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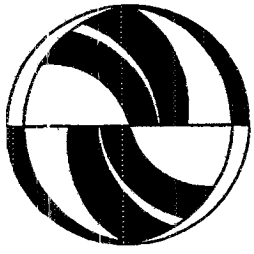
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**Electric Vehicle Manufacturing
in Southern California: Current
Developments, Future Prospects**

Allen J. Scott
(editor)

Working Paper
UCTC No 170

**The University of California
Transportation Center**

University of California
Berkeley, CA 94720

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**Electric Vehicle Manufacturing in Southern California:
Current Developments, Future Prospects**

Allen J. Scott
(editor)

Lewis Center for Regional Policy Studies
and Department of Geography
University of California at Los Angeles
Los Angeles, CA 90024

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Preface

This report is the second major study by the Lewis Center for Regional Policy Studies on the prospects for establishing an electric vehicle manufacturing industry in Southern California. The report is offered here both as an experiment in the formulation and analysis of regional economic development strategies, and as a practical compendium of information to guide policy-makers in their deliberations about how to initiate and sustain an electric vehicle industry in the region. It is our hope that the report will help to further the efforts of the many different private firms and public agencies which, since the late 1980s, have been struggling to place Southern California in the vanguard of electric vehicle development and production. The analysis presented in the pages that follow suggests that these efforts are likely to bear fruit in significant ways.

We wish to thank our financial sponsors — the BankAmerica Foundation; Los Angeles Department of Water and Power; Southern California Edison Company; Transportation Center, University of California, Berkeley; the UPS Foundation; and Volvo North America Corporation — for their generosity in funding this project and for their spirit of public service. We also wish to thank the members of our Technical Advisory Board for their critical readings of an earlier draft of the report. And a special vote of thanks goes to the staff of the Lewis Center — Vanessa Dingley and Diane Ward — for their efficient and painstaking service throughout the course of the project.

Allen J. Scott,
Director,
Lewis Center for Regional Policy Studies

List of Acronyms Used in the Text

ABB	Asea Brown Boveri	MC	Methylene Chloride
AC	Alternating Current	MCT	Metal Oxide Silicon-Controlled Thyristor
AFME	Agence Française pour la Maîtrise de l'Énergie	MEK	Methyl Ethyl Ketone
Al	Aluminum	mg/dl	Micrograms Per Deciliter
APU	Auxiliary Power Unit	MIC	Made in California Working Group
AVERE	European Electric Road Vehicle Association	MITI	Ministry of International Trade and Industry
BMW	Bavarian Motor Works	MOSFET	Metal Oxide Silicon Field-Effect Transistors
BOD	Biological Oxygen Demand	MPH	Miles Per Hour
Btu	British Thermal Unit	MSW	Municipal Solid Waste
CADHS	California Department of Health Services	MTA	Metropolitan Transportation Authority
CAPM	Capital Asset Pricing Model	MVMA	Motor Vehicle Manufacturer's Association
CARB	California Air Resources Board	NaS	Sodium-Sulfur Battery
CAT	Clean Air Transport, Inc	NAV	Next Generation Advanced Electric Vehicle
CD	Compact Disc	NEC	Not Elsewhere Classified
CEVS	Chloride Electric Vehicle Systems Limited	NEDO	New Energy and Industrial Technology Development Organization
CFC	Chlorofluorocarbon	NiCd	Nickel-Cadmium Battery
CFRP	Carbon Fiberglass Reinforced Plastic	NiFe	Nickel-Iron Battery
COD	Chemical Oxygen Demand	Pb	Lead
CSI	Classic Advanced Development Systems, Inc	Pb-acid	Lead-Acid Battery
CUV-ES	Honda's Clean Urban Vehicle/Electric Scooter	PGE	Progetti Gestione Ecologiche
DARPA	Defense Advanced Research Projects Agency	PMMA	Polymethylmethacrylate
DC	Direct Current	PVUSA	Photovoltaics for Utility Scale Applications
DEMI	Dreisbach ElectroMotive, Inc.	RCRA	Resources Conservation and Recovery Act
DOE	U.S. Department of Energy	RIM	Reaction Injection Molding
DWP	Department of Water and Power	RPEV	Roadway-Powered Electric Vehicles
ECC	Electric Commuter Car	RTD	Rapid Transit District
EDF	Electricité de France	RTM	Resin Transfer Molding
EHV	Electric and Hybrid Vehicles	SARA	Superfund Amendments and Reauthorization Act
ENEA	Commission for Nuclear and Alternative Energy Sources (Italy)	SCAQMD	South Coast Air Quality Management District
EPA	Environmental Protection Agency	SCE	Southern California Edison Company
EPRI	Electric Power Research Institute	SCHI	Structural Coordination and Harmonization Initiative
EV	Electric Vehicle	SEVP	Showcase Electric Vehicle Program
FEV	Future Electric Vehicle	SIC	Standard Industrial Classification
FMVSS	Federal Motor Vehicle Safety Standards	SIT	Static Introduction Transistor
FTA	Federal Transit Authority	SMC	Sheet Molding Composite
GM	General Motors	SRRP	Source Reduction Research Partnership
GTO-SCR	Gate Turn-Off Silicon-Controlled Rectifiers	TAO	Technology Advancement Office
HOV	High Occupancy Vehicle	TCA	1,1,1-trichloroethane
HVAC	Heating, Ventilation and Air Conditioning	TCE	Trichloroethylene
IAD	International Automotive Design	TEPCO	Tokyo Electric Power Company
IAM	International Association of Aerospace and Machinists Union	TRI	Toxics Release Inventory
ICE	Internal Combustion Engine	UAV	Unmanned Air Vehicle
ICEV	Internal Combustion Engine Vehicle	UCLA	University of California, Los Angeles
ICV	Internal Combustion Vehicle	UGV	Unmanned Ground Vehicle
IGBT	Insulated Gate Bipolar Transistors	UGV JPO	Unmanned Ground Vehicle Joint Program Office
IO	Input-Output	UPS	United Parcel Service
JEVA	Japan Electric Vehicle Association	US	United States
JPL	Jet Propulsion Laboratory	USABC	United States Advanced Battery Consortium
JSB	Japan Storage Battery	USC	University of Southern California
KWH	Kilowatt-Hour	VOC	Volatile Organic Compound
LA	Los Angeles	ZEV	Zero Emission Vehicle
LACTC	Los Angeles County Transportation Commission	Zn	Zinc
LEV	Light-Electro-Vehicle	Zn-Air	Zinc-Air Battery
LHRI	Loker Hydrocarbon Research Institute		

Executive Summary

The report opens with a brief discussion of the role of regional industrial policy in shaping local developmental trajectories.

An outline of the main varieties of electric vehicle technology is presented. Special attention is paid to the operational characteristics of electric vehicles, the various kinds of components and sub-assemblies that go into the vehicles, and the urban infrastructure requirements needed to support extensive electric vehicle usage. A short summary of electric vehicle developments around the world is appended, with particular emphasis on US, Japanese, and European efforts.

A scenario of possible pathways of development of the electric vehicle industry in Southern California is then sketched out. In the early stages of the industry, vans and other utility vehicles are likely to be the main products, with passenger cars lagging behind. The main issues that are involved in any effort to foster the industry in Southern California concern (a) making an early start, and thus building competitive advantage in advance of other regions, (b) encouraging the formation of the kinds of flexible and collaborative manufacturing networks that provide maximum experimental capacity and industrial maneuverability, (c) continually fostering region-specific increasing returns by policies that encourage the formation of external economies of scale and scope, (d) ensuring that there is an adequate underpinning of social institutions (providing information on evolving technologies and skills, making venture capital available, and so on) supporting the infant industry and ensuring its continued expansion.

Southern California has many advantages for electric vehicle production, the most important being (a) a potentially large local market, (b) widespread support on the part of local governmental agencies, (c) an abundance of skilled labor, (d) an existing and many-faceted industrial base making products that are directly relevant to the electric vehicle industry. Several firms in the region have already made a start in manufacturing many different kinds of components for electric vehicles. Policy now needs to be applied to the tasks of further promoting the industry in the region by e.g. (a) encouraging the formation of collaborative manufacturing networks in the industry, (b) active transfer of skills from local aerospace-defense sectors, (c) investment in basic infrastructural services (e.g. crash testing facilities) and labor skills, (d) continued public investments in electric vehicle technology, (e) governmental support of the market for electric vehicles (e.g. by means of tax rebates for purchasers). The CALSTART consortium has played a particularly important role in the development of the industry because it has begun the task of building a collaborative network of local firms making electric vehicle components. We would argue that *attention now needs to be paid by state policy makers to attracting one or two major car manufacturers to the region to set up (initially small-scale, batch-oriented) assembly facilities*. If this could be achieved, it would complete the circle of electric vehicle manufacturing activities in the region and the resulting network of producers would be an important source of technological-industrial synergies, thus helping to keep the region ahead in the global race to produce electric vehicles.

The recent history of automobile-related industrial production in Los Angeles is laid out, with a further evaluation of the region's potential for electric vehicle production. A specification of a generic electric vehicle based on information provided by CALSTART for its showcase electric vehicle and on data obtained from additional engineering studies is developed.

This electric vehicle blueprint is combined with input-output data for the Los Angeles economy to gauge the impacts of electric vehicle production on the local economy.

Given the foundation provided by the local manufacturing complex, the region's potential for electric vehicle assembly and components production appears to be significant. The small scale and the custom orientation of existing local firms related to the automotive sector is indicative of the flexibility of the region's industrial base and thus its capacity for technological dynamism.

Many of the inputs that may be expected to go into an electric vehicle industry are related to the aerospace, electronics, plastics, and measuring instruments sectors. Based on the technological analysis of a prospective electric vehicle industry, Los Angeles appears to be favorably endowed with the sectors that are likely to play a major role in supplying components to the industry. Employment in the proto-electric vehicle sector is located in approximately 450 local establishments, most of which are relatively small shops.

Input-output analysis reveals that significant numbers of jobs could be created in Los Angeles if local producers and policy-makers targeted the electric vehicle industry. If the region produced components and assembled the electric vehicles necessary to meet the state's compliance with CARB's mandate of 10% zero-emission new vehicles by 2003, Los Angeles could capture over 24,000 jobs. Over 18,000 of these jobs would be added to the manufacturing base of Los Angeles, with the balance occurring in various service sectors.

An effort is then made to analyze the main financial issues surrounding the development of an electric vehicle industry. Here, the report looks at the interplay between industry growth and informed and selective public policy intervention, particularly in the area of capital funding.

A financial analysis is made of a hypothetical small-scale manufacturer who would capture about 25% of the electric vehicle market in California by 1998. Cash flow projections for this manufacturer were developed after discussion with industry leaders. A sensitivity analysis is also performed, and the results are shown to be robust even if there are deviations from these projections.

The financial analysis uses the Capital Asset Pricing Model to value the cost of capital for this electric vehicle project. Five year returns from automotive firms are used to develop a risk coefficient and the analysis indicates that the opportunity cost of capital for the project is at least 10.23%. That is, investors can currently expect to receive this rate of return from capital markets and therefore, an investment in the electric car project must exceed this level. The subsequent analysis examines the sensitivity of the financial projections and looks at three additional issues, i.e. (a) the cost of capital, (b) manufacturing costs, and (c) the sales price of electric vehicles.

The conclusion of this phase of the study is that a financial intermediary be established, called EV Capital, and that it operate with a mandate to encourage private investment in California's emerging electric vehicle industry.

The potential health and environmental impacts associated with the manufacture of electric vehicles are examined in detail. Environmental concerns often are not weighed explicitly in decisions regarding industrial development, and only dealt with later through regulatory activities. Yet, health and environmental assessments must be taken into consideration early in the planning process if clean manufacturing is to be encouraged.

The discussion here presents a product lifecycle approach to identify possible health and environmental impacts of electric vehicle manufacturing, and to examine potential tradeoffs

between different effects that policymakers should consider. Although lifecycle analyses may raise as many questions as they resolve, they make assumptions explicit, illuminate grey areas, and serve to identify opportunities to improve production during the planning process. A lifecycle approach looks at (a) emissions to all environmental media, (b) occupational hazards posed during manufacturing, and (c) consumer risks during use. Full lifecycle assessments ideally include all of the factors involved in a product's manufacture, use, and disposal. This discussion, however, emphasizes only those factors most likely to have a direct impact on the Southern California region.

Five main issues were selected to explore the health and environmental consequences of electric vehicle manufacturing. These are: (a) substitutions of aluminum for the steel or iron components normally used in vehicle production, (b) the manufacture of plastic components and their disposal, (c) electric motor production, (d) electronics production, and (e) the manufacture and recycling of lead-acid batteries. It appears that the first four of these present some health risks and environmental emissions, but they probably will be insignificant relative to current levels of pollution. The greatest concern raised in this and other studies is related to battery manufacturing. Lead-acid batteries are expected to be used in electric vehicles at least in the near term, and thus large numbers of batteries will need to be produced. In 1989, 31 battery manufacturers were located in California, 13 of which were located in Los Angeles County. Los Angeles County also hosts the only two secondary lead smelters currently in operation west of Texas. It is likely that these operations will attempt to expand with the commercialization of electric vehicles. The most obvious health effects associated with battery manufacturing and recycling are emissions of lead and other toxic metals.

Aside from battery manufacturing, it is evident that electric vehicles will help to clean up the air in Southern California given that the most noxious upstream manufacturing processes (e.g., mining, primary smelting, chemical formulation) are not likely to be undertaken in the region. The increased electricity generation and manufacturing in other regions may have adverse impacts in those places. In Southern California, electric vehicle manufacturing may result in significant environmental impacts in and near secondary lead smelters and battery manufacturers. The reduced levels of smog that all residents of Los Angeles will enjoy with increased electric vehicle usage, then, will be offset by intense occupational and local risks for much smaller populations. Whether this is an improvement or not depends on how one weighs such very different sets of variables.

In developing an electric vehicle manufacturing base in Southern California priority should be given to policies that encourage the private sector to adopt and adapt new and existing technologies and related know-how. The associated industrial politics of this process should be seen as highly significant. Economic protocols governing access to resources, inter-corporate relations, rights, work allocation, and public intervention must be developed that keep a wide range of relevant parties involved in the regional economy. What is required is a set of checks and balances that create incentives for business, labor, and government to innovate, build skills, and discourage behavior that destroys the regional capacity to collaborate and respond flexibly to change.

Local and federal transportation technology investments should be leveraged with private-sector funding. This is particularly important because government support of research and development for components and engineering assistance will be necessary to push technology forward and to reduce the costs and risks to be borne by the eventual manufacturer. There

should also be analysis of flexible manufacturing facilities for mass transit and service vehicles, and sub-assemblies and components, as well as initial industrial infrastructure for electric vehicle manufacturing. Policy initiatives must be designed that are proactive and iterative and that address four main issues in technology development, i.e. (a) recent changes in military planning and affairs affecting the size and character of United State's technology investments, (b) the current and future state of the international economy. (c) technological innovation, and (d) the scope of national government action on technology.

Institutional efforts like CALSTART are important. Additional institution-building is needed. "Virtual companies" can be developed to integrate product-manufacturing engineering skills, final assembly, and marketing. Attention should be given to a range of mechanisms to integrate Southern California's basic science, design, and engineering capacities, including those that promote a multiple-skill supplier base. Southern California must also seek collaborative agreements with other industrial regions.

Finally, it is argued that the development of electric vehicle production in Los Angeles offers a double opportunity for the industrial growth of the region. In the first place, electric vehicle production could have beneficial impacts on a broad spectrum of firms that are already present in the area but whose survival is threatened by the decline of aerospace and defense industries. In the second place, the large number of new technologies and products (energy storage systems, lightweight materials, electronics, telecommunications, magnetic motors, etc.) necessary for the commercial production of electric vehicles can find application in several other fields, thus possibly leading to an expansion of the industrial base of Los Angeles.

Los Angeles, indeed, could potentially develop as the site of a major new industrial district focused on advanced transportation equipment. Other industries engaged in the development and production of new transportation systems (such as rail car equipment or maglev trains) and traffic management systems (such as automatic guidance systems or advanced traveler information systems) would find geographical proximity to electric vehicle production advantageous for both shared technologies and labor skills and for the synergetic effects that they would be likely to have on each other.

Chapter One Introduction

Allen J. Scott

In 1991, the Lewis Center for Regional Policy Studies at UCLA published a widely-circulated report on the potential market for alternative-fuel vehicles and the possibility of establishing a manufacturing industry for such vehicles in Southern California¹. The report examined the full range of feasible alternative fuel vehicle technologies, and concluded that the electric vehicle was likely to become the dominant technology in use, both because it has the most decisive impacts in reducing environmental pollution (even when we factor in the effect of increased electricity generation), and because radical improvements in its performance are foreseeable over the next decade or so. Electric vehicles are already a workable means of intra-urban transport, though current battery technology is defective in that it is possible only to travel rather limited distances before recharging becomes necessary. Significant public and private money is now being invested in battery research in the United States and elsewhere, and major improvements are to be expected over the course of the next several years. In the longer run, fuel cells and flywheel batteries will almost certainly be developed as effective sources of power for electric vehicles.

The 1991 study was prompted by two major events. One was the California Air Resources Board rules that establish a market for electric cars in the state by specifying percentages of zero-emission vehicles that must be attained in automakers' fleets by various dates over the next decade. The other was the Los Angeles Initiative of 1988 which led to the selection of Clean Air Transport Inc. to sell and possibly produce hybrid gasoline-electric vehicles in the region over the 1990s. The Initiative has since fallen by the wayside, but it was important in awakening various groups to the potentialities of Southern California as a center for the production of electric vehicles. The Lewis Center study concluded, moreover, that it was indeed within the bounds of possibility that the region might become a center of electric vehicle production. To this end, one of the major recommendations of the study was that a private-public Southern California Capital, Manufacturing, and Technology Corporation be formed for the purposes of promoting the electric vehicle industry in the region. This idea was subsequently

¹ See R. Morales, M. Storper, M. Cisternas, C. Quandt, A. J. Scott, J. Slifko, W. Thomas, M. Wachs, and S. Zakhor, *Prospects for Alternative Fuel Vehicle Use and Production in Southern California: Environmental Quality and Economic Development*, University of California, Los Angeles Lewis Center for Regional Policy Studies, Working Paper No. 2, 1991.

picked up in the federal Advanced Transportation Systems and Electric Vehicle Consortia Act of 1991 which made \$10 million available for the establishment of three regional not-for-profit electric vehicle development consortia in the United States. In response to this legislation, a Southern Californian consortium named CALSTART was formed with participation by many different firms and public agencies, and it then bid successfully for a share of the funds made available by the Act. CALSTART has now moved into a central position with regard to electric vehicle manufacturing in Southern California (as subsequent chapters indicate in detail) and it has become one of the driving forces of a nascent industry in the region.

* * * *

The present report examines in considerable detail the prospects for the further development of the electric vehicle industry in Southern California and its likely fortunes in what has now become a global race by many different firms and regions in various parts of the world to take the lead in the industry. The report looks in particular at the shape and form that an electric vehicle industry might assume in Southern California, and at the kinds of policies most likely to foster its growth. Seven main facets of these issues are discussed in the chapters that follow, namely,

- Current developments in electric vehicle technologies in the United States and around the world, with special emphasis on questions of industrial and commercial feasibility.
- Problems and prospects of building an electric vehicle manufacturing industry in Southern California, together with a scenario of prospective developments.
- The predicted multiplier effects and employment impacts of a putative electric vehicle industry in the region.
- Strategies for financing small- and medium-sized electric vehicle startup companies.
- An analysis of the possible impacts of electric vehicle manufacturing on environmental quality in Southern California.
- A review of actual and needed policy interventions (at the federal, state and local levels) to promote the electric vehicle industry.
- A brief appraisal of the possibility of launching a broadly-based industrial development program in the region, involving not just electric vehicles, but also a wider range of ground transportation technologies and equipment.

In general, the arguments deployed in the rest of this report paint a reasonably optimistic picture of the feasibility of creating a thriving electric vehicle industry in Southern California. This assessment is based on three main considerations. First, Southern California already possesses a diversified, technology-intensive industrial base providing strong initial agglomeration economies, and fully capable of manufacturing all major components and sub-

assembles for electric vehicles. Second, Southern California's confirmed early start in putting together a multifaceted network of electric vehicle component producers sets it significantly ahead of competing regions in the acquisition of manufacturing capability and competitive advantage (though major questions remain as to the ultimate locations of final assembly facilities). Third, the strong commitment that has been made by many different public agencies to the task of setting up an electric vehicle industry in the region, provides a platform of support — and concomitant risk reduction — that is highly favorable to the further expansion of the infant industry in the region. At this stage in the industry's development, moreover, where product and process configurations remain extremely unstable and markets capricious, the emerging flexible and collaborative manufacturing network of small producers in Southern California is a major asset. In any regional economy, such networks usually represent significant articulations of value-adding activity, and as they grow they help to consolidate local know-how, organizational capacity, and competitive advantage.

* * * *

Southern California's infant electric vehicle industry has thus far evolved out of a unique but portentous series of experiments in local industrial development by means of private-public partnership and cooperation. In the present report, it is argued that these experiments will need to be carried further forward if the momentum thus far achieved is to be sustained. In particular, it will be necessary to maintain public support at high levels in order to correct market failures as they appear, to ensure an adequate and continuing flow of innovative technologies and skills to the industry, and to shape high-trust networks of interdependent producers. The claim may be advanced, indeed, that in the new global competition, the most dynamic regional economies around the world are likely to be those that are able successfully to sharpen their competitive edge and to increase market share by building institutions that effectively resolve local problems of coordination and strategic choice.

Japan and Germany have already moved significantly down this pathway of development. And Southern California — despite the inertia of its past history — is now also tentatively poised to test the waters, not just because there are telling arguments (and a number of forceful practical cases) in favor of this course of action, but also because in the current climate of economic restructuring, deindustrialization, and job loss, it has become imperative to stem the tide of decline. One specific manifestation of this trend to greater public involvement in economic development in the region is Project California, which is now moving forward under the aegis of the California Council of Science and Technology to enquire into the possibilities of establishing a major ground transportation manufacturing industry (including electric vehicles) in Southern California and other parts of the state, and into the kinds of policy initiatives that would be necessary to initiate and sustain it. What is particularly striking about Project California is the breadth of political support that it has thus far been able to muster, and there can be little doubt that its work is likely eventually to result in major public action. In the specific matter of public support for the development of an electric vehicle industry, Southern California is, if anything, in advance of any other region in any part of the world at the present time.

That said, the way forward is fraught with serious risks and will almost certainly be attended by many failures. It is important to anticipate such setbacks, and to build durable

political agreements about the way forward. Despite the high initial costs of an early start, the ultimate benefits to the region in terms of jobs, income, and continued technological dynamism are potentially enormous. The experience gained in this effort will provide a valuable lesson and reference point for other local economic development projects.

Chapter Two

Electric Vehicle Technology

Carlos O. Quandt

2.1. Introduction

This chapter outlines the main technological developments, barriers and opportunities associated with a putative electric vehicle (EV) industry. The chapter draws on a review of the literature and a survey of EV research and development efforts worldwide, in order to anticipate the most significant obstacles to the introduction of EVs, and to identify the alternatives that offer the best potential to reach initial market niches. It also examines the role of government agencies and private institutions in supporting R&D on EVs and related infrastructures. The main technical requirements and the areas of rapid technological change of the new industry are also explored, in order to provide a basis to evaluate their degree of compatibility with existing industrial resources and their implications for industrial and regional development.

The chapter begins with an analysis of the suitability of existing EVs to various operational requirements and the different technical alternatives to improve their performance and market potential. This is followed by a discussion of the basic technological areas related to EV production: propulsion systems, battery and alternative power sources, body structure, auxiliary technologies and infrastructure requirements. A preliminary evaluation of the technological opportunities of the EV industry and their effects on the potential for electric vehicle manufacture in Southern California is also included. The concluding sections provide a summary of private and public EV research and development activities at the national and international level.

2.2. Operational Requirements

At the turn of the century, only 22 percent of U.S. automobiles used gasoline; 38 percent ran on electricity and 40 percent were steam-powered. The world's fastest cars were battery-powered. At the First National Automobile Show in New York in 1900, electric vehicles were praised for being "noiseless, odorless, and free from smoke" though they raised concerns about the availability of opportunities for recharging. Steam, electricity and gasoline were considered equally viable alternatives for cars, and electric vehicles remained very popular until the 1920s. The internal combustion engine — and the American automobile industry — jumped to leadership through a sequence of events that included the discovery of vast petroleum reserves

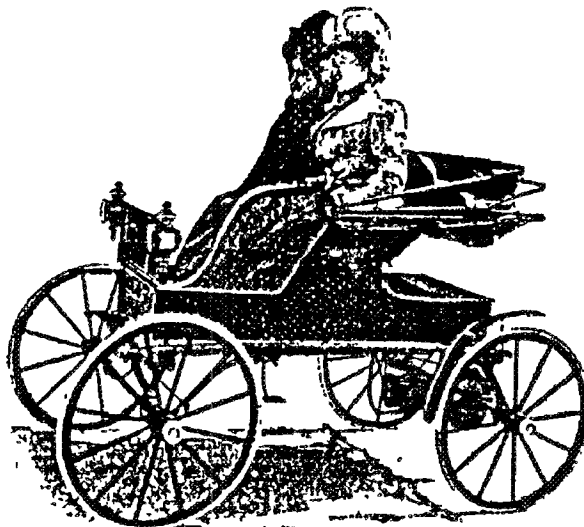
in Texas in 1901, the introduction of the first commercially successful electric starter for gasoline engines in 1912 and the extraordinary success of Ford's mass-produced automobiles.¹

The lasting hegemony of the gasoline-powered automobile has resulted in standards of performance, economy and convenience of utilization that constitute effective barriers to the acceptance of alternative transportation technologies. American consumers have come to expect powerful, efficient and comfortable cars that are capable of driving long distances without refueling, all at a relatively low private cost. They have also come to expect few serious disruptions on either the supply or cost of fuel, in spite of the volatile and politicized nature of world oil markets.²

It should be noted that the expectations of American drivers differ significantly from those in Asia and Europe, due to a series of factors. For example, the cost per gallon of gasoline in Europe in mid-1991 ranged from \$3.05 in Germany to \$4.92 in Italy, while Americans paid an average of only \$1.15. In addition to fuel costs, European and Asian consumers are more likely to accept smaller, lighter and less powerful cars than Americans because of factors such as vehicle taxes, patterns of living and traveling, road standards, urban densities, etc.³

In any case, electric vehicles are not being developed in response to consumer dissatisfaction with conventional cars. Rather, EVs have become a desirable transportation alternative as a result of rising energy prices and intensified environmental concern. Therefore, electric vehicles will achieve a broad market penetration only after they bridge the performance gap between them and gasoline-powered cars in areas such as performance, comfort, safety and overall economy.

Table 2.1 illustrates this performance gap by comparing a series of characteristics of several electric vehicles with a conventional automobile. As the table shows, EVs usually have a more limited range and a lower maximum speed than gasoline-powered automobiles; they also tend to be heavier and to accelerate more slowly than a similarly sized internal combustion engine vehicle (ICEV) counterpart.



The 1899 Woods Electric Car (Source: *The Journal of The Society of Automotive Historians* No. 111, p. 4)

¹ K Wright 1990 "The Shape of Things to Go " *Scientific American*, May; S Kantra and J Yeaple 1992 "120 Years of Popular Science " *Popular Science*, August

² Even during the Gulf War, the real price of gasoline remained near its lowest level in 40 years (D. Yergin, "How to Design a New 'Energy Strategy '" *Newsweek*, February 11, 1991, pp 43-44)

³ G Starr, 1991. *Electric Car Conversion Book* Santa Rosa, CA Solar Electric, C Chan, 1990 "Electric Vehicle Development in Asia Pacific" in *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong

Table 2.1: Electric Vehicle Performance⁴

Vehicle	Range (miles)	Top Speed (mph)	Acceleration (0-60 mph in seconds)	Capacity (passengers)	Curb Weight (pounds)
General Motors "Impact" ^a	120 @ 55mph	75	8	2+2	2200
Nissan "FEV" ^b	160 @ 25mph	81	8	2+2	1980
Tokyo R&D/TEPCO "IZA" ^b	340 @ 25mph	110	n.a.	2+2	3465
BMW "E1" ^c	96 @ 50mph	75	18 (0-50mph)	2+2	1938
Solectria "Force" ^{ad}	60-80	60	21	4	2142
AC Propulsion CRX ^{ad}	131 @ 55mph	75	7.8	2	2740
Ford Econstar (minivan) ^{ad}	100	70	12 (0-50mph)	2 + 850 lb.	3100
Passenger G-Van ^{ad}	90 @ 35mph	52	13 (0-30mph)	7	7672
1992 Saturn SL ^e	450	104	10.3	5	2366

Notes:

- ^a With lead-acid batteries;
- ^b With nickel-cadmium batteries;
- ^c With sodium-sulfur batteries;
- ^d Converted from gasoline;
- ^e Gasoline-powered vehicle included for comparative purposes.

Standards of Performance

EVs have the potential to offer superior dependability, low maintenance, energy-efficient operation and long life in comparison with ICEVs. The life-cycle costs of EVs are expected to approximate those of gasoline-powered vehicles in the near future, though they are negatively affected by the high cost and short life of the battery module.⁵ The cost of energy itself on a per-mile basis is roughly equivalent to the cost of fueling a small gasoline-powered automobile, or approximately 5¢ per mile. This cost could be cut in half with overnight recharging; several utility companies are expected to encourage off-peak EV recharging at reduced rates, thus reducing their oversupply of electricity and imbalances in demand during the night.

Performance criteria comprise maneuverability, acceleration, climbing ability, maximum speed, range and overall dependability. Presently, EVs perform poorly in most of these aspects, with two exceptions: maneuverability and dependability. The first one can be categorized as a neutral criterion, since it is likely to depend more on the characteristics of a particular vehicle than on vehicle technology itself. EVs are most likely to surpass conventional vehicles in powertrain dependability, due to the inherent simplicity of their propulsion systems. This

⁴ Source for the Saturn SL's performance characteristics *Car & Driver*, May 1992 data for other vehicles were obtained directly from published specifications by their respective manufacturers.

⁵ M DeLuchi, Q Wang and D Sperling, 1989 "Electric vehicles performance, lifecycle costs, emissions, and recharging requirements," *Transportation Research* 23A, 3 255-278

potential advantage should not be taken for granted, however. Even though electric motors are extremely simple by design, electronic controllers, inverters and drivetrains add considerable complexity to the system and consequently, potential for failures. The batteries are a particularly weak aspect of EV reliability. Battery performance degrades in low temperatures and also decays with each cycle, particularly when subjected frequently to deep discharging. This affects negatively all other performance standards. EV test users have reported not only unsatisfactory acceleration, climbing ability, speed and range, but also a tendency for performance to decline over time.

Range, speed and acceleration

Even the most advanced EV prototypes display modest range and speed. The maximum range at constant speeds for most EVs rarely exceeds 100 miles on a single charge. This is a major drawback because conventional automobiles can easily travel twice as much without refueling. Climbing ability is another area where EVs perform rather poorly compared to gasoline powered vehicles. EV performance on acceleration and maximum speed is more varied. Although most existing EVs accelerate slowly, the GM Impact has shown that it is feasible to build an electric car that accelerates from 0 to 60 m.p.h. in less than 8 seconds — faster than 98% of the automobiles on the market today. The maximum speed in many EVs is limited by an electronic governor, in order to save power and avoid overheating. The ability to accelerate rapidly and maintain a fairly high cruising speed are deemed more important in most driving situations than a high maximum speed.

Electric vehicle developers have pursued several technological paths to improve EV performance. Yet, EVs are likely to remain at a disadvantage in comparison to conventional automobiles, particularly with regard to range. One obvious solution is to improve the propulsion batteries, the EV's weakest point. It is unlikely that any dramatic improvements in battery performance will occur any time soon. Although news about "revolutionary" batteries appears from time to time, actual progress has been slow and incremental. The different battery technologies are discussed in a separate section below.

Aerodynamics and Energy Efficiency

Performance improvements can be obtained by increasing the vehicle's overall energy efficiency. Once a vehicle is moving, it has to overcome two main forces: rolling resistance and aerodynamic drag. The latter is determined by the vehicle's drag coefficient, speed and frontal area. The average drag coefficient of American cars in the late 1970s was about 0.48; today, it has been reduced considerably, and several vehicles have reached coefficients under the mark of 0.30. The relative importance of aerodynamic efficiency depends on driving conditions. In urban driving, aerodynamic drag accounts for the dissipation of about one-third of the energy that powers the vehicle. In highway driving, the portion of energy required to overcome aerodynamic drag rises to more than 60 percent.⁶

Therefore, aerodynamic improvements are particularly effective at highway speeds, when they are translated into palpable benefits such as reduced energy consumption, greater range and less wind-related noise. This is an area where EVs have advantages over conventional vehicles.

⁶ D. Bleiviss, 1989 "The Role of Energy Efficiency in Making the Transition to Nonpetroleum Transportation Fuels" in: D. Sperling, ed., *Alternative Transportation Fuels: An Energy and Environmental Solution*. Westport, Connecticut: Quorum.

The absence of a heat engine, exhaust system and bulky transmission allows EVs to be built with flat underbodies and small air inlets. This may enable production line EVs to reach drag coefficients as low as 0.19, similar to the ones achieved in the GM Impact and Nissan FEV prototypes.

Rolling Resistance

In average urban driving, approximately one-third of the energy that reaches a car's wheels is expended to overcome rolling resistance. This factor is determined by the vehicle's weight, tire friction, and the characteristics of road surface. Vehicle weight may be reduced by employing light metal alloys and composite materials for the EV's wheels, structural parts and panels (see section on body structure technology below). Tire friction has been reduced through innovative manufacturing techniques and materials. For example, low rolling resistance tires made by Goodyear and Bridgestone have been used in EV prototypes in the U.S. and Japan. The special tires that outfit the GM Impact and Nissan FEV cut rolling resistance in half in relation to conventional highway tires, and even more efficient ones are under development.

In addition to a reduction in friction losses, these high-pressure, lightweight tires may offer improvements in steering precision, riding comfort and braking performance, though the suspension must be adapted to their specific characteristics. The new rubber and polymer compounds allow even conventional automobiles and tires to improve fuel economy by about 4 to 5 percent, according to Goodyear. Moreover, new materials are being introduced in tire manufacturing. For example, a polyurethane tire developed by Polyair Maschinenbau of Austria has shown during field tests with conventional cars that it may contribute to significant reductions in fuel consumption.⁷

Braking Losses

Braking also entails a loss of about one-third of total energy in normal urban driving. Some of this energy can be recovered by the use of regenerative braking, usually by means of a flywheel. In conjunction with a specially designed electronic controller, the system may be programmed to store excess energy. The fraction of kinetic energy thus recaptured is stored and used to supplement or substitute motor power when required. This system is adaptable to any type of propulsion, though it has not been implemented commercially because of its complexity and limited fuel economy benefits.

In contrast with conventional cars, the energy efficiency of electric vehicles may be greatly improved by regenerative braking. Electric motors and batteries have the advantage of being two-way systems, that is, the motor becomes a generator when its shaft is rotated, transforming kinetic energy back into electricity. Thus the motor can be reconfigured as a generator when the accelerator pedal is released, using the braking energy to recharge the battery. This allows an increase in range of approximately 15 percent in normal driving conditions. The use of direct drive motors can also serve to reduce the energy losses that occur in the power transfer mechanisms (transmission and differential gears) of conventional vehicles.

⁷ D Bleviss, 1989 *Op cit*

Hybrid Vehicles

The market potential of EVs is bound to increase as their performance parameters such as range and acceleration approach comparable levels to those of conventional vehicles.⁸ These characteristics in turn demand more powerful propulsion systems and more sophisticated materials and technologies, which add to vehicle cost and detract from market potential. Thus the main challenge for EV development is to maximize the features that are most valued by consumers without incurring prohibitively high costs. It is reasonable to assume that costs will drop with increased vehicle production, but some EV disadvantages are likely to persist.

The introduction of hybrid vehicles could simplify the transition to electric propulsion by reducing these performance disadvantages. For example, EVs equipped with alternative-fueled auxiliary power units could offer immediate air quality improvements and reduce the inconvenience caused by limitations on vehicle range and on availability of recharging stations. However, hybrids are not ZEVs (Zero Emission Vehicles); their environmental benefits are limited when they are not used as pure electric-powered vehicles.

2.3. Safety, Comfort, and Accessory Technologies

In addition to their suitability to the performance parameters discussed above, EVs must satisfy a series of comfort, convenience and safety criteria. These comprise riding comfort, the availability of accessory options, noise level at different speeds, interior room and cargo capacity, instrument readability, ease of handling, braking effectiveness and convenience of maintenance.

Heating, ventilation and air conditioning

The devices required for heating, ventilation and air conditioning (HVAC) pose particular problems for EVs because of their power requirements. Heating is easy enough in ICEVs precisely because of the inefficiency of the internal combustion engine, which wastes the majority of its fuel energy content as excess heat. Part of it can be used for interior warming and defrosting. Conversely, the efficiency of electric propulsion contributes to eliminate both the energy waste and the pollution associated with exhaust gases, oil, coolant and anti-freeze. Although some excess heat can be extracted from both the electric motor and the battery, they seldom provide an adequate amount of heat for vehicle warming. In order to provide a constant source of heat, some EV makers have resorted to extremely unsatisfactory solutions such as a diesel or gasoline-powered heater. High-efficiency heat pumps will minimize this problem in the future.

Air conditioning is also energy-consuming: it may require as much as 40 percent of the power needed to keep an EV at a cruising speed of 30 mph; range is reduced by a similar factor. Some of the alternative solutions for this problem include pre-cooling and pre-warming, that is, air conditioning that turns itself on automatically before departure, while the car is still connected to the grid; improved electronic control and lightweight variable displacement compressors for more efficient air conditioning; specially treated window glazing to reduce

⁸ W Hamilton, 1985 "Electric vehicle design for maximum market potential," SAE Technical Paper No 850226 Warrendale, PA Society of Automotive Engineers

energy radiation through them; and solar cells and fans to aid heating and cooling.

Some examples of the technologies above in electric vehicles include the GM Impact, which is equipped with an efficient heat pump designed to provide heating and cooling with low energy requirements; the Nissan FEV, which features pre-cooling and a rotary-compressor A/C unit that provides both cooling and heating. The BMW E1 utilizes a heat exchanger that warms the vehicle's interior by extracting waste heat from the motor, transmission, battery and electronic components. The temperature can be boosted by an auxiliary heater when needed.⁹

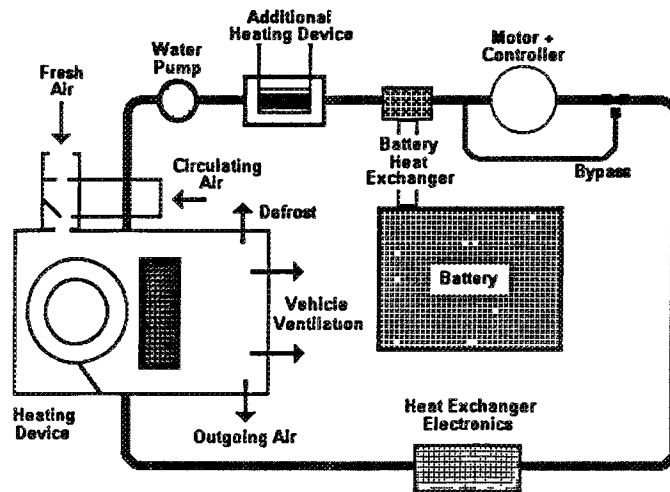


Diagram of the BMW E1's heating system.

Other solutions for HVAC in electric vehicles include the GM concept hybrid vehicle HX3, in which internal cooling is aided by automatic fans powered by an array of solar cells placed on the roof; the Ford Ecostar and the Ford Ghia Connecta, which have solar cell arrays embedded in the windshield; the MYLD, which is equipped with battery warming and vehicle interior quick heating systems that utilize a "latent heat storage cell" plus a roof-mounted 90-watt solar cell that contributes to battery charge.

Power accessories

Many commonly used accessories add a considerable energy burden to EVs. Hydraulic power steering, for example, is energy consuming. It can be replaced by electric steering assist or simply avoided, which is an acceptable option for small EVs equipped with high-pressure low-rolling resistance tires and with added turns on the steering wheel. Power brakes may be boosted by vacuum provided by a small electric pump; alternatively, unassisted brakes with softer brake pads may be used. The use of regenerative braking minimizes the need for conventional brakes, which become indispensable only when the traction battery is fully charged. For larger vans, however, both power steering and power brakes are considered extremely important by most users, as indicated by a survey of electric van drivers.¹⁰

Other features such as power windows, power seats, interior and exterior lighting, sound systems and instruments add up to a sizable energy load. Until more powerful batteries are developed, EVs are likely to compromise on some of these aspects, while more energy efficient devices are also developed, such as electroluminescent displays, low consumption lighting, solar-assisted accessories, etc. Advances in photovoltaics and electronics are likely to introduce rapid

⁹ Source: K Faust, A Goubeau and K Scheuerer 1992 "Introduction to the BMW E1." SAE Technical Paper No 920443 Warrendale, PA. Society of Automotive Engineers.

¹⁰ M W Tripp, 1990 "On-Road Test and Evaluation of the GM Griffon Electric Van," SAE Technical Paper no 900137, in: *Electric Vehicle Technology* Warrendale, PA Society of Automotive Engineers

changes in most of these areas.

One indication of this tendency is the overall growth on electronics content in vehicles, which increased from just \$78 per vehicle in 1980 to \$861 in 1990. It is estimated that the worldwide electronic content of conventional vehicles will grow about 15% per year through 1995.¹¹ The most significant growth of electronic items in ICEVs has been in the engine and powertrain systems, together with new, expensive items such as anti-lock brakes and air bags. EVs would bring an even higher growth to the sector with the increase in the number of electrical systems, accessories (e.g. electric air conditioning, power braking and steering), as well as new instruments and sensors to control the various systems and components via on-board microprocessors.

Other comfort and safety features

For most EVs, interior room and trunk capacity are likely to be quite limited, since the first electric powered passenger vehicles are being designed to be as small and lightweight as possible. Reduced noise level is likely to be a strong point of EVs, due to the virtual absence of engine noise.¹² EVs should enjoy advantages in convenience of maintenance, except for recharging time and battery durability. Finally, the main implication of safety features such as battery insulation, restraint systems, air bags and structural reinforcements is the considerable complexity that they add to the task of optimizing size, interior space and weight of electric vehicles.

2.4. Chassis and Body Structure Technology

Two distinct technological paths are likely to coexist in the electric vehicle market, probably within separate market niches. The first consists in the conversion of existing vehicles to electric propulsion, or the production of models that can be configured as either EVs or ICEVs. The second path involves the employment of new technological solutions and materials to create optimized, purpose-built EVs. The competitive potential of EVs in both cases, and particularly in the latter, will be affected by the introduction of new materials and their impact on several technical aspects, such as weight reduction, aerodynamic performance, crashworthiness, endurance and recyclability.

Purpose-built EVs: materials and manufacturing techniques

The use of light metal alloys and plastics in automobile manufacturing contributes to substantial weight reduction in comparison with steel. For example, the replacement of steel by aluminum with an equivalent structural strength generates a weight reduction of approximately 55 percent;

¹¹ S. Plumb, 1991 "Spectacular Growth Seen in Electronics World" *Ward's Auto World*, August

¹² See, for instance, A. Kalberlah, 1991 "Environmental Aspects of Electric Vehicles and Electric Hybrid Vehicles" Paper presented at *The European Conference on New Fuels and Clean Air* Antwerp, June 18-19, see also R.D. MacDowall, 1990. "Comparative Evaluation of Acoustical Noise Levels of Soleq Evcort EV and ICE counterpart," SAE Technical Paper no. 900138, in. *Electric Vehicle Technology* Warrendale, PA. Society of Automotive Engineers

composite plastic and magnesium would provide reductions of 65 and 75 percent respectively.¹³ In real terms, a production automobile with extensive application of structural composites would weigh approximately 30 percent less than one made of steel. The popularization of electric vehicles is likely to accelerate an already existing trend towards a reduction in the amount of steel used in automobile chassis and bodies.

Glass fiber-reinforced plastic parts were first introduced in mass production cars in the 1950s. The percentage of plastic parts in automobiles has steadily increased since then, in order to help meet more stringent fuel economy requirements and to keep costs down. For example, plastics accounted for only 2.9 percent of the material used in Japanese cars in 1973, and by 1989 it had jumped to 7.5 percent. Similarly, BMW increased the share of plastics in the total weight of its cars from approximately 5 per cent in 1970 to about 10 percent in 1990. A typical automobile has nearly 300 pounds of plastics comprising 20 different types.¹⁴

In addition to non-structural applications, automakers are beginning to incorporate greater amounts of plastic into body components such as bumpers, fenders and door panels. Although they do not withstand the same impact as steel, some of these components such as plastic bumpers already meet existing safety standards. However, the use of composites for critical structural parts still depends on further crash testing, as well as on the economic feasibility of the new materials. For example, aluminum, magnesium, titanium, ceramics, polymers, carbon fiber, Aramid and Kevlar are routinely used in prototype and limited-series automobile fabrication; yet, they are usually unsuitable for mass-produced automobiles, which use simpler components and less expensive materials because of technical and economic considerations.

The new materials offer other advantages in addition to their relative light weight and better resistance. They have a longer lifetime than corrosion-prone steel parts. They make assembly faster and easier because parts that would usually be bolted or welded together can be integrated into a single part. Thus the number of automobile body parts can be reduced to as little as 3 or 4 from the typical 300 to 400.¹⁵ Some of these materials may be adapted to diverse applications and may also incorporate pigmentation into their composition, thus avoiding the need for conventional surface paint. Moreover, composite materials are molded in inexpensive dies that are less costly than steel-stamping tools. They offer many other possibilities: for example, Mitsubishi has developed a concept car that features, among other innovations, a body material that allows the rear deck panel to change contour at high speeds.

Impacts of plastics and composites on automobile manufacturing and recycling

Composites change the way in which cars are designed, manufactured and assembled. The production of complex and strong composite parts for structural applications is a slow process that involves several steps for molding and curing. Hence they are used mostly by specialty automakers in limited production runs. For example, the method known as resin transfer molding (RTM) process is used on the Lotus Elan and Esprit, BMW Z1, Alfa Romeo SZ and

¹³ M Flemings *et al* , 1980 *Materials Substitution and Development for the Light Weight, Energy Efficient Automobile* U S Congressional Office of Technology Assessment

¹⁴ "Dawn of the Enviro-Mobile," *E Magazine*, May/June 1992, p 16, BMW AG 1991 *Current Factbook Recycling of Plastics*

¹⁵ "Efficient Car Revolution Accelerates" *Rocky Mountain Institute Newsletter*, Vol VIII no 1, Spring 1992, p 5

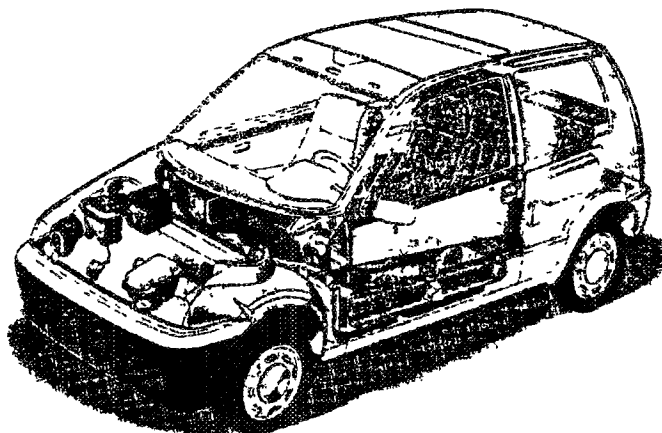
the Dodge Viper. Most composites for large scale use are made by compression molding, which is fast and inexpensive but limits the complexity and strength of the parts.¹⁶ Nevertheless, the rise in research, development and testing of new materials suggest their potential as viable options for many more automotive applications.

For electric vehicles, strong and lightweight body materials are even more crucial, given their range limitations. It is also likely that small production runs will be used in the first years of EV production, due to initial limitations in market size. This suggests that plastics, composite materials and light metal alloys may become major components of electric vehicle bodies at an early stage of production.

The growing variety of automotive materials also raises environmental concerns. The production of light alloys involving aluminum and magnesium is energy-intensive. Plastics, glues and several composites are derived from petroleum and may involve toxic components. Moreover, the new materials complicate the recycling process. Although automobile dismantling is one of the oldest forms of commercial recycling, the current system virtually excludes plastics. Hence the increased use of plastics creates a major disposal problem, since they are almost undegradable and more than 11 million cars are scrapped annually in the U.S. alone.¹⁷

Some possible solutions to minimize the problem include a reduction of the different types of plastics that are used (unlike metal, mixed plastics cannot be recycled together), an increase in the use of materials such as thermoplastic (a polypropylene that can be re-melted and formed back into the same part), the adoption of universal recycling codes on all plastic components, and incentives both for automakers to purchase back recycled products, and for end users to return their vehicles for recycling.

Several automakers have taken steps in this direction. For example, Nissan is intensifying research on the use of thermoplastics; BMW, Nissan, Saab and others code many of their plastic parts; Fiat codes all the plastic components in the "Cinquecento" (which is available in both gasoline and electric versions) by content for recycling.



A cut-out picture of the Fiat Cinquecento showing its recyclable plastic parts

Arguments for Conversions

The technical issues discussed above are likely to be of secondary importance for a considerable segment of the initial electric vehicle market, which may be served by conversions instead of purpose-built EVs. A large majority of on-road electric vehicles are converted from gasoline.

¹⁶ K Wright, 1990 *op cu*

¹⁷ B Winfield, 1992 "Automotive plastics are tough and long lasting That's the bad news, too " *Automobile Magazine*, September, pp 50-51.

Conversion may be chosen for involving less technical, financial and marketing risk, because it takes advantage of existing, proven platforms. It is also argued that the use of "gliders" (i.e., complete vehicles minus engine, transmission, fuel and exhaust systems) as a platform for EVs would be more economical because of a "deletion cost refund." However, automakers are often unwilling to supply "gliders," thus the superfluous components are either removed or left unused. The experience of England and France shows that such economies are seldom realized, because the refund has been far inferior to the cost of items not installed.¹⁸

Conversions are also seen as a way to facilitate the Federal Motor Vehicle Safety Standards (FMVSS) test and approval, because of similarities with existing ICEVs. However, the conversion process may cause major changes in vehicle characteristics such as weight, weight distribution, center of gravity height and location, payload location, vehicle handling and dynamics, including crash worthiness.

Proponents of conversions of gasoline vans for the fleet market see this niche, particularly large fleets, as the key to the introduction of electric vehicles.¹⁹ The reasons for this strategy include: 1) a greater compatibility between current EV performance capabilities and the requirements of fleet vehicles than that of private vehicles; 2) fleet vehicles tend to be garaged and maintained at central locations, facilitating battery recharging, EV servicing and training; 3) fleet buyers are more likely to take total life-cycle costs into consideration rather than initial cost of the electric vehicles when making purchase decisions; 4) large fleets have more flexibility to operate with a mix of electric and conventional vans and thus have a higher propensity to buy EVs than smaller fleets; 5) large fleets are better targets for marketing efforts because of the higher sales potential per customer; 6) their higher public profile gives extra incentives for large fleets to invest in environmentally friendly technology. They also provide an opportunity to demonstrate the technology because of their high visibility; and 7) many of the fleets are utility companies and government agencies that have an interest in promoting electric vehicles.

Supporters of this strategy maintain that, with some government encouragement for commercial fleets to use EVs, it would build the initial demand for these vehicles. This demand would in turn lead to a reduction of EV costs due to economies of scale in production, up to the point where they would be fully competitive with conventional vans. Further increases in production coupled with technological improvements would allow electric vans to enter the passenger fleet-vehicle market and later, the personal car market.

Arguments for purpose-built electric vehicles

Proponents of purpose-built EVs argue that the conversion process leads to technical, production, and economic compromises, resulting in a vehicle which is "unnecessarily heavy, complex, and expensive, and which at least in part, preserves the deficiencies of both systems... Product optimization requires control of all aspects, and to expect an efficient product from a mere drive-

¹⁸ L Leembruggen, 1990 "Townobile Purpose-built Electric Commuter Cars, Vans and Mini-buses." SAE Technical Paper No 900177, in *Electric Vehicle Technology* Warrendale, PA Society of Automotive Engineers

¹⁹ G Mader, G and O Bevilacqua, 1989 "Electric Vehicle Commercialization" in D Sperling, ed , *Alternative Transportation Fuels An Energy and Environmental Solution* Westport, Connecticut Quorum/Greenwood

train and energy source substitution is in defiance of logic.”²⁰ They claim that purpose-built EVs generate much greater confidence in the new technology than current demonstration programs and unsatisfactory adaptations of ICE platforms. *In essence, purpose-built proponents seek product optimization, arguing that the full potential of electric propulsion will be achieved only if all vehicle aspects are optimized for that technology.*

The main problem for small manufacturers would be the risks and costs of competing in a purpose-built EV market. It would require great research and development efforts to perfect a marketable product, and such investment would have to be spread over considerably large production runs. Conversion would reduce the amount of engineering effort and tooling cost. For this reason, the conversion of new and used ICEVs for market segments such as small city cars for private transportation and minivans for the fleet market is likely to persist even after the introduction of purpose-built EVs.

2.5. Battery Technology

The propulsion battery is unquestionably the most difficult component of EV design, since its performance may vary greatly with different conditions of use. Several technological paths have been pursued in the quest for efficient, safe and durable electrochemical cells. Typically, the most powerful batteries are the least durable, and vice-versa. The challenge for developers is to produce a battery that delivers simultaneously:

- 1) specific energy density (i.e., energy per pound of battery) that is high enough to provide sufficient range for most standard applications;
- 2) specific power (i.e., power per unit weight of battery) to provide ample acceleration;
- 3) a life cycle long enough to offset the initial cost, or else a short-life but very inexpensive battery;
- 4) the capability to be fully cycled every day without compromising performance or battery life;
- 5) maintenance and safety characteristics that provide reliable operation over the entire life cycle, minimizing problems such as inaccurate watering and venting or the danger of shocks, spills and explosions;
- 6) flexibility and durability to withstand varied field conditions. These include vibration, temperature changes, variations in daily use, operation at either very low or very high depths of discharge, long periods of vehicle inactivity, the effects of regenerative braking in different traffic situations, etc. These and other road conditions cannot be fully replicated in the laboratory and depend instead on the combination of field results with laboratory experiments.

²⁰ L R Leembruggen, *op cit*

The United States Advanced Battery Consortium (USABC) has defined a set of primary and secondary criteria that EV batteries should meet in the mid- and long-term. These are shown in table 2.2 below.

Table 2.2: USABC Criteria for EV Batteries²¹

PRIMARY CRITERIA	MID TERM	LONG TERM
Specific Energy (Wh/kg)	80 (100 desired)	200
Energy Density (Wh/L)	135	300
Specific Power (W/kg)	150 (200 desired)	400
Power Density (W/L)	250	600
Life (Years)	5	10
Cycle Life (Cycles @ 80% DoD)	600	1000
Ultimate Price (\$/kWh)	< \$150	< \$100
Operating Environment	-30 to 65°C	-40 to 85°C
Recharge Time	< 6 hours	3 to 6 hours
Continuous Discharge in 1 hour	75% of rated energy	75% of rated energy
Power and Capacity Degradation	20% of rated spec.	20% of rated spec.
SECONDARY CRITERIA		
Efficiency c/3 Discharge 6 hour charge	75%	80%
Self-Discharge	< 15% in 48 hours	< 15% per month
Maintenance	No Maintenance	No Maintenance
Thermal Loss (High Temperature Batteries)	3.2 W/kWh 15% of capacity, 48h	3.2 W/kWh 15% of capacity, 48h
Abuse Resistance	Tolerant	Tolerant

The most critical design parameters for battery development are energy density, power and useful life. High energy and power provide acceleration as well as long driving ranges. Long battery life is critical for economic reasons. No commercially available battery performs efficiently in all areas; increasing energy and power almost inevitably results in reduced battery life. The evaluation of battery technologies thus involves a series of trade-offs.

High values on specific energy, energy density, specific power and power density indicate high performance in relation to battery size and weight. Large number of cycles indicate long battery life. For example, given a typical 60-mile range for a lead-acid battery pack, a 1,000-

²¹ Source B Heinrich, 1992 "United States Advanced Battery Consortium " *Electric Vehicle Policy and Technology Conference* Los Angeles, March 5-6, 1992

cycle life means that it would have to be replaced after 60,000 miles. Table 2.3 compares the actual and projected performance of various types of EV batteries with respect to several of these criteria. It is followed by brief comments on the present status of each of the principal EV battery technologies.

Table 2.3: Performance Status of EV Batteries²²

Battery Type	Specific Energy (Wh/kg)	Energy Density (Wh/l)	Specific Power (W/kg)	Cycle Life (cycles @ 80% DOD)	Projected Cost (\$/kWh)	Energy Efficiency (%)
Lead-acid	18-56	50-82	67-138	450-1000	70-100	65-80
Nickel Iron	39-70	60-115	70-132	440-2000	160-300	50-75
Nickel Cadmium	33-70	60-115	100-200	1500-2000	300	65-75
Sodium Sulfur	80-140	76-120	90-130	250-600	100+	60-90
Zinc Air	130-175		50-100	75-100		40
Lithium Iron Sulfide	65-100	110-140	85-120	115-600	100-200	80
Lithium Iron Bipolar	160-200	400-610	480-600	370-1000		
Zinc Bromine	45-90	35-102	90-100	130-500	100-300	48-73
Nickel Zinc	40-85	140-164	160-80	200-500		65-75
Ni Metal Hydride	80		200	1000	200	90
USABC mid-term	80-100	135	150-200	600	150	75
USABC long-term	200	300	400	1000	100	80

The lead-acid (Pb-acid) battery

The *lead-acid* battery remains the most widely used rechargeable battery and still dominates automotive applications. Despite its mediocre performance and limited tolerance to deep discharges, it is a relatively inexpensive and mature technology. It should be the principal near-term option for EVs because it can be easily manufactured in high volume at a reasonable cost.

The following are some examples of recent EVs that use lead-acid batteries: the General Motors Impact, which features a high-power sealed lead-acid battery with gas recombination technology and an AC powertrain; the G-Van, based on the technology of the British-made GM Griffon, with an upgraded motor and lead-acid battery; the NAV, developed jointly by Tokyo R&D and Nippon Steel, in which ten lead-acid batteries power four direct drive motors placed

²² The ranges of values for each battery type reflect actual and projected performance data from diverse sources. There are wide variations in battery performance because many of the EV battery technologies are still experimental. The higher values in the table usually indicate a theoretical potential, not actual performance. Therefore, it is very difficult to make direct comparisons between the different battery technologies. The sources for this table include Terpstra, P 1992 *Electric Vehicle Structures and Components* Tucson, AZ Spirit Publications, U.S. Department of Energy, 1991. *Electric and Hybrid Vehicles 14th Annual Report to Congress for Fiscal Year 1990*, EPRI, 1990 *Battery Development for Electric Vehicles* Palo Alto Electric Power Research Institute, Y. Sera, T. Nakayama and H. Hasuike, 1990 "Conceptual Design of Advanced Batteries for Electric Vehicles," in *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong

outside each wheel; the IZA project, which evolved from the NAV; the Toyota TownAce, a 4-passenger mini-van equipped with lead-acid batteries and a new AC-induction motor; the electric Peugeot J5 and Citroën C25, which are powered by SAFT lead-acid batteries; the electric version of the Fiat Panda, and a host of other converted EVs.

The nickel-iron (NiFe) battery

The nearest contenders to lead-acid are nickel-iron and sodium-sulfur batteries, which offer some improvements in terms of energy levels. The *nickel-iron* battery has an edge on durability and ease of disposal. However, nickel is an expensive material, and this battery cannot be sealed because it emits sizeable amounts of hydrogen while recharging. It also needs constant maintenance and loses power at low temperatures.

Several manufacturers have tested NiFe batteries. For example, Pentastar is developing the TEVan, which is powered by a nickel-iron battery pack made by Eagle-Picher Industries; Nissan has developed a small commuter vehicle called the Micra EV-2, which uses either Matsushita nickel-iron batteries or Shin-Kobe lead-acid ones. Tokyo Electric Power has developed the "MYLD," a compact two-seater powered by 20 Nickel-Iron batteries equipped with battery warming; and one of the EV projects developed by Renault in collaboration with SAFT involves the adaptation of ten Renault Master vans, which were initially equipped with nickel-iron batteries and later with nickel-cadmium.

The sodium-sulfur (NaS) battery

In contrast with NiFe, the component materials of *sodium-sulfur* batteries are fairly abundant and inexpensive, and these batteries would not require maintenance by the user. More conclusive comparisons are not possible because they are not yet widely used and present low life cycle problems at their present technological stage. Nevertheless, sodium-sulfur batteries are favored by several major automakers. Two major battery manufacturers (Asea Brown Boveri and Chloride) have recently opened plants capable of producing significant volumes of NaS batteries for commercial applications. The Chloride-RWE joint venture has established a full-scale pilot plant to produce sodium-sulfur batteries in Manchester, England. Commercial production is planned for 1995.²³

NaS batteries can store as much as three times the energy of equivalent lead-acid ones, although they deliver less power. One drawback is that NaS require high temperatures to operate, in the order of 550 to 650 degrees Fahrenheit. This is a problem mainly when the battery is not in use, and it may be solved by directing a small amount of power for heating purposes, together with appropriate insulation.

Some of the EVs that use NaS batteries include the BMW E-1, a small car that uses batteries developed by Unique Mobility, and the E-2, a stretched version that accommodates a bigger battery pack. BMW has also conducted EV tests in association with Asea Brown Boveri (ABB), which built the DC motors and sodium sulfur batteries for converted BMW 3-series automobiles. In 1992, NaS batteries built by ABB powered a small Swiss car to a world record distance for EVs. The vehicle was driven non-stop for 340 miles at an average speed of 74.4 mph. In the United States, Ford is one of the major developers of NaS batteries. Both of Ford's recently developed prototype minivans — the Ecostar and the Ford Ghia Connecta — are

²³ M. Mangan and S. Preston, 1991 "Sodium-sulphur the time for trials" *Batteries International*, April, pp 44-45

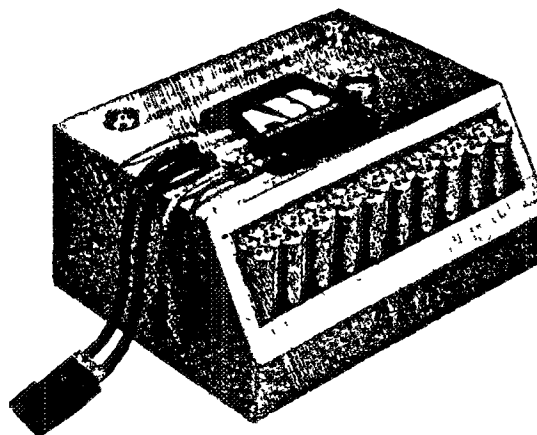
powered by sodium-sulfur batteries.

The nickel-cadmium (NiCd) battery

The remaining technologies are less likely to become readily available. The *nickel-cadmium battery* is technologically superior to the options above in all aspects, but it faces critical problems of safety and costs. Both nickel and cadmium are expensive, and cadmium is highly toxic. Nevertheless, this technology is frequently mentioned as a medium-term option.

Several Japanese manufacturers have chosen NiCd batteries for their EVs. Mitsubishi has developed with Tokyo Electric

Power an EV based on its Lancer wagon in Japan, which uses sealed nickel-cadmium batteries. The "IZA" car developed by Tokyo R&D for Tokyo Electric Power uses NiCd batteries powering four in-wheel direct-drive motors. The Nissan FEV uses a NiCd battery pack that enables it to reach a maximum speed of 81 mph and a range of 156 miles.



The ABB high-energy sodium-sulfur battery

The zinc-air (Zn-Air) battery

The *zinc-air* battery is also considered a long-term alternative for its high energy storage capacity. Its major drawbacks are a limited power density, and the fact that its air supply must be free of carbon dioxide. The Lawrence Berkeley Laboratory is involved in research and development of zinc-air cells in connection with the Electric and Hybrid Propulsion Division of the U.S. Department of Energy.

Luz Industries of Israel plans to commercialize a refillable zinc-air battery for use in electric cars. The battery contains 20 gallons of a slurry containing zinc, which reacts with atmospheric air to generate electricity. The battery can be refilled in approximately 5 minutes. Luz plans to initiate volume production by 1994.²⁴

One successful demonstration of the zinc-air battery was provided recently by Dreisbach ElectroMotive, Inc. (DEMI) of Santa Barbara, California. It supplied newly designed bipolar zinc-air batteries to power the winning car in the first "Electric 200" auto race in 1991. The DEMI battery combines oxygen from the air with a zinc paste and is reported to generate up to eight times the energy of comparable-weight batteries. It offers the advantage of reduced weight, room temperature operation, absence of environmentally objectionable components, extended range and low cost. However, it lasts less than lead-acid batteries and offers less potential for hard acceleration because of its low power density. For this reason, it requires a second "flywheel" battery (e.g. lead-acid or NiCd) to provide peak power for acceleration and passing.²⁵

²⁴ "Refillable electric car battery," *Design News*, October 7, 1991, p 3

²⁵ Dreisbach ElectroMotive, Inc 1992 "DEMI Zinc-Air Traction Battery Development News "

Other battery technologies

Other options indicate a potential for great improvements over lead acid batteries. For example, *lithium-iron sulfide* (high energy density and peak power); *zinc-bromine* (high energy and low costs); *nickel-hydride* and *aluminum-air* (high power and rapid recharging). A lithium-polymer battery is being developed under the sponsorship of USABC. Yet, all of them are at early development stages and cannot be considered for near-term EV use.

There are several examples of concept EVs that use exotic batteries. For example, Honda developed two electric-powered motorcycles: the "CUV-ES" and the "CUV-Canopy," both powered by nickel-zinc batteries. Suzuki has developed an electric minivan based upon its existing high roof light commercial van in Japan. It features a maintenance-free nickel-zinc battery, and solar cells as backup power source. Daimler-Benz has converted two Mercedes 190E into EVs which are powered by high-temperature, maintenance-free sodium-nickel chloride battery packs developed by AEG.

Other recent developments in battery technology

Many of the battery technologies described above have evolved steadily and some of them could reach commercial viability within five to ten years. Although there is sporadic news of major technological breakthroughs, most of them fall short of being realized. For example, in April 1990, *Isuzu's* announcement of a "revolutionary" battery that could be recharged in 30 seconds sent the company's stock skyrocketing by nearly 60 percent on the Tokyo Stock Exchange. The new battery's starting power would be 40 times greater than a conventional lead-acid battery, its output would be 20 times greater, and it would cost less than current batteries. In September 1990, *Japan Storage Battery* announced the development of a potent sealed nickel-cadmium battery for EV use. The battery would have twice the normal life expectancy, 1.25 more power per charge, and one-fourth of the recharging time of conventional batteries.

In 1992, General Motors signed a three-year, \$20 million R&D agreement with *Valence Technology*, which has developed a proprietary solid-state lithium polymer battery. The battery is said to be three to four times more powerful and significantly less expensive than existing batteries. Delco Remy, GM's auto parts division, has placed an initial order for a limited number of the batteries.²⁶

Another revolutionary battery technology was announced in 1992. The battery works on the basis of kinetic energy stored by rotors that spin at high speeds, suspended by magnetic bearings in a vacuum. It is claimed that twenty such batteries would deliver 43.6 kWh, which is three times more energy than a comparable lead-acid cell. This would enable a car to achieve a range of 600 miles, while avoiding the problems of corrosion and toxicity associated with conventional electrochemical cells. A patent was awarded to *American Flywheel Systems* of Seattle on June 23, 1992. The company expects to build a demonstration model within a year.²⁷

²⁶ "Juiced up over a new battery" *Business Week*, August 10, 1992, p. 63

²⁷ "A new spin on electric-car batteries" *Business Week*, July 13, 1992, p. 139

2.6. Alternatives to Overcome Battery Limitations

Roadway-powered electric vehicles (RPEVs)

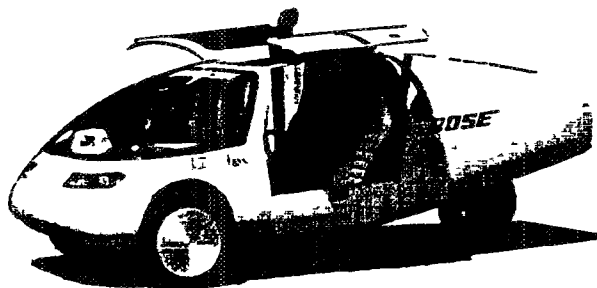
The limited range and performance of electric vehicles are dictated fundamentally by the limited energy storage capability of their battery packs. A lead acid battery, for instance, has a typical energy storage density in the range of 5 percent on a weight basis of a tank of gasoline. One of the alternatives to overcome this major drawback is the roadway-powered electric vehicle (RPEV), which can be powered either by an electrified roadway or by its own batteries when driven on regular streets. The RPEV is not charged by physical connectors, but by induction from a power source buried in the pavement, either under the roadway itself or under parking lots.

With a sufficiently extensive electrified roadway grid, RPEVs could have a practically unlimited range, and their battery requirement could be lowered to as little as 5 to 10 percent of the range sought for a conventional EV. However, the infrastructure costs would be very high. The arterial grid required for practical RPEV operation should cover about 5 percent of the street and highway system, and preliminary estimates of the cost per lane-mile of powered roadway range from \$1-\$2 million.²⁸

Solar-powered and solar-assisted vehicles

Solar energy provides another alternative to overcoming battery limitations. Solar power offers extraordinary potential as a clean transportation technology. Yet, it cannot be considered a feasible automotive energy source for the near future. Several solar-powered research vehicles have been built and tested in the United States, Japan and Australia. These small, lightweight vehicles are still very far from being capable of providing the range, speed performance, comfort and safety features that would be required for consumer marketing. Despite their limitations, however, experimental vehicles display the potential of solar cars to provide cost-effective, pollution-free transportation for market niches with limited trip lengths.

Solar cell technology has evolved rapidly in recent years. Over the last decade, the photovoltaics industry has grown at more than 30 percent annually. The efficiency of solar cells has nearly doubled, and their durability has increased by 50 percent.²⁹ As more efficient solar cells become available at progressive lower cost, these technologies are being introduced as auxiliary rechargers for battery-powered electric vehicles such as the Nissan FEV, the Solectria Flash and several converted EVs. The Mazda 929, a conventional automobile, already offers the option of a solar



The Solectria "Flash," a solar-assisted EV prototype

²⁸ K Nesbitt, D Sperling and M DeLuchi, 1990 *An Initial Assessment of Roadway-Powered Electric Vehicles* Transportation Research Group, University of California, Davis See also Southern California Edison, 1990 *Southern California RD&D Program on Highway Electrification Systems*

²⁹ E Edelson, 1992 "Solar Cell Update" *Popular Science*, June

panel that aids interior cooling; when ventilation is not needed, it switches automatically to trickle charge the battery.

Hybrid vehicles

The third alternative to sole reliance on battery power involves hybrid vehicles, which enhance range and flexibility at the cost of increased emissions. Electric-hybrid vehicles incorporate an auxiliary power unit (APU) or "range extender" in addition to the main propulsion batteries. The two power sources may operate in "parallel" when each one may drive the wheels independently, or in "series" when the engine charges the battery. One example of the first type is the Clean Air Transport "LA-301." The "Chico" city car prototype that was unveiled recently by Volkswagen is a sophisticated example of the "parallel" hybrid. It features constant-demand, fully automatic switch-over between conventional power and electric drive in response to speed and throttle pressure.

In the second type of hybrid, the APU is generally a small internal combustion engine that works as a generator to supplement battery power for longer trips. This type of engine generator is expected to provide a substantial increase in range compared to what it is possible to achieve with the batteries alone, but it exacts a penalty in weight and size. For example, Unique Mobility has developed the "M-91," a van equipped with a 5 kW engine generator that is projected to extend the 60-mile range of a battery-powered electric van to as much as 175 miles. A hybrid version of the "G-Van" that should reach a range of 200 miles is also being tested by EPRI. The utilization of a small engine generator that operates at constant speed facilitates the use of alternative fuels such as natural gas, propane or gasohol.

Fuel cells

In the future, a fuel cell coupled with an electric battery could provide another viable hybrid vehicle option. Fuel cell propulsion systems may cut fuel consumption in half and provide greatly reduced emissions in comparison with the internal combustion engine, through the utilization of non-petroleum fuels.

Sanyo has recently developed a concept electric car that combines nickel-cadmium batteries, solar cells and a fuel cell. The solar panels and the hydrogen fuel cell generate electricity to charge the small battery pack, which lasts for only two hours. The only emissions are water vapor and air. However, the weight and bulk of fuel cells will probably restrict their use to large trucks and buses. The energy density of the fuel cell system is very low: at about 3.8W/lb, it is less than one-third that of lead-acid batteries. Therefore, there is no advantage in trading batteries for a fuel cell in EVs at the present state of the technology.

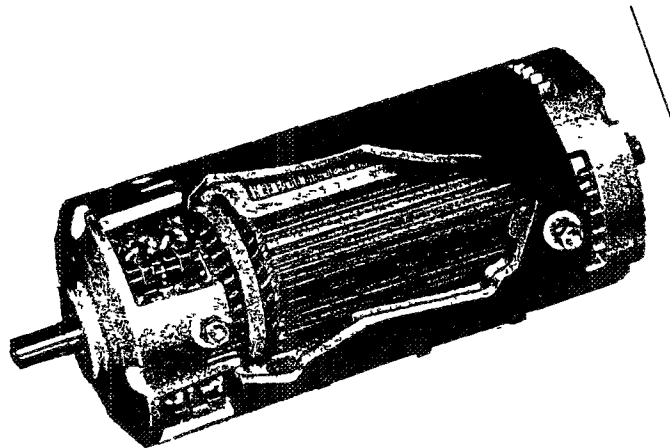
2.7. Propulsion Systems

A thoroughly optimized propulsion system for EVs demands an integrated design process comprising the charger, control system, motor, drivetrain and electrochemical cell. The EV motor must be designed to allow maximum flexibility to the control system in determining the power curve, hence increasing system efficiency and reducing power losses, while maximizing speed and power. Electric motors may operate on either AC (alternating current) or DC (direct current). Recent developments in microelectronics have resulted in lightweight DC-to-AC

inverters, making it possible to use more compact and efficient AC systems than the two types of DC systems (conventional DC and DC brushless) that have been used in EVs.³⁰

Conventional direct current (DC) motors

Conventional DC motors are the most common type. They have several advantages: They are robust, inexpensive, easy to maintain and to control, and do not require inverters, since batteries provide DC power. A typical brush DC motor can reach up to 25 horsepower. Their disadvantages are low operating speeds (below 4000 rpm), brush wear, and low efficiency when operating on partial loads. The inadequate speed and part-load inefficiency entail the use of a gearbox or other variable speed transmission for EV use, thus adding complexity to the propulsion system.



EV Motor made by Advanced DC Motors

DC brushless motors

The permanent magnet DC brushless motors eliminate brush wear, operate at higher speeds (up to 7,000 rpm) and are highly efficient even at part-load conditions. This type of motor can produce much more power than brush DC motors. For example, the motor supplied by Unique Mobility for the BMW E2 reaches 45 hp. The higher speeds and part-load efficiency of brushless motors provide better performance and allows the use of drivetrains that are much simpler than the multiple speed gearboxes usually required by brush DC motors. However, the relative technological sophistication of this type of motor implies high costs.

AC induction motors

AC induction motors also eliminate brush wear, provide a good part-load efficiency and even higher speeds than DC brushless motors, reaching as much as 15,000 rpm. Power output is quite high in the most advanced models. For example, the GM Impact is powered by two AC motors rated at 30 hp each, reaching a 57 hp peak capacity. Their disadvantage is the higher cost and the sophisticated controllers and inverters that are needed to transform the DC power from the battery into alternating current. Nevertheless, applications of advanced AC drives have grown at a rate of 13 to 14 percent annually against 3 to 4 percent for DC drives.³¹

³⁰ G Mader and O Bevilacqua, 1989 "Electric Vehicle Commercialization" in D Sperling, ed , *Alternative Transportation Fuels: An Energy and Environmental Solution* Westport, Connecticut Quorum

³¹ C Chan, 1990 "Electric Vehicle Development in Asia Pacific" in *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong

Drivetrain³²

In comparison with the transmission systems of conventional vehicles, EV drivetrains can be extremely simple. They usually amount to a set of planetary gears that reduce motor speed to the appropriate speed and torque that are needed to drive the wheels. Internal combustion engines must achieve a certain number of rotations to produce sufficient torque, therefore the need for complex transmissions and clutches. In contrast, an electric motor has maximum torque at zero rpm, so there is no need for a low gear to put the car in motion. Nor there is need for reverse gear, because the motor can run in both directions.

Ultimately, decisions such as whether to use direct-drive motors for each wheel or a differential, or whether to use a fixed-ratio or variable transmission connecting the motor to the drive wheels, are likely to depend as much on the characteristics of each vehicle as on cost considerations. For instance, a single motor and a fixed ratio reduction and a conventional differential were used for the G-Van project. In this case, the use of a mass-produced gearbox was considered more cost effective, even though it increases drive system losses.

The Japanese concept cars "NAV" and "IZA" use direct-drive motors, one for each wheel. Although this solution reduces transmission losses, it increases complexity and costs by using four motors instead of one; it also increases the risk of damage when the vehicle hits a pothole or curb, because the motors are placed outside the wheel and unprotected by the car's suspension.

Charger and control system

The charger plays a critical role because it must be adaptable to wide variations in operating conditions. The recharging process requires precise control because excessive charging leads to rapid deterioration of battery plates, while inadequate recharging leads to progressive imbalance within the battery.

The controller/inverter is responsible for providing a regulated power output under varying circumstances, such as very high battery voltages that occur under full charge or during regenerative braking, very low voltages when the traction battery is nearly depleted, or output surges and transients generated by faulty conditions.

The type of motor ultimately determines the complexity of the controller needed to regulate and condition the power output. Conventional DC motors require the simplest form of conditioning, known as "chopping." The operation of the controller ("chopper") produces the peculiar high-pitch sound or "whine" associated with EVs, as it introduces controlled variations on the DC electrical field. AC induction motors demand more complex mechanisms to transform the direct current into alternating current. Brushless DC motors require similarly complex power conditioning, which involves extremely rapid switching of several circuits to control energy flow. The typical whine may be reduced or eliminated in the latter systems by increasing switching frequency to a much higher level that is beyond hearing range.

Since the EV system components are highly interdependent, the control of charging and other energy management functions can be integrated within the electronics of the motor controller, which thus becomes the center of a power management system. Several different

³² The term drivetrain is used here in its strict sense, referring to the parts that connect the motor (or engine) with the traction wheels of an automobile. It includes parts such as the transmission, drive shaft, universal joints and axles, it does not include the motor itself. In some texts, this term is used in reference to the entire propulsion system, including the motor.

technologies are being employed to produce drive electronics that generate more power in smaller packages. These include MOSFET (metal oxide silicon field-effect transistors), IGBT (insulated gate bipolar transistors), GTO-SCR (gate turn-off silicon-controlled rectifiers), SIT (static induction transistor) and MCT (MOS-controlled thyristor).³³

Recent advances in electronics have made possible the development of extremely powerful and compact controllers in comparison with the state of the art of a few years ago. For example, the MOSFET-based inverter/controller designed by Alan Cocconi for the GM Impact delivers an unprecedented 100 kW in a package that weighs approximately 60 pounds. The next generations of electronic circuitry and market expansion in the near future are expected to enable the production of even more powerful and compact motor drive electronics at much lower costs.

2.8. Vehicle Support, Maintenance and Infrastructure Requirements

Vehicle service and maintenance

Even though EVs are expected to be more reliable and simpler to repair than ICEVs, assurance of continued technical support and maintenance is a critical aspect of the commercial viability of electric vehicles. In order to reach and sustain acceptable standards of range and performance, all EV parts and components must be treated as integral parts of a thoroughly optimized system which requires careful maintenance. For instance, if batteries that need watering are put into widespread EV use, it will require either an automatic watering system or else that the user be responsible for regular correct watering. Sealed-type batteries would preclude this problem. For reasons of consumer safety and convenience, EV batteries should be designed to be serviced only by qualified technicians.

A modular design for the batteries and the power management system would also facilitate diagnostics and repair of faulty modules, instead of replacing the entire battery pack or charging/controlling system, for example. This also involves the development of diagnostic equipment and interface units that can be used by service engineers and vehicle operators to identify any faulty component and the nature of the problem. Eventually, a series of on-board diagnostics could be incorporated into the vehicles themselves, as long as it does not imply unacceptable complexity and cost penalties.

The serviceability of EVs should be significantly affected by the fact that the technology is likely to evolve rapidly in the early stages of vehicle production. Although there will be a push for complete design changes in major components, it is desirable that the new units be interchangeable with the ones that fail or are phased out, in order to permit a gradual adaptation of the service force to the new designs, and to reap the benefits of the longer life cycles that EVs offer in relation to ICEVs.

³³ P Morris and D Adams, 1990 "Design Considerations and Component Selection for Volume-Produced EV Controllers " SAE Technical Paper 900578 Warrendale, PA Society of Automotive Engineers

Infrastructure requirements

The existing electrical grid should be able to support a large number of EVs, and it could be adapted to provide ample quantities of recharging points at a relatively low cost.³⁴ Nevertheless, current range limitations of EVs would require an extensive recharging network, including public recharging stations in parking areas and curbside locations. Assuming that all vehicles would be equipped with on-board chargers, regular AC outlets would suffice. Otherwise, stand-alone and mobile chargers should be provided, adding to infrastructure costs.

An early standardization of the interface between vehicle and public grid is desirable in order to facilitate the implementation of recharging stations. However, it should not be as rigid as to preclude future additions of supplementary features such as special rate meters, safety mechanisms and vehicle identification devices designed to ensure proper connections and to prevent unauthorized use of both the outlet and the vehicle.

The electric utilities in the Los Angeles region already have plans for infrastructure changes to serve the future needs of electric vehicles. They include a network of separately metered outlets, which could be operated by coins or credit cards, and "electric service stations." Southern California Edison is planning a network of separately metered outlets, which could be operated by coins or credit cards. There are also plans for "electric service stations." Yet, an EV equivalent of the corner gas station is impractical in the near-term due to the long time required to recharge the batteries, unless quick charge systems are used.

An ample number of recharge stations should be placed at medium- and long-term parking sites, such as business parking lots, shopping centers and airports, in order to supply many recharging opportunities in addition to outlets in household garages. The so-called "opportunity recharging" is an essential aspect of EV infrastructure which is likely to be advanced by a future city ordinance requiring electric outlets to be installed in garages and parking lots of all new construction.

Quick charge systems

One viable alternative to minimize the problems of limited ranges and long recharging times would be a quick charge system using outlets with higher electrical currents than the usual 110 volts of standard outlets. The higher the voltage and amperage, the faster the recharge — provided that the cable, battery and charger are designed to bear the electric load.

For example, the system developed by Nissan and Japan Storage Battery provides a 40 percent recharge in 6 to 7 minutes, and a complete recharge in 15 minutes at special 440-volt recharging stations. This solution would be impractical for residential use because it would involve expensive modifications in household circuitry and distribution systems. Moreover, the vehicles would then need a dual system, for quick charge and for standard 110-volt slow charge. The quick charge system creates a problem for electric companies because it reduces the opportunities to take advantage of their idle capacity during the night through off-peak recharging. Differentiated pricing and "smart controls" could be used to mitigate this

³⁴ W. Hamilton, 1988 *Electric and Hybrid Vehicles Technical Background Report for the DOE Flexible and Alternative Fuels Study* Prepared for the U.S. Department of Energy, Washington, DC

problem.³⁵ Another alternative to quick recharging would be a removable battery module designed to be replaced quickly when exhausted by a fully charged one at service stations.

Impact of EVs on the electrical system

The need for new power sources once the existing electrical capacity is exhausted constitutes a critical aspect of large-scale EV implementation. The environmental impacts of EVs depend primarily on how cleanly electric energy is produced. Although EVs are the only existing alternative fuel vehicles to meet ZEV (Zero Emission Vehicle) standards, the expansion of generating facilities could cause profound environmental impacts, if more fossil fuel-based power plants are built. If EVs use solar-generated electricity, energy production and vehicle operation are essentially pollution-free; if coal-powered plants are used, the environmental impacts would be substantial. Experts contend that even if electricity for EVs is generated using a combination of coal, natural gas, oil, hydroelectric, solar and nuclear power, such as the energy mix estimated by EIA for the year 2000, there would be a major reduction in emissions.³⁶

Utility companies generally have sufficient capacity to support a very large number of EVs, especially if they are charged off-peak, taking advantage of otherwise idle capacity. According to an estimate, 1.2 million electric cars could be on Los Angeles area streets by the year 2010, adding more than 6 billion kWh per year to the Los Angeles Basin's electricity load. This corresponds to less than 10 percent of the region's total power consumption. The Los Angeles Department of Water and Power (DWP) estimates that it can provide electricity for 300,000 cars without extra power generation, and Southern California Edison could provide enough energy for 1 million EVs, or as much as 2 million if they are recharged at night.³⁷ Although it is not clear when expansion would be needed because of EV demand and what types of power sources would be used, an advantage of EVs remains — it is more effective to control pollution at one remote power plant than at thousands of mobile sources.

2.9. Electric Vehicle R&D Programs in the United States

The Electric and Hybrid Vehicles Program

The Department of Energy's (DOE) Electric and Hybrid Vehicles (EHV) Program is one of the principal programs on research, development, testing and evaluation activities to encourage the use of electricity and alternative fuels for transportation in the United States. Under the Electric and Hybrid Vehicles Research, Development and Demonstration Act of 1976, DOE is directed

³⁵ A "smart control" system involves two-way communication between the utility company and the EV charger, so that the utility control center can read the status of the battery, estimate the duration of charging and program it to occur during the early morning hours, when demand for electricity is at its lowest (A Ford, 1992 "The Impact of Electric Vehicles on the Southern California Edison System." Report to the California Institute for Energy Efficiency, Berkeley, California)

³⁶ M DeLuchi, Q Wang and D Sperling, 1989 "Electric Vehicles: performance, lifecycle costs, emissions, and recharging requirements " *Transportation Research* 23A, 3 255-78

³⁷ A Ford, 1992, *op cit* , see also "The Move from Pump to Plug," *Los Angeles Times Magazine*, June 21, 1992, p 10, R Kaiser and C Graver, 1980 "Analysis of the Infrastructure for Recharging Electric Vehicles " *SAE Technical Paper No 800112*. Warrendale, PA Society of Automotive Engineers, M Collins *et al* , 1983 *Impacts of Electric Vehicles on Electric Power Generation*, draft final report, CR-1-983 Palo Alto, CA Electric Power Research Institute

to cooperate with industry towards the following objectives: 1) to promote basic and applied research on electric and hybrid vehicle batteries, controls and motors; 2) to determine optimum electric and hybrid vehicle design; and 3) to design vehicles that emphasize durability, length of practical lifetime, ease of repair and interchangeability of parts. The DOE Electric and Hybrid Vehicles Program consists of four major elements: battery technology development, fuel cell technology development, propulsion systems development, and test and evaluation.³⁸

Table 2.4: EHV Program funding, FY 1991

Program	Funding in \$ millions
Battery R&D	8 950
Ford Modular EV Program	2 750
Fuel Cell	6 950
Fuel Cell Bus	2 000
Test and Evaluation	2.000
User Task Force	1 900
Management Support	700
Total	25.250

In Fiscal Year 1988, Congress provided an appropriation of \$14.1 million for the EHV Program. The appropriations for Fiscal Years 1989 and 1990 were \$13.9 million and 17.7 million respectively. For Fiscal Year 1991, Congress authorized an appropriation of \$25.25 million for electric and hybrid vehicle development. The distribution of funds by subprogram is indicated in Table 2.4.³⁹

The emphasis of the EHV Program is on battery and propulsion systems development. The U.S. Department of Energy has defined battery design concept requirements generally in terms of the maximum, near-term feasible performance of battery and other vehicle control systems. The DOE's emphasis results mainly from the

limitations of current batteries. The limited range, poor acceleration and low top speed provided by lead-acid batteries are the chief justification for concentrating R&D efforts on incremental battery development. However, specialists have argued for a greater diversification of research efforts, since fundamental scientific breakthroughs will be needed in addition to incremental improvements in near-term battery and subsystems design before electric vehicles can displace large numbers of gasoline-powered vehicles.⁴⁰

The EHV program has included as major participants: *Automotive Companies*: Ford Motor Company. *Component and Propulsion System Companies*: Delco/GM, A.D. Little, Booz-Allen & Hamilton, Eaton Corporation, Energy Research Corporation, General Electric. *Battery Companies*: Beta Power, Inc., Chloride Silent Power Limited, Eagle-Picher Industries, Johnson Controls, Inc., Saft America, Westinghouse. *Universities*: Georgetown University, MIT, University of Alabama, Virginia Polytechnic Institute, University of Florida, University of Hawaii, York Technical College. *Fleet Testing*: GTE, Long Island Lighting Co., Detroit Edison, Arizona Public Service, University of Hawaii, City of Alexandria (VA), United States Navy,

³⁸ K Barber, 1990 "An Overview of the Electric and Hybrid Vehicles R&D Program at the U S. Department of Energy," in *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong.

³⁹ *EVAA Newsletter*. 1990 Electric Vehicle Association of the Americas, Oct-Nov.

⁴⁰ P Wuebben, A Lloyd and J Leonard, 1990 "The Future of Electric Vehicles in Meeting the Air Quality Challenges in Southern California " SAE Technical Paper No 900580 Warrendale, PA Society of Automotive Engineers

Southern California Edison, Los Angeles Department of Water and Power.⁴¹

Photovoltaics for Utility Scale Applications

Funds to accelerate photovoltaic production are also becoming more available, particularly through a program called PVUSA (Photovoltaics for Utility Scale Applications), which aims to accelerate the efforts to turn solar energy into electricity reliably and at costs that are economically competitive. Another program called Photovoltaics Manufacturing Technology is designed to lower solar cell prices by improving manufacturing efficiencies. Both programs are sponsored by the Department of Energy, which has most of its \$63.5 million photovoltaics budget earmarked for applied research and production. This signals a major change from previous federal policies. In the 1980s, priority was given to research, while the development of applications was left to the market.

The majority of current projects are directed to large-scale applications by electric utilities, although some of the several solar-cell technologies should reach automotive applications. Southern California Edison and Texas Instruments have invested more than \$10 million in a joint project to develop spherical silicon solar cells. Despite its unremarkable efficiency, this technology is expected to be inexpensive when applied to mass production. One of the first planned applications is a solar recharging station for electric vehicles.⁴²

Electric Power Research Institute

One of the leading private promoters of R&D on electric transportation is the Electric Power Research Institute (EPRI) of Palo Alto, California. It is a nonprofit corporation supported by its membership, which comprises approximately 600 U.S. investor owned, cooperative, municipal and federal utilities. EPRI plans and manages a program of research, development, and demonstration that assists member utilities to meet future electricity needs and develop markets. The Electric Transportation Program is a subprogram created in 1986. Among other EV-related activities, EPRI supports the GM G-Van and Chrysler TeVan programs, a pilot plan for nickel-iron batteries at Eagle-Picher and the Lithium/metal sulfide battery development by Westinghouse.

United States Advanced Battery Consortium

Ford, General Motors and Chrysler have joined forces in a private consortium for the development of advanced EV batteries, the United States Advanced Battery Consortium (USABC). The U.S. Department of Energy and the Electric Power Research Institute also participate through cooperative agreements. USABC has been funded with \$130 million from the Department of Energy as part of an effort to diversify energy sources; an equal amount in matching funds will come from the automakers. This consortium aims to identify promising battery technologies and contract specialists to work in R&D teams coordinated by the consortium participants. It has established a series of primary and secondary criteria for mid- and long-term EV batteries. An advanced battery that provides a demonstration of design

⁴¹ U S Department of Energy, 1990 *Electric and Hybrid Vehicles Program — 13th Annual Report to Congress for Fiscal Year 1989*, U S Department of Energy, 1991 *Electric and Hybrid Vehicles Program — 14th Annual Report to Congress for Fiscal Year 1990*

⁴² E Edelson, 1992 "Solar Cell Update " *Popular Science*, July

feasibility and a pilot plant to build it are scheduled to be available by the end of 1994.

The contracts for the diverse battery technologies to be pursued are currently being announced. The first technology to receive development support from USABC is the nickel-metal hydride battery developed by Ovonic Battery Co. The firm, a subsidiary of Energy Conversion Devices in Troy, Michigan was awarded a \$18.5 million grant. Small versions of the nickel-metal hydride cell are already displacing nickel-cadmium batteries in applications such as laptop computers. The South Korean car maker Hyundai has indicated its intention to use Ovonic batteries for the electric vehicles it plans to start selling by 1995.⁴³ This type of battery has a long life and tolerance to deep discharges—which are important characteristics for EV batteries. However, its cost per kWh is twice that of lead-acid batteries. Similar development grants for other promising technologies should follow.

South Coast Air Quality Management District

California's South Coast Air Quality Management District implements a program to support the development of advanced emissions control technologies and cleaner-burning fuels through its Technology Advancement Office (TAO). It has cosponsored projects such as light-duty methanol vehicles with Chrysler; natural gas trucks with GM, UPS and others; methanol flexible-fuel vehicles with Ford and GM; the electric TEVan with Chrysler, EPRI and Southern California Edison (SCE); and a fuel cell/battery powered bus with US DoE, Georgetown University and the Urban Mass Transit Authority. TAO has also supported the development of a solar-powered EV recharging station with SCE and solar-powered vehicles by three local universities: California State University Los Angeles, California State University Northridge and California State Polytechnic Institute Pomona.

Los Angeles Initiative

The Los Angeles Initiative is a broad coalition of organizations interested in promoting large-scale EV use in the Los Angeles area. It includes the Los Angeles Department of Water and Power, Southern California Edison, the South Coast Air Quality Management District and the Los Angeles City Council, under the leadership of Councilman Marvin Braude. The Los Angeles Initiative put forward a request for proposals in January 1989, aiming to market 10,000 electric vehicles in Southern California by 1995. It brought responses from nineteen firms.⁴⁴

The field of participants was narrowed down to seven and ultimately, three companies were chosen for contract negotiation: Clean Air Transport, an Anglo-Swedish company which was founded to enter the competition; Unique Mobility, a Colorado-based engineering firm that designs and produces prototype EVs and components; and Vehma International, the assembler of the electric G-Van. Vehma (which is now called Conceptor Industries) and Unique Mobility did not receive contracts; CAT has developed a prototype and is currently trying to raise additional funds for the project.

⁴³ "USABC awards its first contract to develop advanced battery " *Keeping Current*, Vol 1, Summer 1992, p 3; "Still going," *Automotive Industries*, March 1992, p 17

⁴⁴ "The Los Angeles Initiative First Step Toward Electric Vehicles " *EV News*, Southern California Edison, Vol 1, No 1, February 1990

CALSTART

CALSTART, a California consortium of 41 companies, was formed in 1991 to create lightweight, energy efficient, and highly reliable components for new transportation systems. It includes five major utilities, several large and small aerospace and high-tech companies, and educational and research institutions. The consortium was initiated in response to a provision in the 1991 federal highway and transportation bill by Rep. Howard Berman, aimed at encouraging public-private partnerships to develop advanced forms of transportation.

CALSTART is partially motivated by the need to convert defense and aerospace facilities to commercial uses, and has converted the Lockheed plant in Burbank into a R&D facility for electric cars. The group has already raised \$14 million of private funds and \$6 million in government funds toward seven development projects the next six years, including production of a prototype "showcase" electric car, development of advanced propulsion systems, service facilities, recharging stations and a testing program for electric vehicles.

CALSTART's Showcase Electric Vehicle Program (SEVP) is well underway. The vehicle was unveiled in late 1992. The main purpose of SEVP is to develop advanced EV components and subsystems from California-based companies and to present them to national and international companies that intend to assemble and sell EVs. SEVP is a collaborative R&D and marketing effort of approximately 20 California companies. The project's original concept was developed by Amerigon, a Monrovia-based company which is in charge of SEVP management. The showcase technologies include electronic systems and controls by Amerigon, Hughes, Intel, Solec and Litton; body components, chassis and wheels by Avery Dennison, Coddington, Composites Automation Consortium, Fairchild Manufacturing, and Kaiser Aluminum; HVAC by Allied Signal and ASHA Systems; and special EV tires by Pirelli Armstrong.

2.10. Opportunities for EV Manufacture in Southern California

The near-term implementation of EVs is hindered by the intrinsic problems associated with new technologies. Electric vehicles are likely to cost the same or more than a gasoline vehicle; yet, they would probably offer lower weight-performance ratios and more limited driving ranges. Even though technological progress and large-scale production would eventually lower the price and improve the performance of the new vehicles, their market potential is likely to remain limited. These obstacles to consumer acceptance can be partly reduced by intensified marketing, assurance of the reliability and benefits of EVs and government support. If both markets and new technological advances are sufficiently developed, the life-cycle costs of EVs may soon be comparable to those of gasoline vehicles. However, the market potential of EVs should not be overestimated, even assuming the environmental benefits and optimistic cost projections of EVs materialize soon and are amply publicized. In the near future, EV market penetration cannot be expected to proceed much beyond applications where speed, acceleration and long driving ranges are not considered essential.

Many automakers, including Ford and Chrysler, are concentrating their efforts on vans for fleets, which are widely perceived as the only significant EV market in the near future, especially where low speed and frequent stops are involved. In addition, it is expected that a single EV will receive different nameplates to spread development costs and to satisfy the initial zero emission requirements for different automakers. Some companies are expected to

subcontract out or enter alliances to meet their percentage of ZEV sales. For example, General Motors and Isuzu, Mazda and Ford, Nissan and Ford are some of the different automakers that are expected to commercialize jointly-developed EVs under different badges.⁴⁵

General Motors surprised many industry analysts by announcing its intention to mass produce a sporty two-seater based on the Impact prototype. First, because it targets a niche that is far from the most secure EV market segment—i.e., utility vans—according to most analysts; second, because large automakers are likely to avoid the risk of investing in small market niches that are commonly regarded as the domain of specialty manufacturers. Several analysts have expressed doubts that GM will be able to produce a marketable vehicle on the basis of the Impact. It is observed that the prototype was developed largely by outside consultants, and that few of the major manufacturers have either the ability or the interest to risk their resources and carry out this type of program from prototype to market.⁴⁶

GM has responded by setting up a small development team entirely separate from its conventional structure, by establishing new market-research methods and by adopting “simultaneous engineering” techniques such as the ones pioneered by Japanese automakers. These techniques are coupled with the experience of Hughes Electronics (a GM subsidiary) in systems integration and computer simulation. Hughes should provide the expertise to optimize vehicle characteristics and reduce trial-and-error testing, to design factory layouts and assembly processes in order to reduce the number of parts and vehicle weight. The ultimate goal is to simplify manufacturing and to cut costs and development time. The potential market should also be expanded, since the Impact would be the first U.S.-built GM car that is aimed to Europe as well. The vehicle will meet European safety standards and come with either right- or left-hand drive.⁴⁷

It is too early to say whether GM has effectively established a head start with its announcement to launch the world’s first mass market electric car, and whether it will carry out its plans, especially after its recent changes in direction. (In fact, recent press reports indicate that GM has now significantly reduced its commitment to the Impact project.) Many experts argue that an industry based on such an innovative technology requires the use of small, multidisciplinary engineering teams that are able to achieve rapid product development by working together in every aspect of the vehicle from concept to finished product. It has been pointed out that in many cases, electric vehicle design, testing, review and prototype development have proceeded without the direct involvement of major automobile manufacturers, and that small companies have also contributed to significant progress in battery development.⁴⁸

Notwithstanding the high R&D costs associated with the new technology, the changes in GM’s customary practices actually suggest that large automakers do not have necessarily a

⁴⁵ M. Maynard and A. Spinella, 1990 “The clean air battle is over, but the war is just beginning” *Ward’s Auto World*, December.

⁴⁶ M. Cone, 1992 “GM and the Juicemobile” *Los Angeles Times Magazine*, June 21

⁴⁷ D. Woodruff, 1991. “GM All Charged Up Over the Electric Car” *Business Week*, October 21.

⁴⁸ P. Wuebben, A. Lloyd and J. Leonard, 1989. *Alternative Fuels: Research and Development Priorities*. Presented at the American Institute of Chemical Engineers Summer National Meeting; D. Reisner, 1990 “The Rechargeable Ni-Zn Battery System for EVs A Current Status Report on Recent Progress” in *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong

competitive advantage in EV production. If a niche market for a high-performance two-seater such as the Impact is developed, there is a window of opportunity for flexible, innovative firms that are capable of bringing a high quality product to market quickly and in relatively small quantities.

Regional potential for EV manufacturing

The prospect of an emerging EV industry opens many opportunities for Southern California, for several reasons. The region comprises the world's prime automobile market; it exhibits the world's largest concentration of design studios from all the major automobile manufacturers and is widely known for setting trends in the auto industry;⁴⁹ California's air quality standards are also trend-setting and now provide the central motive for pioneering large-scale introduction of electric vehicles; its concentration of scientific and technological workers is unparalleled; finally, there is currently a call for commercial applications of advanced technologies to lessen the social and economic impacts of recent cutbacks in defense spending.

There are specific areas of EV production in which it is particularly desirable to take advantage of existing industrial capabilities. For example, there are numerous firms specializing in the production of high value added components that could serve the needs of the EV industry, and also have the potential to reach other markets. An extensive survey of the region's industrial base is necessary in order to identify the regional resources that could be integrated into a local EV industry. The main components of purpose-built EVs, together with a preliminary identification of the areas that hold the potential for substantial technological innovation, may be summarized as follows:

Chassis, structure and body: EVs offer potential for major changes from existing vehicles in frames, suspension, underbody and body components. New materials and manufacturing processes may be employed for these parts, including lightweight and ultra-strong materials such as plastic composite parts and light metal alloys for structural frames, body panels and doors. The fabrication of bumpers, windows, windshield wipers and exterior lighting are less likely to involve major technical changes from existing practices.

Propulsion systems: this aspect of EVs evidently holds the potential for major technological advances. Propulsion batteries, fuel cells, motors, chargers, controllers, transmissions, brakes, wheels and tires are likely to introduce entirely new or significantly changed components and systems in relation to existing vehicles. Depending on vehicle characteristics, some system components such as steering, transmission and drivelines may not involve significant technical changes.

Accessory technologies: EVs will require major changes in areas such as HVAC (passive and active cooling, heating); compact and energy-efficient components (transistors, switches, thyristors, valves, actuators, super capacitors); electronic circuitry and electric wiring; photovoltaic solar cells; advanced sensors to translate physical phenomena such as voltage, current, speed, vibration, motion, heat and pressure into electrical signals; new instruments and controls (e.g. power management system, vehicle identification and anti-theft measures). Other safety and comfort features are likely to

⁴⁹ See, for example, J Lindamood, 1985 "Left Coast Design" *Car and Driver*, September, pp 59-67

produce limited technological change (e.g., seats, interior lighting, sound system, seat belts, air bags).

In addition to the specific EV technologies above, the technical expertise of aerospace scientific and technical workers can be applied in areas such as *systems engineering*, which helps to establish product requirements derived from customer input and technical standards; *simulation* devices and software for development and validation of designs, products and processes; also, development of computer-based simulation for areas such as design of factory layouts, assembly processes and driver-vehicle interfaces; *integration* of hardware and software elements to monitor and control vehicle and component performance; development of *algorithms* to process and interpret signals from sensors and controls in order to enhance systems efficiency; development of hardware and software for computer-based power management; development of methods for *testing and diagnosis* of vehicle electronic systems and equipment, in order to improve life cycle, cost, and quality of components.

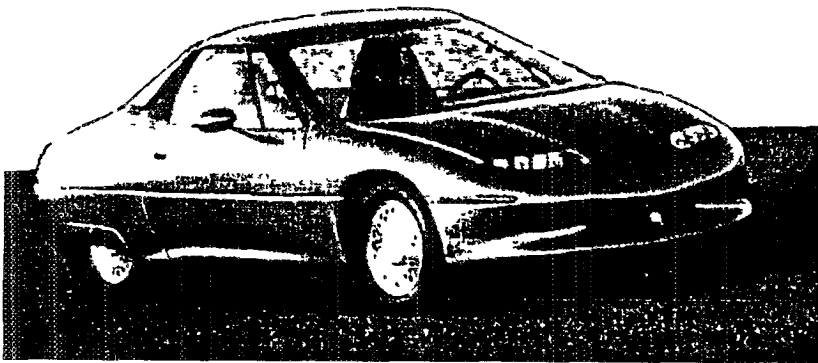
2.11. Electric Vehicle Development in the United States⁵⁰

General Motors Corporation

In January 1990, General Motors unveiled the *Impact* concept EV, a two-seater with a 120-mile range and top speed of over 100 mph. It features a high-power sealed lead-acid battery and an AC powertrain. Goodyear developed special high pressure tires for the vehicle that have roughly half the rolling resistance of conventional tires. GM's Advanced Concepts Center in Thousand Oaks, California, was responsible for the exterior and interior design of Impact. The Impact should be built at the former Reatta Craft Center in Lansing, Michigan, in volumes of 5,000 to 10,000 per year. Production was planned to begin in 1994. GM has established GM Electric

Vehicles, a business unit devised to develop, build and market the electric vehicle patterned after the Impact.

In January 1991, General Motors presented the "HX3," a hybrid mini-van, at the North American International Auto Show in Detroit. The HX3 may run either on electric power from its 32 lead-acid batteries or on a 906 cc three-cylinder gasoline engine. According to GM, the



The GM Impact concept electric vehicle

⁵⁰ This section and the one that follows are based mainly on press reports about electric vehicle development plans and activities. Sources include *Automobile Magazine*, *Automotive Engineering*, *Automotive News*, *Autoweek*, *Batteries International*, *Business Week*, *Car & Driver*, *The Economist*, *Popular Mechanics*, *Popular Science*, *Scientific American*, *Road & Track*, *Ward's Automotive*, *Ward's Auto World* and several major newspapers, in addition to the sources specifically indicated in the text.

battery pack can be fully recharged in about two hours from a 220-volt, 100-amp electrical outlet.⁵¹ The HX3 holds five people and is slightly smaller than a conventional mini-van, although it is considerably heavier. It also displays a distinctive aerodynamic shape with smooth external surfaces and a vast expanse of glass. Internal cooling is aided by automatic fans, powered by an array of solar cells placed on HX3's roof. Unlike Impact, HX3 is not likely to be produced by GM. In addition, General Motors is said to be developing an EV named *Impulse 2*, a heavily modified Astra in a station wagon body, with a range of 65 miles and powered by lead-acid batteries.

Ford Motor Company

Ford has carried out research and development in electric vehicle technology and related componentry for several decades. During the 1980s, Ford developed a minivan based on the Ford Aerostar as a demonstration of the *ETX-II*, an advanced EV powertrain, which was developed by Ford and General Electric under a contract with the U.S. Department of Energy (DOE). This powertrain is wholly contained in a single housing that includes the motor and a two-speed automatic transaxle with a common axis. The electric Aerostar is powered by a sodium-sulfur battery and achieves a 100-mile range and a 65-mph top speed. The *Modular Electric Vehicle Program* (also funded by DOE) is a follow-on program to the ETX effort, with the goal of achieving a lower cost, mass-produced powertrain that is suitable for a range of vehicles.⁵²

Ford has also indicated its intention to initiate a demonstration program in the US and Europe with the *Ecostar*, an electrically powered European Escort minivan, beginning in 1993. The program was designed to help evaluate EV technology and its marketability before Ford introduces a production program to meet the 1998 California ZEV mandate.⁵³

The same platform was used to develop the *Ford Ghia Connecta*, a smaller and lighter six-passenger micro minivan. This concept EV is designed to seat four adults and two children, has a target range of 110-120 miles, a top speed of 70-75 mph and a recharging time of 5-6 hours. The carbon fiber and Kevlar body shell was assembled by Ghia in Italy; the 75-hp motor and electronics were engineered by Ford and General Electric in the US.

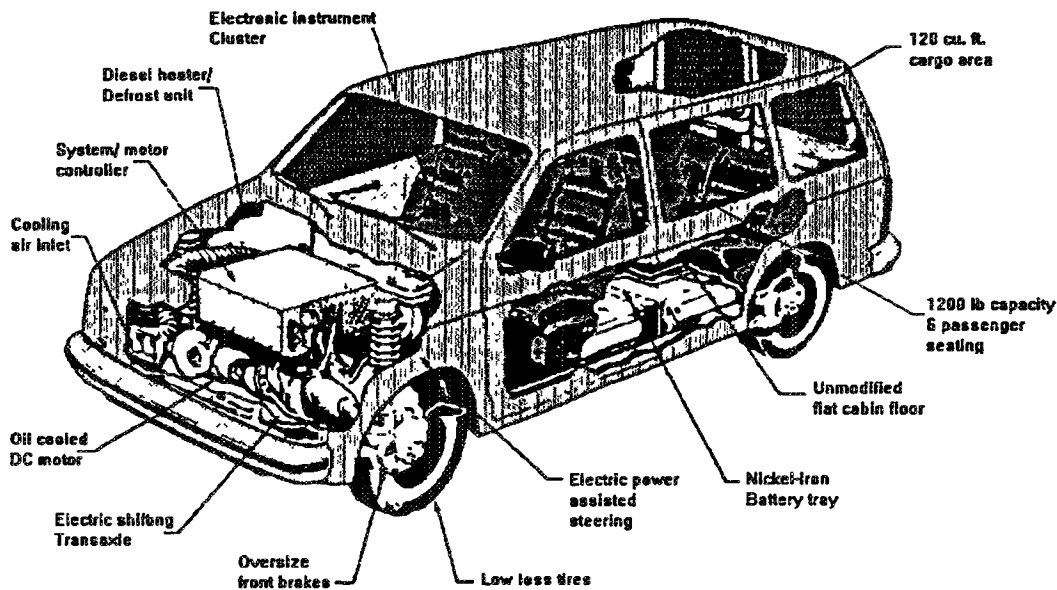
Chrysler Corporation

Pentastar Electronics, a R&D subsidiary of Chrysler, is developing the *TEVan*, which is an adaptation of the seven-passenger minivan body used for the Plymouth Voyager and Dodge Caravan. It is powered by a nickel-iron battery pack developed by Eagle-Picher Industries, a 25 kW, 33 horsepower DC motor and electronically shifted two-speed transmission. The TEVan is being designed to reach a driving range of 120 miles and a top speed of 65 mph. The project is sponsored by EPRI, Southern California Edison, The South Coast Air Quality Management District (SCAQMD) and DOE. Four concept units were built in 1989 and 1990, and production is expected to begin in 1994. Chrysler has also developed the *Epic*, a prototype

⁵¹ M DeLorenzo and W Raynal, 1991 "Volts of Confidence," *Autoweek*, February 18

⁵² B Bates, n.d. "Ford electric vehicle programs," Dearborn, MI. Ford Motor Company.

⁵³ R Sims, R Geyer, M Mehall and R Wallace, 1992 "A systems approach to the development of an electric compact van for worldwide commercial use " Ford Electric Vehicle Program



The Chrysler TEVan

of an advanced electric van.

Other manufacturers

Unique Mobility has been involved in the development of EVs for a number of years. Unique's recent projects include the *Uniq M-90*, a Chrysler T-115 minivan equipped with Sonnenschein lead acid batteries and a DC motor. This hybrid vehicle incorporates an auxiliary power unit (APU). It is a 2-cylinder Honda internal combustion engine that works as a small (4 kW) generator to supplement battery power for longer trips.

The *Uniq M-91* will be equipped with a 5 kW engine generator and is projected to extend the 60-mile range of the M-90 to 175 miles. Unique's application of high-power density brushless DC motor and electronic control technology reduces significantly the size and weight of a typical motor drive. Unique Mobility has also worked on BMW's EV program and with Ontario Bus Industries of Canada on a hybrid bus project.

Many other small manufacturers have produced purpose-built and converted EVs. For example, Bus Manufacturing USA, Inc. manufactured a small transit bus, the *Electric Shuttle Vehicle (ESV)* for the Santa Barbara Metropolitan Transit District. The power source is a lead-acid battery specifically developed for EVs by Chloride, which also supplies the traction controller. The electric propulsion system comprises a DC motor and a transfer case made by Magna International of Canada.

In California, several small companies such as AC Propulsion, Electric Car Company of America, Electro Automotive, Electro Motor Car and Solar Electric Engineering have converted conventional passenger cars to electric propulsion. California Electric Cars, Dolphin Vehicles and 4E Corporation produce purpose-built EVs, called *Monterey*, *Vortex*, and *EXAR-1* respectively. Amerigon is developing a showcase electric vehicle for the California consortium

CALSTART. Other small EV manufacturers in the U.S. include the Doran Motor Company in Nevada, Sebring Auto Cycle and Solar Car Corporation in Florida, Solectria in Massachusetts and Triple O Seven in Washington state.

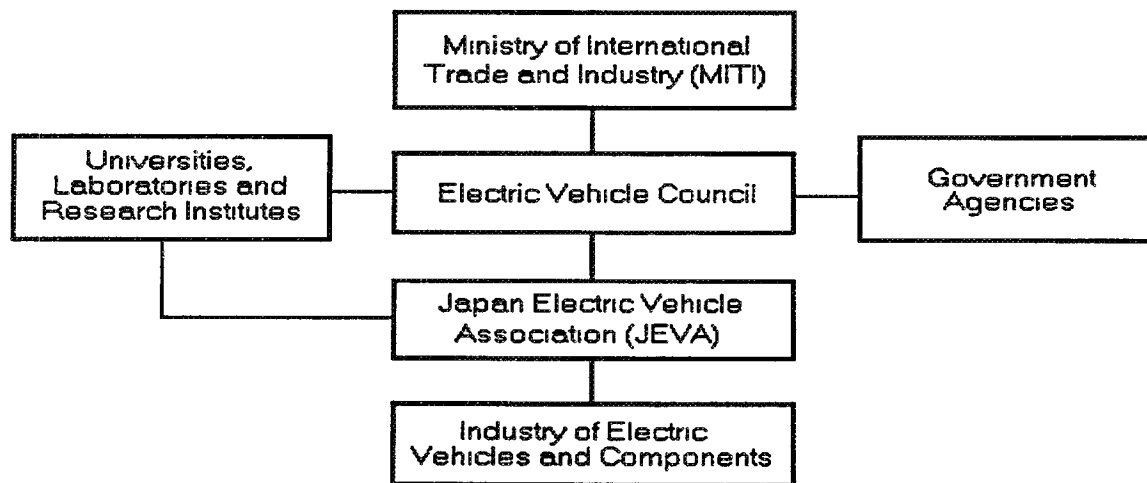
2.12. R&D Programs and Electric Vehicle Development Activities in Selected Countries

Japan

The Ministry of International Trade and Industry (MITI) began a large-scale national R&D program on Electric Vehicles in 1971. The program was conducted by its Agency of Industrial Science and Technology and involved the expenditure of ¥5.7 billion over a six-year period. Current EV development activities in Japan are coordinated by the Electric Vehicle Council, an advisory body to MITI, and by the Japan Electric Vehicle Association (JEVA), which involves government agencies and private corporations.

The EV population master plan set by EVC in 1977 comprised 200,000 on-road EVs and 50,000 off-road EVs in 1986. In 1983, it was amended to the goal of 5,000 and 10,000 respectively for 1991. In late 1991, MITI's third EV plan was announced, establishing a goal of bringing 100,000 EVs per year to the Japanese market by the year 2000. It includes plans for infrastructure demonstrations, standardization and incentives to facilitate EV acceptance comprising tax subsidies, low interest loans, reduced electric rates, road tax reductions, rental subsidies and preferential parking.

Organization of Research, Development and Demonstration of Electric Vehicles in Japan



Source JEVA

JEVA was established in 1976 to promote research, development, testing, standardization and the popularization of electric vehicles. The association comprises 81 companies and organizations, including all the major Japanese automakers and utilities. In addition to research, testing and demonstration projects funded by JEVA itself, the association carries out projects consigned by MITI, by the New Energy and Industrial Technology Development Organization

(NEDO) and by the Japan Motorcycle Racing Organization. JEVA's efforts to introduce EVs in Japan include the "EV Lease Service Project" initiated in 1978. This is a 3 to 6-year lease program which not only promotes the use of EVs, but also provides a valuable tool to collect and analyze information on how different models perform on a variety of operating environments.⁵⁴ In addition, several private companies have worked on both R&D and popularization activities following the guidelines established by MITI. The Environment Agency of Japan requested a budget to subsidize the purchase of 1000 EVs in 1991, but received a much smaller amount and will introduce 152 EVs on a lease program to local municipalities. Daihatsu was scheduled to supply 100 vehicles; Suzuki, 24; Toyota, 14; and Soleq, 4 electric vehicles.⁵⁵

Daihatsu is the leader in Japanese EV development. It has sold nearly 1,000 electric highway-use vehicles since 1967. Powered by lead-acid batteries, these vehicles (such as the *Rugger*, which was manufactured for the Kansai Electric Power Co.) have a 75-mile range at 62 mph, and recharge in eight hours. Daihatsu also developed jointly with Kansai the "BC-7," a one-person three-wheel EV, initially using a lead-acid battery and later a sealed type nickel-zinc battery. In 1991, Daihatsu was reported to be joining efforts with Toyota to develop electric cars.⁵⁶

Honda displayed two electric-powered motorcycles at the 1991 Tokyo Auto Show: the "CUV-ES" (Clean Urban Vehicle/Electric Scooter) and the "CUV-Canopy" (a sit-in scooter with a roof). Both are powered by zinc-nickel batteries.

Isuzu announced in April 1990 the development of a new battery with Fuji Electrochemical. Isuzu is 38.2 percent owned by GM, which would benefit from this technology for its Impact program. In January 1991, Isuzu completed the first prototype of an electric truck developed with the Co-op Electric Vehicle Development Corporation (established in July 1990 by 47 Japanese cooperatives). The 2-ton electric truck utilizes lead-acid batteries; it is called the *Isuzu ELF Electric Transporter* or *Co-op EV-2000* and is scheduled for production in 1994.

Japan Storage Battery (JSB) supplies the batteries for 80 percent of the 650 electric vehicles that operate in Japan. In September 1990, it announced the development of a potent sealed nickel-cadmium battery for EV use. The battery would have twice the normal life expectancy, 1.25 more power per charge, and one-fourth of the recharging time of conventional batteries. Daihatsu was announced as the probable partner for battery development and evaluation. JSB has also developed a sealed type nickel-zinc battery and a sealed lead-acid battery.

Mazda developed a small EV for transmitting live broadcasts of marathon races in 1988. The vehicle, called the *Mazda Electric Bongo*, was used at the Seoul Olympics and later at the International Tokyo Marathon. In 1991, Mazda showed the "HR-X" at the Tokyo Auto Show. It is a mid-engine 2+2 with a *hydrogen-powered*, 2-rotor Wankel engine. It uses an electric motor to add torque to the rotary engine during acceleration, then recharges its high-density battery during deceleration. The reported range is 120 miles. Mazda and Chugoku Electric Power are reportedly investing ¥150 million on the development of an EV based on the MX-5

⁵⁴ Japan Electric Vehicle Association and *Electric Vehicle (For Popularization of Electric Vehicles)*, Tokyo, Japan: JEVA

⁵⁵ P. Brown, 1991 "Updated status as of November 1991 — of the electric and hybrid vehicle programs in Japan." Washington, DC Electric Vehicle Association of the Americas

⁵⁶ *Ward's Automotive*, June 1991

Miata. Three research cars are expected to be completed by the end of 1992. The project targets include a top speed of 87 mph, a range of 112 miles per charge, and an acceleration of 0 to 25 mph in four seconds.⁵⁷

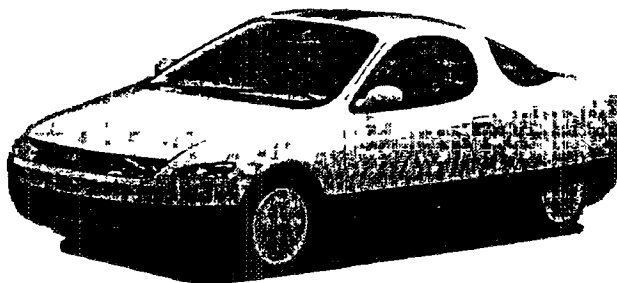


The Electric Lancer by Mitsubishi and TEPCO

Mitsubishi has developed an EV based on its *Lancer* wagon in Japan. The prototype was developed jointly with the Tokyo Electric Power Co (TEPCO). The electric Lancer uses sealed nickel-cadmium batteries and reaches a top speed of 110 km/h and a range of 200 km. In 1992, Mitsubishi also unveiled the "HSR-III". This is a conventional gasoline-powered concept car. However, it features technological advances such as

"active headway," which automatically maintains a safe distance from the vehicle ahead; "active lane control;" and a body material that allows the rear deck panel to change contour at high speeds.

Nissan displayed its *FEV* (*Future Electric Vehicle*) at the 1991 Tokyo Auto Show. The FEV uses a NiCd battery pack that enables it to reach a maximum speed of 81 mph and a range of 160 miles. Nissan highlights the relatively low weight of the battery pack (440 pounds) and its quick charge system, which provides a 40 percent recharge in 6 to 7 minutes, and a complete recharge in 15 minutes at special 440-volt recharging stations.⁵⁸ The \$1.5-million



The Nissan FEV

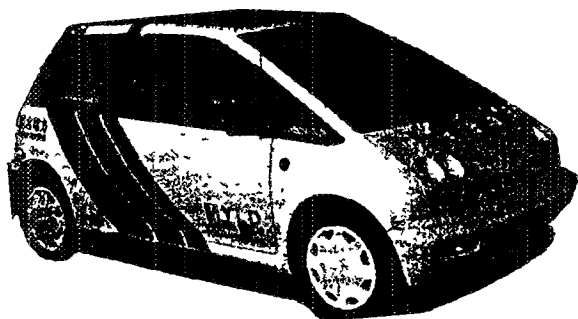
charging system was developed jointly with Japan Storage Battery. These two companies were joined by Tokyo Electric Power and Hokuto Denko in a consortium to study infrastructures and operating systems needed to expand the use of EVs.

Nissan also displayed in Tokyo a *Cedric* model with lead-acid batteries and a *President Convertible* (parade or marathon pace car) with a range of 67.5 miles and a top speed of 25 mph; the company has also developed a small commuter vehicle called the *Micra EV-2*, which is a conversion of the conventional automobile *Micra*, also known as "March" in Japan. This vehicle uses either Matsushita nickel-iron batteries or Shin-Kobe lead-acid ones. In addition, an electric truck for garbage collection was developed jointly in 1985 by Nissan, Fuji Heavy Industries, Hitachi, Japan Storage Battery, Calsonic Corporation and the city of Yokohama. Three such vehicles are still operating. A small experimental electric van was made by Nissan for Kyushu Electric Power. It is called the *Kyuden Van*, which has a 500 kg capacity and 150

⁵⁷ "Mazda, Japan utility plan electric Miata," *Automotive News*, February 24, 1992, p 20

⁵⁸ M Fukino, N Irie and H Ito, 1992 "Development of an Electric Concept Vehicle with a Super Quick Charging System" SAE Technical Paper No 920442 Warrendale, PA Society of Automotive Engineers

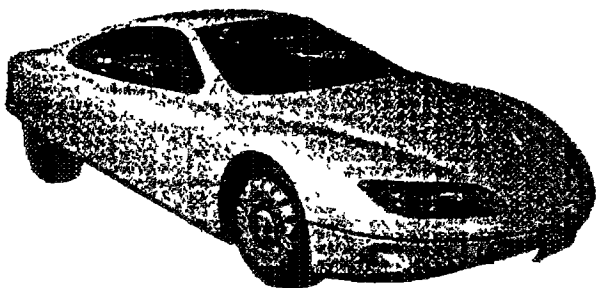
km range. Autech Japan, a subsidiary of Nissan, is also developing a small electric van in a joint project with five Japanese electric utilities (Tokyo, Kansai, Chubu, Tohoku, Kyushu).



The "MYLD" electric van

Sanyo displayed in 1992 a concept electric car, the *Mirai I*, which combines three technologies: solar cells, batteries, and a hydrogen fuel cell. The nickel-cadmium battery pack that drives Mirai's brushless DC motor receives charge from both the solar panels and the fuel cell. The car's top speed is 62 mph, and runs for only two hours on a full charge. Although the fuel cell is emission-free and lasts longer than a battery, its costs are higher and its energy density is less than one-third that of lead-acid batteries.

Suzuki has developed an electric minivan based upon their existing high roof light commercial van in Japan. It features an air-conditioning system, a maintenance-free nickel-zinc battery, solar cells as backup power source, and a microprocessor-based indicator that shows the remaining range corresponding to available battery capacity.



The IZA concept vehicle

Tokyo Electric Power Co. (TEPCO) has worked together with several Japanese automakers on EV development, and also tested a German Volkswagen Jetta EV with sodium-sulfur batteries. TEPCO displayed two EVs at the 1991 Tokyo Auto Show:

1) The "MYLD" (for My Lovely Drive) is a compact two-seater fueled by a 20-cell Nickel-Iron battery. It is equipped with battery warming and vehicle interior quick heating systems which utilize a "latent

heat storage cell." A roof-mounted 90-watt solar cell contributes to battery charge.

2) The *IZA* car was developed by the engineering firm Tokyo R&D. This advanced prototype uses Nickel-Cadmium batteries powering four in-wheel direct-drive motors. Range is reported to reach 340 miles at a constant 25 mph. The power train of *IZA* will be supplied by Meidensha. The car is billed as "the world's fastest EV," with a top speed of 109 mph.

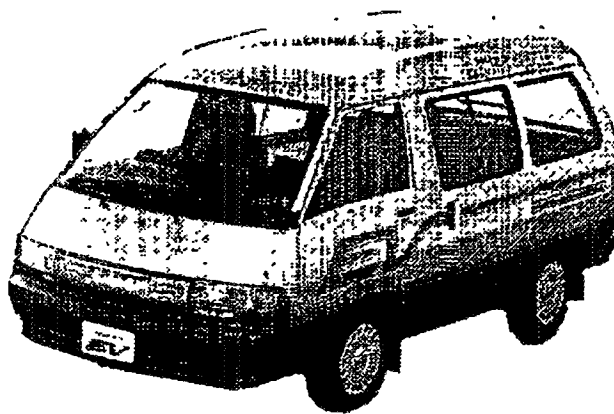
Tokyo R&D and Nippon Steel developed jointly the *NAV* (*Next generation Advanced electric Vehicle*), which was exhibited in Japan in June 1990. Its development cost reached an estimated ¥300 to ¥350 million, which was partly financed by Japan's Environmental Agency. *NAV* is a two-door sedan capable of reaching a top speed of 110 Km/h and a range of 240 Km on one recharge. Its body is made of CFRP (carbon fiberglass reinforced plastic). Ten lead-acid batteries power four direct drive motors placed outside each wheel. Bridgestone developed low rolling-resistance tires for this vehicle, and its aerodynamic external shape was developed through tests at the Japan Automobile Research Institute's wind tunnel.

The *IZA* project, developed by Tokyo R&D for Tokyo Electric Power, evolved from the *NAV*. TEPCO plans to put a series of 10 to 20 *IZA* vehicles into real use by the end of 1992. Tokyo R&D also plans to market an electric scooter by late 1992. *NAV* and *IZA* are the latest

on a series of EVs developed by Tokyo R&D. At the 1987 Tokyo Motor Show, the company presented an electric motorcycle; in 1988, it developed a line of two and three-wheeled scooters; and in 1989, Tokyo R&D exhibited the *Dream Mini*, an electric mini-car commissioned by Chubu Electric Co.

Toyota is reportedly establishing a project team to begin full-fledged EV development, which should include Daihatsu. Toyota has already produced a 4-passenger mini-van (the *TownAce Electric Van*), equipped with lead-acid batteries and a new AC-induction motor developed by Toyota. 14

of these vehicles will be leased to the Environment Agency of Japan (for ¥20 million/year), which will in turn rent them to local government bodies.⁵⁹



The Toyota "TownAce" electric van

Germany

Several government agencies have provided support for electric vehicle efforts in Germany, including the Ministry of Research and Development, Ministry of Transport and provincial governments. The City of Munich has been test driving electric buses. In 1991, the German government announced that electric cars will be exempt from vehicle tax for five years. In 1992, the state government of North Rhine-Westphalia announced plans to encourage the use of electric cars by providing a grant of as much as DM 10,000 for EV buyers.⁶⁰

RWE, Germany's largest power company, has led EV research and development for many years. RWE recently established a joint venture with Chloride of Great Britain for commercial production of a sodium-sulfur battery. Asea Brown Boveri (ABB) has received government support for its advanced sodium-sulfur battery development program. ABB is opening a factory in Switzerland to produce NaS batteries for EVs. Another battery maker, Varta AG, has developed a nickel-based battery which is especially suitable for electric hybrid vehicles.⁶¹ Opel exhibited its *Twin* concept car in 1992, which uses two separate self-contained, interchangeable powertrains: a gasoline-powered module for long trips and an electric one for urban use. In addition, Volkswagen, Audi, Daimler-Benz and BMW have active electric vehicle programs.

BMW displayed the "E1" electric car at the 1991 Frankfurt Auto Show, which was announced as tentatively scheduled for 1995 production. This small passenger car uses sodium-sulfur batteries developed by Unique Mobility and has a reported range of 155 miles and a top

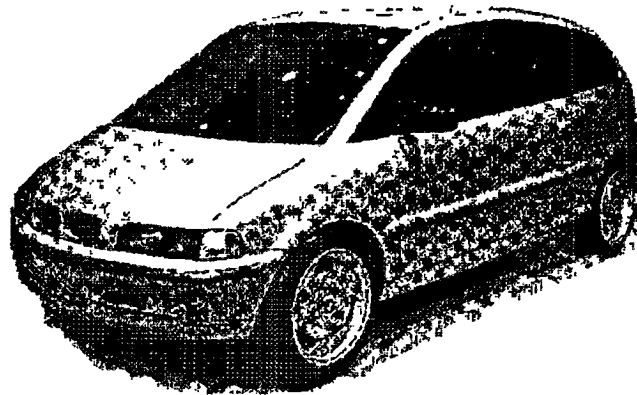
⁵⁹ WARD'S *Automotive*, June 1991.

⁶⁰ P. Ehrhart, A. Grundl, and G. Heidelberg, 1990. "Road Vehicle with Full Electric Gear" in: *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong, "Anti-pollution drive favors electric cars," *International Management*, March 1992, p. 22

⁶¹ "Varta develops new drive battery" *American Metal Market*, March 9, 1992, p. 2

speed of 75 mph.⁶²

A similar model, the "E2," was unveiled at the 1992 Los Angeles Auto Show; it is a stretched version that accommodates a bigger battery pack (reported range is increased to 267 miles) and provides extra interior room. The car was styled by California-based Designworks, which is partly owned by BMW. The German automaker has performed extensive EV and hybrid vehicle research, including eight production-based (3-series) test EVs developed in association with Asea Brown Boveri (ABB), which built the DC motors and sodium sulfur batteries. BMW has also intensified its research into hydrogen power for automobiles.⁶³



The BMW E2

Daimler-Benz has been conducting research on EVs for more than 20 years. It introduced a diesel-electric hybrid bus in 1969. In 1986, it introduced the "Duo-Bus" system, which is a hybrid bus powered by overhead electric lines.⁶⁴ In 1991, Daimler-Benz used two electric *Mercedes 190E* as pace cars in the New York City Marathon. They are powered by high-temperature, maintenance-free sodium-nickel chloride battery packs developed by AEG, a subsidiary of Daimler-Benz. The batteries weigh a total of 805 pounds, have a 3.5 to 4-year life and cost about \$20,000. The experimental vehicles have a range of 112 miles. DAUG, a company of the Daimler-Benz Group, is developing a maintenance-free, gas-tight, high-capacity nickel-cadmium battery for electric vehicles.

Volkswagen has developed jointly with RWE an electric version of the Golf, called the *City STROMer*. A total of 70 vehicles equipped with lead-acid batteries were built and sold, mainly for use in enclosed areas by corporations. A second series of vehicles of the Jetta class has been equipped with newly developed sodium-sulfur batteries produced by BBC. The new battery weighs 276 kg, in contrast with the 400-kg lead-acid battery that was used in the Golf. The state of Bavaria will lease 20 of these vehicles for



The Volkswagen Jetta City STROMer

⁶² *Automotive Industries*, November 1991

⁶³ "BMW's electric cars," *Automotive Engineering*, December 1991, p 53

⁶⁴ Daimler Benz AG, 1991 "The Electric Car — Power from the Plug "

a two-year test on public roads.⁶⁵

Volkswagen has been developing and testing hybrid vehicles for a number of years, including a converted Golf with both electric drive and internal combustion engine.⁶⁶ In 1991, Volkswagen showed its 2+2 hybrid powered "Chico" city car prototype at the Frankfurt Auto Show. It features constant-demand, fully automatic switch-over between conventional power and electric drive in response to speed and throttle pressure. The electric motor is activated when the vehicle is at constant speeds, and all-electric drive is possible. Chico is a hatchback mini with a top speed of 75 mph and range of 250 miles. No production version is planned. Volkswagen is also involved in a joint venture with Swatch from Switzerland to develop an electric vehicle.⁶⁷

France

The main source of support for research and development on electric and hybrid vehicles in France since the early 1980s has been the Agence Française pour la Maîtrise de l'Énergie (AFME). The Agency supports a wide range of activities, including long-term R&D, full-scale demonstrations, and financing of both vehicles and batteries. Simultaneously, an inter-ministerial group (GIVE) carries out the task of stimulating demand and coordinating targeted operations.

The French government is also considering a number of special measures, such as classifying EVs into lower horsepower categories, so that vehicle licenses and insurance premiums are reduced; lowering the write-off (amortization) period from five years to one; reducing the rate of value added tax from the current 18.6 percent that applies to commercial vehicles to a rate of 3 to 5 percent. The city of Paris has announced plans to set up free parking spaces to provide recharging facilities for EVs; under the same initiative, municipal authorities will be supplied with electric vehicles.⁶⁸

Electricité de France (EDF) has supported research and development of EVs for many years, together with manufacturers such as the PSA Group. The result has been the construction of various prototypes tested within the Group. SAFT, one of the world leaders in nickel-cadmium battery development, is preparing an ambitious industrialization plan which aims at drastic reductions in battery costs.⁶⁹

PSA (Peugeot/Citröen) produced its first EV in 1942. In 1984, it produced electric prototypes of the *Peugeot J5*, *Citröen C25*, *Peugeot 205* and *Citröen C15*. In 1989, PSA decided to begin large-scale EV production. In April 1990, Peugeot and Citröen began selling several

⁶⁵ Volkswagen AG, n.d. "Jetta City STROMer — Research for the Future" See also D Kurylko, 1992. "VW electric cars hit Bavaria road," *Automotive News*, January 13, p. 2.

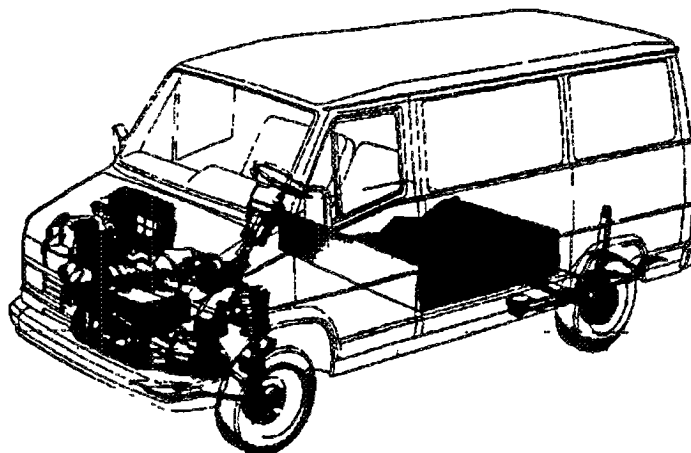
⁶⁶ A Kalberlah, 1990 "Hybrid drive systems for cars." *Automotive Engineering* Vol 99 No 7, July.

⁶⁷ *The Guardian*, "Inventor hopes Swatchmobile will tick over like clockwork" March 14, 1992, p 39.

⁶⁸ AVERE France, 1990 *1991 Electric Vehicles in France*, "M Chirac annonce des mesures en faveur de la voiture," *Le Monde*, March 7, 1992, p 15

⁶⁹ Y Martnod, 1990 "Electronic Control for Peugeot J5 and Citroen C25 Electric Vehicles", F Cornu, 1990 "Light Trucks J5 Peugeot and C25 Citroen Powertrain", J Cornu, 1990 "The Ni/Cd Battery The Actual Best Electrochemical Generator for EV" in *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong

versions of the J5 and C25 electric vans; the introduction of passenger cars was planned for the near future. The electric Peugeot J5 and Citroën C25 are made at the Sevel plant in Val di Sangro, Italy, on the same assembly lines as conventional vehicles. These vans are powered by SAFT lead-acid batteries and sold mainly to fleets of public utilities (such as Electricité de France), municipal authorities and large corporations.



The Peugeot J5 Electric Van

Under the terms of an agreement with Electricité de France, PSA has already delivered 50 electric vehicles of a total of 250 minivans to be produced for EDF over a five year period. A number of Peugeot J9 19-seat buses are also being used in the city of Tours since 1988, and fifteen Peugeot 205 prototypes are being tested in La Rochelle and Brussels. PSA is also developing an electric hybrid that uses a gas turbine as an on-board generator to charge the batteries: a prototype is planned for 1994. Citroën has also developed the *Citela*, a city car with a recyclable body; its claimed range is 130 miles, and top speed is 70 mph.⁷⁰

Renault has developed EV projects in collaboration with SAFT, including ten Renault *Master* vans operating at Châtelleraut as part of an EEC contract. The prototypes were developed between 1983 and 1984. These vans were initially equipped with nickel-iron batteries and later with nickel-cadmium. Electric versions of the *Express* and *Clio* have been undergoing tests since 1985, and different commercial versions of the *Clio* were planned for the early 1990s.

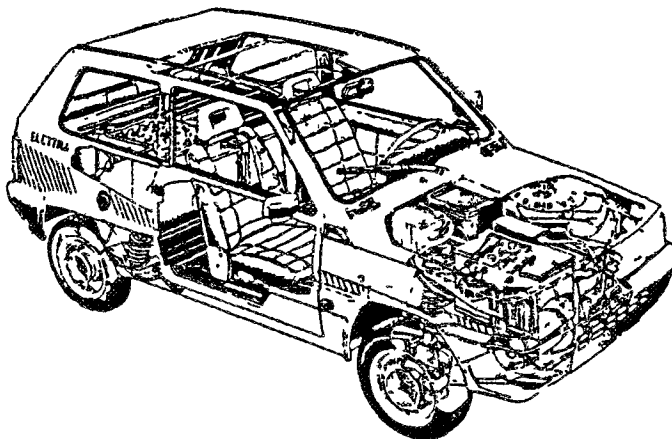
In addition to Peugeot and Renault, other smaller French automakers are also planning or building EVs. Manufacturers such as Aixam, APP, Charlatte, Erad, Jeanneau, Ligier (in association with a British firm), Jeanneau, Rocaboy/Kirchner, SEER-Volta, SEMAT, SITA, Teihol (in association with Air France) are developing EVs. Since 1970, Rocaboy and Kirchner have produced 260 light vans currently in operation with government services, local authorities, and major private firms. SEER-Volta has developed two prototypes based on the Rocaboy-Kirchner model, and had plans to market them as of 1991. SITA is one of the two major French manufacturers of garbage trucks (the other is SEMAT). SITA has sold nearly 100 electric (or diesel-hybrid) trucks and street cleaning vehicles to Bordeaux, Paris and surrounding cities. In cooperation with the City of Paris, it has recently developed the *LAMA L* and the *LADY L*, a street sweeper and a sidewalk cleaner respectively. Both are powered by lead-acid batteries. SEMAT has built and delivered 25 electric garbage trucks for the City of Paris.

⁷⁰ AVERE France, 1990 *1991 Electric Vehicles in France*, "French adopt gas turbine in electric car," *Engineer*, February 6, 1992, p. 36, "Electric car by Peugeot," *The New York Times*, October 15, 1991, p. C14

Italy

The Commission for Nuclear and Alternative Energy Sources (ENEA) began research and development on storage batteries in the late 1970s, in order to evaluate industrial perspectives, and environmental and energy impacts through feasibility studies and technological surveys. These evaluations emphasized the importance of battery storage technologies as part of an energy conservation and environmental protection policy in Italy. In 1983 ENEA initiated a Program aimed at investigating and improving batteries and renewable energy sources.⁷¹

Various R&D programs are being conducted with EEC assistance by the Ente Nazionale per L'Energia Elettrica, the Societa Italiana per L'Esercizio Telefonica, and the Consiglio Nazionale delle Ricerche, in conjunction with several private companies. These organizations are test-operating commercial vehicles in several cities and are also developing small electric and hybrid buses for urban use. The city of Modena has implemented a fleet of electric garbage trucks powered by nickel-cadmium batteries.



The Fiat Panda Elettra

Several small specialty automakers have developed EVs in Italy. Progetti Gestione Ecologiche (PGE), a Milan-based design group, has been developing a turnkey EV rental system for over a decade. The system has been in operation in Brussels, Belgium. The city of Padua plans to use PGE's *Nuova* vehicles in its downtown area. At the 1992 Turin Automobile Show, Ital Design displayed an electric minicar called the *Biga*, and Bertone unveiled a functional version of the *Blitz* electric sports car that had been displayed previously in Geneva.⁷²

Fiat has developed an electric version of its *Panda*, called the "Elettra". It is a 2-passenger city car with a normal range of 70 km and a top speed of 70 km/h. As an alternative to the Panda Elettra's lead-acid battery, an optional nickel-cadmium battery may be used to increase its range to 100 km. Fiat is also offering its new small car, the Cinquecento, in both electric and gasoline-powered versions. All the plastic parts in the Cinquecento are coded for recycling. The vehicle is built in Fiat's FSM plant in Poland.⁷³

United Kingdom

The number of registered on-road electric vehicles in the UK reached approximately 25,000 in 1989. The vast majority of these vehicles are low-speed milk delivery trucks, whose number is decreasing due to a decline on home delivery of milk. Previous programs for research and

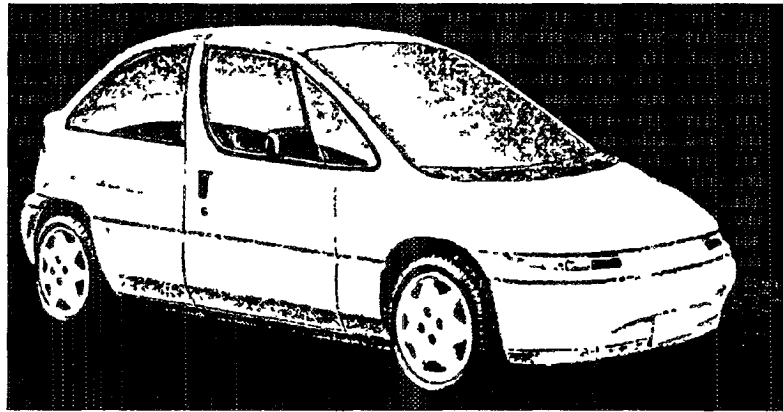
⁷¹ M Conte, 1990 "Status of the Battery Program in Italy" in *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong

⁷² R Cumberland, 1992 "Italian Renaissance" *Automobile Magazine*, September, p.23

⁷³ "Fiat in electric driving seat," *The Guardian*, November 9, 1991, p. 14.

development of general purpose EVs that were sponsored by government agencies such as the Department of Industry have been discontinued. Most EV efforts are now conducted exclusively by the private sector.

Chloride EV Systems Limited (CEVS) manufactures batteries, traction motors, traction controllers, converters and chargers. It participates in many EV programs, including the G-Van. CEVS and Chloride Silent Power (both are part of Chloride's Corporate Operations) participate in the joint venture Chloride-RWE, which was formed to develop sodium sulfur batteries for commercial EV applications (RWE is the largest electric utility in Germany). Chloride and its subsidiaries have been the leaders in EV and battery development in England. Recent research has focused on a room temperature lithium battery. Research has been conducted to comparing the applicabilities of various materials for these lithium batteries. The application of the room temperature molten salt, the organic and inorganic electrolyte system for ambient secondary lithium batteries, has been researched in light of their advantages, problems and potential for development in the high-energy, high-power lithium battery for electric vehicle use.⁷⁴



The "LA-301" hybrid vehicle by Clean Air Transport

Clean Air Transport (CAT) is an Anglo-Swedish company founded in 1989 to enter the competition for EVs sponsored by the Los Angeles Initiative. It plans to manufacture the "LA-301" in three versions (4-seater, minivan and pickup). This small hybrid electric automobile is derived from the Whisper car, which was produced in small scale in Europe. According to the Los Angeles initiative, CAT and two other companies should supply 10,000 EVs by 1995. Initial production may be based in the United Kingdom. International Automotive Design (IAD) is the largest vehicle engineering consultancy in Europe. It is responsible for the design and engineering of the Clean Air Transport's LA-301. The prototype was built at IAD's studio near Worthing, England.

Sweden

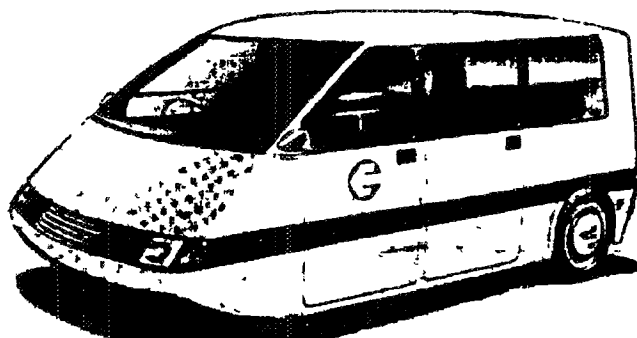
The Department of Electrical Machines and Power Electronics at Chalmers University of Technology has retrofitted a Mercedes 307 van with a water-cooled 60 kW induction motor and a transistor convertor with space vector control. A permanent magnet (PM) synchronous or reluctance motor and an insulated gate base transistor (IGBT) converter is also being developed. Volvo has worked together with SAFT to develop transit buses for the city of Stockholm. Solon AB of Karlstad has developed a two-passenger hybrid car which operates on lead acid batteries only or in conjunction with a gas-powered generator. The seven-kilowatt generator extends the

⁷⁴ W Johnson, 1990 "A Life Support System For Electric Vehicles" in *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong

vehicle's range from 43 miles to 350 miles.⁷⁵

Australia

The Australian Electric Vehicle Association has been actively promoting the application of EVs for many years. Sydney University recently developed an advanced propulsion system for an electric van using a permanent magnet AC motor and a MOSFET inverter/controller. The University of Queensland is continuing development of a hybrid vehicle. Considerable interest also exists in energy storage, supplementation of power in remote



"Townobile" mini-bus developed by Elroy Engineering

power stations, and their application in hybrid vehicles. Australia also promotes the World Solar Challenge, a 3000-km race for solar powered vehicles from Darwin to Adelaide. L&J Huntington Enterprises sells a converted Japanese car, the *Mira ECC* (Electric Commuter Car); Elroy Engineering has developed several models of purpose-built electric vans, buses and commuter cars, named "*Townobile*".⁷⁶

Belgium

Brussels Free University started in 1979 to study a new urban transport system based on electric vehicles. A fleet of 10 electric vehicles built by PGE of Italy has been in use since 1980 in two college campuses of Brussels. The three-passenger EVs have proved their durability by accumulating tens of thousands of kilometers during the course of the project. Research has been conducted on the fleet, the behavior of the vehicles in urban traffic, the technology of electric vehicles currently available on the market, and means to promote their deployment in cities.

A study called "Advanced Electric Drive Systems for Buses, Vans and Passenger Cars to Reduce Pollution" (EDS) was established on initiative of the European Parliament with the aim of studying new technologies for road transport. A number of contracts, granted to specialist companies, universities and research centers all over the European Community, were started in 1990.⁷⁷ The two leading associations for the promotion of electric vehicles in Europe are located in Brussels: AVERE, the European Electric Road Vehicle Association, and CITELEC, an association of European cities interested in the popularization of electric cars.

⁷⁵ J. Falt, R. Karlsson, and J. Hylander, 1990 "Design of Electric Motors and Converters for Electric Vehicles" in: *EVS-10 Hong Kong. 10th International Electric Vehicle Symposium*, University of Hong Kong, "Two-mode traveler" *Popular Science*, July 1992, p. 12

⁷⁶ C. Chan, 1990 "Electric Vehicle Development in Asia Pacific" in *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong

⁷⁷ P. Van den Bossche and G. Maggetto, 1990 "Brussels EV Experiment Anno X Electric Vehicles in Urban Transport;" "EDS. An European Study for New Developments in Automotive Technology to Reduce Pollution" in *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong

Switzerland

Electric cars and buses have been employed as the exclusive form of transportation in several resort areas for many years. JT Design manufactures the *Calypso Electric LEV* (Light-Electro-Vehicle), a small passenger car. It features composite construction, lead-acid batteries and a 12kW, 16hp motor. Swiss watch maker Swatch has announced plans to launch an electric vehicle, the "*Swatchmobile*" in 1994. The car will be developed in a joint venture with Volkswagen. Biel Polytechnic is also participating in the project. In 1992, NaS batteries built by Asea Brown Boveri powered a small Swiss car to a world record distance for EVs. The vehicle — called *Horlacher Na-S Sport* — was driven non-stop for 340 miles at an average speed of 74.4 miles per hour. The Horlacher is a two-seater with a curb weight of only 440 pounds and a top speed of 78 mph.⁷⁸

Finland

The Finnish EV-Project has converted a van for light delivery use. The resulting electric van, called *ELCAT*, has a DC series motor and sealed lead-acid batteries specially made for the project. Its top speed exceeds 70 km/h, driving range per charge is 100 km at 50 km/h. Special attention has been paid to minimizing costs. Two prototypes have been made, and a pre-series of 15 vehicles was initially planned.⁷⁹

Denmark

A mini-car was developed by the Danish manufacturer El-Trans specifically for use in congested urban areas. The two-passenger vehicle, called the *Mini-el*, weighs only 628 lb. — 209 lb. of which are batteries. The range between recharges is 43 miles and top speed is 25 mph. Its primary parts include thermoformed inner and outer body shells with a foam core of rigid polyurethane, as well as a thermoformed canopy. The polymethylmethacrylate (PMMA) resin-formulation technology for the vehicle was developed by Vedril Spa, the acrylic division of Italian chemical producer Montedison.⁸⁰

⁷⁸ "Automotive Newsfront," *Popular Science*, July 1992, p 36.

⁷⁹ J Ryynanen, 1990 "An Electric Vehicle Converted from a Light ICE Powered Delivery Van," in *EVS-10 Hong Kong 10th International Electric Vehicle Symposium*, University of Hong Kong

⁸⁰ "Plastics-shelled electric car weighs just 600 lb (batteries included)" *Modern Plastics*, March 1989, p 27

Chapter Three

Building An Electric Vehicle Manufacturing Industry In Southern California: The Basic Issues

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3.1. Introduction and Preview of Main Arguments

Virtually all of the world's major metropolitan regions, will benefit greatly in environmental terms from the increased development and use of alternative-fuel vehicles. Southern California, however, with its long-standing and exacerbated air pollution problems, will gain to a very significant degree from any major shift in this direction. Several different technologies are currently contending in the race to replace the gasoline-powered vehicle, but it is the electric vehicle that seems most likely eventually to attain commercial supremacy while meeting increasingly stringent emissions criteria. If Southern California will unquestionably benefit from the electric vehicle in environmental terms, might it not also make some claim on the employment opportunities that will flow from this new technology?

A major attraction of the region for electric vehicle production is that — in addition to the large potential local market — it is today one of the world's great manufacturing regions with a wealth of resources that could be readily re-deployed in the service of an electric vehicle industry. According to data published by the Employment Development Department of California, 858,900 individuals were employed in manufacturing in Los Angeles County alone in 1990, and 1,383,200 were employed in the entire seven-county region stretching from Santa Barbara County in the north to San Diego County in the south. That said, in recent years this manufacturing base has been under considerable pressure. It has suffered serious job losses in the aerospace-defense sector as a result of declining federal arms procurements. It has been subject to increasingly intense foreign competition in many of its main products, from furniture to aircraft. In addition, it has seen much of its employment capacity transformed over the last few decades into low-wage low-skill jobs in a proliferating sweatshop sector. Southern California's manufacturing economy, then, is facing severe stresses and strains, and thus, a prospective electric vehicle industry — in addition to its other benefits — offers one possible line of development through which the industrial resurgence of the region may be at least partially accomplished.

In a previous phase of research carried out at the Lewis Center on alternative-fuel vehicles these issues were broached at length¹. It was argued then that an electric vehicle industry is on the verge of making its historical and geographical appearance in the United States, in the form of both a final assembly capacity and a components supplier base. It was also argued that the industry is unlikely to achieve large-scale mass production dimensions in its early stages of development, but is more likely primarily to serve small and rapidly-shifting niche markets. It is thus likely at the outset to adopt highly flexible production technologies and organizational forms as a prelude to its ability to reap significant internal economies of scale. This suggests that in its incipient phases, the industry will in all probability be vertically-disintegrated, and that it will accordingly be linked into dense networks of many different subcontractors and specialized service providers. As the industry grows, it may retain this disintegrated configuration, or, more probably, it may evolve into a flexible mass production sector in the style of modern Japanese car manufacturers with well-organized just-in-time relations to a streamlined hierarchy of upstream suppliers. In either case, at least significant parts of the industry are likely to be marked by definite locational agglomeration, i.e. geographic concentration of producers and their main input suppliers within fairly narrowly-defined regional economic systems.

The eventual development of an electric vehicle industry in the near future is scarcely in doubt at this point. Already, prototype production is well under way in several places, and a number of firms have announced plans to embark on manufacturing for final consumer markets. The major questions for present purposes are, where will the main concentration(s) of production be located, and within what sorts of institutional frameworks? One obvious and plausible answer to these questions is that the industry will develop either in Japan or Europe under the aegis of the aggressive industrial policies that prevail in these two parts of the world. Another possible response is: in the Northeast of the United States where domestic car producers are grappling with the problem of building manufacturing systems capable of meeting the Japanese and European challenge on equal terms. General Motors has actually announced that it is planning to manufacture an electric passenger car (the Impact) at its Reatta plant in East Lansing, Michigan — though the company has also recently indicated that this project is now being relegated to low priority status on its corporate agenda. We may ask, what are the chances that Southern California can become a major world center of electric vehicle production?

In the first place, as chapter 2 suggests, electric vehicles are sufficiently different from gasoline-powered vehicles in terms of their internal organization, materials, and basic design that they almost certainly cannot be assembled in existing vehicle production plants without radical re-tooling and re-training. *A fortiori*, a significant part of the prospective components supplier base for electric vehicle manufacture is likely to be radically different from the car parts industry as it is currently constituted. These remarks suggest that there may be a significant window of locational opportunity for the new industry, and that it is not irredeemably anchored to existing car-producing regions. In the second place, Los Angeles has an enormous aerospace industrial

¹ See R. Morales, M. Storper, M. Cisternas, C. Quandt, A. J. Scott, J. Shifko, W. Thomas, M. Wachs, and S. Zakhor, *Prospects for Alternative Fuel Vehicle Use and Production in Southern California: Environmental Quality and Economic Development*, Lewis Center for Regional Policy Studies, UCLA, Working Paper No 2, 1991

complex with many subjacent sectors that could fairly easily be converted to making products for the electric vehicle industry,² and it is also one of the world's largest centers of automobile design. Particularly important here are the numerous plastics molding firms, foundries, machine shops, tool and die manufacturers, and electronics components producers already located in Southern California. As a corollary, the region also has a major pool of engineering, technical, and skilled craft labor. In the third place, there is a powerful coalition of local groups now materializing in Southern California with the objective of mobilizing the public interest (and public resources) in favor of supporting an electric vehicle industry in the region.

Much of the initial impetus behind the formation of this latter coalition can be traced to the long-term commitment by state and local authorities to reducing air pollution in the Los Angeles Basin. Part can also be traced to awareness that the region's economy is now under serious threat, as already noted. The collective momentum already achieved is based on the participation of politicians at all levels of government (including the congressional delegation), powerful local agencies like the utility companies and the South Coast Air Quality Management District, lobbying groups like the Los Angeles Chamber of Commerce and the Aerospace Task Force (an informal association of aerospace manufacturers sponsored by the Economic Development Corporation of Los Angeles County), large corporations, labor unions, and academic institutions like UCLA, the University of Southern California, and the California Institute of Technology which are all engaged in different aspects of research into the electric vehicle.

In 1989 the Los Angeles City Council adopted an initiative, through the Los Angeles Department of Water and Power, to sponsor the production of at least 5,000 electric passenger cars and 5,000 electric vans by 1995. Three companies were selected out of the eighteen that responded to the initiative, and one of these (a Swedish-British venture named Clean Air Transport) is currently under contract to produce a hybrid gasoline-electric car (the LA 301), with some \$7 million in financing provided by the Department of Water and Power and matching funds from private sources. Clean Air Transport has recently been engaged in prototype manufacturing of the LA 301 in England. However, according to recent press reports, the firm has encountered severe difficulties in its attempts to raise capital for further manufacturing activities, and its future appears to be in some doubt. Amerigon is another venture that has announced intentions to manufacture electric cars in the region in the near future. At the same time, Amerigon's CEO has been a prime mover in the formation of a local not-for-profit consortium (CALSTART) bringing together various state and local agencies, private firms, labor unions, and universities, and which has been successful in raising public funds made available through the federal Advanced Transportation Systems and Electric Vehicle Consortia Act of 1991. One of CALSTART's main objectives is to produce a demonstration electric car using components made by Southern Californian firms, and in this manner both to develop its systems engineering capacities and to organize an effective subcontractor base in the region. Just recently, Solar Electric has opened a plant in south central Los Angeles where it will manufacture purpose-built electric vehicles, and at the same time convert conventional vehicles to electric power.

Even if these early entrepreneurial ventures ultimately fall by the wayside — and it must be stressed at once that the risks they face are enormous — the organizational infrastructures,

² Cf. A. J. Scott *Technopolis*, Berkeley and Los Angeles University of California Press, 1993

know-how, and political mobilization that have already been created in Southern California will surely continue to facilitate local entrepreneurial efforts in both electric vehicle development and components production in the future. Further legislation that will make it more expensive to operate gasoline-powered vehicles, thereby expanding the market for electric vehicles, is also to be expected. There are thus some reasonable grounds for the speculation that a new and growing industrial complex may begin to take shape in Southern California over the next several years, though yet further intensification of the collective efforts already described must no doubt be achieved to sustain the infant industry. Should Southern California indeed manage to make a successful early start in building a viable electric vehicle industry, its acquired first-mover advantages would certainly help it ward off competitive threats from other and later entrants.

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What now follows is an attempt to expand on the previous discussion and to investigate in detail the prospects of and the limitations to efforts to build an electric vehicle industry in Southern California, and particularly in Los Angeles. By their very nature, the arguments presented here are highly speculative and subject to correction as real events unfold. They try to provide a perspective on current and future developments, and hence to give policy-makers and other concerned parties an informed overview of the problems to be faced and possible avenues of resolution. The discussion is broken down into three broad topics, i.e.

- the demand-side and supply-side conditions affecting electric vehicle manufacture in Southern California;
- a description of current resources in the region that might be re-deployed in support of a putative electric vehicle industry, and the outside competitive forces that might constrain the industry's development; and
- a suggested scenario as to how an electric vehicle industry (or at least some parts of it) might evolve in the region over the next decade or so, and the supportive role that policy-makers can play in helping to nurture and sustain these beginnings.

3.2. Demand Side and Supply Side Factors Affecting the Electric Vehicle Industry in Southern California

As things currently stand, there is little in the way of a "natural" market for electric vehicles. As we have already seen (Chapter 2), a number of serious constraining conditions make the electric vehicle a largely inferior choice for the private consumer to gasoline-powered vehicles. These include

- The limited vehicle range per battery charge (from 80 to 120 miles given current technologies).
- The need for an extended period of time (up to eight hours) to recharge the batteries.
- The considerably higher price of an electric vehicle and associated batteries compared

to a conventional vehicle of equivalent size.

It is possible that some of these constraints may be moderated by means of transitional technologies involving various kinds of hybrid vehicle (e.g. electric- and gasoline-driven), but they are likely to put various hindrances in the way of further development for at least a decade or so.

These constraints represent a series of *private* costs, borne by the individual purchaser of electric vehicles; to at least some degree they are offset by the heavy *public* costs that are created by gasoline-powered vehicles as a result of the air pollution they generate in large metropolitan areas. The latter costs involve diminished health and increased death rates for the citizenry at large, reductions in the quality of life, and negative impacts on business both directly and as a result of efforts at administrative regulation. Such predicaments have long been of particular concern in Los Angeles where both physical and historical conditions have given rise to a massive dependence on private cars and a chronic problem of exacerbated air pollution.

Because of these public costs, there is now considerable interest in the Southern Californian region and in the state at large in making a radical attack on the problem by eliminating their principal cause, i.e. the gasoline-powered car. Moreover, because there seems to be little likelihood of resolving the problem once and for all by means of public transport initiatives, the electric vehicle is now seen as being, potentially, a major element of any prospective feasible solution. Indeed, the California Air Resources Board now mandates that two-percent of car-makers' fleets in the state shall be composed of zero-emission vehicles by the year 1998, five-percent by 2001, and ten-percent by 2003. Various other states have now followed California's lead in establishing targets for zero-emission vehicle use within their jurisdictions. In this manner, a market for electric vehicles is now being created politically, and without question the political pressures to shift from gasoline-powered vehicles to electric-powered vehicles will intensify further over the coming years. It seems reasonable to assume that as electric vehicle technologies advance (particularly in the matter of batteries) a "natural" market will begin to supercede the politically-created market, though when this might occur remains an open question at this point.

If the electric vehicle is potentially the solution to our problems of air pollution, might it not also help to resolve some of our economic problems? In other words, a major policy question that must be faced (and indeed is now being faced with some resolution) is this: *Can Southern California take advantage of the coming shift into electric vehicle usage by also actually manufacturing the vehicles locally?* In any attempt to answer this question we must keep firmly in mind the notion that for the time being the market for these vehicles is likely to be small, fragmented, and extremely risky. A major and immediate task that local policy makers must face is how to mitigate these disadvantages and thus to foster the birth and growth of the electric vehicle industry in Southern California.

We need to add at this stage that while efforts to develop electric vehicles have focussed on both private cars and vans, it is the market for electric vans and other utility vehicles that is probably most likely to grow significantly in the immediate future. This follows from the circumstance that many (intra-urban) commercial vehicles travel only short distances per day with frequent stops, and they can usually dispense with high performance criteria in the matter of speed and acceleration. Electric vehicle technologies, as currently developed, meet circumstances such as these in very effective ways. In addition, many public agencies (e.g.

municipalities, electric utilities, park services, etc.) have expressed a particular interest in acquiring electric utility vehicles for their peculiar needs as well as for general demonstration purposes. In all probability, there is also a small market for private electric cars, especially as second cars reserved for commuter purposes in affluent and environmentally-conscious households, though the high costs and limited performance characteristics of these cars put severe limits on their general market appeal. That said, over the next decade or so, the market for electric passenger cars is likely to expand considerably as technologies improve, as manufacturing capabilities are more finely honed, and as average costs of production start to fall.

3.3. Southern California's Competitive Advantages and Disadvantages in Electric Vehicle Production

One of the central questions to be faced in thinking about how to initiate an infant industry in a particular region is, what resources does that region currently possess that might be of service to the new endeavor? All else being equal, the larger and more varied the stock of resources, the easier and more assured of success is the process of initiation. In the case of Southern California the existing resources are rich and varied. They involve four major types of assets:

- a potentially large local market;
- local governmental agencies and other public and quasi-public bodies ready to provide legislative, financial, and other means of support to the emerging electric vehicle industry;
- an abundance of human resources in the form of skilled and technically-proficient labor; and,
- an extraordinarily abundant and many-faceted industrial base with enormous technological assets, and the capability of producing virtually any component in an electric vehicle.

Table 3.1 shows manufacturing employment in a selected set of industrial sectors in Los Angeles County in the year 1990. The table provides information for seven two-digit sectors (employing 491,100 workers) and associated three-digit sectors, thought to be particularly relevant to the input needs of electric vehicle manufacturers. These sectors include rubber and plastics, metallurgical and machinery industries, aerospace-electronics, and other high-technology industries. This rich stock of industrial resources is undoubtedly susceptible to physical re-deployment for the purposes of electric vehicle assembly and components production in the region. One major problem, of course, is that some of these sectors are dominated by defense-oriented firms, and such firms find it notoriously difficult to shift over into forms of manufacturing in which cost-plus, quality-at-any-price strategies must give way before the competitive pressures of civilian markets. Nevertheless, many defense-oriented firms do possess technologies that are potentially of great significance to the emerging electric vehicle and associated components industry; and since 1987 they have been laying off highly-skilled workers who could contribute much if they were to be re-employed in the electric vehicle industry. Furthermore, many of the three-digit sectors designated in Table 3.1 comprise large numbers of small industrial establishments characterized by high levels of production flexibility and a

Table 3.1. Employment in Selected Manufacturing Sectors, Los Angeles County, 1990^a.

Standard Industrial Category	Employment
30 Rubber and miscellaneous plastic products	34.6
306 Fabricated rubber products	4.5
308 Miscellaneous plastics products	28.2
33 Primary metal industries	21.0
332 Iron and steel foundries	3.0
335 Nonferrous rolling	4.4
336 Nonferrous foundries (castings)	7.2
34 Fabricated metal products	64.7
344 Fabricated structural metal products	15.7
345 Screw machine products	8.2
346 Forgings and stampings	6.4
35 Industrial machinery	58.6
354 Metal working machinery	9.4
356 General industrial machinery	7.4
357 Computer and office equipment	12.1
36 Electronic equipment	64.8
362 Electrical industrial apparatus	4.0
364 Lighting and wiring equipment	13.4
366 Communications equipment	5.2
367 Electronic components	25.1
37 Transportation equipment	156.6
371 Motor vehicles and equipment	12.9
372 Aircraft and parts	124.9
376 Guided missiles, space vehicles, parts	15.4
38 Instruments and related products	91.2
381 Search and navigation equipment	63.4
382 Measuring and control devices	13.5

^aSource: State of California, Employment Development Department, *Annual Planning Information, Los Angeles-Long Beach Metropolitan Statistical Area (Los Angeles County)*.

proven ability to function effectively in rapidly-shifting networks of subcontracting relationships.

The latter point is driven home by the observation that CALSTART is now engaged in the production of a demonstration electric vehicle on the basis of a collaborative effort with other manufacturers, most of whom are located in Southern California. As Table 3.2 shows, there are 18 manufacturers currently working on the demonstration vehicle project, and of these, 13 are in Southern California. They are drawn, moreover, from the gamut of industrial sectors noted in Table 3.1. By one estimate, 40% of the components and subsystems in an electric vehicle *must* change relative to their optimal configuration for the gasoline-powered vehicle, and 30% should be improved upon³. The companies that are working together on CALSTART's demonstration vehicle are all capable not only of producing viable components according to given specifications, but also of significant product re-configuration and innovation of the order of magnitude implied by the figures just quoted. It is yet further testimony to the capabilities of Southern Californian manufacturers to note that General Motors' Impact electric car was designed in the region (by AeroVironment), and its electronic controllers made by Hughes of Torrance. Lastly, Southern California is now home to what is probably the largest assemblage of automobile design studios anywhere in the world. Virtually all major car companies, both domestic and foreign, maintain a studio in the region, and there is also a complement of independent design firms that work on a subcontract basis for the large corporations. This local design capacity adds significantly to the region's potential for innovative vehicle research, development, and production, and as we shall see it is potentially an important anchor for the location of important electric vehicle manufacturing resources in the region by major car producers.

Southern California is thus currently well situated to move into the electric car industry. It can offer a number of significant external/agglomeration economies to prospective producers in the matter of both local labor markets and the existing industrial base of the region. Its infant electric vehicle industry has already acquired some of the intrinsic advantages that come with an early start. It has demonstrated an impressive depth and breadth of political support for the use and production of electric cars. Most importantly of all, perhaps, there is emerging in Southern California a network of suppliers who are learning collaboratively to produce technologically-innovative components for electric vehicles. Producers located in the region also enjoy the advantage of the possibility of close cooperation with various state and local governmental agencies. The great merit of this latter arrangement is that it may thus be possible to ensure that there is an optimal match between (a) the design specifications of locally-made electric vehicles, and (b) the specific substantive content of legislative action at the state level in such matters as environmental goals, traffic management, urban planning, and so on.

Despite this optimistic assessment, it would be a major error to presume that Southern California's ascent to mastery of electric vehicle production is now assured. In fact, the region faces extremely serious competition from major vehicle producers in North America, Japan and Western Europe, (though the recent downgrading by General Motors of its Impact program provides Southern California with an added margin of breathing space). Almost all of the major

³ Lon Bell, "The development of an EV component industry in California", in *Electric Vehicle Policy and Technology Conference Proceedings*, Los Angeles. Joshua Newman and Associates and the Electric Vehicle Association of the Americas, 1992

Table 3.2. Participants in CALSTART's electric vehicle demonstration program.

Company	Place (all in California)	Component or Sub-System
Amerigon Inc.	Burbank	Energy management & safety systems
ANSI	North Hollywood	On-board navigation system
ASHA Corp.	Santa Barbara	Passive ventilation system
Avery Denison	Pasadena	Avloy® formable finish
Dowly Aerospace	Duarte	Energy efficient brakes
Fairchild Manufacturing	Sacramento	Underbody panel & auxiliary battery box
Feher Design	Burbank	Variable temperature seat
Group IX Aerospace Systems	Los Angeles	Battery monitor system
HUB Engineering	Burbank	Battery containment system
Hughes Aircraft	Torrance	Inductive charging system
IBM	San Jose	RISC system 8000 component design computers
Intel	Santa Clara	Microprocessors & emulator tools
International Rectifier	El Segundo	MOSFET & IGBT power semiconductors
ITT Cannon	Santa Ana	High voltage wire harness assembly
Kaiser Aluminum & Chemical Corp.	Pleasanton	Recyclable aluminum frame
Pirelli Armstrong	Hanford	Low rolling resistance electric vehicle tire
Translumin International Inc.	Agoura	Solar cell array
Trojan Battery Corp.	Santa Fe Springs	Bi-polar lead-acid batteries

car companies have invested heavily in the creation and improvement of electric vehicle technologies, and in many cases they have advanced very far indeed in developing both conversions of gasoline-powered models and purpose-built vehicles. This is certainly the case with (a) General Motors, Ford, and Chrysler in the US, (b) Toyota, Nissan, Mitsubishi, Suzuki, and Daihatsu in Japan, and (c) Peugeot, Fiat, Volkswagen, Mercedes Benz, and BMW in Europe. All of these companies, among others, have plans to bring a variety of electric cars and delivery vehicles to market in the very near future, and in several cases extensive field tests are now being carried out. Ironically, one of the major stimuli to the recent flurry of interest among these firms in electric vehicle production has been California's strong statutory attack on the problem of air pollution, and many of them (in both the US and elsewhere) have explicitly targeted California after 1998 as their primary market.

The major car producers, too, have a number of established advantages that help to put them ahead of possible rivals in Southern California. First of all, of course, they have had long experience in building and managing large-scale production systems for vehicle manufacture. Second, they have the expertise and the distribution networks that give them a major lead in marketing. Third, they have both the legal and technical ability to deal with the maze of costly regulations governing vehicle safety requirements in the United States. Fourth, they have the engineering and financial resources to meet the onerous front-end research and development costs that are inevitably incurred in the creation of radically new types of vehicles. Under no circumstances, then, can we discount the threat to the Southern Californian effort from the established car industry in other areas.

With this proviso in mind, there is one significant impediment that prevents the major producers from deploying all their acquired competitive advantages to maximum effect at the present time. This resides in the circumstance that battery technology remains in a primitive stage of development, and as a consequence electric vehicles are severely limited in performance, and uncompetitive in regard to price. So long as this state of affairs prevails, electric vehicle markets are likely to be limited in size so that the massive scale advantages of the principal car producers can not be brought fully into play. The work of the new US Advanced Battery Consortium, together with research now being carried out on batteries in a wide variety of other agencies and firms, will certainly in the course of time bring about major improvements in battery technology. In addition, we may reasonably expect that efficient fuel cells will one day substitute for batteries, thus providing a cheap, convenient, and environmentally-friendly on-board source of electricity⁴. For the time being, because of the constraints that the electric vehicle industry faces, it is likely to be typified by large numbers of small manufacturing operations producing vehicles in relatively limited batches and in designs that are both technically and stylistically liable to much instability. Even if we were to assume that Southern California could not in the long run compete in the area of final vehicle assembly, it should nonetheless be able to build a very significant capacity in components and parts production. Indeed, it is currently the main goal of CALSTART to concentrate on the creation of a components industry in Southern California that will supply major electric vehicle assemblers in other parts of the world.

⁴ See *Fuel Cell Commercialization Alliance*, Economic Roundtable, Los Angeles, 1992, also *Status of Fuel Cell Technology for Transit Applications*, ICF Kaiser Engineers, Los Angeles, 1992

3.4. An Electric Vehicle Industry for Southern California? A Scenario of Prospects and Possibilities

It thus seems unlikely that mass production of electric vehicles will occur on a commercially feasible basis for some considerable time to come, whether in Southern California or elsewhere. It is commonly suggested that the break-even point for mass production of cars occurs at the 100,000 *per annum* production level. No manufacturer of electric vehicles is likely to achieve such levels of production for a single model type within the next decade. This means that Southern California's competitive prospects — residing as they do for the most part in the potentialities of niche-oriented flexible manufacturing systems — remain a reasonably good bet, at least for the time being.

What we are now observing in Southern California in regard to the emerging electric vehicle industry is a classic instance of what product cycle theorists call "the period of infancy". This corresponds to the very earliest stages of industrial growth in which we typically find

- a small number of pioneer entrepreneurial firms (such as Amerigon, Clean Air Transport, or Solar Electric);
- industrial product and process configurations that are highly unstable and liable to rapid change;
- considerable subcontracting activity in order to reduce in-house costs of development and production, as well as to enhance flexibility;
- high levels of risk and a high probability of bankruptcy for many participants.

Out of this initial period of ferment there generally emerges a number of key firms which have managed to find superior combinations of technology, management, and marketing strategies⁵. At the same time, this early phase of industrial development is often marked by much spatial agglomeration of the participants. This results both from the intense inter-firm network relations that tend to occur in this phase, and also from the materialization of a local labor market comprising individuals who now begin to acquire specific kinds of skills, information, and sensitivities that are crucial to the industry's effective functioning. Agglomeration is particularly advantageous to producers because it tends to be the focus of significant external economies of scale and scope⁶. It also offers possibilities for setting into place various sorts of institutional infrastructures that help to maintain systemic agglomeration economies in such matters as technological improvement and innovation, labor training, information services, just-in-time processing networks, and so on.

One of the major assets for electric vehicle manufacturing in Southern California is the circumstance that there has been from the outset significant public support for the industry. This support is having the effect of reducing the initial risk levels for the infant industry and therefore — provided always that the forms of support lead in the direction of ultimate commercial success — of accelerating the chances that the Southern Californian electric vehicle industry will shift

⁵ Consider, for example, the emergence of Apple Inc in the mid-1970s as one of the major leaders in the personal computer manufacturing industry

⁶ Cf A J Scott, *Metropolis From the Division of Labor to Urban Form*, Berkeley and Los Angeles University of California Press, 1988

out of the phase of infancy and into the phase of growth. In fact, the shape and form that public policy towards the industry must take remains an open and extraordinarily difficult question. Without in any way attempting to specify the precise terms of actual policy actions and their forms of institutional expression, we would argue that policy does need to encourage as far as possible the following features in the industry and its milieu:

- flexible production systems — so that adaptations to rapidly changing technological and market conditions can be swiftly introduced;
- collaborative inter-firm relations and joint venture activities — so that problems can be creatively resolved by the pooling of resources;
- active transference of skills and technologies from the aerospace-defense industry into the electric vehicle industry;
- the inclusion of many different firms and technologies within the purview of policy-making in order to allow for the possibility of unforeseen and unpredictable advances;
- investment in basic infrastructural services and skills required by the industry (e.g. crash-testing facilities, the training of electric car technicians and repair personnel, etc.);
- continued public investment in research and development for the industry, perhaps by making increased sums of money available to CALSTART or similar consortia.
- general intensification of existing efforts to extend the market for electric vehicles (e.g. by offering tax rebates, parking privileges, reduced electricity prices, HOV lane privileges, re-charging facilities away from home, increased taxes on gasoline, and so on).

In brief, there is a considerable role for governmental and other public agencies, private-public consortia, industry associations, labor unions, citizens' groups, and others in helping to accomplish tasks such as these.

One of the most promising policy-driven initiatives in Southern California in support of the electric vehicle industry is the CALSTART consortium (see chapter 7). It involves complex forms of private-public cooperation; it operates as a collaborative network with considerable internal flexibility; and it is focussed on innovation over a wide range of systems, sub-systems, and components. CALSTART, indeed, has certain resemblances (in embryonic form) to the celebrated private-public partnerships which over the 1970s and 1980s helped to revitalize the local economies of the so-called Third Italy (e.g. CITER for knitwear, CESMA for agricultural machinery, CERCAL for shoes, and QUASCO for construction⁷). With its strongly developed cooperative structures, pooling of technical capabilities, and sharing of risks, it also has something of the character of a proto-*keiretsu*, though it is chiefly a para-market institution, with its main focus on systems engineering for the electric vehicle and on R&D for components production. CALSART is likely to spin-off critical technologies and firms as its capabilities expand. Thus, CALSTART may well prove to be a viable institutional platform out of which at least some significant parts of an electric vehicle industry may begin to emerge in Southern California.

Arguably, however, a key piece of the puzzle is still missing from the emerging electric

⁷ See for example P. Bianchi, "Levels of policy and the nature of post-fordist competition", pp. 303 - 315 in M. Storper and A. J. Scott (eds.) *Pathways to Industrialization and Regional Development*, London: Routledge, 1992.

vehicle industry in Southern California. This remark refers to the conspicuous failure of any major vehicle manufacturer to participate directly in the events currently unfolding in the region (with the exception of General Motors' subcontracting of design and controller development tasks to AeroVironment and Hughes, respectively). Yet as we have already seen, the major car manufacturers already have enormous acquired advantages in the development, production, and marketing of electric vehicles. A major boost to the development of the industry in the region could be achieved by combining in one local production complex (a) some sort of representation on the part of major car manufacturers with (b) the many different initiatives that are now going forward with regard to components development and systems engineering. In view of this comment, it would seem that *policy-makers at both the state and local levels should now be concentrating significant attention on the possibilities of attracting one or two major manufacturers (whether American, Japanese, or European) to Southern California* in order to participate in and to enhance current developments. At the outset this would involve not so much the establishment of major assembly facilities, but the setting up, perhaps, of small craft centers making vehicles in relatively small batches for limited markets. This might be accomplished by persuading companies that already have a design center in the region to upgrade and broaden their local facilities. It would, of course, require material incentives of various sorts to attract major manufacturers to the region, but the time to act is now, before the industry begins to unfold in significant ways in other regions and before it begins to put down roots in those regions and to acquire early mover advantages that would threaten the budding industry in Southern California.

The major problem here is that due to recent and widely-circulated negative press accounts, Southern California is now commonly perceived as offering a hostile business climate for manufacturers. This image is certainly inaccurate in several important respects, and it is in any case subject to considerable qualification⁸. Nevertheless, manufacturers act on the basis of their perceptions of reality, and this means that any effort to attract major car producers to the region is likely to encounter strong resistance at the outset. There is thus a need for a very carefully prepared documentation of the *real* advantages to major producers that would come from locating in the region. Among these advantages are the possibilities of (a) tapping into significant local public support, (b) local access to what is likely to be the first major market for electric vehicles, and (c) participation in a multi-faceted industrial and technological effort involving creative interactions with the developing local supplier base. In this ideal (but obviously difficult to accomplish) scenario, Southern California may well become a major growth pole for the electric vehicle industry, producing a diversity of components and other inputs as well as assembled vehicles; and in this capacity, the region might eventually be capable of serving not only local markets, but also eventually markets in the rest of the country, if not the world. At the very least, the region will quite certainly be a major force in the industry world-wide by reason of its promise as a center of innovative components and sub-systems production.

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In some respects, the electric car industry in Southern California resembles the early

⁸ See, for example, S. Levy and R. K. Arnold, *The Outlook for the California Economy*, Palo Alto Center for the Continuing Study of the California Economy, 1992

aircraft industry. In the first two decades of the present century there was enthusiastic local support for a few pioneer aircraft firms, most of which eventually died out or even moved out of the region altogether. This widespread local support in favor of Los Angeles becoming a major center of the aircraft industry⁹ was in some respects presumptuous given the obvious industrial prowess of the Northeast of the United States at that time. Indeed, over much of the 1920s and early 1930s, the industry was concentrated for the most part in states like New York, Michigan and Pennsylvania. However, throughout the inter-War years the struggling aircraft industry in Southern California received significant public support (in the form of government and military contracts) and the enthusiastic backing of local boosters like Harry Chandler. Eventually, in the 1930s, a number of critical technological breakthroughs (above all Douglas' development of the DC3 and Lockheed's development of the L10 Electra) conferred a decisive competitive edge on Southern Californian producers, and paved the way for the growth of a major agglomeration of aircraft manufacturers and their associated tiers of subcontractors and parts producers in the region.

In brief, a major and eventually dominant center of aircraft production was ushered into being in Southern California. Enlightened public policy might just help to recreate at least some elements of this story for the case of the electric car industry.

⁹ In the 1920s, Los Angeles was even referred to as a potential "Detroit of the aircraft industry", see Scott *Technopolis*, op. cit.

Chapter Four

The Potential Impacts of an Electric Vehicle Manufacturing Complex on the Los Angeles Economy

Goetz Wolff, David Rigby, Don Gauthier and Marco Cenzatti

4.1. Introduction

Does Los Angeles have the industrial capacity and labor skills to produce electric vehicles and their components, and how would the production of electric vehicles effect the local economy? This chapter examines the local potential for electric vehicle production and the potential economic impacts of developing an electric vehicle industry within Los Angeles. The analysis is divided into three parts. Section 2 provides a brief overview of the Los Angeles economy focusing on the automobile industry. This section examines the history of the automobile industry in Los Angeles, the region's current automobile related industrial capacity and its suitability for electric vehicle production. Section 3 extends the general discussion of electric vehicle technology, outlined in Chapter 2 of the report, and details a generic blueprint of an electric vehicle focusing upon key components and production materials. The aim of this section is to provide a build-sheet for the electric vehicle in terms of a series of input-output coefficients. In Section 4 the electric vehicle build-sheet is combined with input-output data to examine the economic impacts of electric vehicle production in Los Angeles. Most attention is given to the employment generating capacity of an electric vehicle industrial complex. The input-output analysis follows various scenarios that distinguish between the production of electric vehicle components and final assembly and between production of electric vehicles for different market shares.

4.2. The Growth And Decline Of The Automobile Industry In Los Angeles

4.2.1. Introduction

Does Los Angeles have the elements in-place for the emergence of an automobile industry based on electric power propulsion? Over the past three-quarters of a century, Los

Angeles has been the major U.S. automobile assembler west of the Mississippi. However, in 1992 Los Angeles reached a low-point in auto-related employment when the last local automobile assembly plant shut down at the General Motors Van Nuys site, after 45 years of operation. It is unclear whether the decline of the automobile industry in Los Angeles is a symptom of industrial restructuring and downsizing within the U.S. domestic automobile industry that is not solely related to local conditions, or whether the Los Angeles region is losing its competitive edge in the production of automobiles and related industrial goods.

This section of the chapter provides a brief overview of the emergence, growth and decline of the Los Angeles auto industry and its potential for transformation. Of particular concern is whether there ever existed a "full-blown" integrated parts and assembly automobile industry in Los Angeles. Examination of more recent industry employment trends, that take into account the cluster of component industries that make up the traditional (i.e. internal combustion-based) automobile industry, leads to the conclusion that, at least for the past three decades, Los Angeles auto assembly plants relied upon parts made outside the region and a local automobile production complex was never very well-developed. While a significant automobile parts industry continues to thrive in the region, its production is focused on the aftermarket.

The existence of automobile assembly plants and related industries, such as parts production, suggests that an appropriately skilled labor force was once, and may still be, available to a fledgling electric vehicle industry in southern California. At the same time, the electric vehicle industry will likely rely not only upon existing automobile related industrial sectors (and their labor forces), but also upon high technology industries, such as electronics and composites, and other sectors, such as plastics, in much larger proportions than traditional automobile manufacturing. Does Los Angeles have the industrial mix and diverse range of labor skills to support a nascent electric vehicle industry? Following a review of the development of the auto industry in Los Angeles, the region's potential as a center of electric vehicle production is briefly considered.

4.2.2. An Historical Overview of the Auto Industry in Los Angeles

Despite the now popular portrayal of Los Angeles as having been one of the key automobile manufacturing centers of the United States, a careful examination of the history of the Los Angeles auto industry suggests that despite the large number of assembly plants that once existed in the region, Los Angeles never developed an automotive industrial complex. The development of automobile production in Los Angeles can be neatly divided into the following three periods.

Pre-Fordist Production

In the first period, between the 1890s and the First World War, a large number of would-be producers began small scale production of the early automobile. As Morales¹ points out, several factors, from the low density of its residential communities and the good climate, to the

¹ Morales, R., 1986 "The Los Angeles Automobile Industry in Historical Perspective," *Environment and Planning D*, 4,3 289-303

higher than average incomes and the relative isolation from the eastern centers of production, stimulated the growth of a local industry. By 1903 automobile circulation (with 250 vehicles) was second only to Chicago and twenty local firms were engaged in the production of automotive products. The Tourist, the most successful LA producer, marketed over three thousand cars between 1902 and 1910, the year of its closure. Despite this closure, in 1914 seventeen firms produced complete automobiles in the Los Angeles area.

Fordist Production

The second period began with the introduction of the assembly line by Ford and marked a turning point for the auto industry well beyond its influence on the Los Angeles region. The success of Ford's innovation rested on the complementary use of dedicated machine tools (allowing the production of standardized components that could be precisely 'assembled' on the line with no need for manual fitting) and on a detailed division of labor which allowed a reduction of workers' skills by limiting tasks to the continuous repetition of the same operation. The new Fordist organization of production drastically revolutionized car manufacturing in several ways. To begin with, it allowed for enormous productivity increases, providing Ford and, shortly afterwards, General Motors, with a considerable lead over traditional producers. Secondly, it generated a rapid increase of output that, on the one hand was made possible by the new production methods, but on the other hand, was also necessary to achieve the economies of scale required to recover the large capital investments demanded by mechanization.

Finally, for Fordist production the concentration of the entire manufacturing process in one location was no longer necessary or, in most cases, even convenient, since each phase of the production process required different machines and different operations performed by workers with different skill levels. Thus, while more capital intensive phases of production that required relatively skilled labor (such as engine manufacturing) remained located around the traditional centers of the mechanical industry, final assembly (the more labor intensive phase of production) progressively moved towards new locations: closer to consumer markets, in order to decrease shipping costs (obviously higher for complete vehicles than for components) and/or in areas with lower labor costs. Thus, while standardization and the growing local market led Ford to begin work on the fully integrated River Rouge plant, Ford also implemented the opposite strategy of dispersing final assembly in various locations. After the first assembly plant opened in Tennessee (1910), four more followed in the next four years, including one in Los Angeles, and by the end of the 1920s Ford had thirty-two.

For Los Angeles the beginning of mass production in the auto industry had two almost contradictory consequences. On the one hand, it brought distinct growth to the auto sector in the region. While artisanal production slowly disappeared, the expansion of the consumer market in the region and the increasing availability of labor during the twenties and again after World War Two attracted, after Ford, an increasing number of final-assembly plants: Chrysler and Willys-Overland opened assembly plants in Los Angeles in 1928; General Motors and Studebaker in 1936. After the war, with the addition of new plants by Kaiser-Frazer (1946), Ford-Mercury (1947), General Motors Van Nuys (1948), and Nash-Kelvinator (1948) the annual productive capacity of the area was approximately 650,000 cars, while employment in the sector

approached 11,000 jobs.²

On the other hand, mass production also severed the relationship between final production and local parts supply. In the pre-Fordist era, local suppliers were indispensable to the small final producers that could not afford (economically and technically) in-house production of all auto parts. Fordist assembly plants, however, relied on shipments of standardized components from the mid-west (either from manufacturing plants of their own company, or from "centralized" producers supplying components to the major automobile companies) with some parts supplied locally such as tires. As a result, the embryonic upstream linkages that the industry was beginning to develop in the region during its pre-Fordist period were cut and the growth of car production remained largely limited to one phase of production, dependent on decisions and shipments from the east. This, however, does not mean that the auto parts industry in Los Angeles died after the advent of Fordism. Rather, it indicates that, after the twenties, parts production developed relatively independently from mass production, and was mostly geared to "specialty" and "aftermarket" production, referring respectively to the production of parts for special use (such as racing or off-road) and to parts that consumers buy off-the-shelf either to replace a part of their vehicle or to 'personalize' it.

In brief, despite impressive employment numbers in its hey-day, a fully-fledged automobile industry never quite developed in Los Angeles. The highest motor vehicle employment level was reached in 1978 at 27,200, but even that was a small fraction of the total U.S. auto industry employment (see Figure 4.1). Los Angeles' auto employment was distributed between two sub-sectors that developed in different directions: Fordist assembly, dependent for supplies and decisions from outside the region and fostering the limited skills necessary in assembly work; and a parts production industry, still largely based on skilled labor and artisanal organization, and relatively independent of the vicissitudes of mass production.

The Contemporary Crisis of the Auto Industry in Los Angeles

As long as automobile production was growing, the different pathways of the two sub-sectors passed unnoticed. Differences in their development became evident when, in the early seventies, as a consequence of the crisis that hit the entire U.S. automobile industry, the third period of automobile production began in Los Angeles. This period should actually be called the end of car production in the area, since a consequence of the rationalization and restructuring which the industry was (and is) undergoing nationally, was the closure of local assembly plants, one after another.

A more careful comparison of the decline of the auto industry in the U.S. reveals further differences in the structure of the industry between Los Angeles and other parts of the country that stress both the peripheral character of its past development and the relative independence of parts production from final assembly.

To begin with, from the early seventies onwards, the crisis of the U.S. automobile industry is evident in Los Angeles as in the rest of the nation in the progressive decline of auto-related employment. Figure 4.2 shows how employment in the entire automotive sector (including both final assembly and component production: Standard Industrial Classification

² Morales (1986), p 208

Figure 4.1

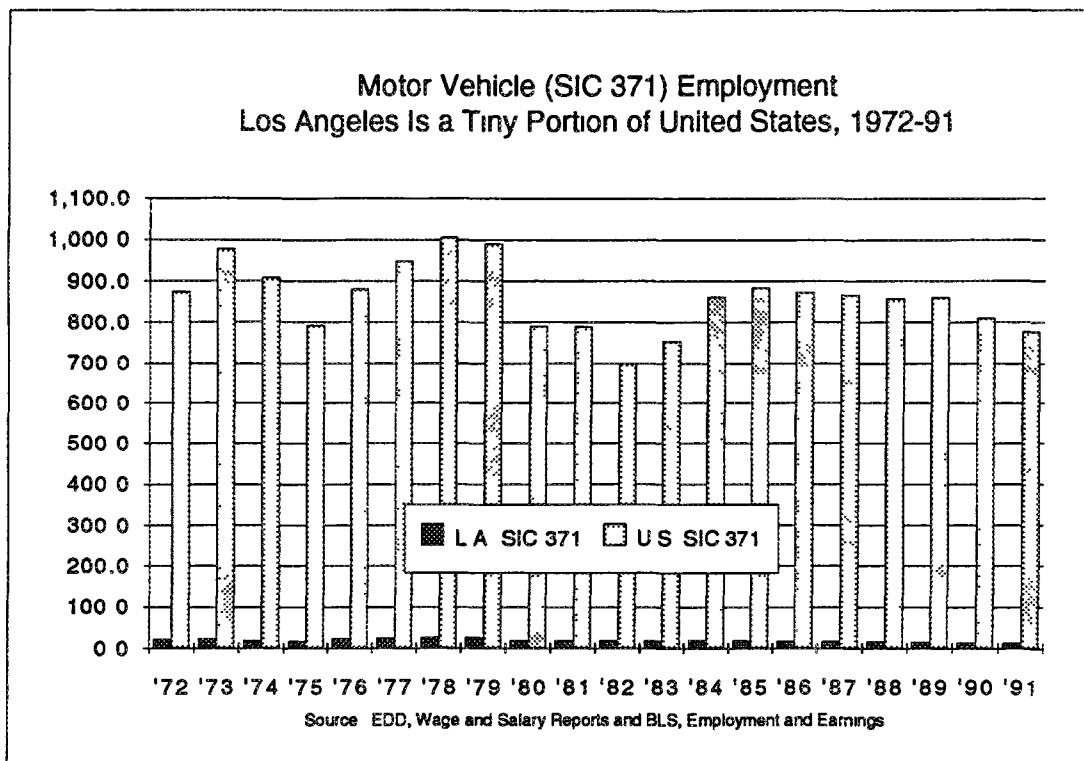
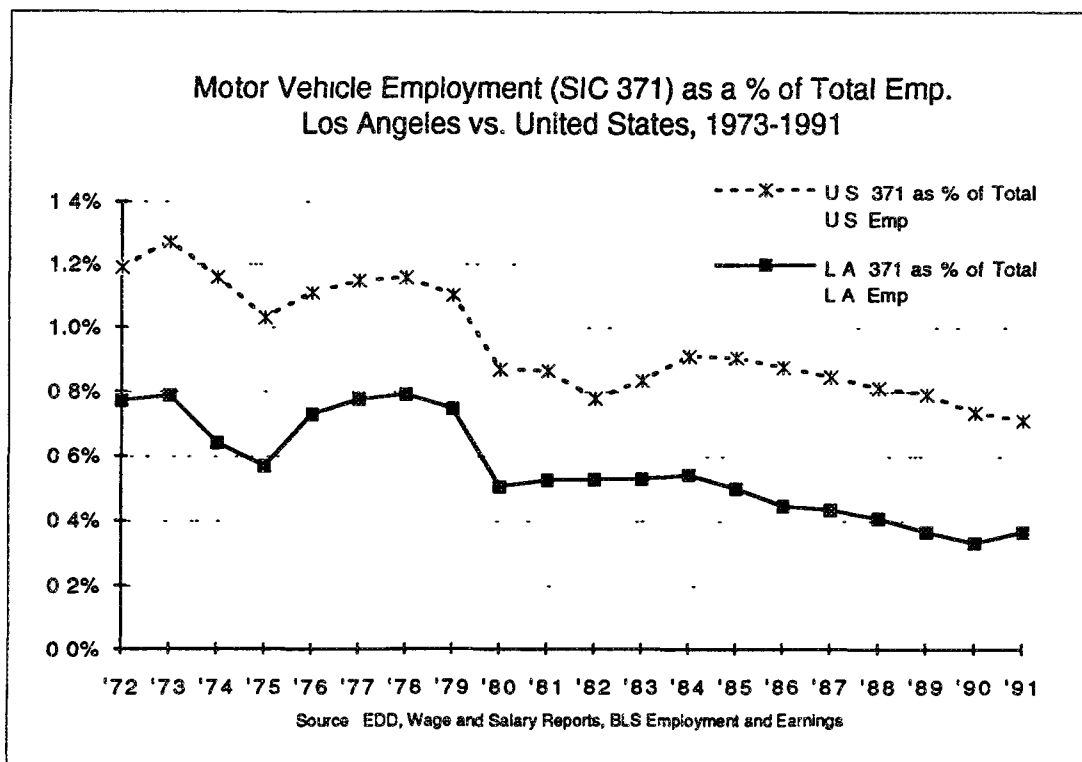


Figure 4.2



(SIC) 371 declined both nationally and locally relative to total employment. The figure also shows that as early as 1972 the automobile sector was under-developed in Los Angeles relative to the nation: local auto-related employment was only 0.8% of total employment in Los Angeles, whereas it contributed over 1.2% of total employment in the nation. More significantly, Figures 4.3 and 4.4 indicate that car production in the area was declining at a sharper rate than in the rest of the country: the location quotient of the industry, already below the national average in 1972, declined even further by 1991 and sectoral employment decreased from 2.5 percent of the nation to less than 2 percent. This represents a decline of 7,600 jobs, approximately one-third of 1972 employment. Figure 4.5 shows employment fluctuations in the auto sector over the business cycle. This figure supports the portrayal of the Los Angeles auto industry as a peripheral component rather than an extension of the core of U.S. auto production, used primarily as a buffer against significant variations in demand.

The second point of interest in comparing the national and local evolution of the industry is that while the low sectoral employment of the industry as a whole in the region and its greater than average rate of decline suggest the increasingly peripheral role of Los Angeles for the industry, the figures for production of auto parts (SIC 3714) offer a different picture, suggesting not only that local parts production withstood the crisis of the industry better than final assembly, but also that the presence of this sub-sector in the region actually grew over the last twenty years despite the decline of the automobile sector in aggregate. Figure 4.6 shows that national employment in parts production remained stable between 1976 and 1986 in relation to employment in total automobile production (SIC 3711 plus 3714), and fell from 50 to about 43 percent in the following five years. By contrast, in Los Angeles, the figure increased from under 40 percent to over 70. In part this growth is magnified by the collapse of employment in final assembly. Absolute employment figures in SIC 3714, however, confirm the growth of this portion of the local auto industry, from 6,500 employees in 1972 to about 8,500 in 1992.

4.2.3. The Structure of the Parts Production Industry in Los Angeles

A temporal and spatial snapshot of the component SICs in the automobile industry for Los Angeles and the United States for 1977 and 1991 provides an introduction to this section of the chapter that focuses more closely on the automobile parts industry. The distribution charts in Figure 4.7 not only reveal the loss of auto assembly (SIC 3711) and tire manufacturing (SIC 3011) in Los Angeles, but also highlight the near absence of the "metal bending" component of the auto industry: automotive stampings. Similarly, SIC 3694, electrical equipment for internal combustion engines makes up a much smaller portion of the L.A. sector. The tremendous increase in SIC 2396, automotive trimmings, apparel findings and related products appears to be more the result of the growth in the "apparel findings" and "related products" activities, such as printing and embossing on fabric. The absolute size of the component sectors of the Los Angeles auto industry over the period of 1977 to 1991 is portrayed in Figure 4.8.

Comparing the relative concentration of the various sectors of auto parts production in L.A. to the U.S. confirms the loose linkages of the parts sectors to mass production. The location quotient data in Figure 4.9 support the contention of the previous pages on the role of aftermarket and specialty production for local part producers. Storage batteries (which even if

Figure 4.3

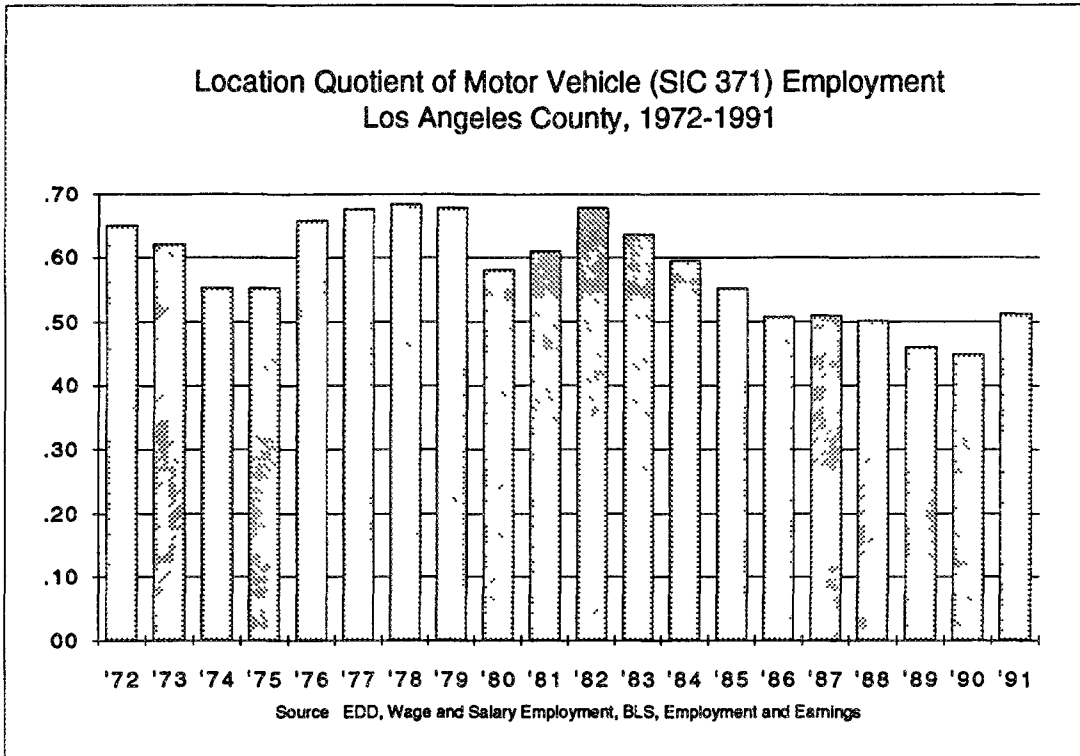


Figure 4.4

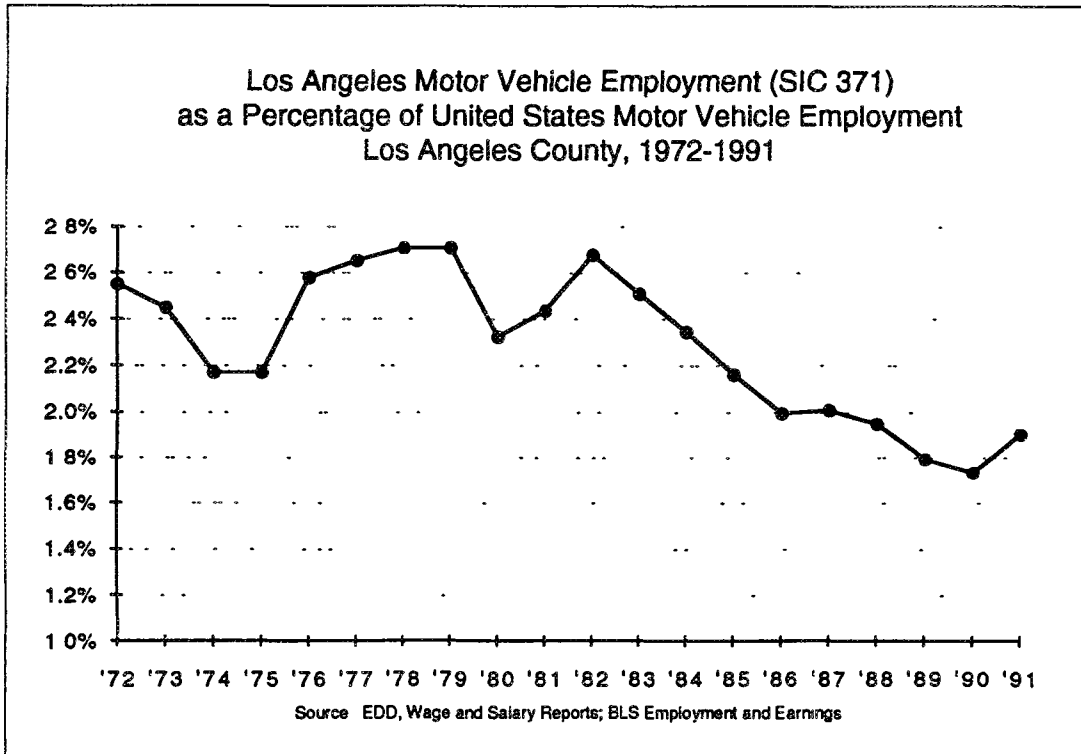


Figure 4.5

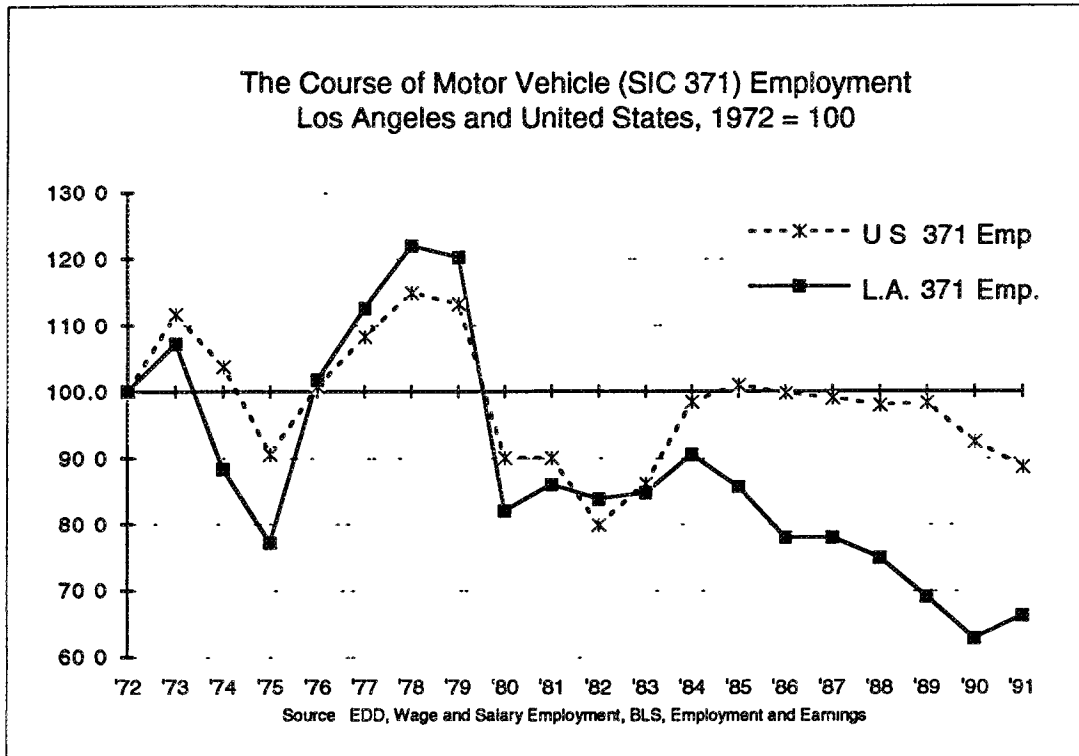


Figure 4.6

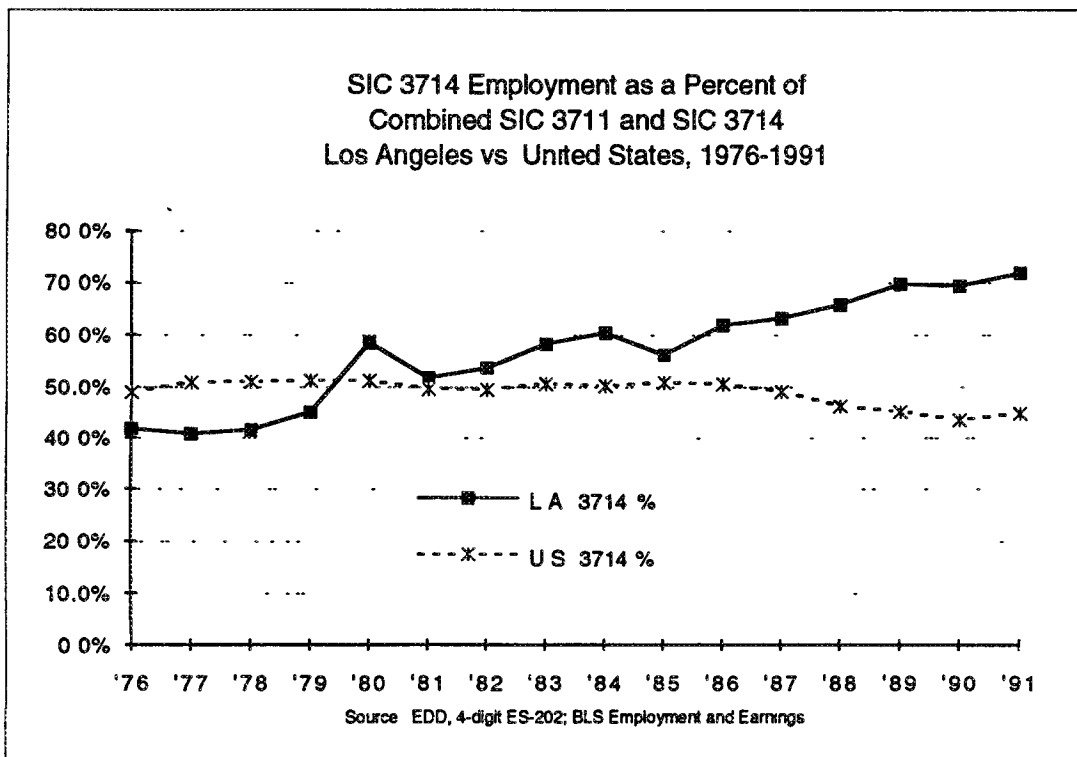
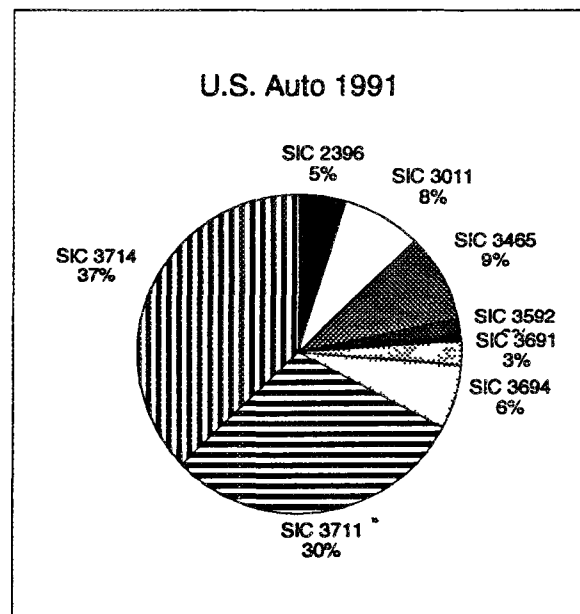
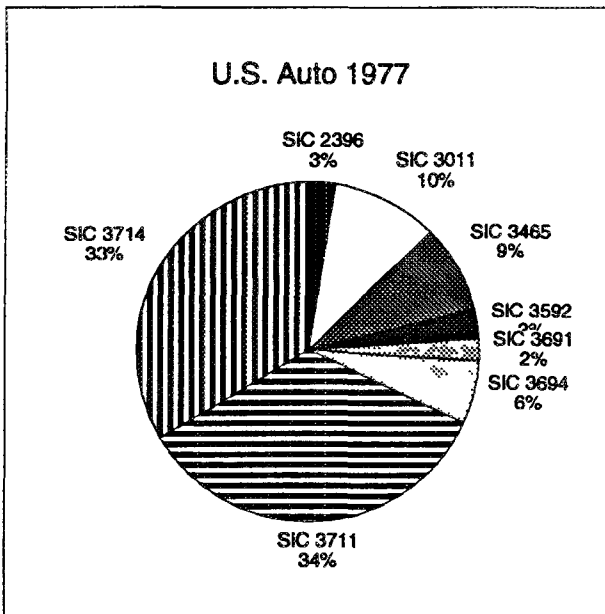
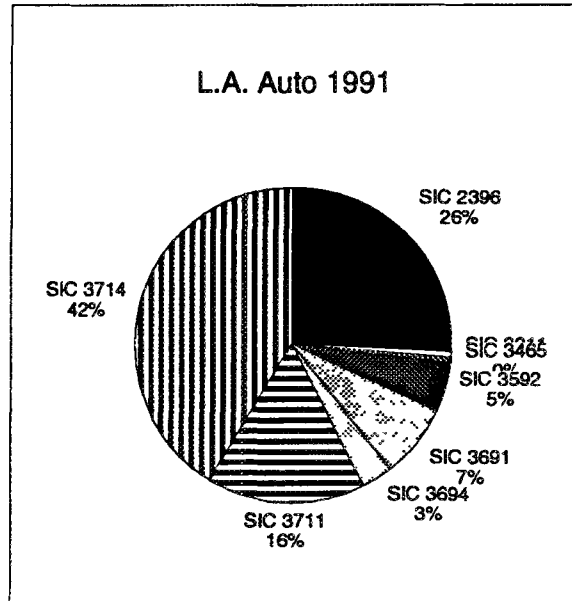
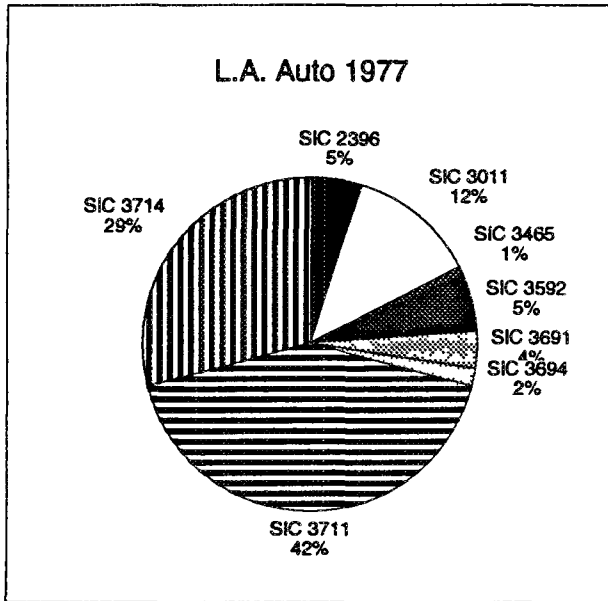


Figure 4.7

**Distribution of Component SICs in the Auto Industry
Los Angeles and the United States
1977 and 1991**

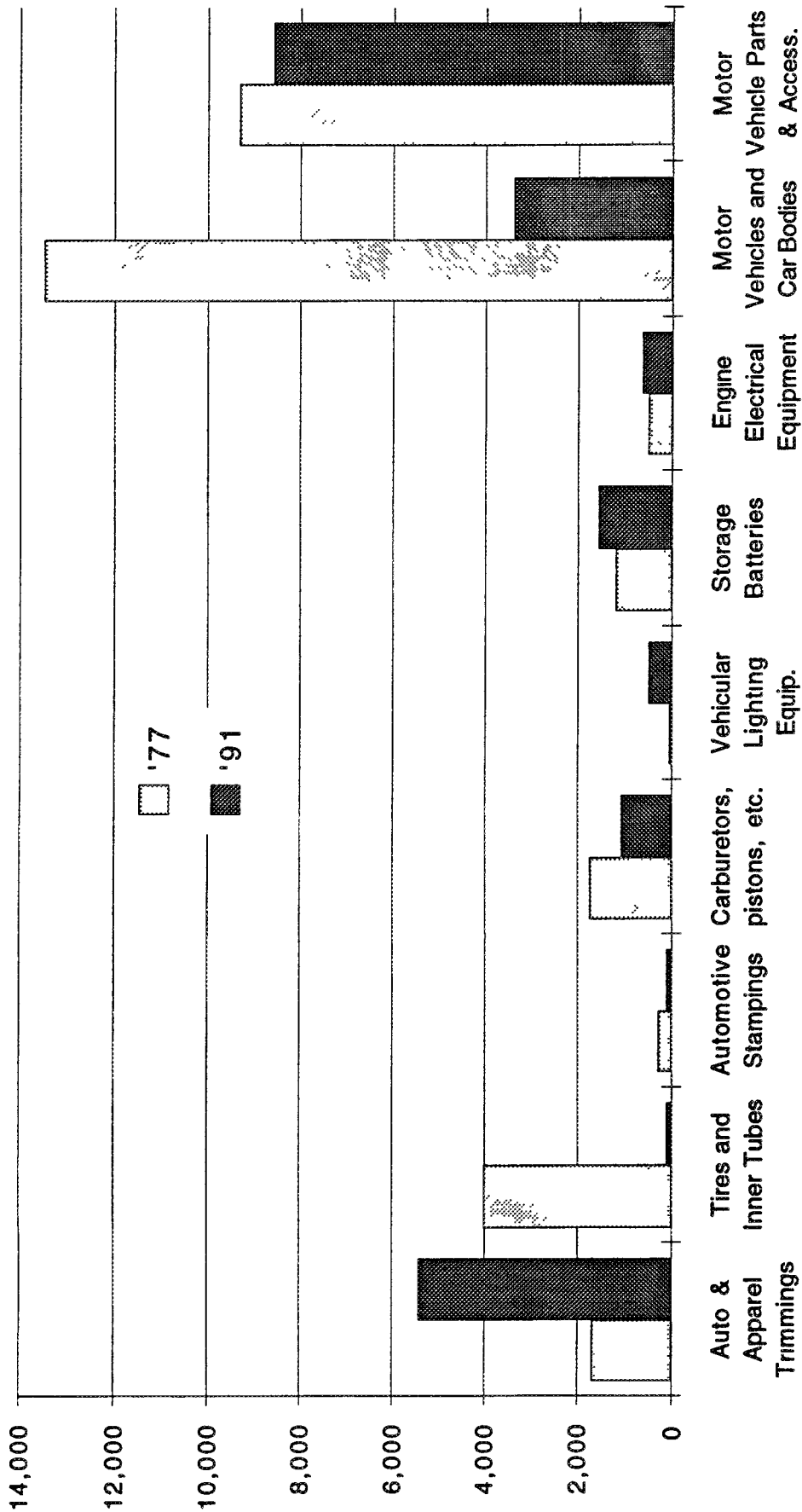


Note SIC 3647 omitted because data missing for U S

Source EDD, ES-202 Files, and BLS, Employment, Hours and Earnings, U S , 1909-90, Vol I and BLS, Employment and Earnings, Revised Establishment Data 1989-92 (August, 1992)

Figure 4.8

Los Angeles Auto Industry Employment
 Distribution by 4-Digit SIC
 1977 Total = 32,200; 1991 Total = 21,300



Source EDD, ES-202 File

not produced for the aftermarket, are however an off-the-shelf auto component) and pistons and carburetors (for special use) manufacture are two of the sub-sectors that are over-represented in the Los Angeles region. Carburetors increased its location quotient by losing employment at a less rapid rate than the nation. By contrast, storage batteries employment growth has continued even after employment in the auto industry began to decline.

In every sector, the U.S. has a greater proportion of large firms than Los Angeles (see Tables 4.1 and 4.2). The dominance of small size firms in these Los Angeles sectors further suggest that local production is limited to aftermarket or special uses. For example, while in the US about 60 percent of piston and carburetor production is carried out in firms with less than 50 employees, in Los Angeles the figure grows to almost 86 percent. In battery production the difference between the national and local figure (respectively 48.9 and 53.9 percent) and the relevance of small size firms is less dramatic. Arguably, this follows from the lower degree of standardization of items produced for the aftermarket. In sum, while automobile parts production in the Los Angeles region is not closely tied to local automobile assembly, the parts sector is nonetheless relatively large and appears to be robust despite shrinkage in local automobile assembly.

4.2.4. Conclusion: The Potential for EV Production in L.A.

Given the foundation provided by the local automotive parts complex, the region's potential for electric vehicle assembly and component production appears significant. As indicated above, the presence of diverse parts production in southern California indicates that local industry is capable of, and local labor is skilled in, the production of a large array of components. Small scale operations and the "custom" (i.e. specialty) orientation of local firms is indicative of the flexibility of the region's automobile-related industrial base. In addition, subcontracting ties and industrial linkages are strong, due in part to the shared technologies, labor skills, and manufacturing processes employed within the largest non-automotive sectors of the regional production system.

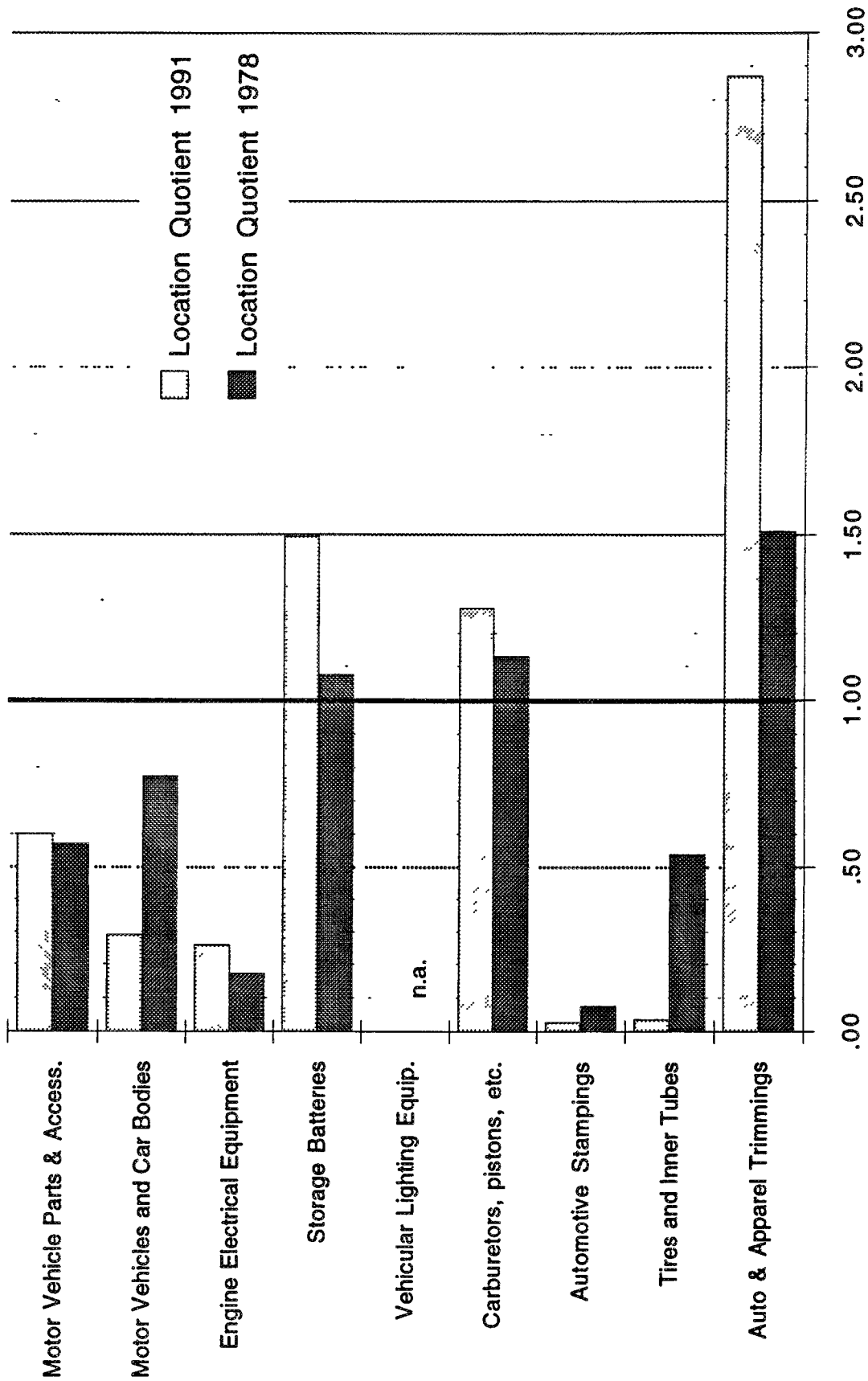
Most of the anticipated emerging electric vehicle sectors are related to the aerospace, electronics, plastics, and measuring instruments sectors. Based on the technological analysis of an electric vehicle dominated industry, Figure 4.10 indicates the sectors that will likely play a larger role in supplying components to an electric vehicle industry. It should be emphasized that the industries identified in this table have not been significantly related to the Los Angeles motor-vehicle sector up to this time. Thus, the employment figures and trends serve only as indicators of the presence of these industries and their relative dynamism. More detailed technological information on the electric vehicle industry is provided in Section 4.3.

As shown in Figure 4.11, those sectors identified as potential growth sectors in an emergent EV industry have, over the period 1977-1991, contributed to an aggregate growth of nearly 8,000 jobs. Net change for the period for each sector is graphically shown in Figure 4.12. Most of the growth was in Current Carrying Wiring Devices, Electronic Components, and Semiconductors, sectors that have been closely linked to the aerospace sector in Los Angeles.

Employment in the proto-EV sector is situated in approximately 450 establishments, most of which are relatively small shops. Two-thirds of these establishments have less than fifty

Figure 4.9

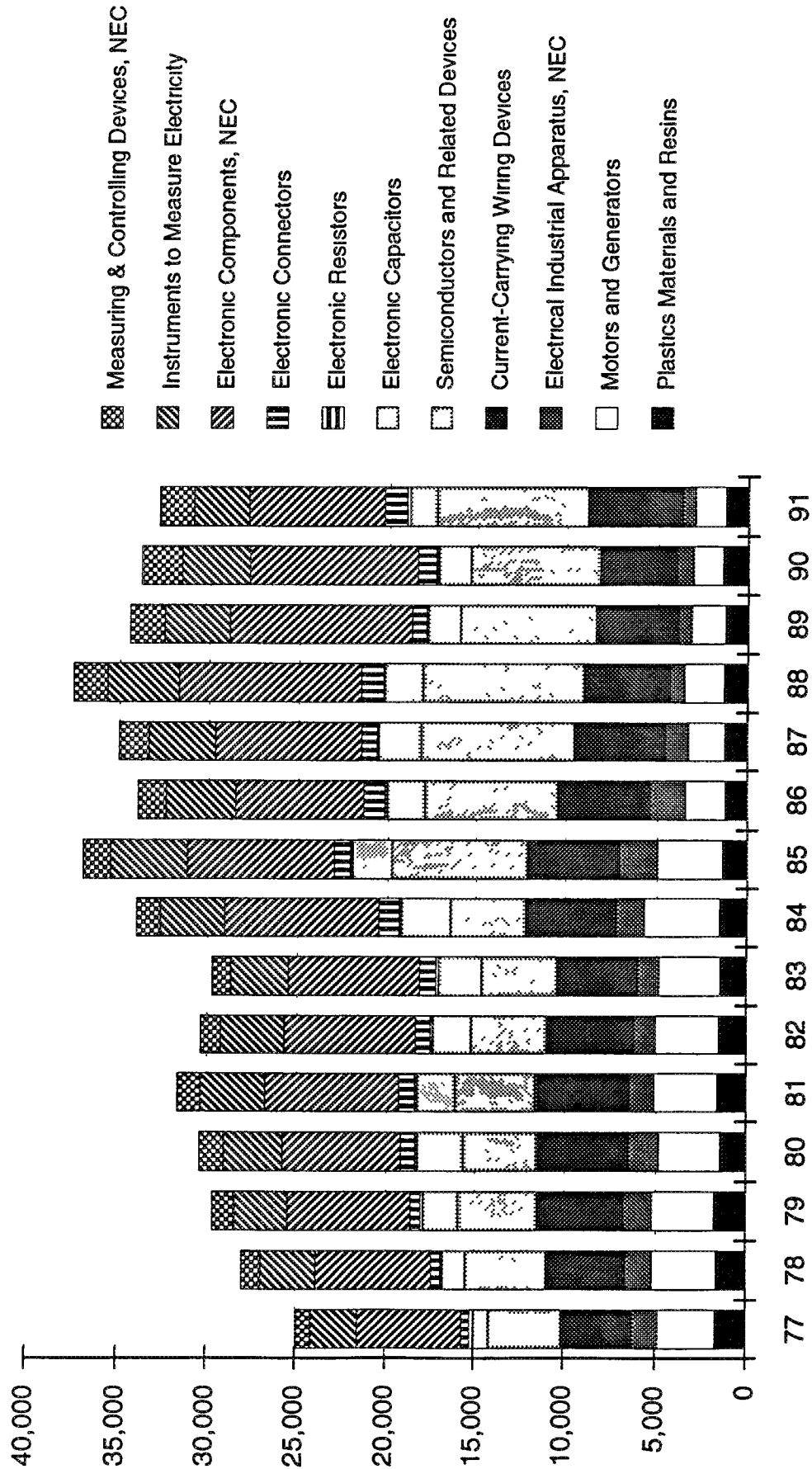
Los Angeles Auto Industry Employment Location Quotient
1978 (Peak Auto Employment) and 1991



Source: EDD, ES-202 File and BLS, Employment and Earnings

Figure 4.10

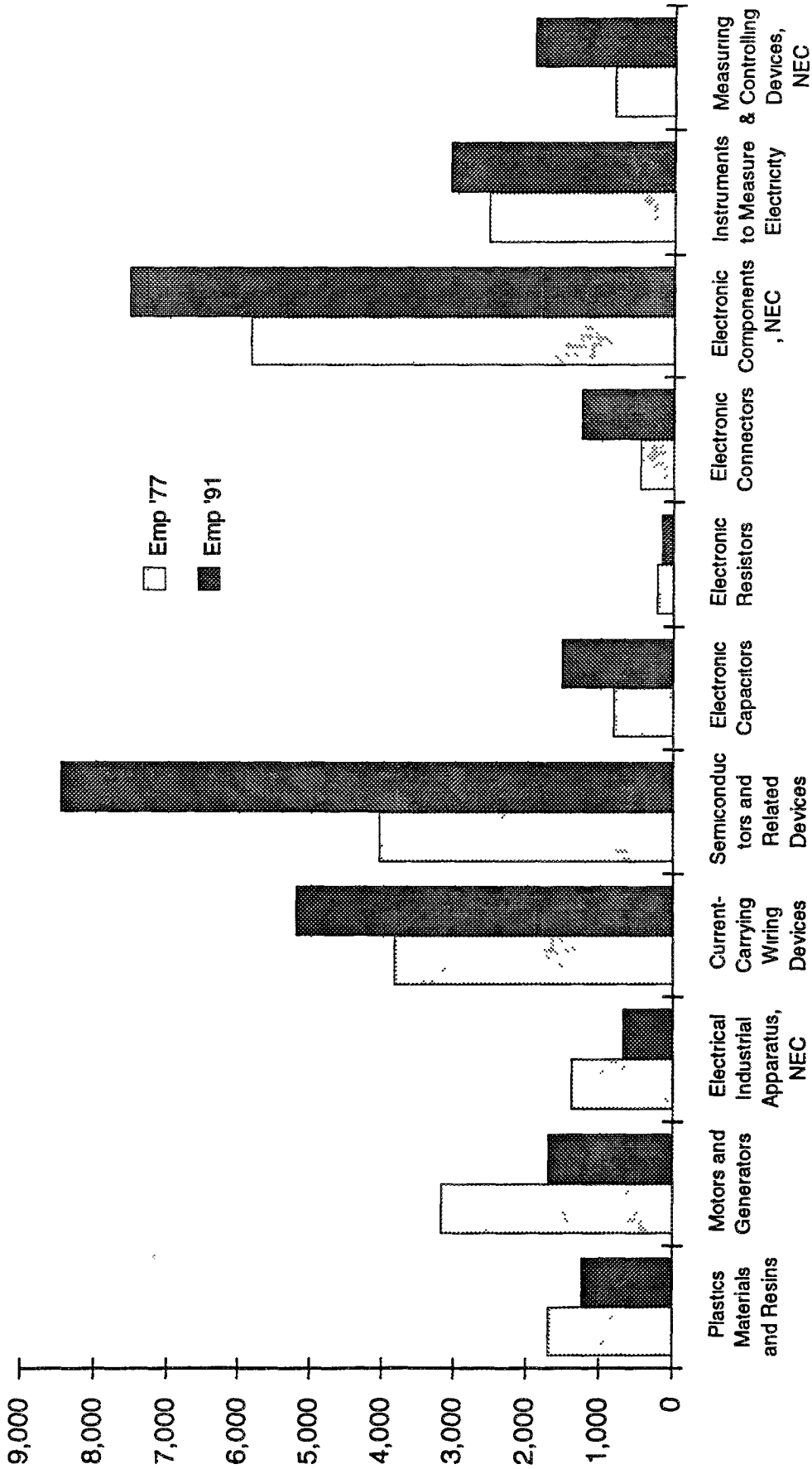
Sectors with Anticipated Increased Share of Inputs for Electrical Vehicle Production
Recent Employment Trends, L. A. County, 1977-91



Source EDD, ES-202 File

Figure 4.11

Los Angeles Anticipated Auto Industry Sectors
 Employment Distribution by 4-Digit SIC
 1977 Total = 25,038; 1991 Total = 32,943



Source EDD, ES-202 File

Table 4.1
Employment Size Distribution of Auto Industry Establishments
Los Angeles County, 1989

Industry	Emp89	Est89	1-9	10-19	20-49	50-99	100-249	250-499	500-999	1,000+
Auto & Apparel Trimmings	3,799	102	34	15	26	16	11	0	0	0
Tires and Inner Tubes	[D]	3	2	0	0	0	1	0	0	0
Automotive Stampings	1,500	14	5	2	5	1	0	0	0	1
Carburetors, pistons, etc	1,170	21	6	3	9	1	1	0	1	0
Vehicular Lighting Equip	244	3	0	0	1	1	1	0	0	0
Storage Batteries	1,296	13	4	1	2	2	1	3	0	0
Engine Electrical Equipment	[D]	20	7	7	2	1	3	0	0	0
Motor Vehicles and Car Bodies	[D]	10	3	4	1	0	0	1	0	1
Motor Vehicle Parts & Access	12,168	193	68	31	43	24	17	7	1	2
Total	20,177	379	129	63	89	46	35	11	2	4

Industry	Est89	Est89	1-9	10-19	20-49	50-99	100-249	250-499	500-999	1,000+
Auto & Apparel Trimmings	102	100 0%	33 3%	14 7%	25 5%	15 7%	10 8%	0%	0%	0%
Tires and Inner Tubes	3	100 0%	66 7%	0%	0%	0%	33 3%	0%	0%	0%
Automotive Stampings	14	100 0%	35 7%	14 3%	35 7%	7 1%	0%	0%	0%	7 1%
Carburetors, pistons, etc	21	100 0%	28 6%	14 3%	42 9%	4 8%	4 8%	0%	4 8%	0%
Vehicular Lighting Equip	3	100 0%	0%	0%	33 3%	33 3%	33 3%	0%	0%	0%
Storage Batteries	13	100 0%	30 8%	7 7%	15 4%	15 4%	7 7%	23 1%	0%	0%
Engine Electrical Equipment	20	100 0%	35 0%	35 0%	10 0%	5 0%	15 0%	0%	0%	0%
Motor Vehicles and Car Bodies	10	100 0%	30 0%	40 0%	10 0%	0%	0%	10 0%	0%	10 0%
Motor Vehicle Parts & Access	193	100 0%	35 2%	16 1%	22 3%	12 4%	8 8%	3 6%	5%	1 0%

Table 4.2
Employment Size Distribution of Auto Industry Establishments
United States, 1989

Industry	Emp89	Est89	1-9	10-19	20-49	50-99	100-249	250-499	500-999	1,000+
Auto & Apparel Trimmings	47,150	1,375	780	220	195	101	49	19	5	6
Tires and Inner Tubes	68,025	147	42	10	14	8	23	14	8	28
Automotive Stampings	122,318	688	89	100	143	137	137	48	11	23
Carburetors, pistons, etc	23,165	147	43	23	22	14	18	15	9	3
Vehicular Lighting Equip	16,164	70	10	5	21	8	10	9	4	3
Storage Batteries	23,247	172	54	13	17	18	29	38	1	2
Engine Electrical Equipment	64,273	450	154	68	67	48	65	26	12	10
Motor Vehicles and Car Bodies	246,643	393	154	62	52	28	25	12	5	65
Motor Vehicle Parts & Access	407,770	2,689	872	418	461	286	313	186	87	66
Total	1,018,755	6,131	2,198	909	992	648	669	367	142	206

Industry	Est89	Est89	1-9	10-19	20-49	50-99	100-249	250-499	500-999	1,000+
Auto & Apparel Trimmings	47,150	100 0%	56 7%	16 0%	14 2%	7 3%	3 6%	1 4%	4%	4%
Tires and Inner Tubes	68,025	100 0%	28 6%	6 8%	9 5%	5 4%	15 6%	9 5%	5 4%	19 0%
Automotive Stampings	122,318	100 0%	12 9%	14 5%	20 8%	19 9%	19 9%	7 0%	1 6%	3 3%
Carburetors, pistons, etc	23,165	100 0%	29 3%	15 6%	15 0%	9 5%	12 2%	10 2%	6 1%	2 0%
Vehicular Lighting Equip	16,164	100 0%	14 3%	7 1%	30 0%	11 4%	14 3%	12 9%	5 7%	4 3%
Storage Batteries	23,247	100 0%	31 4%	7 6%	9 9%	10 5%	16 9%	22 1%	6%	1 2%
Engine Electrical Equipment	64,273	100 0%	34 2%	15 1%	14 9%	10 7%	14 4%	5 8%	2 7%	2 2%
Motor Vehicles and Car Bodies	246,643	100 0%	39 2%	13 2%	13 2%	7 1%	6 4%	3 1%	1 3%	16 5%
Motor Vehicle Parts & Access	407,770	100 0%	32 4%	15 5%	17 1%	10 6%	11 6%	6 9%	3 2%	2 5%

Source: Department of Commerce, County Business Patterns, 1989 (Tape File)

Table 4.3
Employment Size Distribution of Potential E V. Auto Industry Establishments
Los Angeles County, 1989

Industry	Emp89	Est89	1-9	10-19	20-49	50-99	100-249	250-499	500-999	1,000+
Plastics Materials and Resins	1,081	25	6	5	4	8	2	0	0	0
Motors and Generators	0	22	8	5	4	2	2	1	0	0
Electrical Industrial Apparatus, NEC	1,767	33	17	4	5	3	1	3	0	0
Current-Carrying Wiring Devices	1,109	22	10	2	3	3	3	1	0	0
Semiconductors and Related Devices	4,398	45	15	8	7	4	6	3	1	1
Electronic Capacitors	2,202	17	2	2	4	3	3	1	2	0
Electronic Resistors	669	6	0	0	3	1	1	1	0	0
Electronic Connectors	3,594	27	6	4	3	2	9	2	0	1
Electronic Components, NEC	7,680	163	58	27	28	26	21	3	0	0
Instruments to Measure Electricity	3,329	41	15	9	6	4	4	1	1	1
Control Devices, NEC	1,304	45	21	6	10	6	2	0	0	0
Total	27,133	446	158	72	77	62	54	16	4	3

Industry	Est89	Est89	1-9	10-19	20-49	50-99	100-249	250-499	500-999	1,000+
Plastics Materials and Resins	25	100 0%	24 0%	20 0%	16 0%	32 0%	8 0%	0%	0%	0%
Motors and Generators	22	100 0%	36 4%	22 7%	18 2%	9 1%	9 1%	4 5%	0%	0%
Electrical Industrial Apparatus, NEC	33	100 0%	51 5%	12 1%	15 2%	9 1%	3 0%	9 1%	0%	0%
Current-Carrying Wiring Devices	22	100 0%	45 5%	9 1%	13 6%	13 6%	13 6%	4 5%	0%	0%
Semiconductors and Related Devices	45	100 0%	33 3%	17 8%	15 6%	8 9%	13 3%	6 7%	2 2%	2 2%
Electronic Capacitors	17	100 0%	11 8%	11 8%	23 5%	17 6%	17 6%	5 9%	11 8%	0%
Electronic Resistors	6	100 0%	0%	0%	50 0%	16 7%	16 7%	16 7%	0%	0%
Electronic Connectors	27	100 0%	22 2%	14 8%	11 1%	7 4%	33 3%	7 4%	0%	3 7%
Electronic Components, NEC	163	100 0%	35 6%	16 6%	17 2%	16 0%	12 9%	1 8%	0%	0%
Instruments to Measure Electricity	41	100 0%	36 6%	22 0%	14 6%	9 8%	9 8%	2 4%	2 4%	2 4%
Control Devices, NEC	45	100 0%	46 7%	13 3%	22 2%	13 3%	4 4%	0%	0%	0%

Source Department of Commerce, County Business Patterns, 1989 (Tape File)

employees, according to 1989 County Business Pattern data, while only seven establishments had more than 500 employees. Table 4.3 provides detailed employment size distributions for these establishments. It should be noted here that some of the 450 establishments, while open to the idea of shifting production into EV component production, expressed concern that they might lose advantages that accrued from specializing in certain aspects of production for the aerospace sector, for example. A general reluctance to change production techniques and risk investment in re-tooling was also noted, especially given the combined uncertainties of EV technological progress and a sluggish economy.

The potential for growth of other EV-related industries including batteries and fuel cells, composite materials, and plastics should not be overlooked. Other technologies for storing and generating energy in vehicles may also have significant impacts on the aerospace market as well. This would reinforce linkages between two traditional southern California industries - automobile assembly and aerospace.

4.3. Electric Vehicle Technology

This section presents a detailed discussion of emerging electric vehicle technology as one of the alternatives to existing automotive technologies, with the focus on differences in subsystems, materials and technology. Emphasis is also placed on describing the most significant components of an EV and evaluating each in light of its potential impacts on the motor-vehicle industry and its network of suppliers. In doing so, every attempt has been made to buttress assumptions with engineering data. However, given the rapidly shifting state of these technologies, and the lack of a production model to evaluate directly, we have adopted a heuristic approach where data are unavailable. The intent is to describe a possible EV in terms of its technology and illustrate the impacts of, not necessarily the pathways to, a re-configured automobile industry.

4.3.1. A Model Electric Vehicle

The electric vehicle which we describe here will provide the basis for the input-output analysis in Section 4.4. Since a production EV has not yet appeared on the market, we will rely in our analysis on the few prototypes that exist and the preliminary engineering details we have been able to glean from articles and in-person interviews. Primarily, we will rely on the data provided by CALSTART for its Showcase Electric Vehicle, as well as its components and subsystems.

For purposes of our analysis, we will assume the following salient features about the EV to be considered in our analysis:

- 1) A two-passenger, commuter-type vehicle with a range of 100 miles at 55 MPH and a curb weight of about 1800 pounds;
- 2) Monocoque construction with lightweight aluminum frame and chassis, and composite/plastic body parts and underbody panel (to reduce drag);
- 3) Brushless DC motor, nine lead-acid batteries, a regenerative braking system, battery monitor

system, motor controller for performance optimization, and an on-board inductive charging system;

- 4) Safety systems including seat-belts, shoulder harnesses, dual airbags;
- 5) Specially designed, low-rolling resistance tires;
- 6) Passive HVAC system of heated seats, fans, etc.
- 7) Wherever possible, throughout the vehicle, materials have been selected which are lightweight, durable, and recyclable.

Table 4.4 provides a comparison of the anticipated impact of EV technology in terms of the percentage change in part/material use compared to an existing ICE vehicle of a similar configuration (i.e. a domestic Sub-compact). These are primarily estimates based on the number and total weight of various components per vehicle, and the percent change was used to calculate impacts on the input-output coefficients (see Section 4.4 and the Appendices to this chapter on methodology). Table 4.5 presents, by SIC code, those components and subsystems which would be redundant in an electric vehicle. As shown, the major impacts are in SIC 3714, motor vehicle parts and accessories, but these impacts might be mitigated by a thriving EV industry as manufacturers sought to differentiate models based on special features and accessories. For example, the CALSTART vehicle would feature an audio navigation system which employs an on-board CD player to "give verbal instructions to the driver." In addition, fax machines, car phones, passenger-side video systems, and advanced safety innovations could be installed to further enhance the attractiveness of the EV, all of which would stimulate local components production and after-market manufacturers.

Table 4.6 details some of the more significant ICE vehicle components that could be modified for electric vehicles, weighted by degree of difficulty required to make those modifications. A substantial modification would involve a significant technological, material or process change (or some combination thereof), while a minimal modification might require a simple shift in a material or minor design change. As shown, a majority of modifications are minimal to moderate, involving (in most cases) minor material changes, redesign or reconfiguration.

It is important to emphasize that the range of technologies indicated here is limited by the shifting nature of those technologies and the need to establish a baseline for analysis. Alternative fuel vehicles, in general, and EVs in particular, remain full of promise for further innovation and improvement, hence the potential impacts are difficult to discern. For example, fuel cells and super-capacitors may provide cheaper, lighter, and more efficient power than the current lead-acid battery technology, but the high-technology nature of the former choices would dictate markedly different labor skills, materials, and manufacturing processes.

The positive impacts of an EV industry must be evaluated in terms of employment, production organization, technology, and environmental developments. For example, Table 4.7 lists those SIC codes that would be positively impacted by a significant EV assembly industry. These would include electronic or electrical parts and assemblies, as well as batteries, plastics, composites, sensors, and special instruments. However, an EV components industry in Southern California might provide significantly more employment opportunities for skilled workers, higher wages, and regional multiplier effects than an EV industry organized solely around assembly. In addition, the legislated mandates to provide increasing numbers of alternate fuel vehicles in the state, combined with federal Clean Air Act requirements, provides the incentive (i.e. the

Table 4.4 Comparison of EV Technology with ICE Vehicles

Input-Output Code	Description	% Change (ICE - EV)
270402	Adhesives and sealants	-80
280100	Plastics materials & resins	600
320400	Misc. plastic products	25
320500	Rubber/plastic hose & belts	-75
361800	Gaskets	-95
381000	Non-ferrous wire drwg/insul.	30
381100	Aluminum castings	40
381400	Non-ferrous forgings	25
410100	Screw machine products	15
410201	Automotive stampings	-75
420700	Steel springs, except wire	25
500001	Carburetors, pistons, rings	-100
530400	Electric motors/generators	100
550300	Wiring devices	40
530200	Transformers	100
530100	Instruments/measure electric	100
570200	Semiconductors	500
570300	Electronic components, n.e.c.	45
580100	Storage batteries	900
580400	Engine electrical equip.	-
590301	Motor vehicles & car bodies	-
590302	MV parts and accessories	-42
620200	Mechanical measuring devices	-90
270104	Industrial inorganic chemicals	200
430200	ICEs, n.e.c.	-100
350100	Glass, glass products	-15
320100	Tires, inner tubes	-
420300	Hardware, n.e.c.	20
421100	Fabricated metal prods., n.e.c.	-
190304	Automotive trimmings	-10
320302	Fabricated rubber, n.e.c.	10
520300	HVAC equipment	-20
490300	Blowers and fans	10
530700	Carbon & graphite products	300
370101	Blast furnaces/steel mills	-70
370103	Steel wire & related products	-
370200	Iron & steel foundries	-70
370300	Iron & steel forgings	-70
530800	Battery chargers	168

Table 4.5 Redundant Components in an EV-Dominated Auto Industry

SIC CODE	Component
3714	Camshafts
3694	Ignition Coils
3714	Connecting Rods
3714	Crankshaft Assemblies
3714	Internal Combustion Engines and Parts
3714	Fuel Pumps
3714	Fuel System, Lines, and Parts
3829	Gauges, Not electrical
3694	Ignition Wire Sets
3714	Manifold and Exhaust Components
3592	Pistons and Rings
3714	Mufflers and Catalytic Converters
3714	Radiators
3694	Spark Plugs
3714	Oil Filter, Oil Pump and Cooler
3824	Vehicle Tank Meters
3714	PCV Valves

Sources: Personal Interviews at Amerigon, Inc., Burbank, CA

initial market) for production. Finally, if Southern California were to translate its high technology capabilities into an EV industry for the region and were then to supply other environmentally impacted cities, like Mexico City or Sao Paolo, the impacts on the local economy could be enormous. How the industry takes shape and which technologies become predominant will determine, in large measure, the region's development trajectory and economic future.

4.3.2. Materials/Process Technology

This section provides an overview of some of the changes that have occurred in the materials and processes used in automotive manufacture, and suggests some of the possible technologies that might be employed in a reconfigured automobile industry centered on the EV.

The introduction of lightweight materials in automobile production was largely a response to the oil-shocks of the early 1970s and the increased concern with vehicle fuel efficiency. In the mid-1970s, for example, the Ford Motor Company began its Lightweight Vehicle Program to study the technical feasibility of substituting composite materials in automotive components with an eye to decreasing overall vehicle weight and improving fuel-efficiency. As shown in Table 4.8, average vehicle weight has in fact declined with the shift to lighter, stronger materials. The use of plain carbon steel and cast iron, for example, fell over 50% between 1977

Table 4.6 ICE Vehicle Components Requiring Modification for EVs**Modification Required:**

1 -Minimal; 2 -Moderate; 3 -Substantial;

Modifications	SIC	Component
3	3711	Automotive Chassis, Body panels (Shift to Composites, Lightweight Metals)
2	3499	Seat Frames, Metal (Re-design; Shift to lightweight material)
1	2531	Seats, Cushions (Lighter fill materials)
1	3714	Wiring Harness (not ignition) (Re-design; Configure for AC/DC systems)
2	3714	Brakes (Re-design, electrical)
3	3585	Air Conditioning System (Re-design:lightweight, non-CFC, electric)
3	3714	Suspension, struts, shocks (Re-design: light metals/composites)
1	3714	Bumpers (Lightweight, aerodynamic)
1	3629	Battery Chargers (Modify for on-board/public access)
2	3691	Storage Batteries (Reduce size, reconfigure)
3	3629	Capacitors (Optimize, super-capacitor/storage dev.)
2	3621	Electric Motors (Optimize, brushless AC)
1	3564	Fans & Blowers (Re-design; low-power draw)
1	301	Tires (Redesign for lower rolling resistance)

Table 4.7 Industrial Sectors with Increased Share of Automotive Inputs with EV Dominant

SIC CODE	Component
3674	Semiconductors
3674	Photovoltaic Devices
3675	Electronic Capacitors, Super-capacitors
3676	" " Resistors
3678	" " Connectors
3679	" " Components, N.E.C.
3691	Storage Batteries, Lead-acid
2821	Plastics Materials & Resins
3621	Motors & Generators, Electric
3825	Instruments to Measure Electricity
3829	Measuring & Controlling Devices
3694	Engine Electrical Equipment; Voltage Regulators
3629	Power Converters, Battery Chargers
3643	Switches, Panels, Etc. (Current-Carrying Devices)
3674	Sensors (Position, Motion, Temperature, Voltage, etc.)

Table 4.8 Selected Material Requirements by Weight for Typical Production ICE Vehicles, 1977 and 1985

Material	Finished Weight (lb/car)	
	1977	1985
Aluminum	126	140
Plain Carbon Steel	2,478	1,200
High Strength Steel	126	300
Cast Iron	714	315
Plastics	210	245
Magnesium	---	4
Other	546	382
TOTAL	4,200	2,586

Source: American Society of Mechanical Engineers, 1984: **The Impacts of Material Substitution on the Recyclability of Automobiles**. New York: ASME. (pp. 26-27).

and 1985, while lighter materials such as aluminum, magnesium, and plastics increased over the same period.

The impacts of material substitution exacerbated the decline of the U.S. iron and steel industry during that decade, as the demand shifted away from cast iron and steel towards new materials and production techniques. Table 4.9 shows declining steel shipments to the auto industry and the percentage of total U.S. demand for the period 1971 to 1981. Graphite composites, new types of plastic, and improved plastic forming processes (e.g. injection molding) contribute less weight and provide improved durability to automotive parts, and continue to be used in automotive production on a large scale. Powdered steels and carbon fibers, lighter and easier to form into complex curves (for improved aerodynamics), are increasingly being used wherever strength and durability are called for.

Research and development work on composites performed for the aerospace industry may prove to have significant applications for an emerging electric vehicle industry. The B-2 "stealth" bomber and the F-19 fighter, for example, both employ advanced plastics and metal composite materials. Defense contractors, as a result, have acquired valuable production expertise in handling, shaping, and forming these materials. Vehicle weight and aerodynamic performance are perhaps the two most significant factors in electric vehicle design, given that every extra pound translates into reduced range. Composites provide engineers and designers with a wider range of structural materials that can be shaped with relative ease into the more aerodynamic lines required for improved range and performance.

Finally, material recyclability has become an issue as environmental concerns have been forced onto automobile manufacturers. A European consortium has evolved to deal with the increasing problem of scrapped vehicles and BMW has recently announced that it will begin a pilot vehicle recycling program in the U.S., wherein owners will be paid a premium for returning their automobile to the manufacturer for disposal. This would involve marking products with a consistent coding system to differentiate materials used in production.

A multitude of plastics with varying characteristics have been developed that are not only safer, stronger, and cheaper, but also are easier to recycle than conventional metals. The plastics industry, in addition, has been instrumental in adapting newer, lighter materials to automotive production, and the emerging EV industry, where plastics are essential in weight-saving strategies, is certain to provide an expanding market for its products. From door panels to seat frames, plastics are increasingly employed for their weight and durability. As material technology advances in tandem with new processes such as plastic rotomolding and gas-injection, the idea of plastic vehicles (with imbedded steel crash-bars, for example) seems less and less impractical.

In presenting the technological aspects of the EV and its potential development, we have been restrained by a limited range of options based on existing or emerging technologies. As EV technology becomes more sophisticated and today's possibilities become realities, the potential for further innovation and industrial expansion also increases. What this portends for the regional economy becomes more difficult to assess, due to the uncertainties inherent in a rapidly evolving set of technologies.

Table 4.9 Auto Industry Share of U.S. Steel Demand, 1971-1981

Year	Steel Shipments to Auto Industry (1000 tons)	Percent of Total US Demand
1971	17,483	20.1
1972	18,217	19.8
1973	23,217	20.8
1974	18,928	17.3
1975	15,214	19.0
1976	21,351	23.9
1977	21,490	23.6
1978	21,253	21.7
1979	18,623	18.5
1980	12,124	14.5
1981	13,154	15.1

Source: American Society of Mech. Engineers, 1984. Ibid., p.27.

4.4. An Input-Output Analysis Of The Economic Impacts Of Electric Vehicle Production In Los Angeles

In this section, input-output analysis is employed to examine the structure of the Los Angeles automobile industry and the likely impacts of the production of electric vehicle components and motor-vehicles upon the local economy. The analysis is separated into two stages. First, input-output data are used to reveal the under-developed state of automobile production in Los Angeles in relation to the nation. This analysis complements the material of Section 4.2, providing a more detailed investigation of automobile industry linkages and component production in Los Angeles county. Second, employment multipliers are calculated for automobile assembly and component production in Los Angeles and the nation under different scenarios of technology and market share. This stage of the investigation uses the

electric vehicle technology specified in Section 4.3 to reveal the likely economic impacts of electric vehicle production upon the Los Angeles economy. The economic impacts are measured chiefly in terms of employment. Appendices 4.1 to 4.2 of this chapter provide a brief outline of the methodology of input-output analysis and the data employed in this study.

4.4.1. Automobile Assembly and Parts Production in Los Angeles and the Nation

In 1985, the number of automobiles produced in the United States was 8.1 million units.³ Using output data from the Annual Census of Manufacturing and price information from the Survey of Current Business, we estimate that Los Angeles produced about 160,000 automobiles in 1985. This represents about 1.98% of national production. In the same year, U.S. domestic automobile employment registered about 338,161 with Los Angeles contributing approximately 1.84% of national employment. With almost 3.5% of the nation's population concentrated in Los Angeles in 1985, and using population as a surrogate for demand, the size of the automobile sector in Los Angeles appears to be significantly under-represented relative to the nation.

Section 4.2 outlined various aspects of the stunted development of automobile production in Los Angeles. Tables 4.10 and 4.11 below, confirm this relative underdevelopment, revealing the flow of inputs from each (2-digit SIC) manufacturing sector into motor-vehicle assembly (SIC 3711) in the U.S. as a whole and in Los Angeles county. In Table 4.10 the inputs are all manufactured within the U.S. and in Table 4.11 the inputs counted are all manufactured within Los Angeles. These data are taken from input-output accounts of the national economy for 1982 and similar accounts for Los Angeles county in 1985. Some caution must be exercised in drawing conclusions from comparison of these tables for the data are drawn from years that represent very different stages of the business cycle. Input-output coefficients for 1982 may be inflated as fixed costs are spread over fewer units of output. The reader should also recall that in 1992 the last major automobile assembly plant located in Los Angeles closed. The data discussed below predate this closure.

Table 4.10 details the dollar value of direct manufacturing inputs into the U.S. motor-vehicle assembly industry for each million dollars worth of output. These figures are based on the production of conventional (internal combustion engine) automobiles. Each million dollars of output in the national motor-vehicle assembly industry requires manufactured inputs totalling \$568,381. Additional inputs of non-manufactured goods are also required for auto assembly in the U.S. as are inputs of manufactured goods from outside the nation. As may be expected, the motor-vehicle parts and accessories sector is the chief source of inputs into auto assembly, responsible for some 36% of all manufactured inputs. The other key manufacturing inputs originate in the fabricated metals industry (15.6% of the total), the motor-vehicle assembly sector itself (12% of the total), the rubber and miscellaneous plastics sector (8.5 of the total), the machinery (7.2% of the total), the electrical equipment (5.8% of the total) and the textile (4.5% of the total) industries.

Table 4.11 shows the value of manufactured inputs produced in Los Angeles that are sold

³ U S Department of Commerce Survey of Current Business, 1989

**Table 4.10: Direct Inputs per \$1 Million of Output for Motor
-Vehicle and Car Bodies (SIC 3711) in the U.S., 1982**

CURRENT TECHNOLOGY
(Internal Combustion Engine)

SIC	INDUSTRY	INPUTS PER \$1M OUTPUT
3711	Motor Vehicles & Car Bodies	68,244
3714	Motor-Vehicle Parts & Accessories	204,524
3713 (&3715)	Other Motor-Vehicles & Equipment	2,961
20	Food & Kindred	36
21	Tobacco Manufactures	0
22	Textile Mills	25,810
23	Apparel	115
24	Lumber & Wood Products	91
25	Furniture	1,601
26	Paper & Allied Products	1,552
27	Printing & Publishing	5,286
28	Chemicals & Chemical Products	8,577
29	Petroleum Refining and Related Industries	4,450
30	Rubber & Miscellaneous Plastics Products	48,046
31	Leather & Shoes	49
32	Stone, Clay & Glass Products	8,915
33	Primary Metals	15,565
34	Fabricated Metal Products	88,605
35	Machinery	40,791
36	Electrical Equipment	32,707
372-9	Transportation Equipment (not Motor-Vehicles)	4,429
38	Instruments	5,298
39	Miscellaneous Manufacturing	729

TOTAL MANUFACTURING INPUTS 568,381
PER \$1 MILLION OUTPUT OF
MOTOR-VEHICLES

Motor-Vehicle Assembly (SIC 3711) output in the U.S. 1982,
approximately \$71.15 Billion

**Table 4.11: Direct Inputs per \$1 Million of Output for Motor
-Vehicle and Car Bodies (SIC 3711) in Los Angeles county,
1985**

CURRENT TECHNOLOGY
(Internal Combustion Engine)

SIC	INDUSTRY	INPUTS PER \$1M	% NATIONAL OUTPUT
3711	Motor Vehicles & Car Bodies	24,258	35.55
3714	Motor-Vehicle Parts & Accessories	97,573	47.71
3713	Other Motor-Vehicles and Equipment (&3715)	2,345	82.24
20	Food & Kindred	5	13.89
21	Tobacco Manufactures	0	na
22	Textile Mills	25,905	100.37
23	Apparel	472	410.43
24	Lumber & Wood Products	79	86.81
25	Furniture	2,030	126.80
26	Paper & Allied Products	351	22.62
27	Printing & Publishing	6,022	113.92
28	Chemicals & Chemical Products	2,131	24.85
29	Petroleum Refining & Related Industries	1,435	32.35
30	Rubber & Miscellaneous Plastics Products	578	1.20
31	Leather & Shoes	48	97.96
32	Stone, Clay & Glass Products	9,268	103.96
33	Primary Metals	2,965	19.05
34	Fabricated Metal Products	40,280	45.46
35	Machinery	11,810	28.95
36	Electrical Equipment	15,180	46.41
372-9	Transportation Equipment (not Motor-Vehicles)	3,248	73.33
38	Instruments	2,134	40.28
39	Miscellaneous Manufacturing	457	62.69
TOTAL MANUFACTURING INPUTS PER \$1 MILLION OUTPUT OF MOTOR-VEHICLES		248,577	43.73

Motor-Vehicle Assembly (SIC 3711) output in Los Angeles 1985,
approximately \$(82) 2.2 Billion

to the Los Angeles motor-vehicle assembly industry for each million dollars of output. On average, manufactured goods produced in Los Angeles county represent only 43.7% of the value of manufactured inputs that might be expected from national data to enter the local motor-vehicle assembly industry. This immediately suggests that the automobile assembly industry in Los Angeles is not closely linked to the local economy, as the discussion in Section 2 concluded.

Apart from five sectors, apparel, textiles, furniture, printing and publishing and leather, almost all manufacturing industries in Los Angeles supply significantly fewer inputs per unit of output to the local auto assembly sector than they do at the national level. Of particular concern is the under-developed nature of the links between the auto assembly industry and other key sectors of the local economy that have typically been found to have significant multiplier effects. These sectors include the motor-vehicle parts and accessories industry, the metal-working sectors, machinery and electrical equipment industries.

Table 4.11 shows the relatively small size of the automobile parts and accessories industry in Los Angeles. This is significant for, as reported in Section 4.2, a number of commentators have indicated that this industry is particularly strong within the Los Angeles economy. Tables 4.10 and 4.11 in fact reveal that in absolute terms, the motor-vehicle parts and accessories industry is the most under-developed of all manufacturing sectors in terms of local supply to auto assemblers relative to national trends. However, if we compare the ratio of output in the parts industry to output in the assembly industry for the nation and Los Angeles county we find ratios of 0.504 and 0.508 respectively. These figures indicate that more automobile parts are produced in Los Angeles than in the nation in relation to the output of assembled vehicles. We know from Tables 4.10 and 4.11 that these parts are not used directly in the local assembly industry. Thus, locally produced motor-vehicle parts and accessories are produced either for export from the region or for the after-market.

Another way of examining the relative development of the Los Angeles automobile industry complex is to examine the employment effects of final demand for motor-vehicles throughout the economy. Once more, we present such information for Los Angeles and also for the nation to provide a context for the local data. Table 4.12 presents direct and indirect employment associated with \$1 billion of final demand for motor-vehicles assembled in the U.S. The methods employed to calculate these data are discussed in Appendix 4.2 to the chapter. Table 4.13 presents similar data for Los Angeles. The multiplier values for Los Angeles county in 1985 are adjusted for the effects of inflation on final demand.

The total number of full-time jobs created for \$1 billion of final demand from the national motor-vehicle assembly industry is 23,722 (see Table 4.12). Of these, 3,663 jobs would be created directly in the motor-vehicle assembly industry, leaving 20,059 jobs indirectly generated throughout the rest of the economy. A detailed breakdown of employment by major sectors of the economy is provided in Table 4.12.

Total final demand for the output of the motor-vehicle assembly industry in 1982 was approximately \$64 billion. Thus, the total number of jobs in the U.S. motor-vehicle assembly industry is predicted to be 234,432. This figure accords relatively well with that in the Census of Manufactures (240,100). The difference is due to rounding error in the analysis as well as the use of Bureau of Labor Statistics employment figures that diverge somewhat from the Bureau of Economic Analysis data. Total U.S. employment resulting from all motor-vehicle assembly in 1982, both direct and indirect, is estimated to be 1,518,208. This represents approximately 1.8% of the overall U.S. workforce. The number of U.S. manufacturing jobs directly and

indirectly tied to the motor-vehicle assembly industry is 925,696 or 5.2% of all U.S. manufacturing employment. These figures accord well with past studies and confirm the central role the automobile industry plays in most industrialized economies.

Table 4.13 reveals that the reliance of the automobile industry in Los Angeles on imported components exerts a tremendous impact on the region in terms of potential job loss. For each (1982 constant) billion dollars of final demand for motor-vehicles produced in Los Angeles 9,360 workers are employed either directly or indirectly. This represents only 39.5% of the jobs generated in the nation for a similar volume of motor-vehicle output. From Table 4.13, regional direct employment in motor-vehicle assembly is slightly larger than the corresponding national figure. Once more, however, it appears that locally produced intermediate inputs comprise only a small proportion of all inputs into the Los Angeles automobile sector and thus local auto-related employment is well below average.

Some of the region's key manufacturing sectors whose automobile related employment is significantly under-represented, relative to the nation, include the rubber and miscellaneous plastics industry with regional employment per \$1 billion of automobile assembly some 98.78% below the national average, the primary metals industry (96.46% below the national average), the chemicals sector (93.42% below the national average), the machinery (86.38% below the national average) and electrical equipment industries (67.07% below the national average). It must be of some concern that these national growth industries are only weakly connected to automobile assembly activities in the Los Angeles region. With final demand from the Los Angeles auto industry of approximately \$2.1 billion (in 1982 dollars) in 1985, the input-output analysis reveals that in total 30,400 jobs are lost to the Los Angeles economy through purchasing imported inputs into the motor-vehicle industry rather than producing those inputs locally.

4.4.2. The Potential Economic Impacts of Electric Vehicle Production in Los Angeles

Using the description of EV technology from Section 4.3 it is possible to examine the employment effects of shifts in automobile production from conventional internal combustion vehicles to electric vehicles. Lacking clear data on market demand and price for EVs, the following analysis assumes that large volumes of EVs would have a similar price to the average current automobile and that they would be sold in similar quantities. In addition, these claims allow us to assume that as many EV units would be produced for the same \$1 billion of final demand as conventional automobiles. Once more we use the employment multiplier as the means of comparison between conventional and EV technology and also between national and regional employment effects.

The EV technology specified in Section 4.3 is used to estimate employment multipliers in the nation and in Los Angeles. Thus, rather than simply reconfiguring the existing automobile production systems of Los Angeles and the nation independently, to reflect a modified product, we assume that those production systems will be completely transformed. Most importantly, we assume that input coefficients into a new EV motor-vehicle assembly industry from the leading component sectors are identical in both Los Angeles and the nation. This implies that an EV manufacturing system will not evolve directly from the current automobile production nexus, but that it will involve many production sectors not previously

TABLE 4.12: Direct and Indirect Employment per \$1 Billion of Final Demand for Motor-Vehicles and Car Bodies (SIC: 3711), U.S., 1982

CURRENT TECHNOLOGY (Internal combustion engine)

SIC	INDUSTRY	EMPLOYMENT
	Total Direct & Indirect Employment	23722
2	Manufacturing Total	14464
3711	Motor Vehicles & Car Bodies	3663
3714	Motor Vehicle Parts & Accessories	2312
3713	Other Motor Vehicles & Equipment	36
	(&3715)	
20	Food & Kindred Products	25
21	Tobacco Manufactures	1
22	Textile Mills	603
23	Apparel	9
24	Lumber & Wood Products	88
25	Furniture	45
26	Paper & Allied Products	148
27	Printing & Publishing	333
28	Chemicals & Chemical Products	304
29	Petroleum Refining & Related Industries	31
30	Rubber & Miscellaneous Plastics Products	817
31	Leather & Shoes	22
32	Stone, Clay & Glass Products	255
33	Primary Metals	1553
34	Fabricated Metal Products	1815
35	Machinery	1329
36	Electrical Equipment	817
372-9	Transportation Equipment (not Motor-Vehicles)	84
38	Instruments	131
39	Miscellaneous Manufacturing	42
1-10	Primary Activities	423
11	Construction	218
65-68	Transportation, Communication & Utilities	1668
69	Wholesale & Retail Trade	3284
70-77	Services	2773
78-79	Government Enterprises	892

TABLE 4.13: Direct and Indirect Employment per \$1 Billion of Final Demand for Motor-Vehicles and Car Bodies (SIC: 3711), Los Angeles, 1985

CURRENT TECHNOLOGY (Internal combustion engine)

* Final Demand deflated to \$1982 constant *

SIC	INDUSTRY	EMPLOYMENT	% NATIONAL
	Total Direct & Indirect Employment	9360	39.45
2	Manufacturing Total	7221	49.96
3711	Motor Vehicles & Car Bodies	3786	103.36
3714	Motor Vehicle Parts & Accessories	1344	59.43
3713	Other Motor Vehicles & Equipment (&3715)	34	94.44
20	Food & Kindred Products	2	8.00
21	Tobacco Manufactures	0	na
22	Textile Mills	477	79.10
23	Apparel	17	188.89
24	Lumber & Wood Products	10	11.36
25	Furniture	38	84.44
26	Paper and Allied Products	16	10.08
27	Printing & Publishing	106	31.83
28	Chemicals & Chemical Products	20	6.58
29	Petroleum Refining & Related Industries	11	35.48
30	Rubber & Miscellaneous Plastics Products	10	1.22
31	Leather and Shoes	6	27.27
32	Stone, Clay & Glass Products	154	60.39
33	Primary Metals	55	3.54
34	Fabricated Metal Products	587	32.34
35	Machinery	181	13.62
36	Electrical Equipment	269	32.93
372-9	Transportation Equipment (not Motor-Vehicles)	46	54.76
38	Instruments	44	33.59
39	Miscellaneous Manufacturing	11	26.19
1-10	Primary Activities	15	3.55
11	Construction	27	12.39
65-8	Transportation, Communication & Utilities	357	21.40
69	Wholesale & Retail Trade	529	16.11
70-7	Services	1123	40.50
78-9	Government Enterprises	88	9.87

TABLE 4.14: Direct and Indirect Employment per \$1 Billion of Final Demand for Motor-Vehicles and Car Bodies (SIC: 3711), U.S., 1982

ELECTRIC VEHICLE TECHNOLOGY

SIC	INDUSTRY	EMPLOYMENT
	Total Direct & Indirect Employment	19615
2	Manufacturing Total	11524
3711	Motor Vehicles & Car Bodies	3658
3714	Motor Vehicle Parts & Accessories	1343
3713	Other Motor Vehicles & Equipment (&3715)	36
20	Food & Kindred Products	22
21	Tobacco Manufactures	0
22	Textile Mills	550
23	Apparel	8
24	Lumber & Wood Products	73
25	Furniture	45
26	Paper & Allied Products	134
27	Printing & Publishing	288
28	Chemicals & Chemical Products	328
29	Petroleum Refining & Related Industries	28
30	Rubber & Miscellaneous Plastics Products	855
31	Leather & Shoes	20
32	Stone, Clay & Glass Products	185
33	Primary Metals	886
34	Fabricated Metal Products	956
35	Machinery	1009
36	Electrical Equipment	1042
372-9	Transportation Equipment (not Motor-Vehicles)	76
38	Instruments	53
39	Miscellaneous Manufacturing	36
1-10	Primary Activities	345
11	Construction	178
65-8	Transportation, Communication & Utilities	1478
69	Wholesale & Retail Trade	3041
70-7	Services	2314
78-9	Government Enterprises	735

strongly connected to the automobile industry.

Table 4.14 reports the employment multiplier for \$1 billion (in 1982 dollars) of final demand for electric vehicles in the nation as a whole. We anticipate that the shift from the internal combustion vehicle to the electric vehicle will exert a significant negative effect on overall employment. The total direct and indirect employment in the nation associated with \$1 billion of final demand for EVs is 19,615, some 4,107 lower than for the current ICE automobile. With final demand in the range of \$70 billion throughout the early-to-mid 1980s, the overall employment loss associated with a wholesale shift of the U.S. automobile industry to electric vehicles is approximately 287,000 workers.

At the industry level, the sectors suffering the largest absolute drops in auto-related employment with the shift to EVs include metal-working, machinery and automotive components. Conversely, the chemicals, rubber and plastics and electrical equipment industries stand to gain significant numbers of jobs with the development of the electric vehicle.

Table 4.15 examines the employment effects of the shift from ICE automobiles to electric vehicles in the economy of Los Angeles. The figures in Table 4.15 show the employment generated in the key sectors of this region's economy for \$1 billion (in 1982 dollars) of final demand for EVs. Table 4.15 reveals that, unlike the employment trend at the national level, a shift of production from conventional automobiles to electric vehicles would add employment in Los Angeles. Indeed, for every billion dollars of final demand, EV production could generate as many as 862 additional jobs within the Los Angeles economy compared with the production of current technology (ICE) motor-vehicles.

If Los Angeles captured market share with the shift to EV production, the employment effects could be significant. For example, Los Angeles' current national domestic market share is approximately 2%. Thus, over 430 jobs could be added to the local economy for each one percent of market share captured.

The analysis to this point assumes that Los Angeles will produce about 160,000 electric vehicles, a number based upon conventional automobile output in 1985. Currently, there are no major motor-vehicle assembly plants operating in Los Angeles county and thus the direct and indirect employment gains of producing any significant volume of electric vehicles would be significant. Perhaps a better indication of the potential market demand for electric vehicles may be taken from the California Air Resources Board (CARB) mandate that a certain proportion of all new vehicles sold in the state of California should be zero-emission vehicles. CARB requires by 1998 that 2% of all new vehicles sold in the state of California should be zero-emission. With almost 2 million new vehicles sold each year in the state of California, this mandate requires the production and sale of approximately 40,000 zero-emission or electric vehicles. CARB further mandates 5% of all new vehicles sold in 2001 (approximately 100,000 vehicles) and 10% of all new vehicles sold in 2003 (approximately 200,000 vehicles) be zero-emission. Table 4.16 examines the potential employment that would be generated if industries in Los Angeles produced electric vehicles to meet the CARB requirements for zero-emission new vehicle sales.

Using the highest CARB requirement of 10% zero-emission new vehicle sales in California by 2003, Table 4.16 shows that if Los Angeles county produced electric vehicles to meet this volume of market demand, approximately 24,300 jobs would be created in the local area. Over 18,000 new manufacturing jobs would result from the local production of electric vehicles, the bulk of these, about 11,500 jobs in motor-vehicle assembly, parts and accessories

TABLE 4.15: Direct and Indirect Employment per \$1 Billion of Final Demand for Motor-Vehicles and Car Bodies (SIC: 3711), Los Angeles, 1985

ELECTRIC VEHICLE TECHNOLOGY

* Final Demand deflated to \$1982 constant *

SIC	INDUSTRY	EMPLOYMENT	% NATIONAL
	Total Direct & Indirect Employment	10222	52.11
2	Manufacturing Total	7916	68.69
3711	Motor Vehicles & Car Bodies	3384	92.50
3714	Motor Vehicle Parts & Accessories	1459	108.63
3713	Other Motor Vehicles & Equipment (&3715)	30	83.33
20	Food & Kindred Products	2	9.09
21	Tobacco Manufactures	0	na
22	Textile Mills	386	70.18
23	Apparel	19	237.50
24	Lumber & Wood Products	11	15.07
25	Furniture	33	73.33
26	Paper & Allied Products	23	17.16
27	Printing & Publishing	105	36.46
28	Chemicals & Chemical Products	64	19.51
29	Petroleum Refining & Related Industries	17	60.71
30	Rubber & Miscellaneous Plastics Products	596	69.71
31	Leather & Shoes	4	20.00
32	Stone, Clay & Glass Products	87	47.07
33	Primary Metals	103	11.63
34	Fabricated Metal Products	593	62.03
35	Machinery	60	5.95
36	Electrical Equipment	850	84.24
37	Transportation Equipment (not Motor-Vehicles)	42	55.26
38	Instruments	34	64.15
39	Miscellaneous Manufacturing	14	38.89
1-10	Primary Activities	22	41.51
11	Construction	33	91.67
65-8	Transportation, Communication & Utilities	397	26.86
69	Wholesale & Retail Trade	532	17.49
70-7	Services	1222	52.81
78	Government Enterprises	100	13.61

TABLE 4.16: Direct and Indirect Employment in Los Angeles Industry Necessary to Produce Electric Vehicles to meet the California Air Resource Board Zero-Emission New Vehicle Sales in the State of California

ELECTRIC VEHICLE TECHNOLOGY

SIC	INDUSTRY	EMPLOYMENT		
		2% EVs	5%EVs	10%EVs
	Total Direct & Indirect Employment	4863	12156	24306
2	Manufacturing Total	3766	9415	18830
3711	Motor Vehicles & Car Bodies	1610	4025	8050
3714	Motor Vehicle Parts & Accessories	694	1735	3470
3713	Other Motor Vehicles & Equipment (&3715)	14	35	70
20	Food & Kindred Products	1	3	6
21	Tobacco Manufactures	0	0	0
22	Textile Mills	184	460	920
23	Apparel	9	23	46
24	Lumber & Wood Products	5	13	26
25	Furniture	16	40	80
26	Paper & Allied Products	11	28	56
27	Printing & Publishing	50	125	250
28	Chemicals & Chemical Products	30	75	150
29	Petroleum Refining & Related Industries	8	20	40
30	Rubber & Miscellaneous Plastics Products	284	710	1420
31	Leather & Shoes	2	5	10
32	Stone, Clay & Glass Products	41	103	206
33	Primary Metals	49	123	246
34	Fabricated Metal Products	282	705	1410
35	Machinery	29	73	146
36	Electrical Equipment	404	1010	2020
37	Transportation Equipment (not Motor-Vehicles)	20	50	100
38	Instruments	16	40	80
39	Miscellaneous Manufacturing	7	18	36
1-10	Primary Activities	10	25	50
11	Construction	16	40	80
65-8	Transportation, Communication & Utilities	189	473	946
69	Wholesale & Retail Trade	253	633	1266
70-7	Services	581	1453	2906
78	Government Enterprises	48	120	240

production. Significant numbers of jobs would also be added in the rubber and miscellaneous plastics, fabricated metal products and electric equipment sectors. If Los Angeles county had no EV assembly and specialized solely in components production 10,000 manufacturing jobs would be added to the region's economic base.

4.5. Conclusion

An integrated automobile manufacturing complex has never really existed in Los Angeles. The data examined in this chapter reveal that the region's auto-assembly sector has long relied on the import of parts and accessories from outside the local economy. However, a well-developed automotive components sector has developed in Los Angeles geared towards specialized local demand particularly related to aftermarket sales. This automobile parts and accessories sector is large and apparently relatively robust, despite the closure of the region's last remaining assembly plant. This well-developed auto parts industry coupled with the dynamism of the region's high technology industrial base, particularly the electronics, machinery and plastics sectors, suggests to us that the region possesses the technology and skilled labor needed to produce electric vehicles and their components.

Our analysis reveals that significant numbers of jobs could be created in the Los Angeles area if local producers targeted the electric vehicle industry. If the region produced the EVs necessary to meet the state's compliance with CARB's mandate of 10% zero-emission new vehicles by 1993, Los Angeles could capture over 24,000 jobs. Over 18,000 of these jobs would be added to the manufacturing base of Los Angeles representing a net addition to the local production workforce not far short of 5%. The balance would be in services. These represent significant job gains by any measure.

Appendix 4.1

Methods and Data

Investigation of the impact of alternative automobile technologies on U.S. employment is conducted with the technique of input-output analysis. This section of the report presents the methodological bases of input-output analysis and identifies the sources and particulars of the data employed in the analysis. A mathematical description of the input-output technique and the analysis to be conducted in this report is provided in Appendix 4.2 of this report.

A 4.1.1. Input-Output Analysis: A Brief Introduction

Input-output analysis is a framework designed to examine the inter-industry flows of commodities throughout an economy⁴. The input-output method divides an economy into a series of sectors or industries and measures the flows of goods and services between them. An industry may be thought of as a group of firms producing the same or a similar mix of outputs. The technique of input-output recognizes that to engage in production an industry consumes a variety of inputs including raw materials, semi-finished or intermediate goods, capital equipment and labor. These materials must be purchased within the economy or imported from outside. Input-output analysis provides a structured accounting system that records the purchase of inputs within each industry in an economy over a set period of time, usually a year. In addition, input-output analysis also records the sales by each industry to all other sectors within the economy, including sales to consumers and the government, as well as exports. The non inter-industry sales represent consumption by final demand.

The foundation of input-output analysis is the transactions table, a matrix which records the sales and purchases made between all sectors within the economy. An example of a typical transactions table is presented below. The heart of the transactions table is the inter-industry portion of the matrix, the shaded area in Figure A4.1, that illustrates the flow of goods between the "producing" industries of the economy. Each row of the transactions table shows how the output of a particular industry is distributed amongst the other producing sectors, as well as elements of final demand. The sum of the elements along any row for a producing sector in the transactions table records the total output of the corresponding row industry for the stated time period. The columns of the transactions table record the inputs used by each industry in the production of their output. The sum of the values in a producing industry column equals the total value of inputs purchased by an industry in a given period of time.

As well as illustrating flows between producing industries, the transactions table also records the non-industrial inputs to production, chiefly value added or payment to labor, and also inputs such as government services. In addition, the transactions table keeps track of sales made outside the producing sector of the economy, to elements of final demand. Final demand is defined as purchases made for the intention of consumption rather than further processing of commodities, and includes personal consumption expenditure, purchases by government, purchases for investment and export.

A 4.1.2. Assumptions of Input-Output Analysis

The techniques of input-output analysis rest upon a number of critical assumptions regarding the nature of technology in an economy, the capacity of the system to produce different quantities of output and the nature of industrial linkages. The first, and perhaps most important, assumption is that the production technology is one of fixed proportions (Leontief technology), or that there are no economies of scale in production. Thus, in an input-output world, an industry would have to double all inputs in order to double its output. The fixed proportions technology assures that the flow of goods between two sectors of the economy depends on the technology and the

⁴ Useful reviews of input-output analysis are provided by
Leontief, W 1966 *Input-Output Economics* New York Oxford University Press
Miller, R E and P.D Blair 1985 *Input-Output Analysis* Englewood Cliffs, N J Prentice-Hall.

Figure A4.1

INPUT-OUTPUT TRANSACTIONS TABLE

		PRODUCERS								FINAL DEMAND			
		Agriculture	Mining	Construction	Manufacturing	Trade	Transportation	Services	Other	Personal Consumption Expenditures	Gross Private Domestic Investment	Net Exports of Goods and Services	Government Purchases of Goods and Services
PRODUCERS	Agriculture												
	Mining												
	Construction												
	Manufacturing												
	Trade												
	Transportation												
	Services												
	Other												
VALUE ADDED	Employees		Employee compensation										
	Owners of Business and Capital		Profit type income and capital consumption allowances										
	Government		Indirect business taxes										
										GROSS NATIONAL PRODUCT			

Source U S Department of Commerce, Bureau of Economic Analysis (February, 1979)

volume of output of the receiving sector. Production technology is also assumed to be constant over the period of investigation, usually one year. Techniques of production do change through time and these changes may be captured by altering the values of the fixed coefficients production functions (ratios of inputs to output) in the input-output tables of different years.

A second assumption of input-output analysis is that there are no capacity or supply-side constraints on the scale of production. Thus, if demand for an industry's output increases by any amount, the industry is assumed to be able to meet this demand without running-up against any bottlenecks in the supply process.

The assumptions outlined above imply a certain cost. We know that production functions are not of the fixed coefficients variety and that increasing returns are significant in today's economy. Furthermore, we know that the production process is not seamless and free of capacity constraints. These costs imply a certain degree of error in our specifications of the production process. However, with limited information on the variable nature of production technology and capacity, and with the limited ability of the input-output method to incorporate such information, the above assumptions are necessary to examine the effects of changes in demand and production technology throughout an economy.

For the purpose of this study of alternative automobile technologies, the fixed proportions nature of the production process means that while we can alter the proportions of different inputs entering the automobile production sector, indeed that is how we specify the alternative technologies, we assume that the basic organization of automobile production remains unchanged. If the form of the automobile production process were to radically shift in a complementary fashion with changes in product (alternative technologies) the findings of this report would be severely compromised.

A 4.1.3. Applications of Input-Output Analysis and Employment Multipliers

The transactions table, illustrated above, describes an economy in equilibrium, it maps the final demand for goods and services and the inter-industry transactions that are required to satisfy that demand. More than simply describing the form of production in an economy, input-output analysis can be used to examine a number of important economic issues. Input-output methods have been used to predict the impacts of changes in federal taxes on economic activity, to examine the consequences of reductions in federal defense spending, to investigate the income and employment effects of downsizing industries and to analyze industrial and regional linkages.⁵ Input-output also provides a useful framework for tracing energy use and other activities such as environmental pollution associated with inter-industry activity.⁶

A vital ingredient in input-output investigations is the multiplier. The concept of the multiplier may be illustrated with reference to inter-industry flows of commodities. An increase in the demand for the output of one industry, say industry A, will cause a direct increase in output within industry A. However, this does not represent the total additional output required to satisfy the original change in final demand. The additional output of commodity A will result in additional purchases by industry A of the inputs required in production. Thus, industry A will demand additional inputs from industry B and C, for example. These additional demands necessitate an increase in output of industries B and C which in turn place greater demands on their supply sectors, possibly including sector A. These indirect effects will spread throughout the processing sector of the economy. This is not the end of the story of, course, for greater volumes of output in the economy mean increased employment, wages and purchases by households. These induced effects necessitate further increases in industry output. In a general sense, the multiplier measures the ratio of the combined change in economic activity (the sum of direct, indirect and induced effects) to the direct effect. The multiplier thus provides a measure of the degree of economic interdependence of any sector. Sectors with higher multipliers are more closely integrated with the economy as a

⁵ Miernyck, W.H et al 1967. *Impact of the Space Program on a Local Economy: An Input-Output Analysis* Morgantown: Polenske, K.R. 1980 *The U.S. Multiregional Input-Output Accounts and Model* Lexington, Mass Lexington Books. Hewings, G J.D 1985 *Regional Input-Output Analysis*. Beverly Hills. Sage

⁶ Miller, R.E and P D Blair, *ibid* 1985

whole than sectors with relatively small multipliers.

Three of the most frequently used type of multipliers are those that estimate the effects of exogenous changes (such as a new technology) on the output of sectors in an economy, on income earned by households as a result of changes in outputs and on employment that is associated with changes in output. In this study we focus on the employment multiplier, our aim being to uncover the employment impact of variations in new automobile technologies.

A 4.1.4. Methodology

We employ standard methods to estimate the employment multipliers in this study. The steps involved in this procedure are briefly outlined here. For more clarification the reader is referred to Appendix 4.2 of this report. The first step in the analysis is to use the information in the transactions table, together with data on overall employment and output in each of the producing sectors of the economy, to calculate a table of direct or input-output coefficients and labor coefficients for each industry in the economy. These coefficients measure the inputs of all commodities and labor required to produce one dollar of output in each sector of the economy. The input-output coefficients matrix so calculated provides a benchmark of the current technology of the automobile sector against which comparisons of alternative technologies may be compared.

The second step in the analysis is to obtain the Leontief-inverse matrix. This is a matrix of inter-industry coefficients that reveal the direct and indirect input requirements required to produce one dollar's worth of output in each sector of the economy. This is obtained by subtracting the matrix of direct input-output coefficients from an identity matrix and then finding the inverse of this matrix.

The third step in obtaining the employment multiplier is to obtain the product of the labor input coefficient vector and the vector of total input requirements associated with the automobile industry. The elements of this last computation identify the employment within each sector of the economy that is necessary to produce the inputs required to satisfy one dollar of final demand in the automobile industry. The total employment associated with automobile output may then be obtained by multiplying the employment multiplier by total final demand for motor-vehicles.

In this study two basic technologies are contrasted, the internal combustion and electric motor-vehicle industries. For each of these industry technologies input requirements were specified. The different input specifications were then matched with input-output coefficients. Thus a new input-output table of direct requirements was produced for each technology and a separate employment multiplier estimated for each. Comparison of these employment multipliers allow us to gauge the overall employment impact of the different technologies as well as pinpointing the sectors of the economy where employment is likely to increase or decrease.

Once more a note of caution is necessary. This form of impact analysis assumes that all the motor-vehicles produced in the U.S. economy are strictly of one of the technological varieties considered. For each automobile technology, total employment may be obtained with knowledge of the employment multiplier and final demand for motor-vehicles. In the absence of detailed information about changes in consumer demand for different vehicle specifications, without information on the elasticity of demand for automobiles and without a knowledge of the relative prices of the different kinds of automobiles specified, our overall employment projections are limited to a series of relatively simple scenarios. First, we assume that relative prices for the different automobiles, and therefore final demand, remains unchanged. In this scenario, we reveal the overall employment change associated with each technology. Second, we reveal the changes in final demand, output and thus market share required with each technology to maintain current levels of overall employment associated with the automobile industry. Should additional information become available on changes in demand for various automobile specifications, this can be readily matched with the employment multipliers to reveal employment change associated with both variations in technology and consumer habits.

A 4.1.5. Data

The input-output data employed in this survey were provided by the U.S. Department of Commerce, Bureau of Economic Analysis and by IMPLAN, a system of regional economic accounts constructed by the U.S.

Department of Agriculture Forest Service. BEA develop input-output accounts for the national economy on the basis of surveys conducted every five years. Because of the amount of information gathered and its complexity, the most recent input-output accounts for the U.S. economy are based on 1982. IMPLAN input-output data for Los Angeles are based also on the 1982 national census, though they have been adjusted to reflect regional differences in industry structure and they are also updated to 1985. Our analysis uses these data as well as more recent information drawn primarily from the Annual Survey of Manufactures and the Census of Manufactures. Additional data sources are noted in the text.

Comparison of national input-output accounts for 1982 and regional accounts for 1985 is cause for some concern because of the different stages of the business cycle that these years represent. One might expect that in the recession year of 1982, the low rate of capacity utilization would inflate some input-output coefficients. However, more recent comparable data sources are unavailable. Caution must therefore be exercised in drawing conclusions from these data comparisons.

The data in input-output tables are either of a physical, say tons, or a monetary dimension. Because of the difficulty of consistently measuring the heterogeneous outputs of some industries in physical terms, transactions table information is increasingly of the monetary kind. In this study, the transactions between sectors of the economy are measured in U.S. dollars. Further, the transactions are all measured in terms of producer prices, or 'free-on-board' (f.o.b.) prices, rather than wholesale or retail prices and thus ignore wholesale and retail trade margins as well as transport costs.

The input-output data provided by the BEA and IMPLAN includes information on inter-industry transactions, components of value added, final demand and the gross output of each industry. The data is relatively disaggregated: in total the BEA database identifies 570 sectors of the economy, including over 400 manufacturing industries. The IMPLAN database covers approximately 528 sectors.

In the U.S., establishments are assigned to an industry according to their primary product. However, many firms produce several different types of output. In this case, the establishment is classified according to its dominant output, the remaining commodities produced being referred to as secondary products. Because secondary products now constitute such a large proportion of U.S. industrial output, input-output tables are constructed on the basis of the flows of specific commodity types between industrial sectors. Prior to the analysis conducted below, the BEA input-output data was converted to an industry by industry base rather than a commodity by industry base. The IMPLAN data used was also defined at the industry level.

To complement the monetary transactions between the sectors of the economy, analysis of industry employment also requires information on the physical amount of labor employed in each of the producing sectors of the economy. An employment tape, complementary to the BEA input-output series, was provided for this purpose by the Bureau of Labor Statistics. Unfortunately, the labor statistics were not as disaggregate as the transactions data and were thus augmented by information collected from the censuses of agriculture, mining, construction, manufacturing, wholesale and retail trade and selected services. Employment data for Los Angeles was included with the IMPLAN input-output accounts.

To avoid the possibility of aggregation error, analysis of the employment effects of alternative vehicle technologies was performed using all input-output sectors in the databases. While this limits our ability to comprehensively display the data, with the transactions matrix encompassing almost 325,000 cells, it does improve the accuracy of the results.

Appendix 4.2 The Mathematics of Input-Output

In this appendix, the fundamental mathematical structure of input-output accounts is briefly explained. Let us assume that we have information on the flows of goods and services between n different sectors of an economy over a specified period, say one year. Denote the monetary value of the flows from industry i to industry j as t_{ij} . Let us also denote the output of sector i by X_i and the total final demand for sector i by Y_i . Then, the total output of industry i may be written as

$$X_i = t_{i1} + t_{i2} + t_{ij} + \dots + t_{in} + Y_i. \quad (1)$$

The terms on the right hand side of equation 1 represent the sales made by industry i to all other producing sectors of the economy (these are the values in the transactions table) as well as sales to final demand (consuming sectors). Thus t_{i2} represents the sales made by industry i to industry 2 in the year. We can write a series of equations like 1 for all producing sectors of the economy:

$$\begin{aligned} X_1 &= t_{11} + t_{12} + \dots + t_{1j} + \dots + t_{1n} + Y_1 : \\ X_2 &= t_{21} + t_{22} + \dots + t_{2j} + \dots + t_{2n} + Y_2 : \\ &\vdots \\ X_i &= t_{i1} + t_{i2} + \dots + t_{ij} + \dots + t_{in} + Y_i : \\ &\vdots \\ X_n &= t_{n1} + t_{n2} + \dots + t_{nj} + \dots + t_{nn} + Y_n . \end{aligned} \quad (2)$$

Together these equations illustrate the sales and purchases made by all the producing sectors of the economy.

Dividing the flows of commodities to industry j by the monetary value of the output of industry j yields the commodity inputs required to produce one dollar of output of good j . Thus,

$$a_{ij} = t_{ij}/X_j : \quad (3)$$

where a_{ij} is known as a direct input or input-output coefficient measuring the amount of commodity i required to produce one dollar of commodity j . The direct input coefficients a_{ij} , are assumed constant no matter what the volume of output of industry j . Thus, the production functions underlying input-output are of the fixed coefficients or Leontief form and assume constant returns to scale. Once again, the entire series of transactions in our economy may be written in the form of equation 3 as:

$$\begin{aligned} X_1 &= a_{11}X_1 + a_{12}X_2 + \dots + a_{1j}X_j + \dots + a_{1n}X_n + Y_1 : \\ X_2 &= a_{21}X_1 + a_{22}X_2 + \dots + a_{2j}X_j + \dots + a_{2n}X_n + Y_2 : \\ &\vdots \\ X_i &= a_{i1}X_1 + a_{i2}X_2 + \dots + a_{ij}X_j + \dots + a_{in}X_n + Y_i : \\ &\vdots \\ X_n &= a_{n1}X_1 + a_{n2}X_2 + \dots + a_{nj}X_j + \dots + a_{nn}X_n + Y_n : \end{aligned} \quad (4)$$

For ease of exposition, the series of equations 4, may be rewritten in matrix form as:

$$X = AX + Y : \tag{5}$$

where X is an n element column vector of industry output:

A is an $n \times n$ matrix of direct technical input coefficients:

Y is an n element column vector of final demand.

Letting I represent an $n \times n$ identity matrix and rearranging equation 5 we have

$$X = (I-A)^{-1}Y : \tag{6}$$

where $(I-A)^{-1}$ is the Leontief inverse matrix. Each column of this matrix indicates the gross output required from each producing industry in order to produce one dollar of output of the industry identified by the column. Thus, the elements in column j of the Leontief inverse matrix, show the gross output (direct and indirect requirements) of each row industry required to produce one dollar of output of commodity j . Given the technology of the economy (specified by the matrix of direct coefficients A), and given the vector of final demands (Y), equation 6 provides the scale of production in all sectors of the economy sufficient to meet the needs of intermediate and final uses. If the matrix $(I-A)$ is singular then a unique solution to equation 6 exists.

Defining the elements of the Leontief inverse matrix as b_{ij} , and defining labor input coefficients, the physical amount of labor required to produce a dollar of output in industry j as l_j , then a Type 1 employment multiplier for industry j is defined as

$$E_j = \sum_{i=1}^n l_i b_{ij} . \tag{7}$$

The Type 1 employment multiplier calculates the labor necessary to produce the commodities directly and indirectly required to produce one dollar of output of the specified industry.

For clarification, changes in automobile technology are incorporated in this method by altering values of direct input coefficients in the matrix A . As elements of A are changed, so the direct and indirect requirements of production in the economy change and thus the resultant employment multipliers reflect different specifications of technology.

Chapter Five

Financial Analysis of Small Electric Vehicle Production and Recommendations for Public Policy Investment and Capitalization

Jane Torous

5.1. Introduction

The electric vehicle industry evokes images of unbridled entrepreneurship, opportunities for technological creativity, and an expectation that small innovative businesses can promote the technology from a handful of sales into a major mass market. Underlying this scenario is an assumption of available capital, and venture capital in particular.

In stark contrast, a prominent story in *The Los Angeles Times* details the travails of an electric vehicle (EV) bus firm seeking capital; despite a year of active solicitation, the firm had not been able to raise the capital they needed, although there is an estimated \$3.6 billion worldwide market in pollution free shuttles (LAT 3/2/92). A similar plight has been voiced by an entrepreneur in the EV conversion market who would like to expand his market, but faces obstacles in raising additional funds through a secondary stock offering.

This chapter examines the role of public and private investment in the EV industry. If the electric vehicle is going to expand in Southern California then investors will have to be ready to provide seed and start-up funds to local entrepreneurs. We try to illuminate the risk issues and uncertainties perceived by the investor, who is interested in developing a small EV manufacturing plant.

There is currently no major automotive manufacturer in Southern California, although after W.W. II the area was the industry's second largest manufacturing center after Detroit (Morales, 1986). In this chapter, we examine whether the electric vehicle can spearhead a new wave of automotive industry growth. The electric car industry holds some promise: the use of state-of-the-art components and manufacturing techniques suggests that producing the car might be profitable in relatively small and specialized production runs. By offering financial incentives to locate EV industries in the state, and by encouraging local production, the state may set a landmark for environmental policy, expand its industrial and jobs base, and encourage other high technology ventures.

There have been few publicly available financial analyses of the EV industry, with the exception of a short paper by Steiner (1980). Financial projections have surely been developed

by all of the major automotive firms, but are not publicly available. These analyses might not be generalizable, since they are likely to be based on a different type of vehicle from one that a local small, high technology firm might produce using new materials, a leased plant, and small production runs.

Based on interviews conducted for this study it is evident that financial issues are omnipresent for small EV developers. Many small businesses have now completed an initial stage of prototype testing and R&D, but are uncertain if there is sufficient capital they can raise for small scale manufacturing and vehicle development. Financial issues, at this stage, may determine the viability of the industry because unless financial managers are willing to invest in the industry, many local entrepreneurs will not be able to expand their EV development beyond prototype demonstrations.

Likewise, if public policy makers are going to encourage EV development, they need to understand the risks that are perceived by private financial managers. It may be possible to implement public policy that can strategically encourage investment by the private sector. For example, what kinds of financial assistance, ranging from subsidized vehicle purchase, to manufacturer's tax incentives, are likely to be effective, and at which stage of industry development? Although technology for the electric vehicle is openly tested and evaluated by both the public and private sector, the financial valuation of small EV businesses remains a "black box", particularly among public sector analysts.

The plan for this analysis is straightforward: We begin the study by analyzing a project to manufacture new purpose-built EVs. Using production estimates provided by industry leaders, we estimate the project's opportunity cost of capital for this small business — and examine how sensitive its break-even point is to varying capital costs, and to varying vehicle sales projections and unit price. The financial analysis is based on the methodology that a private investor, from a venture capitalist to a commercial bank, would use to evaluate the risk, and return of a proposed EV project.¹

The second part of our analysis examines the outcome of this financial analysis, *vis à vis* its implications for public policy and for public investment. This section of the report is more qualitative, and provides insight into how public policy can work in conjunction with private investors to move the technology out from the research lab and into the streets. One of the findings from the quantitative analysis is that certain aspects of the EV business are very risky for a small or mid-sized business. If the EV industry is to establish in Southern California, then some combination of loan guarantees, tax incentives, or quasi-public funding may be necessary. We ask whether public or private investors can enrich industrial growth by supplying sufficient investment capital, over a long enough term, and at an equitable rate-of-return. We explore this concept and focus specifically on financial sources that can provide equity capital like venture capitalists and green funds, debt capital, such as banks and secured bonds, and other sources —

¹ The electric vehicle industry is an umbrella term which describes the operations of a number of different enterprises, such as battery development and manufacturing, supplies and components, conversion-manufacturers, and purpose-built vehicles. Emphasis in this study is placed on understanding the financial needs of small scale manufacturers, but it is recognized that local battery companies and component manufacturers could supply their products to a Big 3 or foreign automotive firm, as well as to a new, regional end-producer.

At this point in time, battery manufacturers, component suppliers, and end-scale producers share a great deal in common — they face an uncertain and untested market, their greatest expense and need is in Research and Development, and success in one area, say battery manufacturing, is interdependent with success in other areas, like low-cost manufacturing.

like joint ventures. The final recommendation is that a financial intermediary be established, heuristically called EV CAPital, and that it operate with a mandate to encourage private investment in California's EV businesses, work to leverage federal funds, and be an advocate in areas where new jobs and an enhanced tax base can be created by the technology.

5.2. A Break-Even Analysis of an Electric Vehicle Project

This section analyses a hypothetical electric vehicle project. In particular, we consider the financial viability of an investment to mass produce an electric passenger vehicle for the Southern California market. While not exact, the parameters chosen to characterize this project are broadly consistent with actual parameters which would confront a small manufacturer intent on entering this market today.

To illustrate the uncertainties surrounding this electric vehicle project, we conduct a sensitivity analysis with respect to the vehicle's sales price as well as the manufacturer's sales projections. We conclude that the project's break-even point — where the project's net present value exceeds zero or, in other words, where the project becomes economically viable — is extremely sensitive to both sales price and sales projections. Therefore, government actions which effectively lower the vehicle's cost to consumers, such as subsidies and rebates, or mandate an increase in the electric vehicle's market size will necessarily increase the financial attractiveness of this project.

As with all real investments, we show that the economic viability of an electric vehicle project also depends critically on its risk. All other things being equal, the less risky a project, the greater its net present value and, as such, the greater its financial attractiveness. This suggests that government risk sharing endeavors, such as loan guarantees, by effectively lowering the project's opportunity cost will make it more likely that an electric vehicle investment will be made in Southern California.

5.2.1. Forecasted Cash Flows to an Electric Vehicle Project

We first specify the expected cash flows of our hypothetical electric vehicle project. While only illustrative, these assumed cash flows are based on research into the electric vehicle industry as well as discussions with numerous industry leaders.

Initial Investment

Without loss of generality, we assume that our hypothetical electric vehicle project will require an initial investment of \$100 million. This investment today (1992) will permit the production and marketing of the vehicle to commence in 1993 and continue through 2002. The \$100M initial investment is very nominal *vis à vis* the cost of traditional automotive start-ups and thus we emphasize that we are focussing on a new small, high tech business that is likely to be using new materials, advanced manufacturing technology and small scale production.

Revenues

The project's annual revenue is the product of the number of vehicles sold per year and the sales price per vehicle.

To begin with, we assume the vehicle's sales price in 1993 will be \$25,000, thereafter increasing at an annual inflation rate of six per cent. Since this selling price may be necessary at an initial stage of production, but may decrease with additional sales, our analysis also investigates the effects of varying sales prices on the economic viability of the electric vehicle project.

Sales projections are based on the assumption that while sales of the electric vehicle will be minimal in 1993, the firm will have garnered one-quarter of the AQMD's mandated market for electric vehicles in Southern California by 1998 and beyond. We focus on small scale manufacturing, and presume that the initial electric vehicle will reach a niche market. In particular, we project the following annual sales for our electric vehicle: 250 units in 1993, 1000 units in 1994, 2000 units in 1995, 4000 units in 1996, 7500 units in 1997, and 10000 units in each of 1998 through 2002. Again, a sensitivity analysis investigates the effects of varying sales projections on the economic viability of the electric vehicle project.

Variable Costs

The variable costs associated with the electric vehicle project are those costs which vary with the number of units produced and sold. These variable costs include the direct cost of the underlying components, the cost of insurance and warranties, as well as marketing, administrative and labor costs.²

We assume that the direct cost of the underlying components will be \$17,500 per vehicle given a base sales price in 1993 of \$25,000. These direct costs are also assumed to increase thereafter at an annual inflation rate of six percent.

We also assume that the cost of insurance and vehicle warranties varies with the number of units produced and sold. In particular, based on discussions with industry leaders, we assume that the annual cost of insurance amounts to three percent of total revenues in that year while the (present value of the) cost of warranties for vehicles sold in a particular year is five percent of that year's total revenues.

The issue of insurance cost for the EV may be of particular importance to investors, who might shun an investment due to fear of legal liability.

Marketing, administrative and labor cost also vary with the number of units produced and sold. Based on discussions with industry leaders, we assume that annual marketing costs are five percent of annual revenues while annual administrative and labor costs amount to ten percent of annual revenues.

Again, it should be emphasized that this prototype EV manufacturer uses new, flexible, and streamlined means modes for production and assembly.

² We do not vary our cost assumptions in the later analysis. It is unnecessary to do so since our sensitivity analysis varying the vehicle's sales price while holding its costs fixed is equivalent to varying these costs and assuming the vehicle's sales price is fixed.

Fixed Costs

The only fixed cost included in the analysis is the cost of the manufacturing plant. Furthermore, we assume that the plant will be leased at a cost of \$3,000,000 per year in 1993 and increasing thereafter at the assumed inflation rate of six percent. These assumed lease payments reflect prevailing market conditions in the southwestern United States for a moderate to large sized manufacturing facility.

5.2.2. The Opportunity Cost of an Electric Vehicle Project

To determine the economic attractiveness of the electric vehicle project requires that we discount its forecasted cash flows at an opportunity cost which reflects the project's risk. The opportunity cost of an electric vehicle project is its expected return and reflects the business risk inherent in producing and marketing electric vehicles in Southern California.

We use the capital asset pricing model (Sharpe [1964] and Lintner [1965]) to assess the systematic or market risk of the electric vehicle project. The capital asset pricing model recognizes that an investment's market risk, not its diversifiable risk, determines the investment's expected return. In particular, the expected return to investment i , $E(r_i)$, is given by

$$E(r_i) = r_F + \beta_i(E(r_M) - r_F)$$

where

r_F = the risk-free rate of interest

β_i = $\text{cov}(r_i, r_M) / \text{var}(r_M)$ = investment i 's beta or systematic risk

$E(r_M)$ = the expected return on the market portfolio.

Intuitively, according to the capital asset pricing model an investment's expected risk premium, $E(r_i) - r_F$, should increase relative to the market's expected risk premium, $E(r_M) - r_F$, in direct proportion to the investment's beta, β_i . Numerous empirical studies (Fama and MacBeth [1973] and Black, Jensen, and Scholes [1972]) confirm that expected returns increase on average with an investment's systematic risk exposure.

To implement the capital asset pricing model, we must measure the beta or systematic risk of the electric vehicle project. Unfortunately, given the infancy of the electric vehicle industry, market data are not available to assess directly this business risk. As a result, we assume that the electric vehicle project's business risk is approximated by the business risk of the U.S. automobile industry (General Motors, Ford, and Chrysler). However, while the electric vehicle project is certainly an automobile venture, significant differences almost certainly exist between a potential electric vehicle manufacturer and a U.S. automobile manufacturer. This together with the fact that U.S. automobile manufacturers are engaged in a variety of other diversified business projects (for example, financial services and defense) limits our analysis and

should be kept in mind when interpreting the calculations which follow.

Common stock returns to U.S. automobile manufacturers provide information on the riskiness of the underlying industry. To assess the systematic risk exposure of these firms' common stockholders, we first estimate the beta risk of General Motors, Ford, and Chrysler common stock. Monthly returns to General Motors, Ford, and Chrysler common stock for the five year period ending December 1991 were obtained from the University of Chicago's Center for Research in Security Prices (CRSP). The market portfolio was proxied by CRSP's value-weighted (VW) index. The following market model regression was estimated by ordinary least squares

$$r_{it} = \alpha_i + \beta_i r_{vw,t} + \epsilon_{it}$$

The first column of Table 1 provides the corresponding estimated equity betas for General Motors, Ford, and Chrysler. Notice that the equity beta estimates are significantly greater than one, consistent with common stock investments in the U.S. automobile industry being on average riskier than the market as a whole.

Table 5.1
BETAS OF COMPARABLE AUTOMOBILE MANUFACTURERS

FIRM	equity β	D/V	firm β
General Motors	1.14	.604	.453
Ford	1.28	.764	.303
Chrysler	1.78	.802	.354

However, equity betas not only measure the business risk of the underlying automobile industry but also the financial risk confronting these firms' shareholders. This financial risk stems from the fact that firms generally issue interest bearing debt to finance their activities. Therefore, the more leveraged the firm, the more upwardly biased is shareholders' systematic equity risk, β_{equity} , as an estimate of the firm's systematic business risk, β_{firm} .

It follows that the firm's leverage ratio, proxied by the book value of its debt divided by the sum of the book value of its debt and the market value of its equity, allows us to unlever the firm's equity beta and measure the systematic risk of the underlying business. For example, assuming the firm's debt is riskless, we have that

$$\beta_{\text{firm}} = (1-D/V)\beta_{\text{equity}}$$

where

D/V = the firm's leverage ratio.

The second column of Table 1 tabulates leverage ratios for General Motors, Ford, and Chrysler as of December 31, 1991. Corresponding estimates of underlying business risk, β_{firm} , are provided in the third column of Table 1. We minimize the estimation error present in these estimates by taking their value-weighted average as our measure of the systematic business risk of the automobile industry and therefore, by assumption, the systematic business risk of our hypothetical electric vehicle project.

Finally, to complete the specification of the opportunity cost of the electric vehicle project, the capital asset pricing model requires input of the risk-free rate of interest, r_f , as well as the expected risk premium on the market, $E(r_m) - r_f$. Since we have considered the electric vehicle project over a 10 year period the risk free rate is measured by the prevailing 10 year Treasury bond rate of 7%. The expected risk premium on the market portfolio is taken to be the average premium on Standard and Poor's Composite Index over U.S. Treasury bills for the period 1926 to 1988 of 8.4% (Ibbotson Associates [1989]).

Taken together, the capital asset pricing model provides the following estimate of the electric vehicle project's opportunity cost:

$$7\% + .384 \times 8.4\% = 10.23\%.$$

5.2.3. Sensitivity Analysis

The economic viability of our hypothetical electric vehicle project is measured by the project's net present value — the present value of the project's operating cash flows less the project's initial investment. Operating cash flows are obtained from the project's forecasted cash flows by assuming a ten year straight-line depreciation schedule and a 34% corporate tax rate. Given these assumptions, together with the posited cash flows and an opportunity cost of capital of 10.23% results in a net present value of approximately \$35.66 million. In other words, the present value of the project's operating cash flows exceeds its initial investment by \$35.66 million, and, as such, our hypothetical electric vehicle project is an extremely viable investment project.

However, how sensitive is this conclusion to the numerous assumptions underlying our analysis? Is the project's economic viability more dependent on certain factors than others? This section explores the robustness of the electric vehicle project's economic viability to our underlying assumptions.

Sensitivity Analysis with respect to the Cost of Capital

Figure 5.1 presents the electric vehicle project's net present value as a function of alternative costs of capital, holding all other factors constant. For example, it may be argued that the systematic business risk of the electric vehicle project is not accurately proxied by the automobile industry's systematic business risk and therefore the assumed cost of capital of 10.23% is inappropriate. However, from Figure 5.1 we see that the economic viability of the electric vehicle project is extremely robust with respect to the assumed cost of capital. In particular, the project's internal rate of return of approximately 16% implies that the project remains economically viable for any opportunity cost of less than 16%.

Furthermore, notice from Figure 5.1 that by decreasing the cost of capital, we substantially increase the project's economic viability and therefore increase the likelihood of the electric vehicle project being undertaken. Decreasing the cost of capital from 10.23% to 9.23% increases the project's net present value by approximately \$8.15 million.

This analysis suggest an important policy role for the government in promoting the electric vehicle industry in Southern California. By entering into a risk-sharing arrangement with electric vehicle manufacturers whereby the government assumes some fraction of the manufacturers losses in return for a corresponding insurance premium, the government would hasten this industry's development by effectively lowering its cost of capital. This arrangement could be similar to the government's risk-sharing role in residential mortgage markets where such government sponsored enterprises as the Federal National Mortgage Corporation ('Fannie Mae') and Federal Home Loan Mortgage Corporation ('Freddie Mac') have substantially increased the affordability of housing by effectively lowering residential mortgage rates.

Sensitivity Analysis with respect to Sales Projections

The sensitivity of the electric vehicle project's economic viability with respect to assumed sales projections is summarized in Figure 5.2. Here we fix the sales price of the vehicle and vary the scale of our sales projections from .2 or 20% of our assumed sales projection to 2.0 or 200% of our assumed sales projection.

As can be seen in Figure 5.2, the electric vehicle project's economic viability is fairly robust with respect to varying sales projections. In particular, the project's break-even point with respect to sales projections is approximately .70 . In other words, sales would have to fall to less than 70% of our assumed sales projection before the project would no longer be economically viable.

The robustness of the project's economic viability with respect to sales projections follows from our assumption that the sales price per unit exceeds variable costs per unit. As a result, for a wide range of sales, the resultant proceeds per unit are sufficient to cover the project's fixed costs. However, for low enough sales, fixed costs are not covered and the project is no longer economically viable.

Our hypothetical electric vehicle project is characterized by relatively low fixed costs or, in other words, relatively low operating leverage. By further decreasing the firm's operating leverage, we would necessarily increase the robustness of the project's economic viability with respect to sales. Hence, government actions to lower electric vehicle manufacturers' fixed costs, such as subsidizing lease payments and reducing property tax bills, would make manufacturers

Figure 5.1

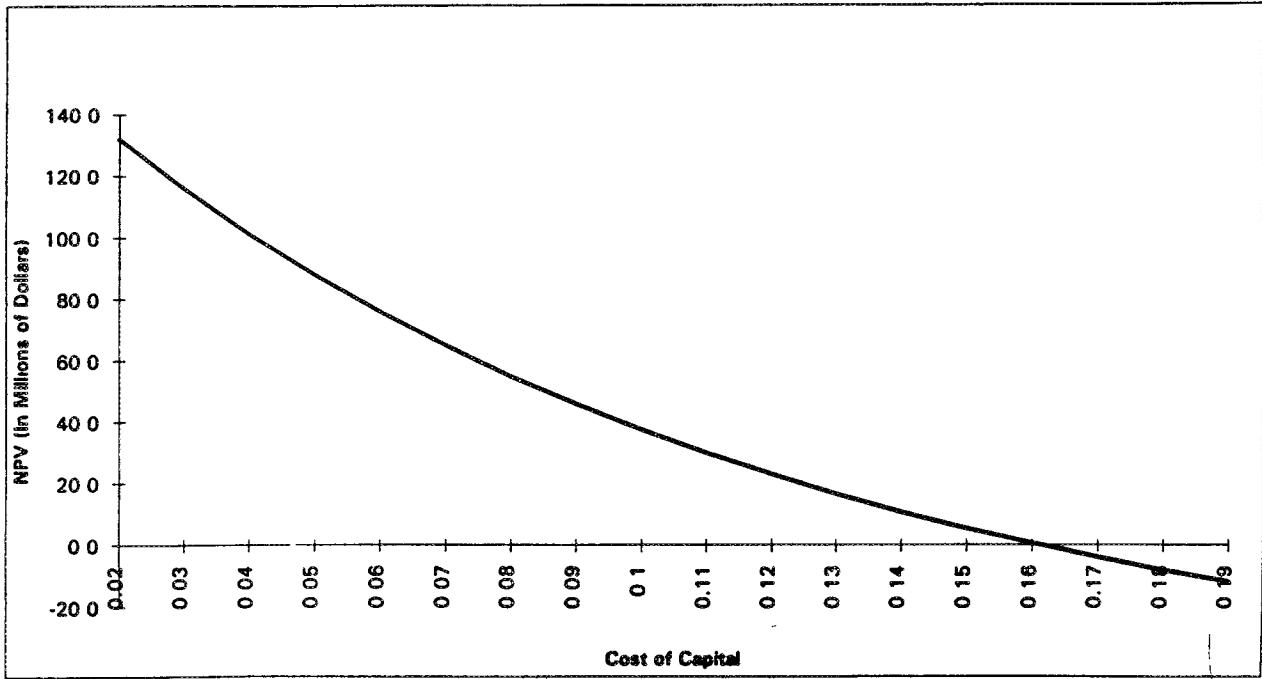
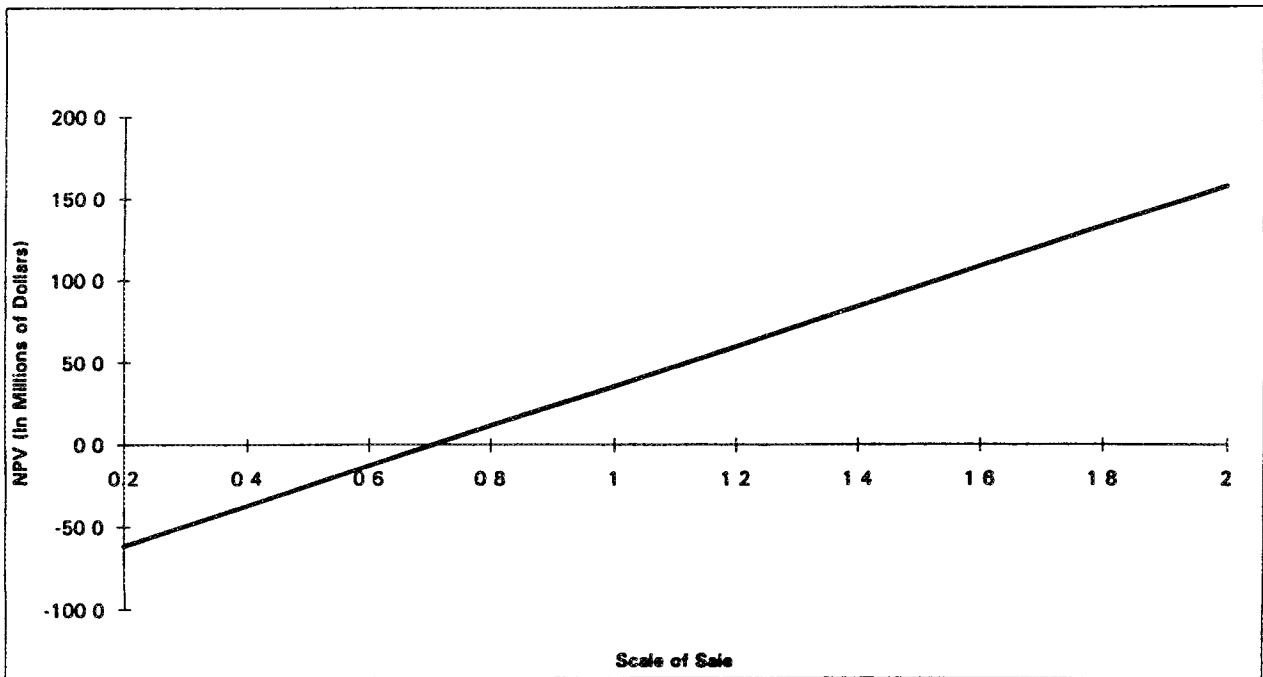


Figure 5.2



better able to endure variability in the demand for the electric vehicle.

Sensitivity Analysis with respect to Sales Price

As can be seen in Figure 5.3, the economic viability of our hypothetical electric vehicle project is extremely sensitive to the vehicle's assumed sales price. Here we vary the vehicle's sales price holding fixed our sales projections and determine the project's corresponding net present value.

Notice that holding everything else fixed, the electric vehicle's break-even sales price is approximately \$23000. That is, if the sales price is only \$2000 less than we assumed, or equivalently, if costs per unit are only \$2000 more than we assumed, the electric vehicle project is no longer economically viable. Intuitively, by reducing the proceeds per unit sold, the project's fixed costs are less likely to be covered making the project less economically viable.

However, this analysis is unrealistic since it assumes that the market demand for the electric vehicle remains unchanged as its price varies. Estimates of the price elasticity of market demand for all models and types of automobiles in the United States range from -1.0 to -1.7 (Owen [1983]). Figure 5. 4 repeats our analysis assuming the price elasticity of demand for the electric vehicle is -1.35 (the midpoint of the estimated range). That is, we assume that for every 1% decrease (increase) in the sales price of the electric vehicle, the assumed sales projection increases (decrease) by 1.35%. However, our earlier conclusions remain unchanged: the economic viability of our electric vehicle project is extremely sensitive to the assumed sales price.

Government actions which subsidize the consumer's purchase of the electric vehicle are critical to the industry's financial vitality. Examples of such actions include direct rebates and tax credits. These actions would ensure that electric vehicle manufacturers could charge prices more than sufficient to meet their variable costs and, as a result, remain profitable.

5.2.4. Investment as a Strategic Option

The preceding section provided a discounted cash flow analysis of a hypothetical electric vehicle project. Since this investigation was predicated on a number of assumptions, we conducted a sensitivity analysis to ensure the robustness of our conclusions to particular assumptions.

However, to this point we have ignored the electric vehicle project's valuable long-term strategic benefits. For example, the project's acceptance and the electric vehicle's subsequent success may produce a cascade of new commercial developments. If the value of these future growth opportunities is sufficiently large, the manufacturing project should be accepted even if a straight net present value analysis suggests rejection. This is precisely why public utilities and other institutions are making considerable investments in the electric vehicle technology with no apparent immediate cash flow consequences.

Many investment projects include discretionary opportunities to invest in subsequent assets. These future investments are like strategic options on the underlying assets. For example, if the passenger vehicle is successful, it may become desirable to expand the project by subsequently producing electric trucks, electric buses, etc. Precisely how and when these

Figure 5.3

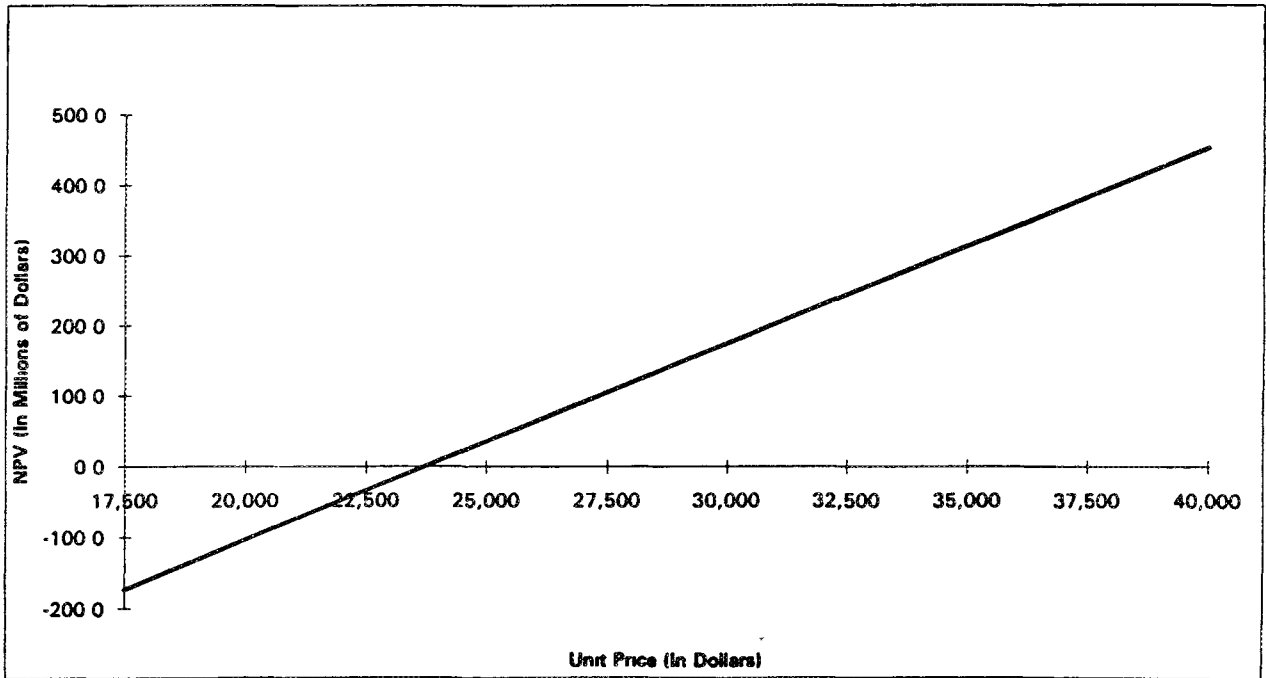
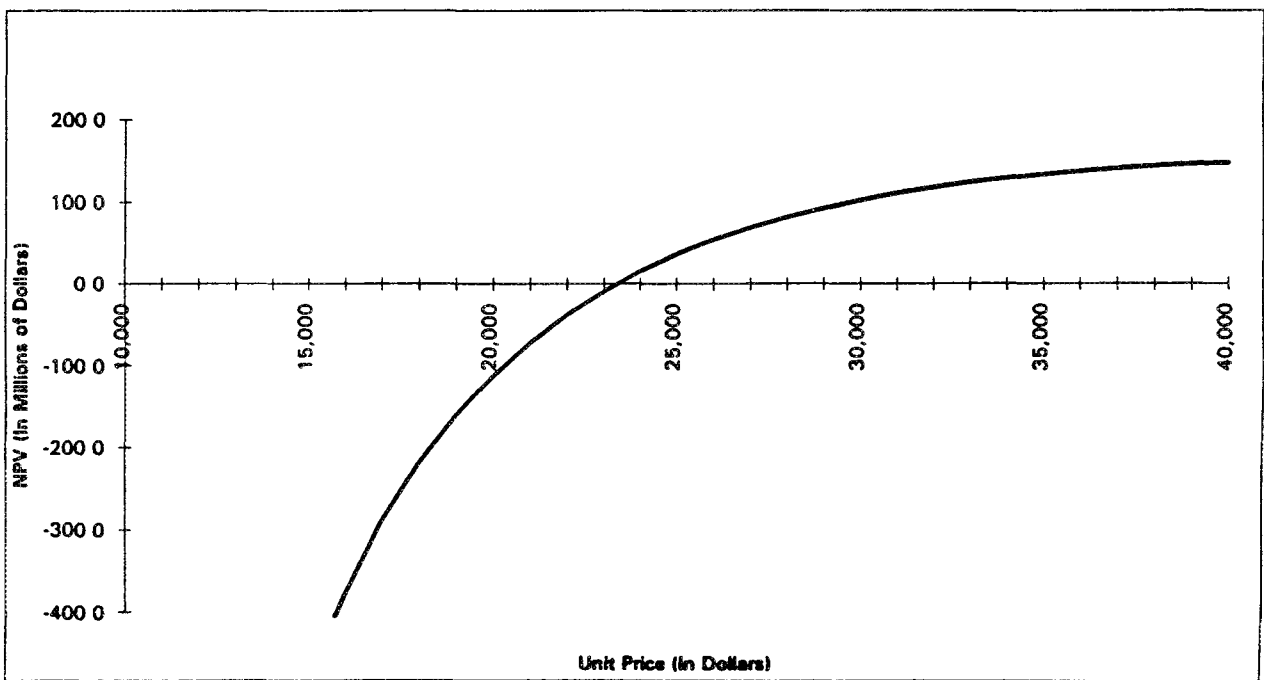


Figure 5.4



subsequent investment decisions will be made will depend on future events. But the attractiveness of these future investment opportunities depends critically on the assets put in place today.

In general, any investment project whose implementation can be deferred, that can be subsequently modified by the firm, or that creates new investment opportunities should be analyzed keeping in mind its strategic options. By ignoring these strategic options, potentially valuable projects like the electric vehicle can be erroneously rejected.

Paradoxically, the riskier the underlying asset, the more valuable a project's strategic options. Options are rights—not obligations. As such, an option will only be exercised when it is in the firm's best interest. The more volatile the underlying real asset, the more likely the firm will find it worthwhile to exercise its strategic options. For example, the electric vehicle's strategic options are more valuable the more volatile the price of oil. More volatile oil prices make it more likely that when oil prices are high (perhaps because of political tension in the Middle East), consumer demand for the electric vehicle will permanently increase.

In summary, the preceding section's net present value analysis understates the financial attractiveness of the electric vehicle project. This follows from the fact that the discounted cash flow analysis ignores the strategic options embedded in the electric vehicle project. While difficult to value precisely, given the volatility of energy prices, these strategic options make investment in Southern California's electric vehicle industry extremely attractive.

5.3. Policy Analysis and the Role of Public/Private Investment

When an electric vehicle project is evaluated on financial grounds, instead of technological ones, the outcome is somewhat mixed. On the one hand, we saw that a small company could produce about 10,000 vehicles a year, and under certain conditions, maintain profitability. However, investment in this small business was clearly risky and private investors would have to be convinced of the project's long term viability. The analysis suggests a role for public policy programs to alleviate private investor's reservations across three main areas: first, to reduce the cost of capital; second, to reduce the variable costs of production through tax incentives or subsidized manufacturing, and finally, to lower the end user-cost for purchase of the vehicle.

In this section, we will consider each of these findings in somewhat greater detail, and integrate each of these policy recommendations *vis à vis* the existing role that is being played by traditional financial sources, like venture capitalists, banks, green funds, and others. These issues are of vital concern to the development of the electric car industry in California. There appears to be a limited window of opportunity for small entrepreneurs to gain a foothold in the EV market, and lead the technology. Unless the interest of public or private financial investors is "turned on" for small entrepreneurs who need to expand their operations, current levels of R&D work stand to be shelved. If California does not use this window of opportunity to help small EV entrepreneurs, then it is likely that the industry will be left to the foray of large manufacturers, whom, it appears, have more options to keep the innovation "frozen" and inactive, or delay its introduction. Another scenario is that foreign manufacturers will use this opportunity to acquire rights to EV research developed in U.S. labs and by small California businesses.

5.3.1. Cost of Capital

It is beyond the scope of this analysis to construct a social benefits model. However, Steiner (1980), is among those who argue that the cost of capital may be lower for public investors. As he points out, the electric vehicle holds promise for the improvement of social welfare, through better air quality and reduced pollution control costs. Thus, if the public were to invest in the project, a lower cost of capital could be justified, and this would make it more likely that entrepreneurs could expand their EV operations.

There is currently a large social subsidy of the internal combustion engine automobile which should be recognized, and these resources could be used in programs to lower the cost of capital if they were shifted to support of EV technology. This line of inquiry is speculative, but Zuckerman (1992) quotes a number of studies which try to estimate the internal combustion engine subsidy: e.g., he states that The California Department of Transportation gives the sum of \$2500 per vehicle as the difference between what is collected by state and federal revenues and what is spent by government to support motor vehicle services. German researchers have developed a higher estimate, based on road construction and maintenance, air pollution costs, traffic noise costs, etc. The German study (cited in Zuckerman, 1992) did not include the cost of health care arising from exhaust emissions. Just as this current analysis has investigated a rate of return model for the private investor, a future study should use the same methodology to construct one for the public investor, considering in particular, the hidden factors of health costs, air pollution control, and pollution remediation.

After the 1970s energy crisis, similar issues about the cost of capital were raised, but from a rather different social perspective. At that time, social policy was dominated by a need to protect the US economy from future shocks in energy prices. Project Independence (1974) analyzed surrounding issues and concluded, "The investor in domestic energy project projects faces substantial international, political, and economic uncertainties which preclude the application of traditional investment arithmetic. Rather than offsetting these uncertainties with a demand for a higher expected rate of return on investment, the investor may very likely seek political guarantees or projects which pay out in substantially shorter periods."

One means in which federal or state government can reduce the cost of capital to the investor is to provide a guarantee for investors in EV projects. Government guarantees currently exist across a number of different areas — the most visible are VA, FNMA, FHLMC guaranteeing residential mortgages and mortgage backed securities. However, different levels of guarantee or loan programs also extend to the area of marine ship building the import and export of finished goods and agriculture (cf. Nevitt, 1989). On occasion, loan guarantees have been made to financially teetering companies like Lockheed and Chrysler. At the state level, guaranteed loans have also been used as part of economic development corporations (EDCs) since they encourage the private sector to provide funding or to share in the risk of extending credit. Initial funding for EDCs is appropriated by state legislatures but the programs often become autonomous by raising funds through bonds, interest payments from loans, and from guarantee fees (SBA, 1988).

A number of businesses have claimed that United States policy discourages entry into new markets because the cost of capital is higher for US companies than for foreign competitors (e.g, Electronics Capital Corporation Report, 1989, Teece, 1992). It is a complex issue, but one factor that has not been seized by policy analysts is untapped potential to lower the cost of

capital through government support of dual-use technologies. There are a number of innovations, like an advanced EV battery and component materials which are of importance to both consumers and to military/industrial applications. Government programs which guaranteed investment in high technology businesses might encourage commercial applications in the EV industry, but at the same time, strengthen technical applications of new technology.

5.3.2. Cost of Manufacturing and Production

A second policy area identified by the financial analysis was to increase profitability and reduce risk by minimizing the fixed costs of production. There are few benchmarks of what fixed costs might actually be for small EV scale production. A positive example of reduced manufacturing costs is the current free loan of aerospace facilities to the CALSTART consortium — however, for this to have long-run impact, this lease would have to be extended beyond its current two year term.

There are a number of state and federal programs which can assist small businesses reduce the cost of manufacturing, such as location in a designated business enterprise zone (Lister, 1990) and Investment Development Bonds (Union Bank, 1992) and investment tax credit programs. California's Investment Development Bonds, for example, have used banks and like sources as a guarantor, so that eligible manufacturers can qualify for up to \$10,000,000 in reduced-rate loans. When available, the IDB is exempt from federal, state, and local income tax, allowing them to be marketed at rates between lower than comparably rated corporate bonds. They are available to businesses that can create new manufacturing jobs. However, there are several problems matching EV businesses directly to this program, and to other existing economic incentive projects.

Many of these programs have very specific collateral requirements — for example, an IDB is typically secured by a bank, and financial ratios to qualify for it are based on standard risk analyses. In contrast, small EV entrepreneurs may hold few material assets since their wealth is measured in "intellectual property", and the potential of income from future royalties or licenses. Existing incentive programs are likely to weight against new technologies and small, innovative start-ups.

A second limitation of existing programs is that they favor high-technology organizations that reach the manufacturing stage of development. While our quantitative analysis did not focus on the pre-production, R&D phase of development, most EV businesses in California also need funding and facilities to pursue basic R&D functions, and manufacture on a very small or test scale. One means to help reduce fixed costs for these small businesses may be to provide shared facilities for vehicle testing and certification.

Grants from the AQMD, CARB, and the utilities have sponsored much of this R&D and other research has taken place under federal SBIR programs and at local universities. (proceedings, NTI, 1992). Entrepreneurs who have been supported by SBIR loans identify tremendous difficulty bridging from R&D work on batteries into small scale manufacturing (personal conversation). One proposal put forth (NTI, 1992) is that SBIR funding should be positioned to the next-level of investor as a badge of technical credibility and capability. This would require educating investors about the EV industry, at large.

5.3.3. Cost of Sales and Warranty Issues

A third area identified by the quantitative analysis focusses policy attention directly on the cost at which the vehicle can be sold (and indirectly, the cost of marketing and providing warranty for vehicles). To date, the largest focus of research and public policy has been here, from the Japanese MITI proposal to provide a rebate per vehicle to California's current policy of providing a discounted annual license tax rate for EVs and providing a \$1,000 state income (LEV) tax credit.

We saw in the quantitative simulation that the project was not profitable below a selling price of about \$23,000. Without subsidy, this up-scale price clearly exempts the vehicle from certain niche markets that have been identified by research like that of a second vehicle, a low-cost, low-mileage vehicle for retirees, or for students. The price may also discourage some fleet buyers, who would incur extended and higher lease payments.

Government policy — and particularly California state policy — may have already played an important role in reducing this area of financial risk. It is commonly observed that the supply of electric vehicles, but not demand, has been mandated by the Clean Air Act (NYT, 11/26/91). To the extent that this legislation is enforced, and not weakened or diluted before 1998, then entrepreneurs and manufacturers alike are assured that they have a market — it may initially be composed of public fleet buyers or some other specialty buyer, but it is a market, nonetheless. Holding fast to the Clean Air vehicle mandate helps to reduce risk to investors. A case-example has been examined by Rosenbaum (1987); the fact that the Federal Government backed away from the 1986 fuel efficiency standards required by 1975 legislation, ended up costing Chrysler million of dollars invested in tooling and design to produce autos meeting anticipated standards. "The winners", cites Rosenbaum, "were Ford and General Motors whose fleets would have violated the standards". Abrupt changes in (environmental) policy impose an a high economic cost on the business sector, and erode investor confidence in environmental investments. For this reason, consistency upon the part of the AQMD and CARB is essential in reducing risk.

An issue that is not raised as frequently as the need for vehicle rebates for end-users, is insurance and liability issues for the end-user. There are currently no federal standards to ensure crash-testing of conversion vehicles, and at least two small entrepreneurs (private conversation) believed that they had to merge ultimately with a large, established automotive manufacturer because of legal exposure which would bankrupt smaller scale firms. It is not clear what role public policy might play, although in the nuclear power industry, this has been resolved by having the federal government act as a provider of catastrophic — last resort insurance.

There are two very immediate and very practical steps that state government can take, while larger issues — like liability claims are resolved. One step is to encourage EV adoption by state and government owned fleets, which in California number more than 12,000 federal (non-military) automobiles and an estimated 147,000 state, county, and local cars. (MVMA, 1990) The Energy Act of 1992 targets some of these fleets and helps to create market demand. A second step is to work closely with banks and finance companies which provide financing for new vehicle purchase, and effectively lower the cost of a loan for EV purchase or lease. California banks and finance companies might be convinced to offer more favorable leases if loan officers were educated about both the environmental benefits of EV use and economic benefits of a longer service life.

The selling price for a fleet buyer or for general public will greatly depend upon a comparison with the selling price of existing gas vehicles *vis à vis* the finished EV vehicle, its mileage range, conveniences, safety features, and cost of maintenance. Lacking a final, showroom ready vehicle to sell the public, market research depends upon a number of inferential steps -- (for an innovative market test see Turrentine, Sperling and Kurani, 1992). Nonetheless, given today's experience from EV conversion costs, and the expected cost of production, there appears a sizeable gap today between cost and what buyers might reasonably pay. Thus, a role for public policy is to measure the true cost of narrowing this difference.

5.3.4. Existing Capital Sources

As part of this study, we investigated and compared different financial institutions to assess their level of interest and investment in the electric vehicle industry. The type of financial involvement is closely associated with the stage of development -- with private investors and R&D sources playing a dominant role at emergent stages of business growth -- and a public stock offering or commercial-bank loan coming into prominence at end stages of manufacturing (Brophy, 1974).

Among existing EV businesses in the state, almost all have been self-financed by private entrepreneurs. There has also been limited public funds and backing by the utilities, such as funds provided for the LA Initiative and for CALSTART. However, most small business entrepreneurs have entered the area, without the backing of these sources. Interesting cases in point are AC Propulsion, which is purported to have begun in a garage (Los Angeles Times, X,/92) Green Motors and Haba Batteries in which the owners invested savings from other successful business ventures.

In order for these small businesses to grow, they will have to have some assurance that the EV market is a real one and they will have to access working capital. **Commercial banks** are an unlikely source for this because (1) they are seldom a source for high technology business growth and (2) they have a number of lending restrictions, under FIRREA, which prohibit investment without strict collateral guarantees. In addition, recent losses from the real-estate industry have severely constrained the banking industry's robustness. **Small business loans** are available up to a maximum of \$750,000 which may fund one round of financing, but are unlikely to provide for long-term needs. In particular, they do not provide assistance for long-term R&D, for evaluation, and testing. So called **Green Funds** or environmentally conscious investors are a third source, and there is an estimated \$600 billion invested according to some type of social criteria, at large. (Los Angeles Times, 4/20/92). In the current stock markets they have tended to underperform other investments, and this has led to some debate whether their investment goals are well served by social, instead of financial, decision making. The federal government provides **SBIR** grants to a number of small technologically-based firms in the EV area, but these may not be businesses that invest in less technical, engineering issues, but equally important, infrastructure needs. Moreover, there is no "California SBIR" , which would help direct research towards the specific needs of EV development within the state. Finally **Joint Ventures** between automotive firms, component manufacturers, battery firms, and other companies are very prevalent, and have helped to reduce the risk to any particular firm. However, Arias (1992) is among those who have identified certain negative aspects of joint

ventures like the USABC: they favor a concentration of power among biggest firms which then set industry timetables, agendas, and standards in their own interest, and second, they tend, "to act as a sponge and suck up R&D funds from sources that would normally fund small entrepreneurs (like the utilities) (Wall St. Journal, 12/5/91). A new opportunity from Defense Conversion Programs is in process and may provide opportunities for small business that can develop co-funded partnerships with larger businesses, federal laboratories, and universities (ARPA, 1993).

In view of the limited number of outside funding sources that exist for the small EV entrepreneur, this study also investigated the role of venture capitalists. Venture capital has played a major role in the growth of two major industries in California — electronics and biotechnology, and we wanted to see if its financial goals were well matched to those of EV industry entrepreneurs. The full results of this survey are reported elsewhere (Torous, 1992), and the following data is based on a mail survey of 104 venture capitalists with a relatively high response rate of 38 percent. Surveys were sent to all California venture capital companies in Pratt's Guide to Venture Capital (1992) that listed an interest in areas directly or peripherally related to vehicle production or environmental remediation, and also to a smaller list of environmental venture capital firms with environmental interests.

Among 34 companies responding with completed questionnaires, 11 of them or 33% said that they had recently evaluated a business plan from a company in the EV area. Four of the companies reported that they currently had small investments in an EV related business. A fifth firm had an investment in solar energy. All respondents viewed the EV industry as very risky, and the average rating of risk was 2.6 where a maximum rating was 1.0, and the minimum was 5.0. Interestingly, the third of the sample who had reviewed an EV business plan consistently rated the EV industry as less risky, across nine separate measures of risk. Although the difference between the two groups is not always statistically significant, those reviewing an EV business plan tended to see somewhat higher market demand for the vehicles, less risk from post-sales warranty and liability, less risk from the technology being outmoded and from foreign competition, and finally, less risk from inexperienced management teams. This suggests that more information about the industry may have alleviated some of their concerns (or alternatively, because they were more favorably predisposed to the industry, then tended to read and remember the business plans.)

The venture capitalists viewed legislation in California as being an impetus to encourage the industry, but cited the "business climate" in the state as a deterrence to locating an industry here. A few respondents also mentioned that Detroit had an advantage in this industry. Interestingly, respondents could differentiate between different types of EV firms: they evaluated those companies that want to manufacture new purpose built EVs to be less risky than either conversion firms or component suppliers.

From the relatively high response rate to this study, it is evident that venture capitalists did take note of EV technology, and are interested in helping or learning more about it. However, it is also evident from the survey results that a number of risk issues must be resolved before they will be enticed, at large in investing in the industry. It is noteworthy that the State of California has in the past, considered programs to interest the venture capitalists in new technology and provide them with specific financial and tax incentives to support new growth (State of California, 1980). This report recommended lowering the state's capital gain's tax, establishing tax credits for early round investors, allowing increased pension fund investment,

and other public venture capital mechanisms to allow the state to play a more strategic and forward-looking role in new business development.

5.4. Conclusion — EV Capital

We have showed that from a purely financial analysis, an investment in the electric vehicle industry is risky and would meet with some skepticism on the part of private investors. We have demonstrated this empirically through a sensitivity analysis of a small EV business, and we have discussed it qualitatively by surveying investors in the state.

However, we have also shown that selective intervention of public policy can play an important role in reducing this skepticism and bringing forward investment capital need to help small businesses advance. The final recommendation of this report is that a financial intermediary, provisionally named EV Capital, ("EV Cap") be considered. There are many different areas of intervention ranging from selective tax incentives to showcasing R&D, high-tech businesses with venture capitalists, and providing the investment community with assurance about California's long-term commitment to maintain the Clean Air Act regulations. It is noteworthy, for example, that those venture capitalists who seemingly had more knowledge — they had read a business plan from an EV related business — viewed the EV industry as less risky than their colleagues who had no information. Evidently, risk can be reduced if investors learn more about the technology.

This intervention must be guided by a vision of where the industry is headed and an ability to weave together a package of financial options, for businesses at different growth stages — from a complicated interplay of tax policy, legislation, public funding sources, and private ones. Informally, EV Cap has already been a loose confederation of interested parties and contributed locally to successful creation of organizations like CALSTART. To provide broader service it needs to be empowered by state government, recognized by the private investment community, and be actively charged to put muscle behind the legislation's advocacy of Clean Air standards. An immediate goal might be to learn lesson's from California's financial policies during the 1970s' as the state tried to back solar energy programs (e.g. SAFE-BIDCO). There is also an important corollary currently being tested, about developing dual-use technologies, and leveraging the investment of the federal government in defense R&D into civilian EV-products.

The charter of EV-Cap should be two-fold: to encourage private investment in California's high-technology new business ventures, and in the process benefit local economies from successful new small business creation. In addition to being an advocate, EV CAP might provide a modest investment pool (\$3M-\$8M) for small R&D investments, and could regenerate its own funds from a royalty from R&D funded product development; from specified revenues source funding a reserve; from a bond issuance; or from a linked deposit with the State Treasury. In addition, an addendum to Clean Air Act would provide a new type of incentive for EV investment in California. This amendment would give manufacturers a choice: either they could continue to meet 1998 standards by manufacturing, or, instead by contributing a like investment to an EV-Cap R&D pool, which would then be used to seed small high-technology EV businesses. Finally, an organization like EV-CAP could seize an opportunity from the current spin-off from federal research and large science-based corporations to help small firms reduce the cost of acquiring market knowledge, redeploy highly skilled manpower and, channel

capital into new areas of transportation and scientific entrepreneurship.

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Chapter Six

Electric Vehicles, Industrial Development and Environmental Quality in Southern California

Julie A. Roque

6.1. Introduction

6.1.1. Industrial Design vs. Environmental Management

Currently in the United States, sources of industrial pollution and hazards are assessed only after specific plans for new facilities are proposed. New projects are not evaluated and compared against competing proposals to weigh the economic benefits they promise with the deleterious public health and environmental risks they may pose. In short, economic development decisions rarely incorporate health and environmental concerns. New industries are identified and encouraged to develop while health and environmental issues are dealt with after-the-fact by separate governmental agencies that are responsible for regulating them.

To some degree, the dichotomy between industrial development and environmental management is inevitable, at least within our current economic and governmental systems. Development decisions generally are made on a grander scale, with planning agencies involved in encouraging growth of whole industrial sectors within large regions. The environmental impacts of industrial activities, on the other hand, are exceptionally site-specific and dependent on the microstructures of the processes that they involve. Separate institutions have been established to deal with industrial development, and with environmental quality and public health. Local economic development agencies and regional coalitions of city governments usually take the lead in attempting to attract new businesses, and their primary concerns are to increase tax bases and to create new jobs. Alternatively, environmental management generally is the domain of state governments. Most programs enacted by state environmental agencies work under the delegation of authority of the federal government to implement and enforce federal legislation although a number of states have enacted parallel or additional environmental legislation. Similarly, occupational and consumer hazards often are regulated at the state level. And while larger states may have regional offices for implementing these and other programs, siting decisions, permitting procedures, and the adoption of other environmental policies usually

remain centralized at the state level.

To maximize economic benefits without sacrificing public welfare, however, it is imperative that industrial development and environmental decisions be linked. Adoption of the "cleanest" production processes possible can be encouraged most effectively at the planning stages of new facilities and industries. For public officials to weigh explicitly the economic gains of new businesses against potential environmental costs, analyses of emerging industries must be performed before development decisions are made. In other words, health and environmental assessments must become part of the development process.

6.1.2. Electric Vehicles: "Clean" Products?

This chapter examines the potential environmental consequences associated with proposals for an emerging industry: the manufacture of electric vehicles (EVs) in Southern California. EVs provide an unusually interesting case study because they are being promoted across the nation, but particularly in the Los Angeles area, as "clean" technologies and one solution to regional air quality problems. EVs do not discharge the hydrocarbons and the nitrogen oxides emitted by conventional cars and trucks that form Los Angeles' infamous smog. And as a number of researchers have already illustrated, even the air pollutants from stationary sources (i.e., power plants) that produce the electricity required to recharge EVs, given the fuel generating mix of Southern California, do not offset the benefits gained in air quality from driving EVs. (This is discussed in Section II.) Some researchers also have pointed out that energy security in the United States would be enhanced by shifting to EVs powered primarily by domestic fuels. Almost half of the gasoline used in the United States currently is imported, while only about 5% of the electricity used in the United States today is generated from imported fuels. (Mader 1991)

Policymakers, interested in capturing the economic benefits associated with the development of new industries currently are encouraging the establishment of Southern California as the manufacturing base for EVs. Yet the question remains: *what will be the public health and environmental impacts associated with building these vehicles?* Clearly, almost all manufacturing carries with it some costs. The crucial issue is to what degree these costs offset some of the benefits captured in shifting toward driving EVs.

Defining products as "clean," "green," or environmentally sound is not a straightforward problem. Methods for analyzing the total environmental costs throughout the entire lifecycle of a product are not well developed, but a proposed framework for characterizing and assessing the environmental impacts of various stages in the lifecycle of consumer products is outlined below. Such an approach then is applied to EVs in Section II. This assessment is limited primarily because of the lack of data concerning EVs - products and an industry that do not yet exist. Therefore, lessons are drawn from existing industries that might manufacture certain components of EVs. In Section III, projections of the number of EVs that will be built and how the industry might develop are used to describe the environmental costs that Southern California, as well as other regions, might incur. Issues that are raised by the EV assessment, and such analyses in general, and improvements in manufacturing processes relevant to EVs that would enable the EV industry to develop "cleanly" also are discussed.

It is important to emphasize that this chapter represents a first attempt to analyze the

public health and environmental implications of the *entire* EV lifecycle from manufacturing to product disposal. While the titles of some previous studies purport to describe the environmental effects or the lifecycle costs of EVs, only one report that was identified during this project began to examine multiple impacts from all stages of manufacturing, as well as operation and final disposal. This gap appears to be indicative of the lack of information about all of the possible production steps for EVs; of how complicated such an analysis would be to complete; and especially how researchers draw boundaries for their work that reflect a piecemeal, but detailed and technical, approach to managing new sources of wastes and hazards. In contrast, the purpose of this discussion is to propose a general framework for analyzing emerging industries of many types, and to identify specific issues in the EV case that require further study.

6.1.3. Analyzing Industrial Processes: A Lifecycle Approach

The term "product lifecycles" refers to all stages of manufacturing consumer goods, the use of those goods, and their ultimate disposal. The production of most consumer goods requires a number of different inputs, and involves multiple stages of manufacturing and processing. Further, products can be used and disposed of in many different ways.

Lifecycle analyses or assessments have been proposed to evaluate all of the potential human health and environmental impacts associated with consumer products. In general, materials and energy are inputs at each stage of a product's lifecycle. Wastes also are generated at each stage, which then are released into the environment or recycled back into the manufacturing stream for the same or other products. A lifecycle approach enables decisionmakers to identify the most important issues of concern and helps to force analysts to make explicit all of their assumptions. Such analyses map out all of the processes that lead to the manufacture of a product, its use, and its disposal or reuse. And unlike media-specific environmental assessments, lifecycle analyses include wastes released to all environmental media (air, water or land) throughout the product's lifecycle. (Fava *et al.* 1991) They also should characterize other hazards posed during the manufacture of the product (e.g., occupational risks) and to consumers during use of the product.

6.2. Wastes & Hazards in the Manufacture of Electric Vehicles

Researchers have performed studies to estimate the environmental effects of EVs, but despite the usage of the term "lifecycle" in several papers, almost all of the reports that were identified examined only impacts associated with the operation of EVs. (DeLuchi 1991; Dowlatabadi, *et al.* 1990; EPRI 1989; Finson, *et al.* 1992; Fischetti 1992; Ford 1992; Gordon 1991; Lloyd & Leonard 1992; Lloyd, *et al.* 1991; LA DWP; Mader 1991; O'Connell 1990; SCE 1991; Sperling 1991; Sperling, DeLuchi & Wang 1991; Wang, *et al.* 1990; Wuebben, *et al.* 1990) "Lifecycle" costs were defined by most authors only as the environmental costs associated with driving and recharging EVs throughout those vehicles' lifetimes; none of these reports attempted to provide a full accounting of the health and environmental costs associated with manufacturing and disposal, as well as operation. Other studies did begin to account for full lifecycle costs by comparing dollar costs of EVs over their lifetimes to internal combustion

vehicles (ICVs). (Bevilacqua-Knight 1992; DeLuchi, *et al.* 1989) These costs, some including vehicle purchase prices, presumably represent some of the different potential effects posed by EVs and ICVs. Other reports simply compared the dollar costs of manufacturing batteries for EVs against other fuels. (CARB 1990a; CARB 1990b) Clearly, such analyses provide an extremely weak basis for comparison because most environmental impacts are not internalized.

One exception to the many studies that focused only on operation is a report that was prepared for the U.S. Department of Energy in 1980. (Singh, *et al.* 1980) Interestingly, they suggested that the negative impacts of manufacturing EVs (particularly local air emissions, wastewater loadings, solid waste, and occupational hazards) would become more serious, possibly outweighing the benefits gained from driving EVs. They also claimed that while EVs would save petroleum, they would require more total energy for production and operation. Their results, however, were based on proposals for EVs that are no longer current and it is not clear whether their conclusions are relevant today. (They assumed, for example, that these vehicles would operate with DC motors and outdated battery technology.) A more recent report, *Methodology For Analyzing the Environmental and Economic Effects of Electric Vehicles: An Illustrative Study*, prepared for the U.S. EPA's Office of Mobile Sources, did mention that manufacturing hazards should be accounted for but did not attempt to evaluate them. (ICF 1991)

6.2.1. Operating Costs of EVs

Almost invariably, studies that have examined the environmental consequences associated with EV operation (which is essentially emission-free) and recharging compared those impacts to tailpipe emissions from ICVs. These studies found that an overall improvement in air quality could be obtained, even after accounting for additional emissions from increased electrical generation by stationary power plants. The degree to which increased stationary source emissions are offset by decreased vehicle tailpipe emissions, however, varies with the times of day that EVs are recharged (peak hour charging would increase emissions more than offpeak charging) and the fuel generating mix used to produce electricity. The generation of nitrogen oxides is reported to be most sensitive to the time of day that EVs are recharged, and their net production (from ICV tailpipes versus stationary sources) could increase or decrease depending on the assumption of the analysis. (Lloyd & Leonard 1992)

Most researchers examined a series of scenarios to assess the additional energy capacity that would be required to recharge EVs. This demand depends on the types of batteries used, their range, and the times most EVs would be recharged. Southern California Edison (SCE) currently has an oversupply of electricity and could power one million EVs, or twice that if they recharged at night. (Cone 1992) One recent study calculated that the supplemental electricity required, as a percentage of the total electricity supplied by SCE, would be between 4 and 15% over the next twenty years. (Ford 1992)

The burning of fossil fuels to generate electricity produces most of the same air pollutants as those emitted from ICVs: nitrogen oxides, hydrocarbons and volatile organic gases (VOCs), carbon monoxide, carbon dioxide, particulates, and some air toxics (e.g., benzene, formaldehyde). In addition, power plants emit sulfur oxides, of primary concern as an acid rain precursor with the burning of high sulfur coal in the eastern United States. Of course the generation of air pollutants from stationary sources depends upon the type of fuel used. The

average generating mix used to make electricity in the United States is 55% coal; 7% oil; 7% natural gas; and 31% nuclear and renewable fuels. According to EPRI, with this average fuel mix the recharging of EVs would result in only 5.2% of the nitrogen oxides; 0.03% of the carbon monoxide; 0.04% of the nonmethane organic gases (hydrocarbon precursors to smog); and 0.50% of the particulates emitted by an equivalent number of ICVs. A different author reported that recharging EVs would release 25% less carbon dioxide. (Fischetti 1992)

Other researchers examined regional scenarios and agreed that shifting to EVs would drastically reduce hydrocarbons, carbon monoxide, and benzene with any energy generating mix. They did not draw any conclusions about particulates and sulfur dioxide, however, noting instead that regional acid deposition could increase or decrease, depending on power sources. Some predict slight increases in nitrogen oxide emissions on a national scale, and significant, local increases in particulates and sulfur dioxide near power plants. (ICF 1991) Producing the power to recharge EVs would emit less greenhouse gases, particularly carbon dioxide, nationwide, unless coal is used to generate electricity. (DeLuchi 1991; Dowlatabadi *et al.* 1990)

In short, shifting to EVs will decrease total air emissions, unless the EVs are powered primarily or entirely by coal-fired plants. The use of EVs powered by electricity generated from coal would increase greenhouse gases including carbon dioxide, nitrogen oxides, hydrocarbons, carbon monoxide, sulfur oxides, and other air toxics such as formaldehyde and benzene. (Gordon 1991) Further, an increased reliance on EVs will shift the location of air emissions because ICVs emit pollutants during operation, primarily in urban areas, while stationary sources often are in more rural areas. The timing of air emissions also may change as ICVs pollute mainly during morning and evening rush hours. EVs, on the other hand, are expected to be recharged mostly overnight, in the late evening to early morning. The added demand for electricity, then, would be experienced during these hours. (ICF 1991) (Location and timing are especially important variables in the production of ozone from nitrogen oxides and hydrocarbons in urban areas.)

6.2.2. The EV Lifecycle

An ideal assessment of EVs would consider all other steps in the lifecycle in addition to operation. Such an analysis would require that a complete list of the components of EVs be obtained, and the health and environmental impacts of each component's manufacture be characterized. The assembly of these components would be evaluated, as would their disassembly and disposal. Assumptions about what an EV would be, and about how and where the industry would develop, however, must be made.

Current proposals for EVs include converted ICVs, hybrid electric/gasoline powered vehicles, and vehicles specially designed to maximize speed, acceleration, and/or vehicle driving range while relying completely on batteries. Some of these types of vehicles are in operation, while others remain in a prototype stage or even on the drawing board. Yet, some assumptions must be developed for a lifecycle assessment as each of these different types of vehicles would pose different environmental consequences. Batteries upon which EVs will run may be composed of different substances with different lifespans and different types of hazards in their manufacture, use and disposal. Similarly, different materials (especially aluminum and plastics) may be used to produce certain components. And various proposals for EVs have projected

different vehicle lifespans that would determine manufacturing and waste generation rates.

Clearly, some assumptions must be made and boundaries drawn for the performance of a lifecycle assessment. The remainder of this chapter examines five aspects of the production of EVs: substitutions of aluminum for steel or iron components; the manufacture of plastic components and their disposal; electric motor production; electronics production; and the manufacture and recycling of lead-acid batteries. These materials and components were selected because they are most likely to differ significantly from parts found in ICVs in terms of the types and/or quantities of raw materials used. It was assumed that other parts (e.g., the vehicle interior, bumpers, tires, windows, accessories) would be similar to those in ICVs. This discussion was narrowed by emphasizing downstream manufacturing processes, assuming that these would be the most likely operations to be expanded in the Southern California region to meet future demands for EVs. Table 6.1 lists three categories of potential health risks or environmental impacts upon which each step of the EV lifecycle could be assessed. An abbreviated lifecycle diagram of an EV is illustrated in Figure 6.1.

The following sections are based on general information obtained from a number of sources: emissions permits for particular firms; self-reported discharge data; waste audit manuals; and industry, governmental and environmental publications. Analogies to the production of similar products can be drawn to assess the environmental impacts of manufacturing components that are not being made in large quantities today. Some processes, however, present special problems. For example, some of the new plastic composites that may be used in EVs may be composed of very different materials, and produced by very different processes from those used currently in other applications. The electronics industry, on the other hand, actually is a conglomeration of many businesses that produce various components and employ a wide variety of manufacturing processes.

Table 6.1

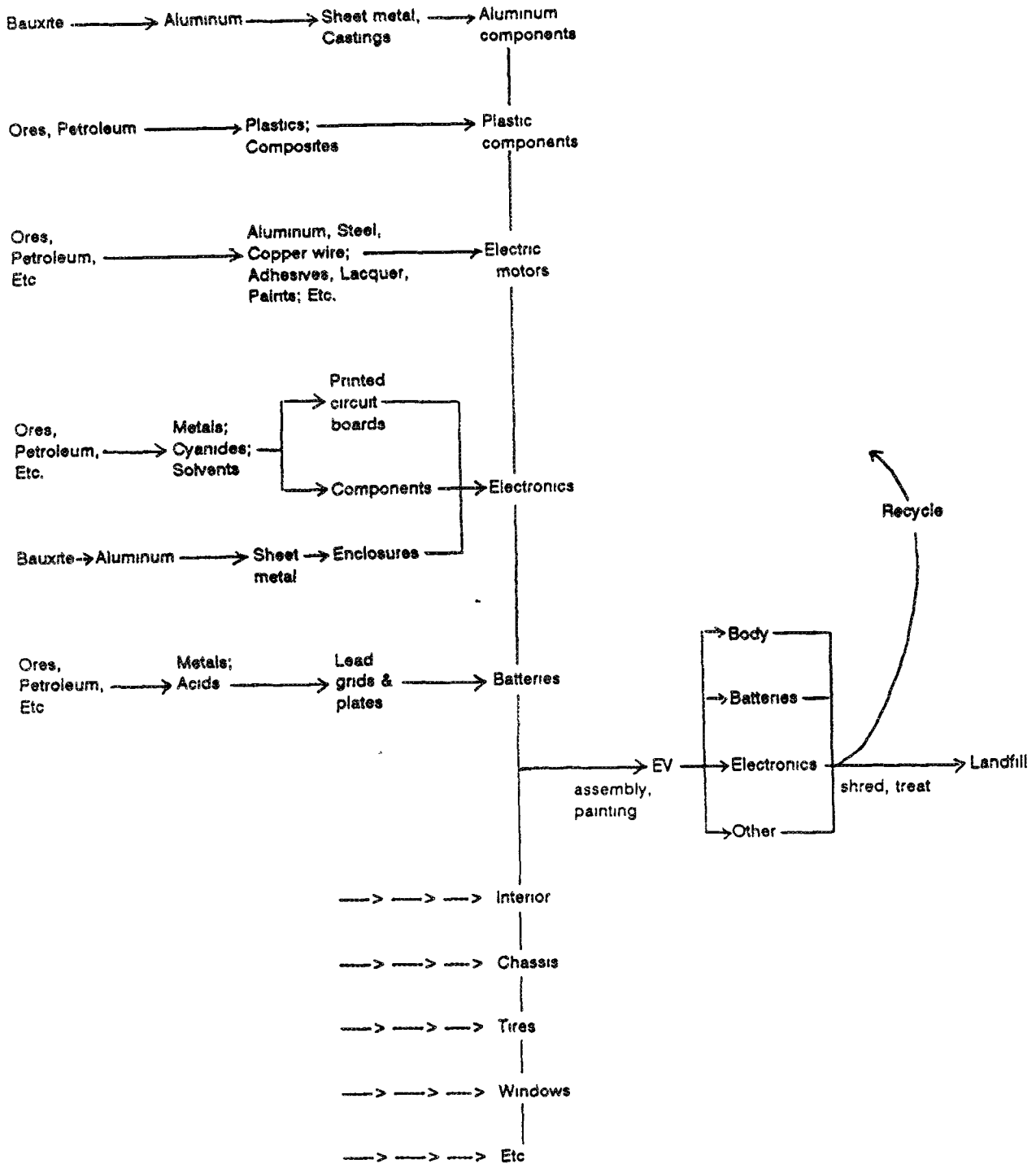
POTENTIAL HEALTH & ENVIRONMENTAL IMPACTS OF MANUFACTURING & MAINTAINING EVs

1. Resources - Material & Energy Use
 - renewable resources
 - nonrenewable resources

2. Environmental Impacts (routine & accidental releases)
 - air emissions
 - water discharges
 - hazardous wastes
 - solid wastes
 - other (noise, ecological impacts, aesthetics, etc.)

3. Direct Injuries
 - occupational risks
 - consumer hazards
 - other environmental damage

Figure 6.1: THE LIFECYCLE OF AN ELECTRIC VEHICLE



6.2.3. Aluminum Substitutions

To extend driving range and increase acceleration, EVs will need to be lighter in weight than ICVs to offset the mass of the batteries they will carry. Most EV designs currently propose the use of aluminum bodies; the GM Impact for example, will be built with aluminum. (Fischetti 1992; D. Hill 9/9/92) The substitution of aluminum for iron or steel will present different environmental impacts than ICVs in the manufacturing and the disposal stages of the lifecycle.

In 1989 and 1990, most ICVs were approximately 68% by weight iron or steel; 5% aluminum; and 7.5% to 12% plastics and plastic composites. The remaining weight of vehicles is composed of other metals, rubber, glass, fluids and lubricants. Aluminum can be substituted for certain steel or cast iron parts and cuts the weight of those parts by 40 to 50%. Sheet or wrought aluminum is used for body panels, vehicle doors, hoods, deck lids, and fenders. Other applications of aluminum are in suspension systems, various engine components, drive shafts, radiators, frames, brake pedal arms, wheel rims and other body reinforcements and brackets. Aluminum alloys are used for interior and exterior trim, grilles, wheels, air conditioners, intake manifolds, water pumps and automatic transmissions. (The Aluminum Assn 1992; Corcoran 1992; Parker 1992; SMC Automotive Alliance 1992; Winfield 1992; Wolfson 1992)

The production of aluminum vehicle components is a multi-step process. As illustrated in Figure 6.1, these processes include mining, the extraction of primary aluminum from ore, the fabrication of sheet metal or ingots, and the final formation or casting of components. Downstream manufacturing steps do not pose significant hazards to the ambient environment, although metal working may pose occupational risks through exposures to dusts and fumes, spot welding and the use of adhesives for assembling aluminum parts and frames. These hazards, however, are generally controllable with protective equipment in the workplace. The major environmental impacts associated with the production of aluminum components arise in earlier steps in the manufacturing chain, particularly mining and the extraction of primary aluminum which are highly polluting and energy-intensive.

The serious environmental consequences posed by mining are not experienced directly in Southern California. While the United States is one of the world's leading producers of aluminum, 90% of the bauxite consumed is imported from Australia, Guinea, Jamaica, Brazil and other nations. The predominant domestic sources of alumina (another source of aluminum) are in central Arkansas, and, to a lesser degree, in Alabama and Georgia. (The Aluminum Assn. no date) In 1991, transportation (including commercial and military aircraft) accounted for just 16.5% of the total shipments of aluminum in the United States. (The Aluminum Assn 1992) The extraction of aluminum most often is performed by passing electricity through bauxite, reducing aluminum oxides to aluminum metal. Byproducts from this process include red mud wastes that are difficult to dewater and must be allowed to settle for years in slurry lakes, during which caustic effluent may leak. Dust from these impoundments may be a problem if they are not covered with water. Dust problems also occur with the handling of alumina and the coke that is burned as fuel.

The major hazardous waste from primary aluminum smelting operations is the cyanide-containing potliner. Fluoride emissions from smelting cells, hydrocarbons evolved during anode baking, and particulates, emitted into the air from refinery stacks may present significant, local environmental concerns. Pollution control devices (e.g., electrostatic

precipitators, dry scrubbers) are relatively effective in capturing these pollutants, but are costly. Water effluent from secondary smelters and fabricators contains oils, graphite, and chemical contaminants. (Kirk-Othmer; McCawley & Baumgardner 1985; Singh, *et al.* 1980) And, as emphasized above, the environmental impacts associated with the generation of the electricity required to produce aluminum inputs ought to be accounted for in any assessment of these processes. Generating electricity produces a variety of air pollutants, depending on the fuel mix, which may have local, regional, and/or global effects on the atmosphere. (See previous section, *Operating Costs of EVs.*)

As with mining, the environmental effects associated with the smelting of both primary and secondary (recycled) aluminum will not be felt directly in Southern California. Smelters currently are situated in the southeastern United States and are not expected to relocate, even if EV manufacturing is centered in the Southern California region. All environmental costs (and benefits), as well as their distribution, however, ought to be accounted for in a lifecycle analysis.

While the production of iron, steel and aluminum all involve highly polluting and energy-intensive processes, some of the environmental impacts associated with their production can be offset with recycling. Currently, over 11 million vehicles are recycled in the United States each year, supplying 37% of all ferrous scrap. (Automotive Dismantlers & Recycling Assn) In 1991, 2,425,000 tons of aluminum scrap were consumed in the United States, supplying over 31% of the domestic supply of aluminum. (Parker 1992) Sixty percent of the aluminum in vehicles today is comprised of recycled scrap, and more than 85% of it in junked cars is reclaimed and recycled. (The Aluminum Assn 1991)

The use of scrap iron and steel to produce new steel reduces air pollution from mills by 86%; water pollution by 76%; and solid wastes by 105%. (The reduction in solid waste is obtained by the recovery of both consumer wastes and by reductions in wastes from processing virgin ore.) In addition, recycling iron and steel scrap reduces the use of virgin materials by 90%; the use of water by 40%; and the generation of mining wastes by 97%. Further, recycling iron and steel consumes just 26% of the energy required to produce those materials from virgin ore. (Institute of Scrap Recycling Industries).

In comparison to steel, the production of aluminum from virgin ore is both more polluting and far more energy-intensive, but reductions in environmental emissions and the energy required to produce an equivalent amount of aluminum can be achieved by producing ingots from recycled scrap. Table 6.2 compares the water usage, other air emissions, water pollutants, and solid wastes for producing steel and aluminum from virgin and recycled inputs. (Because aluminum is lighter than steel or iron, the weight of vehicle components made of aluminum is cut approximately in half: one pound of aluminum replaces roughly two pounds of steel.) The production of primary aluminum is far more energy-intensive than the production of steel, but net energy savings from the use of aluminum can be realized, however, with recycling, through improved fuel economy, and in reductions in the energy needed to fabricate parts. The production of aluminum from scrap requires only 5% of the energy required to produce it from bauxite, reducing the depletion of nonrenewable fuels and the pollution from their combustion. (Institute of Scrap Recycling Industries) Table 6.3 contrasts the energy requirements for vehicles with steel, primary aluminum, and secondary aluminum components. Lifecycle energy requirements to produce steel and aluminum vehicle components are compared in Table 6.4.

Table 6.2

ENVIRONMENTAL IMPACTS OF STEEL & ALUMINUM PRODUCTION
(per metric ton carbon steel and one half metric ton aluminum)

	<u>STEEL</u>		<u>ALUMINUM</u>	
	<u>Virgin materials/ BOF</u>	<u>30% home scrap, 70% obsolete/ electric furnace</u>	<u>Virgin materials</u>	<u>Secondary smelter w/ auto scrap</u>
Water Discharged (liters)				
Process	76,597	683	160,266	4,193
Mine drainage	360	63	1,091	5
Air Emissions (grams)				
Particulates	9,697	1,009	36,654	1,166
Sulfur oxides	3,033	2,875	88,603	662
Carbon Monoxide	963	3,103	34,684	3,475
Hydrocarbons	1,785	1,732	86,804	5,205
Nitrogen oxides	1,844	3,549	138,628	6,751
Aldehydes	24	29	611	40
Organics	8	26	265	58
Ammonia	63		1,050	
Flourides				1,000
Chlorides				
Water Pollutants (grams)				
Suspended solids	27		1,595	875
Dissolved solids	1,114	277	18,567	2,544
BOD	4		150	
COD			1,093	
Oil and grease	2	2	327	
Iron	2		14	
Phenols	0.2		77	
Sulfide	0.2		10	
Ammonia	5		15	
Cyanide	0.1		3	0.1
Flouride	11		1,000	
Chloride				1,700
Cadmium				0.02
Lead				0.04
Manganese				0.045
Solid Wastes (kilograms)				
Overburden	6,665	1,216	28,800	218
Process	4,841	105	15,478	295
Post-consumer		-889		-1,149

Source: Niemczewski, 1984. p. 33-34.

Table 6.3

ENERGY CONTENT OF Al vs. STEEL

	<u>lb/vehicle</u>	<u>Btu/lb</u>	<u>Btu/vehicle</u>	<u>Difference Btu/vehicle</u>
'85 ICV				
steel	1,716	15,450 - 20,100	26 - 34M	
cast iron	450	10,300	4.6M	
subtotal	2,166		31M - 39M	Base
EV (aluminum)	1,083	65,500 - 105,000	71M - 114M	+32M to +83M
EV (recycled Al)	1,083	3275 - 5,250	3.5M - 5.5M	-35.5M to -25.5M

Sources:

Weights of steel and iron parts for a 1985 internal combustion engine vehicle from Niemczewski 1984. p 30
 Weight of aluminum parts in 1992 and beyond EVs assume substitution for all iron and steel parts with a 50% reduction in weight.

Ranges of Btus/lb from SMC Automotive Alliance 1992, and Aluminum Association 1991.

Table 6.4

LIFECYCLE ENERGIES FOR STEEL & ALUMINUM PARTS

Steel part	15,450 Btu/lb
Aluminum part	55,040 Btu/lb
Gasoline energy	130,500 Btu/lb

	<u>Steel part (20 lbs)</u>	<u>Aluminum part (10 lbs)</u>
Energy to produce part (Btu)	309,000	550,400
Lifetime fuel consumed (Btu)	<u>2,610,000</u>	<u>1,305,000</u>
Total Btus	2,919,000	2,855,400

Source: The Aluminum Association, 1991.

6.2.4. Plastic Components

Plastics also could enhance energy efficiency, and several automobile manufacturers have produced body panels composed almost entirely of composite plastics. (Bleviss 1989) Although manufacturers do not appear to be planning to manufacture all-plastic bodies in the near future, it is likely that EVs will contain greater percentages of plastics than vehicles on the road today. (Winfield 1992) The substitution of plastics for certain components, like aluminum, will reduce vehicle weight and increase driving range, speed and acceleration.

Automotive plastics often are composite blends of resins, fiberglass or other fiber substrates, metals, and plastics, or thermosets. Thermosets provide greater strength and durability by undergoing molecular cross-linking reactions during molding. Both composites and thermosets essentially are nonrecyclable; composite mixtures of materials cannot be separated and thermosets, when heated, degrade rather than melt. Technology to recycle process scrap thermosets does exist but styrene emissions appear to be limiting. (CA DHS 1989; Hartt & Carey 1992) Common examples of thermosets are latex, ABS, millable polyurethane, silicone, and neoprene. In ICVs, styrene butadiene rubber elastomers and latexes are used for tires, bumpers, and weatherstrip. Instrument panels, consoles, front radiator grilles, and headlight housings often are made of acrylonitrile-butadiene-styrene, while instrument panel lenses and battery cases can be made of styrene-acrylonitrile. Unsaturated polyester resins, which are reinforced plastics or composites like fiberglass, are used for truck camper tops and recreational vehicles. Other styrenes also may be used in some inorganic pigments. (Radian Corporation 1990)

A second class of plastics are thermoplastics which, in contrast to thermosets, can be melted and remolded into the same or other products. Nylon, acrylic, polyvinyl chloride, polyethylene, polypropylene, and polyester all are thermoplastics. Chemical reagents added to plastics to obtain desired characteristics, however, may affect their recyclability. Such additives include fillers or fibers for enhancing flexibility, elasticity, strength, electrical conductivity. Other additives are UV stabilizers, colorants, flame retardants, antioxidants, antistatics, preservatives, fungicides, smoke suppressants, and foaming agents. Thermoplastics are used for vehicle doors, bumpers, body panels, air ducts, engine compartment linings, intake manifolds, fuel tanks, radiators, cable covers, and electrical components (e.g., distributor caps). Air bags are manufactured from nylon, as may be seat belts, interior upholstery, seats, and floor or trunk linings. Thermoplastic resins that are being developed now are tough enough for thrust washers, valve seats, valve guides, piston rings, high-temperature bushings, and electrical connectors. (Hoechst 1992; Wolfson 1992)

While it is not yet obvious what specific plastics will be used in EVs, it is most likely that they will at least resemble those already in use in ICVs today. The manufacture of chemical precursors and the formulation of plastics involve the use of hazardous and toxic chemicals. Plastics are produced from hydrocarbons such as ethane, ethylene, propylene and styrene obtained from petroleum refining. Emissions of many of these materials present both acute and chronic health hazards such as organ damage and cancer; styrene, for example, is flammable and oxidizes readily to glycols, benzaldehyde, and/or benzoic acid, all which pose human health effects. (Glycols are associated with reproductive disorders and benzaldehyde is a suspected carcinogen.) Styrene also combines with ozone to yield benzaldehyde and formic acid, and in chlorinated water it will react to form chlorohydrin. Chemical fumes may be released when

plastics are heated for molding into components or for recycling, posing toxic occupational exposures as well as environmental impacts. A variety of hazardous solvents such as acetone, methyl ethyl ketone (MEK), methanol, methylene chloride (MC), trichloroethylene (TCE), xylene, and toluene are used as carriers in reinforced plastics (e.g., fiberglass), and evaporate during the formation of products. Some of these chemicals are associated with a range of human health effects including cancer, neurological disorders, and organ damage. (CA DHS 1989; Radian Corporation 1990)

In addition to the hazardous materials used to produce plastics themselves, an assortment of glues and other adhesives are used in the manufacture of plastic products. Adhesives often contain 70% or more solvents which evaporate when they set. These solvents commonly are aliphatic hydrocarbons, (e.g., hexane and heptane), ketones (acetone, MEK), or alcohols, all which contribute to the formation of smog. Many of these materials also are flammable and toxic. Aromatic hydrocarbons, such as xylene and toluene, are sometimes used as carriers, as may be 1,1,1-trichloroethane (TCA) or other chlorinated solvents. TCA and MC may be used as cleaning solvents in the application of adhesives. (SRRP 1991a)

The production of plastic products also is energy-intensive. As shown in Table 6.5, however, plastics can save energy in comparison to steel and aluminum throughout the lifecycle of a component. The energy requirements for the manufacture of an intermediate-sized vehicle hood from steel and from aluminum are compared to one made of sheet molding composite (SMC). Similar calculations are available for other types of plastics. The total embodied energy content of 73 million kilograms of reaction injection molding (RIM) and polyurethane/ABS materials, for example, is equivalent to 183 million liters of oil, while the same parts in steel would require 194 million liters of oil. In addition, 33 million liters of oil energy could be saved by reduced fuel requirements with the same substitutions of plastic for steel. (*Automotive Engineering* 1991)

Automobile manufacturers already are substituting plastics in ICVs to increase fuel economy. Plastics accounted for 2.9% of the weight of cars in 1973 and 7.5% in 1989 (Wolfson 1992); another source reports that in 1991 plastics comprised 13% of the weight of new cars. (Jones 1992) The substitution of plastics for certain components in EVs, however, should not increase the production and use of these materials significantly in comparison to the national demand for a huge variety of plastic products. (Singh, *et al.* 1980)

Two concerns over the increasing percentages of plastics in automobiles are the energy requirements for their manufacture and their solid waste impacts. Both of these issues could be addressed with recycling; the use of recycled plastics save more than 80% of the energy required to produce the same components from virgin plastics. (Institute of Scrap Recycling Industries, no date) Unlike aluminum and other metals, however, plastics generally are difficult to recycle. They are cumbersome to sort and, unlike mixed metals, minimal levels of contamination will ruin entire batches. (Wolfson 1992)

More than eight million automobiles are junked each year, and 75 to 80% of vehicle parts already are recycled. The remainder, however, of which approximately half is plastics, must be landfilled. In 1988, only 1.1 tons of the 14.4 tons of automotive plastics generated were recovered from the solid wastestream. New recycling processes for plastics are being developed, but there may be sixty or more different types of plastic in a single vehicle and sorting them for recycling is too expensive to be worthwhile. Further, certain components such as dashboards and steering wheels often contain a combination of different plastics that cannot

be separated for recycling. As a result, an estimated three million tons of shredded auto parts end up in landfills each year. (Corcoran 1992; Finson, *et al.* 1992; Jones 1992; *Environmental Vehicles Review* 1991a; SMC Automotive Alliance 1992; Wolfson 1992)

Table 6.5

ENERGY NEEDS FOR THE MANUFACTURE OF INTERMEDIATE-SIZED VEHICLE HOODS

	<u>Part wt (lb)</u>	<u>Material energy needs Btu/lb</u>	<u>Energy to produce M Btu</u>	<u>Energy savings M Btu</u>
Steel	33.5	20,100	1,090	base
Aluminum	14.2	105,000	2,400	-1,310
SMC	22.0	24,700	640	+450

Energy Savings Relative to Steel:

<u>Material</u>	<u>Wt diff lb/hood</u>	<u>Lifetime energy savings M Btu</u>	<u>Mfg savings MBtu</u>	<u>Total Energy Savings M Btu</u>	<u>Gallon of fuel</u>
Steel	base	base	base	base	base
Aluminum	19.3	2,328	-1,310	1,018	6.8
SMC	11.5	1,387	+450	1,837	12.2

Source: The SMC Automotive Alliance, 1992.

6.2.5. Electric Motors

An electric motor, for the most part, consists simply of two metal parts, one of which fits inside the other. An electromagnetic field, generated by power supplied through bands of copper wire wrapped around the outer part (the stator), causes the inner part (the rotor) to spin. The rotor and stator generally are made of cast metals (aluminum and steel or alloys). The

copper wires are coated with organic lacquers, and motors may be painted with oil-based finishes. Other hazardous materials that can be used in the manufacture of electric motors are resins in solvent carriers, cutting and lubricating oils, acetylene (for welding), acids, and cleaning solvents. Electroplating that may be performed involves the use and discharge of toxic metals such as chromium.

A full lifecycle assessment would account for the production of all inputs to electric motor manufacturing. This section, however, is narrowed to downstream manufacturing processes as these are the most likely to be expanded with a growing market for EVs. (The environmental impacts associated with upstream metals acquisition and processing were discussed in the previous section on *Aluminum Substitutions*.) The amounts of metals and other materials that are consumed in the production of electric motors is negligible in comparison to all other uses. In comparison to internal combustion engines, the solid waste impacts of electric motors should be positive: they are much smaller, they are far simpler to disassemble for recycling, and they do not contain the oil and other fluids that internal combustion engines do.

As mentioned earlier, the metal working processes (casting, cutting, welding, etc.) in building electric motors pose occupational hazards that are generally controllable. The use of organic solvents, paints, lacquers, and toxic metals, however, can present serious risks to workers and nearby residents if they are not handled and managed properly. Styrene and other hazardous organics may be emitted from ovens used to dry finishes, and extremely toxic metals (e.g., chromium VI) can be emitted from plating processes. The human health effects associated with such materials range from skin irritations to neurological effects and cancer risks. The discharge of volatile organic compounds also will contribute to the regional formation of smog. The reported air emissions (organic gases, nitrogen oxides, sulfur oxides, carbon monoxide, and particulates) of one medium-sized electric motor manufacturer are summarized in Table 6.6.

6.2.6. Electronics

To power the electric motors that are now used in all proposed models, EVs depend on inverters composed of electronic components that convert the electrical current from the batteries from DC to AC. Electronics also are used to match and control the power supply from the batteries to that which is needed by the motor under different driving conditions. Electronics consist of both printed circuit boards and electronic components. It is almost certain that printed circuit board manufacturing and assembly operations now established in Southern California would expand with the development of an "EV industry."

The manufacture and assembly of electronic components involves wafer fabrication (growing crystals from silicon, gallium arsenide, or other materials); wafer assembly (cutting wafers into chips); printed circuit board fabrication (electroplating, etching, and cleaning); and assembly (packaging in plastic or ceramic "boxes," attaching and soldering components onto boards, and removing excess flux). These processes rely upon a variety of hazardous materials that include gases such as arsine and phosphine which are more toxic than those used by any other industry in the United States. They also use heavy metals in plating baths (copper, tin, lead, nickel); strong acids, TCA, and chlorofluorocarbons (CFCs) for etching; acid and alkali cleaning agents, detergents and organic solvent cleaners (many of which are chlorinated); and solder and rosin fluxes for the assembly of components on boards. Fluoride wastes that are

Table 6.6: AIR EMISSIONS FROM THE MANUFACTURE OF ELECTRIC MOTORS
(lbs per year, operating 24 hr/day x 5 days/wk x 52 wk/yr)

	<u>Organic gases</u>	<u>Nitrogen oxides</u>	<u>Sulfur oxides</u>	<u>Carbon monoxide</u>	<u>Particulates</u>
General fuel burning	79.31	1,472.90	9.40	396.55	84.98
I.C. fuel burning	267.26	447.58	1.13	415.38	16.10
Use of organics	37,698.35				
Process emissions	0	0	0	0	609.81
Total (lb/yr)	38,004.92	1,920.48	10.53	811.93	710.89
Total (ton/yr)	19	0.960	0.005	0.406	0.355

Air Toxics (lb/year):

Xylene	437.68
Methylene Chloride	323.4
Styrene	5378.2
Toluene	961.71
Chromium VI	0.307

Source: Reuland Electric, Facility Emission Summary Form

generated in the electroplating and etching of printed circuit boards, and waste oils from machinery must be disposed of as hazardous wastes. (CA DHS 1987b; CA DHS 1991a; SRRP 1991b)

Solvents, metals, acids and alkalis from these processes generally are pretreated and then discharged into wastewater treatment systems, landfilled as hazardous wastes, or treated on land. Some of these wastes (waste oils and metal sludges, for example) can be contained effectively, but solvents and spent process baths can cause environmental problems at manufacturing facilities and in landfills or hazardous waste incinerators. Silicon Valley in Northern California, for example, contains more EPA Superfund sites than anywhere else in the country due to the concentration of electronics firms there. The variety of hazardous wastes regulated under the Resources Conservation and Recovery Act (RCRA) that are produced by printed circuit board manufacturers is illustrated in Table 6.7. It is important to note the vague descriptions of many of these wastes that are provided by the manifest system and which limit the extrapolation of

Table 6.7: HAZARDOUS WASTES FROM 57 PRINTED CIRCUIT BOARD FIRMS

<i>California Waste Code</i>	<i>Description</i>	<i>Tons Generated/Year</i>
111	Acid solution w/ metals	3847.53
112	Acid solution w/o metals	166.03
113	Unspecified acid solution	86.63
121	Alkaline solution w/ metals	4000.05
122	Alkaline solution w/o metals	61.00
123	Unspecified alkaline solution	204.58
131	Aqueous solution w/ reactive anions	635.24
132	Aqueous solution w/ metals	4628.18
134	Aqueous solution w/ organic residues < 10%	70.26
135	Unspecified aqueous solution	242.90
141	Off-spec inorganically	52.72
151	Asbestos	64.38
171	Metal sludge	798.23
172	Metal dust	189.25
181	Other inorganic solid waste	450.86
211	Halogenated solvents	519.35
212	Oxygenated solvents	90.93
213	Hydrocarbon solvents	3.81
214	Unspecified solvent mixture	236.13
221	Waste oil and mixed oil	814.87
222	Oil/water separator sludge	107.11
223	Unspecified oil waste	406.61
241	Tank bottom waste	109.40
261	PCBs	15.20
271	Organic monomer waste	13.75
272	Polymeric resin waste	21.19
281	Adhesives	5.63
291	Latex waste	4.16
321	Wastewater treatment sludge	89.24
331	Off-spec organics	30.75
342	Organic liquids w/ metals	4.17
343	Unspecified organic liquid	124.75
351	Organic solids w/ halogens	21.43
352	Other organic solids	202.66
411	Alum and gypsum	1.67
421	Lime sludge	174.46
461	Paint sludge	95.07
491	Unspecified sludge waste	352.03
512	Other empty containers	348.02
513	Other empty containers < 30 gal.	460.28
541	Photographic chemicals	8.10
551	Lab chemicals	116.56
571	Fly ash, bottom ash, retort ash	10.96
611	Contaminated soil	75.49
711	Liquids w/ cyanides > 1000mg/l	9.74
723	Liquids w/ chromium (VI) > 500 mg/l	12.51
741	Liquids w/ halogenated organics > 1000 mg/l	4.17
	Total	19,988.14

Source: California Department of Health Services, 1987 (CA DHS 1987b). p. 19.

waste generation rates for new processes. (CA DHS 1987b; CA DHS 1991a; Silicon Valley Toxics Coalition 1992)

Volatile organics used primarily for cleaning in the electronics industry are emitted into the air routinely. The chlorinated solvents used most widely in the electronics industry today are TCE, TCA, MC, perchloroethylene (perc) and CFC-113. In 1986, 40,000 metric tons of CFC-113 were used in electronics applications; 17,000 metric tons each of TCA and MC were used in 1985. (SRRP 1991b) Chlorinated solvents are safer to use but pose chronic health risks (including cancer) to both workers and local communities. In addition, solvents such as TCE, carbon tetrachloride and CFCs rise through the atmosphere and degrade the protective stratospheric ozone. Although they are being phased out by many larger firms, CFCs still are used widely for vapor degreasing and critical cleaning in most of the electronics industry because they provide good solvency, rapid evaporation, and dry with no detectable residue. (Reinhardt 1992; Silicon Valley Toxics 1992) Aliphatic hydrocarbon solvents (kerosene, mineral spirits, Stoddard solvent, heptane) are general cleaners and degreasers that can contribute to regional smog formation. Toluene, turpentine, and xylene are aromatic hydrocarbons with known toxicities for organ damage and cancer risks. Ketones, such as acetone and MEK, are used to remove paints, resins and coatings but are toxic and also contribute to smog. Most of these nonchlorinated solvents have low flash points and are flammable. Other significant occupational risks also are associated with the electronics industry. Researchers recently, for example, have reported additional evidence for links between exposures to the glycol ethers used in etching processes and reproductive effects in workers. (Weber & Gellene 1992) During soldering, workers may be exposed to lead and other toxic metals (e.g., cadmium, arsenic, beryllium); organic solvents; and rosin fluxes that decompose to formaldehyde and other hazardous compounds. (Lead Industries Assn 1990)

6.2.7. Batteries

Alternative fuel cells that would provide greater driving ranges between charges, be more compact, and have longer lifespans have been proposed to power EVs. (See Quant in this report, and Bates 1992; DeLuchi, Wang & Sperling 1989; O'Connell 1990) The battery industry is committing significant resources to improving the lead-acid technology, however, in an attempt to retain - and increase - their markets with the introduction of EVs. (The Advanced Lead-Acid Battery Consortium 1992) Further, most EV manufacturers agree that lead-acid batteries will be used at least in the near term. This section discusses the potential health and environmental consequences only of lead-acid batteries primarily for that reason. There also is a lack of information readily available on the manufacture of alternative batteries as they are not currently produced and recycled at the same levels as lead-acid batteries.

The use of lead-acid batteries probably would lead to greater mining of lead in the short run, and greater smelting particularly by recyclers until EVs shift to other types of batteries. The energy requirements for lead production (mining, concentration, smelting and refining) are lower than those of any other of the major metals, using only 25% of what is required for copper and less than one half that for zinc. Lead ranks only after aluminum, copper and zinc among the nonferrous metals in terms of usage. (Woodbury 1985)

The United States has some of the largest lead reserves in the world, and in 1990,

primary lead smelters produced approximately 400,000 tons of lead while secondary smelters produced about 900,000 tons, most (85%) of which came from spent automobile batteries. There are three primary lead smelters in operation in the United States: one in central Montana and two in southeastern Missouri. In contrast, there are 23 secondary lead smelters in operation in the United States, some that are owned by lead-acid battery manufacturers and others that are independent, but only three west of Texas. (U.S. EPA 1992) Nearly two thirds of all the lead produced in the United States in 1990 (800,000 tons) was destined for use in storage batteries. Batteries are produced for a variety of applications, but automobiles clearly account for the majority; roughly 72 million new car batteries were produced in 1990. (Battery Council International; Gruber 1991; U.S. EPA 1992; Wojton 1990; Woodbury 1985) Two companies, GNB and RSR, recycle approximately 65% of all lead-acid batteries collected in the western United States. (Theodore Barry & Associates 1989) Spent lead-acid batteries were declared hazardous wastes by the U.S. EPA in 1985, and many of the materials generated in the recycling process meet EPA's definition to be regulated as hazardous wastes. (Apotheker 1990; Gruber 1991; Kafka 1990; Singh, *et al.* 1980)

Until recently, batteries have been the bottleneck in the development of the EV. Technologies other than lead-acid only now are becoming commercially feasible, and the lead-acid batteries required to power an EV are so heavy that it has been difficult to obtain acceptable driving performances. Lead-acid batteries also are likely to be the bottleneck in the development of an EV manufacturing industry because of the large numbers of batteries that will be required and the significant health and environmental impacts associated with their manufacture.

The increase in battery production and recycling that is expected to accompany the commercialization of EVs will pose extremely high local impacts near manufacturing facilities, and extremely high occupational risks. Increased battery manufacturing in Southern California also would contribute to regional environmental problems such as smog and wastewater pollutant loadings (as does most heavy manufacturing). Currently, however, there is not the capacity for managing and recycling the large numbers of batteries that would be generated by EVs, and it is unlikely that additional capacity will be added soon. (GNB 1992) According to one industry representative, stringent air quality regulations in the South Coast air basin precludes the expansion of battery recycling facilities here. (A. Saldana 9/4/92) It is quite probable, therefore, that spent batteries will be shipped elsewhere for recycling and/or disposal. Recycling capacity and alternatives for lead-acid batteries are being studied currently by the Los Angeles Department of Water and Power; their report should be available by the end of 1993. (C. Zidonis, Sept 1992)

The manufacture of new batteries, and the generation of spent ones, will rise exponentially if EVs enter the market as planned. Projections for the number of EVs on the road range from the minimum of 2% of the new vehicle fleet, or approximately 40,000 cars, in 1998, to more than 500,000 EVs in 2003 and up to 1.2 million in 2010. (Cone 1992; SCE 1991) Most EVs, including the GM Impact, the GM HX3, AC Propulsion's CRX, and the Opel Impuls 2, currently use 28 to 32 ten volt lead-acid batteries with a total weight of between 850 and 1100 pounds. (*Automotive Engineering* 1992; Cone 1992; Dunne 1992; Fischetti 1992; Mader 1991; Reynolds 1992) These EVs appear to be the most likely to be marketed in the near future, although others have proposed EVs that would use as few as 18 batteries. (Bates 1992; Gay, *et al.* 1992) Designers and manufacturers predict that batteries would last two to three

years, and would cost \$1500 to \$2,000 to replace. (Cone 1992; Dunne 1992; Fischetti 1992; Reynolds 1992)

A typical lead-acid battery contains 17.5 to 20 pounds of lead, 9 to 11 pounds of sulfuric acid, and 1.6 to 3 pounds of polypropylene for the case. In ICVs, batteries have an average life of 3 to 4 years. The U.S. EPA recognizes an 80% recycling rate is being achieved for lead-acid batteries, while other sources report rates of 80 to 85%. (Apotheker 1990; Battery Council International; Calif Adm Health & Safety Code; Finson, *et al.* 1992; Gruber 1991; Smith, Bucklin & Associates 1992; Theodore Barry & Associates 1989) A recent report performed for the Battery Council International, on the other hand, claims that 97.8% of all types of batteries were recycled in 1990, up from the 1989 rate of 95.3%. (Smith, Bucklin & Associates 1992)

An additional 5,000 tons of spent batteries from the 10,000 EVs proposed for California by 1995 is relatively small, especially in comparison to national waste generation rates. In 1990, for example, it was estimated that 850,000 tons of spent lead-acid batteries had to be managed in the United States. The increase in spent batteries associated with 10,000 EVs, then, is equivalent to less than 1% of 1990 national levels and approximately 3.5% over 1988 California levels. (Theodore Barry & Associates 1989)

In the longer run, however, manufacturing and recycling batteries to be used by a growing number of EVs will become a significant problem if they continue to rely on lead-acid batteries. EVs now each require 28 to 32 batteries, in contrast to one in each ICV, and these need to be replaced more often. An upper bound estimate, assuming that 1.2 million EVs will be on the road by the year 2010 and that each will rely upon 32 lead-acid batteries, is that as many as 37.2 million additional batteries - or over half of the total 72 million batteries already produced today - will be required to power just EVs. (The 1.2 million batteries that would be used by an equivalent number of ICVs were subtracted.) Because EV batteries might last only half as long before they have to be replaced, this value would have to be doubled to calculate the number spent batteries that would be generated.

These calculations become more dramatic when put into a California context, which is appropriate since that other regions in the United States also are considering adopting similar initiatives to promote EVs. If 1.2 million of the eight million cars on the road in California were replaced with EVs with 32 batteries each, 45.2 million batteries would be in use at one time. If EV batteries were replaced every two years and ICV batteries every four, 20.9 million spent batteries would be generated each year (assuming a steady state). In contrast, two million would be generated if EVs were not introduced. In other words, over ten times as many spent lead-acid batteries could be produced with the introduction of EVs over the next 17 years.

It is most likely, of course, that EVs will have to adopt alternative battery technologies to become marketable, particularly because of the high cost of replacing the entire battery pack and the limited ranges lead-acid batteries can offer. One lead-acid battery manufacturer, for example, predicted that demand will increase just four-fold over the next twenty years (rather than by a factor of ten) by assuming that half of EVs in the year 2010 will use other types of batteries. California does not, however, have the recycling capacity to handle even this number of batteries. (GNB 1992) Under this scenario, approximately 47 million spent batteries will be generated each year, in contrast to the 10 million per year generated today. It also must be noted that alternatives to lead-acid batteries probably will pose significant, although different, health and environmental risks as well. (ICF 1991) The main source of toxic cadmium in

landfills, for example, is rechargeable batteries. (Reinhardt, *et al.* 1992)

In addition to lead and sulfuric acid, the manufacture of lead-acid batteries involves the use of smaller amounts of other hazardous chemicals. These include organic solvents (in cooling towers and for cleaners); paints, enamels and thinners; other acids; and metals such as antimony, arsenic, cadmium, copper, manganese, nickel, tin, and zinc to produce alloys for various applications. Fossil fuels that may contain impurities such as benzene, formaldehyde, and chlorine also are needed to melt lead and lead alloys for casting.

In recycling spent lead-acid batteries, batteries are broken apart and the acid is allowed to drain. The acid from spent batteries is of low grade, and therefore is neutralized (rather than recovered) and discharged to wastewater treatment systems. Polypropylene battery cases are ground and recovered, and then sent to plastic recyclers who can reuse them to make new cases; polyethylene separators and other material become feed for the furnace. All lead scrap is melted and slag, formed from lead sulfide in the furnace, must be disposed of as a hazardous waste. (The slag from primary smelters is exempt from RCRA regulations.) An average battery with 18 to 20 pounds of recyclable lead will produce roughly 2.2 pounds of silica-based slag that contains about 5 grams of lead. By weight, 98% of a spent battery can be recycled and only the equivalent of the lead in less than one battery is released to the environment from recycling facilities for every 24,000 recycled. (EPRI; GNB Incorporated; Gruber 1991; U.S. EPA 1992)

The most obvious concerns with battery manufacturing and recycling are worker exposures to and air emissions of lead particulates for which there are stringent occupational and environmental standards. Lead is a notorious toxin that is associated with colic, anemia, neuropathy, kidney effects, and reproductive toxicity at high blood levels ($>40\mu\text{g}/\text{dl}$). At lower doses (between 10 and $40\mu\text{g}/\text{dl}$), the effects of lead are decreased IQs in children, increased blood pressure, and enzyme inhibition for heme synthesis. Lead can cause neurologic disease and affects the metabolism and activation of vitamin D, which in turn compromises bone integrity. Increased incidences of kidney cancer with exposures to lead also have been observed in animals. Children and fetuses are especially susceptible to lead and no threshold is apparent for the neurobehavioral and developmental effects in children nor for cardiovascular effects in adults. (ICF 1991; Isherwood, *et al.* 1988; U.S. EPA 1991)

Lead bioaccumulates in the environment and chronic exposure may cause serious health effects at levels lower than those established for acute effects. The major pathways of exposure to lead are inhalation of particulates, and consumption of particles deposited on soil, vegetables or house dust. Workers in smelters and who handle municipal solid waste (MSW) ash are at greatest risk of exposure in occupational settings. Leachate from landfills also may contain mobilized lead and have the potential to contaminate drinking water supplies. Of 786 National Priority List (Superfund) hazardous waste sites, 55 are listed with lead as a significant contaminant. It also was estimated that 20% (120) of the companies or sites on the Superfund list in 1985 were former lead processing facilities (battery breakers, secondary lead smelters, or scrap metal dealers). (Apotheker 1990; U.S. EPA 1991)

The U.S. EPA 1991 has developed emission factors for discharges of lead from primary and secondary smelters. Using the TRI data collected under SARA and by assuming a 95% recycling rate nationally, they calculated annual discharges of lead to the air, water, and land from primary and secondary smelters, and from MSW incinerators that receive unrecycled batteries. They also calculated the quantity of lead that ends up in MSW landfills. These estimates are summarized in Table 6.8.

While lead is the most prominent concern in battery manufacturing, other pollutants may prove to be limiting factors to the expansion of production and recycling and manufacturing facilities in Southern California. Air emissions of traces of cadmium, for example, pose carcinogenic risks. Further, a representative of a secondary smelter explained that they are operating near capacity and are unlikely to receive the necessary air emission permits for criteria pollutants (carbon dioxide and sulfur oxides) to build an additional furnace. (A. Saldana 9/4/92)

Table 6.8

LEAD TO THE ENVIRONMENT FROM SECONDARY SMELTERS
(metric tons per year)

	<u>Air Emissions</u>	<u>Land Discharges</u>
Primary smelters	473	6,028
Secondary smelters	560	3,750
MSW incinerators	282	5,319
MSW landfills		76,618

Emission factors in (lb/lb lead produced) x 10,000:

	<u>Air</u>	<u>Land</u>	<u>Water</u>
Primary smelters	8.4	151.4	0.056
Secondary smelters	1.8	47.2	0.055

Source: U.S Environmental Protection Agency, 1991.

6.3. Summary

6.3.1. Overall Impacts in Southern California?

The results of a full lifecycle analysis are not unidimensional and should be presented in a manner that preserves as much information as possible. Summing environmental releases across different routes of exposure or different environmental media cannot be justified as health and environmental impacts often vary with these factors. Summing effects experienced in different locales or different geographic regions also should not be done as aggregate data will mask regional or site-specific variations in energy and material requirements, and in the types

and magnitudes of hazards presented and pollution generated. And it clearly makes no sense to sum across potential impacts of different natures; risks of different types of health effects such as cancer and neurological damage, for example, clearly cannot be added, nor can such human health impacts be summed with ecological or other environmental consequences.

To project the implications of manufacturing EVs, some measure of the health and environmental costs per unit of production for each industrial sector that would contribute to an EV industry could be developed. Some of the measures of production levels that might be used as a denominator for such 'hazard indices' are: units of production (numbers of motors, batteries, etc.); numbers of employees; total sales; or, value added. While actual units of production would be most accurate, often such data are not available even on an aggregate level. Other variables measure production rates indirectly, and their accuracy probably varies from industry to industry. For example, number of employees reflects how labor intensive an industry is, and may vary on a facility level depending on whether or not, or to what degree, production is automated.

These hazard indices then could be multiplied by anticipated production rates (for each sector) to calculate the needed resources, the environmental discharges, and other risks that might be incurred with various levels of production. Although such indices would not be linear, but rather complicated functions of the size and structure of manufacturing processes, they could provide an initial glimpse into which operations are likely to be the most detrimental to public health and the environment. In 1987, for example, the California Department of Health Services estimated the waste generation of copper from typical large and small printed circuit board manufacturing operations. (CA DHS 1987b) Assuming linearity, their rates could be normalized to some measure of production (e.g., per component or square inches of board) to extrapolate emissions increases with increased component manufacturing. Unfortunately, estimates of waste generation rates such as these are not available for most pollutants.

A 1993 report by the Economic Roundtable titled "Jobs and Air Quality: Analysis of Emissions per Job by Industry in the South Coast Basin" ranked industrial categories defined by four digit SIC codes, and individual manufacturing firms, by the quantities of air pollutants they emit. Numbers of employees simply were divided into total annual emissions of five air pollutants (or classes of pollutants): reactive organic gases (precursors to photochemical smog), nitrogen oxides, sulfur oxides, carbon monoxide, and particulates. Although the intention was to identify industries that might maximize jobs and minimize pollution, there are problems with this study which highlight the dangers in using such estimates to evaluate which particular industrial sectors public development interests might choose to promote. Most notably, while these are the most ubiquitous air pollutants, they are not the most hazardous. In the case of EV manufacturing, for example, ambient and occupational exposures to lead in battery manufacturing and to the array of extremely hazardous compounds used in the electronics industry clearly are of much greater concern than incremental changes in ambient concentrations of the pollutants addressed in the Economic Roundtable study. Secondly, ambient concentrations of these pollutants are not likely to be affected measurably with the development of a manufacturing base for EVs in Southern California. Currently the background concentrations of these pollutants are high, due to the fact that they are emitted by most manufacturing facilities. Finally, there is no indication in the report that any corrections were made to account for employees whose presence has no correlation to levels of production. Office, sales and clerical staff, for example, may have been included in some firms' count if they are located at

manufacturing sites. In other cases, however, people in these positions may be situated elsewhere.

A more important challenge to the use of studies like that of the Economic Roundtable for targeting specific industries for development is raised with the recognition that there are innumerable possibilities for how and where an EV industry might develop, and these factors will determine the nature, the magnitude, and the geographic and social distributions of detrimental health and environmental impacts. Although some scenarios may be more plausible than others, it is not yet obvious which components will be manufactured in Southern California, or which parts will be made elsewhere and perhaps shipped here only for assembly. Each scenario suggests different impacts: producing more components in Los Angeles could result in higher process discharges, but shipping them will result in greater transportation-related pollution.

The location of specific sources is important because certain environmental effects (e.g., smog) are geographically-specific, and because some airsheds and wastewater treatment systems are already heavily burdened with industrial wastes and may not be able to accommodate increased pollutant loadings. The siting of new pollution sources in such areas may have adverse effects, while discharging wastes in less sensitive environmental regions or to facilities with greater treatment capacities available may enable hazardous materials to be managed effectively. In addition, economies of scale usually can be captured by traditional pollution control devices and techniques which operate more efficiently on highly concentrated wastestreams. Thus, small manufacturing firms may pollute more per unit of production in comparison to larger firms that are able to finance capital intensive - but cleaner - operations. If linear relations between production rates and hazardous exposures or discharges are assumed, extrapolations may be overestimates if the increased production of components is accommodated by existing manufacturers. They may be underestimates, on the other hand, if small firms are created to meet added demands.

Despite these limits, potential health and environmental impacts associated with the manufacture of EVs can be described qualitatively. Table 6.9 summarizes the major health and environmental impacts associated with the manufacturing processes described in the previous sections. These are ranked as negligible, low, moderate and high in comparison to ICVs (for operation) and other industrial processes in Table 6.10.

It is apparent that regionally, EVs will help to clean up the air in Southern California given that most manufacturing, and certainly not the upstream processes (mining, primary smelting, chemical formulation), will not be undertaken here. Even if assembly and some parts manufacturing are developed locally, the environmental impacts associated with these processes would be only incremental increases to existing industrial emissions. In addition, most of the electricity consumed in the Los Angeles basin is produced from natural gas, a relatively clean fuel, and 70 to 80% of it is generated elsewhere. Studies indicate that reductions in ozone levels, sulfates and nitrates would be gained in Los Angeles, particularly if the power required for recharging was produced elsewhere, (Bevilacqua-Knight 1992; Dowlatabadi *et al.* 1990). It appears, then, on the basis of use (i.e., driving EVs versus ICVs), that a shift to EVs would improve local air quality. Other activities also affected by the introduction of EVs could benefit the local environment; less oil refining in the Southern California air basin, for example. Impacts on air quality outside the basin, however, would depend the type(s) of fuel used and the percentage of the electricity generated by particular sources at different locales.

Table 6.9

PRIMARY HEALTH & ENVIRONMENTAL IMPACTS ASSOCIATED WITH EVs BY SCALE

	<u>Individual (Occupational or Consumer)</u>	<u>Local & Regional</u>	<u>International/ Global</u>
Operation	Explosion hazards during battery recharging	Air pollution from power sources; spent batteries (air, water & land pollution)	Acid rain, greenhouse gases from power generation; use of nonrenewable fuels
Aluminum Substitution	Mining hazards; smelter workers exposed to toxics; metal working risks	Hazardous mining wastes; air, water & land discharges from smelting & component manufacturing	Significant energy consumption & associated pollution; transportation risks with Al importation
Plastic Substitutions	Exposures to hazardous organics	Nonrecyclable plastics to solid wastestream; air & land discharges of hazardous organics	Energy consumption & associated pollution; petroleum use
Electric Motors	Metal working risks; exposures to toxic metals & organics	Waste oils, etc.; air emissions of solvents & painting materials; wastewater discharges of metals & solvents	
Electronics	Worker exposures to reproductive toxins, carcinogens, & other hazardous chemicals	Air, water & land discharges of toxic metals, solvents, acids, & alkalis; VOCs contribute to smog formation	Emissions of stratospheric ozone depleters
Lead-acid Batteries	Extremely high exposures of lead to workers	Extremely high local lead emissions; lead-bearing hazardous wastes; acid wastewaters; toxic metals & organics to air, water & land; criteria air pollutants & air toxics from fuel burning	

Table 6.10

RANKING OF HEALTH & ENVIRONMENTAL CONSEQUENCES OF EVs

	<u>Consumer/ Occupational</u>	<u>Local</u>	<u>Regional</u>	<u>Internat'l/Global</u>
Operation (battery recharging)	negligible	low/mod (depending on fuel mix & source)	low/mod (depending on fuel mix & source)	low/mod (assuming an ave fuel mix)
Aluminum Substitutions				
extraction/smelting	high	high	high	moderate
metal work	low	low	low	negligible
paint/lacq	moderate	moderate	low	negligible
Plastic Substitutions				
formulation	moderate	moderate	moderate	mod/low
molding	moderate	moderate	low	negligible
assembly	moderate	low	low	negligible
Electric Motors				
metalwork	low	low	low	negligible
paint/lacq	moderate	moderate	low	negligible
Electronics	mod/high	mod/high	moderate	mod/low
L-A Batteries mfg/recycling	high	high	moderate	low

EVs may, however, impose significant local environmental impacts, particularly in and near secondary lead smelters and battery manufacturers. EPA's emission factors and GNB's estimate that 47 million batteries will be generated each year to meet the 20% EV requirement can be used to estimate the additional lead that might be discharged from secondary smelters in California by the year 2010. If an average battery contains 18 pounds of lead and a 95% recycling rate is achieved, 72 tons of lead per year lead will be emitted into the air; 1,897 tons to land; and 2.2 tons to waterways. This is an increase over nationwide emissions from secondary smelters by 13% for air and 50% for land.

6.3.2. Opportunities for "Clean" Manufacturing & Minimizing Impacts

The final component of a full lifecycle analysis is an improvement analysis, or an "...evaluation of the needs and opportunities to reduce the environmental burden associated with energy and raw materials use and environmental releases throughout the entire life cycle of the product, process, or activity." (Fava, *et al.* 1991, xviii) Once capital expenditures have been made, firms often are more resistant to changing their operations. The performance of a lifecycle analysis early in the planning stages of a developing industry, however, enables "clean" technologies to be incorporated into the design of manufacturing processes.

Strategies to reduce or minimize the environmental impacts of manufacturing EVs ought to be encouraged (or required) as industries develop. All production processes should be reviewed to reduce the use of toxic or hazardous chemicals wherever possible. Waste audit and/or waste reduction documents for a number of industrial operations are available from the California Department of Health Services, the U.S. EPA, and other governmental agencies, trade associations and technical assistance programs across the country. (See CA DHS 1987a, 1987b, 1988, 1989, 1991a, & 1991b; and SRRP 1991a, 1991b, & 1991c.) Classic waste reduction techniques recommended for electroplating, for example, include: segregating wastes; substituting materials that are easier to recycle or are water-based; and extending process bath lives with monitoring and treatment. Wastes can be reduced by operating process baths at lower concentrations; using wetting agents; and improving rinsing with air or workpiece agitation. Water can be conserved by using multiple counterflow rinse tanks and flow controls. (CA DHS 1991a)

Operating procedures for individual processes within industries vary widely and also determine the magnitude of both environmental impacts and occupational risks. In some manufacturing applications, for example, water-based degreasing agents can be substituted for solvents that are more toxic, contribute to the formation of smog, the depletion of the stratospheric ozone layer, and/or global warming. Many of these water-based substitutes are relatively innocuous and can be used, treated and disposed of safely. The automation of certain industrial processes also can minimize worker exposures to hazardous chemicals so that only negligible quantities of wastes are released to the environment.

Because huge numbers of spent lead-acid batteries most likely will be generated, it is imperative that an effective recycling system be established. Battery firms are exploring an electrolytic method of production (electrowinning) as a clean alternative, but the development of this process does not appear feasible in the near term without a sizeable public investment. Thirty-four states, including California, have enacted battery recycling laws, and federal battery recycling legislation is being discussed as a means to stabilize the price of lead. Secondary smelters are especially susceptible to market fluctuations because while they have to purchase scrap, primary smelters obtain it from ongoing, mixed metal mining operations. But even before it was mandatory, the rate of battery recycling always was 65% or higher. Secondary smelters were able to compete with primary smelters until they became subject to stringent hazardous waste regulations under RCRA, establishing economically unequal operating conditions. (Calif Adm Health & Safety Code; *Electrical Vehicle Progress* 11/15/90; Motor Vehicle Manufacturers Assn 1992; Theodore Barry & Associates 1989; U.S. EPA 1992)

Air emissions also are probably going to be a limiting factor in expanding recycling facilities. The U.S. EPA's Office of Air Quality Planning and Standards is likely to lower the

federal National Ambient Air Quality Standard for lead although most secondary lead smelters are not now in compliance with the current standard. A 1987 report prepared for the U.S. EPA found that roughly two thirds of the domestic secondary smelters operating in 1976 had closed by 1986 due to stringent environmental regulations and low lead prices. As a result, the national capacity for recycling lead dropped from 1.3 million metric tons in 1980 to 800,000 metric tons in 1986; it rose to 930,000 metric tons by 1989 with the industry operating at 87% capacity. (Battery Council International; Gruber 1991; Smith & Daley 1987; U.S. EPA 1991)

In addition to introducing "clean" manufacturing techniques, it is important that opportunities to minimize the the environmental impacts posed in other stages in the EV lifecycle also be identified and promoted. To minimize environmental impacts and materials and/or energy use, for example, the potential for reuse and recycling should be considered now in the design of EVs. Currently in the United States, an estimated \$15 billion a year is saved by the recycling of used automotive parts compared to cost of manufacturing new parts. (*Environmental Vehicles Review*, 1991a) While one optimistic source reports that that EVs may be up to 85% recyclable (*Environmental Vehicles Review* 1991b), choices of materials for various components in EVs and the ease of disassembly will determine whether they can be recycled economically.

Automobile manufacturers in Europe have taken a lead in recycling that might provide valuable lessons for the United States. BMW (among others) established a pilot facility at their Landshut, Germany factory in June 1990 to improve methods and minimize the time and cost of disassembling old BMWs. They also are working to redesign BMWs so that they are more recyclable by making them easier to disassemble and by not manufacturing parts of mixed materials (e.g., plastics and metals). A Volkswagen "laboratory" in Leer, Germany has been successful in removing metals from bumpers and then grinding the plastic into pellets which are mixed with fresh resin to form new bumpers. Since May 1991, about 20% of the material in new bumpers came from old ones. The main limitation to this recycling has been the lack of a steady stream of scrap materials due, in part, to the fact that not all bumpers made of same materials. To ease the separation of different plastics, Volkswagen is redesigning their cars so that they will use fewer different plastics. The plastic gasoline tank in the VW Golf that went into production in summer 1991, for example, has 11 fewer parts than previous design. (BMW AG 1991; Corcoran 1992; Motor Vehicle Manufacturers Assn 1992)

German manufacturers also are stamping government standardized codes that identify different materials. Yet, these efforts still address only 30% to 40% of the thermoplastics typically found in cars. In the United States, the Society for Automotive Engineers has issued a standard for labeling various plastics used in cars. Automakers' recycling codes are different than those for household plastics, however, and different collection systems are needed. In addition, markets for post-consumer plastic auto scrap do not exist currently. (Corcoran 1992; Wolfson 1992)

Laws have been proposed in Europe that would make the complete recycling of automobiles the responsibility of the manufacturers. Germany, for example, is proposing to require auto manufacturers to take back cars free of charge. Sweden charges a "scrapping premium" to help recycle cars, and requires owners to prove they have responsibly disposed of a car before it is removed from the tax rolls. (Jones 1992; Parker 1992; Wolfson 1992)

To obtain the greatest air quality improvements in Southern California, the most polluting (and most heavily used) vehicles should be targeted first for substitution with EVs. Automobiles are the largest source of air pollution; statewide, they produce 24% of the non-methane

hydrocarbons, 27% of the nitrogen oxides, and 55% of the carbon monoxide emitted into the air. Researchers from the Bureau of Automotive Repair and the Air Resources Board, however, have found that just 7% of the cars on the road emit 50% of the total carbon monoxide while 50% emitted only 0.3%; 6% of all vehicles emitted 50% of the hydrocarbons, while 50% emitted 3%. (California Senate Office of Research, 1991) Pulling the most polluting cars off the road and replacing them with EVs would optimize the tradeoffs between tailpipe emissions and the environmental effects of operating EVs.

6.3.4. Lessons from a Lifecycle Approach

Clearly, the largest barrier to completing a full analysis of complex products like EVs is the lack of data that reflect geographical variations and differences in specific manufacturing processes. Analogies to other industrial operations, however, can be drawn. And, although lifecycle analyses may raise more questions than they resolve, they can make assumptions explicit, illuminate surprises, and serve to identify during the planning process opportunities to improve production. Such an approach also may elucidate basic policy choices, and competing goals (such as health and economics) may become apparent when environmental analyses are incorporated into development decisions. A means to reduce occupational exposures and environmental emissions, for example, is to automate manufacturing processes. Automation, however, can reduce significantly the number of jobs that are created with new industries. One such situation is Hughes which automated their assembly of electronic components and decreased the number of employees they needed by a factor of at least forty. (D. Hill 9/9/92)

A lifecycle analysis must be bounded in a way that will limit data collection. Yet, these boundaries should not be so restrictive as to reduce the analysis to where it no longer provides a full evaluation of the potential effects of all hazards in each environmental medium. It also is imperative that the impacts at all scales which might be imposed on various regions be identified. Possible results when analyses are bounded too narrowly is that pollutants are transferred from one medium to another; that equally hazardous (but different) materials are substituted for others; contamination is diluted to minimize local effects but present worse regional problems; or that pollution simply is exported to other areas.

Even once a lifecycle analysis is completed, defining a baseline for evaluating its results may not be a straightforward task and "better" choices should not be precluded. It may appear that EVs will reduce smog in Southern California, for example, at least as long as coal is not burned locally to generate the electricity required for recharging. But the conclusion that EVs are environmentally sound is based only on a comparison the operation and recharging of EVs. Instead, EVs ought to be evaluated throughout all manufacturing stages and compared to other transportation and land use alternatives.

Such a conclusion also is based on the assumptions that the tradeoff between smog and toxics such as lead is positive. But the introduction of EVs will cause dramatic increases in concentrations of lead and other heavy metals near battery manufacturers and secondary smelters in Southern California. The lower level hazards of ozone that all Los Angeles residents face, then, will be replaced with intense occupational and local risks imposed on a much smaller population. Whether this is an improvement depends on how such very different concerns are weighed. Further, other regions probably will bear at least some of the environmental impacts

associated with the use of EVs in Southern California. Batteries are likely to be exported to other regions for recycling and, as mentioned earlier, most of the electricity that will be used to recharge EVs will be generated elsewhere.

And, although Los Angeles might benefit overall with the use of EVs, it is important to keep in mind that the emissions of certain air pollutants from stationary sources may, in the aggregate, be greater than ICV tailpipe emissions if coal is burned to produce electricity. Decisionmakers in these regions ought to consider their local circumstances, however, before policies to encourage EV use are adopted. The northeast United States and countries such as China, for example, rely primarily on coal for electricity, and increased power generation could lead to serious local and regional air quality problems (sulfates, particulates, acid rain) that might outweigh even the local benefits of driving EVs, much less their manufacture.

6.3.5. The Driving Force? Environment vs. Development

This study initially was intended to examine the potential health and environmental effects associated with the manufacture of EVs in Southern California. During the course of this investigation, however, a larger question was raised. That is: will industrial development initiatives like the current effort to promote EV manufacturing determine the quality of the environment in Southern California, or will environmental regulations ultimately shape the economic base of the region?

For the most part, the State of California is recognized across the nation for its progressive and tough environmental laws and regulations. Further, the South Air Quality Management District, unable to comply with federal and state standards for ozone, has adopted a far reaching plan to control sources of air pollution. As a result, more stringent limits are imposed on industrial sources of air emissions (especially hydrocarbons) in the South Coast air basin than essentially anywhere else in the world. This was reflected in a conversation with a representative of the National Electric Manufacturers Association who indicated that firms in Los Angeles never would be able to obtain the air emission permits necessary for all of the processes involved in the production of electric motors; presently, bands of copper wire are laquered in other states for motor manufacturers located here.

As discussed above, the capacity to manage the anticipated volume of lead-acid batteries that will accompany the introduction of EVs into the California automotive market does not exist currently. Yet, battery manufacturers do not anticipate they will be granted air permits to expand their processes. It remains to be seen whether Southern California policymakers will discover an environmentally sound means to manage the spent batteries that will be collected once EVs are on the road. It also is not clear at this time who (or which regions) will bear the health and environmental costs associated with EV manufacturing, or whether the economic benefits of EV production will be captured here. As the EV industry develops and policies to promote the use of EVs are debated, the lifecycle framework proposed here should be revisited time and time again, revising and refining the assumptions upon which a full assessment might be based.

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Chapter Seven Technology Policy Issues In Building an Electric Vehicle Manufacturing Base In Southern California

John P. Slifko

7.1. Introduction

In developing an electric vehicle manufacturing base in Southern California priority should be given to policy instruments that assist organizational capacity in the private sector for the adoption, adaptation, and diffusion of both new and existing product and process technologies and related know-how. The contextual industrial politics should be seen as highly significant (industrial politics will be defined in a special sense). Critical attention should initially be given to the need for institutional mechanisms to develop a vendor-base of California companies supplying advanced transportation systems and electric vehicle components and sub-systems with subsequent attention to manufacturing process and implementation. There should be an emphasis on leveraging local and federal transportation technology investments with private-sector funding within the framework of a coordinated (horizontally and vertically integrated) technology policy.

Four ongoing revolutions in technology development will require the development of policy initiatives capable of iteratively engaging new local, regional, state, national, and global realities. These revolutions have been more than capably analyzed elsewhere.¹ Individually and cumulatively they considerably impact the technological trajectory along which an advanced transportation systems and electric vehicle industry may develop in the region. They are:

- the revolution in military planning and affairs changing the size and character of United State's technology investments
- the revolution in the international economy
- the revolution in the process of technological innovation
- the revolution in the scope of national government action on technology.

¹ Alic, John A Branscomb, Lewis M Brooks, Harvey Carter, Ashton B Epstein, Gerald L. Beyond Spinoff Military and Commercial Technologies in a Changing World Harvard Business School Press, Boston Massachusetts

In the midst of these four structural metamorphoses, Southern California is in an almost unique position in the United States to address concurrently each of the changes with adroit and effective policies, or alternatively, policy drift could leave the region enfeebled. Each of these revolutions should be considered opportunities to aid in the development of an electric vehicle and advanced transportation systems industry in Southern California.

Policy formulation in support of an advanced transportation systems industry in Southern California should proceed with a clear recognition of three patterns of institution building possible supporting the region's developing electric vehicle industrial base.² The first is externally oriented and would exist to ensure the maximum influence over federal policy and dollars, and the international system, and is likely to be dominated by major corporations involved in high-technology such as electronics and aerospace, utilities, and transit agencies; and a second pattern which is internal and integrative would seek to enhance the flexibility of small and medium-scale firms, working with large established firms, through the provision of collective services and the innovative recombination of resources. This latter pattern will likely be advocated by academics, some political leaders, and some talented small- and medium-scale firms. Organized labor has advocated both positions in Southern California. A third approach, the fusion of these two approaches is possible, but emphasis should first be to build an integrated regional base from which to develop external initiatives.

CALSTART, a recently formed non-profit advanced transportation systems and electric vehicle consortium marks a point of departure for the potential industry in California. Until the CALSTART consortium, the utilities in Southern California were supporting advanced transportation industrial development in the mid-west or overseas and the legislative initiatives they fostered supported only the use of alternative fuel and electric vehicles in California, but neither their California manufacture, nor the development of the essential underlying components and sub-systems. CALSTART was established to develop critical supplier expertise in the vendor base supporting advanced transportation systems and electric vehicles.

What has been lacking and what will be required is a coordinated technology policy in Southern California subjacent to state, federal, and international initiatives — in other words, regional and integrative approaches concurrent with externally oriented approaches and institutions. Examples, of nascent regional, state, and national collaboration in technology development already exist in California, for example, the South Coast Air Quality Management District (SCAQMD) support of the CALSTART consortium (SCAQMD was the first agency to support the idea of an advanced transportation systems industry in Southern California, as well as the first supporters of the Showcase Electric Vehicle Program — CALSTART's first program.); an additional example is SCAQMD's development of the Locomotive Fuel Cell Propulsion Systems Task Force, and potentially a Locomotive Fuel Cell Systems Consortium. The South Coast Air Quality Management District should also be acknowledged for ongoing efforts at indigenizing technologies and related manufacturing know-how into the region from national and international sources, such as space frame architecture and other technologies to optimize mass transit vehicles intended to be manufactured in the region and that will use the

² Analee Saxenian has discussed the politics of business organization in Silicon Valley and contrasts two patterns of institution-building one which is externally oriented, the other internal and integrative. These two patterns are being repeated in the advanced transportation systems industry in Southern California. Saxenian, AnnaLee "Divergent Patterns of Business Organization in Silicon Valley" in Storper, Michael and Scott, Allen J., Editors, *Pathways to Industrialization and Regional Development*, Routledge, New York and London, 1993.

Ballard Fuel Cell from Vancouver, Canada.

The recent development of the New Partnership/New Directions, National Transportation Agenda by the Los Angeles County Transportation Commission (LACTC) is an additional example (LACTC recently merged with the Rapid Transit District to form the Metropolitan Transit Agency [MTA]); as well as CALNET, an informal alliance of regional and state transit agencies that — in pursuing federal defense reinvestment dollars — have collectively rationalized proposal criteria to minimize redundancy, identify and highlight individual agency expertise and technology priorities, and maximize job opportunities for Californians. The planning work of these single-purpose agencies needs to be further imbricated in broader regional institutional and public- and private-sector activity. Thus, for example, ongoing MTA staff work in creative procurement reform henceforth establishes as bidding criteria that proposals include (i) participation plans by networks of local suppliers, and (ii) some elements for the commercialization of advanced transportation technologies. In many cases, the enabling sub-systems are the same as electric vehicles: i.e. advanced materials, electronics, communications, sensors, drive systems, etc. These synergies should be commercially exploited. This is one example of the type of new technological-institution building that needs to be diffused throughout the region.

This is not to be construed as a reference to the need for a single regional government, rather as a call to collective activity in support of technology-intensive industries like the electric car. And these local efforts must operate within some degree of alignment to policy initiatives in Sacramento and Washington, and to the extent they currently exist, with the minimal financial resources flowing from Washington to the Southern California region and the state. Currently more dollars are transferred from California to Washington D.C. than the converse.

Regional economic development in support of an electric vehicle and advanced transportation systems industrial base does not require at this stage large federal infusions of dollars flowing into California's national laboratories or large aerospace companies. Rather, smaller infusions of federal dollars should move through new private-sector and non-profit institutional media in support of networks of small- and medium-scale companies that are currently establishing the components and sub-systems industry in the region and where much of the innovation and commercialization ability resides.

In turn, the private-sector infrastructure (firms learning from each other) should also maintain the organizational capacity to work with larger domestic and overseas original equipment manufacturers, and with the national labs and other institutions in the state like the Jet Propulsion Laboratory and the California Institute of Technology. The smaller federal "carrots" leveraged against a range of non-federal sources can be important for small- and medium-scale firms in component and sub-systems development, but equally important as organizing tools in fostering associational behavior among firms for technology transfer, modernization services, and rapid commercialization techniques.

Federal and state seed funds are important because government provision of enabling research and development for components and engineering assistance will be a necessary part of the equation in creating an electric vehicle industry in order to push technology forward and to reduce the costs and risks to be born by the eventual manufacturer. Such R&D activity will concern both final assembly and components. Other parts of the final equation for an electric vehicle industry will concern possible scales of operation (number of vehicles to be made), and the mix of vehicles (number of lines in a facility, flexibility, types of vehicle); equally important

will be securing initial private and public market commitments.

Establishing manufacturing infrastructure for larger vehicles, such as for fuel cell transit buses, electric battery school buses, rail technology, service vehicles, trucks, and related satellite industries (communications and electronics) can be a central component in California grand strategy to advance collaboration and innovation inter-diffusion with the Michigan automobile industry and the larger industrial mid-west. At least one organization, The Made In California Working Group, an alliance of public- and private-sector decision makers and academics, has dedicated considerable time and resources in implementing this approach.

An illustration can be given: a precision effort at swiftly launching the already referenced SCAQMD fuel cell locomotive initiative would provide an invaluable learning curve for mid-west industry in fuel cell technology as a propulsion system. The considerable problems in developing and commercializing fuel cells which are performance and cost competitive with existing engines should not be underestimated. At this stage in the development of fuel cell technology it is impossible to select the best propulsion and fuel technology for electric vehicles and other transportation modes. There will probably not be a single winner and it may take several hundred million dollars to explore the opportunities and identify potential winners - and several billion dollars to develop production versions and production facilities for a number of fuel cells with different modal applications.³

California in developing fuel cell technology for locomotives, buses, and utility vans, and other vehicles as exotic as unmanned air vehicles for military purposes and environmental research, will provide Californian and Michigan advanced transportation systems and electric vehicle industries with critical insights, valuable time in the global arena, and political underwriting for an important but underfunded technology: fuel cells. This is only one but an important example of potential Michigan/California/United States grand strategy supporting advanced transportation systems technology, others will be given in this chapter.

7.2. CALSTART: A Non-Profit Advanced Transportation Systems and Electric Vehicle Consortium

CALSTART is a non-profit consortium of utility, industry, government, labor, and environmental organizations. The labor/business/government partnership presents one platform by which California could assume a leadership role in the emerging advanced transportation systems industry. CALSTART's participants, sponsors, and board members include:

- 5 major utilities
- over 20 small, medium, and large United States corporations (mainly in Southern California)
- 4 universities and research institutions
- a labor union
- an environmental organization

³ Al Sobey, Testimony for California Energy Commission, Hearing on "Competitive Leading-Edge" Alternative Fuel-Vehicle Technologies, May 27, 1993, Los Angeles, California

The consortium was formed initially by AMERIGON (a Southern California company and Southern California Edison (a major utility) in response to federal legislation; specifically, the Advanced Transportation Systems and Electric Vehicle Consortia provisions of the Intermodal Surface Transportation Reauthorization Act of 1991. The legislation established a national competition providing 1:1 matching grant awards to winning consortia to develop supplier expertise in components and sub-systems, and to assist participating companies in rapidly commercializing advanced transportation technologies using, to the extent practicable, existing aerospace and defense technologies, capabilities, and supplier firms. It was intended that sub-national consortia would be funded enhancing "local synergies" and simultaneously sector-specific innovation in the national advanced transportation industry. Twenty seven consortia were in competition for the federal funds with four final winners, including CALSTART.

The legislation was drafted in order to integrate energy, environment, transportation, economic development, and technology policy areas, including issues of defense conversion. The legislative intent was to pursue synergies in grouping diverse policy areas because of the political, institutional, financial, technological, knowledge, and skill resources that emerge in the process — a type of policy entrepreneurship.

Following the architecture of the legislation, CALSTART was conceived as a sector-specific institution and simultaneously as a regional organization optimizing local synergies existing in the various regional economies of the state. Awareness of this nexus is important. Until recently, industrial/technology policy has been considered exclusively the domain of sector-specific strategies promulgated at the national level. Part of what is new in California via CALSTART is the recognition that technological innovation is both a functional (sector-specific) and a regional (sub-national) phenomenon. The intention of the legislation that led to CALSTART was to tap this very rich and very real confluence of forces.

Technological innovation can be viewed as a collective phenomenon which needs to be understood as an organization/institution and in terms of a network. Those firms concerned with developing and commercializing technologies are comprised at their core of sets of intra-firm relations with enveloping "territorial" institutions each with their own practices based on unique geographies and histories; and each embedded in very real national and international structures and flows.

Precisely when capital and technology flow at increasing rates of speed around the world an iterative process between localities and their institutions and wider geographic constituencies should be considered an important policy arena. CALSTART, while just underway and certainly experiencing growing pains, is generally considered an innovative program and a promising experiment in technology policy, local synergism, and business/government/labor partnership.

This chapter reports the fact that one of the first programmatic efforts of CALSTART, the Showcase Electric Vehicle Program (SEVP), is well underway and so far successful. The SEVP was intended to pull together a range of companies that could develop components and sub-systems for the nascent global electric automobile industry. The process of preparing the automobile did, as anticipated, pull together a diverse range of companies and give them a platform to demonstrate their components around the world as the car has now begun to travel to foreign auto shows and around the country. As of early 1993, over a dozen major domestic and foreign automobile firms have visited CALSTART's Burbank headquarters to discuss matters of mutual interest in components and sub-systems in California. (It must be emphasized

that the SEV was never intended to go into production, but merely to showcase California components and sub-systems domestically and around the world.)

In establishing a crucial vendor base for the advanced transportation industry, California maintains certain competitive advantages as well as structural weaknesses. California's aerospace industry has considerable expertise in creating efficient, lightweight, and reliable electromechanical products for defense and space programs. And the region contains, perhaps, the largest assemblage of small- and medium-scale firms in the world with the Tokyo/Osaka geographic axis as the likely second largest concentration.

It is important to point out that there is clear evidence of a supporting public- and private-sector technological-institution infrastructure in Japan, Germany, France, Italy, and other countries in the critical aerospace vendor base, as well as in other sectors, that is non-existent in California. But, as earlier stated, it is precisely in the aggregate of small- and medium-scale companies where a significant portion of the innovation is likely to occur in the fledgling advanced transportation industry. This must be of concern to decision-makers.

CALSTART offers one opportunity to exploit the state's technological strengths and remedy its institutional weaknesses. With the strengths and weaknesses in focus, CALSTART's stated intention is to pursue several short- and medium-term goals. CALSTART is intended:

- to develop a vendor-base of California companies supplying advanced electric vehicle components to automotive customers worldwide (The legislative intent was/is to establish sub-national consortia with an overlapping vendor-base for bus and rail technology as well, in other words, a flexible and collaborative manufacturing network.)
- to serve as a statewide information clearinghouse and center of activity for advanced transportation systems
- to provide access to inexpensive space and administrative services by inviting participants to utilize the 155,000 square-foot facility in Burbank donated rent-free by Lockheed, and
- to coordinate and provide external relations and fundraising activities for program participants.

In pursuit of these goals, CALSTART has under way three initial core programs, two Electric Vehicle related programs, two support programs, and important ancillary projects. These programs are designed to be mutually reinforcing and to optimize CALSTART's contribution in strengthening the national manufacturing base of the advanced transportation systems industry.

7.2.1. Core Programs

Showcase Electric Vehicle Program

The Showcase Electric Vehicle Program is a collaborative effort of approximately 20 California companies developing advanced components for electric vehicles. The program has already assisted companies in marketing these components to automotive companies by exhibiting them in a working prototype of an electric vehicle demonstrating their capabilities in auto shows around the world. Participating companies have contributed cash and R&D expenses to support the effort. The SEVP participants have drawn upon unique regional technologies and knowledge — including from the defense, electronics, and aerospace sectors — to develop proprietary products for worldwide sales.

Infrastructure Program

To assist in the successful commercialization of electric vehicles, CALSTART has developed a comprehensive infrastructure program to provide all the support systems necessary for successful consumer use of the vehicles. This program consists of six vital elements: charging stations, service/technical/education/centers, battery recycling and disposal, public awareness campaigns, utility system impact analysis, and community integration. By coordinating the efforts of the five major California utilities and key companies, this CALSTART program is intended to leverage limited financial resources, develop uniform standards, set the stage for customer acceptance, and create a more credible automaker interface.

Electric Bus/Mass Transit Program

CALSTART's Electric Bus Mass Transit Program seeks to develop advanced clean intermodal and mass transit systems. The program's main objectives are to develop zero-emission electric bus propulsion systems and to encourage development of highly efficient bus accessory systems. In addition, the program will enhance public awareness and acceptance through electric bus demonstration programs, and encourage commercial manufacture by developing optimized electric bus design specifications.

7.2.2. EV-Related Programs

Neighborhood Electric Vehicle Program

CALSTART's Neighborhood Electric Vehicle (NEV) Program seeks an early market niche for electric vehicles — using EV's for short trips to mass transit nodes and around the neighborhood. The program has been conducting extensive market research and is formulating plans to design and test a prototype commercially viable NEV, drawing upon the supplier base of advanced components developed through the other CALSTART programs. Safety will be designed into the vehicle from the beginning by conducting super computer crash simulations at the Lawrence Livermore National Laboratory. The goal is to demonstrate the viability of an NEV in order to engage an automaker to mass produce it drawing upon California technologies.

Electric Vehicle Testing

CALSTART's Electric Vehicle Testing Program (EVTP) is intended to provide a rapid and cost-effective means to test California-supplied components in converted electric vehicles experiencing actual driving conditions. The program will also transfer advanced California components into commercially converted EV's creating an early market for these products.

7.2.3. Support Programs

University and Federal Laboratory Research

One part of CALSTART's strategy is to build linkages to the world-class research programs at California's universities and laboratories. In some instances, CALSTART will provide space at its Burbank facility for research needs.

Discretionary R&D Program

CALSTART's Discretionary R&D Program will support small California companies with high-potential, advanced transportation technologies. CALSTART intends to provide these companies with the additional capital needed to develop, test and commercialize their technologies, ensuring that California does not miss opportunities in the new technologies market. In addition to funding, CALSTART also offers these companies its facility, equipment, and test capabilities.

In addition to the value of the economic and technological opportunities that CALSTART may demonstrate through its goals and programs, the consortium is perhaps of greatest value as a contemporary institution chartered in July of 1992. The consortium should be assessed for lessons in restructuring California and the United States technology policy in the 1990s. In this regard, the SEVP is highly illustrative of the associational behavior that will be essential to the success of small- and medium-scale companies in global competition.

7.3. Industrial Politics

The term industrial politics is used here not as a reference to government strategy, writing legislation, allocating resources, or setting rules and regulations. Rather it refers to a wide set of collective factors that determine the forms of production a region or nation might evolve. At its core industrial politics can be seen as the working out of collective agreements about strategy, structure, appropriate behavior, priorities, and rights. Viewed in this way, interpretations of the market, workplace struggles, conflicts between large firms and sub-contractors, or projects to foster innovation, have critical importance in setting an industrial approach in a given region or nation. To focus on any single set of factors in explaining industrial growth — like government strategy or firm management — would be misleading.⁴

In the United States the organizing principle that has defined industrial politics and

⁴ Friedman, David, 1988, *The Misunderstood Miracle*, Cornell University Press, Ithaca and London

practices is and has been hierarchy. Alternative approaches to a hierarchical set of industrial practices do exist. The "protocol economy" concept as used by David Friedman and Richard Samuels is illustrative.⁵

Friedman and Samuels argue that Japan has evolved a "protocol economy" where small- and large-firm producer associations, local, prefectural, and national agencies, regional business groups, industry groups, technology centers, and organized labor are bound together in networks that establish certain rights for industrial actors to question, as they attempt to influence, economic decisions without commanding outcomes.

Friedman writes:

"Japanese protocols governing resource access, rights, work allocation, state intervention, and the like, keep a wide range of players in the nation's economic game and cut off only those at the extremes — wild eyed entrepreneurs of companies in irreversible decline, for instance — that cannot muster sufficient support among banks, bureaucrats and other firms to obtain the resources they need. The protocol economy erects a set of checks and balances that creates incentives for Japanese business to collectively and continuously innovate, build skills, and avoid behavior that would destroy their capacity to collaborate, and respond flexibly to change."⁶

United States' industry has been experiencing profound structural changes since the 1970s witnessed in the dis-integration of major firms, the proliferation of sub-contracting relationships, and the flattening of mid-management numbers at major corporations. Superimposed on these structural changes, California in 1993 is experiencing a strong recession, defense downsizing, and social tensions, that bring questions of technology/industrial policy and economic development into sharp relief.

The crisis affords an opportunity to rework the industrial practices and economic protocols that have been the standard since the end of World War II. CALSTART, for example, by bringing all of the players to the table — industrial, labor, financial, bureaucratic, political, as well as large- and small-scale companies, each with different agendas — has the potential incrementally to influence the industrial "system" of the region, and even the state.

As an illustration, postwar Japan and the northeast section of Italy illustrate widely divergent yet similar growth-generating productive systems.⁷ The concept of "productive system" as used by Michael Best and others in describing various technology and industrial regions of the world signifies a group of interrelated institutions by which goods and services are created. In this approach the term "system" is exceedingly instructive because it emphasizes

⁵ Samuels, Richard Rich Nation, Strong Army, forthcoming 1993, Ithaca, Cornell University Press; Friedman, David, Samuels Richard "How to Succeed Without Really Flying: Japan's Technology and Security Policy and the Japanese Aircraft Industry" MIT paper.

⁶ Friedman, David forthcoming 1993 Getting Industry to Stick. Enhancing High Value-Added Production in California, MIT paper

⁷ Best, Michael, The New Competition Institutions of Industrial Restructuring, Harvard University Press, Cambridge, Massachusetts, 1990.

that the organizational features of a firm cannot be examined in isolation from institutions that interact with firms, for example, supplier and buyer relations, inter-firm associations, worker organizations, financial institutions, and local, regional, state, and federal government agencies. This overall approach can accurately be considered the spatial (regional) and institutional (organizational and extra-firm capacity for innovation and synergy) equivalent of the systems engineering approach regnant in the existing Southern California aerospace industrial production system. The task is to broaden the understanding of industrialists throughout the region as to the full implications of the term "system" in late twentieth century manufacturing.

In Best's analysis the new competitive playing field is one in which productive systems are oriented to continuous improvement in product and process in contrast to the older forms of competition in the Fordist system in which the production system is geared only to minimize cost for a given product and process. In Best's "New Competition" economic analysis must account for the capacity for collective action to reshape production-related institutions as new challenges and opportunities develop. The policy implications of this perspective are significant. Up until now technology/industrial policy in the United States has been based upon the idea that government's role is to promote price competition (with recent policy emphasis on fostering cooperative research [1980s], and even more recent, emphasis on collaborative manufacturing [early 1990s]). But if enhanced inter-firm transactions — and institutions that foster these — are a condition of success for small- medium- and large-scale firms and shops, then policy initiatives based upon the ideal competitive market may contribute to actual industrial decline.

Finally, in addition to the knowledge/policy gap, two additional hindrances exist that retard the successful development of collective agreements for industrial strategies/direction, and appropriate behavior and rights in Southern California: a language gap and partisan politics. Both deficiencies are critical matters and exist as statewide problems.

As Analee Saxenian has observed about Silicon Valley in northern California:

"Silicon Valley is best viewed as a hybrid form which mixes the principles of flexible specialization and mass production and which is little understood, even by its own participants. In the shadow of the hegemonic practice of mass production in America, the region's producers have failed to develop either a language which allows them to articulate their shared interests, or institutions which allow them to govern their own relationships and respond collectively to external threats."⁸

And so in the current industrial and economic difficulties, California's various industrial regions seem incapable of finding ways to work together or collectively to share pain to preserve future options. The only responses to date have been ideological, partisan, or simply for show. The lack of a genuine technology policy in the region and state subjacent to a national policy has meant the virtually unchallenged media overemphasis on the problems of the major aerospace and defense contractors, to the neglect of important emerging industries like medical instruments, and potential industries like advanced land systems and advanced materials. And it has allowed the status-quo pentagon-pork-barrel approach to military planning and emerging technologies (with no discussion of the relevance of individual weapons systems) to continue

⁸ "A Response to Richard Florida and Martin Kenney", *California Management Review* (spring, 1991) pp 136-143

emanating from California's "leaders", to the detriment of the defense industry, national security, and economic security.

7.3.1. High Performance Work Organization

For purposes of brevity only one incipient program is mentioned here as a reference point from which to view the wider CALSTART effort: the High Performance Work Organization (HPWO), a subprogram in CALSTART. This example can assist in demonstrating that the evolution of this new institution can occur in fundamentally different ways based on diverse agendas, and a wide variety of still-to-be-made decisions. Each existing and future project has the potential to influence the organizational practices of CALSTART, and to help shape new economic protocols for manufacturing and technology in California — well beyond the organizational boundaries of CALSTART.

The HPWO is a CALSTART effort of considerable potential importance to the region and the state. It has the potential, as does CALSTART in toto, to influence industrial development efforts in the necessary reindustrialization of the region and state.

The HPWO is being developed in a model agreement between the International Association of Machinists and Aerospace Workers (IAM) and AMERIGON as part of the development of a "manufacturing enabling infrastructure" as conceived by the union for the advanced transportation industry in California. The HPWO is intended to reduce bureaucracy by giving front-line-workers more responsibility for many tasks — from quality control to production scheduling. A central component is the concept of productivity bargaining within a framework of constant renewal of worker skills through general education and school-to-work transitioning, and public and privately-financed continuing on-the-job-training. This effort is intended to reorient students, trainees, and workers to the value of skills-acquisition, and encourages the belief that there is a market for the training they pursue.

The key elements of the HPWO are:

- use of all available resources to achieve economies of scale regardless of firm size;
- a consumer-driven, as opposed to a producer-driven, orientation to the production of goods customers want at a price they will pay;
- use of well-educated and trained workers to extend the functioning of leading-edge technologies, and to make use of the large amounts of data/information available;
- recognition that the return to investments on human resources is higher than return on investments in physical capital; and
- an industrial relations system geared to the organization of production and its rewards; and productivity negotiations through collective bargaining.

An important element in the IAM/AMERIGON approach is an activity-based cost accounting system still being refined. As manufacturers have adopted new manufacturing techniques like computer-aided-design, just-in-time stock management and total quality control,

it is oftentimes discovered that existing accounting systems are woefully out-of-date.⁹

A central argument in this approach is that companies understand how to measure the costs of labor and materials but not those of other overheads. This approach worked well when the costs of labor and materials were the most important factors of production. But in the nineties other costs makeup a much larger share of each product's value.

The goal is to develop systems that produce products at a "target cost" and to reduce that cost over the lifetime of the product. The techniques used to do that can help refine the factory. In today's factory where small batch production is the order of the day and where machines have to be retooled quickly cost-accounting must keep pace. And in addition to faster-machine tool changes, other factors like: quality producing a boost in market share; product flexibility; improving competitiveness; and small-batch production having shorter delivery times leading to greater customer satisfaction are all intangibles that have a huge value in the market, but are not picked up by traditional internal accounting practices.

With activity-based-costing all of a company's activities are considered as product costs — from logistics to marketing, distribution and administration. It involves tracing the costs of all services to individual products. Production can occur using this system in "natural groups" with office and manufacturing workers teamed into "cells" and organized around the flow of materials and information. This makes it easier to trace costs to products. IAM/AMERIGON proposes moving a portion of the savings captured by the activity-based costing into worker skills improvement. The IAM/AMERIGON program can produce qualified persons inspired to improve productivity in exchange for job security to organize production in such a way that it is consumer-driven as opposed to producer-driven so that innovation and the component produced can be supplied at a price customers will want to pay.

It is intended that the work force be qualified in all dimensions of technology critical to innovation: including the free-flow of ideas, skills, knowledge, and machines, and personnel wholly familiar with cost analysis and other information systems. Labor agreements are being formed incorporating these incentives and goals and the model labor agreements will have portability of skills and production goals and benefits.

IAM planning for production enhancing infrastructure contains other components. This includes the implementation of electronic networks such as a Skills Matching Network and a Manufacturing Information Network.

The industrial politics and economic protocols necessary to build competitive shops must be imbricated in supporting regional institutional systems in California. Efforts to enhance productive capacity must begin on the shop floor with the focus expanding to consider extra-firm relations and finally the international system. The International Association of Machinists and Aerospace workers have taken a proactive — and perhaps in California, unprecedented — approach in working with a small firm, AMERIGON, in fashioning new production enhancing techniques. The discussion here has emphasized their developing system with AMERIGON concerned with the organization of production on the shop floor. In the concluding section of this chapter the union's work in developing organizational mechanisms for the extra-firm provision of collective services, as well as in establishing international capabilities for the globalized production and sales of technology will be alluded to.

It remains to be seen whether the union's activities with AMERIGON will impact the

⁹ Costing the Factory of the Future, Business Section, The Economist, 3/3/90, p 60

other participants in CALSTART, or if it will influence activities beyond the organizational boundaries of CALSTART. Industrial politics and the union's endurance and skill will be the determinants. CALSTART certainly can develop along a variety of still to be determined pathways.

7.4. Leveraging Federal Investments Into a Coordinating Technology

7.4.1. Federal Defense Dollars As a First Step in Leveraging Local Resources / A "Brick-By-Brick" Approach in Developing Washington/California Economic Policy

On October 23, 1992, President Bush signed the FY 1993 DOD Authorization Bill (P.L. 102-258). The bill provides for over \$1.7 billion for "reinvestment and conversion" — activities aimed at smoothing the transitions and difficulties that will result from reduced federal spending on defense — and over \$500 million of those monies are for high-technology initiatives. The legislation was designed to enhance national security and simultaneously strengthen a unified United States industrial base. It should be highlighted that the same "dual-use" technologies that are integrated within the advanced transportation systems industry, and that are intended to be major emerging industries in their own right (like advanced materials, sensors, and power electronics), have great relevance to the proposed National Competitiveness Act to be discussed below.

All federal funds, no matter their source, must be leveraged wisely against non-federal matching funds. In this regard, in the next 30 years, \$184 billion will be spent on transportation improvements in Los Angeles County alone. This money is already in the pipeline with a sales tax approved by California voters. This spending is linked to additional funds up to \$30 billion in adjacent counties — an average regional expenditure of \$7 billion a year. In anticipation of the leveraged expenditure of these funds a planning priority should exist in California regarding the currently authorized and appropriated \$1.7 billion in funds in the Defense Reinvestment And Economic Development provisions of the National Defense Authorization Act FY 1993. These funds are authorized and appropriated and are a starting point in setting the political infrastructure in connecting joint Washington/California economic initiatives.

A strong Los Angeles County focus on these funds is appropriate because of the considerable transportation funding resources in the pipeline in Los Angeles County that could be used as non-federal matching funds, and because of the significant human and technological resources of the aerospace and defense industries in the county. It is also appropriate that these funds be targeted to small- and medium-scale firms supplying both commercial and aerospace and defense primes with components, sub-systems, and flexible manufacturing capacity. This type of investment is explicitly written into both the Berman legislation and the defense provisions.

While the funds are of considerable relevance the matter of fundamental importance is that the Berman legislation and the defense reinvestment and economic development legislation intentionally have nearly identical institutional approaches. The legislative intent of both focus on:

- manufacturing networks and extra-firm institutions
- the importance of increased manager and worker skills
- the necessary codetermination of environmental and economic goals
- the significance of innovation diffusion, and small- medium scale firm modernization
- finding mechanisms for small- and medium- scale firms to work collaboratively with large established firms.

Regional goals in pursuing and aligning the federal seed funds with transportation technology projects and funds in the region should be:

- (i) to focus the political will of the region
- (ii) to pursue high value-added products and projects
- (iii) to fuse industrial design, product engineering, manufacturing engineering skills, and basic science
- (iv) to establish a unified industrial base in Southern California capable of production for commercial markets, as well as military and aerospace
- (v) to promulgate firm modernization for clean manufacturing processes
- (vi) to assist transportation technology or manufacturing projects that pursue (or show the organizational potential to pursue) the indigenization of domestic or overseas process or product technologies
- (vii) to enhance the funding appeal of the region in dealing with diverse federal agencies (A single funding package could be developed with an overarching rationale.)
- (viii) to induce widespread collaborative manufacturing networks and a public awareness of the industrial infrastructure as it really is (It is composed of clusters of small- and medium-scale companies capable, with some institutional assistance, of flexibly working with a range of major commercial and military companies.)

7.4.2. The Proposed National Competitiveness Act

The Views and Estimates paper of the House Committee on the Fiscal Year 1993 budget for civilian R&D was fundamentally an argument for investment strategies to target three of the principle problems facing the national economy with the approach highly germane to establishing an electric vehicle manufacturing base in Southern California. The paper tackles three problems: (i) the decline of U.S. competitiveness (In this regard, it presents a remarkably similar approach both to the Berman legislation and the Defense Reinvestment and Economic Development Provisions.) (ii) the need to manage carefully the shift of United States military infrastructure into productive civilian investments and (iii) the need for increased energy security.

The suggestion is made in the first two parts of the report that a two-step process is

needed: first, to bring down the "fire wall" between defense and civilian discretionary spending in fiscal year 1993 and should total approximately \$14 billion over five years.

The third portion of the House report focuses on the approximately \$28 billion in federal R&D programs under the jurisdiction of the Committee. It provides recommendations funding these programs in fiscal year 1993.

The Committee identified numerous opportunities for new programmatic initiatives for the strengthening of existing conservation and renewable energy programs. A number of key technology areas for increased research and development offer significant potential for environmentally sound economic growth and enhanced United States competitiveness — as well as for a potential electric vehicle industry in Southern California.

According to the Committee priorities should include:

- electric vehicles and batteries
- turbine and hybrid automobiles
- fuel-cells
- high efficiency electric motors
- national critical advanced materials
- photovoltaic and renewable energy sources.

The Committee's recommendations for renewable and conservation programs would require funding over the next five years at a level averaging about \$1 billion annually. The Committee's proposals restore an emphasis on supporting the research and development process in all of its' stages, from basic research, through technology development and demonstration, through commercialization, rather than focusing on basic, long-term research.

The Committee also concurred in the President's proposed increase of \$50 million to fund initial government/industry work on electric hybrid vehicles. Also, the Committee acknowledged that the Intermodal Surface Transportation Efficiency Act of 1991, established a new comprehensive and coordinated surface transportation research program at the Department of Transportation. Budget information concerning the surface transportation program was not available at the time of the Committee's report submission to the Budget Committee but the research and development program was acknowledged as important and recommended for increased funding.

The National Competitiveness Act if passed will instruct the Department of Commerce to be the lead agency. One of grant programs at Commerce, the Advanced Technology Program (ATP) is especially relevant to the electric vehicle and advanced transportation systems industry in Southern California. In the Bush administration the program provided grants to private firms and consortia to develop advanced pre-competitive and generic technologies (This nomenclature could be replaced in the Clinton Administration with the term "enabling technologies" thereby implying a downstream thrust toward commercialization.) There is strong industry support for the program, and with a rapid expansion, and an increased acceptance of funding projects and technologies downstream, the program could become an important civilian alternative funding source for advanced ground systems and electric vehicles.

Aeronautics and advanced transportation systems and electric vehicles together integrate numerous underlying technologies and systems and each should be more extensively supported via the Advanced Technology Program. In pursuit of an advanced transportation systems and

electric vehicle industry in Southern California, the region would do well to place particular policy attention on the aeronautics/transportation technology linkages/synergies and highlight this relationship to analysts and decision-makers within the Commerce Department program. Merit-based policy initiatives in this area should be developed with political underwriting.

The Committee recommended that funding should be sufficient to maintain 100 new grants per year, which would require about \$300 million annually. The Committee recommended the increase in this program should start in Fiscal Year 93 at \$100 million above baseline to begin a transition to a more aggressive program. Technology development and deployment work in aeronautics and advanced transportation within the Department of Commerce, as well as relevant programs in other agencies like the Advanced Research Projects Agency, and the Department of Energy, should be articulated more fully via an interagency working group working from within the Advanced Transportation Systems and Electric Vehicle Program at the Federal Transit Administration (FTA) in the Federal Department of Transportation that was established via the Berman legislation. The Advanced Transportation Systems Program in FTA can be a "microcosm" from which to develop more fully a comprehensive national advanced transportation systems technology development and deployment effort at the Federal Department of Transportation which currently exists with large "gaps" and without a systems approach. In addition, state and local entities, business, with political leadership have fared successfully in technology projects at FTA and the region should build on this momentum.

7.5. California Is Technology Rich But Lacks the Institutions For Strategic Planning and Rapid Commercialization

Advanced transportation systems are users of a range of high technology. This includes the integration of technologies in advanced materials, power electronics, manufacturing process, telecommunications, sensors, batteries, fuel cells, and high technology in general. Planning and production analysis should proceed with an awareness that (i) advanced land systems can develop a broad base for a variety of technologies and manufacturing systems in California in adjacent industrial sectors, (ii) given California's capabilities in aerospace, special attention should be given to the synergies that exist between advanced land transport systems and aeronautics.

To illustrate the general way that production and planning analyses should occur five dual-use product and process technologies will be discussed in this section that have applications in advanced land systems and equally important applications in other sectors. As one illustration of the synergies that exist between advanced land systems and aeronautics, there will be a brief mention of the Air Force's More-Electric-Plane initiative.

7.5.1. The Fuel Cell

The Jet Propulsion Laboratory, The California Institution of Technology, Loker Hydrocarbon Institute and Local Synergies

A fuel cell is an electrochemical device that converts the chemical energy of a fuel and an oxidant directly to electricity. An attractive point is that fuel cells produce electricity without

using moving parts. They cleanly, quietly, and efficiently convert the stored chemical energy of the fuel being used into electrical energy. Fuel cells can be used in factories, commercial facilities, homes, utilities, and can power locomotives, buses, and automobiles.

Simply put, fuel cells combine hydrogen with oxygen from the air to produce electricity. In a transportation platform, this hydrogen can be produced from methanol or other hydrocarbon and alternative fuels.

The Department of Energy has been sponsoring important research on advanced reformer and hydrogen storage technologies and this work should continue. But a significant breakthrough has occurred at the Jet Propulsion Laboratory (JPL) in Pasadena, California. Funded by the Defense Advanced Research Projects Agency (DARPA), JPL has succeeded in developing a fuel cell system that bypasses the reformer and utilizes direct liquid feed. This breakthrough in combination with fundamental catalytic research underway at Caltech's Beckman Institute, and alternative fuels work at Loker Hydrocarbon Institute (LHRI) is extremely promising for across-the-board advanced transportation systems applications.

The goal of the DARPA fuel cell program has been to develop (starting with methanol) fuel versatile near ambient temperature fuel cells to supply power needs for future defense applications. JPL has currently demonstrated technology that bypasses the reformer entirely and uses a direct liquid feed utilizing methanol for low to medium power applications. In the longer term, flowing from fundamental science in catalytic research at Caltech, and fuel research at LHRI, the goal is to use hydrocarbon and alternative oxygenated fuels in fuel cells designed for medium to high power applications.

The intended military applications of direct methanol fuel cells is for armored vehicles (2kw, 16 kwh), unmanned undersea vehicles (10 - 14 kw, 350kwh), and a soldier suit for air-conditioning and protection from chemical and biological attack.

The JPL effort is going forward with Caltech, U.S.C., M.I.T., Giner Inc., and others, as close collaborators. JPL's role in the direct methanol fuel cell program is to evaluate not only methanol but other candidate fuels; to demonstrate technology at the cell level; to interface with program participants and to provide support to DARPA in program coordination. Finally, JPL is to assist in transferring the technology to industry.

The uniqueness of the JPL direct methanol and alternative fuels fuel cell is that there are no shunt current problems, minimal thermal and water management issues, it is fuel versatile, has simple design, amenable to scale up, has low temperature operation, and it is suitable for low to medium power applications, with advances to be made in higher power applications.

In the JPL direct methanol fuel cell, the methanol moves in direct oxidation through the fuel cell — in standard systems the methanol would be passed through a mixer, vaporizer, reformer, shift converter, and then through the fuel cell. The advantages of direct oxidation is that it reduces volume and weight by 20 - 24%, improves reliability through reduced complexity, reduces costs, and has a low thermal signature.

JPL plans for 1993-1994 include completing the evaluation of catalysts, electrolytes, and alternative fuels from MIT, Caltech, Harvard, and USC's LHRI. JPL will fabricate electrodes with advanced catalysts and evaluate advanced polymer electrolytes. Methanol is being used as the most viable fuel in the present work. The proton exchange membrane has been selected as the most viable electrolyte. Fundamental chemical research is underway at Caltech's Beckman Institute that is anticipated to replace expensive platinum/ruthenium as the best compatible catalyst for oxidation.

It is planned that JPL will in 1993-94 optimize cell design for liquid feed methanol fuel cells and demonstrate the technology with advanced catalysts and electrolytes. One of the most exciting aspects of this work concerns the use of natural gas: superacids developed at LHRI are billions of times stronger than 100% sulfuric acid and they make possible remarkable new hydrocarbon conversions, including medium transformations of methane (natural gas moving to a room-temperature liquid).

In practical terms this means that natural gas at the well-head, in a high-value added process, can now be converted to liquid form, existing at room temperature, and subsequently shipped anywhere in the world. This effectively means the safe transport of natural gas fuel to existing liquid fuel infrastructure around the world and an environment-friendly, liquid, ambient temperature natural gas that can be used as a powerful, non-toxic fuel for fuel cell electric vehicle transportation. In such a world, you simply will pull up to existing gas stations in your fuel-cell powered high-performance electric vehicle and fill up with natural gas out of the gas pump.

LHRI has been working on this fundamental chemistry since its inception in 1977 based on Professor George Olah's work on superacidic direct conversion of natural gas into higher hydrocarbons and oxygenated fuels. Superacids are defined as acids stronger than 100% sulfuric acid. Olah's work resulted in development of systems up to 10 to the 12th power (trillion) times stronger than sulfuric acid. At these extreme acidities, methane (CH₄) becomes quite reactive and allows conversion into either higher hydrocarbons or derivatives such as methanol, dimethyl ether, dimethoxymethane (methylal), trimethoxymethane higher ethers and the like.

Previously the utilization of natural gas in the synthesis of methyl alcohol or synthetic fuels involved its burning to synthesis gas (CO plus H₂) and in that process consuming half of the fuel and with enormous capital costs; then reconstituting, in catalytic, high-energy-need reactions, the needed products. This processes — the Fischer-Tropsch process — is for the production of syn-fuels.

The chemistry being developed by LHRI opens up the possibility of obtaining convenient oxygenate fuels using natural gas. These liquid fuels, such as dimethoxy-methane are now actively being pursued as clean burning fuels for newer generations of fuel cells. Other practical application of LHRI basic research involving new acid (superacid) chemistry are the upgrading of natural gas liquids (the by-products of the natural gas industry) to high octane gasoline and the development of new oxygenated diesel fuel supplements enhancing cleaner burning and cetane numbers (the diesel equivalents of MTBE type gasoline additives). Another major practical development presently under commercialization by industry is an additive technology allowing the environment-friendly and safe continued use of hydrogen fluoride technology in refineries thereby eliminating toxic aerosol clouds in case of refinery accidents.

These particular chemistry technologies are outlined here as a clear demonstration of how innovation can move across industrial sectors. The example of a critical diffusion of technology between Loker Hydrocarbon Institute, an important institution in the research complex supporting the global petroleum industry, and a potential electric vehicle industry in Southern California is indicative of the fact that the organizational capacity must exist in Southern California to adopt and adapt existing and new technology from diverse sectors. The point of origination of a technology is inconsequential in the emerging rapid and global technology development process. The challenge is in having the capability to design and implement rapid commercialization and diffusion.

7.5.2. AVCON INC. — A Small Company With A Generic Technology: Active Magnetic Levitation Bearings

The Air Force has funded development of a magnetic levitation bearing for jet engines that can withstand temperatures much higher than those for conventional bearings, with the goal of increasing the thrust-to-weight ratio of military powerplants. AVCON Inc., of Northridge, California is designing the bearing for a generic advanced fighter engine and Pratt and Whitney will test the bearing in a turbine shaft simulator rig under subcontract to AVCON.

For the Air Force work, the magnetic bearing will support a 60 in.-diameter rotor shaft under conditions of 800F, 24,000 rpm. and 1000lb. radial loads.¹⁰ Existing ball bearings must operate below 500F because of oil breakdown. Magnetic bearings will permit an engine to operate without a lubrication system. Current engine bearings run under 300F.

Active magnetic bearings which levitate rotating shafts are making inroads into other industries. This includes niche areas, such as in centrifugal compressors for the pumping of natural gas, in electric power plants, petroleum refining, machine tools, satellites, and military weapons. AVCON Inc. intends to extend the technology into advanced transportation systems with applications in buses, trains, and cars. For example, it may be workable for shuttles to be powered by onboard 60-pound flywheels spinning at more than 100,000 rpms — the spinning wheel generating electricity as a mechanical battery. The technology has obvious applications as a stationary power source for military or commercial end-users. In essence, magnetic suspension relies on the repulsion of like poles of magnetism. If a shaft is lined up with north poles, and placed in a cylinder lined with north poles, it will suspend in mid-space.

In a mechanical battery a rapidly whirling fly-wheel, housed in an evacuated enclosure, relies on superstrong fiber composites because the rim of the wheel will be moving at such high speeds. In a catastrophic event, the fiber composite flywheel begins to unravel like a coil of yarn generating significant heat within the enclosure but without fragments escaping the container. In an accident, safety issues then become those concerned with heat management, not flying fragments.

The AVCON magnetic bearing design employs an array of permanent magnets for the suspension function, sensors to monitor deviations from the centered shaft position or orientation, and electromagnets — activated by error signals from the sensor system — to establish restoring and stabilizing forces.¹¹ The AVCON arrangement uses permanent magnets to produce an axially oriented field and electromagnets that generate circumferential fields producing a compact, light bearing.

AVCON, using high-energy permanent magnets of neodymium-boron-iron and high-saturation-flux ferromagnetic cores, has a design that has demonstrated air gap unit loading exceeding 150 psi. Analysis indicates 300 psi. is possible. The permanent magnet bias hybrid design can use a much simpler and smaller servo-electronics system than conventional systems that employ only electronics system than conventional systems that employ only electromagnets.

¹⁰ Dornheim, Michael A. Advanced Magnetic Bearings Aim for Higher Engine Performance, Aviation Week and Space Technology, August 17, 1992

¹¹ Regional Editors, Hybrid Design Lightens Magnetic Bearings, June 11, 1990

And servo power consumption is very low.¹²

While research continues some companies such as Magnetic Bearings Inc. (Roanoke, Virginia), AVCON Advanced Controls Technology Inc. (Northridge, California), Aura Systems Inc. (Los Angeles), Allied-Signal Aerospace Co. (Torrance, California), and Mechanical Technology Inc. (Latham, New York), are now producing bearings for industry. As knowledge increases there will be reduced costs through volume production.

In automobile, buses, and trains, today's magnetic bearings are too expensive to replace existing metal bearings and instead companies like AVCON are developing applications intended for energy storage flywheels — mechanical batteries — in what would be part of a potent electronic propulsion system. AVCON is currently involved in the development of separate mechanical batteries with two companies, one firm is interested in applying them to autos, the second to mass transit.

A potential competitor to active bearings has emerged in the form of passive magnetic bearings that use bulk superconductors. Superconductor materials would use a passive system that is stable without active electronic controls. The energy savings are diminished because of the power required to generate cryogenic temperatures for the superconducting materials. Argonne National Laboratories and United Technologies are working in this area. And Allied-Signal is developing bulk superconducting material for passive magnetic bearings under a contract with the Defense Advanced Research Projects Agency.

Allied-Signal in California is developing active magnetic bearings for use in satellite motion control, and in a joint effort with AVCON, for use in gas turbine engines employed in an aircraft's auxiliary power unit. This is intended to have multiple applications including in the Air Force's More-Electric-Plane initiative. Fuel cells which will be a competitor to mechanical battery technology in land systems also have applications on-board the Air Force's More-Electric-Plane when the auxiliary power unit has been turned off on the runway and the plane is stationary. One of the important lessons here is the concept of being able to shuttle power from different sources and at different times through the various sub-systems of the more-electric-aircraft. This systems view of the more-electric aircraft will be repeated on much larger scales on the post-Gulf War battlefield, as it will in integrated advanced land systems in the world's great metropolitan regions. Southern California must exploit the financial and technological synergies that exist in this landmark sectoral juxtaposition.

The AVCON magnetic bearings demonstrate how a variety of technologies existing in Southern California can be brought to bear on a new problem or opportunity. In this case, sensors, magnetic levitation bearings, composite materials, and power electronics are all integrated in the development of mechanical batteries. It is one more clear demonstration of the technological prowess of Southern California.

Furthermore, there are a range of other lessons demonstrated in the AVCON case. It is a classic example of a small firm that could use regional business development services in launching an important technology. Additionally, the founder of AVCON left a major Southern California aerospace firm because of its unwillingness to develop this critical technology after years of trying to persuade the major company to commercialize the bearing but to no avail. The speed with which AVCON has acted in engaging new markets and in accelerating the development cycle are illustrative of the strengths of the small firm over the large firm.

¹² Ibid

The last point concerning a faster development cycle is worth special mention. Within the last few years, AVCON has succeeded in significantly reducing the volume and weight of the servo-electronics surrounding the magnetic levitation bearings far in excess of what had been accomplished by the aerospace-military-industrial complex of Southern California. The lesson is clear. Increasingly, the military will rely on technology development cycles, quality, and costs driven by commercial factors of production. The paradigm of "spin on" does not lay in a distant future it is a necessity in this country and a functioning policy and production reality in Japan and parts of Europe.

7.5.3. Hybrid Electrical Vehicles With Zinc Batteries And Ultracapacitors

Many regard batteries as the enabling technology for electric buses, vans, and cars. Many battery development efforts are underway, the most visible being that of the U.S. Advanced Battery Consortium (USABC). Short term programs focus on advanced lead-acid batteries that have high power capability and therefore give good battery application. However, range suffers because of the low energy density characteristics of this battery type. Longer term programs concentrate on high energy batteries that resolve the range issue, but at present provide limited power.

The more fundamental need is to accomplish both goals simultaneously. Progress toward that end can be substantially accelerated by combining a high energy battery technology that shows significant promise but has low energy density, with an ultracapacitor, a device that provides the needed high power capability.

AMERIGON, A CALSTART participant, has proposed a program to the Defense Advanced Research Projects Agency to address the fundamental issue of hybrid development. The program is intended to advance government capacitor technology to provide a superior energy source for electric buses, vans, and cars; advance the development of an environment-friendly energy source (zinc/air battery, carbon/potassium hydroxide/stainless steel capacitor); and provide high energy storage, military capacitors that are very light-weight and cost effective.

An ultracapacitor can be defined as a capacitive device having an energy density greater than 1 Wh/kg (3.6 kj/kg). There are several types of ultracapacitors being developed, but the design of interest for electric vehicle applications consists of bipolar cells made up of foil electrodes coated with thin layers of micron size metal oxide particles and an aqueous or organic electrolyte between the electrodes.

There has been considerable work done in recent years to improve the energy density (J/gm or Wh/kg) of capacitors for weapons systems, medical instruments, and small scale electronics applications. None of that work was directed to electric vehicle applications, but recent studies at Idaho National Energy Laboratory indicate the devices developed to date point the way to the use of ultracapacitors in land vehicles.

The devices fabricated thus far are small in size with energy storage capacity only several hundreds Watt-seconds. These devices can be scaled up to a larger size and then configured in parallel to attain the energy storage required for electric vehicles. Higher voltage can be attained by increasing the number of cells in series. Prospects for improving ultracapacitor performance using organic electrolytes seem good with the primary uncertainties being the effect of changing the electrolyte on the resistance and life of the devices.

The CALSTART ultracapacitor/battery hybrid program also affords numerous lessons in how the technology development process is rapidly changing into new organizational contours. Some of those lessons are: the importance of small firms in being able to work together in a rapid and focused fashion; the role that the small firm(s) can play in pulling a technology out of a national laboratory; the need to emphasize environmental quality in technology development decisions; the importance of the "fusion" of technologies; the importance of defense conversion to national competitiveness and in unifying the regions industrial base. Finally, there is a demonstration of the simple fact that various technologies are in competition at this point in the emerging electric vehicle and advanced transportation systems industry — fuel cells versus mechanical batteries versus battery/ultracapacitor hybrids, versus other possibilities such as the Stirling Thermal Engine. The competing technologies, of course, being a healthy situation.

7.5.4. Hub Engineering And Advanced Materials

Using material provided by Dow Chemical, HUB Engineering, a technology transfer firm and CALSTART participant, supplied a battery box for CALSTART's Showcase Electric Vehicle Program. The box which is designed to hold a 500-pound battery system, is made from an all-thermoplastic sandwich of fiber-loaded plastic over a foam core. HUB also intends to apply lightweight materials to rail and bus structures to promote maximum performance.

It is HUB's objective to develop world-class manufacturing systems for producing composite structures creating a competitive industry that goes beyond local product needs. With an emphasis on product flexibility, world market focus, and manufacturing process, HUB is representative of the legislative intent of the Berman legislation. (HUB also can be viewed as representative of the much wider advanced materials industry that California policy makers should concern themselves with.)

HUB Engineering uses a system of concurrent actions in management and engineering which leads to rapid development of products and expedites implementation of results. HUB has assembled a team whose express purpose is to develop and design products and production systems for fiber reinforced and unreinforced plastic parts. The team is experienced in the composites technology and represents many years of design, analysis, testing, tooling, and manufacturing of major fiber reinforced and unreinforced plastic structures. HUB is reaching into the wealth of specific capabilities that are available in the field of advanced materials in California as a result of the research, development, and production of weapons systems over the last fifty years.

It is the intent of HUB Engineering to provide the best product and process designs possible. Developing low-cost, high-rate production systems is required to assure the cost-competitive methods and designs which will be needed to create a self-sustaining composites industry.

HUB believes these processes should be product cost driven rather than technology driven except in areas of safety and environmental sensitivity. Therefore, evaluation of the system and cost and projection of the product cost is a constant effort by the HUB team as the design and development of both product and process proceed. Since the various technical disciplines will perform their development tasks concurrently, the product and process costs, environmental and safety requirements, and the recyclability of unused materials and products will receive

thorough, on-going-review and inclusive consideration.

It is intended that HUB will be involved in the technology of polymer composite material structures (fibers and resins) for manifold advanced transportation systems. In pursuit of its objectives this company intends to be responsible for:

- composite parts, loads and structural analysis;
- composite parts design;
- composites materials selection;
- composite materials parts testing;
- tool design;
- tool fabrication;
- production analysis;
- process development;
- automation development and application;
- cost analysis;
- manufacturing selection;
- manufacturing tracking.

HUB technologies illustrate, as do each of the technologies discussed in this section, a set of aerospace and defense capabilities that will be lost to the nation in the current defense downsizing through non-utilization or piece-meal foreign appropriation without a national policy with subjacent regional institutions capable of (i) adopting, adapting, and diffusing existing as well as new technologies (ii) rapid commercialization for each of the industries that are integrated in the advanced transportation systems industry, (iii) safeguarding intellectual property. In essence this will require strategic planning by industry, government, environmental, and labor leaders that contain simultaneously sector-specific and multiple-sector strategies and institutions, as well as collective services for local synergies and innovation.

7.6. California and the New Technology Development Process

7.6.1. Spin-On: Japanese Strategic Planning for an Emerging Aerospace Industry

After a 40-year preoccupation with commercial development, Japan is now expanding defense production to compete effectively in aerospace.¹³ The FSX effort, the industrial context of the Japanese systems of manufacturing in which it takes place, as well as the national and international politics, has great relevance for the current discussion concerning an emerging electric vehicle industry in Southern California.

Japanese policy makers have seen the military aerospace sector and the FSX as crucial to developing a civilian aerospace industry. They intend aerospace to revitalize Japan's heavy

¹³ Samuels, Richard J and Whipple Benjamin C 1989 in *Politics and Productivity How Japan's Development Strategy Works*, edited by Chalmers Johnson, Laura Tyson, and John Zysman, Ballinger

industrial sector and diffuse the benefits of high-technology throughout the economy. It is their informed conclusion that aerospace manufacturing has close ties to the machinery, housing, automotive, leisure, and service industries, and Japanese officials often compare it to a tree whose "roots" (process technologies) and "fruits" (products) will sustain Japan well into the next century.¹⁴

One of the most significant factors in Japan's strategic decision to nurture the military side of the aerospace industry has to do with their advocacy of the technology paradigm "spin-on". This nomenclature is used to contrast the notion of "spin-off" that has dominated as the industrial policy paradigm in the United States throughout the Cold War period. In the thinking of Japanese industrialists, both domestic and foreign military aerospace markets — for components and sub-systems, if not for finished aircraft — afford Japanese firms the opportunity to profit further from technologies they originally developed for civilian purposes.

In fact, the ongoing transformation of the entire aerospace industry from simply bending metal to integrating advanced technologies has focused analysis and planning efforts on fields in which Japan has growing strengths: materials, micro-electronics, computers, telecommunications, and high-technology in general.¹⁵ The general public had occasion to notice the validity of the spin-on approach during the recent Gulf War. Numerous press reports in both the United States and Japan reported the fact that American warplanes and missiles used in the Gulf War would not be able to fly without key Japanese components.

It must be clearly understood that the industrial requirements of the fighter aircraft business have changed significantly in recent years. In the older production systems there was extensive stress on size and speed capabilities and this rested largely on advanced techniques for metal-bending. But this has all changed.

Richard Samuels and Benjamin Whipple have described the F-16 and F-18, moving through the 1970s, as transitional aircraft that blend old and new product and process technologies. The newer generations of aircraft will rely heavily on a broad range of new technologies. The broadest range of companies in Southern California, including some of those involved with CALSTART, need to examine the enabling technologies used concurrently in all of the advanced land transport systems and in the newer generation of commercial and military aircraft now emerging in advanced materials, power drive systems, communications, and electronics.

Samuels and Whipple have discussed in various forums the ongoing changes in the aerospace industry including composite materials for lighter weight, less visibility, and more streamlined contours — also "fly-by-wire" systems. And they state "... researchers have joined these new technologies into control-configured vehicles, or CCV's. Extremely agile CCV's, with odd-looking air-frames, unstable aerodynamics, and constant computer control, have flight capabilities more akin to a flying saucer than a traditional plane." Other technologies can be added to the list, and it can be stated that the new fighters are in many ways more akin to an electronic vehicle than a traditional plane.

In addition to the financial and technical demands required by these machines, new managerial and institutional challenges are also emerging. These problems are magnified when

¹⁴ Samuels and Whipple, *Technology Review*, p 44

¹⁵ Samuels and Whipple, *Technology Review*

development and production take place concurrently as is increasingly happening in globally competitive industries. And the new technologies are bringing about structural changes. For the first time ever, U.S. prime contractors have been teaming to spread costs and risks that a leaner Department of Defense is no longer absorbing.¹⁶ This may culminate in two or three U.S. producers making their exit from the business.

In this emerging competition Japan has a structural and protocol advantage in aerospace just as they have capably constructed one in automobiles. In the United States and in Europe the traditional industrial structure resembles a pyramid with a limited number of large prime contractors at the top. Typically a winning prime contractor on a defense contract will manufacture the main structures and perform final assembly, integration, and testing. Contracts for large sub-systems are shared among other primes and a larger number of sub-system manufacturers, and this work in turn is let out to thousands of small component fabricators and machine shops.¹⁷

In contrast to the American aerospace and defense industry, the Japanese counterparts are organized as divisions of diversified heavy industrial companies. These are affiliated with important *kieretsu*, the large-finance centered groups. Consequently, in Japan aerospace is more closely tied to other industrial sectors, both within the firms and within the *kieretsu*. This associational behavior promotes the identification and diffusion of technologies with a wide variety of applications and markets.

In addition, Japanese aerospace is far more openly collusive.¹⁸ This associational behavior is described as a "friendship club" (*nakayoshi kurabu*). And national policy encourages cartelization. Even before the First Aircraft Industry Promotion Law of 1954, government planners were and have been encouraging cooperation among firms, and every major aerospace program is divided so that the "Big Four" companies participate. This work sharing backed by state support provides a stability to the industry that is lacking in Southern California.

7.6.2. The International System: Two-Way Technology Transfer in Four Dimensions

Discussion of Japan-United States technology and competitiveness relations might seem too broad a topic in considering an advanced transportation systems and electric vehicle industry in Southern California. That notion is incorrect. The policy focus of electric vehicle manufacture in Southern California must expand from the shop-floor, to extra-firm relations, to regional, state, and national policy initiatives, to the international system.

Southern California must develop a coherent set of strategies at each of these levels. The region must develop policy responses to efforts like the IAM/AMERIGON High-Performance Work Organization that approach the functioning of the shop-floor with new concepts, the region must develop common national agendas with other states like Michigan (i.e., lobbying in Washington together for adequate federal policies to address the process revolution occurring

¹⁶ Samuels and Whipple, p 47

¹⁷ Ibid, p 47

¹⁸ Samuels and Whipple, p 48

in technology development, or working with states like New Mexico on fuel-cell development.) And, internationally, among other things, Southern California must develop strategies to engage automobile manufacturers in the United States in Europe and Japan.

While operating as an integrated region within a globalized production base, the labor/industrial/government/environmental leadership in Southern California must understand that mechanisms need to be forged that directly engage other industrial districts from around the nation and world. In this process, if Southern California focuses on its agenda of developing institutions to enhance environmental quality while operating from a globalized technology base then overall United State's competitiveness will increase.

The focus in this section on Japan is used not only to illustrate the importance of Japan and California in the global race for an electric vehicle, but also to illustrate the across-the-board policy skills that need to be developed in Southern California before an electric vehicle/hybrid industry might develop. Any consideration of United States-Japan trade and technology issues must consider individual regions like the Mid-west United States and Southern California, or Kakamigahara, while, simultaneously, being set in the broader context of overall United States-Japanese relations.

Harold Brown has stated "The position of these two economic superpowers exhibit both complementarity and imbalance.¹⁹ What is essential is that in this decade the two nations reach a new equilibrium. This will include Japan assuming primary responsibility for its own conventional defense and the United States will need to be more productive and competitive than it is now."²⁰

Ominously the apparent weakness in political will and of constructive and cooperative leadership among both business and political leaders that Brown discussed in his 1990 Washington Quarterly article is still evident in the opening days of the Clinton Administration. What is required is a coordinated United States technology policy with subjacent but increasingly autonomous regional technological-institutions. Southern California shops and firms increasingly must have the ability to engage directly industry in the world's great productive regions whether it be in the mid-west, Japan, in Europe, or elsewhere.

As an illustration, the leadership of the Toulouse Metropolitan Technopole and the Regional Government Toulouse Midi-Pyrenees (an aeronautics and space industrial complex) of France already have been conducting discussions with political and business leaders in Southern California regarding the potential for cooperative activities in developing electric vehicles. Increasingly in Europe with the advent of the Community there are attempts by the leadership of industrial regions in many countries, even in a centralized country like France, for greater autonomy and direct industrial relations with other industrial complexes.

As to the United States and Japan, Brown summarizes the situation well:

"The United States and Japan will be competing and collaborating in a context of increasing technological parity. This will require the United States to develop a

¹⁹ Brown, Harold, Competitiveness, Technology, and U S -Japan Relations, The Washington Quarterly, Summer 1990

²⁰ Brown, p 89

clearer strategy for U.S. Japanese linkages in science and technology. Mutually beneficial collaboration in science and technology should be a goal, but special efforts will be required in order to expand technology transfers to the United States and to develop criteria for judging the potential benefits and risks of specific types of collaboration. Hence the questions of technical access arises."²¹

He then concludes:

"Political leadership, business acumen, and an understanding of the technological drives that power both competition and cooperation will be needed to provide the necessary realistic assessment of self-interest to carry out the necessary bargaining and renegotiation."²²

Increasingly international business transactions will be carried out by corporations that are rationalizing their operations and dispersing their design, development production, distribution, and marketing operations world-wide, while clustering (regionalizing) them within major markets rather than concentrating them at home. In so doing, they will come to rely on complex global networks of wholly and partly owned affiliates, suppliers, and strategic partners (who may include putative rivals).²³ In this situation, Southern California must develop the institutions that integrate and protect internal resources, attract world-wide producers and sellers, and provide external reach to indigenize technologies and related know-how currently non-existent in the region.

A recent report in the Japan Digest²⁴ stated that the United States requested that Japan ease curbs on exports to the U.S. of space technology and equipment with military potential. The report disclosed that NASA is offering Japan the secrets of the reentry shield technology used on the shuttle and equipment with military potential and in return is interested in acquiring sensors and other Japanese electronic items. The Japan Digest quoted a diplomatic note to Tokyo saying that the United States hopes that "the Japanese government will focus its attention on the difficulties posed, for both the United States and Japanese space industries, by its current policy that Japanese space technology and equipment exported to the United States may not be used for defense or dual-use purposes... Action in this area would facilitate balanced, reciprocal flow of and access to space technology and equipment." Up until now most pressure from the United States has been aimed at getting Japan to import rather than to export such equipment.

A second report in the Japan Digest occurred on the same day as the announcement about the United States request for access to Japanese aerospace technology and the proposal for two way technology transfer. The Digest reported that Honda will soon begin test flying a prototype of a small business jet it has produced in the United States. Honda stated they have no intention

²¹ Brown p. 91

²² Brown, P 95

²³ Ahe, John Branscomb, Lewis et al Beyond Spinoff

²⁴ The Daily Japan Digest, (4/1/93), Arlington, Virginia 22203

of getting into the aerospace business and gave a description of the plane with an x-wing design, with forward swept wings, that give it excellent maneuverability. The American Defense Advanced Research Projects Agency built such a plane in the 1980s, but it flew only a few times before being mothballed. The Defense Agency plane's flight control surfaces had to be run by computer — in other words, a "more-electric-plane" — because the adjustments needed to keep it in the air were beyond the capability of a pilot. Honda reported the purposes of the plane were to apply the results to the needs of the automobile industry. It also seems likely that the Japanese firm must be developing operations for sub-systems and components for "spin-on" to the global military and commercial aerospace industry.

These two reports in juxtaposition tell an interesting story for labor, business, and government leaders in Southern California. The stories taken together demonstrate each of the revolutions in technology development outlined earlier and they show the importance of institutional mechanisms to enable adequate response to these changes.

Using Japan as a case in point, Southern California must have the institutional ability to develop two way technology transfer with Japan over the range of advanced transportation system technologies that were used illustratively in this chapter: such as advanced materials, a range of energy storage devices including fuel-cells and ultracapacitors, magnetic levitation bearings, sensors, electronics, and other important sub-systems. Firms operating on their own have no incentive either to consider the needs of a regional industrial complex, or of the technological needs of their home nation. Imbricated in a network of other firms, in a blend of cooperation and competition and assisted by government, technologies held within firms and public institutions suddenly acquire a greater value-added for the whole region. In the context of international trade and technology relations, if Southern California is to foster the commercialization of the full range of advanced transportation technologies resident in Southern California through small- medium- and large-scale firms, then the region's business, political, academic, and labor leadership must assist in establishing the extra-firm organizational capacity to do so. Furthermore, regarding Japan, there should be an explicit recognition that technology and trade relations will increasingly be centered at the mid-way point of commercial and military markets as "spin-on" becomes a dominant practice.

This latter point creates a situation that is simply waiting for the next crisis unless clear policies and strategies are forthcoming. As Richard Samuels recently discussed in the Japan Digest, the FS-X controversy demonstrates that when a country like Japan "equates security with technological autonomy" and then is forced to share, and when one like the U.S. which "equates security with military strength," fails to learn well and to reconceptualize its security needs, "reciprocity is an issue on which bilateral relations can flounder."²⁵

What will be required is technology diffusion in four dimension: between the respective commercial and military industrial bases of the mutual countries. Bilateral negotiations on these issues have the potential to significantly alter the global view of both nations in the 1990s.

The question of U.S.-Japan commercial-military technology integration cannot in the 1990s be set aside, but the focus can productively be placed on international and environmental commercial transactions. For example, Carter and Nakasone after examining major challenges

²⁵ Samuels, Richard Facing Japan as a Technological Superpower, *The Japan Digest*, (5/2/93)

and key impending issues in U.S.-Japan relations²⁶ focused considerably on commerce and further concluded that bilateral relations between the two countries would be best worked from a global perspective.

Among the international institutional initiatives put forward by the two leaders was a U.S.-Japan initiative to strengthen measures against global warming and to transfer efficient and clean manufacturing and advanced technologies to protect the environment to developing countries. Concerning bi-lateral issues, the leaders proposed a Structural Coordination and Harmonization Initiative (SCHI). SCHI would go beyond the Structural Impediments Initiative and involve private business and the research communities on both sides of the Pacific.

Some specific elements of the proposed SCHI can be mentioned here. They are:

- reform and increase the transparency of Japan's business practices
- reduce the twin deficits in the United States (This would include a rationalization of military spending.)
- improve two way technology transfer.

This last point was intended as part of a package that would include an expanded Japanese commitment to basic research including joint U.S.-Japan funding of basic science efforts in the environment, alternate energy systems, and high-speed rail and advanced aviation. Measures to accelerate two-way technology transfer through market forces were given an important emphasis.

The world of the 1990s is in essence a transition period to a new, but as yet undiscernible system configuration. Are there important options for California for winning through collaboration with Japan, Europe, and others? The answer is yes. As an illustration, in 1993 Silicon Valley chipmaker Advanced Micro Devices and Japan's electronics giant Fujitsu declared that they would jointly develop "flash" memories (devices that retain stored information when the power is shut off and that could someday replace hard discs).

An additional dimension California is likely to invoke involves a rich spectrum of Pacific Rim and Asian investors. If the big foreign investor of the '80s was Japan, other Asian players are fast moving into position. The Chinese influence in California will grow dramatically as new money from mainland China, which has accumulated more than \$50 billion in foreign currency reserves, and at least seven new banks from Taiwan, now among the most highly capitalized, begin to make their presence felt in the Southland. Other investment possibilities exist in Korea, Southeast Asia, as well as India. In each of these cases, the most sophisticated players in moving to establish their own automobile industries, instead of fighting to take market share from the existing world powers in the internal combustion engine technology, should rationally attempt to take an "auto leap" to the electronic vehicle of the 21st century through strategic partnering with those strong California companies and institutions that currently hold the world's premier electronic vehicle technology.

The question remains only as to whether Southern California will demonstrate the political and business leadership necessary to exploit the remarkable strategic possibilities that currently exist. Similarly, it remains to be seen if the region will maintain its current leadership

²⁶ Carter, Jimmy and Nakasone, Yauhiro Ensuring Alliance in an Unsure World The Strengthening of U S -Japan Partnership in the 1990s, The Washington Quarterly, Winter 1992.

role in the national and international system in electronic vehicle research and development and, more importantly, whether it will maintain its lead as the technologies move further downstream toward manufacturing implementation. These answers are likely to be determined by business/government actions taken or not taken in 1993 given the 1998 California mandate for electric vehicles and the roughly five year lead time necessary in automobile development.

7.6.3. The Fusion of Southern California's Fundamental Science, Industrial Design, Product Engineering, and Manufacturing

Companies compete on the basis of existing products, not those yet to be created. Building upon this fundamental, a view of technology commercialization has emerged commonly termed the "cycle view".

In the cycle view speed becomes important. The longer the improvement cycle, the more likely it is that competitors will drive their own improvements into the marketplace first. In the cycle view, equal significance is given to expertise in all manufacturing functions: fundamental science, industrial design/marketing, production engineering, and manufacturing engineering; and the concurrent integration of these functions is stressed. The approach also stresses the significance of complementary and ancillary assets. This includes mobilizing and integrating elements like industrial design houses, supplier firms, distribution, and service networks.

Southern California must develop the institutions that can integrate human and technological resources regionally and simultaneously develop complementary externally oriented institutions for state, national, and international activities.

Some examples are illustrative. It is not a well known fact but true nevertheless that Southern California is home to the international design and advanced concept studios of all of the world's major car makers. In the main, these studios are style centers and very little concerned with product or manufacturing engineering with some very important exceptions. A central question for the region is how to integrate these regional design strengths with fundamental science, product engineering, and manufacturing engineering capabilities.

First, there is a task of fundamental education to be performed in the region. The importance of the industrial designer needs to be stressed to product engineers, manufacturers, scientists, government agencies, and political leaders. In an era where maturing technologies are exchanged for new and purchasing trends are in constant flux, it is obvious that innovation and design must play an increasing role in addressing the marketplace. The task is to integrate fully the designer with the product engineer and the manufacturing engineer. The designer can in many cases lead this process because the designer is a problem solver and the primary focus of an industrial designer is to develop marketable concepts and specifications for new products, or for the revision of existing products, so as to optimize product performance, value, appearance, and marketability for the manufacturer. The designer in this process will consider the manufacturer's business objectives, budget constraints, targeted market, technical requirements, and production capabilities as well as pertinent distribution, sales, and service procedures. The result will be a final synthesis of visual, tactile, safety, convenience, functional, cost and pricing attributes of a product, product family, or system.

With this more comprehensive view of industrial design the physical presence of the world's auto designers in Los Angeles begins to take on added importance. In early 1993

CALSTART and AMERIGON approached the Federal Transit Administration in the Department of Transportation to discuss the appropriateness of using federal transit funds for the development of a "running chassis" capable of being used by broad ranges of domestic and overseas original equipment manufacturers with individually designed shells to be fitted on the CALSTART/AMERIGON chassis. The Transit Administration approved the funding with the request that CALSTART develop an expanding chassis concept so as to fit the requirements of small transit vehicles as well.

AMERIGON and CALSTART have a range of talented individuals now assigned to this program, nevertheless, it needs to be emphasized strongly that CALSTART and California lack fundamental experience in the tooling capability and automobile manufacturing engineering and related expertise for this chassis. A note of caution is also in order in assuming that the AMERIGON/CALSTART electric vehicle running chassis, as currently conceived, can be effectively utilized in an expanded version in smaller mass transit vehicles. Nevertheless, CALSTART may be able to engage the world's auto manufacturers in using the CALSTART running chassis as a basic platform for electric and other types of vehicles and to provide tooling and manufacturing expertise by first approaching the major car makers through their advanced concept and international design studios in Southern California.

CALSTART and California should see this as one more opportunity to indigenize necessary flexible manufacturing expertise into the region. The complexities and the need for cutting-edge and hands-on-experience in original equipment automobile manufacture cannot be overemphasized to California industry. The "running chassis" program illustrates two points: (i) the importance of integrating experienced manufacturing engineers and companies from Detroit in developing California's technology, components, and sub-systems. (The manufacturing, economic, and strategic cases must be made as to why any of the "Big Three" automakers, or overseas manufacturers, would want to participate in the CALSTART running chassis program.); (ii) the importance of mechanisms/incentives to involve Detroit companies.

California is unlikely to be successful in developing a components and sub-systems industry or final assembly capability for the electric car without genuine Michigan participation in California; or without Michigan/California cooperation on a common national technology policy agenda to be pursued with vigor in Washington. In a separate and antecedent initiative a CALSTART member, the Los Angeles Department of Water and Power, has spent several millions of dollars in developing the Los Angeles 301, a hybrid electric vehicle car project that has now stalled. Part of the problem of the LA 301 program has been lack of interest by the Big Three. Public investment dollars are a scarce resource that must be carefully targeted.

The CALSTART "running chassis" is a specific instance of a more generalized strategy that must establish fused design, product engineering, and manufacturing capabilities in the region. The same strategy can be effected in different ways. For example, a multiple-skilled supplier base in Southern California offers an excellent export base. Smitka and Friedman²⁷ have argued, for example, that Japanese manufacturers remain highly dependent on the design and manufacturing capabilities of their suppliers within Japan for complex sub-systems. In fact, Japanese auto firms have become highly dependent on purchased sub-assemblies rather than

²⁷ Smitka, Michael J. Japan's Economic Challenge, Testimony Before the Joint Economic Committee, United States Congress, October 1990, and Friedman, David. Japan's Immense Trade Surplus Conceals Substantial Vulnerability (Opinion-Editorial) Los Angeles Times

simple parts and their ability to turn out a new car without multi-skilled supplier inputs has become jeopardized. According to analysts like Friedman and Smitka, because of insularity, the domestic relationships in Japan are growing stale and manufacturers are reaching out globally for fused design and manufacturing services. Southern California has the opportunity to foster multiple-skilled supplier inputs based in small- and medium-scale collaborative manufacturing networks in pursuit of the Japanese markets. Southern California has prodigious strengths in design and product engineering but will need to develop and import greater flexible manufacturing capability. Hybrid manufacturing capacity could then be anticipated; for example, flexible manufacturing companies from Detroit working collaboratively with those California aerospace firms with hydro-forming capabilities is a viable manufacturing scenario. (Hydro-forming is an aerospace and automobile manufacturing process that allows the even shaping of metal sub-assemblies.)

With the correct institutional supports, the region could develop hybrid collaborative manufacturing networks with some degree of flexible specialization. As stated earlier, to a considerable degree the international design and advanced concept centers in Southern California are style centers. But three of the studios have degrees of uniqueness and can be used as an important illustration of a flexible specialization potential in the Southland: Designworks/USA of Newbury Park, AeroVironment of Monrovia, and Classic Advanced Development Systems in Valencia.

Designworks/USA is a design consultancy located in Newbury Park just north of Los Angeles. It is located amid a cluster of other design studios in the northern Los Angeles/southern Ventura County region. This geographic cluster consists of Designworks/USA, Volkswagen of America/Audi of America, General Motors Corporation Advanced Concepts Center, and Volvo Concept Center. What makes Designworks/USA perhaps unique in Southern California as a design center is the extensive range of industrial sectors with which it is involved and the self-reflection in the corporate culture that conceives of design as a cultural resource, a mechanism for innovation diffusion, and equally valuable as an instrument for economic growth and environmental and social education.

The design teams at Designworks/USA work with a broad range of clients always shooting for quality products with high performance in both design and marketability. The organizational approach for innovation and invention is through what is called Strategic Design and Planning, SDP.

SDP is used as a foundation in establishing criteria for project design and business planning. The approach strives for an in-depth understanding of both the markets within which the client competes and the cultures which embrace those consumers who are the beneficiaries of high quality in the performance-oriented products.

The approach is also capable of seeking out new markets in adjacent industries for innovative adaptations of the clients' products. Among other things this can reduce the price of components used in electric vehicles and strengthen the business position of the vendor-base.

SDP forms the core of every project undertaken at the design center and the organizational capacity is established and directed through a Competitive Advantage Network, CAN. CAN consists of in-house designers, technical advisors, and business and marketing professionals who contribute to the success of all facets within a product's life-cycle. The objective of CAN is to assist Designworks/USA's clients in defining and achieving product development goals. This is accomplished by providing close communication with the client to

integrate ideas into a cohesive plan and image. Of great interest Designwork/USA always plans that the resultant design educates, informs, and gratifies, and most importantly, the design is intended to serve a purpose beyond what is intended, and responds to the demands of society.

One of the relevant projects of Designworks/USA is the BMW E2 Electric Car. In developing an electric vehicle to meet American legislative requirements, driving conditions, and styling taste, BMW AG worked with Designworks/USA, in which BMW has a 50% share. The collaborative result of these two companies has been a four-passenger prototype sedan that differs from the E1, an earlier European version. The E2 was presented at the 1992 Greater Los Angeles Auto Show.

The design center has a long history of design in airline, train, and automotive systems that has given it an impressive fund of knowledge that includes automotive design but moves beyond it. With the exception of Nissan Design International in San Diego, which has taken brief excursions outside of automobiles in designing products like medical instruments, Designworks/USA is unique among design and concept centers in Southern California.

However, beginning from a different discipline, equal market flexibility and depth of talent is demonstrated by AeroVironment, a small engineering firm that was created in 1971 to help business and government recognize and meet their environmental and energy objectives. AeroVironment has great breadth but it is not a "pure" design center idea, rather it could be classified as a research and development and rapid prototyping center composed of mechanical, civil, and other types of engineers.

AeroVironment was created to help business and government recognize and meet their environmental and energy objectives. The company exists with a can-do culture that has resulted in this team pioneering five aviation/advanced transportation vehicles acquired by the Smithsonian Institution. The underlying philosophy and culture that emerges from visiting the AeroVironment facility is that technology exists to meet human and environmental need.

There is a strong staff diversity that includes leaders in fields of air quality, hazardous waste management, renewable energy, and fuel-efficient vehicles. Of great importance, the services and products provided by AeroVironment display an understanding that these fields are interconnected.

Among the relevant programs AeroVironment has implemented is the solar-powered Sunraycer and battery powered G.M. IMPACT. AeroVironment's "skunk works" philosophy combines systems engineering, project management, advanced theory, broadbased technology, prototyping, and field testing. This approach is applied to high-efficiency advanced transportation vehicles, aerodynamics, hydrodynamics, composite structures, electronics, and renewable energy.

Classic Advanced Development Systems, Inc. is located in Valencia, California and presents a different view of what can take place at the advanced concept and international design centers in Southern California. Just as Designworks/USA and AeroVironment were unique, Classic Advanced Development Systems Inc. (C.S.I.) is one-of-a-kind. C.S.I. specializes in manufacturing consulting and simulation services in processing, materials handling, and robotics. This is an advanced concept and design center that focuses not on the fusion of industrial design and product engineering skills, but on integrating these fundamental skills with manufacturing process. Using sophisticated solid 3-D animated simulation software, C.S.I. provides simulation support during all phases of a projects' development.

In support of the manufacturing function, C.S.I. provides a broad range of simulation

services that include manufacturing process analysis, production scheduling analysis, mechanical downtime analysis, operator sequencing analysis, and flexible manufacturing system analysis. State-of-the-art computer simulation resources, together with extensive experience in process simulation, allows C.S.I to manage any process engineering project. Computer animated models in three-dimensional graphics reflects the manufacturing environment in critical detail. The system can identify and quantify a system's bottlenecks, including, "operator phasing". Other benefits include determining engineering line rates, maximizing resource utilizations, and optimizing buffer sizes and locations.

C.S.I. uses simulation to determine the lead time for "just-in -time" truck deliveries, establish warehousing capacities, or coordinate material handling resources with production requirements. Whether designing a new material handling system or working to improve the performance of an existing system, the simulation services are designed to provide an evaluation of various proposals to better assess the best working alternative.

The company uses an extensive solid 3-D animated library of industrial robots and mechanical components to simulate accurately the operation of robotic and kinematic systems. Robot workstations or mechanical designs can be modelled and optimized in terms of component selection, placement, motion, control sequence, and cycle time. This analysis, when done prior to purchasing equipment, will eliminate excess spending and significantly improve return on investment.

In integrating more closely the fundamental science, design, product engineering, and manufacturing skills of the region the institutional focus should be internal and integrative and construct the organizational capacity for the constant recombination of resources and the provision of collective services. Simultaneously, it should be externally oriented in pursuing limited federal dollars, complementary state and federal policies, as well as competitive gains in the international system.

7.6.4. Emerging Technologies and the United States' "Grand Strategy": Implications For An Advanced Transportation

The near 50 year period of the Cold War ultimately came to mean the expenditure of about \$500 billion per year by the Soviet Union and the United States, alone. Some analysts have commented on the enormous opportunity costs involved that prevented the superpowers from dealing effectively with a range of domestic social and economic growth problems.²⁸ And a concern has developed that the relative industrial decline of the US during the last decades of the Cold War period has, in fact, severely cut into the economic foundations of the post-World War II international security system at the same time that industrial and technological challenges from overseas are creating a new international system that minimizes United States influence.²⁹

In response, new concepts of "grand strategy" have now begun to emerge that concurrently address economic, military, and diplomatic policy areas, and that encompass the

²⁸ Rosecranze, Richard, A New Concert Of Powers, Foreign Affairs, Spring 1992.

²⁹ Borrus, Michael, Zysman, John 1992 Rethinking America's Security, The American Assembly, Columbia University, The Council on Foreign Relations, W W Norton, New York and London

multiple threats to peace posed by issues like global climate change and economic vulnerability. Two of the industries that should be assessed in the context of emerging United States "grand strategy" in the post-Cold War and post Gulf-War period are aeronautics and the automobile industry.

In mid-1993 a group of representatives of business, labor, and government have assembled the Made In California Working Group, to develop industry business plans and manufacturing implementation for advanced transportation systems, and other sectors, as well as to fashion a wider grand strategy for California. The group is indicative of the cutting-edge organizational experimentation now beginning to take place in California and will be discussed in the final section of this chapter.

It is certain that the implementation of grand strategy will first require overcoming existing difficulties in executive-legislative coordination in Washington. The more immediate question for California and the Southern California region, however, is whether the state can strategically and directly participate in a key leadership role in the emerging multi-polar international system directly through the mobilization of its intellectual, industrial, and political strengths. The simple matter of the electric car, a "green" industry not yet even in existence to any significant degree, may provide some measure of insight and a point of departure in addressing the larger question. Strengthening California's national and international leadership role should be at the forefront of the state's environmental, labor, industrial, and political leadership.

It needs to be understood that Southern California's geography, culture, and economy, since World War II, have been indelibly impressed by the history of the nation's European and Pacific wars and military engagements, and the Gulf War may yet leave its impress upon the state. In fact, the Gulf War placed in juxtaposition to the electric car provides an odd but illuminating demonstration of the state's possible technological leadership in one important facet of the emerging international manufacturing system: commercial "spin-on" to the defense industry.

The recent Gulf War was essentially the first major military confrontation to employ a broad variety of robotic vehicles which contributed significantly to strategy, tactics, and battle prosecution. Cruise missiles and remotely-controlled bombs and missiles attacked wide-ranging targets; unmanned aircraft were used in reconnaissance, surveillance, battle damage assessment, and target designation; and unmanned ground and underwater vehicles cleared mines and unexploded ordnance.³⁰ At least four countries (United States, Britain, France, and Germany) used robotic air, land, and sea vehicles in the war. These technologies were indeed impressive but they should be considered only the first stage toward impending development of "smart" and "brilliant" intelligent machines.

The world's first combined demonstration of unmanned ground vehicles (UGV) and unmanned air vehicles (UAV) was held at the Marine Corps Development Command, Quantico, Virginia, during November 1990. It was sponsored by the Unmanned Ground Vehicle Joint Program Office (UGV JPO). Never before had UGVs and UAVs been used in combination. Live video, displayed on three monitors (one for each unmanned vehicle), permitted observers to track the progress of the battle step by step. This should be considered a preview of the "air-

³⁰ Mattingly, Mack and Finkelstein, Robert *Combat Robotics From the Kaiser to the New World Order*, Royal United Services Institute and Brassey's Defense Yearbook, 1992, London, Washington, New York

land nonlinear battlefield of the coming millennium."³¹

While the eight-pound battery-powered electric motor Pointer UAV, developed by AeroVironment in Monrovia, California, served with the Army and Marines in Desert Storm (AeroVironment also developed G.M.'s IMPACT electric car.), the UGVs are still developmental with some of the first demonstration vehicles intended to reach the field in 1993. Because of the necessity for light-weight efficient technologies the interdiffusion of innovation between more-electric and all-electric aircraft and more-electric and all-electric unmanned ground vehicles, may well create a leap in technology components and sub-systems in this decade that will place the electric vehicle as a crucial innovation center of automobile technology.

It is evident that the coming large-scale introduction of combat robotics will have profound tactical, strategic, organizational, political, cultural, economic effects that are difficult to foresee.³² What can be stated with certainty is that the emerging generation of air and land robots (some teleoperated) currently have their source of innovation in the military, but this will change very shortly with the subsequent center of innovation located in the commercial sector.

This generalized movement is already easily observable in the movement towards a unified arms industry in Europe. Within the context of a single European market, transnational industrial cooperation efforts are directed toward civilian demand. Defense analysts in Europe clearly recognize that military demand no longer determines progress in technology. The arms industry will accordingly increase its dependency on commercial industry and its economic health. Conversely, commercial industry will benefit from the availability of subsidies supporting military projects purported to be in the interest of defense.³³

California should listen to these distant rumblings and seek to interpret them. It must be crystal clear that an effective grand strategy will be critical to California's technological future. With stiff competition coming for the first time from foreign sources, California's aerospace, electronics, and defense industry will not survive without the implementation of genuine competitive strategies and organizational reform. Blaming the state's industrial failures on environmental regulation, workers' compensation, or immigration will ultimately be seen as diversions away from the more urgent task of implementing genuine industrial change.

7.7. Present Realities/Next Steps

7.7.1. The Necessity For Grand Strategy In Aeronautics And Automobiles

The current status of the U.S. aeronautics industry was highlighted during President Clinton's February 1993 trip to Washington state to visit employees of Boeing Aircraft Inc.. President Clinton stated that his administration would support efforts to help revitalize the U.S. aeronautics industry and fight unfair trade practices abroad. At the same time, congressional

³¹ Mattingly and Finkelstein, p 252

³² Mattingly and Finelstein, p 259

³³ Drown, Jane D , Drown, Clifford, and Campbell, Kelly, A Single European Arms Industry? Brassey's, Pergamon Press, New York 1990

policymakers were considering legislative proposals to assist the U.S. aeronautics industry to compete globally and develop new technologies. Both S. 419 and H.R. 1675 (the Aeronautical Technology Consortium Act of 1993) call for the creation of a new Government-industry relationship to address the current problems of the U.S. aeronautical industry both domestically and abroad. Supporters of these initiatives point out that the success of SEMATECH, as well as the need to respond to Airbus, both indicate that a similar effort would work for the aeronautics industry.³⁴

Concurrently, President Clinton's Clean Car initiative outlined in the Clinton/Gore Report of February 22, 1993 clearly demonstrates a commitment by the Administration to improve the global position and competitiveness of the United States auto industry, and to push the technological envelope on clean car technologies. This occurs at a time when the car industry as a whole has experienced major financial losses. The primary (but not the only) cause was foreign competition. The industry is rapidly correcting reliability and design problems, but it will take years to recover the buyer loyalty which has been lost. To recover the market share the manufacturers must make major investments in new product designs and facilities.³⁵ A recent study by the University of Michigan estimated that the U.S. manufacturers would have to spend \$225 billion on new cars and trucks in the next four to five years to remain competitive. This is about three times the recent rate of expenditures. It is doubtful that the industry can find these funds without government support. Moreover, by 1996 less than half of the automobile platforms which will be marketed in the United States will be produced by United States companies. This is down from 1991 when 70 percent were produced by United States manufacturers.

In the globalized production base described in this chapter it is clear that the global arms industry will increase its dependency on commercial industry. Conversely, commercial industry will benefit from the availability of subsidies made in the interest of defense. The interdiffusion of innovation across these industrial sectors can provide the United States cost savings, a unified industrial base with more rapid development cycles, greater production quality, and the fusion of whole new industries. Such an industrial profile supported by relevant technology policies is an important goal to work towards.

In the main, technology policies have been fashioned in the United States only at the sectoral level; whereas in this and other chapters it has been argued that sector-based strategies must be paralleled with policies that build upon local technological capacities and institutions. Increasingly, in the United States, regions will be central to the governance of technology-based competitiveness policies — as they already are in many other countries — and inter-regional policy initiatives could prove equally significant.

Michael Storper has argued that the region should figure in the governance of technology

³⁴ McLoughlin, Glen J and Moore Glen J Aerotech A Proposal For A Government-Industry Consortium in Aeronautics Technology, Congressional Research Report For Congress, April 19, 1993

³⁵ Sobey, Al Testimony for Senate Hearing Subcommittee on Clean Air and Nuclear Regulation, Opportunities To Reduce Automotive Emissions, April, 27 1993

policy in two principal ways:³⁶

"Since the technology cores of many industries to which specific public goods are directed are themselves highly localized, it follows that the specific public goods are directed largely to particular regions in the country. This is a fairly radical departure from traditional American policy logic of territorial indifference."

"The second way the region figures in it is as one of the levels at which appropriately focused groups of actors — those who would be the receivers of specific public goods — can come together to propose the kinds of goods they need, mobilize their own resources to participate in the production of such goods, and compete with other such groups in the national territory. The region is not the only such economic community which is appropriate for implementation purposes: groups of firms in sectors, for example, are another obvious candidate."

Storper maintains that regionally or inter-regionally based groups of actors are not meant to supplant communities of sectorally-based actors, general national policies, or even the role of individual firms. The goal of regional or inter-regional strategies is to build on existing strengths, through collective strategic choice, coordination, investment, and better connections to R&D, the possibility of making products with growing markets and with technology learning effects.³⁷ As an illustration, an incipient regional/inter-regional industrial strategy, the Mich-Cal strategy, is being formulated by members of the MIC Working Group working in Southern California and with full participation by engineers and analysts in Michigan. Their work is discussed in the next section.

7.7.2. The Made In California Working Group

A group of public officials and their staff, consultants, corporations, business analysts, and academics came together in early 1993 in Southern California to discuss the potential for comprehensive technology policy in the state of California. The group is composed of agency officials, as well as state and federal elected representatives, including officials and representatives from the South Coast Air Quality Management District, Congressman Julian Dixon (D-California), Congressman Howard Berman (D-California), the office of California State Treasurer Kathleen Brown, UCLA faculty, and others. The group has been discussing what technological-institutions are necessary to enhance California's overall competitiveness with a specific focus on manufacturing implementation. Members of the group have been conducting interviews and holding meetings with small- medium- and large scale firms to discuss institutional questions related to regional and national competitiveness and have initially targeted

³⁶ Storper, Michael A New Economic Regionalism? Technology-Based Competitiveness Policy and Regional Governance, Options for the Clinton Administration, Lewis Center for Regional Policy Studies, UCLA, paper prepared for presentation to International Seminar "The First 100 Days of the Clinton Administration", Centro de Investigaciones sobre Estados Unidos de America, Universidad Nacional Autonoma de Mexico, June 3-4 1993

³⁷ Ibid

six industries for additional work: communications, information technologies, medical instruments, environmental technologies, garments/textiles, and advanced transportation systems.

The MIC group has the potential to be a significant support to the advanced transportation systems and electric vehicle industry in Southern California and is an excellent illustration of the current effort in the region to develop new institutional infrastructures to address the four revolutions in the technology development process that were outlined in the introduction of this chapter. As part of its mandate, the Made In California Working Group has constructed the initial outlines of a Michigan/California (Mich-Cal) strategy. Some elements of that strategy can be discussed here.

Members of MIC have begun a detailed multi-phase analysis that investigates the concrete requirements for bringing advanced transportation systems production into existence, building up from the engineering of specific mass transit, rail, and other large platforms, to manufacturing processes, R&D, and markets. It is anticipated that the Mich-Cal strategy could become an important component in the Clinton/Gore Clean Car Task Force. Fuel cells can be used as a concrete illustration of regional/inter-regional technology policy and how strategic regional policies might be integral to a successful Clean Car Initiative for the Administration.

According to many analysts, unless the United States changes the national fuel cell program level, priorities, and strategy, reliable, economically competitive, American designed fuel cells will probably not be available for purchase for 20 to 30 years.³⁸ With this time frame it is almost a foregone conclusion that the fuel cell industry will be dominated by foreign companies. The development of fuel cells can be accelerated at a cost but with scarce federal resources decision-making must be strategic. Assuming successful testing of a series of sequentially improved fuel cell propulsion systems, it appears logical that prototype fuel cell locomotives could be demonstrated with subsequent near term volume production, and buses could follow a similar time schedule. But the more demanding applications such as trucks and cars will take several years longer — even with an expedited program.³⁹

Initiatives in California, then, like the South Coast Air Quality Management Districts' Fuel Cells for Locomotives effort provide the critical learning curve for fuel cell technology in Detroit for use in passenger cars. Similarly, fuel cell development for use in aeronautics with appropriate scale up and deployment in advanced land transport applications (or vice versa) could prove significant to the industrial Midwest, as well as to California.

Advanced materials and electronics are two other industries where regional/inter-regional strategies can be effectuated; in addition, finding ways of linking electronically the basic science, design, and product engineering skills in California with manufacturing engineering skills in Michigan could develop not only a stronger multiple-skill supplier base in the nation but inaugurate supplier consortia with real time integration into United States "virtual companies" that combine marketing, finance, final assembly, and other industrial essentials. This could include the establishment of entrepreneurial outplacement processes using personnel from downsized aerospace and automobile companies. Unintended fusions of technology and human skills are likely to take place in this environment with unpredictable satellite industries emerging

³⁸ Al Sobey, Fuel Cells — Where Do We Go From Here, Princeton Work Shop on Fuel Cells, Center for Energy and the Environment, Woodrow Wilson School of Public and International Affairs, October 21, 1992

³⁹ Ibid

with possible benefits for both industrial regions.

A more complete formulation and implementation of the nascent Mich-Cal strategy could prove significant to both the aeronautics and automobile industries and could involve the formation of multi-state regional technology alliances. Michigan could be expected to work with Ohio and possibly other states; and California could be expected to work with New Mexico, possibly Arizona, and others. These two regional alliances supporting different categories of fuel cells involved in different modal applications would each assemble one or two competing fuel cell consortia. This would be in contrast to the organizational structure that currently exists in the United States Advanced Battery Consortium that has no strategy for regional governance of technology.

7.7.3. Next Steps

A high-profile policy forum

In California, organizations trying to achieve either (a) cooperative research or (b) collaborative manufacturing goals are currently operating in an industrial culture and climate that is fragmented and in profound transition and all too often based on older practices designed for a different era. In the recent past, for example, ideas like "just-in-time" delivery, "total quality management," "long term supplier commitments" — concepts that when part of an integrated strategy for corporate improvement have value — were used to avoid comprehensive corporate improvement and these things became part of the problem they were intended to cure. In isolation from supporting ideas and debate, any single organizational effort like CALSTART, cannot hope to survive in a regional and statewide policy and intellectual vacuum even if the organization were to remain successful as an island of excellence.

It therefore becomes essential to create a first-rate, high-profile forum/think tank to foster a new pole in Southern California's economic policy thinking. The purpose of such a forum would be to:

- (i) describe in general the managerial, labor, and other initiatives competitive manufacturers need to adopt;
- (ii) describe how firms working jointly in programs such as CALSTART can learn and implement appropriate standards of design, collaborative innovation, or production quality;
- (iii) consider all ancillary public and private initiatives that could support industrial development, such as financial or technological support (If this policy forum already existed it could be assisting CALSTART in refining elements in the High Performance Work Organization and in constructing new ancillary institutions like a financial intermediary or a technology incubator for small aerospace spin-off companies [CALSTART has proposed this latter idea to its Board of Directors as Project Hatchery.]

- (iv) help distinguish initiatives like CALSTART from more traditional, less useful political or corporate strategies.

California remains technology-rich but institutions-poor in developing techniques for rapid commercialization, and in fully understanding collaborative manufacturing and fundamental revolutions occurring globally in the technology development process. Such a forum in Southern California as described above is crucial.

An Export Trade Company

Business analyst David Friedman, the International Association of Machinists and Aerospace Workers and Congressman Howard Berman (D-California) have proposed to the Made In California Working Group the formation of the United States Export Trade Corporation. The 1982 Export Trade Company Act can be used as the legal basis for this proposed organization.

Southern California business enterprise must develop mechanisms to engage buyers and sellers from around the world. California enterprises must have the organizational capacity to adopt and adapt technologies from around the world to: (i) become adept in working with foreign producers; (ii) be capable of adapting their own skills to world markets; (ii) be capable of simultaneously protecting or leveraging their own technologies and know-how from piecemeal foreign appropriation.

Southern California, and for that matter, US firms face several difficulties in dealing with overseas markets. In the first instance, existing sales or procurement conduits are typically foreign trading companies or agents. This mode of operation isolates companies from end users, consequently cutting off chances to learn production techniques, seek out new technologies, expand import or procurement efforts directly, or license-produce foreign products. An example is Boeing, which sources for billions of dollars of equipment in Japan through the Tokyo agent of a federation of Japanese aerospace firms without making any concerted effort to survey or learn from the hundreds of firms that make its products. The flow of technology and know-how is entirely one-way from Boeing to Japan.

An Industrial Design Initiative (IDI)

Despite California's leading role in the world in industrial design, both California and the United States lag in recognition of the need for creating a positive environment for design and utilizing it as a major resource for competitiveness. Designworks/USA, and others, have long argued that California should step into the leadership vacuum.

Design can be used as an integrator in the technology development process and in getting the core technology to the end user and establishing support for long term use. Using a regional competitive advantage — the design strengths of California — Southern California industrial designer, Maureen Thurston, along with leadership from Designworks/USA, has proposed IDI as a resource base for projects supported or developed by the MIC Working Group. The proposal is to create an infrastructure for technology and design innovation while allowing both private industry and the consumer to benefit from a developing business culture and products in a family of companies that account for design. Projects assisted by the MIC Working Group, for example, could be supported by the IDI and would have early involvement with the development and integration of core technology and niche-market driven product. These

companies could more easily see were the future of design is going before actual products are manufactured.

IDI has been conceived as a creative problem solving institution with its primary focus on developing marketable concepts and specifications for new products, and for the revision of existing products, so as to optimize performance, value, appearance and marketability for MIC related manufacturers. IDI is to consider the manufacturer's business objectives, budget constraints, targeted market, technical requirements, and production capabilities, as well as pertinent distribution, sales, and service procedures in determining the best synthesis of visual, tactile, safety, convenience, functional, cost and pricing attributes of a product, product family, or system. The proposal has been advanced that the IDI establish a MADE IN CALIFORNIA design label for the projects supported by the MIC working Group which would come to mean the best in design and product and be recognized around the world.

New Institutions for the Administration of Intellectual Property Rights

Michael Storper at UCLA has already proposed to some members of the MIC Working Group that the organizational capacity be developed to provide incentives for California production, through the administration of a system of intellectual property rights — such as patents and licenses. The main incentive for California production in this regard would be preference in licensing of technology, as well as contractual commitments made by private sector participants who would benefit from the pre-competitive research and development. In an era characterized by an increasing pace in the globalization of technology, this idea should be fully articulated because of the use of federal, state, and local funds for (i) product development, (ii) market creation, and (iii) subsidies for collaborative manufacturing. Manufacturing enterprises aided by the MIC Working Group could have participation by domestic or foreign original equipment manufacturers.

Such openness would not be a first. The European Community's publicly supported Esprit and Jessi programs already permit U.S. companies to participate in their activities. In return, the EC expects the American companies to involve themselves in research, development, or production within Europe. California could do the same with its extensive array of technologies applicable to electronic and hybrid vehicle manufacturing, asking in exchange, for example, the transfer of state-of-the-art downstream process skills from Japan.

At a minimum, for example, foreign participation in California projects developed to commercialize ultracapacitors developed at Lawrence Livermore, or fuel cells and batteries developed at Jet Propulsion Laboratory could be made contingent on payment to the American participants. But more attractive than that, the MIC Working Group should consider implementing institutional ability to negotiate reciprocal memberships in consortia from participating nations.⁴⁰ The Toyota/Nissan joint development of electric vehicle technology is an applicable example.

Moderate proposals such as these become imperative in pursuit of national interest in an age of global technology. For over a decade, there has been an acceleration of two mutually reinforcing trends that have already been referenced in this chapter as constituting revolutions in technology development. They are the convergence in technical capabilities of industrialized

⁴⁰ Harrison, Bennet, *Winning Through Collaboration*, Technology Review, January 1993

nations and the global integration of formerly discrete national technical enterprises. The swift growth of technical competence outside of the United States makes it increasingly difficult for U.S. based companies to derive sustained competitive advantages from superior research capabilities alone. Companies must be assisted in harnessing and exploiting dispersed resources and technical and manufacturing capabilities from around the world.

In summary, two recommendations made by the National Academy of Engineering in a book published as part of a series on prospering in a global economy may be referred to here. First, the Academy's Committee on Engineering as an International Enterprise stated that above all, state and federal policy makers in the United States in cooperation with corporate and academic leaders should develop a broad national consensus regarding the need to improve technology development, adoption, adaption, and diffusion throughout the U.S. industrial economy. Second, to accomplish this, the United States must develop the essential human, financial, regulatory, and institutional infrastructure to compare more advantageously with other nations in attracting the technical, managerial, and financial resources of globally active private corporations and individuals.⁴¹ The Committee stated this was the most important conclusion of its study.

⁴¹ Lee, Thomas H and Reid, Proctor P (Editors) National Interests In an Age of Global Technology, National Academy of Engineering, National Academy Press Washington, D C 1991

Chapter Eight

The Electric Vehicle Industry In Southern California: Future Prospects And Wider Developments

Marco Cenzatti

8.1. Electric Vehicle Production and Industrial Districts

It has already been suggested earlier in this report that creating an electric vehicle manufacturing industry in the Los Angeles region is predicated on the presence and growth of an industrial structure that in many respects follows the development of what recent industrial studies have named "industrial districts."¹

First, studies of industrial districts stress the advantage of vertically disintegrated and geographically clustered production systems over more traditional forms of integrated and standardized production for the flexibility that these systems offer. In part, as this report points out, the need for flexibility derives from the newness of the electric vehicle industry and, therefore, from its need for rapid adjustment of output and production processes to technological change, as well as from its limited market. Furthermore, studies focusing on the flexibility of industrial districts have shown that flexibility is not necessarily a temporary phase of industrial development that is replaced by vertical integration and product standardization as the product matures. In places as different as Japan, Germany, Italy, and even in some parts of the United States, flexible production systems are successfully challenging mass production in an increasing number of sectors, where either a large standardized market never materialized or where demand is becoming increasingly fragmented, uncertain, and niche oriented.² As Japanese "lean" production shows, this tendency toward flexible production has made inroads even in automobile production, the most classical case of Fordist mass production. As a result, the development of the electric vehicle industry in a flexible vertically disintegrated configuration does not only depend on its newness and is not necessarily limited to its early stages, but reflects a general

¹ For recent studies on flexible production systems and industrial districts see G. Becattini (ed.), *Mercato e Forze Locali. Il Distretto Industriale*, Bologna: Il Mulino, 1987; M. Piore and C. Sabel, *The Second Industrial Divide*, New York: Basic Books, 1984; A. J. Scott, *New Industrial Spaces*, London: Pion, 1988.

² The form of these industrial districts is different in different places and sectors, ranging from systems composed exclusively of small firms, to systems in which a major assembly facility functions as anchor of the entire system (for example at the center of a system of Just-In-Time suppliers).

tendency of industrial systems under particular technical and market conditions.

Second, the present report also converges with industrial district studies in attributing importance to the presence and development of strong external linkages between firms. In integrated production, R&D activities, coordination between phases of production, exchange of information, and flow of components take place largely within the firm, while in disintegrated systems these functions are most of the time outside the scope of manufacturing units. As a result, in existing industrial districts other firms, agencies, and institutions have developed in order to supply financial and marketing services, facilitate the exchange of information between manufacturers, and pool resources for R&D. In the districts examined by flexible specialization studies these external-to-the-firm-but-internal-to-the-system functions have grown 'naturally', in parallel to the expansion of manufacturing activities. Thus a major issue from the perspective of this report — tackled in Chapters Seven and Five — is how to provide these services in order to initiate and support the growth of an electric vehicle district.

The third point of convergence between electric vehicle production and industrial district studies is the importance that local preconditions play in the development of a district. Whether the districts under study are the Italian ones, which evolved out of artisanal traditions and small shops, or the cluster of electronics firms in Santa Clara County, which found a fertile terrain in the research institutions of the area, most studies stress the essential role that the availability of skilled labor, technical expertise, entrepreneurship, specialized suppliers, and opportunities for research and development in the new industry play in preparing the ground for the growth of industrial districts. The presence of non-standardized activities in the Los Angeles region, ranging from automobile design centers, to large numbers of (small) mechanical firms, to the entire complex of firms and suppliers forming the aerospace industry, already provides a similar set of preconditions on which electric vehicle production can be based.

Continuing the parallel between the development of electric vehicle production in Southern California and the evolution of industrial districts, one further element should be pointed out. Although industrial districts are usually characterized by the dominance of production in one specific sector (i.e., by "vertical specialization" in the different phases of production of one type of commodity and its components), the activities of the district are rarely limited to that sector alone. In fact, the industrial growth of a district is more often based on "lateral specializations," denoting the presence (or the development) of other industries that share similar labor, technological, and manufacturing requirements and that find proximity to the original activities advantageous. In some cases lateral specialization follows the success and growth of the original specialization. Thus, for example, specialized districts such as Prato and Sassuolo (in Central Italy) have developed over time from the production of textiles and ceramics (respectively) to lateral specializations in the production of machine-tools for the trade (e.g., looms and clay mixing machines).³ In other cases, the starting point is the existence of a broad range of linked activities from which a dominant vertical specialization derives. Automobile production in the Tokyo region, for example, is a specialization based in part on the presence

³ See G. Fuà and C. Zacchia, *Industrializzazione Senza Fratture*, Bologna: Il Mulino, 1983 for the Prato case; S. Brusco, *Piccole Imprese e Distretti Industriali*, Florence: Rosenberg and Sellier, 1990 for Sassuolo.

in the area of a wider network of metals and machinery producers.⁴

Electric vehicle production in the Los Angeles area can play both roles, inducer and induced. On the one hand, the electric vehicle industry presents itself as a possible focus for a series of technical and labor skills, industrial capacities, and specialized producers — from electronics to metal working machine shops — which are already present in the area (indeed that already characterize Los Angeles as a mosaic of industrial districts). This role is particularly important today, when other industries — aerospace and defense — that in the past supplied an important element of cohesion among the various elements of the system, are in crisis. The success of electric vehicle production would also have a feedback effect, supporting and reinforcing the presence of these sectors.

On the other hand, electric vehicle production can function also as a starting point from which other "lateral" specializations, that share a reliance on intense R&D activities, on the electronics industry, etc., could develop. In fact, Los Angeles' competitive advantage rests on an industrial environment that is particularly fertile for industries either developing new products or undergoing a process of restructuring towards 'flexibilization' of their products, production processes, and division of labor. Therefore, while Southern California has a limited appeal to standardized firms and phases of production in search of low production costs on the basis of cheap labor, weak environmental constraints, or public subsidies, the region is well situated to attract and/or foster the growth of firms that could lower their production costs by taking advantage of the external economies of scale and scope that the region's "industrial atmosphere" can offer. Electric vehicle production can function as a catalyst of this process, by taking advantage of the existing characteristics of the region, by spinning off a host of innovations and improvements of various technologies and components which can easily find application in different fields, and by synergistically intersecting with other directions of industrial growth. The purpose of the next section is to speculate on some of the possibilities for such an expansion.

8.2. Towards an Advanced Transportation Equipment Industrial District

It would be difficult (and probably pointless) to try to guess all of the possible directions in which progress in electronics, battery technology (or development of fuel-cells), research in light materials, improvement of electric motors and controllers, and all of the other technologies involved in electric vehicle production might be applied. Instead, the three following sketches focus on three possible (and complementary) directions in which electric vehicle production in Southern California can progressively evolve out of strict electric vehicle manufacturing and extend into a wider system of transportation industries. This begins with the growth of industrial activities as part of the growth of electric vehicle production and its product differentiation; then proceeds to expand the picture by considering the development and production of infrastructures needed for electric vehicle viability; and concludes by showing the synergies that could develop at the point of intersection between the electric vehicle industry and other advanced transportation industries and technologies under study. These examples illustrate the role that electric vehicle production can play by directly stimulating the industrial growth of the region.

⁴ See A J Scott, *Metropolis From the Division of Labor to the Urban Form*, Berkeley University of California Press, 1988

This fits in with, and reinforces, the creation of a broader industrial district whose specialization lies not in one specific sector, but in the R&D and production of a wide range of new transportation technologies and equipment in general.

8.2.1. Flexible Electric Vehicle Production

As already mentioned, one of the causes for the increasing importance of flexible production systems is the uncertainty of demand and the breakdown of traditional mass markets into an increasing number of specialized niche markets. This tendency is particularly evident in the automobile market, where the few standard models of the past have been replaced, over the last decade or so, by a segmentation of demand in specific niches ranging from differentiation of main-stream cars (roadsters, "luxury" or "sport" sedans, hatchbacks, station-wagons, mini-vans, etc.)⁵ to the proliferation of special use vehicles (off-road, dune-buggies, All-Terrain-Vehicles, Recreational Vehicles, "monster trucks," "low riders").

Electric vehicle production is likely to fit into this process of market differentiation and perhaps will even accelerate it. Even in its early stages, when production is likely to be limited to manufacture of electric vans for public or commercial use (see Chapter Two), product differentiation will probably already begin to play a role. Although the platform (i.e., the motor-transmission-chassis sub-assembly) for these vehicles is likely to be limited to a few models, the different purpose of each fleet (mail delivery, refuse collection, passenger shuttles, local delivery of goods, etc.) will require different body characteristics. Thus, despite their structural standardization, electric vans are likely to be characterized by features and appearance tailored towards specific market niches. Furthermore, it is possible that in the long run the stabilization of electric vehicle technology, and the reduced number of components necessary for electric vehicle production (compared to internal combustion engine vehicles) will lead to upstream standardization (of components and sub-assemblies). However, it is equally probable that the very simplicity of electric vehicle assembly will also encourage downstream differentiation (of the finished product), to reach a variety of market niches and, in fact, to create some of its own (for example developing "stripped-down" cars for urban or neighborhood use, and vehicles for the handicapped).⁶

Electric vehicle production in Los Angeles can address both ends of this spectrum. At one end, as Chapters Three and Seven suggest, Los Angeles is in a particularly advantageous position to develop production of components for electric vehicles. At the other end, the presence of several car design centers and its long-standing tradition of car customizing and specialty production in the region (see Chapter Four) can be a starting point to tap into and develop ever-new market niches and opportunities for electric vehicle use.

Thus, the tendency of automobile demand towards market differentiation, the projected

⁵ The reduction of yearly sales of the best selling models is an example of this fragmentation: while through the 1960s sales of best selling car models were regularly above the 400,000 units, the sales of the two 1992 best sellers combined (Ford Taurus and Honda Accord) did not reach 250,000 units

⁶ See, for example, the "station cars" proposed by National Station Car Consortium (*Concept Status*, Oakland, CA: Bevilacqua-Knight Inc., 1993). These electric vehicles are foreseen to be available for lease or rent at transit stations for short trips, returning to the station after each trip (or at least daily)

availability of a large spectrum of electric vehicle components in the area, and the presence of skills and activities already geared to production for specialized niche-markets could trigger a "virtuous circle" of increasing electric vehicle production based on the expansion of the market as much as on the differentiation of demand.

8.2.2. Transportation Infrastructures and Services

The second opportunity for development begins from the fact that EVs are not self-contained products, but must be accompanied by a fixed support system that also depends on new technological and manufacturing development. In order for electric vehicles to become marketable beyond 'fleet' use, a capillary network of refueling stations must be put in place to offset its limited fuel-autonomy. One of the solutions under development is electrified roadways;⁷ a second solution depends on "opportunity-charge" stations for quick on-the-road refueling. Both systems are still in the experimental stage and several improvements are necessary for their diffusion (e.g., development of power conditioners and better materials for electrified roadways, reduction of charge time for the stations, energy storage plants for both, in order not to increase demand of electricity during peak periods). The presence of electric vehicle production in Southern California (with technologies and R&D similar to electricity delivery systems), the obvious interaction between the two industries, and the fact that California is likely to be the first market for both, would create a strong mutual advantage for the locational proximity of the two.

An additional consideration is that, partly as need and partly as opportunity, electric vehicles can be the triggering factor in developing traffic management systems that can be applied to other means of transportation. Studies are already under way suggesting systems for freeway automatic guidance (keeping the vehicle centered in the lane, automatic braking to keep distance between vehicles, etc.), interactive mapping (supplying drivers with on-line information on their position and traffic conditions), and intelligent traffic control (timing and coordinating traffic signals according to traffic flow, and giving priority to emergency and public transportation vehicles). In various degrees these systems require road modifications, vehicle re-design (to incorporate mechanism for automatic guidance, tracking systems, etc.), and the development of electronic communication networks (between vehicle and monitoring center, between computer and traffic signals, etc.).

By developing the electric vehicle industry, the Los Angeles area would enjoy a twofold competitive advantage for becoming a center of development and production of these Intelligent Vehicle Highway Systems. On the one hand, its strong electronic and mechanical industry would supply the base providing the sensors, computers, communications systems, and in-vehicle products (computer displays, steering-braking-acceleration aids, etc.) necessary for the Intelligent

⁷ A short section of powered roadway was built in 1985 by Caltrans in Sacramento. In 1986 PATH set up more test roadways. In 1988 the Playa Vista electrified roadway test began (in collaboration with Bechtel, General Motors, Southern California Edison, Westinghouse). The system is composed of 1) cables (or bus bars, or core elements) embedded in the road and excited with AC current by an external power source, thereby creating a magnetic field. In the PATH project the "bus bars" are made of an iron cores made of grain-oriented silicon iron laminations placed around aluminum cables, and 2) a magnetic inductive device mounted underneath the vehicle which extracts electrical energy from the magnetic field. (Nesbitt, Sperling, De Luchi, *An Initial Assessment of Roadway Powered EVs*, 1990)

Vehicle Highway Systems. On the other hand, the development of electric vehicles and the road modifications that they are likely to entail offer an excellent opportunity for testing and optimizing the integration between vehicle and infrastructures.

8.2.3. Other Transportation Equipment

Finally, the R&D, technologies and manufacturing capabilities required for electric vehicle production, for the development of recharging networks, and for new traffic management systems can overlap with the existing preconditions (and with new 'preconditions' that they would create) of the region to expand further the area of specialization. Thus, for example, further development of electric motors and controllers can lead to applications in propulsion systems for boats and ships. R&D in, and eventually production of, super-conductive magnets and transmission lines (for electric roadways), magnetic energy storage coils (for energy storage plants) can dovetail with similar research proceeding for the development of maglev trains.⁸

Similarly, intelligent traffic control systems can be applied to mass transit systems in several ways. In fact, electronic and computer technologies to monitor traffic and supply drivers with real-time information about road conditions can also be integrated into bus and light rail transit systems to coordinate schedules, avoid delays, reduce lag-time in switchyards, etc. In this case, Southern California would be in an advantageous position to initiate the development of a new generation of means of public transportation. Given the limited overall demand for buses and rail cars and their standardization, it is unlikely that Southern California could become a center for producing traditional bus or light rail cars in competition with established producers.⁹ However, the strength of the region in electronics, the possible development of advanced traffic management systems, and its specialization in electric vehicles, motors and technologies could be the starting point for the district's further expansion into production of communication and control equipment and components that can be integrated into new or refurbished vehicles.

Production of components for electric vehicles is not the only or the most important factor that could lead to the development of an advanced transportation equipment industrial district in the Los Angeles region. The \$183 billion that the Los Angeles Metropolitan Transportation Authority is projected to spend over the next thirty years for the improvement and expansion of the transportation infrastructure of the region, is a far more convincing argument for triggering such a development. The California Council on Science and Technology's *Project California* estimates that the core of such a district will be the production of components, systems, and road equipment for Intelligent Vehicle Highway Systems which

⁸ Maglev trains work on the principle of a magnetic field keeping the train suspended over (or below) a rail. Movement is obtained by continuous switching of polarity between the fixed and moving elements. Prototypes and testing facilities already exist in Japan and Germany. In the US several proposals are under consideration, including a the construction of a line between Anaheim and Las Vegas.

⁹ According to *Project California (Progress Summary, December 1992, p 3)* national demand for new buses is limited to about 3,000 units a year and the largest part of demand for rail cars is fulfilled by refurbishing and maintaining existing cars.

could generate, by the year 2002, about 60,000 jobs. By comparison, according to the same estimate, electric vehicle production will amount to only 7,000 jobs.¹⁰ The point emphasized here, however, is that manufacturing of electric vehicle components is not a self-contained sector, but the R&D, the technical and labor skills, and the specialized producers needed for its development largely overlap with those of the other industries that would make up the district. Thus, the 'early start' of Southern California in electric vehicle manufacturing can be *one* of the building blocks for the creation of the "industrial atmosphere" on which further expansion of the district can take place.

8.3. Conclusion

This report and other recent studies (such as The South Coast Air Quality Management District, see Chapter Seven, page 174) stress the opportunities of focusing electric vehicle production in Southern California on the manufacture of components, on the development of a system of spatially clustered production units specializing in specific phases of the production process, and collaboration among firms in the development of new technologies. This is also the direction in which the CALSTART consortium is moving. These suggestions derive from the characteristics of Los Angeles' industrial structure, from the flexibility that the new industry requires to accommodate the expected high rate of innovation, from the limited initial market, and from the difficulty of raising the large amounts of capital needed for the production of complete electric vehicles (from R&D to marketing and distribution).

The role that the electric vehicle industry could play in complementing the development of other high technology industries and ultimately in moving towards the creation of an advanced transportation equipment district adds one more element to consider in focusing on flexible production systems. In fact, the affinity of technologies, R&D and the technical and labor skill used in electric vehicle production and the other transportation industries mentioned above, suggests that electric vehicle parts development and production can be an advantageous starting point from which to branch out in these new directions. Electric vehicle production, therefore, should not be considered as an isolated possibility for the revitalization of Los Angeles industrial structure, but as part of a broader industrial strategy for the region. The creation of consortia and financial infrastructures for electric vehicle production is obviously a first and important step in establishing an electric vehicle industry. However, it is equally important to identify and support processes and technologies within the electric vehicle industry so that by overlapping with similar developments in other transportation sectors, they will stimulate growth and diversity in the advanced transportation equipment industrial district.

¹⁰ These estimates of job creation are limited to the phases of production whose potential for location in California is considered "strong" or "moderately strong." Employment in electric vehicle manufacturing, therefore, excludes final assembly that, according to Project California, has little chance to be located in the region (Project California, *Advanced Transportation Business Analyses*, Los Angeles Monitor Company, 1992)

These estimates are consistent with the conclusions of Chapter Four. The authors conclude that by the year 2003, the production of electric vehicle components will result in approximately 10,000 manufacturing jobs in Southern California

