Chapter 8

Technology Innovation and Policy: A case study of the California ZEV Mandate

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Abstract

This chapter presents an analysis of California's Low Emissions Vehicle (LEV) and Clean Fuels regulation, with a focus on the Zero Emissions Vehicle (ZEV) mandate. Utilizing the Technology Innovation System (TIS) framework adopted from Bergek et al (2005, 2008) and Hekkert et al (2007), we analyze the major factors that contributed to the development and deployment activities of low-emission, hybrid and zero emission vehicle technologies within the context of the ZEV mandate.

Keywords: California, Zero Emissions Vehicle, technology innovation and policy

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1. Introduction

This chapter presents an analysis of California's Zero Emissions Vehicle (ZEV) mandate in the context of the state's Low Emissions Vehicle (LEV) and Clean Fuels regulation[1]. The ZEV mandate began as a requirement that the auto industry produce a specific volume of pure electric vehicles, but was modified over time to accommodate an evolving understanding about the status of zero-emission and low-emission technology development.

Several factors make this study of California particularly relevant and revealing in relation to the U.S. and globally. California's 38 million people make it by far the most populous state in the U.S., accounting for about 12% of the country's population (U.S. Census Bureau 2009)(see Table 8.1). It is the largest state economy in the USA, and the eighth-largest in the world - in 2009, its GDP of $1,891 billion accounted for 13.4% of the country's GDP. Historically it has also had the dubious distinction of the worst air quality in the U.S. In response, the state has developed and administered some of the country's most aggressive emissions reduction programs. Over four decades, it has become recognized both nationally and internationally as a leader in environmental policy. Federal law has enabled California to adopt mobile source emission standards independent from, and more stringent than federal standards, acknowledging the special air quality problems of the state as well as its pioneering air pollution control efforts (National Research Council 2006). Additionally, several US states as well as other countries have followed California's standards, which in turn has contributed to spurring technology development nationally and globally (Shulock, Pike et al. 2011).

[1] Collantes, G. (2006) noted that over time, due to changes within the policy framework, the ZEV mandate evolved into a ZEV program. This distinction is important; however, for consistency, we will refer to the regulation throughout this chapter as the "ZEV mandate."

Two decades of declines in atmospheric levels of NO_2, CO, airborne lead and smog-causing Ozone (O_3) in California's urban areas have been largely attributed to reduced vehicle tailpipe emissions (FHA 2011) in response to programs like California's LEV/ZEV. Between 1970 and 1995, Vehicle Miles Traveled (VMT) in California more than doubled from 103 billion to 270 billion while population grew 60% from 20 to 32 million people (CARB 1997). By 2008, VMT had risen to above 320 billion miles, keeping at a steady 10-11% of US-wide VMT over the last decade. The impact of California's vehicle emission policies can be gauged by the fact that despite the increase in number of vehicles and miles traveled (Figure 8.1 and Table 8.1), smog-forming emissions from the state's passenger cars have declined (Bedsworth and Taylor 2007).

Box 8.1 Types of Electric Vehicles

Pure Battery Electric Vehicles (BEVs) use an all electric motor drive (instead of an internal combustion engine), which is powered by a battery system and charged via the energy grid (Chan 2002).

Conventional Hybrid Electric Vehicles (HEVs) utilize battery and electric motor components, in addition to an internal combustion engine(Chan 2002).

Plug in Hybrid Electric Vehicles (PHEVs) use the same components as a conventional HEV, but use a larger battery with a plug-in charger for grid energy which is then stored in the on-board battery (Jorgensen 2008).

Fuel Cell Electric vehicles (FCEVs) use hydrogen as its fuel source. FCEVs are not currently commercially available.

The purpose of this chapter is to provide an analysis of the California ZEV mandate and its impact on innovation in vehicle technology with a particular focus on activities within the U.S. This case study relies on academic literature, government reports and publicly available databases to detail how the ZEV mandate originated and developed over time, and how it contributed to the development and deployment of Hybrid Electric Vehicles (HEV), Plug-in Hybrid Vehicles (PHEV), and Battery Electric Vehicles (BEVs) (See Box 8.1 for definitions). To develop our analysis, we rely on the theoretical policy process framework proposed by Bergek et al (2005, 2008) and Hekkert et al (2007). The rest of this chapter is organized as follows. In section 2, we provide historical background on the political forces that created and shaped the ZEV mandate, describe how California's vehicle emissions standards have impacted the U.S. new vehicle market, and discuss recent regulatory changes and the future of the ZEV mandate. Section 3 analyzes outcomes of the ZEV mandate using a technological innovation system (TIS) framework adopted from Bergek et al (2005, 2008) and Hekkert et al (2007) to illustrate how the ZEV mandate influenced technology development and innovation in alternative vehicle technologies. Section 4 presents the summary and conclusions.

Chapter Scope

At the outset, it is important to note that the ZEV mandate does not stand alone. California transportation policies include regulations and incentives that cover what is commonly referred to as the "three legged stool" (CARB 2008): vehicle miles traveled, vehicle technology, and the carbon content of vehicle fuels. Examples of each of these themes and corresponding California legislation is shown in Table 8.2. California policies exist within a backdrop of federal regulations including vehicle tailpipe emission standards and the Corporate Average Fuel Economy standard[2]. While there are a variety of U.S. and state policies to choose from in framing our analysis of policy effects on technology innovation, we have focused our analysis around the California ZEV mandate, which some have referred to as "one of the most daring and controversial air quality policies ever adopted"(Collantes 2006; Collantes and Sperling 2008). In our analysis of innovation, we focus primarily on low-emission, HEV, PHEV and BEV

[2] The CAFE standard, set by the federal government and initially passed in response to the 1970s oil embargo, is a sales weighted average fuel economy standard (miles per gallon).

technology development. While we recognize that the ZEV mandate has also contributed to the development and anticipated deployment of FCEVs, which are expected to be sold into the California market in the 2015 timeframe, we have chosen to concentrate our analysis on technologies that are either in the market or coming to market this year.

2. The ZEV mandate: A brief summary of its history and evolution

Command and control regulations have been the centerpiece for U.S. regulation of the vehicle market, and litigation plays a strong role in affecting new policies (Mikler 2005). This system stands in contrast to other countries, such as in the EU and Japan, where policy creation occurs in a comparatively more collaborative atmosphere between government and industry, combined with market pressures for fuel efficient vehicles (Mikler 2005). Based on an exemption from the federal government, California, and in the context of this chapter, the California Air Resources Board (CARB), is uniquely positioned to set its own vehicle standards that affect cars sold in California and in states that choose to implement California's policies.

The California Air Resources Board

The California Air Resources Board (CARB) was established in 1967 with a mission to protect and safeguard public health, welfare and ecological resources by reducing air pollutants. CARB is a California government agency within the California Environmental Protection Agency, and is overseen by a full time chair and ten part-time members appointed by the governor. CARB policy has had far-reaching impact within and beyond state boundaries due to the culmination of three separate pieces of federal and state policy: the federal Clean Air Quality Act (CAA) of 1967, California Assembly Bill 234 enacted in 1987, and the 1988 California Clean Air Act (CCAA). Prior to 1967, California enacted mobile source emission standards independent of the federal government. The federal CAA sets tailpipe emission standards, and preempted all states except for California from regulating mobile source emissions. Under this legislation, California could continue to pursue its own regulations as long as they were more stringent then federal standards and provided that California could demonstrate compelling and extraordinary circumstances that necessitated the stronger standards. All other states can choose to either adopt California or federal standards but cannot set their own unique standards. New emission standards must be granted a waiver by the federal EPA, which itself is a time consuming process that presents an element of uncertainty to all stakeholders. Prior to 1987, California had applied uniform emission standards to vehicles that met particular weight categories. Assembly Bill 234 was introduced to promote alternative fuels and created the Advisory Board on Air Quality and Fuels, which introduced several concepts that were applied in the LEV program including creating different emissions performance levels (Collantes and Sperling 2008). In 1988, CARB received additional statutory direction through the Sher Act, also known as the California Clean Air Act (CCAA) that set the foundation for the eventual development of the ZEV mandate. The CCAA required CARB to take necessary, cost effective, and technologically feasible regulations to protect air quality and to meet particular air quality standards.

The LEV Program and the ZEV Mandate

Original inception

CARB established the LEV program in 1990 to combat poor air quality conditions in metropolitan areas by setting tailpipe emissions standards for volatile organic chemicals, carbon monoxide, particulate matter, NO_x, formaldehyde, and fleet average requirements for non-methane organic gases. Air quality was so poor that it did not meet federal requirements, putting the state at risk of losing millions of dollars of federal highway funds unless air quality improved (Shnayerson 1996). Air quality conditions coupled with public environmental awareness, strengthening of the federal CAA, and the emergence of BEV prototype programs - particularly the high profile General Motors' EV program - contributed to the legislative environment that formed the original program (CARB 1990b; Shnayerson 1996; Collantes and Sperling 2008). Instead of creating a single vehicle emission standard, the LEV regulation deviated from prior regulations by creating four different emissions performance levels that would meet the program's requirements, including the ZEV category (Collantes 2006) (see Table 8.3). Thus, the original 1990 ZEV mandate was an important component of the larger LEV program, and was designed as a technology forcing policy[3]. It required progressive increases in the sales volume of EVs - two percent of new vehicle sales by major manufacturers[4] were required to be ZEVs by 1998, and 10% by 2003. Although electric vehicle/battery technology was still relatively immature, the mandate was intended to accelerate the development and deployment of these types of vehicles(Collantes and Sperling 2008).

LEV I standards were first adopted for California in 1990, and covered 1994 through 2003. LEV I was adopted by New York, Massachusetts, Vermont and Maine. Over time the LEV program and the specifications of the ZEV mandate have been modified. LEV II amendments were adopted in 1999 and ran from 2004 to 2010. LEV II has been adopted by Maine, Vermont, New Jersey, Rhode Island, Connecticut, Oregon, Washington, Maryland, Arizona, New Mexico, and

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[3] We refer to this policy as "technology forcing" even though it was designed as a performance standard for zero emissions, as batteries were the only viable technology available at the time, to meet the policy requirements

[4] "Major" manufactures were defined as companies with total sales over 35,000 units annually in California. Flower, B. A. (1997). "Electric Vehicles: A Breath of Fresh Air for the Next Millennium." Pace Environmental Law Review: 329-372, ibid. Major manufacturers included Chrysler, Ford, General Motors, Honda, Mazda, Nissan, and Toyota. Manufacturers who had sales below this level were exempted, but could still participate in the program if they sold electric vehicles and generated ZEV credits to be sold to regulated companies Collantes, G. and D. Sperling (2008). "The origin of California's zero emission vehicle mandate." Transportation Research Part A: Policy and Practice: 1302-1313..

Pennsylvania (Sullivan 2009). The benefits to a particular state to adopt California's standards can include facilitating state air quality goals or more readily meeting federal air quality standards through reduced vehicle emissions (National Research Council 2006).

Review and Revision

The LEV/ZEV program required biennial review to evaluate the status of ZEV technology and allow for policy modifications as needed. Due in part to the reviews as well as legal challenges, the ZEV mandate has undergone a number of modifications. In its current form the program allows for more manufacturer flexibility in accumulation of ZEV credits for low-emission vehicles and includes additional categories of ZEV vehicle types. The regulation still requires that manufacturers sell a minimum number of ZEV vehicles; however, much of the program requirements can be met through low-emission vehicle technologies such as hybrid and plug-in hybrid electric vehicles. For a timeline of changes to the ZEV mandate, see Table 8.4.

Twenty years after the ZEV mandate was introduced, ZEVs are beginning to emerge in the commercial market in California. In the interim, automakers have also been successful in introducing a large number of hybrid electric vehicles which further advanced a wide range of electric-drive technologies such as motors, controllers, regenerative braking, X-by-wire systems, and hybrid batteries. These technologies have enabled significant vehicle emissions reductions compared to when the program began.

Current status of the LEV/ZEV Program

LEV I and LEV II focused on tailpipe emissions reduction only, and not a 'well-to-wheel' lifecycle consideration. Also, as Table 8.3 indicates, Greenhouse Gas (GHG) emissions were not included in the emissions standards. Even as smog-causing emissions have been declining, gross GHG emissions increased 4.3% from 2000-2008 to 477.7 million CO_2e (CARB 2010b), and the transportation sector remains the largest source of California's gross GHG inventory at about 36%[5]. CARB is currently preparing to develop and integrate existing LEV, ZEV, and new greenhouse gas requirements as part of a new LEV III program (CARB 2010a) which aims to accelerate the numbers of plug-in hybrids and pure zero emission vehicles sold into the California market from 2017-2025 (CARB 2011).

3. Technological Innovation System (TIS)

Institutional structures can have a profound impact on industry, and a technological innovation system (TIS) framework can help highlight processes by which industry innovation evolved. Seven TIS processes are used to frame this analysis of how a California policy influenced innovations in electric vehicle technologies (Bergek 2005; Hekkert, Barnes et al. 2007; Bergek 2008). Table 8.5 lists these processes, along with the corresponding indicators used in this study.

Knowledge development and diffusion

As the ZEV mandate evolved, sustained participation from public-private partnerships[6] and research efforts contributed to direct and indirect electric vehicle technology improvements. Prior to implementation of the ZEV mandate, only a few U.S. public-private government programs, with limited funding were dedicated to development of electric and hybrid vehicle technologies (Burke, Kurani et al. 2000). In 1990, funding for government programs that supported this type of technology development was at $18 million; by 2000, related funding had increased to $100 million (Burke, Kurani et al. 2000).

[5] Note that from 2000-2008, the per capita emissions as well as emissions per unit GDP declined continuously. In 2008, in response to the recession and high fuel costs, there was a drop in vehicle miles traveled for the first time since 1974. 2008 also saw a small decrease in statewide GHG emissions, attributed to a drop in transportation emission.

[6] Public-private partnerships are joint ventures that leverage government programs with private resources.

Research and development efforts were fragmented across different U.S. companies and federal programs prior to the ZEV mandate. After its implementation, a variety of U.S.- based partnerships emerged to support battery, electric, and hybrid vehicle technology development as shown in Table 8.6 (Burke, Kurani et al. 2000). This included the formation of the U.S. Advanced Battery Consortium (USABC), a battery consortium between the "Big Three" automakers: GM, Ford and Chrysler (Shnayerson 1996). The USABC was formed to leverage private research and development with federal resources (Shnayerson 1996). The US Department of Energy (DOE) had previously been funding dispersed advanced battery research efforts; with the USABC, federal money was focused to one pool and private money was included for collaborative research and development efforts toward advanced batteries. In 1991, $130 million in DOE money was equally matched by the Big Three and several utility companies (Shnayerson 1996).

Another criterion that indicates knowledge development and diffusion is patent activity, since companies tend to patent the technologies to which they are the most committed (van den Hoed 2005). By searching the annual number of patents related to EVs through the U.S. Patent and Trademark Office online database and controlling for overall changes in patent activity, Burke et al (2000) found that the introduction of the ZEV mandate was coincident with a substantial increase in patents related to EVs. Prior to 1991, average annual EV-related patents were declining by one patent per year. From 1992-1998, EV-related patents were increased by an average of 20, annually. In 1998, EV-related patents increased six-fold from 1980 levels (Burke, Kurani et al. 2000). A related analysis by van den Hoed (2005) broke out patenting activity by BEV, FCEV, and HEV; all of which increased on an average annual basis from 1990-2000. However, in the late 1990s battery electric vehicle patents began to taper off while patents for

FCEVs and HEVs continued to climb(van den Hoed 2005). Using the same patents database, we searched for the phrase ‘electric vehicle’ in the title of the patent, from 1976-2010. As can be seen in Figure 8.2, EV-related patent activity remained strong from 2000 to 2010. In fact the highest count (94 patents with ‘electric vehicle’ occurring in the title) was as recent as 2010[7]. Some have suggested that the ZEV mandate spurred battery technology development related to EVs (Mader 2006) and this U.S.- based summary of patent activity and tracking the development of alliances between actors, also implies a relationship between the policy and relevant technology development efforts. However, others have noted that a variety of international factors may have also contributed to sustained and related research and development efforts, particularly in the EU and Japan (Ahman 2006). Ahman (2006) notes that the ZEV mandate had the initial effect of reinvigorating EV efforts in Japan, but points out the importance of global energy issues and government support coupled with company leadership and vision that sustained Toyota’s efforts in developing the Prius. In France, around the same time that the ZEV mandate was originally introduced, the government-controlled electric company, auto and government research agencies pledged to work cooperatively toward the goals of putting 100,000 EVs on the road. The pledge was voluntary and non-binding; but demonstrates the complexity of the international automotive political environment that makes it difficult to determine to what degree the ZEV mandate *alone* may have affected worldwide knowledge and diffusion efforts related to ZEV and low emission technologies.

Influence on the direction of search

Over its evolution, the ZEV mandate created a variety of pressures that influenced the direction of search. The direction that the ZEV mandate initially pushed the industry was toward BEVs.

[7] As many as 22 EV-related patents had been filed in the first quarter of 2011.

However, as Sam Leonard, GM's former director of automotive emissions control noted, CARB, by insisting on a zero emissions standard, may have leaped over what would have been a more logical move toward hybrid technology (Shnayerson 1996). Despite research and development efforts by the Big Three, and federal funding, the costs of the battery technologies could not, according to the industry, be reduced to a competitive level to meet the timeline stipulated by the original ZEV mandate (Bedsworth and Taylor 2007).

The LEV/ZEV program required joint biennial reviews, which allowed CARB to (i) remain flexible in the face of technological challenges and setbacks, (ii) re-structure regulations and targets, and (iii) respond to industry (in)ability to meet the ZEV requirements. As a part of the 1995 review, CARB convened a Battery Technology Advisory Panel (BTAP) comprised of experts, who found that the primary battery chemistries, lead-acid and nickel-cadmium, would be available, however, their range and performance would not be at the level needed to meet consumer and cost needs (Brown 1999). Findings included the status of development of lithium-ion or nickel-metal-hydride components, which BTAP estimated would not be ready for another 15 years (Brown 1999). As a result of the findings of the 1995 BTAP, the ZEV mandate was modified in 1996. Changes included eliminating the near term ZEV requirements for 1998-2001, while retaining the 2003 10% requirement (Bedsworth and Taylor 2007).The memorandum of agreement (MOA) that erased this percentage requirement also formalized specific numbers of ZEVs per automaker to be put on the road by 1997 (Shaheen, Wright et al. 2002; greenpeace.org 2004), and allowed automakers to earn program credits for very-low emission vehicles. In exchange, DaimlerChrysler, Ford, GM, Honda, Mazda, Nissan and Toyota committed to put BEVs on the road and maintain battery research and development efforts (CARB staff 2001; Shaheen, Wright et al. 2002).

In 2000 CARB convened another BTAP, which found that battery technology was still highly cost prohibitive but also found that automakers were pursuing parallel technology that would achieve similar emissions goals as compared to BEVs and were shifting from BEV technology to HEVs (Bedsworth and Taylor 2007). In 2001, CARB revised the ZEV mandate to include more flexibility including reducing the percentage of pure ZEVs required and introducing a ZEV category that allowed hybrid vehicles to satisfy a portion of the ZEV requirement, and offering credits based on the vehicle's energy efficiency (Shaheen, Wright et al. 2002).

Although the policy remained responsive to perceived technological bottlenecks, continuous relaxations of the ZEV mandate and the uncertainty of waiver approval by the USEPA also had negative consequences. Regulatory uncertainty can slow private-sector innovation and although the ZEV mandate resulted in investment in areas that would subsequently benefit EV technologies, frequent changes to the program also caused fluctuations in investment and in certain cases industry overinvested based on expectations that the standard would remain in effect (Bedsworth and Taylor 2007; CALSTART 2009).

In addition to modifying the mandate to adapt to technological bottlenecks, and continuing to direct research and development activities toward low emission and ZEV technologies, a variety of other supportive U.S. policies and programs have also ramped up over the last 20 years. Federal, state, and private investment in electric drive vehicles now total over $10 billion, including ARRA investment[8] (California ETAAC 2009).

The overall relevance of the ZEV mandate in terms of influencing automakers toward ZEV production was well summarized at a 1990 hearing presentation, where Ms. Liwen Kao, CARB

[8] ARRA refers to the American Recovery and Reinvestment Act of 2009, a federal economic stimulus package.

staff, stated that "… without the mandate, it is uncertain whether manufacturers would be willing to commit the resources needed to accelerate the commercialization of ZEVs" (CARB 1990b).

Entrepreneurial experimentation

One of the more compelling results of the ZEV mandate has been its ability to spur entrepreneurial and research activity in the areas of EV components and materials innovations (Burke, Kurani et al. 2000)**.** Research funded by government and private sources has resulted in spillover technologies including improved electric drive systems and improved emission control technologies to meet the evolving regulation (California ETAAC 2009)**.** Current efforts include research in the areas of batteries, electric motors, and electric infrastructure readiness.

Nanotechnology is currently being pursued to develop batteries that are light, cheap, and have high energy densities (Burke 2009). Simultaneously, potential applications for the second-use of batteries are also being investigated. Although battery performance in vehicles is expected to degrade over time, they are expected to retain large portions of their initial storage capacity. Second-uses could make the life-time value of the battery pack more economical and potentially include solar photovoltaic-applications for load leveling and/or energy storage or for telecommunications backup systems (Burke 2009).

Entrepreneurial support for EV development, outside of the ZEV requirements, include a variety of state and federal research and incentive programs that are intended to help address high incremental battery costs for electric-drive vehicles. These programs include PNGV, FreedomCAR, the 2009 ARRA, and California's Assembly Bill 118, which authorized up to $120 million per year over seven years to develop alternative fuel and vehicle technologies(Ward, Olson et al. 2010). Investments have included hybrid-electric and battery electric vehicle research, development and demonstration programs, charging stations, and truck-stop electrification projects.

Innovation in developing complementary technologies combined with supportive California and federal government programs have contributed to supporting the end-goal of the ZEV mandate in terms of helping to reinforcing relevant technology development efforts within the U.S.

Market formation

The ZEV mandate was fundamentally a supply-side policy that required automakers to introduce clean vehicles to market. The mandate has also been accompanied by a number of consumer, or demand-side policies that have included investment in infrastructure, federal and state tax credits for vehicle purchases, and planned state purchases of EVs. A 2000 CARB staff reported noted that "because ZEVs are a relatively new technology and are currently produced in limited quantities, they are more expensive than conventional vehicles. To enhance vehicle marketability in the near term and to assist in the transition to large volume production, it is vital to provide support, both monetary and non-monetary, in the form of vehicle and infrastructure incentives" (CARB staff 2000). Programs including federal tax credits and private market formation efforts did just that.

As part of the ARRA, federal tax credits were made available for new vehicle purchases after 2009 for HEVS, PHEVs, and alternative fuel vehicles. Additional state incentives are available to California drivers including single-occupant use of high Occupancy Vehicle (HOV) lanes for clean alternative fuel vehicles, and in 2010 the state began offering purchase rebates to individuals who purchased or leased HEVs or PHEVs. Other states offer many incentives including tax credits and rebates, sales tax exemptions, parking and carpool lane incentives for new hybrid, EV, PHEV purchases, reduced electricity charging rates for BEVS, and electric car conversions. Research suggests that apart from incentives, gasoline prices are also a strong motivator for new HEV purchases (Diamond 2009).

Outside of the ZEV requirements, private and public purchases can help encourage larger production volumes, which allow manufacturers to benefit from increased economies of scale and help focus investment toward needed supporting infrastructure (Bedsworth and Taylor 2007). The US EPA stipulates purchase requirements for alternative fuel vehicles for federal fleets (Pilkington 1998). Private attempts at market formation have included a number of strategies including:

- Large fleet purchases. For example, in 2010, General Electric Company announced plans to purchase 25,000 EVs, and approximately 12,000 2011 Chevrolet Volts(Layne 2010).
- Lease programs aimed towards developing consumer acceptance. For example, Honda's Charter Lease Program, a leasing program of its EV PLUS four-passenger battery-powered EV. Lease terms included unlimited mileage, comprehensive insurance, 24-hr roadside assistance, and a partnership with Edison EV to provide equipment service (CARB staff 1998).
- Focusing on the fleet market. Toyota focused on the fleet market for its electric RAV4 EV, a five-door sport utility vehicle (CARB staff 1998).

The ZEV mandate, federal and state incentives, private and public fleet purchases, and companies looking to establish themselves as market leaders in EV technologies have all contributed to supporting market formation in low-emission and ZEV technology.

Legitimation

Legitimizing new technologies can be framed in terms of social and industry acceptance of new technologies. One way to gauge legitimacy is to understand how strong industry motivation is to engage in research and development activities in low emission and ZEV technologies.

In 2000, CALSTART, an organization that promotes clean technology in the transportation industry, conducted interviews with 134 member companies. Respondents were asked about the importance of the ZEV mandate to the success of their companies; for the years 1990-99, 80% responded that the program was very/somewhat important, and 90% viewed the policy as very/somewhat important to the future success of their business (Burke, Kurani et al. 2000). Research and development efforts are still focused around the battery, as its cost and capability are primary barriers to the commercial viability of BEVs and PHEVs. As of 2009, PHEV battery costs exceeded $1,000/kW-hr (Howell, Barnes et al. 2009). The US ABC has set a goal for reducing battery cost to $293/kW-hr for a 40-mile plug-in and $500/kW-hr for a 10-mile range plug-in (Alamgir 2008)[9].

Increasing numbers of actors and supporting actions contribute to technology legitimation. As another indicator of this, manufacturers are setting their own targets and ramping up investment in EV and low emission vehicle offerings. Nissan has announced that it expects 10% of its global sales to be EVs by 2020 (LeBeau 2009) and Volkswagen announced that it expects 3% of its global sales in 2018 to be EVs (Merchant 2010). Additionally, Tesla is actively marketing its Roadsters, the first highway-capable EV available in the US, and Ford, BMW, Volkswagen, Th!nk, and Mitsubishi are conducting battery vehicle demonstrations (Shulock, Pike et al. 2011) in addition to launching the upcoming production programs shown in Table 8.7. Company goal setting for EV market share may be due in part to the ZEV mandate, but companies may also be

[9] Miles refers to the number of miles a PHEV can travel on battery power alone.

responding to a number of factors including uncertainty in the petroleum market and/or pressure to establish themselves as market leaders.

Resource mobilization

State and federal funding programs have served to bolster the California's clean vehicle mandates by making research and development funds available, creating federal low interest loans, and creating consumer incentives for purchases. Prior to passage of the 1990 ZEV mandate, EV-related government programs were allocated $18 million (1990), which increased to $100 million in 2000 (Burke, Kurani et al. 2000). After the passage of the ZEV mandate, a litany of federal, state, local and utility incentives emerged to support the budding EV market including tax credits and rebates, demonstration and research and development programs, employee incentive programs, and discounted electricity charging rates (CARB staff 1998). Similar incentives have continued, and as of 2009 the federal government and other states were committed to $7.7 billion for manufacturing, federal tax credits on alternative vehicle purchases, and EV demonstration projects (California ETAAC 2009).

In 2009, the Advanced Technology Vehicle Manufacturing Program, a federal program which included private matching funds created a goal of producing 170,000 EVs (by Tesla and Nissan) and included supporting fiscal instruments including $500 million in loans to Fisker Automotive to manufacture an EV (by 2010) and 75,000-1000,000 Plug-in EVs (by 2012). Additional DOE funding (2009) included $1.5 billion in grant money for manufacturing batteries, components (and recycling); and $500 million for electric drive components (California ETAAC 2009). Low-interest federal loans included $5.9 billion to Ford for retooling for production of 13-fuel efficient vehicles including 10,000 PHEVs scheduled for market debut in 2011, and Nissan received 1.6$ billion in loans to retool a Tennessee plant to make PHEVs and produce over 200,000 advanced-technology batteries annually (California ETAAC 2009).

In terms of California-specific fiscal support AB 118**,** the Alternative and Renewable Fuel and Vehicle Technology Program, funded by new vehicle license fees, has allocated significant funds to addressing low carbon infrastructure deployment and invests in clean vehicle technologies (Shulock, Pike et al. 2011).

In California, this increase in investment has led to over 60 companies that focus on researching or manufacturing electric drive components (CALSTART 2009) and CARB estimated that PHEVs, EVs, and FCEVs will consist of one-third of the California vehicle fleet by 2030(CARB 2008).

The importance of the ZEV mandate in creating a more advantageous environment for obtaining resources is highlighted in the 1995 BTAP report, which notes that advanced battery developers felt that the ZEV mandate had been a crucial component to obtaining outside investment (Kalhammer and et al 1995). As described above, support from complimentary US programs also contributed to developing low emissions and ZEV technology.

Development of positive externalities

Complementary policies, infrastructure investment, and research on complementary products have lead to technologies that have benefited the commercial viability of EVs. Advances in battery technology have benefited BEVs, HEVs and PHEVs (BTAP 2000). State, federal, and public-private partnership support for charging stations for PHEVs and EVs are helping to ensure that the market for these new vehicles are complimented with needed infrastructure.

According to the California Energy Commission, as a result of the ZEV mandate, over one million PZEVs and AT-PZEVs have been introduced to the market (Ward, Olson et al. 2010).

4. Conclusion

In this chapter we used a TIS framework to assess the manner and the extent to which the ZEV mandate played a role in driving innovation in ZEV and low emission vehicle technology. Twenty years after the ZEV mandate was introduced, we are just now seeing the commercial introduction of pure ZEV technologies into the California market. In the interim, we saw the introduction of numerous technologies that contributed significant emissions savings and introduced the electric-drive platform that is essential for ZEVs.

A number of significant factors emerged that supported ZEV and low emission vehicle innovation, particularly in the U.S., including complementary state and federal policies that supported alliances between actors, provided resources for research and development, and established programs to support infrastructure readiness activities. Vehicle electrification policies and low emission vehicle technologies were also being implemented in other countries, which likely complemented many of the efforts highlighted in this chapter, especially given the multinational nature of the major players in the auto industry.

These complementary policies and government resources appear to be working together to achieve ZEV and low emission vehicle technology innovation in a way that Hekkert et al. (2007) describe as “motors of change” or “virtuous cycles”. Additionally, advances in low emission vehicle technologies may have also been part of the “virtuous cycle” leading to advances in ZEV technology. According to the 2007 BTAP report “*it is the Panel’s opinion that HEVs, due to their success, are providing major support to future mass market ZEVs by continuing to* *stimulate advances in electric drive systems, electric accessories, and battery technologies. Also, they are increasing consumer awareness of electric drive technology and the associated benefits*" (Kalhammer, Kopf et al. 2007).

CARB documentation implies that the ZEV mandate did indeed provide an important foundation for this virtuous cycle for ZEV and low emission vehicle technology development and deployment. A 2000 CARB staff report noted that: *"The ZEV requirements have been instrumental in promoting battery, fuel cell, component and vehicle research and development. These requirements have also been successful in spawning a large variety of extremely low-emission vehicle technologies."* (CARB staff, 2000).

Relaxation of the mandate in response to perceived technological bottlenecks, combined with the uncertainty inherent in the US EPA waiver process may have resulted in investment fluctuations in private sector innovation (National Research Council, 2006).

While the ZEV mandate did result in changes within each TIS category, the policy exists within an intertwined state, federal, and international environment. Thus, as is the case in many technology forcing policies, it is difficult to determine the degree to which the ZEV mandate *alone* influenced the development of zero-emission and low-emission vehicle technologies. However, in tracking the changes that occurred within each TIS subcategory before and after implementation of the ZEV mandate (see Table 8.8) the conclusion that emerges is that the policy played a driving role by creating a focus for complementary state and federal policies and for public and private resources that supported the emergence of ZEV and low emission vehicles. Indeed, ZEV remains an important component of ongoing LEV III formulations. Despite the complexity of the LEV/ZEV story, in an independent review of standards for mobile source emissions standards in the U.S., the National Research Council recommended that the EPA continue to provide California an exemption that allows it to set its own standards (National Research Council, 2006). The importance of this federal level policy decision must be emphasized – it underpins vehicles emissions controls in the U.S. by allowing California to continue to be a state laboratory for innovation. In this context, the ZEV mandate has played an important role in driving innovation and appears set to continue to do so.

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Table 8.1 California profile (1980-2007)

Year	Population (million)	Passenger vehicles (million)	New registrations (million)[a]	Motor vehicle fuel (billion gallons)	VMT (billion)[b]	Ozone violations (Days)[c]
1980	23.5	13.2	0.96	11.3	168	212
1990	29.6	16.8	1.44	13.4	235	192
2000	33.9	19.1	1.77	14.8	307	147
2007	37.6	22.1	1.68	15.7	328	127

Data Sources: California Census; Federal Highway Administration; California Department of Finance

[a]Includes all vehicle types
[b]1980 and 1990 figures are interpolated.
[c] Days above California 8 hr-maximum standard, for South Coast Air Resource Basin.

Table 8.2: California policy examples

Policy Type	Policy Example
Vehicle Miles Traveled	SB 375 (Steinberg), was signed into law in 2008 and established regional GHG reduction targets from land use and transportation network management.
Vehicle Technology	AB 1493 (Pavley), was initially passed in 2002 to regulate greenhouse gas emissions in new passenger vehicles. However due to litigation and initial denial of waiver by the U.S. EPA under the Bush administration, California was not able to implement the program until 2009 when U.S. EPA under the Obama administration, issued the necessary waiver for California to implement the policy. The LEV/ZEV program is also a vehicle technology policy and is covered in detail in this Chapter.
Carbon Content of Vehicle Fuels	The Low Carbon Fuel Standard, adopted in 2007, requires a 10% reduction in the carbon intensity of all transportation fuels by 2020.

Table 8.3: LEV Categories

	1990 Definition		
	NMOG*	**CO**	**NOx**
Transitional Low-Emission Vehicles (TLEVs)	0.125	3.4	0.4
Low Emission Vehicles(LEVs)	0.075	3.4	0.2
Ultra-Low-Emission Vehicles (ULEVs)	0.04	1.7	0.2
Zero-Emission Vehicles	0	0	0

*NMOG: Non-methane organic gases. All criteria pollutants are shown in grams/mile. Source: (CARB 1990a)

Table 8.4: Mandate Revisions- Timeline and Highlights

Year	ZEV Revision Highlights
1990	ZEV mandate adopted as part of the LEV I regulation, requiring two percent of all passenger cars sold by large vehicle manufactures be ZEVS for the 1998-2000 model years, 5% for the 2001-2002 model years; and 10% for the 2003 model year. (CARB staff 2001)
1996	To account for more time needed to development related ZEV technology; CARB dropped the sales requirements for 1998-2002;,and maintained the requirement for 10% ZEVs for 2003. CARB developed a Memoranda of Agreement with seven vehicle manufactures to offset the emissions benefits lost by dropping the 1998-2002 sales requirements. In return, the vehicle manufactures agreed to introduce 1,800+ BEVS in California between 1998-2000. CARB committed to helping develop the ZEV market. (CARB staff 2001)
1998	LEV II was modified to allow for other near-zero emission vehicles to count toward the 10 %ZE requirements (Partial ZEVs). Four percent of large manufacturer sales still had to meet the “full” ZEV requirement(CARB staff 2001). Pure ZEVs are considered to have zero tailpipe emissions (e.g. BEVs or FCEVs). PZEVS have to meet stringent tailpipe emission standards and come witl 15 year, 150,000 mile emission warranty. (CARB staff 2009)
2001	Manufacturers were still required to meet the 10% by 2003 requirement; but this year’s amendments created new categories by which large manufacturers could earn ZEV credits for low emission vehicles. 60% of the ZEV requirement could be met with PZEVs; and 20% could be met with advanced technology vehicles (AT PZEV) including gasoline hybrid-electrics. Intermediate manufacturers could meet its full ZEV requirement through PZEV/AT PZEV credits. Manufacturers could also earn credits by introducing vehicles early to market (CARB staff 2003). AT PEVs are considered to be vehicles with higher tailpipe emissions than PZEVs, and utilize ZEV-technologies (e.g. electric drive). Credits could also be obtained through Neighborhood Electric Vehicles (NEVs). (CARB staff 2009)
2003	ZEVs were redefined to include five vehicle types including NEVs, low and mid-range EVs, BEVs, and FCEVs. PZEVs could count up to 6% of the ZEV requirement, and AT PZEVs could count up to 2%. This policy was implemented in 2005; while still allowing manufacturers to count credits for vehicles produced prior to 2005. The amendments created two defined paths for manufacturers to meet the ZEV mandate- the “Base path” included banked credits to count toward 2% of the ZEV requirement annually; while an “Alternative Path” included new ZEVs introduced to market at one time, within a three year window. In response to legal challenge, the regulation also removed fuel economy/efficiency references and restarted the ZEV percentage requirements with the 2005 model year(CARB staff 2004; CARB staff 2009).
2008	Created new ZEV and AT PZEV categories (including the Enhanced AT PZEZ, which was defined as using hydrogen or electricity for fuel) and allowed the Enhanced AT PZEV to meet 90% of the ZEV requirement in the near term and 50% in the medium term (2012-2017). (CARB staff 2008)

Note: This table is by no means all encompassing; it conveys a sense of the important changes that have taken place over time.

Table 8.5: TIS Framework and Indicators

Processes	Description	Indicators applied in this analysis
Knowledge development and diffusion	The generation of breadth and depth of the knowledge base of the TIS, and the diffusion and combination of knowledge.	Development of alliances between actors Patents
Influence on the direction of search	The existence of incentives and/or pressures for actors to enter the TIS, and to direct their activities towards certain parts of the TIS.	Evolution of supportive regulations and targets/goals Technological potential and bottlenecks
Entrepreneurial experimentation	The probing into new technologies and applications in an entrepreneurial manner.	Variety of technologies and applications
Market Formation	The articulation of demand, the existence of standards, and the timing, size and type of markets actually formed.	Market supporting mechanisms
Legitimation	Legitimacy is a matter of social acceptance and compliance with relevant institutions.	Public opinion towards the technology captured by surveys of views Number of actors and supporting actions
Resource Mobilization	The extent to which the TIS is able to mobilize competence/human capital and financial capital.	Volume of money available in different parts of the system
Development of positive externalities	The generation of positive external economies, such as pooled labor, knowledge spillovers, specialized intermediate goods, and complementary products, services and infrastructure.	Development of complimentary products and technologies) Infrastructure readiness activities

Table 8.6: Private, State and Federal Partnerships

Program Name	Year Formed	Description
U.S. Advanced Battery Consortium	1991	Domestic automakers and the federal government. Dedicated to supporting electric vehicle battery research and development.
US Council for Automotive Research (USCAR)	1992	Ford, Chrysler, and GM, to partner on research and development of advanced vehicle technologies. USCAR has also supported the PNGV and FreedomCAR efforts (below).
Partnership for a New Generation of Vehicles (PNGV)	1993	Domestic automakers and the federal government. Dedicated to support electric vehicle technologies and hybrid-electric vehicles. In 2002, the program evolved into the Bush FreedomCAR program to focus on hydrogen and fuel cell technologies.
California Fuel Cell Partnership	2000	Foreign and domestic automakers, California state and local agencies and hydrogen refueling companies. To promote and develop fuel cell vehicle technologies and infrastructure
Plug-in Hybrid Electric Vehicle Research Center, UC Davis	2007	Funded by CARB and CEC funds to partner with government agencies and industry to research issues of PHEV commercialization and provide policy guidance.
GM- Electric Power Research Institute- Electric Utility Industry Collaboration	2008	GM and 30 major utility companies and EPRI. To ensure that the grid and related codes and standards are prepared for the introduction of the Chevy Volt to the market.
Project Get Ready, Rocky Mountain Institute	2009	Partners with regional jurisdictions across the U.S. to prepare these communities for plug-in vehicles and to support the federal goal of one million plug-in cars by 2015
National Plug-in Vehicle Initiative (NPVI)	2009	Sponsored by the Electric Drive Transportation Association, a partnership between auto and utility companies, battery and component manufacturers and government representatives. To support widespread adoption of Plug-in electric vehicles.
PEV Collaborative Council	2010	The PHEV Center and CEC partnered with public and private stakeholders to form the Collaborative Council, charged with creating a strategic plan for PEV readiness in California.
Ready, Set, Charge!	2010	Utility, auto, and electric vehicle supply equipment companies, local and state representatives. To develop a statewide plan to overcome EV infrastructure challenges.

Sources: (Bedsworth and Taylor 2007; Rocky Mountain Institute 2008; Ward, Olson et al. 2010; USCAR 2011)

Table 8.7: Commercial BEVs and PHEVs

Vehicle	Manufacture	BEV/PHEV	Electric Range	Model Year
Roadster	Tesla	BEV	245 mi	2010
LEAF	Nissan	BEV	100 mi	2011
VOLT	GM	PHEV	40 mi	2011
ActiveE	BMW	BEV	120 mi	2011
Transit Connect Electric	Ford	BEV	80 mi	2011
Focus Electric	Ford	BEV	100 mi	2011
i-MiEV	Mitsubishi	BEV	75 mi	2011
Karma	Fisker	PHEV	50 mi	2011
Coda Sedan	Coda	BEV	100 mi	2011
F3DM	BYD	PHEV	62 mi	2011
E6	BYD	BEV	250 mi	2011
Prius Plug-in Hybrid	Toyota	PHEV	14.5 mi	Unknown
Smart ED	Daimler	BEV	70 mi	2012
Rav4-EV	Toyota	BEV	100 mi	2012
Think City	Think!	BEV	120 mi	2012
Model S	Tesla	BEV	160-300 mi	2012

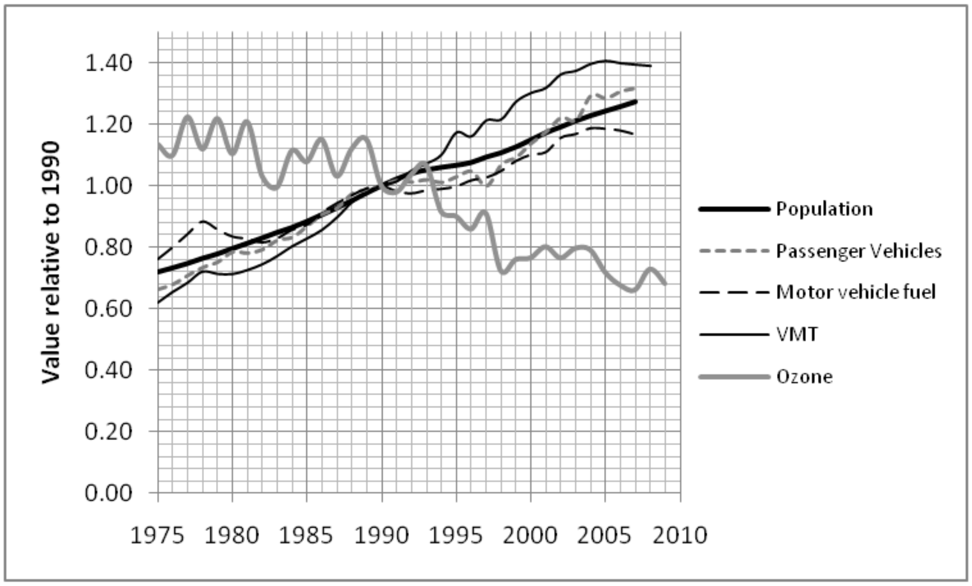
Table adapted from "Taking Charge,"(California Plug-In Electric Vehicle Collaborative 2010)

Table 8.8: ZEV Implementation: Before and After

Processes	Indicators applied in this analysis	ZEV Implementation: Before and After Changes
Knowledge development and diffusion	Development of alliances between actors Patents	• Increase in the number of Private, State, and Federal Partnerships dedicated to supporting zero emissions vehicle technologies • Increase in the amount of public-private research money available • Marked increase in EV- related patent activity
Influence on the direction of search	Evolution of supportive regulations and targets/goals Technological potential and bottlenecks	• Increase in federal, state, and private investment and incentive programs • Mandate was modified over time in response to technological bottlenecks • Technological potential for hybrids may have been hindered due to CARB's initial focus on ZEV technology.
Entrepreneurial experimentation	Variety of technologies and applications	• Increased market for spillover technologies including batteries, improved electric drive systems and improved emission control technologies • Increased incentives for entrepenurial efforts in the area of alternative fuel and vehicle technologies.
Market Formation	Market supporting schemes Variety of customer groups	• Increased government support for market formation of alternative vehicle technology including: infrastructure, federal and state tax credits for vehicle purchases, and planned state purchases of EVs • Customer groups including private, government, and companies were targeted in early market formation efforts.
Legitimation	Public opinion towards the technology captured by surveys of views Number of actors and supporting actions	• CALSTART surveyed transportation companies, who felt that the ZEV mandate was either very/somewhat important to the future success of their business. • Manufacturers are now setting their own EV targets and pursuing battery vehicle demonstration programs. • State and Federal efforts include overcoming infrastructure challenges including the deployment of public charging stations
Resource Mobilization	Volume of money available in different parts of the system	• Government support increased to include federal and state tax credits, research and development resources, and grants and loans to private companies for EV components and plant retooling.
Development of positive externalities	Development of complimentary products and technologies) Infrastructure readiness activities	• Advances in battery technology, infrastructure investment and advances in vehicle componetry have benefited the viability of a variety of advanced vehicles.

Sources:(Shnayerson 1996; Burke, Kurani et al. 2000; van den Hoed 2005; Bedsworth and Taylor 2007; Rocky Mountain Institute 2008; California ETAAC 2009; Ward, Olson et al. 2010; Shulock, Pike et al. 2011; USCAR 2011)

Figure 8.1 California profile: 1975-2009



Data Sources: Same as for Table 8.1

Figure 8.2 US patents related to EV: 1976-2010