CALIFORNIA AIR RESOURCES BOARD

RESEARCH DIVISION

SECONDARY BENEFITS OF THE ZERO-EMISSION VEHICLE PROGRAM

Staff's Summary of Work Performed by
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Secondary Benefits of the ZEV Program

A. Introduction

This report summarizes the positive economic and technological "spin-offs" from the Air Resources Board's (ARB or Board) Zero-Emission Vehicle (ZEV) program. It describes how technological innovations that stem from efforts to comply with the ZEV regulations have improved products that are *not* subject to those regulations. Also, the report presents information on the economic and research activities related to electric vehicles, ZEV compliance efforts, and the spin-off technologies.

The information summarized in this report has been developed under ARB Contract #99-328 by Andrew Burke, Ph.D., and Kenneth Kurani, Ph.D., from the Institute for Transportation Studies of the University of California, Davis (UCD). Their report, "Study of the Secondary Benefits of the ZEV Mandate", is an appendix to this report. It includes economic data developed by CalStart, under sub-contract to Dr. Burke.

This report is being published as an adjunct to the staff report, "2000 Zero Emission Vehicle Biennial Program Review", which describes progress by automakers and the ancillary industries toward compliance with California's ZEV regulations. The biennial review will be evaluated by the Board in September 2000.

B. Background

1. ZEV Regulations

The Board adopted the initial ZEV regulations in 1990. Those regulations required each major automaker to provide at least two percent of its 1998 light-duty vehicle sales in California[1] as "ZEVs" – vehicles with no tailpipe or evaporative emissions at all during their useful lives. Additionally, the required minimum ZEV fraction of sales increased to five percent in 2001 and ten percent in 2003. Pure electric vehicles (EVs) were regarded as the only potential ZEV technology.

In 1996, the Board removed the requirement for ZEV sales for 1998 through 2002. Instead of requiring sales in those years, the Board entered into "memoranda of agreement" with the major automakers. In aggregate, the automakers committed to putting up to 3,750 EVs[2] with advanced battery technologies into use in California by the end of 2000. ARB committed to facilitating the introduction of EVs into commerce, in part by promoting the establishment of charging stations.

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[1] The regulatory quota actually refers to the percent of vehicles delivered to California for sale.

[2] The actual required number depends on the attributes of the vehicles produced. Approximately 2000 vehicles will be placed.

In 1998, as part of its "low-emission vehicle (LEV) II" actions, the Board amended the ZEV regulations again, to their current form. The regulations now require each major automaker[3] to provide at least four percent of its light-duty vehicle sales as true ZEVs (which are expected to be EVs) in 2003. The remainder of the overall 10-percent ZEV requirement may be met by providing true ZEV vehicles as another six percent of vehicle sales. However, that portion may also be met with a greater number of non-ZEV vehicles having some or all of the following special characteristics: Super Ultra-Low Emission Vehicle (SULEV) exhaust emissions, extended durability, zero evaporative emissions, zero-emission operability, advanced on-board diagnostics, and low fuel-cycle emissions[4]. The actual number of qualifying non-ZEVs that will complete an automaker's compliance with the nominal ten-percent ZEV requirement will depend on which of the characteristics these vehicles possess.

The revised ZEV regulations promote the development of non-EV technologies, such as fuel cells for vehicles, on-board reformers for hydrogen production, and hybrid vehicles. These developments are part of the economic activity and technological spin-offs discussed in this report.

2. Previous Work

Two reports [1,2] commissioned by the Electric Power Research Institute (EPRI) discussed economic and technological activities stemming from EV developmental work, from the adoption of the original ZEV regulations (1990) until 1995. One report [1] tabulated survey responses from 55 people in ZEV-related industries on their opinions of the effects of the ZEV regulations on their companies' products and activities. The companies in the survey worked in six technological areas: batteries, rechargers, power electronics, power trains, fuel cells, and energy management systems. Table 1 shows the numbers of respondents who recognized an influence of the regulations on their company's products and activities.

Table 1. Number of Responses* over Six Technological Areas

Statement about Technology	Agreed	Partly Agreed
ZEV spurred inventions.	13	13
ZEV spurred significant improvements.	13	11
ZEV spurred production.	20	23
ZEV spurred new investment.	32	16

*out of 55 total responses in 1995 Source: Turrentine and Kurani [1]

The authors also found that the number of granted patents with the key words "electric" and "vehicle" increased nine-fold between 1990 and 1994.

[3] Automakers selling 35,000 or more passenger cars and light-duty trucks annually in California.

[4] Low fuel-cycle emissions – emissions from producing, transporting, and marketing the vehicle's fuel.

The other EPRI report [2] identified the benefits of improved EV technologies in eight types of non-ZEV applications, shown in Table 2.

Table 2 "Spin-Off" Applications of EV Technologies in 1995

Non-EV Application	Technologies	Improvements
electric mowers, other lawn/garden tools	batteries, AC motors, brushless DC motors	reduced noise & emissions, avoidance of gasoline storage, ease of starting
electric boats	batteries, drive trains, power electronics	reduced noise & emissions (compared to gasoline-powered)
electric wheel chairs & scooters	batteries, drive trains, rechargers	greater mobility & reliability
emergency lighting	batteries	greater reliability
airplanes	batteries, energy management systems	less maintenance, greater reliability, less weight
telephone switching	batteries	less down time, better performance
all vehicles	heating & A/C	less energy use, more comfort
electric utilities	batteries, energy management systems	more efficiency & versatility in generation, transmission, and service

Source: Turrentine and Kurani [2]

C. Methods in the Current Work

The UCD contractors and ARB staff developed various criteria to identify economic and technological developments stemming from the ZEV program. Any post-1990 technological development that is directly used in on-road EVs is considered a primary product of the program. Such primary developments are not themselves the subject of this report. However, the *economic activities* resulting from such developments *do* count as secondary ZEV benefits. Additionally, if a primary EV technology has (or is expected to have) non-EV applications, those applications are also considered secondary benefits. Finally, certain other activities and technological developments are included as secondary ZEV benefits because the ZEV program stimulated their advancement, even though they are not EV technologies. Such indirect secondary benefits are attributed to the ZEV program because of:

- the timing of the activity or development relative to the adoption of the regulations (e.g., increases in patent activity and federal research budgets after adoption of the regulations)

- explicit statements by parties to the activity (as in the case of the Advanced Lead-Acid Battery Consortium)
- potential utility for ZEV compliance by means other than EVs (e.g., vehicles meeting SULEV emission standards, fuel cells, hybrid vehicles)

In part, the identification of the ZEV program as a contributory cause or stimulant for certain activities and developments is based on the contractors' professional experience in the fields.

Information about the economic activity resulting from the ZEV program has been gathered by CalStart, through contacts with its associated companies, and by the contractors' review of public literature from the United States Department of Energy (DOE) and other sources.

D. Findings

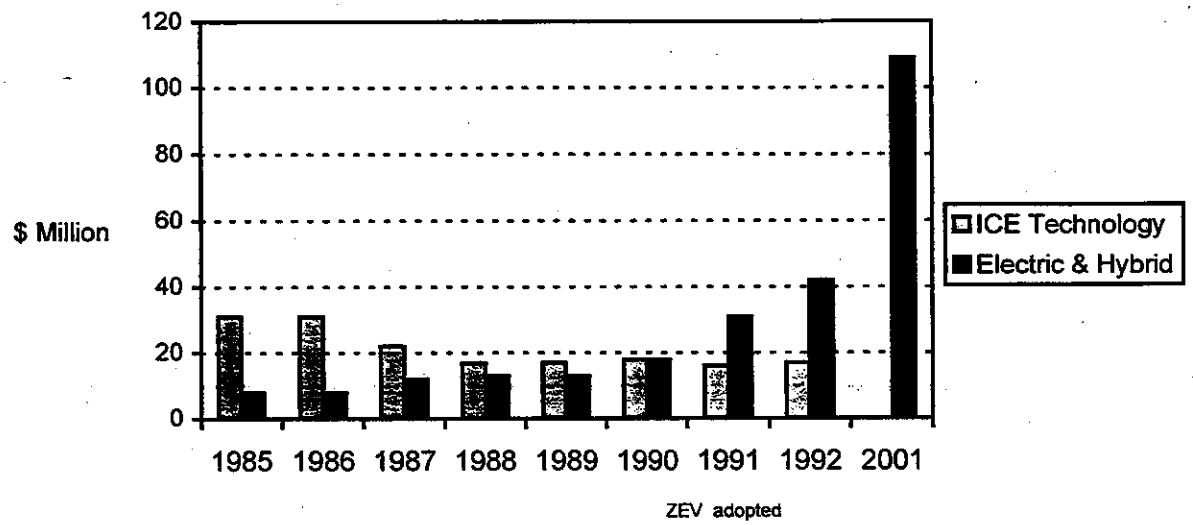
Current work has confirmed and amplified the results of the EPRI-funded studies and has identified additional ZEV spin-offs. The ZEV program has spurred large federal and corporate research and development (R&D) investments in EV-related technologies and in vehicle technologies that automakers have pursued as potential low-emission alternatives to EVs. These efforts have produced technological innovations and advances that otherwise would probably not have existed today. This R&D productivity is evidenced by a very large increase in patent activity. (See Figure 2, page 7.) These advances have considerable potential economic value outside of direct EV applications and should provide emission reductions beyond what is expected from ZEV compliance alone.

The findings presented in the UCD contractors' report are summarized below. They are organized in three categories of secondary benefits: Economic Activity, Advances in Clean Vehicles, and Technological Developments and Their Uses.

1. <u>Economic Activity</u>

- *Federal R&D Funding.* The ZEV program rejuvenated federal support for R&D of EV and related technologies, mainly via the DOE and Department of Transportation. Figure 1 shows relevant DOE budget data over time. After the ZEV regulations were adopted in 1990, funding for "electric and hybrid propulsion" increased strongly, while funding for R&D of internal combustion engines declined. DOE's two national laboratories in California have received a share of the increased federal funding. The R&D consortia discussed next have also benefited from the increased availability of federal monies.

Figure 1. DOE Budget History [5]



- *R&D Consortia.* Several consortia have been founded in response to the ZEV program. These consortia have conducted important projects on EV technologies, with risk factors that discouraged individual companies from pursuing these projects privately. This work has not only advanced EV technology and the prospect of ZEV compliance, it has also contributed to the technological spin-offs described in this report.

  The following consortia emerged primarily as a result of the ZEV program.

  -- United States Advanced Battery Consortium (USABC)

  -- Advanced Lead-Acid Battery Consortium (ALABC)

  -- Electric Vehicle Association of the Americas

  -- Japan Electric Vehicle Association

  The USABC and the ALABC together have spent over $500 million on ZEV-related R&D.

  Other consortia have been founded for R&D of vehicle technologies other than EVs. Their existence is <u>not</u> attributable to the ZEV program, but their programs have been advanced by EV technological improvements. These consortia include:

  -- Defense Advanced Research Projects Agency (DARPA)

  -- Partnership for a New Generation Vehicle (PNGV)

  -- California Fuel Cell Project

[5] The data source was published in 1993. Analogous data are not available for later years. The bar for 2001 reflects budget requests for programs similar, but not necessarily identical, to program budgets indicated for other years.

These entities have spent well over a billion dollars in R&D since the ZEV regulations were adopted. However, the EV-related portion of those expenditures is not identifiable.

- *Private Business*. Many companies have been formed to conduct the programs funded by the federal government and/or the consortia or to provide the products and services used in EV and spin-off technologies. In a CalStart survey of 134 companies, 15 of the 22 respondents were founded after the ZEV regulations were adopted. Tables 3 and 4 summarize economic data obtained through, or based on, this survey. It is clear that the ZEV regulations have been an important economic factor for most of these companies. *However, since the sample size is small, the numbers presented here should not be viewed as a complete statement of the role of the ZEV program in the California economy or of its importance to technology development.*

Table 3. Percent of 22 Survey Responses

	Yes	Partly	No
Company's EV technology is sold in non-EV markets	53%	n/a	47%
Company was founded because of ZEV regulations	26%	n/a	74%*
ZEV regulations have been important to company's existence and growth	32%	47%	21%
ZEV regulations will be important to continued growth.	42%	47%	11%

* includes the 7 companies founded before 1990; about half of those founded *after* 1990 attributed their foundings to the ZEV regulations.

Table 4. Private Economic Activity Related to Electric Vehicle Technologies

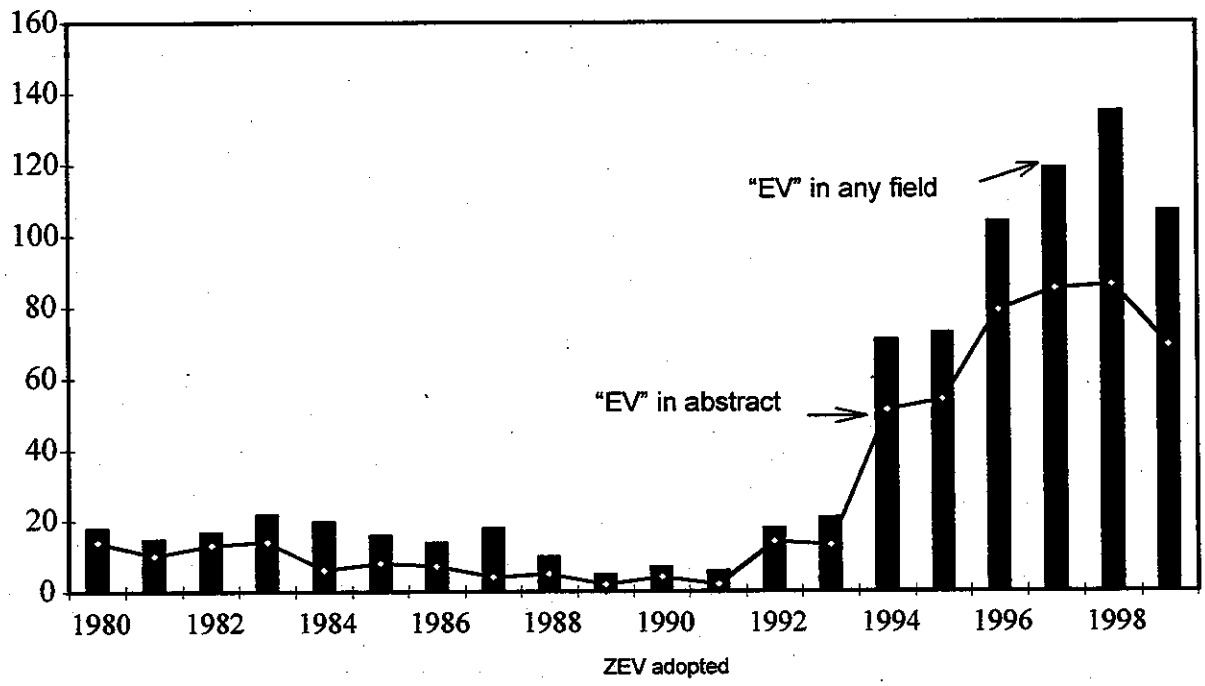
	Among 22 Survey Responses		Extrapolated to 134 Companies*	
	Today	In 2004	Today	In 2004
Jobs in California	574	850	3,500	5,200
California Sales ($million / yr)	65	62	400	375
Investment rate ($million / yr) ^	25	103	150	(not estimated)

* identified by CalStart; these are not necessarily all the firms affected by the ZEV program.

^ needed to pursue EV and spin-off markets

- *Patent Activity*. The R&D activity resulting from the ZEV program dramatically increased the number of U.S. patents related to EV technology. From 1980 to 1991, the number of patents mentioning EVs in their abstracts averaged only about seven per year, despite federal funding of EV programs. After 1991, the annual count has increased almost every year and has averaged about 55 patent applications annually since 1994. Figure 2 shows the numbers of patents with "electric vehicle" in the abstract or any search field.

Figure 2. EV-Related Patents



2. Advances in Clean Vehicles

- *NLEV Standards*. The National Low-Emission Vehicle Standard (NLEV) will prompt the introduction of low-emission vehicles in five northeastern states more quickly than is otherwise mandated by the Clean Air Act. The NLEV standards are the result of negotiations among those states, the Ozone Transport Commission (OTC), and the United States Environmental Protection Agency. The negotiations created NLEV as an alternative for automakers to the OTC's desire that the northeastern states adopt California's low-emission vehicle standards, including ZEV. Four states--New York, Vermont, Maine, and Massachusetts--have adopted ZEV standards based on the California model. The combined introduction of NLEV and ZEV standards on the East Coast should facilitate further development of low-emission technologies nationally.

- *SULEVs*. The early existence of vehicles meeting the ARB's SULEV exhaust standards is due, in part, to the ZEV regulations. Some of the technology used to achieve the SULEV standards is the result of automakers' efforts to develop vehicles that might qualify as alternatives to true ZEVs. The automakers' success in meeting the SULEV standards demonstrates the practicality of pursuing standards more stringent than those in the original California low-emission vehicle program. Work is continuing in the industry to achieve emission levels even closer to the ZEV emissions.

- *Light-Duty Hybrids*. The development of hybrid vehicles was initiated in an effort to extend the range of EVs and was, therefore, ZEV-related. Recent work in light-duty hybrids has been driven mainly by the efforts of the PNGV consortium to meet national goals for fuel economy and carbon dioxide (CO_2) emissions, rather than to achieve ZEV compliance. However, improved electric driveline components (motors and power transmission) and better batteries--which are ZEV spin-offs--have been important to the current developmental status of light-duty hybrid vehicles. Hybrid vehicles will be useful in meeting LEV standards and reducing CO_2 emissions.

- *Heavy-Duty Hybrids*. The development of heavy-duty hybrid vehicles has paralleled that of light-duty hybrids and uses many of the same improvements in motors, batteries, and electronics. Hybrid buses that are now being commercialized in the U.S. are capable of particulate matter (PM) emissions comparable to those from compressed natural gas (CNG) engines.

- *Fuel Cells*. The development of fuel-cell-powered vehicles is partially dependent on the ZEV-stimulated development of electric driveline components. In addition, automakers have a strong interest in fuel-cell vehicles as potential alternatives to ZEVs (e.g., via partial ZEV credits). The R&D effort on fuel cells for vehicles has advanced fuel-cell technologies (for stationary applications) that are beginning to appear commercially.

3. <u>Technological Developments and Their Uses</u>

- *Ultracapacitors*. Electro-chemical capacitors, developed explicitly for use in EVs, have many potential uses in non-vehicular systems for both industry and consumers. Cost has discouraged their use so far, but mass production would substantially reduce the cost.

- *Batteries*. The demand to improve EV range has led to major improvements in battery technologies that have many non-EV applications.

  – <u>Pulse-power batteries</u> have been developed as low-cost substitutes for ultracapacitors to provide high power of short durations. They are used in hybrid vehicles, as well as cell and mobile telephones

- Lead-acid battery technology has seen substantial improvements in recharging time, energy density, and longevity. Lead-acid batteries are widely used in existing non-road EVs (e.g., forklifts, airport vehicles, golf carts, wheelchairs). Also, the improvements in lead-acid batteries promote the auto industry's plans to convert to 42-volt electric systems. A 42-volt system will enable electric braking, electric power steering, electric valves, and other power-demanding innovations that can reduce fuel use in conventional vehicles.

- Zinc-air batteries were initially developed for EV use. Because of low cost and high energy density, they have an extensive potential use in consumer electronics. They are currently used in hearing aids and computers.

- Zinc-bromine batteries were also initially developed for EVs. Electric utilities use them in load-leveling applications.

- Nickel-metal hydride and lithium battery technologies have advanced through efforts to apply them in EVs. These improved batteries are also suitable for use in load-leveling, telecommunication applications, and consumer products, such as lawnmowers and wheelchairs. They may also be useful in 42-volt automotive systems.

- *Battery Systems.* The critical demand for faster, more complete recharging of EV batteries and better battery longevity has spurred major improvements in the testing, monitoring, and charging of batteries. These improvements are promoting the displacement of diesel vehicles by electric vehicles in fleets of forklifts and airport ground-support equipment. (This has been demonstrated by recent proposals submitted to the ARB's "Innovative Clean-Air Technologies" grant program.)

- *Electric Auxiliaries.* The effort to increase the range of EVs has prompted improvements (better efficiency) in electric automotive auxiliaries, such as power steering, power brakes, and air conditioning. Besides extending the EV range, these electric auxiliaries are attractive as potential replacements for the less efficient, bulky hydraulic devices now used in conventional vehicles. Upcoming hybrid vehicles will use electric auxiliaries. They will also be immediately useful in new conventional vehicles if the industry converts to a standard 42-volt power system.

- *Electric Motors.* EVs require motors and drivelines that are compact, efficient, and responsive over wide ranges of power and RPM. This has led to the development of advanced electric motors and electronics. These innovations are particularly useful in transit systems and industrial applications and are also being applied in the PNGV program to develop vehicles with very high fuel economy.

- *Low-Speed EVs.* The commercial field of low-speed electric transportation has undergone major developments since the adoption of the ZEV regulations. Low-speed vehicles include electric bicycles and scooters, "city EVs" (small street-worthy vehicles), and "neighborhood EVs" (similar to golf carts). These vehicles have excellent economic potentials, even though some of them (e.g., bicycles and scooters) do not qualify as ZEVs under the ARB regulations. To date, most sales have been bicycles and scooters to overseas markets. However, eleven California companies are involved in the sale of low-speed EVs, and Nissan, Ford, Honda, and Toyota are all developing city EVs, using driveline components developed for ZEVs.

- *Power Quality.* Electric utilities have considerable use for advances in energy storage and power-quality electronics stemming from EV development. Utilities and their customers need energy storage, power maintenance, and uniformity of power quality. These needs are increasing as more power is generated by diurnal or intermittent sources, such as solar and wind, and as consumers use more power-quality-sensitive equipment. Improved lead-acid batteries and ultracapacitors are particularly applicable. Utilities are also interested in used EV batteries for utility application. This could give EV batteries a salvage value that would greatly offset their initial costs to EV owners.

E. Conclusions

The ZEV program has spurred increased patent activity and major R&D efforts by federal and private organizations. The ZEV regulations renewed a national interest in EVs and related technologies and stimulated federal R&D in this area. There have been significant technological advances resulting from this R&D and from automakers' efforts to develop EVs and alternatives to EVs. Some of these technological advances promote emission prevention beyond what is expected from ZEV compliance alone.

Several ZEV-related technologies have substantial actual or potential economic value in non-EV applications. These innovations have come from a segment of industry whose size and economic health depend, in part, on continued development and implementation of the ZEV program. Although the total economic effect of the ZEV program has not been estimated, a limited analysis of 134 companies indicates $400 million in annual sales related to ZEV-derived technologies, from an annual investment of $150 million. Although non-EV applications have accounted for a small portion of the sales thus far, these potential applications are in major sectors of the economy. When fully applied by industries and utilized in consumer products, the ZEV-derived innovations will benefit the economy and air quality of California.

References

1. Turrentine, Thomas and Kurani, Kenneth; Advances in Electric Vehicle Technology from 1990 to 1995, EPRI, TR-106274, February 1996.

2. Turrentine, Thomas and Kurani, Kenneth; Technological Spin-Offs and Other Indirect Benefits of New Electric Vehicle Technologies, EPRI, TR-106275, February 1996.