gas and Electric, with a consequent decreased estimated sales of electric cars.[237]

To summarize, the implementation of a new technology in an area which is highly embedded in society is not easily achieved. The pushing actor has to stay on top of the process, which obviously few actors have the opportunity and capability to do. But when, and if, these obstacles can be coped with, it can also be argued that *the creation and managing of a technological controversy is a way to influence technology.*

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[235]Toyoda 1996, pp. 21-22. According to historian, Kanehira Maruo, such a statement is within the Japanese culture a strong commitment.

[236]Sperling 1995, pp. 123-124. Also, in late 1994, Governor Wilson signed into law a bill (taking effect in Jan. 1995) that will cut 400 million USD of proposed increased rates for a support of electric (and gas-powered) cars by the electric utility industry in California (San Francisco Chronical 1994).

[237]Pacific Gas and Electric Company 1994, pp. 7-1, 7-2.

Postscript to licentiate thesis

The story outlined in this reprinted licentiate ends in early 1996, and most material is collected before that date. The focus of the study is on processes of the introduction of 'pure' electric cars. The reason is not so much that hybrid or fuel cell technologies is ignored, but that we (me and my supervisor Kanehira Maruo) regarded the zero-emission vehicle process as the driving force for all kinds of electric propulsion technologies in cars. It seems that the successful development of an electric hybrid vehicle often is preceded by the successful development of a pure electric car.

The general impression we had in early and mid 1990s — that we were looking at and being part of the beginning of a major technological shift — is today not only an impression but is also supported by actions taken by car manufacturers (especially that of Toyota and Daimler-Benz). Two years ago, it was still a radical thing to say that electric car technologies was entering the realm of car technology. Today we hear representatives from the auto industry saying that this is actually taking place. The processes of technology and especially that of the expectations around it, has thus changed faster than we anticipated.

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