EPA-460/3-74-020-b

OCTOBER 1974

IMPACT OF FUTURE USE OF ELECTRIC CARS IN THE LOS ANGELES REGION: VOLUME II - TASK REPORTS ON ELECTRIC CAR CHARACTERIZATION AND BASELINE PROJECTIONS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Alternative Automotive Power Systems Division
Ann Arbor, Michigan 48105

EPA-460/3-74-020-b

IMPACT OF FUTURE USE OF ELECTRIC CARS IN THE LOS ANGELES REGION: VOLUME II - TASK REPORTS ON ELECTRIC CAR CHARACTERIZATION AND BASELINE PROJECTIONS

Prepared by

W. F. Hamilton, J. C. Eisenhut,
G. M. Houser, and A. R. Sjovold

General Research Corporation
P. O. Box 3587
Santa Barbara, California 93105

Contract No. 68-01-2103

EPA Project Officer:

C. E. Pax

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Advanced Automotive Power Systems Development Division
Ann Arbor, Michigan 48105

October 1974

This report is issued by the Environmental Protection Agency to report technical data of interest to a limited number of readers. Copies are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations - as supplies permit - from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711; or, for a fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151.

This report was furnished to the U. S. Environmental Protection Agency by General Research Corporation in fulfillment of Contract No. 68-01-2103 and has been reviewed and approved for publication by the Environmental Protection Agency. Approval does not signify that the contents necessarily reflect the views and policies of the agency. The material presented in this report may be based on an extrapolation of the "State-of-the-art." Each assumption must be carefully analyzed by the reader to assure that it is acceptable for his purpose. Results and conclusions should be viewed correspondingly. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Publication No. EPA-460/3-74-020-b

INTRODUCTION

This report is published in three volumes:

Volume 1, Executive Summary and Technical Report

Volume 2, Task Reports on Electric Car Characteristics and Baseline Projections

Volume 3, Task Reports on Impact and Usage Analyses

Volume 1 is a comprehensive account of the effects that electric cars would have on the air quality, energy use, and economy of the Los Angeles region in 1980-2000. Volumes 2 and 3 contain ten individual reports documenting the analyses on which Volume 1 is based. These reports detail the methods, data, assumptions, calculations, and results of the study tasks, and were originally published at the conclusion of each task.

Task reports in Volume 2 project future characteristics of electric cars and of the Los Angeles region in which they would be used, as follows:

1. D. Friedman and J. Andon (Minicars, Inc.) and W. F. Hamilton, Characterization of Battery-Electric Cars for 1980-2000

   Postulates electric vehicle performance requirements, projects representative future battery characteristics, calculates urban driving range versus total car weight, and estimates energy and material requirements for selected driving ranges.

2. G. M. Houser, Population Projections for the Los Angeles Region, 1980-2000

   Projects population of California's South Coast Air Basin, which includes greater Los Angeles, by county and age group.

3. W. F. Hamilton and G. M. Houser, Transportation Projections for the Los Angeles Region, 1980-2000

Projects Los Angeles freeway and transit networks, auto population, auto usage, auto size and age distributions, and average fuel consumption.

4. J. Eisenhut, Economic Projections for the Los Angeles Region, 1980-2000

Projects employment and income for the South Coast Air Basin, and the payroll and employment of businesses involved in production, distribution, and maintenance of automobiles and parts.

5. A. R. Sjovold, Electric Energy Projections for the Los Angeles Region, 1980-2000

Summarizes the US energy situation as forecast in recent studies, and in this context projects electric energy production and consumption in the South Coast Air Basin, noting energy available for electric car recharging and its basic sources.

Task reports in Volume 3 project impacts due to various levels of electric car use and investigate possible future levels of use, as follows:

6. J. R. Martinez and R. A. Nordsieck, An Approach to the Analysis of the Air Quality Impact of Electric Vehicles

Selects the "DIFKIN" computer model and linear rollback as means for analyzing future air quality in the South Coast Air Basin, designates important cases for investigation, and details required methodology.

7. J. R. Martinez and R. A. Nordsieck, Air Quality Impacts of Electric Cars in Los Angeles

Forecasts stationary and vehicular pollutant emissions in spatial and temporal detail, with and without electric cars, and calculates consequent air quality levels relative to Federal standards.

8. A. R. Sjovold, Parametric Energy, Resource, and Noise Impacts of Electric Cars in Los Angeles

As a function of percentage electric car use, forecasts total energy consumption and petroleum consumption in the South Coast Air Basin through the year 2000; compares annual consumption and rolling inventory of key electric car materials with past and projected US production, consumption, and reserves; analyzes possible reductions of community noise from electric car use.

9. J. C. Eisenhut, J. A. Cattani, and F. J. Markovich, Parametric Economic Impacts of Electric Cars in Los Angeles

Projects life cycle costs of alternative electric cars in comparison with conventional cars; analyzes and projects changes in employment and payroll in industry segments impacted by electric cars, including service stations, battery manufacturing, auto parts and repairs, and auto sales; considers overall regional and national economic impacts of electric cars.

10. W. F. Hamilton, Usage of Electric Cars in the Los Angeles Region, 1980-2000

Analyzes 1967 data to determine distributions of daily driving range in Los Angeles and the applicability of limited-range electric cars; reviews market trends and estimates the potential free-market sales of electric cars in the South Coast Air Basin; hypothesizes particular levels of electric car use for impact evaluations; and considers relative economic incentives likely to be required to obtain these usages.

TASK REPORT 1

CHARACTERIZATION OF BATTERY-ELECTRIC CARS FOR 1980-2000

D. Friedman

J. Andon

(Minicars, Inc.)

W.F. Hamilton

ABSTRACT

Possible battery-electric cars for 1980-2000 are characterized in sufficient detail to support a comprehensive study of their potential impacts if used in the Los Angeles area. The characterization is based on assumptions that driving range should suffice for significant segments of travel at reasonable overall cost, that improved safety will be required, and that performance need only be sufficient to maintain traffic flow.

After a parametric analysis of weight versus range between recharges in urban driving, specific ranges are selected, and energy and materials requirements determined for two- and four-passenger cars using alternative batteries representative of possible future types. Although both cars are in the subcompact size category, the four-passenger car has freeway capability and adequate daily range with lead-acid batteries for second-car use, or with advanced batteries for more general use. The four-passenger car characteristics include:

Battery Type	Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur
Test Weight, pounds*	3,975	3,530	2,950	2,655
kilograms	1,803	1,602	1,338	1,204
Battery Weight, pounds	1,500	1,090	570	300
kilograms	681	495	259	136
Urban Driving Range, miles	54	144	145	146
kilometers	87	232	233	235
Range at 30 mph, miles	183	375	309	317
kilometers	295	604	497	510
Recharger Energy, KWH per mile	0.79	0.51	0.41	0.45
KWH per kilometer	0.40	0.32	0.25	0.28

*With 450-pound payload.

CONTENTS

CONTENTS (Cont.)

ILLUSTRATIONS

ILLUSTRATIONS (Cont.)

ILLUSTRATIONS (Concl.)

TABLES

1 INTRODUCTION

Work reported here is part of a larger study of the impacts of electric cars used for personal urban transportation. Impacts of principal concern include effects on the mobility of drivers, on air quality, on energy production and consumption, on resource use, and on the economy. The focus is on impacts in the Los Angeles region in the years 1980, 1990, and 2000.

The object of this report is to summarize electric car characteristics for use in the impact calculations of the overall study. In this limited context, car characteristics of major concern include daily driving range, acceleration and gradability, accommodations for passengers and luggage, safety, energy consumption, and required materials and components. Battery technology and car design thus need be pursued only to the extent required to establish these characteristics.

The basic approach taken here is to characterize electric cars parametrically as a function of range between recharges. Because energy storage capability of present and future battery systems is limited, daily range capability is critical in determining the applicability of the electric car to typical travel needs as well as its energy consumption, materials requirements, and costs. Other characteristics of electric cars were not given parametric treatment since an excessive number of cases would thus require analysis.

This report begins with a brief review, in Sec. 2, of the characteristics of existing gasoline cars and existing or proposed electric cars. With this background, performance requirements and parameters other than daily driving range are considered and selected in Sec. 3; these include accommodations, acceleration, weight, aerodynamics, driveline efficiency, tire losses, and safety provisions. Section 3 also presents basic formulas used in calculating power requirements. Next, in Sec. 4, driving cycles for calculating power requirements and driving range between recharges are defined. Battery technology is reviewed in Sec. 5, and promising types for vehicular use are described. Daily driving range is calculated in Sec. 6 for the different battery types as a function of vehicle weight. Particular daily ranges for further consideration in the impact study are selected in Sec. 7 after a brief review of typical driving patterns and the costs of battery depreciation. For these cases, finally, energy and materials requirements are estimated, in Sec. 8, for the battery systems and the electric vehicles.

Since the work reported here is intended only to provide an orderly basis for an overall study of electric car impacts, detailed design analyses, innovative approaches, or even a thorough review of the literature have not been attempted. The literature, in fact, is immense: one authority has noted that "...it is almost impossible to say anything on the subject which has not already been printed." References 1-3 will introduce the reader concerned with further detail to almost 2,000 electric vehicle papers, books, and articles.

Because it has been a subject of frequent concern, the competitive position of electric cars deserves special mention here. Previous investigations have often assumed, implicitly or otherwise, that electric cars must be competitive with conventional ICE* cars as to acceleration, or accommodations, or costs, or driving range. Here, however, no such assumptions are necessary or appropriate. The electric cars characterized here are intended to provide maximum net benefits to broad classes of users at given levels of battery technology. The prospective market penetration of such cars, and the particular circumstances under which they would actually find wide usage, are considered elsewhere in the overall impact study.

Finally, it should be noted that this study is limited to battery-powered electric automobiles. It does not consider other alternatives to conventional ICE cars, such as fuel-cell electrics, hybrid-electrics,

*Internal-combustion engine.

steam and gas turbine cars, or ICE cars drastically redesigned for minimum energy consumption and environmental impact.

2 VEHICLE PERFORMANCE

Vehicles currently in use vary widely in performance. Predominant vehicle parameters that determine performance (acceleration and top speed) are vehicle weight, power available, aerodynamic resistance, rolling (road) resistance, and drive ratio.

Aerodynamic resistance is not significant at speeds under 30 mph, so it is possible to obtain a preliminary indication of a vehicle's acceleration and hill-climbing performance from its weight-to-power ratio. Figure 2.1 shows curb weights and powers for a number of passenger cars, mostly four-door sedans with six- or eight-cylinder engines.[4] The lowest weight-to-power ratio shown, indicating high performance, is 6.8 kg/kW

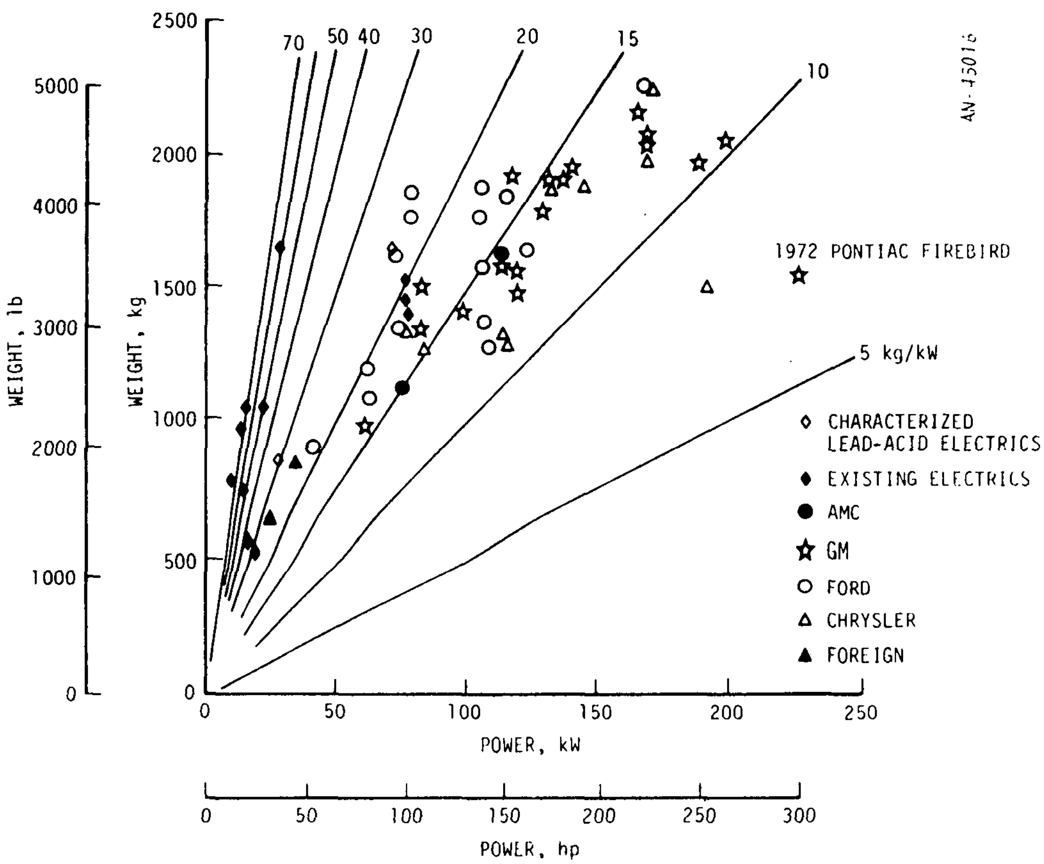


Figure 2.1. Weight-to-Power Ratios for Various Automobiles

(11.2 lb/hp) for the 1972 Pontiac Firebird, and the highest ratio for IC vehicles, indicating low performance, is 25 kg/kW (41 lb/hp) for the 1972 Hondas and VW beetles.

A selected list of electric cars proposed or built in the last 10 years is presented in Table 2.1 to show representative design goals and claims. Typical electric car weight and power parameters from Table 2.1 are plotted in Fig. 2.1 to compare their performance criteria. Most of the electric vehicles have weight-to-power between 20 and 70 kg/kW (49 to 115 lb/hp). Three electric vehicles (Cortina Estate Car, City Car Pinto, and GM Electrovair) are in the 18-to-20-kg/kW (30-to-33-lb/hp) range, which compares favorably with the majority of gasoline-powered automobiles. These higher performance electric cars suffer from limited range between battery charges and high cost for the battery power source. As Fig. 2.1 indicates, most of the electric cars, especially those with lead-acid batteries, are poor performers. The two lead-acid battery-electric cars characterized in this report are also shown. These performances are higher than for most of the other electric cars of Fig. 2.1, but still lie at the lower fringe of conventional car performance.

A comparison of the estimated practical maximum energy storage capability of gasoline with that of several different battery materials points to the main problem of electric vehicle power sources:

Gasoline	1,130 W·hr/lb
Lead-acid battery	20 W·hr/lb
Nickel-zinc battery	50 W·hr/lb
Lithium-sulfur battery	140 W·hr/lb

Gasoline has an advantage of eight times over the highest-energy-storage battery. Since energy storage is a direct indication of the distance an electric vehicle can travel between battery charges, it is evident that electric vehicle range between charges is the most important design parameter. Requiring enough battery energy to achieve a minimum acceptable range between charges usually means large battery packs and allocating a good portion of the vehicle weight to the batteries.

TABLE 2.1

ELECTRIC CARS OF THE LAST DECADE

	Vehicle Curb Weight, lb	Drive Motor(s)	Maximum Speed, mph	Energy Source and Capacity	Range, Miles
Comuta	1,200	Two 5 hp; Series DC	40	Lead-acid 48V (384 lb)	37 @ 25 mph
GM 512	1,250	8-1/2 hp; Series DC (54 lb)	40	Lead-acid 84V (329 lb)	47 @ 30 mph
Sundancer 2 ESB	1,600	---	---	Lead-acid 86V (750 lb)	70-75 on SAE Residential
Marquette Westinghouse	1,730	Two 4-1/2 hp DC (45 lb)	25	Lead-acid 72V (800 lb) 8 KWH	50
Henney Kilowatt Union Electric	2,135	7.1 hp; Series DC	40	Lead-acid (800 lb) 8 KWH	40
Yardney	1,600	7.1 hp; Series DC	55	Silver-zinc 12 KWH (240 lb)	77
Allectric West Penn Power Co.	2,160	7.1 hp; 72V DC	50	Lead-acid 72V (900 lb) 9 KWH	50
"Mini" GE	2,300	10.9 hp; DC Motor	55	Lead-acid and Nickel Cadmium	100 @ 40 mph
American Motors and Gulton Ind.	1,100	---	50	Lithium-Nickel Fluoride (150 lb) and Nickel Cadmium (100 lb)	150 with regeneration
ESB Renault	---	---	40	Lead-acid (72V)	25-35
Rowan Electric	1,300	2 DC Compound	40	Lead-acid	100
Allectric II West Penn Power Co.	2,300	7.1 hp; DC Motor	50	Lead-acid (900 lb)	50
Super-Electric Model A Carwood and Stelber Ind.	---	Two 2 hp	52	Lead-acid (520 lb)	---
Cortina Estate Car	3,086	40 hp; 100V (150 lb)	60	Nickel-Cadmium (900 lb)	39.9 @ 25 mph
Comet Ford	3,800	85 hp	70	Sodium-Sulfur (1086 lb)	---
City Car Pinto	3,200	40 hp	50	Lead-acid (956 lb)	39 @ 40 mph
Mars II Electric Fuel Propulsion, Inc.	3,640	15 hp; DC	60-65	Lead-acid 96V (1700 lb) 30 KWH	70-120
Electrovair GM	3,400	100 hp; AC induction	80	Silver-zinc 530V (680 lb) 19.5 KWH	40-80
Electrovan GM	7,100	125 hp; AC induction	70	Hydrogen-Oxygen Fuel Cell 180-270 KWH	100-150
Allis Chalmers Karmann-Ghia	3,440	---	---	Lead-acid 120V (1534 lb)	60 @ 60 mph
Chrysler-Simca	---	---	---	Lead-acid (1400 lb)	40
Electric Fuel Propulsion, Inc.	3,400	---	85	Lead-acid Cobalt	150-175
Falcon Linear-Alpha	---	25 hp; AC induction motor	60	Lithium-nickel Fluoride (360 lb)	75 @ 30 mph

Since energy storage is difficult and costly in electric cars, maximum overall efficiency is much more important than for conventional cars. All possible parameters that have to do with power consumption--aerodynamic drag, rolling friction losses, drive line efficiency, accessory power requirements, etc.--must be carefully considered in the design of electric vehicles.

3 ELECTRIC VEHICLE PERFORMANCE REQUIREMENTS

3.1 VEHICLE TYPES

Largely because of their inherent weight and cost, electric cars are ordinarily conceived as relatively small utilitarian vehicles. For this impact assessment it is desirable to characterize two rather different alternatives in this "small and utilitarian" category. The first presents the bare minimum in accommodations, performance, and daily range, with limited mobility adequate only for key trips. The second, a much larger vehicle, offers accommodations and performance approaching that of conventional subcompact cars, together with sufficient range to provide unimpaired mobility relative to typical daily driving patterns. The first vehicle characterized here is capable of supporting key public needs on roads and streets constituting feeder and collector-distributor routes, largely used for home-to-work and family business trips. Of course, some of these trips currently involve freeway travel but 68 percent of all trips, as indicated on the next page, are short enough so that a lack of freeway capability may not incur an unreasonable time penalty.

Table 3.1, from Ref. 5, shows that for many trips the seating capacity need not exceed two, supporting the assumption that basic daily travel may be equivalent to a to-and-from-work trip and a business-related-to-work trip totaling 25 to 30 miles per day (10,000 miles per year). It is estimated that the average speed for work trips (during peak hours) is less than 25 mph, with peak speeds of 30 to 40 mph for non-arterial and non-freeway usage. (The premise here is that the average person attempts to find employment within a half-hour drive one-way--for a 10-mile trip, the average velocity is thus 20 mph.)

The second vehicle characterized must satisfy the public needs for use of arterial roads and freeways for most work, family, social, and recreational trips--other than vacations. As such, its range must be greater and it must provide for an occupancy of three to four. Accordingly

TABLE 3.1

PASSENGER CAR USE[5]

Purpose of Travel	Percentage Distribution: Trips	Percentage Distribution: Travel	Average Trip Length One-Way (Miles)	Average Occupants Per Car
Earning a Living:				
To and From Work	32.3%	34.1%	9.4	1.4
Business Related to Work	4.4	8.0	16.0	1.6
Total	36.7	42.1	10.2	1.4
Family Business:				
Medical and Dental	1.8	1.6	8.3	2.1
Shopping	15.4	7.6	4.4	2.0
Other	14.2	10.4	6.5	1.9
Total	31.4	19.6	5.5	2.0
Educational, Civic or Religious	9.4	5.0	4.7	2.5
Social and Recreational:				
Vacations	0.1	2.5	165.1	3.3
Visit Friends or Relatives	9.0	12.2	12.0	2.3
Pleasure Rides	1.4	3.1	19.6	2.7
Other	12.0	15.5	11.4	2.6
Total	22.5	33.3	13.1	2.5
All Purposes	100.0%	100.0%	8.9	1.9

it must operate at speeds of the order of at least 50 mph; in order to retain some performance margin it should be able to achieve a top speed of 65 mph.

Figure 3.1 illustrates traffic flow (per lane) through an intersection for various green light ("go") times as a function of acceleration capability in miles per hour per second. As shown, the number of vehicles through an intersection does not increase appreciably above 3 mph/sec of acceleration for longer "go" times. This acceleration level allows 1,050 vehicles to pass through an intersection each hour for 30-second "go" times. Although this acceleration is significantly less than the performance Americans currently consider acceptable, it is comparable to the performance they normally achieve at traffic signals. The authors have assumed that in the postulated environment of 1985 it would be tolerable to the driver and would not significantly reduce accident avoidance capability. For comparison, the VW Beetle accelerates at an average of

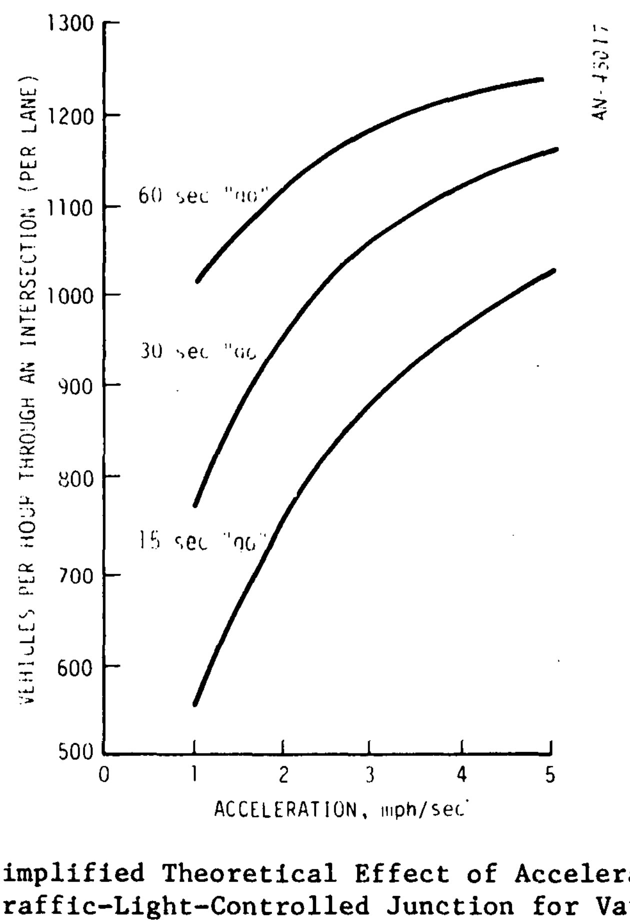


Figure 3.1. Simplified Theoretical Effect of Acceleration at a Traffic-Light-Controlled Junction for Varying Green Light ("go") Times

5 mph/sec to 30 mph, while the Pinto and the Vega can achieve an average of 6 mph/sec to 30 mph. A figure of 3 mph/sec corresponds roughly to the performance of the '54 VW with its 30-hp engine. The point is that urban traffic flow would not be seriously compromised by such a performance capability, so it was chosen for the two-passenger urban vehicle.

For the four-passenger car, the ability to merge with fast-moving freeway traffic requires somewhat higher acceleration capability. Accordingly, an acceleration capability averaging 4 mph to 40 mph was selected, with nearly 5 mph/sec to 30 mph. This, as noted above, is close to the performance of the VW Beetle, though somewhat less than that of domestic subcompacts.

The acceleration requirements for these two vehicles are shown in Fig. 3.2. The 3-mph/sec average (0 to 30 mph) acceleration for the urban car indicates that 30 mph is reached at the end of 10 seconds; the 4-mph/sec average (0 to 40 mph) acceleration for the four-passenger vehicle indicates 30 mph is reached in six seconds, and 40 mph is reached at the end of 10 seconds.

3.2 POWER

Power requirements to achieve the performance of Fig. 3.2 depend on several related factors: total vehicle weight, aerodynamic drag, tire losses, and drive-line efficiencies. Total vehicle weight is primarily dependent on battery weight, which, in turn, is determined by battery performance and by design range between recharges.

Design range between recharges is treated parametrically in Sec. 6; here we offer examples of power requirements for specific cars, and describe the methods for calculating the various factors noted above which influence power requirements.

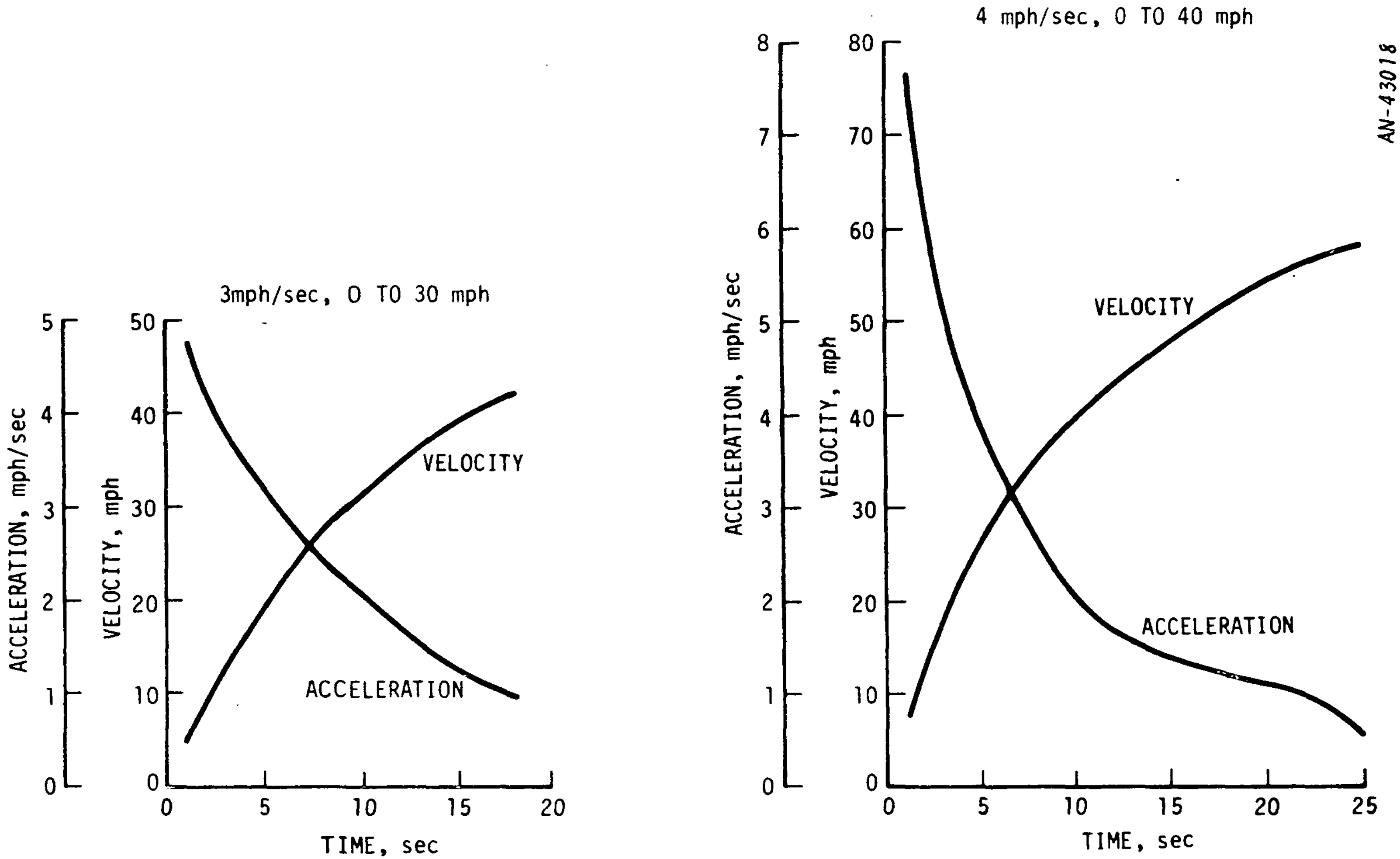


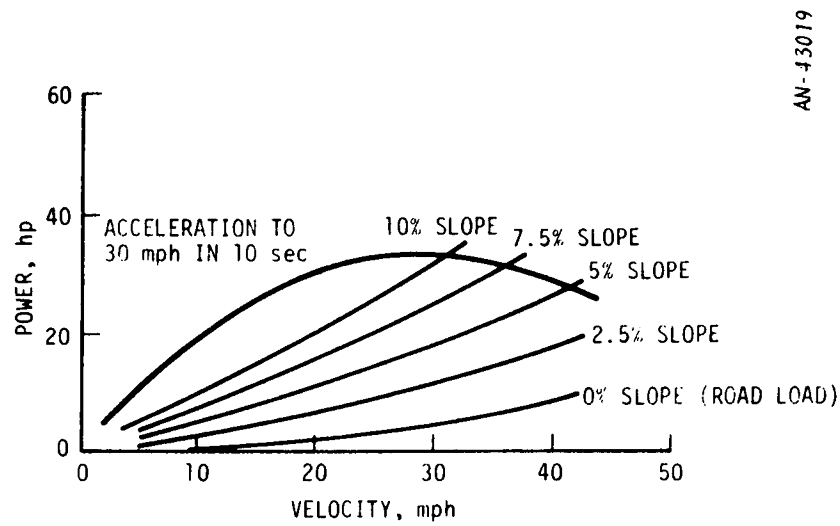
Figure 3.2. Performance Curves for Vehicles with 3- and 4-mph/sec Average Acceleration

The highest power requirements are for cars powered by lead-acid battery; even for very long design ranges cars powered by other battery types are lighter. The battery output power requirements of two- and four-passenger lead-acid battery cars are shown as examples in Fig. 3.3. Their characteristics, as developed in subsequent sections of this paper, are summarized as follows:

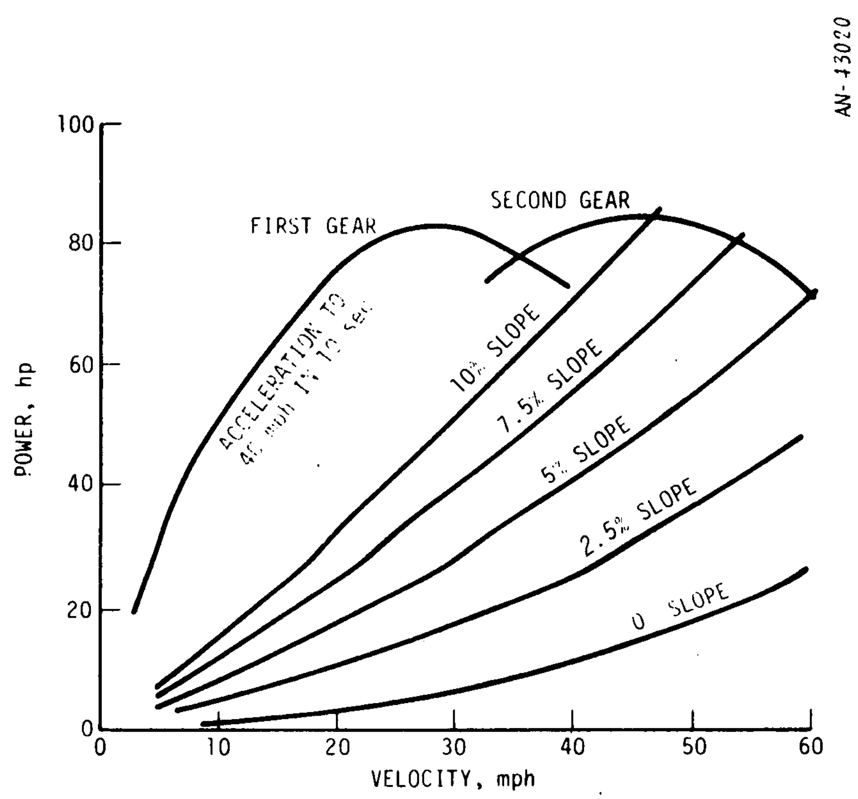
	Two-Passenger Car	Four-Passenger Car
Test Weight	2,100 lb	3,975 lb
Aerodynamic Drag Coefficient	0.4	0.4
Frontal Area	18 ft^2	22 ft^2
Mechanical Efficiency	90%	90%
Electrical Efficiency	70%	80%
Tire Profile	Low Aspect Ratio	Low Aspect Ratio
Maximum Power	33 hp	85 hp

3.3 WEIGHT

Safety considerations strongly affect the electric car characteristics, as does the weight of the required power source. The structure is reinforced by an amount dependent on the weight of the power source. Using these main vehicle criteria, the two-passenger vehicle may be conceptualized as a somewhat wider and longer Honda 600, and the four-passenger vehicle as a 1972 Pinto modified with lighter bumpers, seats and other features to reduce weight without loss of crashworthiness. These vehicles have curb weights of 1,350 and 2,100 pounds, respectively. Removing their engines decreases their curb weight to 1,070 and 1,530 pounds. Using these last two weights as the basis for our conceptual battery-electric versions, the test weight of these two cars breaks down as follows:



(a) Two-Passenger Car



(b) Four-Passenger Car

Figure 3.3. Power Requirements for Acceleration and Hill-Climbing

	Two-Passenger Car (35-mi range)	Four-Passenger Car (55-mi range)
Weight Without Power	1,100 lb	1,625 lb
Battery	550 lb	1,500 lb
Payload	300 lb	450 lb
Motor	117 lb	315 lb
Controller	33 lb	85 lb
Curb Weight	1,800 lb	3,525 lb
Total Test Weight	2,100 lb	3,975 lb

The weight without power is the basic vehicle weight without engine, plus an allowance for additional structure to support the batteries. This allowance was taken as 10 percent of battery weight in excess of the original engine system weight (30 pounds for the two-passenger car and 95 pounds for the 4-passenger car above). Recent developments have not altered the performance which was anticipated in 1968 from the electric power-train components for the near term (1980).[6] DC electric motors are anticipated to weigh 3.5 to 4 pounds per (peak) horsepower; controls weigh between 0.7 and 1.3 pounds per horsepower. Although, for peak performance capability, lead-acid batteries might weigh 8 to 10 pounds per horsepower (a power density of 75 to 100 W/lb), the relationship between power and energy density[7] suggests a minimum battery weight of about 15 pounds per peak horsepower (a power density of 50 W/lb).

That the battery weights selected for these cars are heavier than those required for original minimum performance goals* is due to energy considerations rather than power requirements. Whereas power available determines vehicle acceleration, energy determines vehicle range between charges. (Energy requirements are discussed in Sec. 8.1.)

3.4 AERODYNAMIC DRAG

The aerodynamic drag of vehicles is calculated from the following expression:

*As given by Fig. 3.2.

$$D = 0.00119 C_D A V^2$$

where C_D = drag coefficient

A = frontal area of the vehicle, ft^2

V = velocity, ft/sec

The drag coefficient for the assumed vehicles was considered to be 0.4, which is midway between the lowest and highest drag coefficients of today's automobiles (0.3 and 0.5).[8-10]

The two-passenger car was estimated to have an average body width of 4-1/2 feet and a body height of 4 feet, resulting in a frontal area of 18 square feet. The four-passenger car was estimated to have an average body width of 5-1/4 feet and a body height of 4-1/4 feet, resulting in a frontal area of 22 square feet. The four-passenger car is wider than the two-passenger car because of its greater side crush requirements.

3.5 DRIVE LINE EFFICIENCIES

Efficiencies for the drive-line are identified in Fig. 3.4. A mechanical efficiency (which includes transmission, final drive gears, and differentials) of 90 percent is widely accepted in present vehicle design. Electrical efficiencies (motor and controls) of 70 and 80 percent (Fig. 3.3) may be optimistic by today's practice, but should be attainable by the 1980s. These figures do not include battery or charger. The heavier four-passenger car has a two-speed automatic transmission. By increasing motor speed and efficiency at low driving speeds, this transmission accounts for its higher electrical efficiency of 80 percent.

3.6 TIRES

The rolling friction of tires should be held to a low value, since it substantially affects the power needed to propel the car, particularly at the low speeds characteristic of the vehicles described here. Recent tire developments have greatly reduced tire-connected losses. The table following lists power losses for several tire designs and compares their effects on driving characteristics with a standard-design tire.

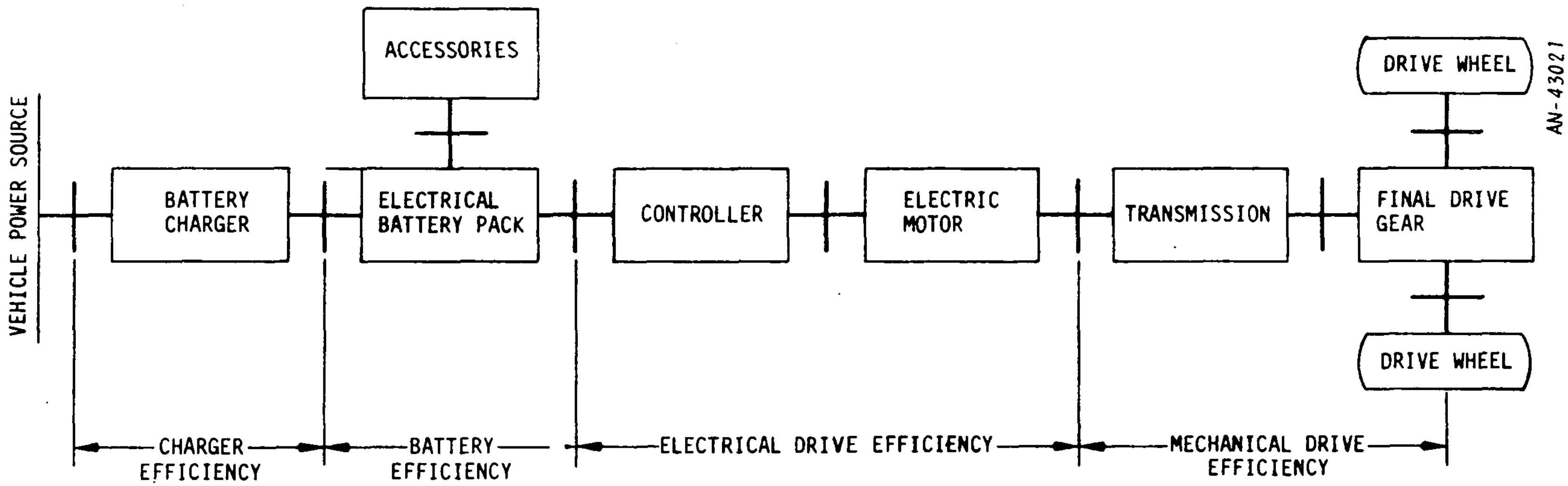


Figure 3.4. Electric Car Drive Train Functional Organization

TIRE PERFORMANCE AND HORSEPOWER LOSS AT 50 MPH[11]

SOURCE: Goodyear Tire and Rubber Company

Design Rating	Ride	Wear	Stability	Traction	Total hp Loss 2500-Pound Vehicle
Standard 6.70-13 (bias ply)	100	100	100	100	6.0
Belted Radial	80	175	95	105	4.8
Special Compounding	80	140	95	90	3.8
Gauge Reduction	80	130	90	90	3.6
Reduced Deflection	75	140	95	90	2.8
Low Aspect Ratio	65	150	100	95	2.5

As is evident, the low aspect ratio tire would be the desired choice for electric car tires. While ride will suffer, the limited energy of an electric vehicle is the overriding consideration.

The rolling resistance of a car is determined by the following expression:[12]

$$R = (W/50)(1 + 0.0014V + 0.000012V^2)$$

where R = rolling resistance, lb
W = vehicle weight, lb
V = vehicle velocity, ft/sec

Ninety percent of this resistance can be attributed to the tire. The remaining losses are due to bearing and seal friction. Therefore, when tire resistance is lowered, the above road resistance expression can be reduced by that part of the amount shown in the above table. For instance, the low aspect ratio tire vehicle could be considered as having a rolling resistance of [(2.5/6.0)/90% =] 46 percent of the standard bias ply tire resistance.

3.7 COMFORT AND CONVENIENCE

Vehicle interior dimensions on today's automobiles are primarily dictated by marketing considerations, not weight. Therefore, the vehicles postulated in this report could be two-door coupes with easy entrance and egress, and with leg room, head room and seating width comparable to current full-size vehicles. The occupant would sit further aft in the vehicle relative to the base vehicle's current seating configuration to allow for maximum structural and interior stroke during impact.

Passenger compartment heating can require considerable power in cold climates: up to 70 percent of propulsion energy.[13] In the mild weather of Los Angeles, however, sufficient heating for passenger comfort should be derivable from power losses in the electric motor and controller.

In Los Angeles, there are no days with a minimum temperature below freezing in the average year. The average daily minimum temperature in the coldest month of the year, January, is 45°.[14] Average annual heating load is 1,451 degree-days, less than one-third that of such large cities as St. Louis and Philadelphia.[15]

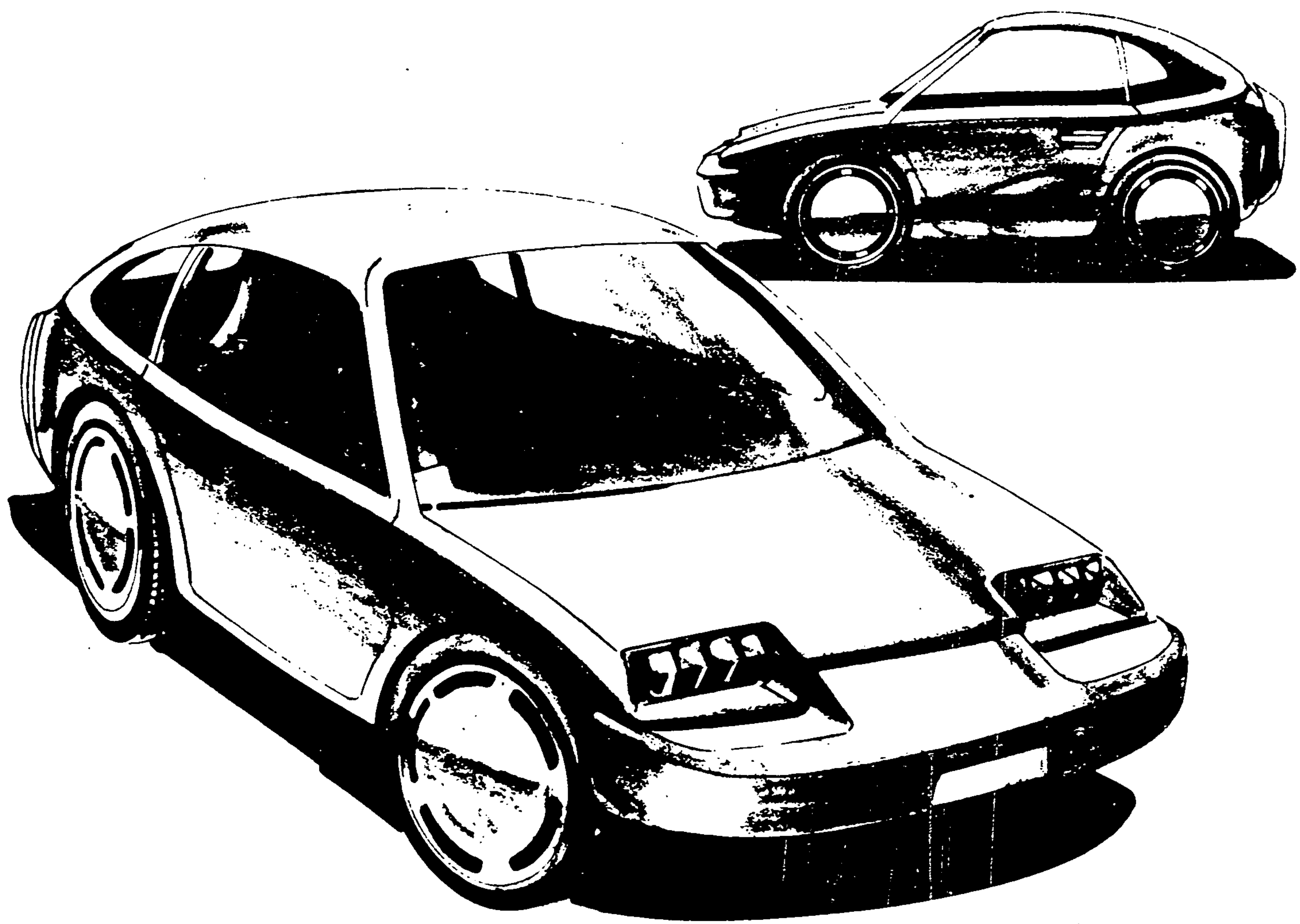
As will be shown in Sec. 8, battery output of the four-passenger car ranges from 0.27 to 0.35 KWH/mi in urban driving. At 80 percent efficiency, motor and controller heat rejection is 0.054 to 0.07 KWH/mi, and, at the average driving cycle speed of 24 mph, 1.3 to 1.7 kW of heat are thus available (4,400-5,700 Btu/hr). This is over twice the heat similarly available in the GM 512 electric car (0.66 kW, or 2,260 Btu/hr, at 30 mph on a 40° day).[13] Since the GM 512's heating was deemed adequate for passenger comfort on 40°-50° overcast days, the four-passenger cars characterized here should achieve equal adequacy in Los Angeles in January.

A preheater operated from the power lines during recharging just before car use might be desirable. In the GM 512, 1.2 KWH of preheating was required on 15°-20° days. For the larger cars characterized here for warmer climates, no more energy for preheating should be required (1.2 KWH is less than 10 percent of recharge energy required for propulsion purposes in typical daily driving).

Air conditioning was not included in cars characterized here. In 1973, only 30.4 percent of US subcompacts sold were equipped with air conditioners;[16] it thus seems likely that only a small minority of motorists would opt for air conditioners in electric cars, where it could substantially reduce driving range due to its considerable power requirement. Near the coast in the Los Angeles Basin, air conditioning is almost unnecessary. Inland, however, annual air conditioning loads for buildings are about half those of such cities as St. Louis, and about equal to loads in cities like Philadelphia.[17] Cooling actually required for a four-passenger subcompact is about 2.6 kW, which can be provided by a high-efficiency electric air conditioner requiring 1.3 kW of input power.[18] This input power is 15 to 20 percent of propulsion power required by the four-passenger cars in urban driving, as shown in Sec. 8. Continuous use of an air conditioner would thus decrease driving range by 25 percent or more, since battery efficiency declines as its load is increased.

3.8 VEHICLE SPACE DESIGN

Electric vehicle space configurations comparable with the cars characterized in this report are shown in Figs. 3.5 through 3.9. Figure 3.6 suggests a possible spatial arrangement for the two-passenger vehicle powered by lead-acid batteries. Spaces for the passenger, batteries, electric drive train, and crushable structure are shown. Figure 3.8 suggests a configuration for the lead-acid battery-powered four-passenger car. The lead-acid batteries are considered crushable material and are located accordingly. Figure 3.9 shows the lithium-sulfur-battery-powered four-passenger car. Since these batteries must not be crushed they are



AN-43056

Figure 3.5. Possible Two-Passenger Vehicle Configuration

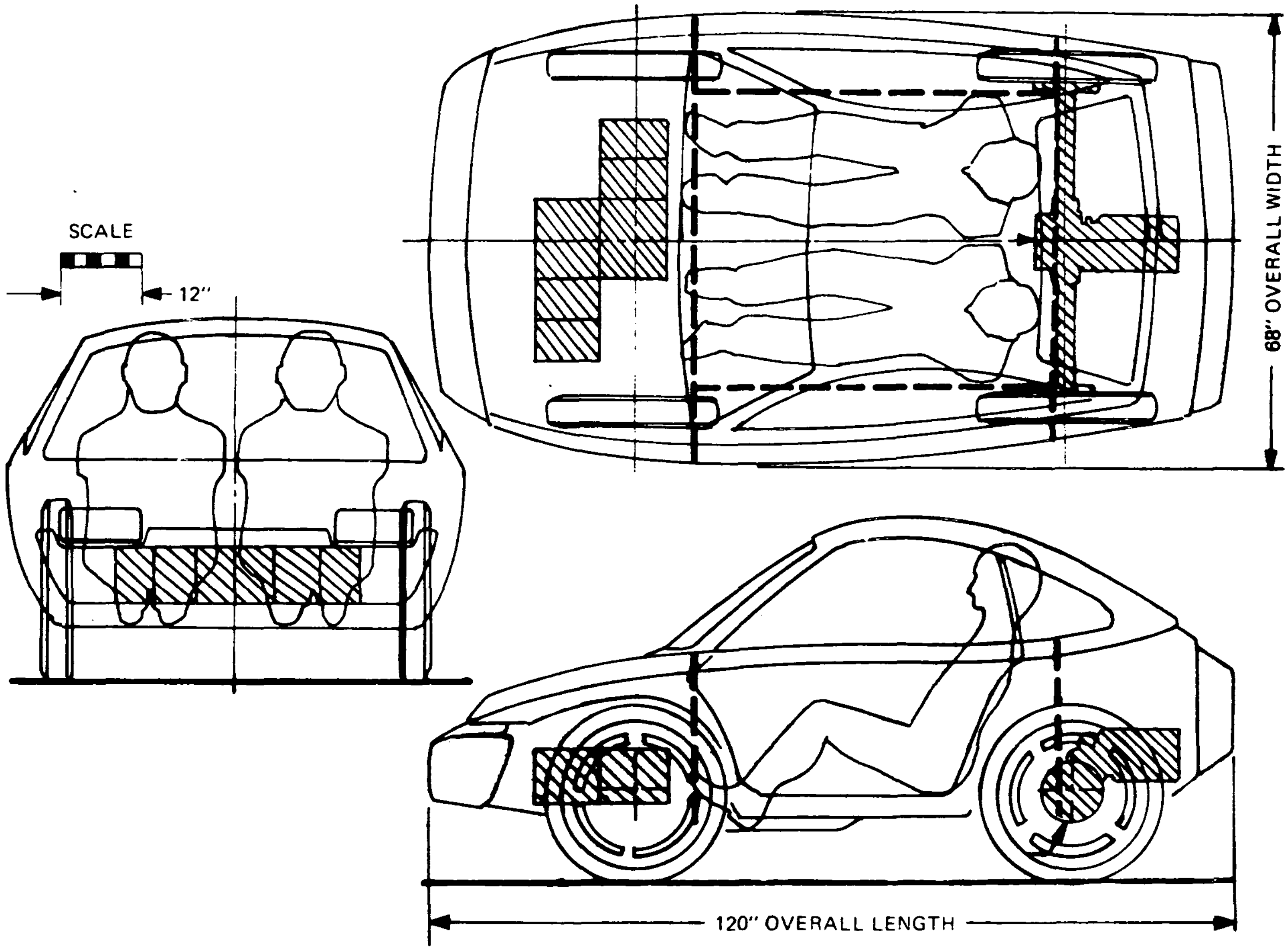
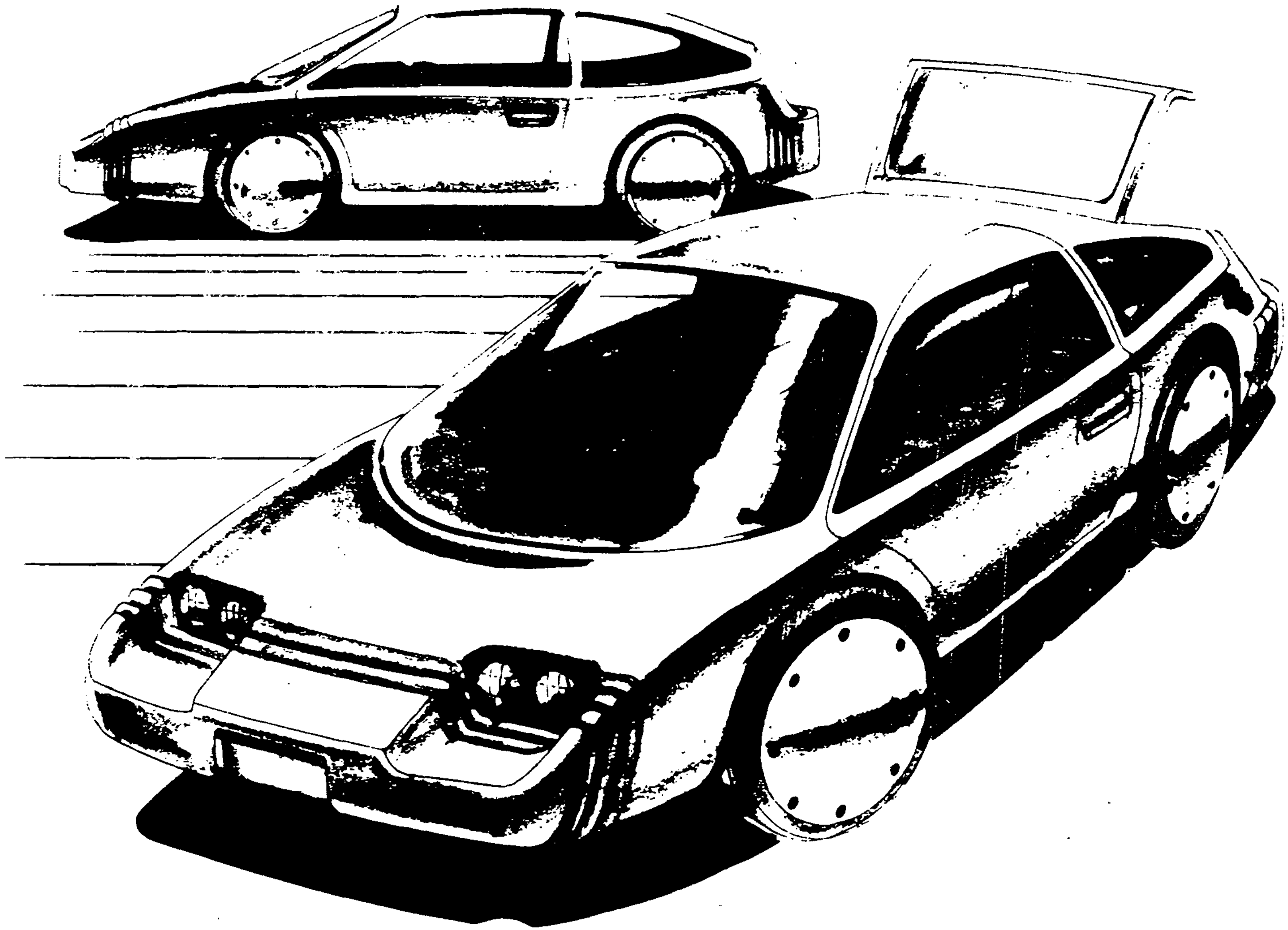


Figure 3.6. Possible Spatial Arrangement of the Two-Passenger Electric Vehicle Powered by Lead-Acid Batteries



AN 43055

Figure 3.7. Possible Four-Passenger Vehicle Configuration

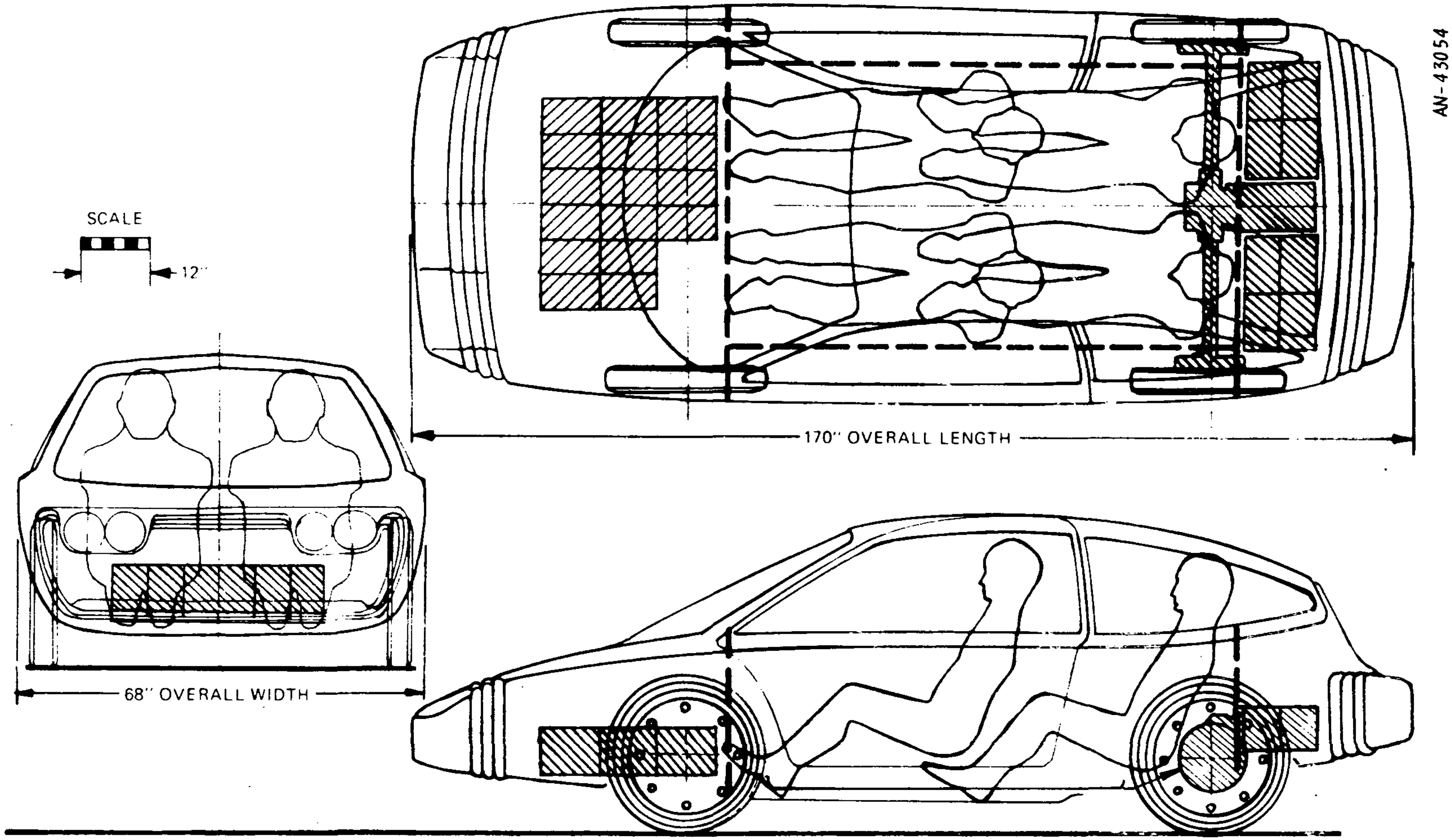


Figure 3.8. Possible Spatial Arrangement of the Four-Passenger Electric Vehicle Powered by Lead-Acid Batteries

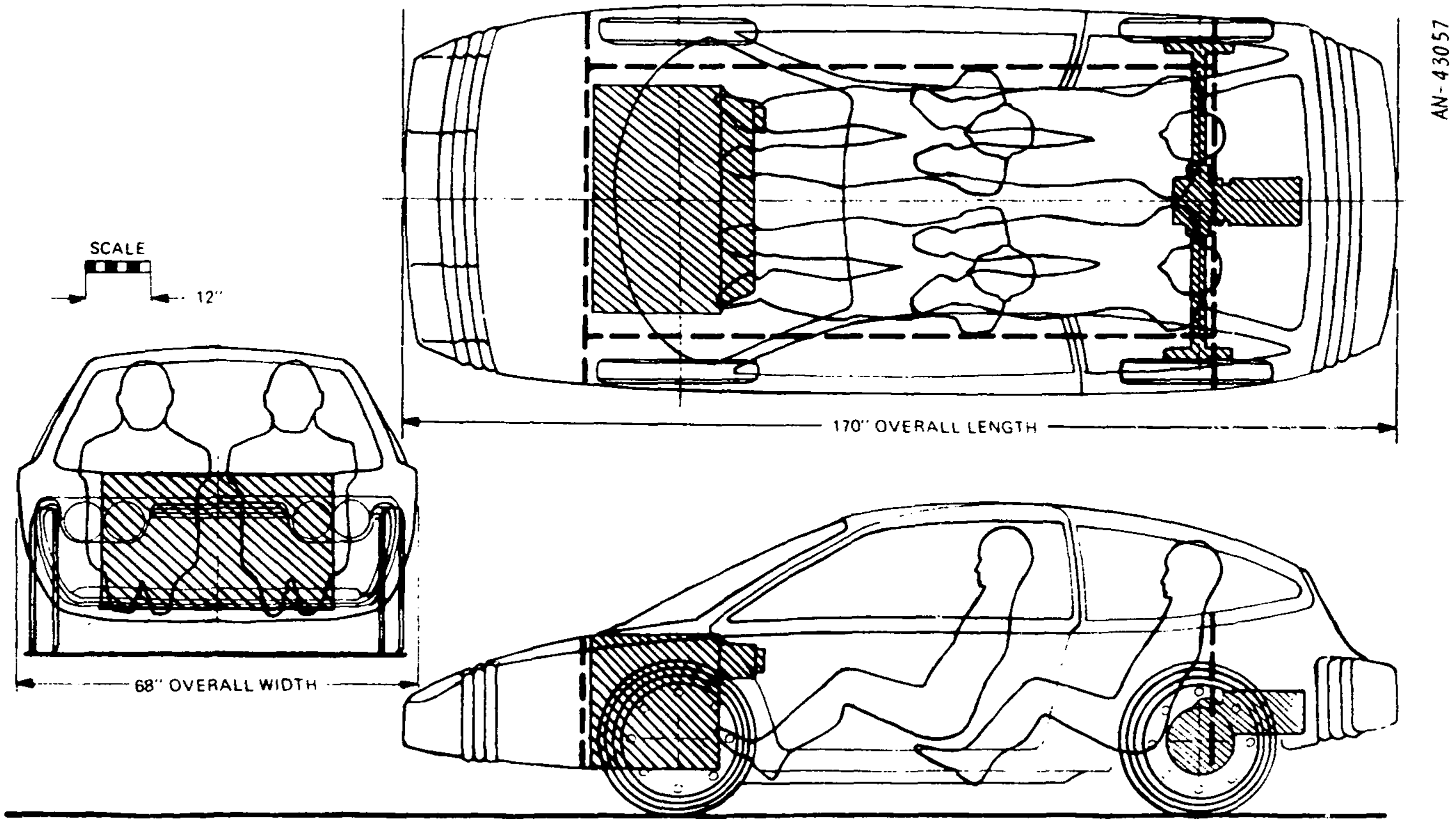


Figure 3.9. Possible Spatial Arrangement of the Four-Passenger Electric Vehicle Powered by Lithium-Sulfur Batteries

not located in the crushable part of the vehicle, thus restricting stroking during an accident.

3.9 SAFETY

Other studies[20,21] show that safety considerations strongly influence vehicle design, particularly in mixed traffic circumstances involving substantial percentages of unequal-mass vehicles. Lighter vehicles are at a substantial disadvantage in any collision. It has been projected that if the driving habits, and street, road, and highway patterns do not change (and these usually have a very long time constant for change), severe casualties would dramatically rise to 2-1/2 times the current rate as the percentage of small cars in the population increases, in spite of current and proposed Federal Motor Vehicle Safety Standards.

This increase is due primarily to unequal-mass impacts, and the statistical frequency with which such unequal-mass collisions occur. As the small car percentage of the population increases beyond 50 percent, the situation is alleviated. However, the trends indicate that the situation is likely to be at its worst between the 1980 and 1990 timeframe.

More and more, safety considerations dictate the physical characteristics of vehicles. In particular, the structural crush and the deceleration distance of the occupant within the compartment (against the restraining force of seat belts, air bags, etc.) must, in sum, constitute a distance sufficient to allow the occupant to be decelerated from the impact velocity within acceptable injury criteria.[22]

The estimated usage of automobiles is approximately one hour per day at an average speed of 25 mph. High-energy-density, high-temperature batteries cannot be turned off and allowed to reach room temperature. As a result of these and other design considerations, all high-temperature cells are generally stacked and/or assembled in a single cube-like configuration. This allows for good thermal and electrical connections between cells and for efficient insulation procedures to maintain battery temperature at low energy cost during non-operating storage intervals.

Having the battery all in one large box runs counter to current design trends dictated by safety requirements. Two different kinds of safety considerations are important here: one is occupant safety in impact, and the other is occupant safety due to the secondary effects of impact.

In order to provide enough crush stroke at the front of a small car in high-speed impacts, it is necessary to design the car so that its internal combustion engine is driven underneath or between the front seat occupants. Because an ICE engine is a very rigid block of aluminum or iron, this function is simple compared to doing the same thing with a high-temperature-battery case. Doing so either imposes rather severe weight penalties on the case in order to provide the necessary integrity, or requires the safe containment of the hot cells and any other potentially damaging battery constituents (corrosive fluids, etc.).

A review of the possibilities indicates that on a cost-effectiveness basis there would be a preference for protecting the high-temperature battery so as to maintain its integrity during and subsequent to impact. Such modifications are not always consistent with current vehicle configurations. As a result, it appears that a new vehicle configuration may be desirable to optimize the safety aspects of high-temperature-battery-powered vehicles. For 1985 car configurations currently under study for safety, this suggests locating the battery under the front seat occupants and raising the height of the vehicle accordingly. This may allow some shortening of the length of the vehicle but forces no other unacceptable or inconsistent modifications of the vehicle. Figure 3.9 shows an alternative arrangement, in which required crush space is placed ahead of the battery, which in turn is ahead of the passenger.

4 DRIVING CYCLES FOR DETERMINING VEHICLE RANGE

The driving cycles used to determine the range of electric vehicles have been evolved through the years by the SAE, beginning with (1) simple constant-speed velocity runs, (2) constant speed with one or several vehicle accelerations per specified distance, and finally, (3) prescribed velocity-time cycles combining given accelerations and constant-speed segments. At the present time two commonly used driving cycles are the Residential and Metropolitan Area Driving Cycles listed in the SAE Handbook (J-227).[23] These driving cycles are described in Fig. 4.1 and Table 4.1. The Residential Driving Cycle has a maximum speed of 30 mph, and the distance per cycle traveled is 0.858 miles. The Metropolitan Area Driving Cycle has a maximum speed of 45 mph, and distance traveled per cycle is 0.996 miles. The Federal Driving Cycle developed for exhaust emission measurements was derived from measured driving data in the Los Angeles area.[24-26] The Federal Driving Cycle is shown in Fig. 4.2.

The Federal and SAE Metropolitan Area Driving Cycles were compared and found to have approximately the same energy expenditure per mile. Figure 4.3 shows a comparison of range calculations for these two driving cycles using the same electric car. Since calculated range was nearly the same for each cycle, either driving cycle may be used for these calculations. Because of shorter computer time, the SAE Metropolitan Area Driving Cycle was used for the four-passenger car to simulate average driving in the Los Angeles area. For the two-passenger car, which is not intended for high-speed highway and freeway driving, the lower speed SAE Residential Driving Cycle was used.

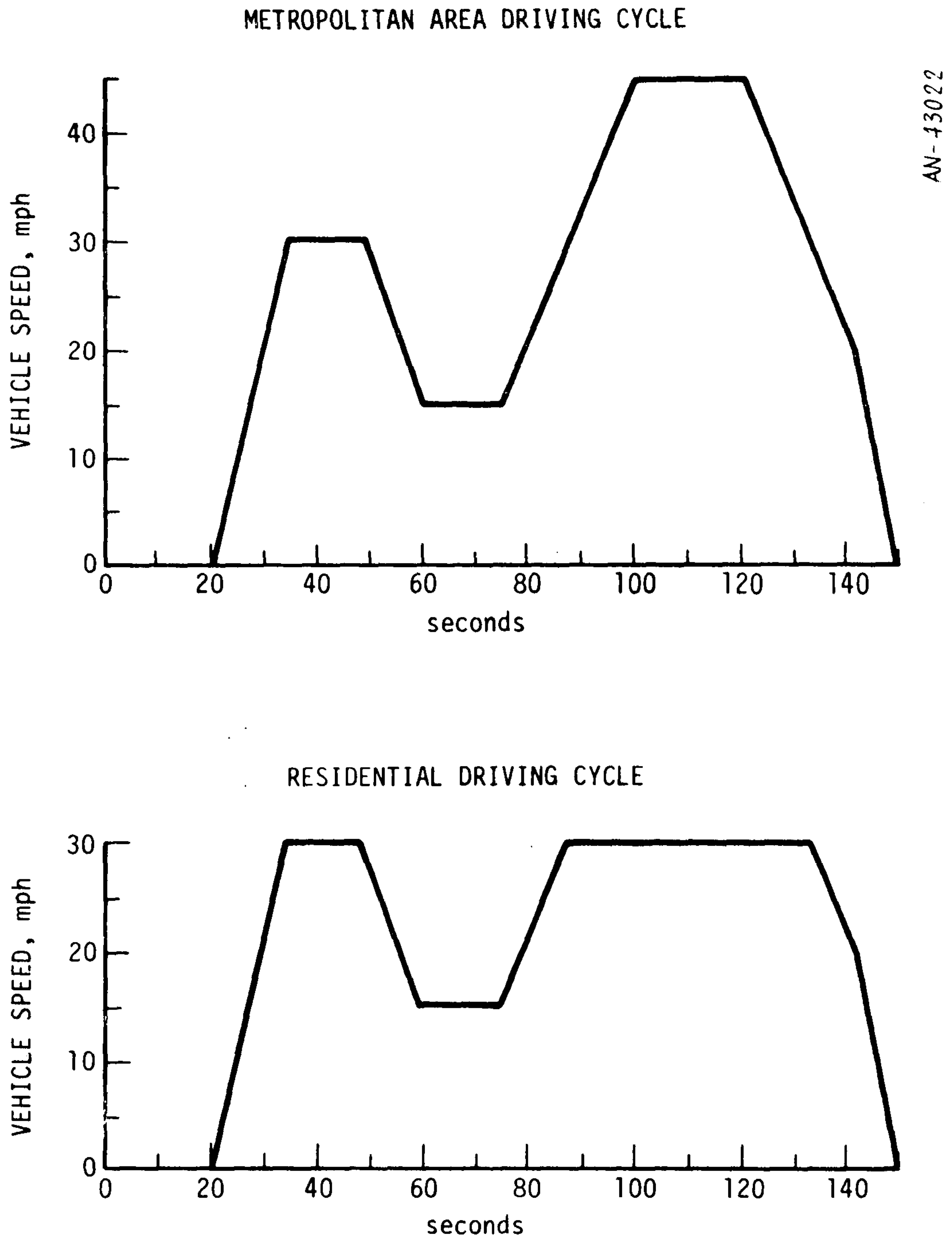


Figure 4.1. Electric Vehicle Driving Cycles

TABLE 4.1

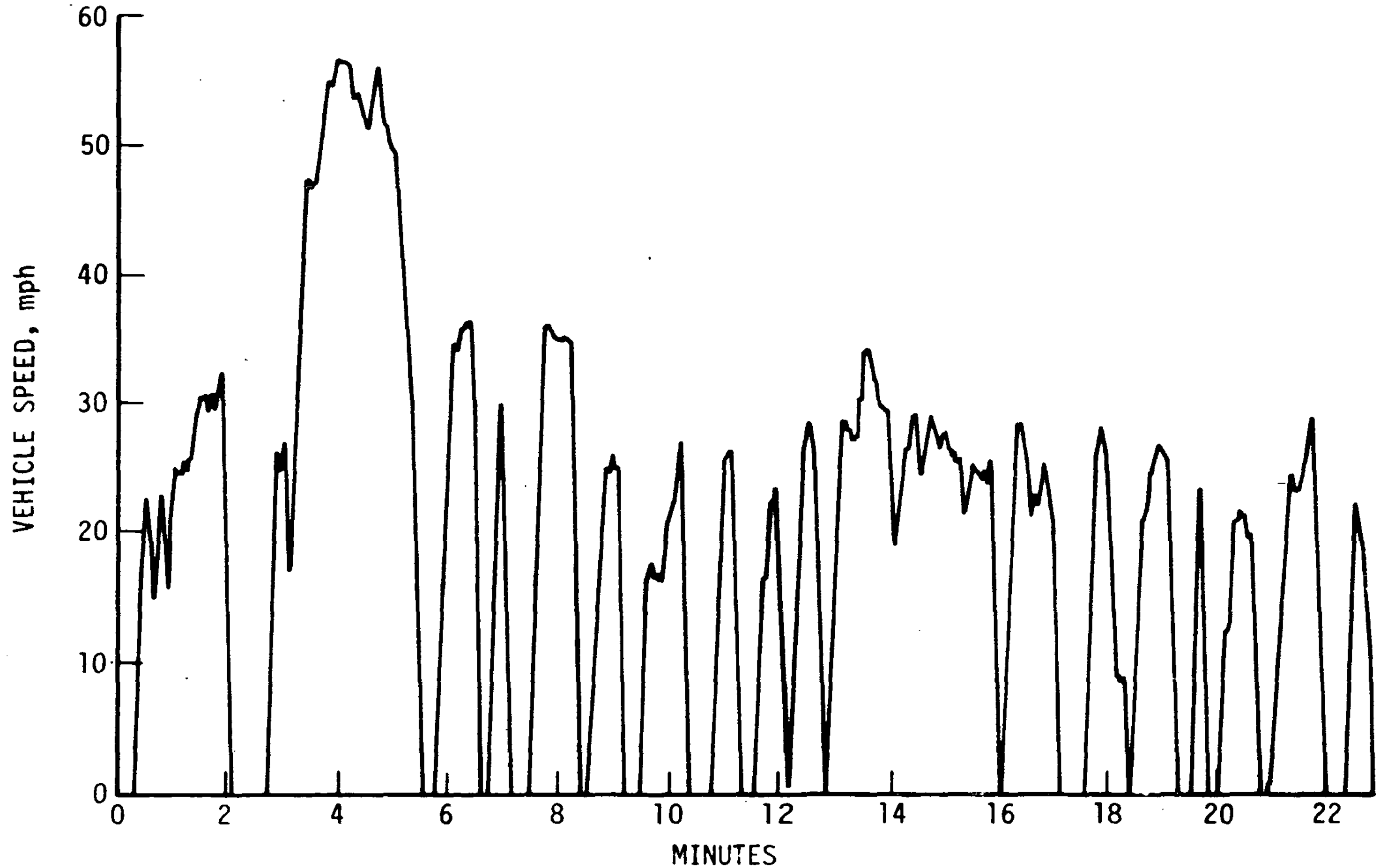
ELECTRIC VEHICLE DRIVING CYCLES

Test Schedule for Residential Driving Cycle

Mode	Average Acceleration, mph/sec	Time, sec	Cumulative Time, sec
Idle	0	20	20
0-30 mph	2.14	14	34
30 mph constant	0	15	49
30-15 mph	-1.37	11	60
15 mph constant	0	15	75
15-30 mph	1.20	12.5	87.5
30 mph constant	0	46.5	134
30-20 mph	-1.20	8	142
20-0 mph	-2.50	8	150
Repeat Cycle			

Test Schedule for Metropolitan Area Driving Cycle

Mode	Average Acceleration, mph/sec	Time, sec	Cumulative Time, sec
Idle	0	20	20
0-30 mph	2.14	14	34
30 mph constant	0	15	49
30-15 mph	-1.37	11	60
15 mph constant	0	15	75
15-45 mph	1.20	25	100
45 mph constant	0	21	121
45-20 mph	-1.19	21	142
20-0 mph	-2.50	8	150
Repeat Cycle			



AN-43023

Figure 4.2. Vehicle Speed Over the Federal Driving Cycle

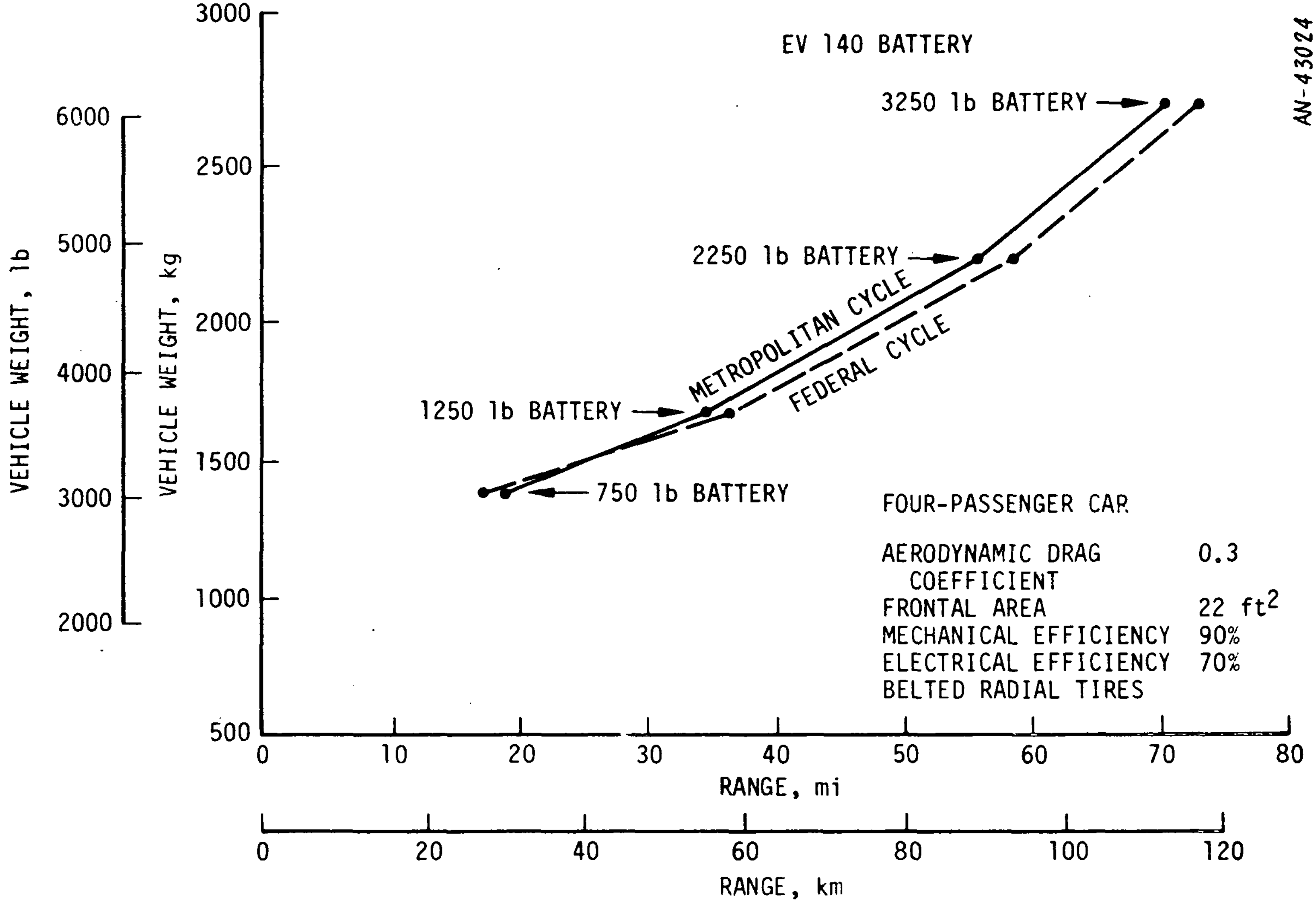


Figure 4.3. Range Calculation Comparison of the Metropolitan Area Driving Cycle and the Federal Driving Cycle

5 FUTURE ELECTRIC VEHICLE BATTERIES

The capability of future electric storage batteries is the key to the viability and utility of future electric cars. The absence of electric cars on today's highways is directly traceable to the lack of a traction battery with adequate energy density, cycle life, and economy.

Authoritative surveys of battery development for electric cars are available in the literature.[27-31] These, and a very limited investigation of active battery development projects, have served as the basis for selecting and describing batteries considered here. Selected batteries are representative of a wide range of future possibilities; a summary of their characteristics appears in Table 5.1. Additional factors in the selection and description of each battery appear in the following subsections.

TABLE 5.1

SUMMARY PROJECTION OF BATTERY CHARACTERISTICS

	Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur*
Specific Energy,** W·hr/lb	13	44	70	140
W·hr/kg	29	110	155	310
Specific Power, W/lb	100	70	60	150
W/kg	220	155	130	330
Approximate OEM price, dollars per KWH	20-25	25-35	10-15	15
Energy Efficiency,** percent	46	66	70	62†
Availability	1978	1980	1985	1990

*Includes energy for maintaining battery operating temperature when not in use.

**Assumes overnight recharge, and discharge in urban driving as modeled in Secs. 6 and 8.

†Molten-electrodes.

5.1 LEAD-ACID BATTERIES

This study of electric car impacts focuses on three specific future years: 1980, 1990, and 2000. For electric car impacts to be significant in the first year, 1980, there must be a substantial number of electric cars on the road, implying mass production beginning at least several years earlier, in, say, 1978. This in turn necessitates a selection of car design and a decision to proceed into production around 1975. In consequence, only batteries which are already near production status are reasonable candidates for the 1980 electric cars.

Among the prospects of Table 5.1, only lead-acid batteries have reached this near-production status. A substantial lead-acid battery capability has been developed for electric vehicles, largely to support electric golf carts, and will be further improved in coming years.

Golf cart-type batteries are midway in cycle life and energy density between starting-lighting-ignition (SLI) batteries, which are designed for high energy and power density in shallow-cycle automotive use, and industrial traction batteries intended for maximum deep-discharge life and economy of delivered energy in fork lift trucks. Figure 5.1 summarizes the electrical performance of three advanced batteries of the golf-cart type. Each of these batteries has actually been operated in an electric car. The Delco battery was specifically designed for the experimental 512 electric car built by General Motors.[13] The other two batteries were developed by ESB, Inc., as high-performance additions to the ESB line of golf-cart batteries, and were tested in the ESB Sundancer electric cars.[32*] The LEV-115 battery is intended to provide a significant increase in cycle life with modest increase in energy density. The EV-140 battery is intended only to provide a much larger improvement in energy density. Whereas current golf-cart batteries commonly offer lifetimes of around 300 deep-discharge cycles, the LEV-115, in contrast, may achieve substantially greater life.[33]

---

*Personal communication, ESB, Inc.

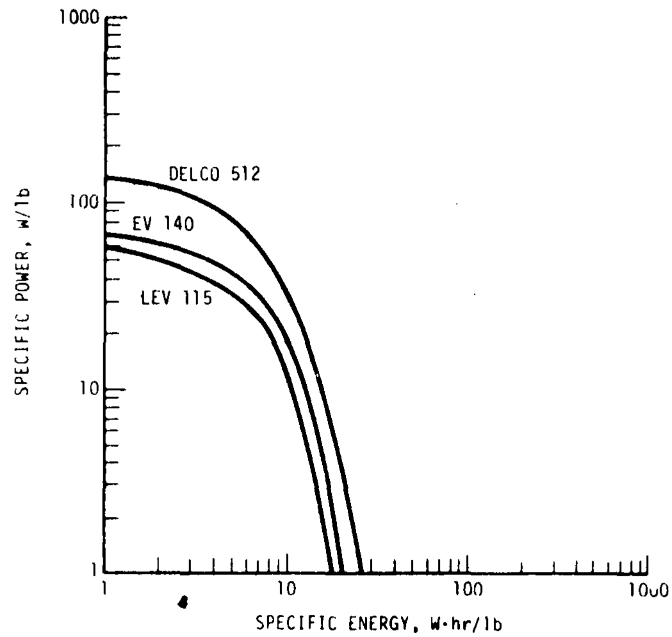


Figure 5.1. Specific Power Versus Specific Energy for Lead-Acid Electric Car Batteries

---

The composite battery performance illustrated in Fig. 5.2, between that of the 512 and EV-140 batteries, was chosen to characterize lead-acid traction batteries for 1980 electric cars. This performance has been the basis of range calculations for different battery weights to be described in this report.

If electric cars are used as conventional automobiles, they will be infrequently driven long distances in a single day. As a result, in most driving days their batteries will not be fully discharged. In estimating battery life and consequent battery depreciation costs, it is thus necessary--implicitly or explicitly--to predict battery cycle life as a function of cycle depth.

Cycle life, even at a single discharge depth, is not easily or confidently predictable. It is time-consuming and expensive to determine by testing, and may require years. Moreover, it depends significantly on

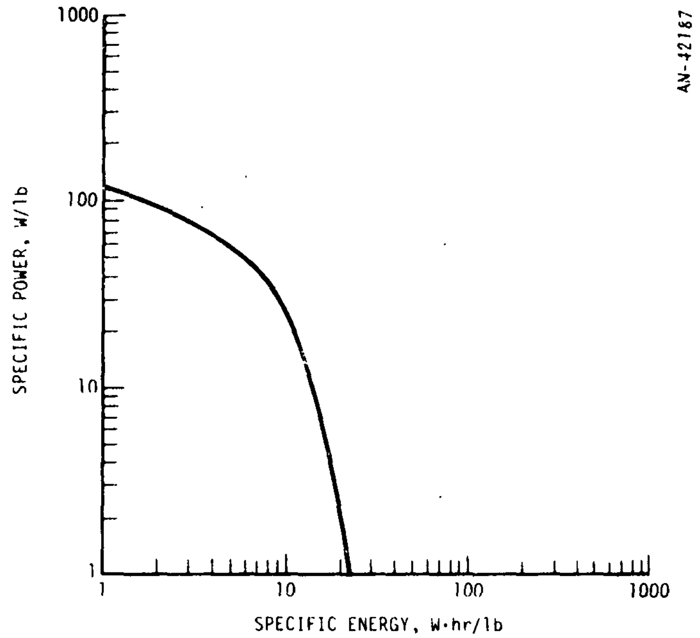


Figure 5.2. Assumed Specific Power Versus Specific Energy for 1980 Lead-Acid Electric Car Batteries

---

such conditions of operation as rates of charge and discharge, amount of overcharging, and both thermal and mechanical environments. Even for the widely used lead-acid batteries, scarcity of published data means projections of cycle life versus cycle depth must be qualitative in derivation. In this study, the range of possibilities assumed is shown in Fig. 5.3. The "best" life reflects current expectations for the lower energy-density battery designs, while the "poorest" corresponds to the very-high-energy density designs.* Thus associating the "best" life with the highest performance assumed in Fig. 5.2 implies considerable optimism about improved battery longevity by 1980. Both "best" and "poorest" lifetimes are carried throughout this study to show the range of uncertainty due to cycle life.

The energy efficiency of electric vehicle batteries may be defined as the ratio of energy removed during discharge to energy returned during

*Private communication, ESB, Inc.

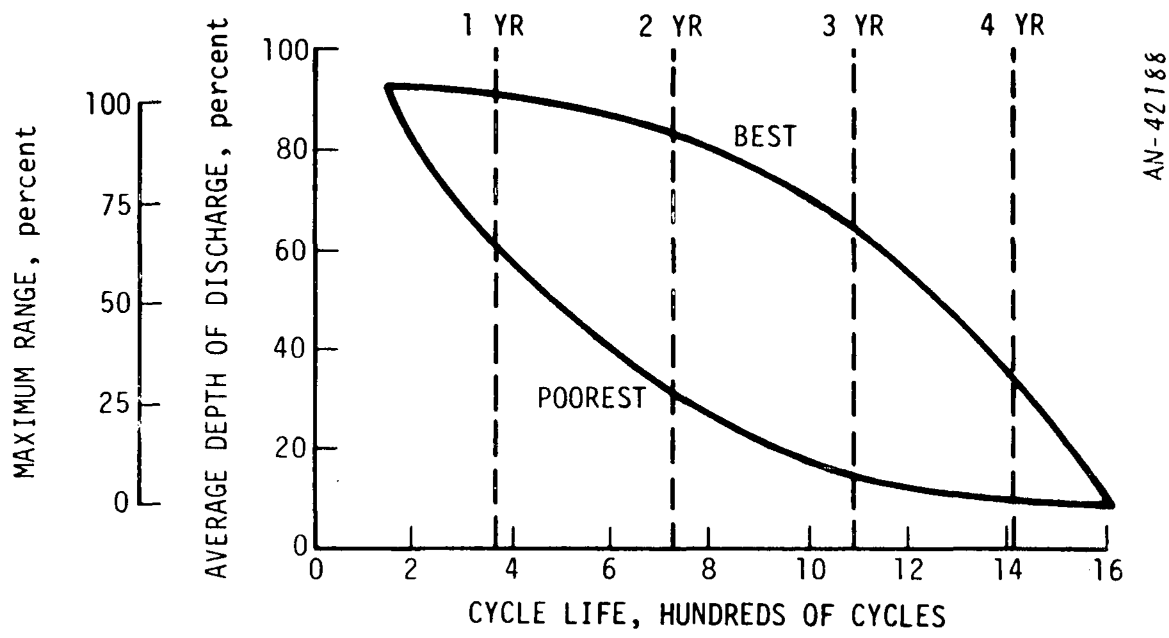


Figure 5.3. Assumed Life of 1980 Lead-Acid Electric Car Batteries

---

recharge to the original fully-charged state. In the analysis of this report, overall efficiency was taken as the product of a separate discharge efficiency with a charge efficiency.

For convenience, the discharge efficiency was assumed to be specified by Fig. 5.2, since this form of battery description was used as the basis of battery discharge modeling as described in Sec. 6. Discharge efficiency was taken as the ratio of energy removed during full battery discharge at driving power levels to energy available at a low power level corresponding to the 20-hour rate often used in battery ratings. Residual state of charge was assumed to be independent of discharge power level, though at high power levels this is incorrect. The accuracy of this assumption is discussed in Sec. 8.1.

Charging efficiency was defined as the ratio of the energy withdrawable from the battery at a low (20-hour) rate to the energy required for subsequent full recharge. This efficiency is a function of charging rate and should include a modest degree of overcharge because it is beneficial to battery longevity. In this study, charging is assumed to be accomplished overnight at a tapering rate during a maximum of 8 hours, with efficiency of 83 percent. A recommended 8-hour charging profile is shown in Fig. 5.4.[34] It provides a total of 197 ampere-hours to a 100-AH cell (an overcharge of 5 to 15 percent is generally recommended), and requires 242 watt-hours in all. If the cell will deliver 200 watt-hours at a low rate, then the charging efficiency is 83 percent.

The electrical performance of electric vehicle batteries may be expected to decline during their lifetimes. The descriptions provided so far characterize the battery while it is still relatively new. At the end of its life, battery energy capacity may be reduced to 60 to 70 percent of the initial rating; in fact, the end point of battery life is usually defined in terms of a specific capacity reduction (often to 60

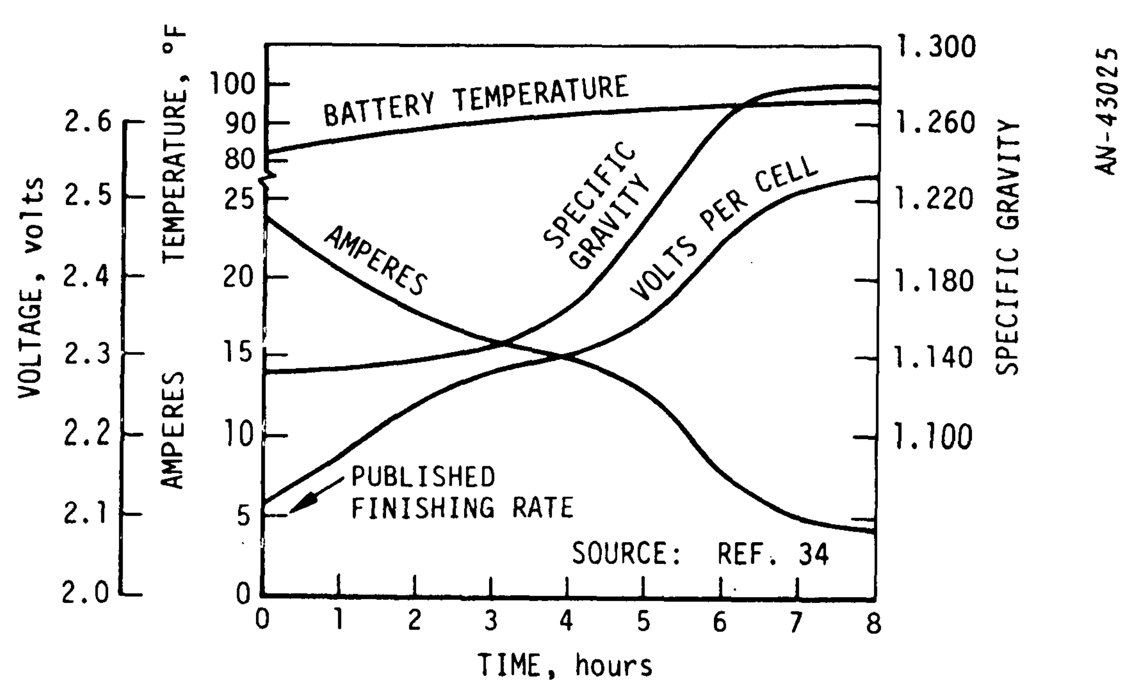


Figure 5.4. Typical Modified-Potential Charge Profile for Lead-Acid Electric Vehicle Batteries (100-AH Cell)

percent).* Battery energy and power may also be substantially degraded by low temperatures; in sub-zero weather, much of the battery capacity will disappear, as shown for a typical lead-acid cell in Fig. 5.5.[34] This reduction in capacity increases at high rates of discharge, as indicated for a different type of lead-acid cell in Fig. 5.6.[35]

Battery electrical performance capability will also decline, of course, during discharge in a single day's driving. The amount of this decline depends not only on particular cell design, remaining charge, temperature, and battery age, but also on the manner in which the battery has been charged and discharged. No simple summary of the performance decline is thus possible. The situation is reasonably illustrated by Fig. 5.7, however, which shows available terminal voltage versus current for a battery discharged at the 6-hour rate to various extents.

The loss in capability with discharge is clearly most pronounced at high load currents, as might be demanded in electric cars for acceleration, hill-climbing, or maximum speed. Generally, however, the car's motor controller will employ current-limiting circuitry to constrain maximum current, motor torque, and vehicle acceleration to moderate levels, so reduced battery voltage will have little effect until very near total discharge.

5.2 NICKEL-ZINC BATTERIES

The theoretical superiority of nickel-zinc alkaline batteries over lead-acid batteries has long been recognized. Only recently, however, have practical problems in cell construction been overcome in developmental research. Now, two separate development activities suggest that nickel-zinc batteries will offer a viable alternative to lead-acid batteries in the marketplace before the end of this decade.

---

*Private communication, L. Unewehr, Scientific Research Staff, Ford Motor Co.

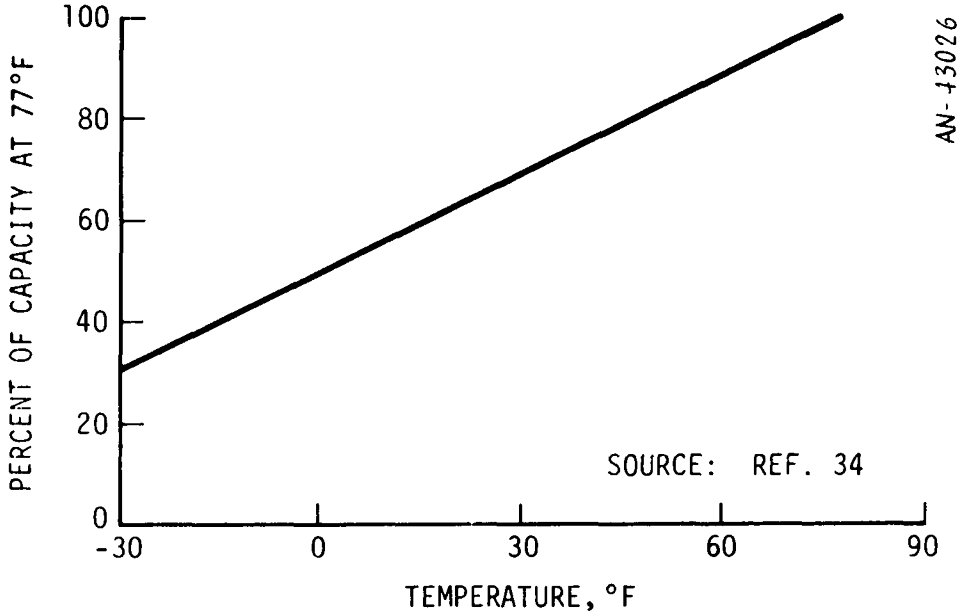


Figure 5.5. Lead-Acid Electric Vehicle Batteries, Capacity Versus Temperature

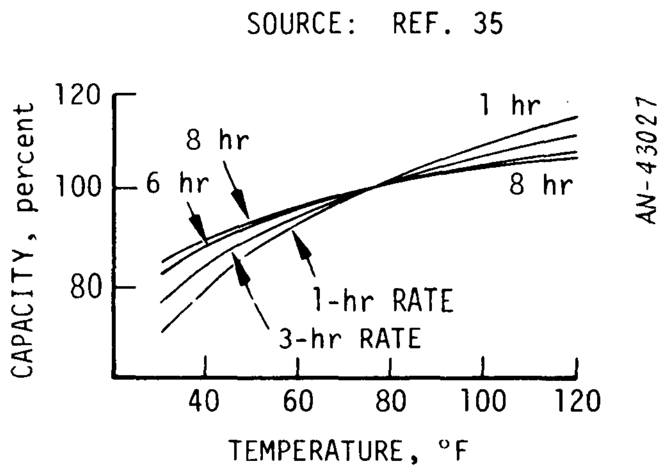


Figure 5.6. Effect of Temperature on Lead-Acid Battery Capacity

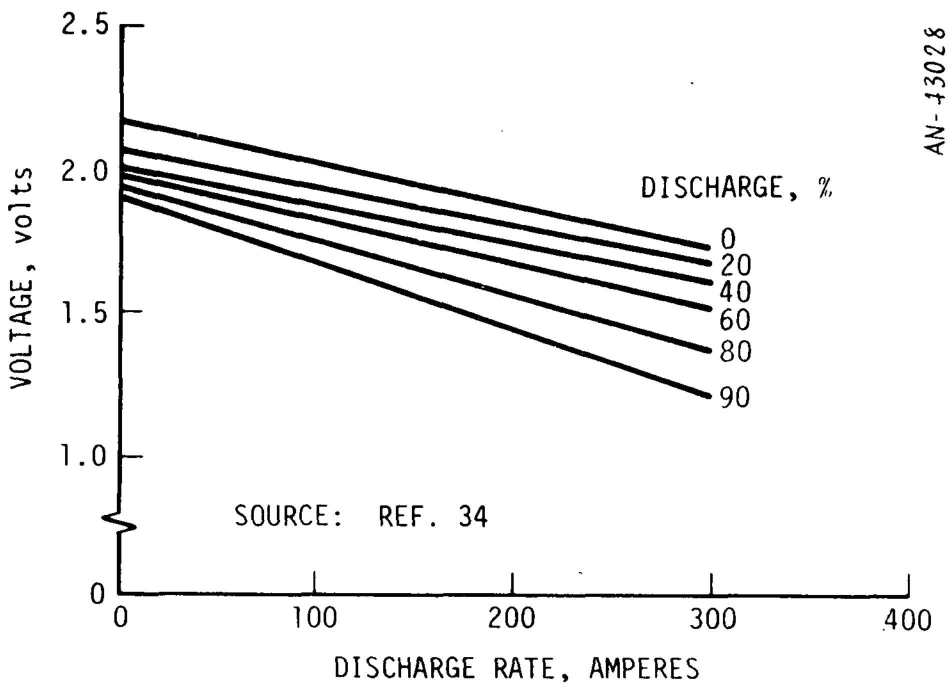


Figure 5.7. Lead-Acid Electric Vehicle Batteries, Voltage and Current Versus Percentage of Discharge for a 100-AH Battery Discharged at 6-hour Rate at 77°F

Energy Research Corporation has developed and tested sealed 7 and 25 ampere-hour nickel-zinc cells.* Even in this small size, energy density is 30 watt-hours per pound and life is over 250 deep-discharge cycles. A life improvement to 500 to 700 cycles and an energy density of over 40 watt-hours per pound (in larger cells) are current research targets. Expected costs per watt-hour are less than twice those of lead-acid batteries.

Gould, Inc., has had vented nickel-zinc cells in laboratory sizes under development and test for several years.** Sufficient success has been achieved that 400-ampere-hour cells have been designed and are now being constructed for field tests which will include vehicular use during 1974. Given satisfactory results, manufacturing is planned by the end of 1976. After an additional two years, in 1978, improvements in cell

---

*Private communication, Alan Charkey, Energy Research Corporation.

**Private communication, Mark J. Obert, Gould, Inc.

ampere-hours and watt-hours per pound from 480 to 580, and from 40 to 50 (5-hour rate) are anticipated.* Performance expected of the initial and improved production cells is shown in Fig. 5.8.

Projected cycle life and cycle depth for the Gould production cells are shown in Fig. 5.9. These are based on extrapolations of experimental results shown in Fig. 5.10, and assume life ends when cell capacity has fallen to 60 percent of its original value.** Though these curves do not show it, the experimental data is encouraging in that it reveals that capacity levels off somewhat above 50 percent after its initial decline, and remains above 50 percent for many hundreds of cycles before further drop. This leads to two inferences: even after very long cycle life, specific capacity may exceed that initially provided by lead-acid batteries; and

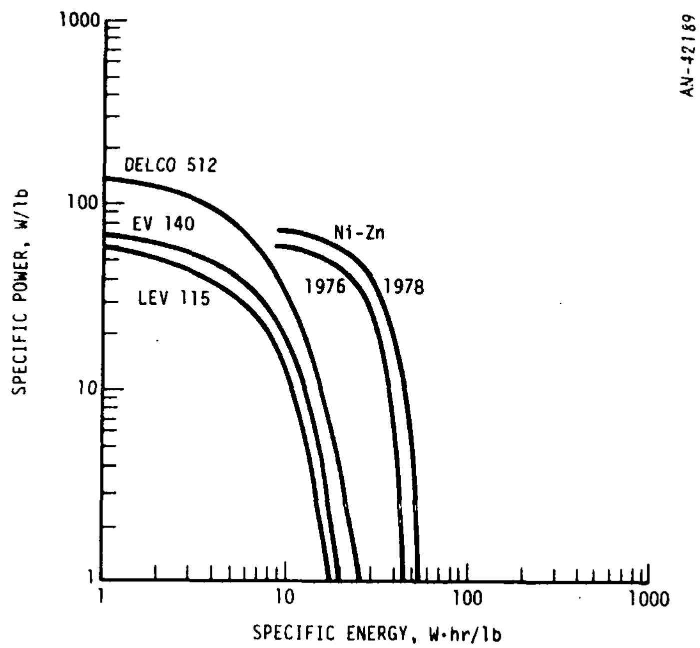


Figure 5.8. Specific Power Versus Specific Energy Projected for Nickel-Zinc Traction Batteries

*Private communication, Claude Menard, Gould, Inc.

**Private communication, Claude Menard, Gould, Inc.

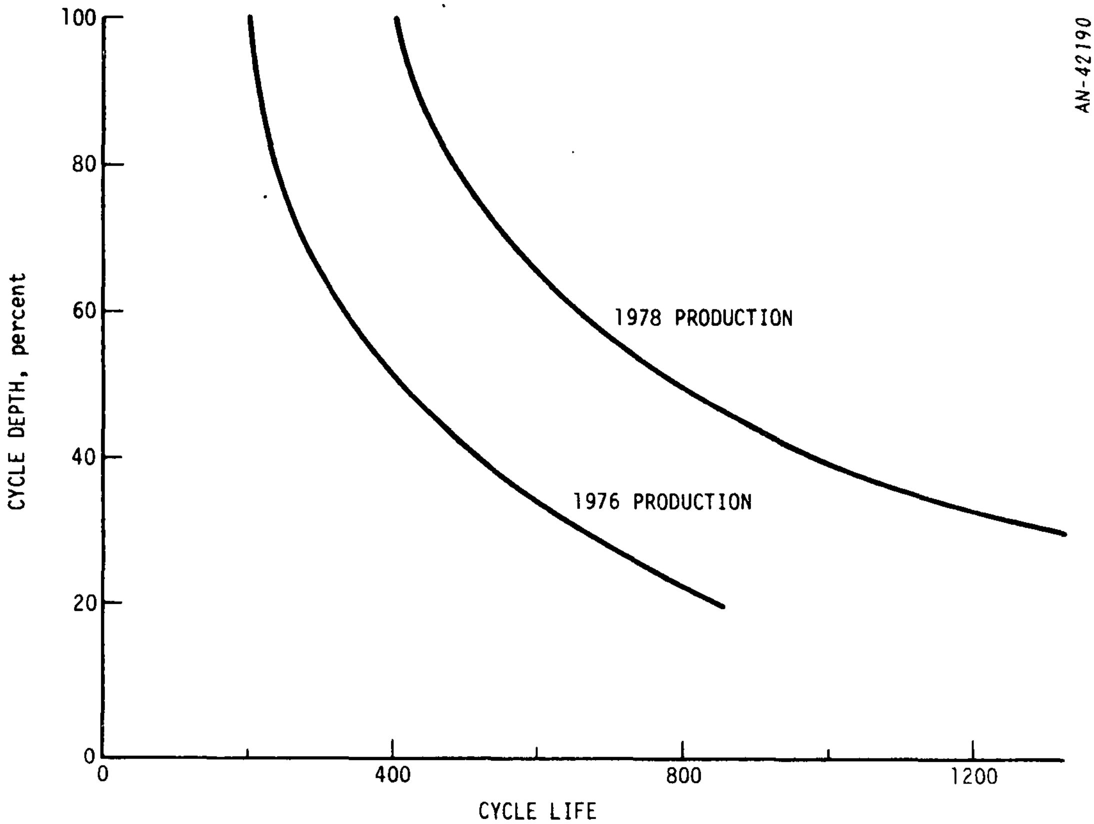


Figure 5.9. Projected Cycle Life for Ni-Zn Electric Vehicle Battery (to 60 percent of Original Capacity)

degradation of capacity may be significantly reduced by redesign to preserve the working area of the zinc electrode, which now is diminished with use and thus reduces capacity. Overall, it seems reasonably conservative to forecast the availability of nickel-zinc electric vehicle batteries with a 400-cycle life by 1980.

The estimated OEM price of the nickel-zinc batteries in quantity production is around $35 per KWH. Once regular usage patterns are established and volume recycling is in progress, this may fall to $25 per KWH.*

*Private communication, Claude Menard, Gould, Inc.

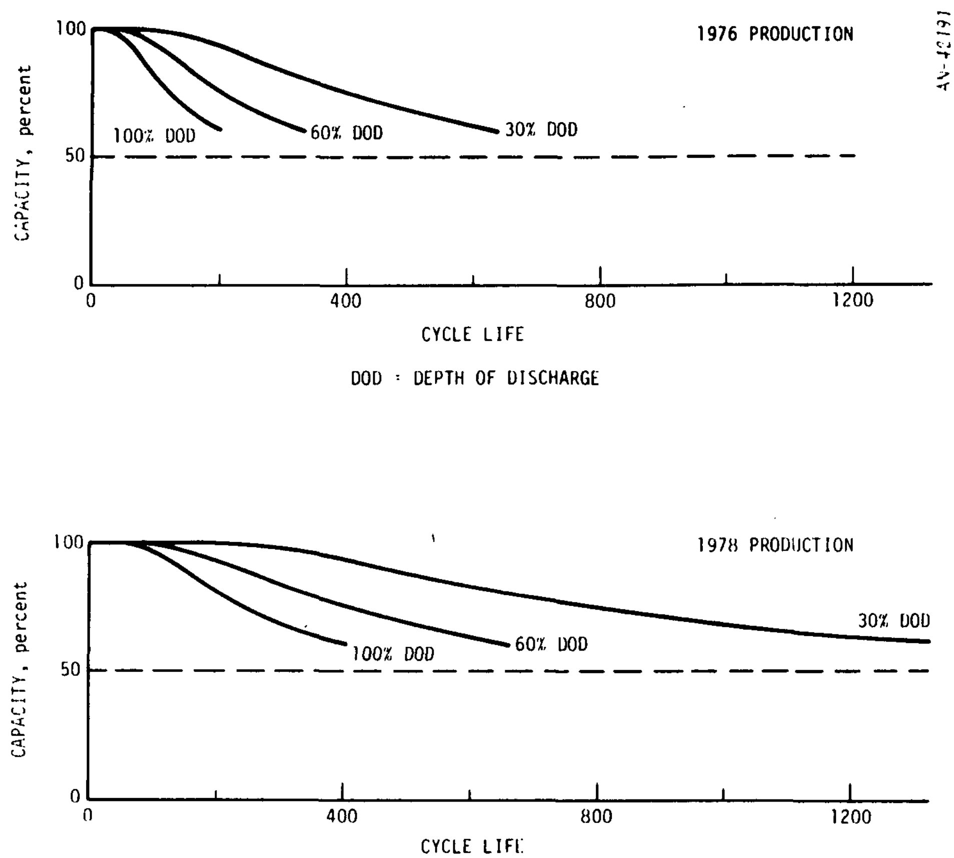


Figure 5.10. Projected Capacity Reduction for Ni-Zn Electric Vehicle Battery

---

In projecting these costs, 5-hour discharge rates are assumed. The Gould cells are being optimized for this particular rate. Much higher discharge rates may be obtained by appropriate cell design, but battery costs may be more than doubled as a result. For electric cars, the lower price is preferable as the reduction of energy density at high specific powers is not an important sacrifice.

The energy efficiency of overnight recharge of the nickel-zinc traction batteries is expected to be above 80 percent. Discharge energy efficiency is implicit in Fig. 5.8.

5.3 ZINC-CHLORINE BATTERIES

A zinc-chlorine battery for automotive use is the express objective of a 5-year development program at Energy Development Associates.[36] EDA is a research and development partnership between wholly owned subsidiaries of Gulf and Western Industries, Inc., and Occidental Petroleum Corporation. The demonstrated potential of the zinc-chlorine system not only motivated the formation of EDA, but has reportedly led to an agreement for cooperation with Gould, Inc., in which Gould contributes its porous titanium technology for battery electrodes, and acquires options to produce the batteries for stationary use by electric utilities and for standby power use in the United States and Canada, as well as for mobile use including electric cars.[37]

An experimental zinc-chlorine battery was built and installed in a Vega automobile in 1972.[38] Though far from a production battery system, it demonstrated important potential, including a total range of 152 miles at a speed of 50 mph.

The development objectives of the EDA program, in Table 5.2, are expected to be achieved in 1978-79.[39] Thus it seems possible that electric cars utilizing zinc-chlorine batteries could be produced as early as 1980. This battery system represents a major advance in performance and technology, however, and past developments in battery technology have often progressed slower than originally anticipated. Accordingly, the availability of zinc-chlorine batteries meeting the performance goals of Table 5.2 is projected here for 1985 rather than 1980.

The key to the zinc-chlorine battery system is storage of chlorine as chlorine hydrate.[40] Chlorine gas under pressure, or liquid chlorine, is corrosive, difficult, and dangerous to handle and store, but the hydrate is very much more tractable. Usage of a hydrate store involves plumbing, pumps, a heat exchanger, and a refrigerator in addition to the assembly of battery plates and electrodes; thus it is truly an energy system rather

TABLE 5.2

ZINC-CHLORINE BATTERY GOALS

Delivered Energy (4-hr rate)	50 KWH
Battery Weight (total system)	700 lb (318 kg)
Charge Time (minimum)	4 hr
Volume (total system)	10 ft^3 (0.28 m^3)
Cycle Life	500-5,000
Overall Energy Efficiency	70%
Peak Power (30 sec)	40 KW
Cost (estimated)	\$500-\$750
Energy Density (4-hr rate)	70 W•hr/lb (155 W•hr/kg)
Power Density (30 sec)	57.2 W/lb (125 W/kg)

than simply a battery as generally conceived. A diagram and explanation of system operation prepared by EDA is reproduced as Fig. 5.11. The goals of the EDA program include a prototype 1,000-pound battery by the end of 1975. Analysis and extrapolation of laboratory data show that the eventual result of the development program should provide the performance of Table 5.2.

A typical current-versus-voltage curve for an EDA cell is shown in Fig. 5.12. In the target battery, 40 mA/cm^2 at 2 volts corresponds to a 4-hour discharge. From this reference point and the data of Fig. 5.12, the specific power versus specific energy as shown in Fig. 5.13 may be computed.[41]

To be conservative, it may be assumed that in Table 5.2 the higher estimated cost and the lower estimated cycle life will prevail. Since cycle life versus cycle depth is not now known, it may be simply assumed that total energy delivered by the battery during its life is independent of cycle depth. Thus a capability of 500 full discharges becomes equivalent to one thousand 50-percent discharges, or two thousand 25-percent discharges.

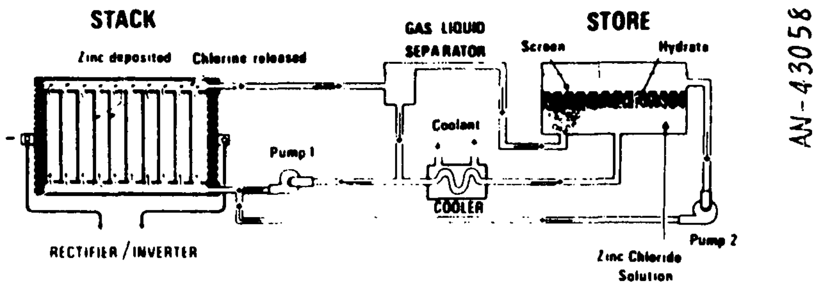


Figure 5.11. The EDA Zinc Chlorine Battery System

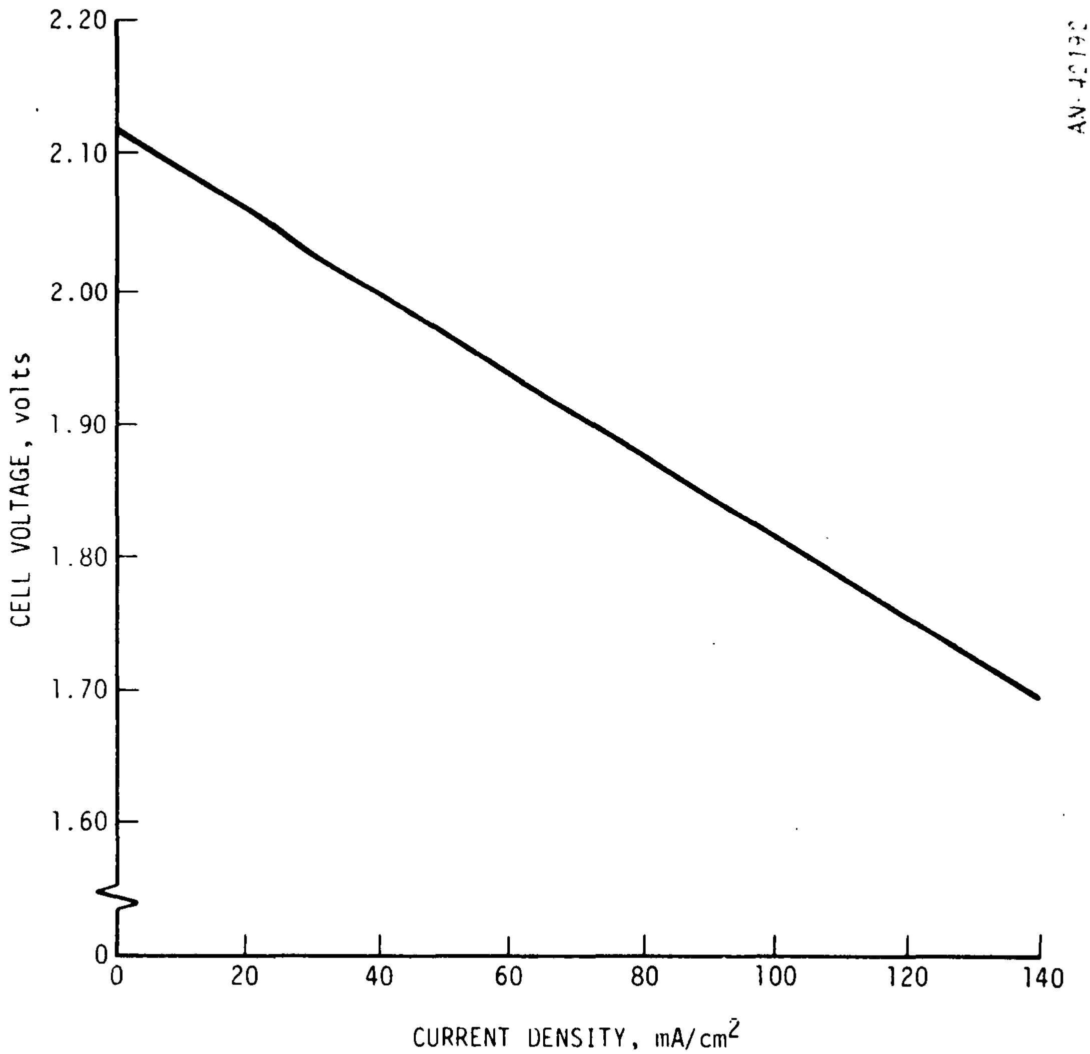


Figure 5.12. Zinc Chlorine Cell Discharge Curve

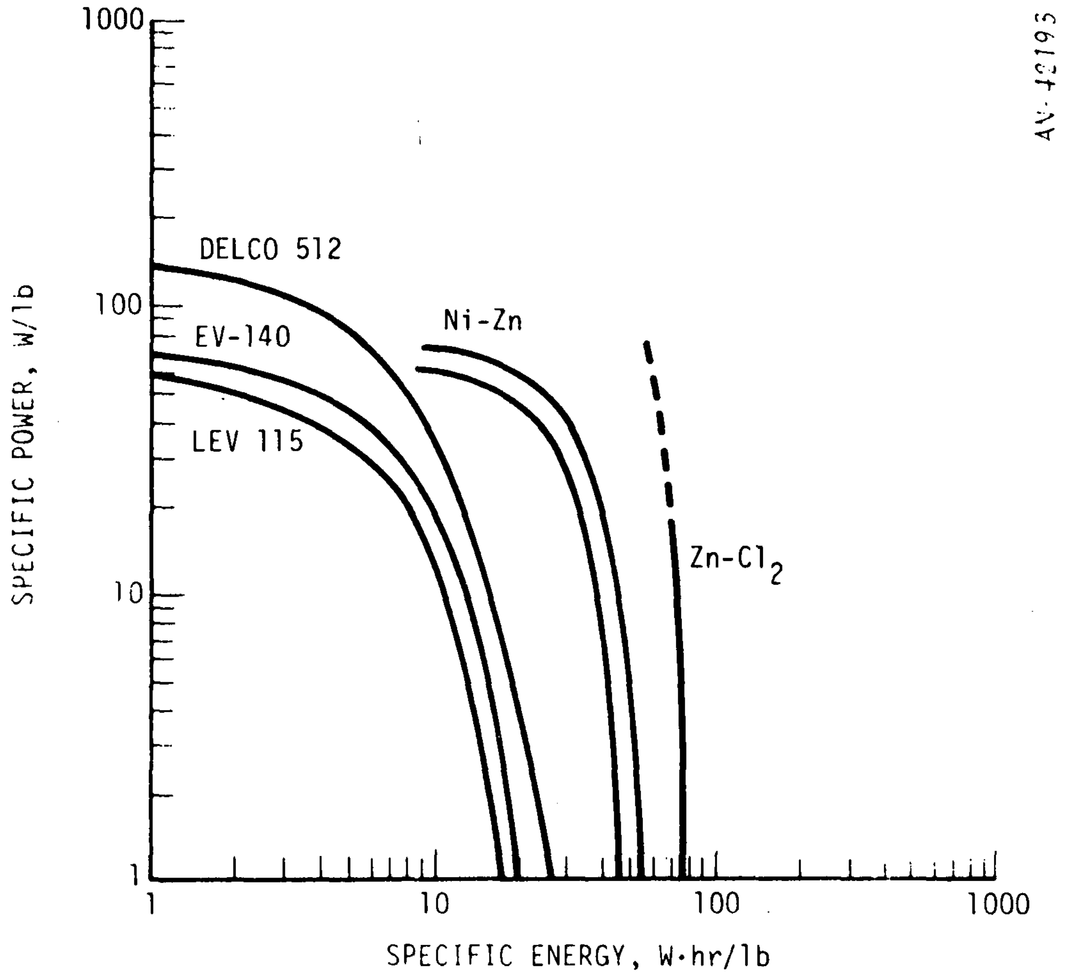


Figure 5.13. Specific Power Versus Specific Energy Projected for the Zinc Chlorine Battery System

5.4 LITHIUM-SULFUR BATTERIES

It has long been recognized that non-aqueous batteries with molten-salt electrolytes might provide extremely high specific energy densities. Well over a dozen research organizations have active programs in development of such batteries, both in the United States and abroad.[42]

Of the US programs, that at Argonne National Laboratory is by far the largest. It has recently been operating at a budget level of $1,250,000 per year, with prospects for continued growth as further accomplishments are demonstrated and as added effort is applied to alleviating US energy problems.

The ANL program is primarily directed at batteries for utility peak-shaving.[43] Siting problems, environmental constraints, and safety challenges have for several years drastically slowed initiation of planned construction by electric utilities, and in consequence, insufficient capacity for meeting peak-hour demands threatens to become commonplace. The ANL program is to produce an electric storage battery which can economically store electric energy generated during off-peak periods, as very late at night. By making this energy available to meet peak power demands of the following day, requirements for total installed generating capability can be significantly reduced.

Because battery technology being developed for this application is inherently suited for vehicular use, the ANL program includes specific efforts to develop an electric car battery. The objectives of these efforts include installing a vehicular battery built by a commerical subcontractor in a test vehicle by 1980. Considering the many uncertainties yet to be resolved, 1990 is probably an early year for initial production of such autos.

Until recently, development effort was focused on batteries employing molten-lithium and molten-sulfur electrodes.[44-46] Though this potentially enables very high energy densities, up to 150 watt-hours per pound, it also poses difficult problems of diffusion and corrosion. These problems are dramatically reduced by use of solid electrodes, but energy density is thereby halved.

Goals in the solid-electrode ANL battery program are shown in Table 5.3. Solid lithium-aluminum and metal sulphide electrodes will be used

TABLE 5.3

TENTATIVE ANL PERFORMANCE GOALS FOR ELECTRIC AUTOMOBILE BATTERIES

(With Solid Electrodes)

	Subcompact	Compact
Automobile Characteristics		
Loaded Weight, kg (lb)	800 (1,763)	1,250 (2,756)
Range, Miles	100	100
Energy Usage, KWH per mile	0.20	0.35
Battery Goals		
Cost, Dollars	600	800
Weight, kg (lb)	135 (297)	230 (507)
Energy Storage Capacity,* KWH	20	35
Peak Power, KW	32	60
Cost/Unit Weight, $/kg ($/lb)	4.45 (2.02)	3.50 (1.59)
Specific Energy, W·hr/kg (W·hr/lb)	148 (67)	152 (69)
Specific Power, W/kg (W/lb)		
Peak (15-sec bursts)	237 (108)	260 (118)
Sustained Discharge (2-hr)	74	76
Recharging Time, hr	5	5
Battery Life, yr	3-5	3-5
Cycle Life	1,000	1,000
Rate of Heat Loss, watts	125	150

*Delivered on discharge at the battery terminals.

with an electrolyte of lithium chloride-potassium chloride eutectic, operated at about 400°C. A complete battery is constructed by stacking cells and cylinders and packing the cylinders in a well-insulated box with an electric heating system. The heating is necessary to maintain battery operating temperature while it is standing idle; during charging or discharging battery loss may be more than sufficient to maintain operating temperatures, and some cooling may be needed. A complete conceptual battery is illustrated in Fig. 5.14. It is much too early to predict electrical performance, cost, and life of such batteries in detail. For the moment, it suffices to assume that the program objectives of Table 5.3 will be met. If they are, the resultant battery will be so similar to the zinc-chlorine battery of Table 5.2 in terms of specific energy, life, and cost that at this point it cannot be meaningfully distinguished on performance and impact grounds.

Accordingly, only the liquid-electrode version of the lithium-sulfur battery is considered further in this study. It is assumed to achieve twice the specific energy goal of Table 5.3 as shown in Fig. 5.15, but to comply with other current performance goals.

Overall energy efficiency of the molten-salt batteries is diminished by heating requirements in a manner dependent on battery usage. Accordingly, it is accounted for separately in range calculations for electric cars in this study. Energy efficiency exclusive of heater power for the high-temperature batteries has yet to be firmly established. At the moment, overall charge-discharge efficiencies of 70 percent for the solid-electrode battery and 80 percent for the more optimistic molten-lithium, molten-sulfur battery will be assumed.*

It should be noted that this lithium-sulfur battery is not the only prospect for attaining energy densities of well over 100 watt-hours per

*Private communication, P.A. Nelson, ANL.

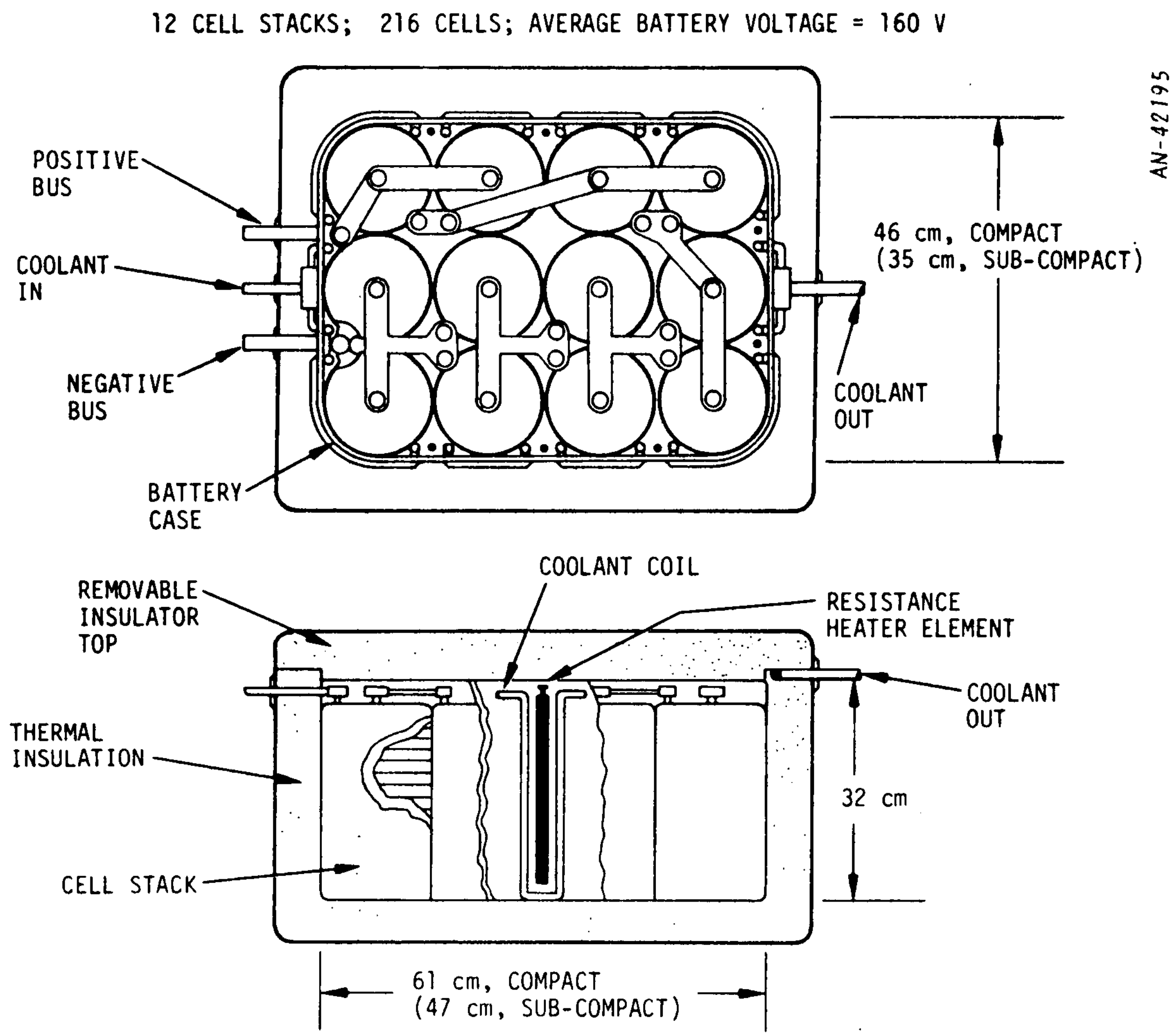


Figure 5.15. A Conceptual Lithium-Sulfur Electric Car Battery

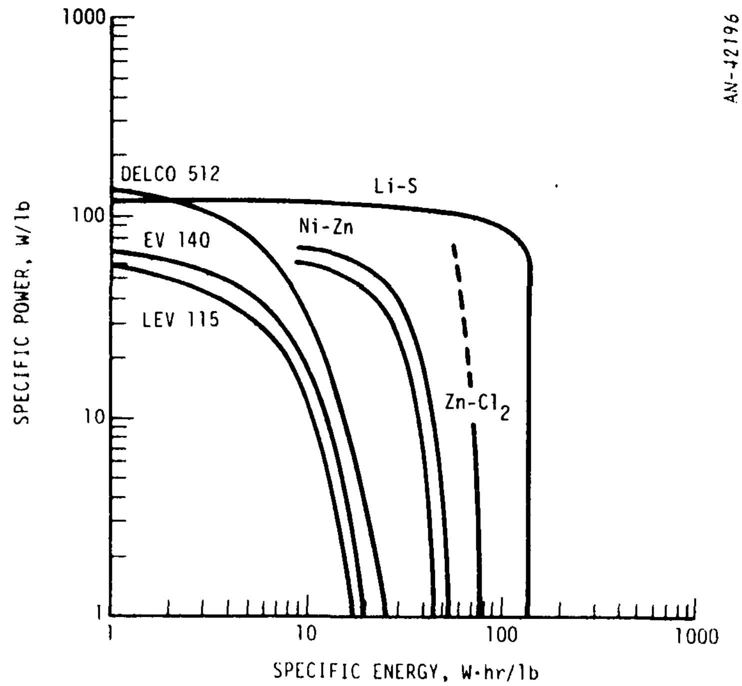


Figure 5.15. Power and Energy Density Curves for Various Electric Vehicle Batteries

---

pound. Worldwide, a dozen research programs are pursuing sodium-sulfur battery development, and four more are addressing lithium-chlorine systems.[42] The relative prospects for these different developments cannot be conclusively appraised now. Their number and diversity, however, clearly suggests that by 1995 battery energy densities of 100 to 150 W-hr/lb may be achieved, if not by the lithium-sulfur system then by one of the others.

6 PARAMETRIC RANGE CALCULATION

Computer simulations were developed to calculate ranges between recharge for electric automobiles in specified driving cycles. Each simulation consisted of two parts: a power demand model, to determine the electric power requirement of the electric auto for each time increment in a given driving cycle, and a battery discharge model, to determine the progressive depletion of battery capacity in meeting these incremental power requirements. The power demand model employed the equations developed in Sec. 3. The battery discharge model was an approximation developed to utilize available data.

For simplicity, a single battery discharge model was used for all the batteries described in Sec. 5. Since relatively little data is available for advanced batteries now under development, the battery model was simply based on the summary charts of specific power vs specific energy for each battery presented in Sec. 5. For each time increment, the battery model first calculated the specific power level required of the battery; then it determined the associated specific energy level from the battery chart; finally, it determined the fraction of battery capacity required at this specific energy level to meet the total energy requirement of the auto during the time increment. Battery exhaustion was assumed when the sum of these fractional capacity reached unity. Further details are presented in the appendix.

Though this model is conceptually similar to other models which have been verified by comparison with test data, its accuracy is not thereby assured. The model obviously omits much desirable detail: its cutoff conditions (minimum acceptable terminal voltage at given discharge current) are implicit in the specific power and energy chart, rather than explicitly invoked at each step of the driving cycle; furthermore, it does not allow for battery recuperation during decelerations and stops, or for any residual energy available after the (implicit) cutoff conditions are reached.

The validity of any such model can only be established by comparison with experimental results. For estimation of electric car range, this is undertaken immediately. For estimation of electric car energy consumption, it is addressed in Sec. 8.1.

6.1 COMPUTER PROGRAM VERIFICATIONS

The range calculation of the computer simulation was tested by regeneration of published experimental results. Inputs for the simulation were taken directly from the published data wherever possible. Where published data was unavailable, as in the case of the battery characteristics of the EFP test car, data from similar vehicles or components was used.

EPA has furnished a range test of the EFP Electrosport car driven on the Federal Driving Cycle. The range obtained was 25.0 miles. The computed range was 24.7 miles, using an energy discharge curve for a LEV-115 battery from ESB and the vehicle parameters listed below:

Vehicle Weight	5500 lb
Battery Weight	2240 lb
Frontal Area	24 ft^2
Aerodynamic Drag Coefficient	0.4
Mechanical Efficiency	90%
Electrical Efficiency	70%
Road Load Friction	$R = (W/50)(1+0.0014V+0.000012V^2)$

Where W = weight of vehicle, lb

V = vehicle velocity, ft/sec

Another computer comparison was made using range data from the Sundancer vehicle.[10] The vehicle parameters that were used in this comparison are as follows:

Vehicle Weight	2000 lb
Battery Weight	840 and 816 { for LEV-115 and EV-140 batteries, respectively
Frontal Area	12 ft^2

Aerodynamic Drag Coefficient	0.3	
Mechanical Efficiency	92%	
Electrical Efficiency	70% and 80%	for contactor controller and SCR controller, respectively.
Low Aspect Ratio Tires		

The comparison of range calculations and tests reported on the SAE Residential Driving Cycle was as follows:

	Computer Range miles	Test Range miles
LEV-115 Battery		
Contactor Controller	56	55-60
SCR Controller	68	70-75
EV-140 Battery		
Contactor Controller	66	75-80
SCR Controller	79	75-80

The comparison of computer and actual tests for this vehicle is favorable. It would be expected that the actual tests would be higher, since there were some additional miles obtained on the vehicle when it could not completely follow the driving cycle.

6.2 CARS WITH CURRENT LEAD-ACID BATTERIES

Range calculations were made for the two assumed vehicles using various battery types and weights. The battery types that were used were the LEV-115, EV-140, and Delco 512 lead-acid batteries. The power and energy density curves of these batteries are shown in Fig. 5.1.[13*]

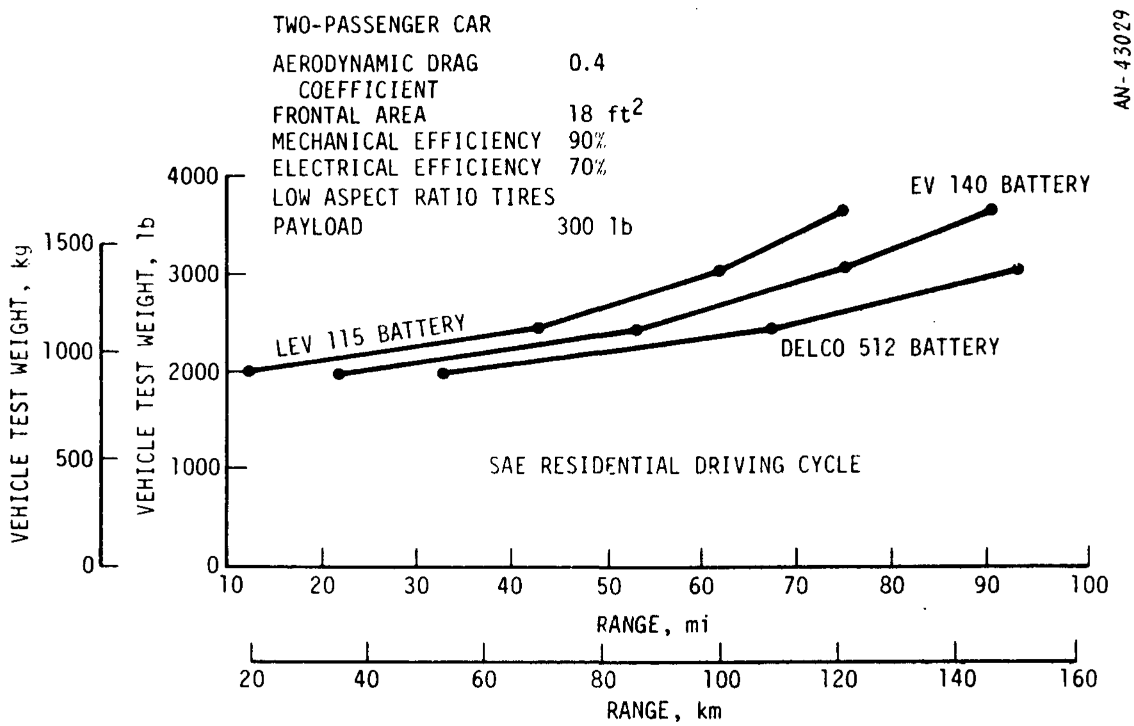
*Personal communications with ESB and Argonne National Laboratories.

Range calculation results using the lead-acid batteries are shown in Fig. 6.1. Assuming a maximum range of 35 miles between battery charges, the two-passenger car needs about 800 pounds of LEV-115 batteries, about 600 pounds of EV-140 batteries, or about 500 pounds of Delco 512 batteries. To obtain a 55-mile range on the four-passenger car, we need 2,300 pounds of LEV-115 batteries, 1,800 pounds of EV-140 batteries, or 1,300 pounds of Delco 512 batteries.

As noted in Sec. 3.5, the electrical efficiency (controller and motor efficiency) of the four-passenger car was assumed to be higher than that of the two-passenger car because a two-speed automatic transmission was included to raise motor speed and efficiency during low-speed driving. The extra complexity and cost of such a transmission was deemed unwarranted for the two-passenger car.

The Delco 512 battery has not been developed for long life under deep discharge conditions. It is felt that this lightweight battery could be made acceptable, but it may lose some of its high-energy storage capability during this development towards long life. Therefore, we have assumed that a lead-acid battery somewhere between the EV-140 and the Delco 512 batteries can be developed for the 1980s that will have adequate life in the range shown in Fig. 5.3. The remainder of our calculations for the lead-acid battery are for a battery having a power and energy density curve between the EV-140 and Delco 512 batteries. This assumed battery is termed the 1980 battery and its power-energy density curve is shown in Fig. 5.2.

No allowance was made for accessory operation in these range calculations. Power requirements of basic accessories are shown in Table 6.1. Even if operated simultaneously, a relatively infrequent condition, their total power requirement is only 227 watts. As Sec. 8 shows, the four-passenger electric cars require an average of about 0.3 KWH/mi in urban driving, or 7.2 kW at the average driving cycle speed of 24 mph. The



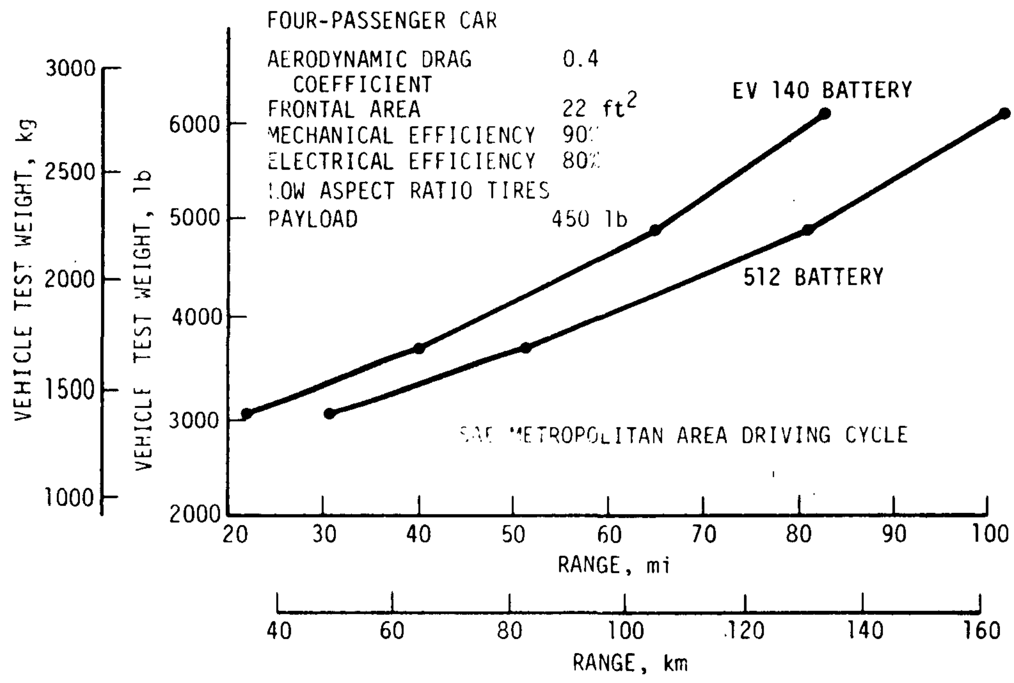


Figure 6.1. Urban Driving Range For Cars With Current Storage Batteries

TABLE 6.1

ACCESSORY POWER REQUIREMENTS[47] (watts)

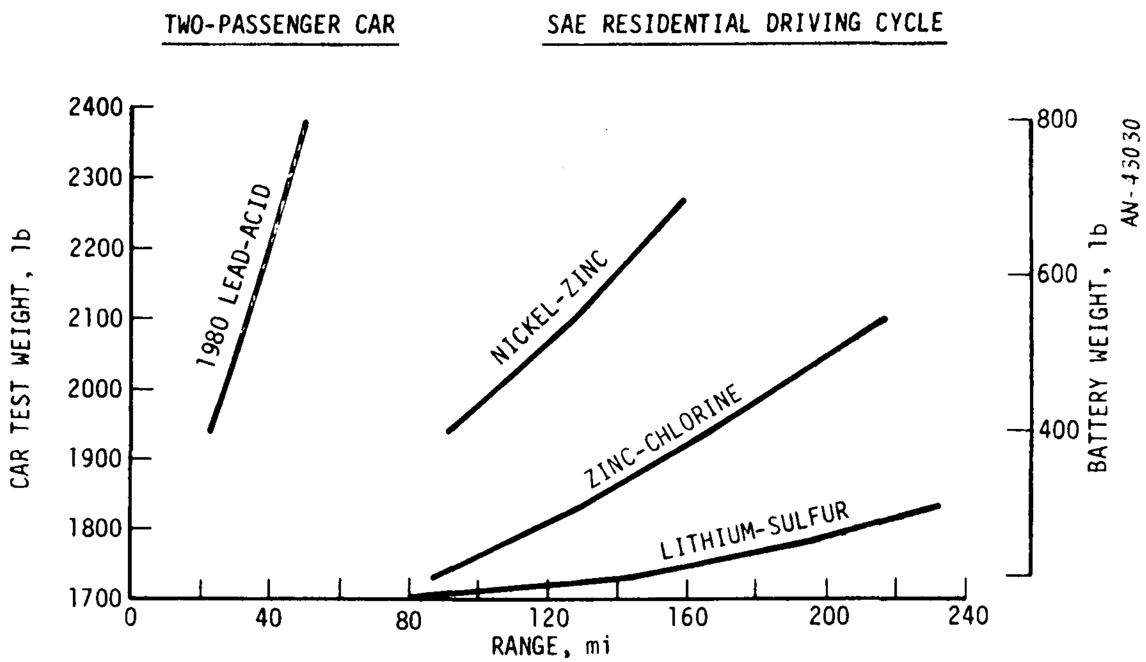
Service Lights, High Beam	46.8
Service Lights, Rear	24
License Plate Lights	18
Windshield Wiper Motor	12
Defroster Fan Motor	24
Heater Fan Motor	24
Clock	0.6
Radio	60
Dash Lights	18
	227.4

total accessory load would be about 3 percent of the propulsion power requirement from the battery, and thus would reduce range by an amount negligible in comparison with uncertainties in battery performance and modeling.

Because of the weight of the four-passenger cars with lead-acid batteries, power steering and power braking might be desirable options imposing additional power requirements. If braking power were provided by an electric pump with vacuum accumulator, about 8 watts of electric power would be required.[18] Though peak power steering requirements may reach 1 horsepower in stationary quick turns of the steering wheel, typical driving demands are near 0.1 horsepower, or 75 watts;[18] together, the average loads imposed by efficient power braking and steering subsystems should be less than the accessory total of Table 6.1, with similar implications for range.

6.3 CARS WITH FUTURE STORAGE BATTERIES

Figure 6.2 shows driving range between recharges for two- and four-passenger electric cars with the future storage batteries described in Sec. 5.



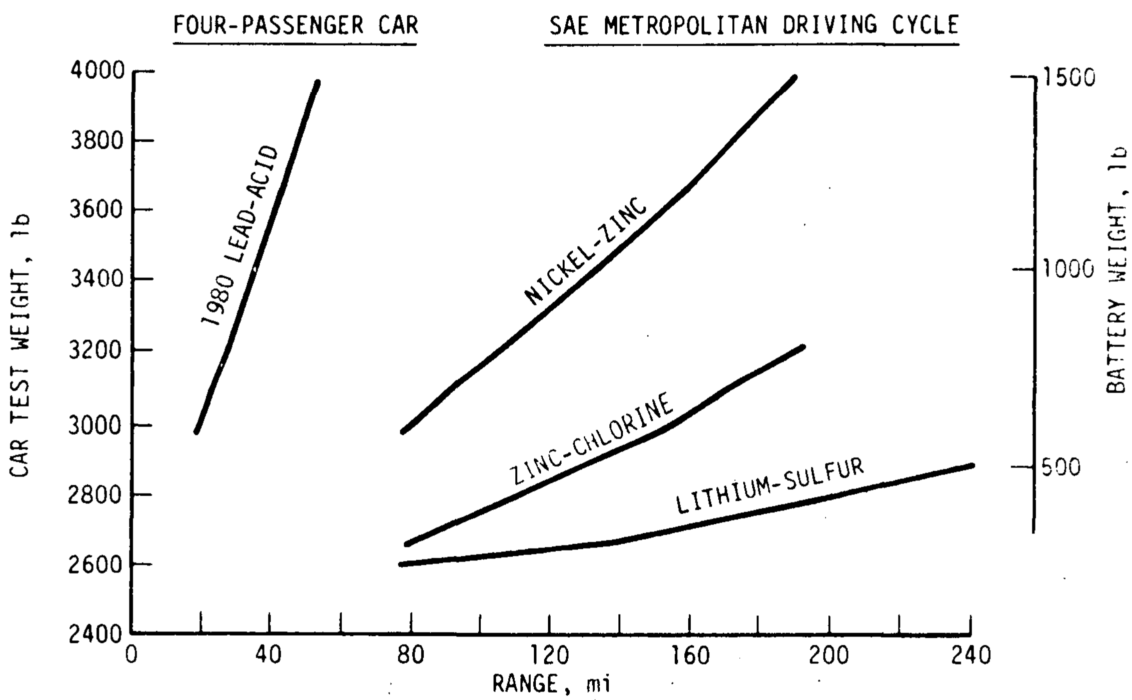


Figure 6.2. Urban Driving Range for Cars with Future Storage Batteries

At a given battery weight, ranges of these cars in constant-speed, level driving are considerably greater than in stop-start urban cycles. Figure 6.3 shows the variation of range versus speed in steady driving for cars with particular battery weights. These weights are those selected as described in Sec. 7 to give ranges appropriate for different patterns of urban daily driving.

It should be understood that the range calculations presented in this report apply to a car with a fully charged new battery pack operating in typical Los Angeles weather conditions. Moreover, the range is calculated with the car traveling on a specific driving cycle. Once the car cannot make a specified acceleration, the run is considered complete and the range is thus determined. Typically, however, the car could be driven slowly, without expending energy at the rate required for the accelerations of the driving cycle, for several additional miles. If the car is driven during colder weather (32°F instead of 80°F), the car range could be reduced roughly 25 percent. Obviously, as the battery nears the end of its life, acceleration and range are reduced.

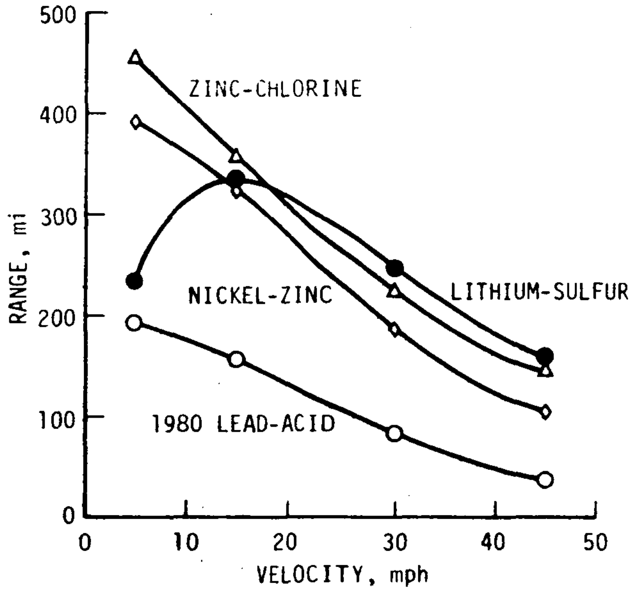
6.4 RANGE IMPROVEMENT

Because of manufacturing lead times, we do not anticipate substantial increases in range over those shown in Fig. 6.2. For the 1980 period, the various schemes often suggested to improve the range of cars using lead-acid batteries are more complex and difficult to bring to production. As much as a 30-percent improvement in the estimated range, however, is a clear possibility. For instance, ESB (Electric Storage Battery Inc.) has been proposing a flywheel-battery combination.[48] They believe that an Algeir hydro-mechanical transmission is available in concept (due to the existence of a 15-horsepower production unit) which has a speed range continuously variable from full speed forward to full speed in reverse, yet with very high efficiency. They propose to drive the flywheel from batteries with a small DC motor at a maximum power level corresponding to the average energy requirement. This would allow the batteries to operate

VEHICLE RANGE AT CONSTANT SPEEDS

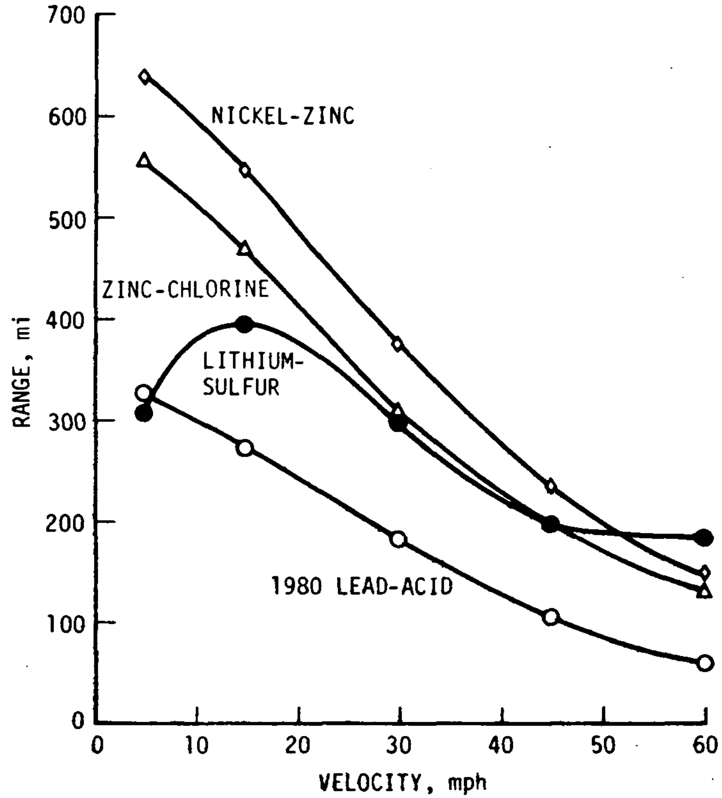
TWO-PASSENGER CAR

	LEAD-ACID	NICKEL-ZINC	ZINC-CHLORINE	LITHIUM-SULFUR
CURB WEIGHT, lb	1800	1685	1580	1430
TEST WEIGHT, lb	2100	1985	1880	1730
BATTERY WEIGHT, lb	550	435	340	200



FOUR-PASSENGER CAR

	LEAD-ACID	NICKEL-ZINC	ZINC-CHLORINE	LITHIUM-SULFUR
CURB WEIGHT, lb	3525	3080	2500	2205
TEST WEIGHT, lb	3975	3530	2950	2655
BATTERY WEIGHT, lb	1500	1090	570	300



AN-43031

Figure 6.3. Constant Speed Driving Range for Cars with Future Storage Batteries

at the lowest practical power density and, therefore, the highest possible energy density, which would extend battery life and driving range. The flywheel would be connected to the variable-speed hydro-mechanical transmission and, in turn, to the driving wheels. With such a transmission almost any power level could be achieved for acceleration performance, although the battery would supply power only at an average level. A further feature of the system is that during deceleration the transmission could regenerate energy into the flywheel. Regeneration into a battery system is not as efficient and tends to shorten battery life due to rapid charging. Since the system is currently in prototype, tests have not yet been run, but computer analysis indicates a 30-percent improvement in range will result.

Another often-discussed possibility is a hybrid-electric car which incorporates an internal-combustion engine to supply energy for battery recharging and propulsion. A variety of possibilities have been suggested for hybrid combinations of different types. Most of these have emphasized current performance requirements for the purposes of reducing engine emissions and increasing battery range while preserving the possibilities for all-electric operation. The two systems most frequently considered are the parallel and series hybrids. In the former, the engine or the motor, or both, may be used to drive the vehicle, while in the latter the engine drives a generator which, in turn, augments battery power during acceleration and provides some degree of recharge during operation. Both systems have been extensively pursued and reported;* although this configuration is beyond the scope of this study, the following comments are in order: possibilities exist for substantial improvement in performance and range. They do have the disadvantages of some increased complexity.

---

*By Aerospace Corporation, TRW, and Minicars, among others.

7 SELECTION OF DRIVING RANGE

The basic parametric car descriptions of Sec. 6 are inadequate to support a comprehensive study of the impacts of electric car use. Specific battery weights, car weights, and ranges must be chosen in order to keep the impact analysis bounded to a reasonable extent.

The basic factors in range selection are patterns of use on the one hand, and economic costs on the other. The greater the range between recharges, the more generally useful the car will be. Long range, however, necessitates a heavy and expensive battery which may impair car driveability and increase battery depreciation costs to undesirable levels.

Concurrent with this characterization of electric cars, an analysis of automobile usage was conducted separately within the overall impact study. Data on actual daily driving range, however, was not available in time for the choice of electric car range here. Accordingly, usage data from the literature was employed.[49] Though synthetic, it offers a reasonable guide, as shown in Fig. 7.1. Especially for automobiles in the 3000-mile-per-year (MPY) and 6000 MPY categories, increasing ranges up to about 50 miles dramatically reduce the fraction of days on which the driving range will be inadequate. At longer ranges, however, relatively little is gained by doubling range and battery weight.

7.1 LEAD-ACID BATTERY CARS

The limitations of lead-acid storage batteries make driving range expensive to obtain, both in amortization costs and in driveability. To support selection of driving ranges for the lead-acid battery cars, the following preliminary analysis was made of depreciation and energy costs as a function of battery weight and daily range.

There are a number of factors which influence the calculation of battery depreciation. Each is dependent upon battery design, construction, environment, and usage. Little or no reliable information is

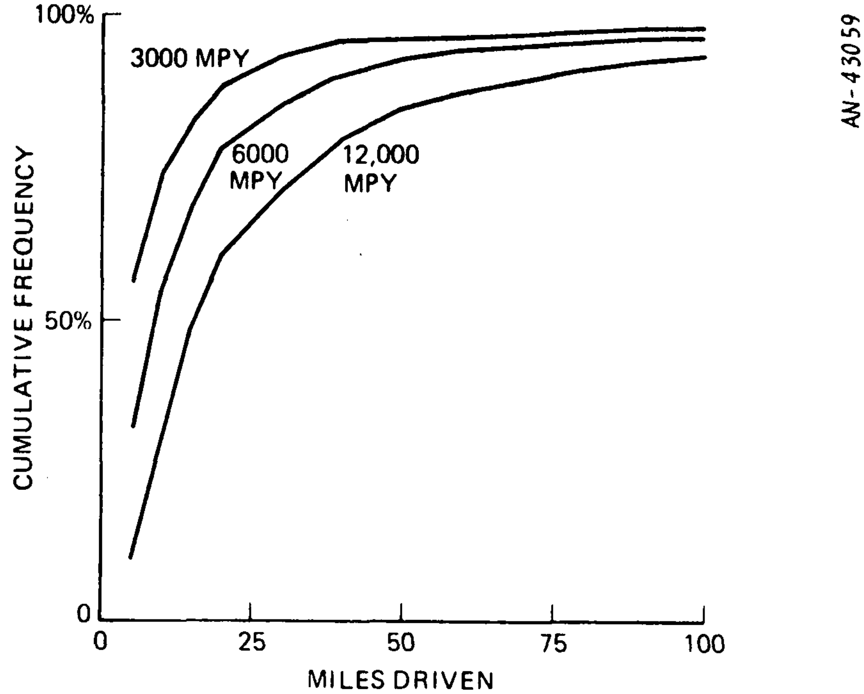


Figure 7.1. Cumulative Frequency of Daily Auto Usage

available which would allow us to characterize the best electric vehicle battery which might be available in the 1980s. Even to the extent that characterizing information is available, there is little likelihood of being able to identify usage and its relationship to depreciation. As a result, a large amount of speculation and judgment is unavoidably included in this discussion.

Battery life is dependent on depth of discharge, rate of discharge, rate of charge, amount of overcharge, methods for sustaining charge, and environmental characteristics. For instance, leaving the battery connected in a trickle charge mode produces positive grid corrosion, while long periods of inactivity without charging produce sulfation. Both limit battery life.

Figure 5.3 illustrated the cycle life as a function of depth of discharge and as a function of range utilization for the "poorest" and "best" electric vehicle battery. Actually, the "best" estimate is based on a laminar grid battery, taking into account (by judgment) the effects of consumer usage and charging equipment commensurate with such usage. The "poorest" is a 1967 estimate of 1972 battery performance of the Delco 512 type. In the remaining discussion we have utilized the "best" curve. Figures 7.2 and 7.3 are the estimated maximum ranges for the two- and four-passenger vehicles, respectively, as a function of battery weight. The calculations leading to these curves are described in Sec. 6.

It was estimated in 1967[50] that the 1972 battery cost per pound to an original equipment manufacturer would be in the 35-cent-per-pound range. Since the retail price is 2-1/2 times the OEM price, the cost of a replacement battery in 1973 dollars is likely to be of the order of 90 cents per pound. Figure 7.1 is an estimate of the "cumulative frequency of daily auto usage" with three different yearly ranges. If we assumed that battery weight determines the maximum range and that average daily usage would be calculated by dividing the yearly usage by 365, we can determine the daily percent utilization of range. From Fig. 5.3, we can also determine the cycle life for various usages, and by dividing the price of the battery by the cycle life, determine the cost per cycle, and by dividing that by the cycle range, the cost per mile.

The assumption was made that the battery providing the best range (EV-140) could somehow be coupled with the best (LEV-115) cycle life, although in fact the greater ranges are associated with the poorer cycle and vice versa. (This is the measure of optimism built into the results.) Figure 7.4 illustrates the cost per mile for battery depreciation as a function of battery weight for the two-passenger car for the three different usage levels and Fig. 7.5 is the equivalent information for the four-passenger car. It should be noted that in each case a minimum cost per mile is achieved on the 12,000-mile-per-year usage for battery weights providing maximum range (with high battery performance) of almost 50 miles, about 50 percent greater than average daily usage.

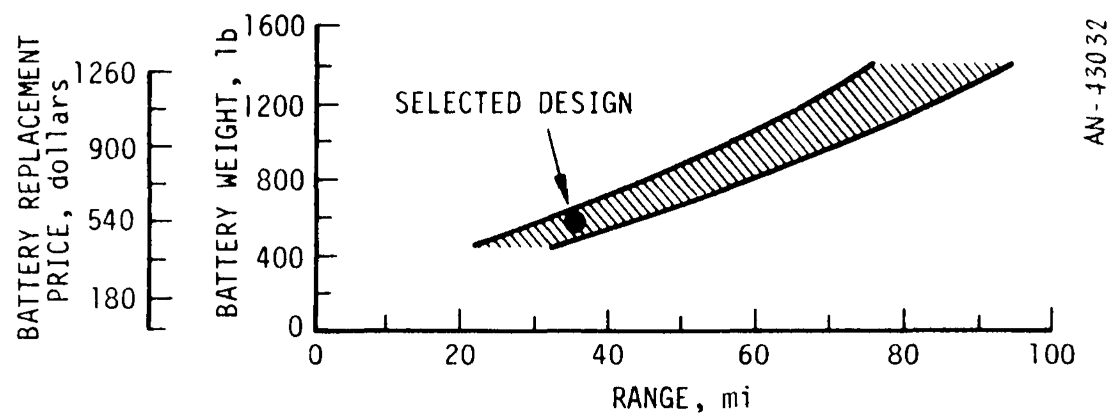


Figure 7.2. Two-Passenger Car Maximum Range on the SAE Residential Driving Cycle as a Function of Lead-Acid Battery Weight and Cost

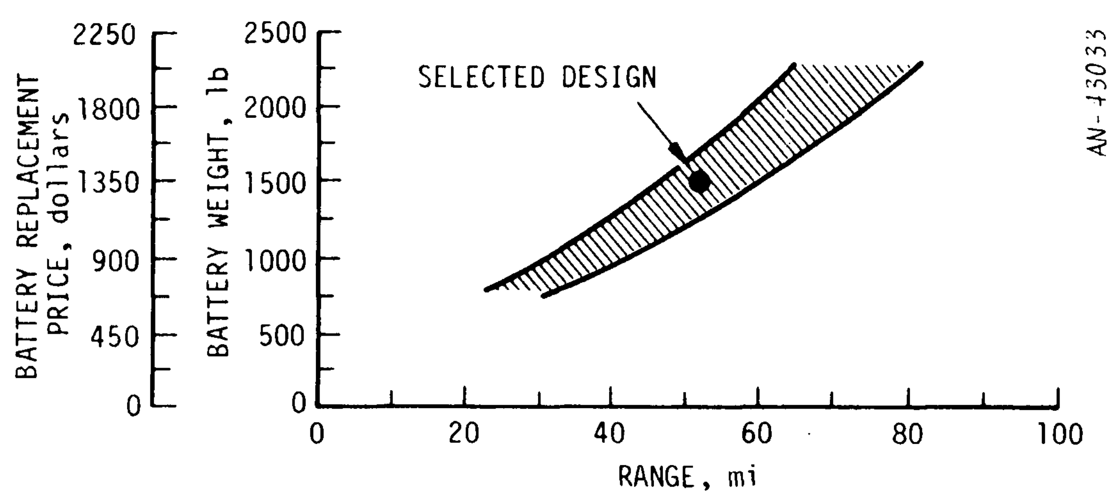


Figure 7.3. Four-Passenger Car Maximum Range on the SAE Metropolitan Area Driving Cycle as a Function of Lead-Acid Battery Weight and Cost

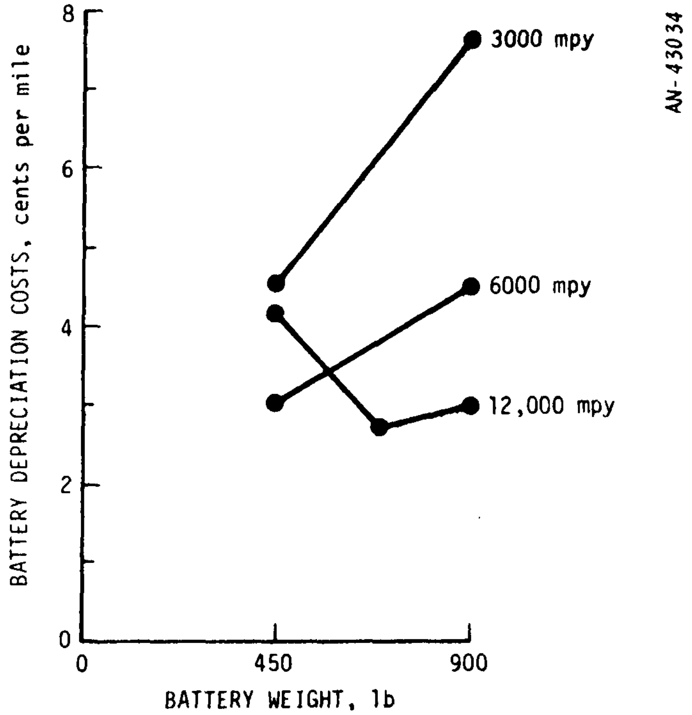


Figure 7.4. Two-Passenger Car Lead-Acid Battery Depreciation Costs Versus Battery Weight for Average Usage

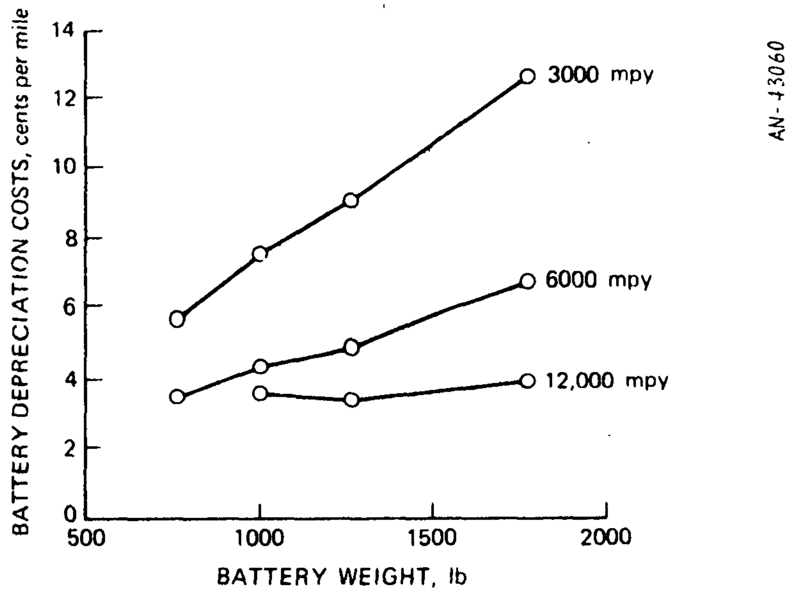


Figure 7.5. Four-Passenger Car Lead-Acid Battery Depreciation Costs Versus Battery Weight for Average Usage

As will be shown in Sec. 8, energy costs for these electric cars are relatively low. The depreciation costs of Figs. 7.4 and 7.5 are thus likely to dominate operating costs. Overall, then, range selection boils down to a tradeoff between the cost of battery depreciation and the applicability of the car to typical daily driving patterns. The longer-range cars are adequate for more driving days and more usage classes in Fig. 7.1; but longer range increases battery weight, with increased battery depreciation costs unless most of the range capability is used on the average day.

The four-passenger car with lead-acid batteries is intended for wide application, in the 6,000-12,000 mile per year range (the average US car is driven about 10,000 miles per year). Figure 7.1 shows that daily ranges of at least 50-100 miles are desirable for applicability to a large percentage of driving days in these usage classes. Figure 7.5 shows that at 12,000 miles per year usage, depreciation costs are almost independent of battery weight, but at 6,000 miles per year usage, they rise substantially with battery weight as range increases from 50-75 miles and beyond. A battery weight of 1,500 pounds, giving a range of about 55 miles, was selected for impact study. Even with the optimistic battery life assumptions of Fig. 7.4, this results in battery depreciation costs in the vicinity of 5 cents per mile at usages of 6,000 miles per year.

The two-passenger with lead-acid batteries is intended for very limited application, to local driving off freeways and major highways. Average annual usage is likely to be in the 3,000-to-6,000-mile range. Battery weight of 550 pounds and a maximum range of 35 miles were selected for this car. At 3,000 miles per year, this also results in 5 cents per mile battery depreciation costs. At 6,000 miles per year, depreciation would be less, but in either case, the depreciation cost is high considering the limited accommodations and performance offered.

This preliminary review of depreciation costs and range requirements is not, of course, intended to be definitive. Both subjects are major topics for further analysis in this study of electric car impacts.*

7.2 OTHER BATTERY CARS

For the other battery cars of Sec. 6, higher battery energy density allowed selection of a nominal range of 145 miles. This appears to be a reasonable minimum for general urban driving applications: it is adequate, according to Fig. 7.1, for almost 95 percent of days for cars driven 12,000 miles per year or less, which includes some 70 percent of all cars. For the limited-capability two-passenger cars, this may seem excessive; but except in the case of nickel-zinc batteries, the battery packs are so small already that there is relatively little left to be gained by further reduction in size. In the case of the more expensive nickel-zinc battery, driving range was reduced for the two-passenger car as far as battery power limitations permitted. At ranges much below 100 miles, available battery power becomes insufficient for this car to follow the SAE Residential Driving Cycle.

Table 7.1 summarizes the weights of selected cars, together with ranges between recharge calculated as in Sec. 6.

*See Task Reports 9 and 10 (Vol. 3).

TABLE 7.1

CHARACTERISTICS OF SELECTED CARS

Battery Type	Two-Passenger Cars				Four-Passenger Cars			
	Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur	Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur
Vehicle Curb Weight, lb	1,800	1,085	1,580	1,430	3,625	3,080	2,500	2,205
Battery Weight, lb	550	435	340	200	1,500	1,090	570	300
Nominal Battery Energy, KWH	12.6	23.5	25.7	28	34.5	58.9	43.1	42
Urban Driving Range, mi	35	100	144	144	54	144	145	139
30 mph Range, mi	82	188	226	247	183	375	309	317

8 ENERGY AND MATERIAL REQUIREMENTS

8.1 ENERGY REQUIREMENTS

As described in Sec. 6, the simulation used to determine driving ranges of electric cars included a model of power demanded from the car battery, and the battery discharge in providing this power. Energy supplied by the battery per mile of driving is automatically calculated by this model. Determination of overall energy required per mile of electric car operation requires two additional steps: estimation of charging energy which must be supplied to the battery to restore it to the fully charged state, and estimation of the efficiency with which power-line energy is transformed to battery charging energy.

Table 8.1 shows energy supplied by the various car batteries per mile of driving, together with estimated power-line energy required per mile during recharge, and consequent battery efficiency. Charger efficiency, assumed to be 97 percent, is not included in the battery efficiency; combined charger and battery efficiency is equal to the energy delivered as a percent of power-line energy supplied. Because battery efficiency data in Sec. 5 varies, the entries for efficiency and overall consumption in Table 8.1 were determined by different methods for the different batteries.

For the lead-acid battery, it was assumed that the recharging process was 83 percent efficient, as shown in Sec. 5.1 from Fig. 5.4, and that energy to be replaced after discharge in the driving cycle was equal to that available at the 20-hour discharge rate. This last is a questionable assumption: during the driving cycle, which involves periods at relatively high power, Fig. 5.2 shows that considerably less energy is actually available from the battery than could be obtained at the 20-hour rate; how much of the difference is dissipated during discharge and how much remains stored in chemical form is the issue. Transient polarization and subsequent recuperation phenomena are well known in lead-acid

TABLE 8.1

ESTIMATED ENERGY REQUIREMENTS

	Energy Input to Battery Charger,* KWH per Mile	Battery Efficiency, Percent	Battery Energy Output,** KWH per Mile
Two-Passenger Car			
Lead-Acid	0.44	42	0.18
Nickel-Zinc	0.30	62	0.18
Zinc-Chlorine	0.25	70	0.17
Lithium-Sulfur†	0.32	54	0.17
Four-Passenger Car			
Lead-Acid	0.79	46	0.35
Nickel-Zinc	0.51	66	0.33
Zinc-Chlorine	0.41	70	0.28
Lithium-Sulfur†	0.45	80	0.27

*Charger efficiency: 97 percent.

**Calculated SAE Residential Driving Cycle for two-passenger cars, on SAE Metropolitan Area Driving Cycle for four-passenger cars.

†Charging input energy includes an allowance for maintaining battery temperature while idle; see text.

batteries; clearly, then, some fraction of the 20-hour energy not available at higher rates remains stored in the battery after the car reaches maximum range in the driving cycle. Since the battery discharge model is insufficiently detailed to reveal this remaining energy, the only verification of the accuracy of the full-discharge assumption is a comparison with test results. Table 8.2 shows reported recharge energy per mile for various electric cars in actual tests, as well as for the four-passenger lead-acid car of this characterization. It also shows energy consumption per mile per pound of car test weight, a parameter which should be

TABLE 8.2

COMPARATIVE ENERGY USAGE OF LEAD-ACID BATTERY CARS

	Energy Use, KWH/mi			Specific Energy Use, W·hr/mi/lb	
Car	Test Weight, Pounds	30 mph	Urban Driving*	30 mph	Urban Driving*
GM 512[13]	1,650	0.196		0.119	
ESB Sundancer[32]	2,000		0.31-0.37		0.155-0.185
EFP Mars II[51]	4,650	0.4		0.086	
EFP Electrosport[52]	5,980	0.447		0.075	
Four-Passenger Characterization	3,975	0.234	0.79	0.059	0.199

*SAE Metropolitan Area Driving Cycle (J 227).

approximately constant from car to car on the same driving cycle, whether at a constant 30 mph or in a driving cycle. The specific energy consumption of the characterization appears a bit low at 30 mph, but in urban driving it is about 10 percent higher than the upper end of the range reported for the ESB Sundancer, a car with similar total driving range, battery performance, and high-efficiency design. The implication is that some energy does remain in the battery which need not be replaced during recharge, but the assumption of full replacement is not seriously in error. Accordingly, the resultant energy consumptions are used without further modification.

For the nickel-zinc battery, the recharge efficiency was assumed to be the same as the lead-acid battery, 83 percent, and required recharge energy at the battery terminals was assumed to be that available in a 20-hour discharge. With the battery charger efficiency of 97 percent, the overall system efficiency is that shown in Table 8.2, from which the energy input figures were derived. It is much higher than that of the lead-acid battery because performance degrades less under increasing load, as is clear from Fig. 5.8.

For the zinc-chlorine battery described in Fig. 5.13, energy available on discharge is nearly 95% of that available at the 20-hour rate, suggesting improved efficiency. Overall energy efficiency in vehicular use, however, is projected at 70 percent by the developers. This figure has been adopted in Table 8.2. How the 30-percent energy loss is allocated among battery system elements has been largely documented by the developers, as follows: 9 percent to the refrigeration required to form chlorine hydrate during recharge; 2 percent to pumping of the electrolyte during charge and discharge; 1 percent per day to static self-discharge; 5 percent to coulombic inefficiency. To this may be added the 5-percent loss during discharge implicit in Fig. 5.13.

According to the developer, the lithium-sulfur battery may reach 80 percent charge-discharge efficiency. Published data on early laboratory charge and discharge histories suggests this optimistic goal may be met: charge voltage is approximately 20 percent above discharge voltage over a considerable range of charge, with 95 percent coulombic efficiency. Energy available in discharge is relatively high, as Fig. 5.16 shows, for a wide range of specific power levels. Heater power to maintain battery temperature, however, exacts a considerable toll from overall system efficiency. Approximately 200 watts of heater power are estimated to be required. It is assumed that this requirement is obviated by internal losses during the hour of daily operation and the 8 hours of daily recharge, so that only 15 hours of heater operation are required, for a total of 3 KWH per day. Since the typical daily driving distance is 30 miles, this is a substantial quantity relative to energy delivery requirements, which are 5.1 KWH for the two-passenger car and 8.1 KWH for the four-passenger car. Heater energy will be supplied during battery recharge, increasing requirements accordingly. Energy requirements shown in Table 8.2 for lithium-sulfur batteries assume 80 percent basic efficiency, with average daily driving and heating loads as noted above.

8.2 MATERIAL REQUIREMENT

Except for the power source, the materials used for the electric vehicles characterized in this report would be similar to those of the present-day automobile. Thus, differences would primarily be those arising as an electric motor, motor controls, and a battery power pack are substituted for an internal-combustion engine system. Tables 8.3, 8.4, and 8.5 give a breakdown of the materials added by each of the electric power train components. Table 8.6 shows the materials eliminated due to removal of the internal combustion engine system.

TABLE 8.3

BATTERY MATERIAL WEIGHTS (pounds per car)

	Two-Passenger Car	Four-Passenger Car
Lead-Acid Battery		
Lead	176	481
Lead-Oxide	180	489
Antimony	9	24
Electrolyte	156	426
Polypropylene	20	56
Filled Polyethylene	7	20
Epoxy	2	4
Total Weight	550	1500
Nickel-Zinc Battery		
Nickel	145	362
Zinc Oxide	130	328
Potassium Hydroxide	44	109
Electrolyte	39	96
Polypropylene Oxide	26	64
Plastic Separators	13	33
Band and Terminals (Copper or Nickel)	4	11
Miscellaneous	34	87
Total Weight	435	1090
Zinc-Chlorine Battery		
Zinc	38	64
Chlorine	41	69
Water	119	200
Titanium	20	34
Frames, Electrodes, Mountings	20	34
Heat Exchanger (Titanium and Coolant)	11	17
Support Structure	11	17
Miscellaneous	80	135
Total Weight	340	570
Lithium-Sulfur Battery		
Lithium	11	17
Sulfur	45	66
Electrolyte	42	63
Porous Graphite	15	23
Porous Stainless Steel	19	29
Stainless Steel Housing	40	61
Aluminum Casing	5	7
Thermal Insulation	11	16
Insulation, Connectors, Misc.	12	18
Total Weight	200	300

TABLE 8.4

ELECTRIC MOTOR MATERIAL WEIGHTS

(pounds per car)

	Two-Passenger Car	Four-Passenger Car
Copper	17.5	47.2
Iron	70.2	189.0
Steel	14.0	37.9
Aluminum	10.7	31.5
Solder, Connectors, Misc.	4.6	9.4
Total	117.0	315.0

TABLE 8.5

CONTROLLER MATERIAL WEIGHTS

(pounds per car)

	Two-Passenger Car	Four-Passenger Car
Copper	3.3	8.5
Steel	11.5	29.8
Aluminum	8.3	21.2
Solid State Devices	3.3	8.5
Plastics	3.3	8.5
Solder, Connectors, Misc.	3.3	8.5
Total	33.0	85.0

TABLE 8.6

GASOLINE POWER MATERIAL WEIGHTS ELIMINATED BY CONVERSION TO BATTERY POWER

(pounds per car)

	Two-Passenger Car	Four-Passenger Car
Steel	95	180
Iron	91	175
Aluminum	4	8
Copper	6	10
Plastics	16	30
Misc.	38	72
Total	250	475

APPENDIX

COMPUTER PROGRAMS

A.1 INTRODUCTION

Three computer programs have been developed for the purpose of performing electric car parametric studies. The major parameter of interest is the vehicle range when driven according to various set driving cycles. The three programs differ only by virtue of the driving cycle used. The three programs are ELCP1, ELCP2, and ELCP3. They are based on the DHEW Federal Driving Cycle, and the Residential and Metropolitan Area Driving Cycles of SAEJ227, respectively.

The computer programs use the driving cycle in the form of velocity at finite time data to determine the vehicle power requirements. The power requirements are then used to discharge the batteries with a dynamic load profile. The driving cycle simulation is then continued until the battery cannot fulfill the cycling power requirements.

The range of the vehicle under any particular driving cycle is reached when the battery can no longer supply the power required to complete a cycle.

A.2 DESCRIPTION

Calculations used in these programs are widely employed in automotive studies.[53] The vehicle load calculations proceed on an iteration period of 2 seconds. The acceleration is simply

$$A = DV/dt$$

The rolling resistance R_R is given by

$$R_R = W/50[1 + (1.4 \times 10^{-3}V) + (1.2 \times 10^{-5}V^2)] \qquad (1b)$$

where V = vehicle velocity in ft/s

W = vehicle weight in lb

The air drag resistance R_d is given by

$$R_d = 0.00119A_oC_dV^2$$

where A_o = frontal area in ft^2

C_d = drag coefficient

The acceleration resistance R_A is given by

$$R_A = (W/32.2)A$$

The resistance due to roadway slope R_S is given by

$$R_S = W(A1/100)$$

where $A1$ = percentage of slope

The road power is then calculated as

$$P = V(R_R + R_d + R_S + 1.1R_A)$$

where the 1.1 factor on the acceleration load is used to approximate the rotary acceleration load.

The power required from the battery is calculated as P_B

$$P_B = P/(E_M E_E) + P_A/E_A$$

where E_M = mechanical drive efficiency

E_E = electrical drive efficiency

P_A = accessory power

E_A = electrical accessory efficiency

The battery discharge data required comes in the form of a plot of specific power versus specific energy. This curve, taken from experimental constant discharge data, is then put into the computer program.

The power required in the cycle is then used to discharge the battery by relating the power requirement to the energy availability. This is accomplished by comparing energy required and energy available from the battery.[54] As the vehicle uses energy traveling through the cycle, the battery is discharged as follows:

$$K = \sum \frac{P_B \, dt}{E_A}$$

where K = percent battery energy used divided by 100

E_A = energy available at P_B , watts

and E_A is determined from the battery power and energy density curves.

The battery is considered discharged to its cutoff voltage when K = 1.

The computer programs are written in the BASIC computer language. Input variables for the program include:

vehicle weight

frontal area

drag coefficient
battery weight
battery specific power versus specific energy
rolling resistance formula
accessory power
driving cycle
electrical and mechanical efficiencies
regenerative braking effects
slope effects

The output of the program includes the range in miles, running time in hours, and the energy expended in watt-hours.

These input variables are exercised parametrically to determine their independent and interdependent effect on vehicle range.

The program outputs in the form of vehicle ranges and power usage may be plotted against the various input trends. This will be useful in projecting vehicle type usage on the basis of electrical vehicle competitiveness.

COMPUTER PROGRAM SYMBOLS LIST

A	vehicle acceleration, mph/s
A0	frontal area, ft^2
A1	slope, percentage grade
B	regenerative braking factor, percent
C	drag coefficient
E	mechanical drive efficiency
E0	electrical drive efficiency
E1	electrical accessory efficiency
E2	total energy regenerated
H	highest power requirement
I	time, seconds
J	velocity at previous time interval, ft/s
K	percent of battery power used/100
L	data time counter
M	number of data points in cycle
M1	total travel range, miles
N	estimated number of seconds required
P	power required from battery, ft·lb/s
P0	motive power, ft·lb/s
P1	accessory power, watts
P2	power required from battery, watts
P3	W·hr available at present discharge rate
P4	W·hr/lb available from battery
R	rolling resistance, lb
R0	air drag resistance, lb
R1	slope or grade resistance, lb
R2	linear acceleration force, lb
T	cycle time of highest power requirement, seconds
T0	total run time, hours
T1	calculation interval (dt), seconds
V	velocity, ft/s

Computer Program Symbols List (Cont.)

V1	velocity, mph
V2	velocity, km/hr
W	vehicle weight, lb
W0	total energy expended, W•hr
X	specific power, W/lb
Y	battery energy density, W•hr/lb
Z	battery power density W/lb
S	number of data sets of battery
W1	battery weight, lb

ELCP1, BASIC Language Computer Program

for simulating electric vehicle performance on
the DHEW Federal driving cycle.

AN EXAMPLE OF A COMPUTER RUN USING THE FEDERAL DRIVING CYCLE

ELCP1 16:51PDT 10/02/73

POWER REQUIREMENTS FOR FEDERAL DRIV. CYCLE

*****INPUT PARAMETERS*****

WEIGHT POUNDS	FRONTAL AREA SQUARE FEET	DRAG COEFF.	BATTERY WT. POUNDS	ACCESSORY POWER WATTS
3075	22	0.3	750	0

EFFICIENCIES:

MECHANICAL	ELEC.DRIVE	ELEC. ACESS.
0.9	0.8	0.8

REGEN. BRAKING POWER FACTOR = 0 %

NO SLOPES NEGOTIATED

*****OUTPUT*****

TOT. ENERGY WATT-HOURS	PEAK POWER WATTS	AT TIME SECONDS	RANGE MILES	RUNNING TIME HOURS
5605.92	49358.	196	17.1211	0.845

ELCP1 11/12/74

```
100 DIM Z(100),Y(100)
105 READ B,W1
110 READ W,C,A0,A1
120 READ E,E0,E1,P1
150 PRINT"   POWER REQUIREMENTS FOR FEDERAL DRIV. CYCLE"
160 PRINT
170 PRINT "*****INPUT PARAMETERS*****"
180 PRINT
190 PRINT "WEIGHT    FRONTAL AREA    DRAG COEFF.    BATTERY WT.";
200 PRINT "  ACCESSORY POWER"
210 PRINT "POUNDS      SQUARE FEET                    POUNDS";
220 PRINT "       WATTS"
240 PRINT W,A0,C,W1,P1
250 PRINT
260 PRINT "      EFFICIENCIES:"
270 PRINT "MECHANICAL   ELEC.DRIVE   ELEC. ACESS."
280 PRINT E,E0,E1
290 PRINT
300 PRINT "REGEN. BRAKING POWER FACTOR = ";B;" %"
310 PRINT
320 IF A1=0 THEN 350
330 PRINT "  SLOPES ARE NEGOTIATED"
340 GO TO 430
350 PRINT "  NO SLOPES NEGOTIATED"
370 PRINT
430 J=W0=H=E2=0
440 E3=0
450 K=M1=0
460 DIM S(1400)
470 READ N,M,T1
475 READ Q
476 MAT READ Z(Q),Y(Q)
480 FOR L=1 TO(M+1)
490 READ S(L)
500 NEXT L
510 FOR I2=1 TO N
520 FOR L=1 TO (M+1) STEP T1
530 I0=(L-1)
540 I=I0+I3
550 V=S(L)*1.4667
560 A=(V-J)/T1
570 J=V
580 V2=S(L)*1.609
590 R=(W/50)*(1+.0014*V+.000012*V^2)
591 R=.46*R
600 R0=.00119*C*A0*V^2
610 R1=W*(A1/100)
620 R2=(W/32.2)*A
630 IF R2<0 THEN 650
640 GO TO 670
```

```
650 R3=(B/100)*R2
670 P0=V*(R+R0+R1+1.1*R2)
672 IF P0<0 THEN 676
674 GO TO 680
676 P0=V*R3
680 P=P0/(E*E0)+P1/E1
690 P2=P*1.356
700 W0=W0+P2/(3600/T1)
710 IF I>M THEN 760
720 IF P2>H THEN 740
730 GO TO 760
740 H=P2
750 T=I
760 X=P2/W1
770 GOSUB 9000
780 P4=F
800 P3=P4*W1
801 M1=M1+(V/5280)*T1
810 K=K+(P2*T1/3600)/P3
820 IF K>=1 THEN 920
880 NEXT L
890 I3=I3+(M+1)
900 NEXT I2
910 GO TO 2130
920 T0=I/3600
930 PRINT
940 PRINT "*****OUTPUT*****"
950 PRINT
960 PRINT "TOT. ENERGY    PEAK POWER     AT TIME          RANGE";
970 PRINT "          RUNNING TIME"
980 PRINT "WATT-HOURS        WATTS        SECONDS            MILES";
990 PRINT "            HOURS"
1000 PRINT W0,H,T,M1,T0
1010 GO TO 2150
1020 DATA 0,570
1030 DATA 2950,.4,22,0
1040 DATA .9,.8,.8,0
1050 DATA 16,1370,2
1052 DATA 6
1054 DATA 0,18,35,65,114,114
1056 DATA 75.7,73.5,71.4,67.1,58.6,0
1060 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1070 DATA 2.7,5.1,7.5,10.4,14.4,16.6,18.3,19,20.2,21.8
1080 DATA 22.1,22.3,22,21.5,21.1,20.7,19.9,17.5,15.2,15
1090 DATA 15.1,15.2,15.7,16.6,16.6,20.5,22.2,22.8,22.6,22.5
1100 DATA 21.5,19.3,17.7,16.1,15.5,16.8,18.5,20.5,22.4,
1110 DATA 23.8,24.2,24.6,24.8,24.6,24.4,24.5,24.5,24.5,24.5
1120 DATA 24.6,24.8,25.1,25.4,25.4,25.2,25.1,25.2,25.7,26.26
1130 DATA 26,26.2,27,28,29,29.3,29.7,30,30.4,30.5,30.4,30.3
1140 DATA 30.3,30.2,30.3,30.5,30.1,29.7,29.7,29.9,30.2,30.6
```

```
1150 DATA 30.8,30.8,30.3,29.9.29.8,29.9,30.3,30.9,31.3,32,32
1160 DATA 32,31.9,31,28.7,24.6,20,15.3,11.7,6.5,2.8,0,0,0,0
1170 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1180 DATA 0,0,0,0,0,0,0,0,0,0,0,.2,4.9,6,14.3,16.5,20,22.4,24.2
1190 DATA 25.7,26.5,25.9,25.5,25,25.1,25.5,25.7,26,27,26.4
1200 DATA 24.8,22.2,19.6,18,17.6,18.5,18.8,20.3,22.5,24.9,27.8
1210 DATA 31,34.3,36.4,37.8,39.4,40.8,42,43.7,44.9,45.8,46.5
1220 DATA 47.2,47.2,47.1,47.1,47,47,47,47,47,47,47.2,47.8,48.2
1230 DATA 48.7,49.2,49.7,50.2,50.6,51.1,52.2,53.2,53.9,54.3,54.5
1240 DATA 54.8,54.8,54.4,54.4,54.6,54.9,55.2,55.4,55.8,55.9,56
1250 DATA 56.1,56.2,56.2,56.3,56.3,56.2,56.2,56.2,56.1,56,55.7,55.1
1260 DATA 54.8,54.3,54.1,53.8,53.7,53.7,53.8,53.9,54,53.8,53.4
1270 DATA 53.1,52.8,52.2,52.1,52,51.8,51.6,51.5,51.4,51.5
1280 DATA 51.8,52,52.6,53.2,53.8,54.2,54.9,55.2,55.5,55.7,55.5,55.2
1290 DATA 54.7,53.9,53,51.8,51.4,51.2,51.2,50.4,49.8,49.3,49.9
1300 DATA 49.7,49.5,49.4,49.3,49.2,48.9,48,47.6,46.8,45.4,44.3
1310 DATA 43.1,42,40.7,39.5,38,36.4,34.6,33.2,32.1,31.1,30.8
1320 DATA 30.8,30,28.5,26,23.5,21.1,20,18.9,17.7,16.2,13.8,11.5
1330 DATA 8.6,6,1.5,.2,0,0,0,0,0,0,0,0,0,0,0,0,.2,7.2,10.7
1340 DATA 13.5,16.5,18.9,21,23.2,24.6,26.1,28,29.1,30.7,31.1
1350 DATA 31.8,32.5,33.2,33.9,34.2,34.7,34.3,34.1,34.5,35.2
1360 DATA 35.8,35.7,35.8,35.9,36,36.1,36.1,36.2,36.2,36.1,36
1370 DATA 35.3,34.5,33.6,31.5,28,25.3,23,20.2,17,14.3,11.2,
1380 DATA 7.5,4,.8,0,0,0,0,0,0,2.1,6,10.6,14,16.9,20,23,24.7
1390 DATA 25.8,27.6,29.2,29.8,30,29.8,29.5,29.2,28.7,27.5
1400 DATA 24.8,21,17,13.4,10,5.3,1.5,0,0,0,0,0,0,0,0,0,0,0,0
1410 DATA 0,0,0,0,0,.3,3,8,13,14.5,17,20.1,22.5,25.2,27.1
1420 DATA 28.1,30.3,32.1,33,34.1,35,35.3,35.8,35.9,36,36
1430 DATA 35.9,35.8,35.8,35.9,35.8,35.7,35.5,35.4,35.2,35.2
1440 DATA 35.2,35.2,35.2,35.1,35,35,35,35,35,35,35,34.9
1450 DATA 34.9,34.9,34,33.2,31.5,29.5,27.5,25,22,18.9,15.5,12.5
1460 DATA 10,6.2,2.5,0,1,3.2,5,6.1,7.8,9,10,11,13.2,15.3,16.9
1470 DATA 18,19.1,20.3,21.2,22.2,23.3,23.9,24.5,25.1,25.1
1480 DATA 25.1,25.1,25.1,25.1,25.5,26,26,25.9,25.8,25.5,25.2
1490 DATA 25.2,25,24.8,24.5,23.5,17.5,12,7.5,1.8,0,0,0,0,0,0,0
1500 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,2.5,5.3,8.5,12.2,14.9
1510 DATA 15.7,16.9,17.1,17,17.5,18,18,17.9,17.9,17.2,17.1
1520 DATA 17.1,17.2,17.1,17,17,17,17,17,17.2,18.2,18.8,20
1530 DATA 20.9,21,21.1,21.5,21.9,22.2,22.4,22.5,22.4,22.4,23.5
1540 DATA 25,26,26.5,27,27.4,27.8,24.8,19.5,16,11.3,.2,0,0,0
1550 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,.2,3.9
1560 DATA 6.6,9.3,11.3,13.5,14.3,16.3,18.2,20.2,21.6,22.9,24.2,
1570 DATA 25.1,25.4,25.8,26,26,26,25.9,26.2,26.6,26.3,25.1,25
1580 DATA 22.9,20.3,18,15.5,13.6,10.4,7.8,4.5,2.9,1.5,.1
1590 DATA 0,0,0,0,0,0,0,0,0,0,0,.1,.5,2.1,3.7,5.1,8,10.7,12.8
1600 DATA 14.3,15.2,16.8,16.7,16.5,17.5,18.8,20,20.7,22.2,25.2,22.1
1610 DATA 22.2,22.8,23.5,23,22.1,21.5,19.8,17.5,13.5,9.8,6.9,5,3.9,.3
1620 DATA 1.3,.2,2.5,6,9.2,12,13.7,15.6,17.5,19.3,21,22.5,24.2,25.4
1630 DATA 26.2,27,27.5,27.9,28.1,28.6,28.4,28.3,28.1,28,27.8,
1640 DATA 27.2,26.2,24,21.5,19.6,18,15.6,13.8,10.5,7.5,3.5,1.5
```

```
1650 DATA 1.5,1,0.2,5.2,8.8,12.5,15.4,17.5,18.3,19.20.5,
1660 DATA 21.9,23.2,24.8,26.2,27.2,28,28.2,28.8,29.1,29
1670 DATA 29,28.9,28.7,28.6,28.5,28.3,27.9,27.9,28,27.7,27.8,
1680 DATA 27.8,27.8,27.8,28,28.7,29.7,30.8,32,32.8,33,33.3,
1690 DATA 33.8,34.1,34,34,34,34,33.9,33.5,33.2,32.9,32.4,32,
1700 DATA 31.9,31.8,31.2,30.3,30,30,30,30,29.9,29.8,29.7,29.5,
1710 DATA 29.2,28.9,28.3,27.5,26.3,24.5,22.8,21.2,19.8,19.2
1720 DATA 20.2,21.1,21.7,22.2,23,23.6,24.6,25.2,26.2,26.3,26.8
1730 DATA 26.7,26.7,27.3,27.8,28.2,28.7,28.9,29,29.2,28.9,28.4
1740 DATA 28,27.5,26.2,25.3,25,25.1,25.3,25.5,25.7,26.2,26.8,
1750 DATA 27.4,28,29,29.3,29.2,29.1,29,28.9,28.9,28.8,28.4
1760 DATA 28.3,28,27.9,27.4,27.1,27.5,27.8,28,27.9,28,28,28.1,
1770 DATA 28,27.8,27.3,26.9,26.8,26.7,26.6,26.6,26.5,26.4,25.9
1780 DATA 25.8,25.8,25.8,26,26.1,25.5,24.2,22.6,22,21.8,22,22.5
1790 DATA 23,23.8,24.3,24.5,24.9,25.1,25.2,25.2,25.3,25.2,25,25
1800 DATA 25,24.9,24.8,24.7,24.5,24.5,24.9,25,24.9,24.9,24.2
1810 DATA 24.3,25.1,25.8,25.5,24,22,20,18.9,16.6,12.6,7.6,5,1.2
1820 DATA .1,0,0,.8,4.4,9,13.9,15.9,17.2,18.5,20,21.3,22.2,23,
1830 DATA 24.8,26.2,27.1,27.8,28.2,28.3,28.3,28.2,28,27.7,27.3
1840 DATA 27,26.8,26.2,26,25.3,24,22.7,21.7,21.8,22,22.5,22.9
1850 DATA 23,23,23,23,22.9,23,23.5,24.2,24.9,25.1,25.3,25.9,26
1860 DATA 25.6,25,24.5,23.9,23.7,23,22.7,22.2,21.8,21,13.8,15,
1870 DATA 11.2,7.2,3,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1880 DATA 0,0,0,0,0,0,0,0,0,0,1.5,4.6,8,11.2,14.2,17,18.2,19.9
1890 DATA 21.8,22.8,23.8,24.9,25.6,26.5,26.8,27.2,28,28.1,28
1900 DATA 27.7,27,26.9,26.4,24.8,22.5,21.8,21.1,18.8,15,12.9,
1910 DATA 11.1,10.8,10.2,9.7,9.3,9,8.9,9,9.8,9,8.7,8.3,7.2
1920 DATA 5.5,4.6,3.3,1.8,0,.3,.8,2.4,4,7.3,10.5,13.1,13.9,14.4
1930 DATA 16,18.1,19.8,20.9,21,21.1,21.2,21.6,22,22.7,23.3,24.3
1940 DATA 24.9,24.9,25,25.1,25.2,25.7,26,26.3,26.7,27,27,27,
1950 DATA 26.9,26.9,26.9,26.8,26.7,26.5,26.1,25.6,25.1,23.8,
1960 DATA 22.1,20.1,18.2,16.3,14.5,12.5,8.7,4.8,.6,0,0,0,0,0,
1970 DATA 0,0,0,0,0,0,0,0,0,0,.1,4.3,9.7,13.5,16.2,19.3,21.2
1980 DATA 23,23.6,23,22,19.5,16.6,11.6,7.5,3.5,.2,0,0,0,0
1990 DATA 0,0,0,0,0,0,0,1.2,5.4,8,8,10.9,12.5,12.8,13.1,
2000 DATA 12.9,13,13.1,13.5,14.2,15.4,17,19,20.2,21.7,21.8
2010 DATA 21.8,21.9,21.4,21.2,21.3,21.9,21.9,21.8,21.7,21.6,
2020 DATA 21.5,21.2,20.5,19.8,19.4,19.8,20,20,18.9,17,
2030 DATA 14.9,12.9,5,7.4,5.6,3.2,2.1,.1,0,0,0,0,0,0,0,.7,
2040 DATA 1.1,1.1,1.1,1.1,1.2,2.5,3.8,4.8,6,7.2,9,10.9,10.5
2050 DATA 9.5,8.4,8.1,9.7,12.5,15,18,20.3,21.3,22,22.5,23.5,
2060 DATA 24,24.3,24.6,24.2,24,23.7,23.5,23.5,23.5,23.6,23.7
2070 DATA 24,24.5,24.8,25,25.2,25.5,25.8,26,26.1,26.3,27.2,
2080 DATA 28,28.5,28.8,29,28.8,28.2,26.5,23.1,19.6
2090 DATA 15,9.3,4,.3,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
2100 DATA 0,0,0,0,0,0,0,1.8,5.6,9.7,12,14,15.8,17.5,19,19.9
2110 DATA 20.5,21.6,22,22.4,22.4,22,21.6,21.2,21,20,19.7,18.3
2120 DATA 17.2,16.2,15.2,13.5,11,7.8,5,1.5,0,0,0,0,0
2130 PRINT
2135 PRINT"OUTPUT:"
```

```
2140 PRINT"INCREASE ESTIMATED TIME ,N,TO DETERMINE RANGE."
2145 PRINT"TIME";TAB(17);"WATT-HRS";TAB(32);"MILES";TAB(49);"K"
2147 PRINT I,WO,MI,K
2150 STOP
9000 REM ROUTINE FOR PIECEWIZE LINEAR FUNCTION
9010 REM Z IS ARRAY OF ABSCISSA VALUES; Y IS ARRAY OF ORDINATE VALUES
9020 DEF FNC(D)=Y(D-1)+(Y(D)-Y(D-1))*(X-Z(D-1))/(Z(D)-Z(D-1))
9030 IF X>=Z(1) THEN 9060
9040 F=FNC(2)
9050 GO TO 9120
9060 FOR D=2 TO Q
9070 IF X>=Z(D) THEN 9100
9080 F=FNC(D)
9090 GO TO 9120
9100 NEXT D
9110 F=FNC(Q)
9120 RETURN
9160 END
```

ELCP2, BASIC Language Computer Program

for simulating electric vehicle performance
on the SAE Residential Driving Cycle.

AN EXAMPLE OF A COMPUTER RUN USING THE SAE RESIDENTIAL DRIVING CYCLE

ELCP2 17:31PDT 10/03/73

POWER REQUIREMENTS FOR SAE J227 RESID. DRIV. CYCLE

***** INPUT PARAMETERS *****

WEIGHT POUNDS	FRONTAL AREA SQUARE FEET	DRAG COEFF.	BATTERY WT POUNDS	ACCESSORY POWER WATTS
3030	18	0.4	1400	0

EFFICIENCIES:

MECHANICAL	ELEC. DRIVE	ELEC. ACCESS.
0.9	0.7	0.8

REGEN. BRAKING POWER FACTOR = 0 %

NO SLOPES NEGOTIATED

***** OUTPUT *****

TOT. ENERGY WATT-HOURS	PEAK POWER WATTS	AT TIME SECONDS	RANGE MILES	RUNNING TIME HOURS
18395.	34904.8	35	75.0514	3.64917

```
100 DIM Z(100),Y(100)
110 READ B,W1
120 READ W,C,A0,A1
130 READ E,E0,E1,P1
150 PRINT "   POWER REQUIREMENTS FOR SAE J227 RESID. DRIV. CYCLE"
160 PRINT
170 PRINT "***** INPUT PARAMETERS *****"
180 PRINT
190 PRINT "WEIGHT    FRONTAL AREA    DRAG COEFF.     BATTERY WT";
200 PRINT "  ACCESSORY POWER"
210 PRINT "POUNDS    SQUARE FEET                      POUNDS";
220 PRINT "          WATTS"
240 PRINT W,A0,C,W1,P1
250 PRINT
260 PRINT "       EFFICIENCIES:"
270 PRINT "MECHANICAL   ELEC. DRIVE     ELEC. ACCESS."
280 PRINT E,E0,E1
290 PRINT
300 PRINT "REGEN. BRAKING POWER FACTOR =";B;"%"
310 PRINT
320 IF A1=0 THEN 350
330 PRINT "SLOPES ARE NEGOTIATED"
340 GO TO 370
350 PRINT "NO SLOPES NEGOTIATED"
360 PRINT
370 J=W0=H=E2=0
380 K=M1=0
390 READ N,M,T1
400 READ S
410 MAT READ Z(S),Y(S)
420 FOR I =1 TO N STEP T1
430 L=(I-1)-INT((I-1)/M)*M
440 IF L<=20 THEN 540
450 IF L<=34 THEN 560
460 IF L<=49 THEN 580
470 IF L<=60 THEN 600
480 IF L<=75 THEN 620
490 IF L<=87.5 THEN 640
500 IF L<=134 THEN 660
510 IF L<=142 THEN 680
520 V1=20-(L-142)*2.5
530 GO TO 690
540 V1=0
550 GO TO 690
560 V1=(L-20)*2.14
570 GO TO 690
580 V1=30
590 GO TO 690
600 V1=30-(L-49)*1.37
610 GO TO 690
```

```
620 V1=15
630 GO TO 690
640 V1=15+1.2*(L-75)
650 GO TO 690
660 V1=30
670 GO TO 690
680 V1=30-(L-134)*1.2
690 V=V1*1.4667
700 A=(V-J)/T1
710 J=V
720 V2=V1*1.609
730 R=(W/50)*(1+.0014*V+.000012*V^2)
731 R=.46*R
740 R0=.00119*C*A0*V^2
750 R1=W*A1/100
760 R2=(W/32.2)*A
770 IF R2<0 THEN 790
780 GO TO 810
790 R3=(B/100)*R2
810 P0=V*(R+R0+R1+1.1*R2)
812 IF P0<0 THEN 816
814 GO TO 820
816 P0=V*R3
820 P=P0/(E*E0)+P1/E1
830 P2=P*1.356
840 W0=W0+P2/(3600/T1)
850 IF P2>H THEN 870
860 GO TO 890
870 H=P2
880 T=I
890 X=P2/W1
900 GOSUB 9000
910 P4=F
920 P3=P4*W1
930 M1=M1+(V/5280)*T1
940 K=K+(P2*T1/3600)/P3
950 IF K>=1 THEN 980
960 NEXT I
970 GO TO 1140
980 T0=I/3600
990 PRINT
1000 PRINT "***** OUTPUT *****"
1010 PRINT
1020 PRINT "TOT. ENERGY   PEAK POWER      AT TIME            RANGE";
1030 PRINT "          RUNNING TIME"
1040 PRINT "WATT-HOURS      WATTS         SECONDS            MILES";
1050 PRINT "             HOURS"
1070 PRINT W0,H,T,M1,T0
1080 GO TO 1190
1090 DATA 0,550
```

```
1100 DATA 2100,.4,18,0
1110 DATA .9,.7,.8,0
1130 DATA 25000,150,2
1140 PRINT
1150 PRINT"OUTPUT:"
1160 PRINT"INCREASE ESTIMATED TIME ,N,TO DETERMINE RANGE."
1170 PRINT"TIME";TAB(17);"WATT-HRS";TAB(32);"MILES";TAB(49);"K"
1180 PRINT I,WO,MI,K
1190 STOP
9000 REM ROUTINE FOR PIECEWISE LINEAR FUNCTION
9010 REM Z IS ARRAY OF ABSCISSA VALUES: Y IS ARRAY OF ORDINATE VALUES
9020 DEF FNC(D)=Y(D-1)+(Y(D)-Y(D-1))*(X-Z(D-1))/(Z(D)-Z(D-1))
9030 IF X>=Z(1) THEN 9060
9040 F=FNC(2)
9050 GO TO 9120
9060 FOR D=2 TO S
9070 IF X>=Z(D) THEN 9100
9080 F=FNC(D)
9090 GO TO 9120
9100 NEXT D
9110 F=FNC(S)
9120 RETURN
9130 DATA 6
9140 DATA 0,18,35,65,114,114
9150 DATA 75.7,73.5,71.4,67.1,58.6,0
9160 END
```

ELCP3, BASIC Language Computer Programs

for simulating electric vehicle performance on
the SAE Metropolitan Area Driving Cycle.

AN EXAMPLE OF A COMPUTER RUN USING THE SAE METROPOLITAN AREA DRIVING CYCLE

```
ELCP3          11:43PDT     10/16/73

   POWER REQUIREMENTS FOR SAE J227 METRO. DRIV. CYCLE

***** INPUT PARAMETERS *****

WEIGHT     FRONTAL AREA     DRAG COEFF.      BATTERY WT  ACCESSORY POWER
POUNDS     SQUARE FEET                          POUNDS        WATTS
 3075           22              0.3              750            0

     EFFICIENCIES:
MECHANICAL    ELEC. DRIVE      ELEC. ACCESS.
 0.9             0.8              0.8

REGEN. BRAKING POWER FACTOR = 0 %

NO SLOPES NEGOTIATED

***** OUTPUT *****

TOT. ENERGY   PEAK POWER     AT TIME          RANGE       RUNNING TIME
WATT-HOURS      WATTS        SECONDS          MILES           HOURS
 6034.71        33972.7        101           18.9477        0.798611
```

```
100 DIM Z(100),Y(100)
110 READ B,W1
120 READ W,C,A0,A1
130 READ E,E0,E1,P1
150 PRINT "   POWER REQUIREMENTS FOR SAE J227 METRO. DRIV. CYCLE"
160 PRINT
170 PRINT "***** INPUT PARAMETERS *****"
180 PRINT
190 PRINT "WEIGHT    FRONTAL AREA    DRAG COEFF.     BATTERY WT";
200 PRINT "  ACCESSORY POWER"
210 PRINT "POUNDS    SQUARE FEET                     POUNDS";
220 PRINT "        WATTS"
240 PRINT W,A0,C,W1,P1
250 PRINT
260 PRINT "      EFFICIENCIES:"
270 PRINT "MECHANICAL   ELEC. DRIVE     ELEC. ACCESS."
280 PRINT E,E0,E1
290 PRINT
300 PRINT "REGEN. BRAKING POWER FACTOR =";B;"%"
310 PRINT
320 IF A1=0 THEN 350
330 PRINT "SLOPES ARE NEGOTIATED"
340 GO TO 370
350 PRINT "NO SLOPES NEGOTIATED"
360 PRINT
370 J=W0=H=E2=0
380 K=M1=0
390 READ N,M,T1
400 READ S
410 MAT READ Z(S),Y(S)
420 FOR I =1 TO N STEP T1
430 L=(I-1)-INT((I-1)/M)*M
440 IF L<=20 THEN 540
450 IF L<=34 THEN 560
460 IF L<=49 THEN 580
470 IF L<=60 THEN 600
480 IF L<=75 THEN 620
490 IF L<=100 THEN 640
500 IF L<=121 THEN 660
510 IF L<=142 THEN 680
520 V1=20-(L-142)*2.5
530 GO TO 690
540 V1=0
550 GO TO 690
560 V1=(L-20)*2.14
570 GO TO 690
580 V1=30
590 GO TO 690
600 V1=30-(L-49)*1.37
610 GO TO 690
```

```
620 V1=15
630 GO TO 690
640 V1=15+1.2*(L-75)
650 GO TO 690
660 V1=45
670 GO TO 690
680 V1=45-(L-121)*1.19
690 V=V1*1.4667
700 A=(V-J)/T1
710 J=V
720 V2=V1*1.609
730 R=(W/50)*(1+.0014*V+.000012*V^2)
731 R=.46*R
740 R0=.00119*C*A0*V^2
750 R1=W*A1/100
760 R2=(W/32.2)*A
770 IF R2<0 THEN 790
780 GO TO 810
790 R3=(B/100)*R2
810 P0=V*(R+R0+R1+1.1*R2)
812 IF P0<0 THEN 816
814 GO TO 820
816 P0=V*R3
820 P=P0/(E*E0)+P1/E1
830 P2=P*1.356
840 W0=W0+P2/(3600/T1)
850 IF P2>H THEN 870
860 GO TO 890
870 H=P2
880 T=I
890 X=P2/W1
900 GOSUB 9000
910 P4=F
920 P3=P4*W1
930 M1=M1+(V/5280)*T1
940 K=K+(P2*T1/3600)/P3
950 IF K>=1 THEN 980
960 NEXT I
970 GO TO 1140
980 T0=I/3600
990 PRINT
1000 PRINT "***** OUTPUT *****"
1010 PRINT
1020 PRINT "TOT. ENERGY   PEAK POWER      AT TIME            RANGE";
1030 PRINT "        RUNNING TIME"
1040 PRINT "WATT-HOURS       WATTS        SECONDS            MILES";
1050 PRINT "           HOURS"
1070 PRINT W0,H,T,M1,T0
1080 GO TO 1190
1090 DATA 0,570
```

```
1100 DATA 2950,.4,22,0
1110 DATA .9,.8,.8,0
1130 DATA 25000,150,2
1140 PRINT
1150 PRINT"OUTPUT:"
1160 PRINT"INCREASE ESTIMATED TIME ,N,TO DETERMINE RANGE."
1170 PRINT"TIME";TAB(17);"WATT-HRS";TAB(32);"MILES";TAB(49);"K"
1180 PRINT I,WO,MI,K
1190 STOP
9000 REM ROUTINE FOR PIECEWISE LINEAR FUNCTION
9010 REM Z IS ARRAY OF ABSCISSA VALUES; Y IS ARRAY OF ORDINATE VALUES
9020 DEF FNC(D)=Y(D-1)+(Y(D)-Y(D-1))*(X-Z(D-1))/(Z(D)-Z(D-1))
9030 IF X>=Z(1) THEN 9060
9040 F=FNC(2)
9050 GO TO 9120
9060 FOR D=2 TO S
9070 IF X>=Z(D) THEN 9100
9080 F=FNC(D)
9090 GO TO 9120
9100 NEXT D
9110 F=FNC(S)
9120 RETURN
9130 DATA 6
9140 DATA 0,18,35,65,114,114
9150 DATA 75.7,73.5,71.4,67.1,58.6, 0
9160 END
```

TWO-PASSENGER CAR, SAE RESIDENTIAL DRIVING CYCLE

	Vehicle Weight,* lb	Battery Weight, lb	Range, mi	Running Time, hr	Total** Energy Watt-hours	Specific Energy W·hr/mi	Mileage mi/KWH
1980 Lead-Acid Battery	1,940	400	23.2	1.13	4,057	175	5.72
	2,050	500	30.9	1.51	5,632	182	5.49
	2,100	550	34.4	1.68	6,431	187	5.35
	2,160	600	37.9	1.84	7,229	191	5.24
	2,380	800	51.0	2.48	10,496	206	4.86
Nickel-Zinc Battery	1,940	400	91.0	4.43	15,899	175	5.72
	2,050	500	116.0	5.64	21,162	182	5.48
	2,100	550	127.9	6.22	23,779	186	5.38
	2,160	600	138.6	6.74	26,361	190	5.26
	2,270	700	159.7	7.76	31,579	198	5.06
Zinc-Chlorine Battery	1,730	200	87.2	4.24	13,938	160	6.26
	1,830	300	129.1	6.27	21,527	167	6.00
	1,940	400	166.5	8.09	29,066	175	5.73
	2,050	500	200.8	9.76	36,583	182	5.49
	2,100	550	217.2	10.55	40,348	186	5.38
Lithium-Sulfur Battery	1,705	175	80.9	3.93	13,808	170	5.87
	1,730	200	144.4	7.02	24,885	172	5.80
	1,780	250	194.2	9.42	34,125	176	5.68
	1,830	300	232.8	11.3	41,706	180	5.56

*Includes 300-pound payload.

**Output from battery.

FOUR-PASSENGER CAR, SAE METROPOLITAN DRIVING CYCLE

	Vehicle Weight,* lb	Battery Weight, lb	Range, mi	Running Time, hr	Total Energy** Watt-hours	Specific Energy W·hr/mi	Mileage mi/KWH
1980 Lead-Acid Battery	2,985	600	18.4	0.78	5,295	288	3.47
	3,205	800	27.4	1.15	8,276	302	3.31
	3,425	1,000	35.4	1.48	11,303	319	3.13
	3,645	1,200	42.9	1.80	14,391	335	2.98
	3,975	1,500	52.9	2.22	19,076	361	2.77
Nickel-Zinc Battery	2,985	600	77.8	3.26	22,103	284	3.52
	3,205	800	106.7	4.47	32,148	301	3.32
	3,425	1,000	133.3	5.57	42,404	318	3.14
	3,645	1,200	157.8	6.60	52,768	334	2.99
	3,975	1,500	189.9	7.94	68,308	360	2.78
Zinc-Chlorine Battery	3,655	300	78.5	3.28	20,395	260	3.85
	2,765	400	104.7	4.38	27,998	267	3.74
	2,985	600	151.5	6.34	43,083	284	3.52
	3,205	800	192.9	8.07	58,117	301	3.32
Lithium-Sulfur Battery	2,600	250	77.2	3.24	20,838	270	3.70
	2,655	300	138.6	5.80	37,881	273	3.66
	2,765	400	195.9	8.19	55,235	282	3.55
	2,875	500	241.3	10.09	70,008	290	3.45

*Includes 450-pound payload.

**Output from battery.

TWO-PASSENGER CAR

	1980 Lead-Acid Battery	Nickel-Zinc Battery	Zinc-Chlorine Battery	Lithium-Sulfur Battery
Vehicle Test Weight, lb	2,100	1,985	1,880	1,730
Battery Weight, lb	550	435	340	200
Charging Energy, KWH	15.7	29.2	31.9	34.7
Battery Energy Available, KWH	12.6	23.5	25.7	28.0
Range + Energy, mi @ KWH				
SAE Residential Cycle	35 @ 6.4	99.7 @ 17.7	144 @ 24.5	144 @ 24.8
5 mph	194 @ 12.3	392 @ 23.5	453 @ 25.7	233 @ 28.0
15 mph	158 @ 11.3	322 @ 23.5	357 @ 25.6	336 @ 28.0
30 mph	82 @ 9.2	188 @ 21.7	226 @ 25.3	247 @ 28.0
45 mph	37.7 @ 7.1	105 @ 19.3	137 @ 29.8	160 @ 28.0

FOUR-PASSENGER CAR

	1980 Lead-Acid Battery	Nickel-Zinc Battery	Zinc-Chlorine Battery	Lithium-Sulfur Battery
Vehicle Test Weight, lb	3,975	3,530	2,950	2,655
Battery Weight, lb	1,500	1,090	570	300
Charging Energy, KWH	42.8	73.2	53.5	52.6
Battery Energy Available, KWH	34.5	58.9	43.1	42.0
Range + Energy, mi @ KWH				
SAE Residential Cycle	54 @ 19.1	144 @ 47.0	145 @ 40.8	139 @ 37.0
5 mph	326.8 @ 33.8	640 @ 58.9	557 @ 43.1	305 @ 42.0
15 mph	272 @ 32.3	548 @ 58.9	468 @ 43.0	394 @ 42.0
30 mph	183 @ 28.6	375 @ 57.5	309 @ 42.6	298 @ 42.0
KWH/mi	0.156	0.153	0.138	0.141
45 mph	106 @ 24.6	232 @ 53.2	198 @ 42.0	199 @ 42.0
60 mph	58 @ 20.4	148 @ 48.9	129 @ 40.8	182 @ 42.0

REFERENCES

1. S. Appelt, Electric Vehicles, A Bibliography, 1928-1966, Bonneville Power Administration, Portland, Oregon.

2. E. S. Starkman, "Prospects of Electrical Power for Vehicles," SAE Paper 680541, August 12, 1968.

3. An Evaluation of Alternative Power Sources for Low-Emission Automobiles, Committee on Motor Vehicle Emissions, National Academy of Sciences, Washington, 1973.

4. Automotive Industries, March 15, 1972.

5. Automobile Facts, 1972, Motor Vehicle Manufacturers Association, 1972.

6. "An Electric Automobile Power Plant Survey," Address given at Institute of Electrical and Electronic Engineers National Convention, New York, N.Y., March 18, 1968.

7. Subpanel Reports to the Panel on Electrically Powered Vehicles, Part 2, "The Automobile and Air Pollution," US Department of Commerce, Washington, D.C., December 1968.

8. R. G. S. White, "Rating Scale Estimates Automobile Drag Coefficient," SAE Journal, Vol. 77, No. 6, July 1969.

9. D. M. Tenniswood and H. A. Graetzel, "Minimum Road Load for Electric Cars," SAE Paper No. 670177, January 1967.

10. R. S. McKee, et al., "Sundancer: A Test Bed Electric Vehicle," SAE Paper No. 720188, January 1972.

11. D. M. Tenniswood and H. A. Graetzel, "Minimum Road Load for Electric Cars", SAE Paper No. 670177, January 1967.

12. NAPCA Vehicle Design Goals, Revision A, November 30, 1970; Revision B, National Air Pollution Control Agency, Ann Arbor, Michigan, February 11, 1971.

13. J. J. Gumbleton, et al., Special Purpose Urban Cars, SAE Paper 690461, May 1969.

REFERENCES (Cont.)

14. US Bureau of the Census, Statistical Abstract of the United States: 1973, Washington, D.C., 1973.

15. The Weather Handbook, Conway Publishing Co., Atlanta, 1963.

16. Calculated from air conditioner sales by model and sales by model in Automotive News 1973 Almanac.

17. Handbook of Air Conditioning, Heating and Ventilating, 2nd Edition, Industrial Press, New York, 1965.

18. L. R. Foote, et al., Electric Vehicle Systems Study, Report No. SR-73-132, Scientific Research Staff, Ford Motor Co., Detroit, October 25, 1973.

19. P. A. Nelson, et al., ANL High-Energy Batteries for Electric Vehicles, presented at the 3rd International Electric Vehicle Symposium, Washington, February 1974.

20. Subcompact Car Crashworthiness Proposal, Minicars Inc., National Highway Traffic Safety Administration Contract HS 113-3-746, February 1973.

21. Research Safety Vehicle Proposal, Minicars, Inc., National Highway Traffic Safety Administration Contract HS-4-00844; July 1973.

22. Subcompact Car Driver Restraint System Proposal, Minicars, Inc. (Contract No. HS-113-3-742), June 1973.

23. Electric Vehicle Test Procedure - SAE J 227, SAE Handbook, 1973, (p. 939).

24. "Federal Driving Cycle" Federal Register, November 10, 1970, or SAE Handbook, 1973, pp 927-8.

25. D. M. Teague, Los Angeles Traffic Pattern Survey, SAE Paper No. 171, August 1957.

26. G. C. Hass, et al., Laboratory Simulation of Driving Conditions in the Los Angeles Area, SAE Paper No. 660546, August 1966.

27. E. David, M. Obert, Electric Vehicles: Challenge to the Battery Manufacturer, presented to 3rd International Electric Vehicle Symposium, Washington, D.C. February 1974.

28. H. J. Schwartz, Electric Vehicle Battery Research and Development, NASA TM X-71471, presented at Electrochemical Society Meeting, Boston, Mass., October 7-11, 1973.

29. J. H. B. George, Electrochemical Power Sources for Electric Highway Vehicles, C-74692, Arthur D. Little, Inc., Cambridge, Mass., June 1972.

30. D. V. Ragone, Review of Battery Systems for Electrically Powered Vehicles, SAE Paper 680453, May 1968.

31. An Evaluation of Alternative Power Sources for Low-Emission Automobiles, Report of the Panel on Alternate Power Sources to the Committee on Motor Vehicle Emissions, National Academy of Sciences, Washington, April 1973, pp. 65-86.

32. R. S. McKee, et al., Sundancer: A Test Bed Electric Vehicle, SAE Paper 720188, January 1972.

33. L. R. Foote, et al., Electric Vehicle Systems Study, Scientific Research Staff, Ford Motor Co., Report SR-73-132, October 1973, p. 116.

34. G. A. Mueller, The Gould Battery Handbook, Gould, Inc., Mendota Heights, Minnesota, 1973, p. 355.

35. C. L. Montell, Batteries and Energy Systems, McGraw-Hill Book Co., New York, 1970, p. 124.

36. The Zinc-Chloride Battery, Energy Development Associates, Madison Heights, Michigan (undated).

37. Advanced Battery Technology, Vol. 10, No. 4, April 1974.

38. C. J. Amato, A Zinc-Chloride Battery--The Missing Link to a Practical Electric Car, SAE Paper 730248, January 1973.

39. Reference 27, Fig. 5.

40. P. C. Symons, Batteries for Practical Electric Cars, SAE Paper 730253, January 1973.

41. P. C. Symons, Performance of Zinc Chloride Batteries, Presented at 3rd International Electric Vehicle Symposium, Washington, February 1974.

42. P. A. Nelson, et al., The Need for Development of High-Energy Batteries for Electric Automobiles, Argonne National Laboratory, January 1974, Appendix Table VIII.

43. Reference 42, Sec. III.

REFERENCES (Cont.)

44. E. J. Cairns, et al., Development of High-Energy Batteries for Electric Vehicles, Progress Report for July 1970-June 1971, Argonne National Laboratories #7888, July 1971.

45. E. J. Cairns, et al., Development of High-Energy Batteries for Electric Vehicles, Progress Report for February 1972-July 1972, Argonne National Laboratories #7953, August 1972.

46. E. J. Cairns, et al., Development of High-Energy Batteries for Electric Vehicles, Progress Report for August 1972-June 1973, Argonne National Laboratories #7998, February 1973.

47. Flywheel Feasibility Study and Demonstration, LMSC-D007915, Lockheed Missiles and Space Co., Sunnyvale, 30 April 1971.

48. G. Kugler, Electric Vehicle Hybrid Power Train, ESB, Inc., 1972.

49. S. J. Kalish, The Potential Market for On-the-Road Electric Vehicles, Electric Vehicle Council/Copper Development Association, New York, May 1971.

50. C. W. King, Comparisons of Alternate 40-hp Power Trains, A Specific Analysis of Electric Component Weight and Price, Delco-Remy Division, Dayton, Ohio, 1967.

51. J. E. Greene, An Experimental Evaluation of the MARS II Electric Automobile, CAL No. VJ-2623-K-1, Cornell Aeronautical Laboratory, Buffalo, N.Y., February 1969.

52. Laboratory Report prepared for Electric Fuel Propulsion, Inc., March 30, 1972, by W. F. Volk, J. R. Miller Test Center, Dana Corporation.

53. H. H. Hwang and Paul C. Yuen, "A Feasibility Study of the Electric Car for Hawaii", Department of Electrical Engineering, University of Hawaii, Second International Electric Vehicle Symposium, November 1971.

54. D. F. Taylor and E. G. Siwek, The Dynamic Characterization of Lead-Acid Batteries for Vehicle Applications, General Electric Company, Research and Development Center, SAE Paper No. 730252.

TASK REPORT 2

POPULATION PROJECTIONS
FOR THE LOS ANGELES REGION, 1980-2000

G.M. Houser

PREFACE

This is the first task report in a series projecting baseline conditions for a study of electric car impact. The complete series comprises:

Task Report 2	Population Projections for the Los Angeles Region, 1980-2000
Task Report 3	Transportation Projections for the Los Angeles Region, 1980-2000
Task Report 4	Economic Projections for the Los Angeles Region, 1980-2000
Task Report 5	Electric Energy Projections for the Los Angeles Region, 1980-2000

The projections in these reports are to support a comprehensive analysis of the impacts of electric cars. Thus it is changes relative to the baseline projections, rather than the absolute projections themselves, which are ultimately most important. Largely for this reason, detailed forecasts are neither needed nor justified here. Instead, projections are based on straightforward extrapolation of existing trends, making maximum use of existing forecasts and analyses in the literature.

Projections of the sort offered in these reports generally cover a range of possible futures reflecting a range of assumptions about future rates of change. Here, however, only a single baseline case can usefully be offered. The study of electric car impacts to be supported by this baseline is itself a multi-dimensional parametric analysis. Overall study resources are insufficient to pursue this parametric impact analysis for more than one baseline.

The key assumption guiding the selection of the baseline in these reports is that the future of Southern California will be characterized by much slower growth than in the past, with an attendant higher quality of life for residents than otherwise would be possible. This is very much in accord with the current wish of the public as manifested in the 1972 referendum on the Coastal Zones Protection Act, under which planning for and protection of the California coastline is now in progress; the "Mammoth Decision" by the California Supreme Court requiring environmental impact statements for private as well as public projects, and the subsequent concurrence in this decision by the California Legislature; and the Clean Air Act Amendments of 1970, together with subsequent court interpretations, which reflect public desire for obtaining and maintaining excellent air quality in both urban and rural areas. It is also in accord with current population trends, wherein the rates of natural increase and immigration are much less than in the past.

In particular, this baseline projection assumes that there will be no dramatic alterations in long-established underlying factors in regional development. Thus it does not anticipate such dramatic technological breakthroughs as efficient conversion of solar to electric power or wide-scale deployment of personal rapid transit or dual-mode transportation systems. Similarly, it anticipates no dramatic sacrifice of economic and social patterns to environmental goals, such as would occur if no further construction of electric power facilities were to be allowed, or if drastic gasoline rationing were put into effect (as has been proposed in recent EPA rule-making required by current Federal air quality legislation).

CONTENTS

ILLUSTRATIONS

TABLES

1 INTRODUCTION

The purpose of this report is to present population projections for the South Coast Air Basin (SCAB) for the years 1980, 1990, and 2000. These data serve as the basis for the energy, transportation, and economy projections prepared under contract to the Environmental Protection Agency for a study of the impact of the electric automobile in the Basin.

The South Coast Air Basin consists of all of Orange and Ventura Counties and parts of Los Angeles, Riverside, San Bernardino, and Santa Barbara Counties. With the exception of Santa Barbara, all of these counties are members of the Southern California Association of Governments (SCAG).

SCAG has subdivided the member counties into Regional Statistical Areas (RSAs). The boundaries of these RSAs coincide with the boundaries of the Air Basin and are shown in Fig. 1.1. To determine population for the SCAB area it was necessary only to delete the population in the RSAs outside the boundary from whole-countywide data. Projections for each RSA are shown in the appendix. For Santa Barbara County (not a member of SCAG), study area data was extrapolated from figures provided by the Santa Barbara County Planning Department.

Scaling factors used to adjust whole-county data to the study area are shown in Table 1.1. These factors represent the percentage of total county population in the study area.

Time and resources did not permit a detailed demographic study. The data in this report was drawn and extrapolated from published sources, specifically forecasts and projections which were obtained from State, County, and private agencies. These agencies include the California Department of Finance,[1] Southern California Association of Governments,[2,3] Southern California Edision,[4] Wells Fargo Bank,[5] Los Angeles Regional Transportation Study (LARTS),[6] United California Bank,[7] Security Pacific

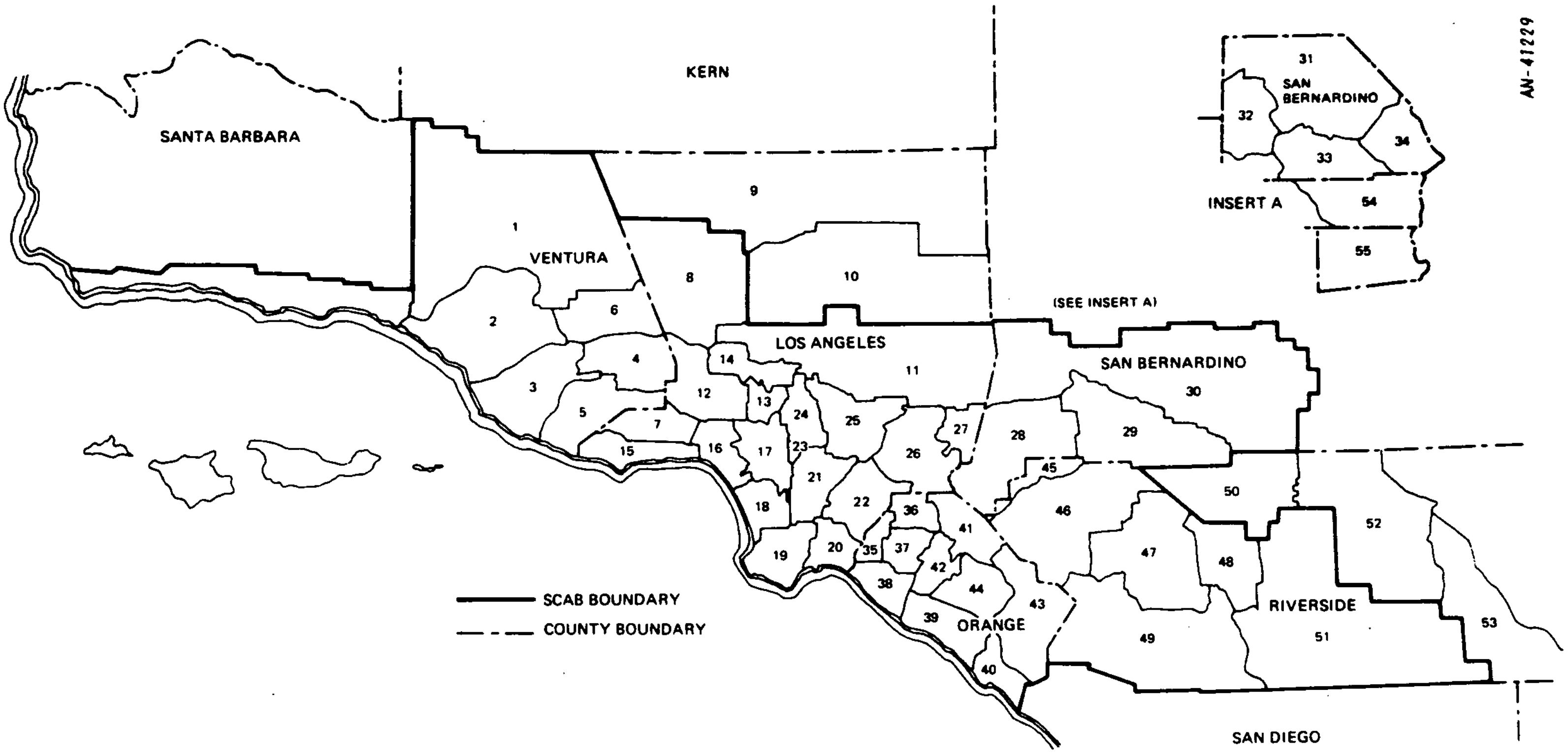


Figure 1.1. RSA Boundary Map

TABLE 1.1

PERCENTAGES OF COUNTY POPULATIONS IN SOUTH COAST AIR BASIN

County	Actual			Projected		
	1950	1960	1970	1980	1990	2000
Los Angeles	99	99	98	98	98	98
Orange	100	100	100	100	100	100
Riverside	72	70	71	72	72	72
San Bernardino	88	84	83	83	84	85
Santa Barbara	64	55	60	60	60	60
Ventura	100	100	100	100	100	100

National Bank,[8] and the planning departments of the counties. A review of these publications clearly indicates that the rate of natural increase and rate of immigration are decreasing each year. As a result, the use of reduced population projections for planning purposes is increasing rapidly. This is demonstrated in Table 1.2, which shows that population projections prepared by SCAG (and officially accepted by its member counties) were consistently lower each year than those prepared the previous year for the same time periods. (These figures are presented for comparison purposes only, and therefore have not been adjusted to fit the Air Basin. Santa Barbara County, not a member of SCAG, is not included.)

SCAG has recently declared that its Series D forecast* is too high and should be replaced by a revised lower forecast as soon as possible.[3] The new forecast will be a combined Series D and E. This forecast applies the Series D factors to all areas in the counties which are outside the critical Air Basin and the Series E to all areas inside the Basin. The

*Essentially the same as Department of Finance Series D-150 shown in Table 3.1, in Sec. 3 of this report.

TABLE 1.2

COMPARISON OF PROJECTIONS

Date of Projection	Projection 1980	1990	2000
1970[9]	13,062,000	15,748,000	--
1971[10]	11,634,300	13,900,000	16,062,500
1973[2]	11,070,070	12,205,160	13,164,730

Department of Finance is also currently preparing a combination D/E projection for the area.

Additionally, in the Basin, the Environmental Protection Agency, the State Water Resources Control Board, and local water quality control boards require that Series E forecasts be used exclusively in planning and facilities grants.

On the basis of the above, we have concluded that the most reasonable choice of projections for this study is the Department of Finance Series E. For the South Coast Air Basin, this projection is identical to the DOF Series D/E.

Section 2 of this report presents these projections as well as brief historical data for the area. Section 3 contains alternative population forecasts.

2 PAST AND PROJECTED POPULATION

2.1 SOUTH COAST AIR BASIN POPULATION, 1950-1970

In 1950 the total population of the Basin was 4,900,518. Eighty-five percent of this total regional population resided in Los Angeles County. San Bernardino ranked second with 5 percent, and Orange third with 4 percent. Riverside, Ventura, and Santa Barbara contained only 3, 2, and 1 percent, respectively.

While the proportion of population to the total of the region remained almost constant in the outlying counties for two decades, changes in Los Angles and Orange County were more pronounced. By 1960, Los Angeles had dropped to 78 percent, and by 1970 to 71 percent. Orange County, however, continued to increase to 9 percent of the region in 1960 and 14 percent in 1970. These figures are presented in Tables 2.1 and 2.2.

Los Angeles County experienced substantial and almost continuous growth in the first 70 years of the century. This growth rate has slowed

TABLE 2.1

POPULATION BY COUNTY (SCAB ADJUSTED)

County	1950	1960	1970
Los Angeles	4,135,687	5,986,771	6,866,566
Orange	216,224	703,925	1,419,200
Riverside	123,046	215,191	322,766
San Bernardino	248,142	423,591	555,519
Santa Barbara	62,832	93,255	154,920
Ventura	114,647	199,138	375,600
Totals	4,900,578	7,621,871	9,694,571

TABLE 2.2

PERCENTAGE OF SCAB POPULATION IN EACH COUNTY

County	1950	1960	1970
Los Angeles	85	78	71
Orange	4	9	14
Riverside	3	3	3
San Bernardino	5	6	6
Santa Barbara	1	1	2
Ventura	2	3	4

dramatically in recent years. The County population decreased more than 70,000 between 1970 and 1972. As a result, the L.A. County Planning Department has recently made a substantial downward revision of planning figures from 8,700,000 to 7,700,000 for 1990.

Orange County has experienced very rapid growth in the past 22 years. During the 1950-1960 period, it was the fastest growing county not only in Southern California, but also in the entire United States. Once primarily an agricultural area, it is now the second most populous county in California. Much of Orange County's growth has been through immigration from adjoining counties.

Riverside and San Bernardino Counties as a whole have been growing at a slower rate. Most of the growth in these counties, however, has been in the areas which are part of the South Coast Air Basin. The mountains and desert areas not included in SCAB are growing at a much slower rate.

Population growth in Ventura County, the second fastest growing county in the 1960s, has been extensive and is attributed mostly to immigration.

Santa Barbara County grew rapidly in the period from 1960 to 1970, but has experienced a substantial slowdown in recent years. As in San Bernardino and Riverside, the portion of the County in the South Coast Air Basin has grown at a faster rate than that outside the boundaries.

2.2 PROJECTIONS FOR 1980, 1990, AND 2000

Population projections for the study were developed using Department of Finance Series E-0 projections. Series E-0 projections incorporate a fertility rate of 2.1 births per woman and zero net immigration to the state. Some migration between the counties has been incorporated by the Department of Finance which utilizes forecasts provided by individual county planning groups wherever possible.

The SCAB area population is projected to reach 12.4 million by the year 2000. These projections are shown in Table 2.3 (1970 is included for comparison) and graphed in Fig. 2.1. In the period 1980 to 1990 the net increase is expected to be approximately 973,844 and thereafter will slow to 784,914 in the period 1990 to 2000.

TABLE 2.3

PROJECTED POPULATIONS (SCAB ADJUSTED)

County	1970	1980	1990	2000
Los Angeles	6,866,566	7,179,578	7,514,150	7,757,680
Orange	1,419,200	1,774,000	2,122,500	2,408,300
Riverside	322,766	370,440	408,384	434,016
San Bernardino	555,519	635,780	730,128	812,260
Santa Barbara	154,920	179,640	208,020	233,340
Ventura	375,600	488,400	618,500	741,000
TOTALS	9,694,571	10,627,838	11,601,682	12,386,596

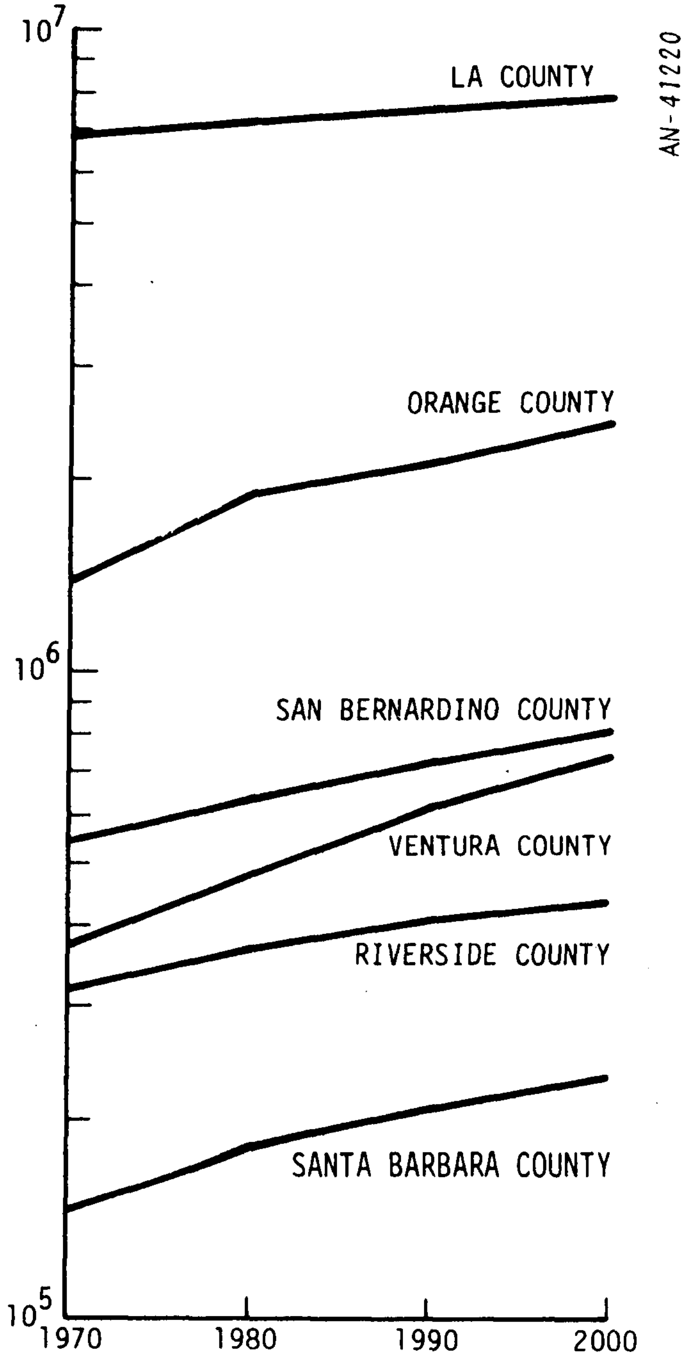


Figure 2.1. Projected Population by County

As stated earlier, the rate of growth will vary from county to county. The projected compound annual growth rates for the years 1970 to 2000 are shown in Table 2.4.

Projections of age distribution are shown in Fig. 2.2 and Table 2.5.* Figure 2.2 clearly shows a substantial drop in population under 18 years of age and an increase in the 18 to 65 age group. The percentage of people in the over-65 age group for the area remains almost constant.

Profiles of age distribution by county are shown in Figs. 2.3 through 2.8. Changes are less noticeable for Los Angeles, Riverside, and San Bernardino Counties, with those counties containing a larger percentage of the over-65 age group and less marked changes between the

TABLE 2.4

FUTURE GROWTH RATES, 1970 TO 2000

County	Projected Annual Growth Rate
Los Angeles	0.38%
Orange	1.78%
Riverside	1.00%
San Bernardino	1.47%
Santa Barbara	1.37%
Ventura	2.29%

*These projections were developed for SCAB from whole-county age distribution data provided by the Department of Finance.[1]

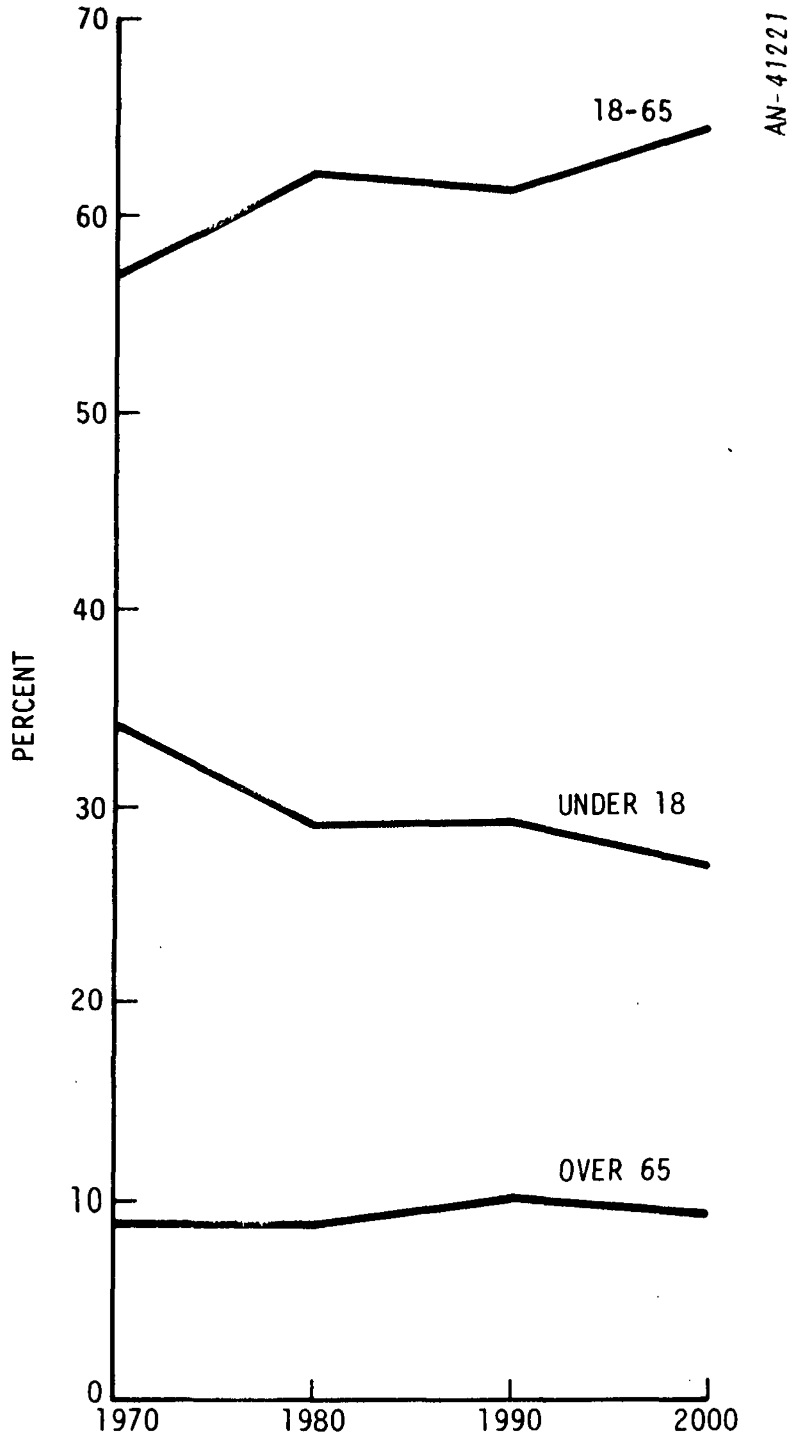


Figure 2.2. Population Age Distribution

TABLE 2.5

POPULATION BY AGE GROUP

	1970	1980	1990	2000
Under 18	3,245,843	3,108,879	3,358,800	3,330,528
18-64	5,571,451	6,536,673	7,121,554	7,939,840
Over 64	877,277	982,220	1,121,288	1,116,313

under-18 and 18-to-65 group. In Orange, Santa Barbara, and Ventura Counties, however, the drop in the under-18 age group and increase in the 18-to-65 groups is much more pronounced. Increases in the 18-to-65 age group, of course, will have the greatest impact on the demand for automobiles and/or public transportation.

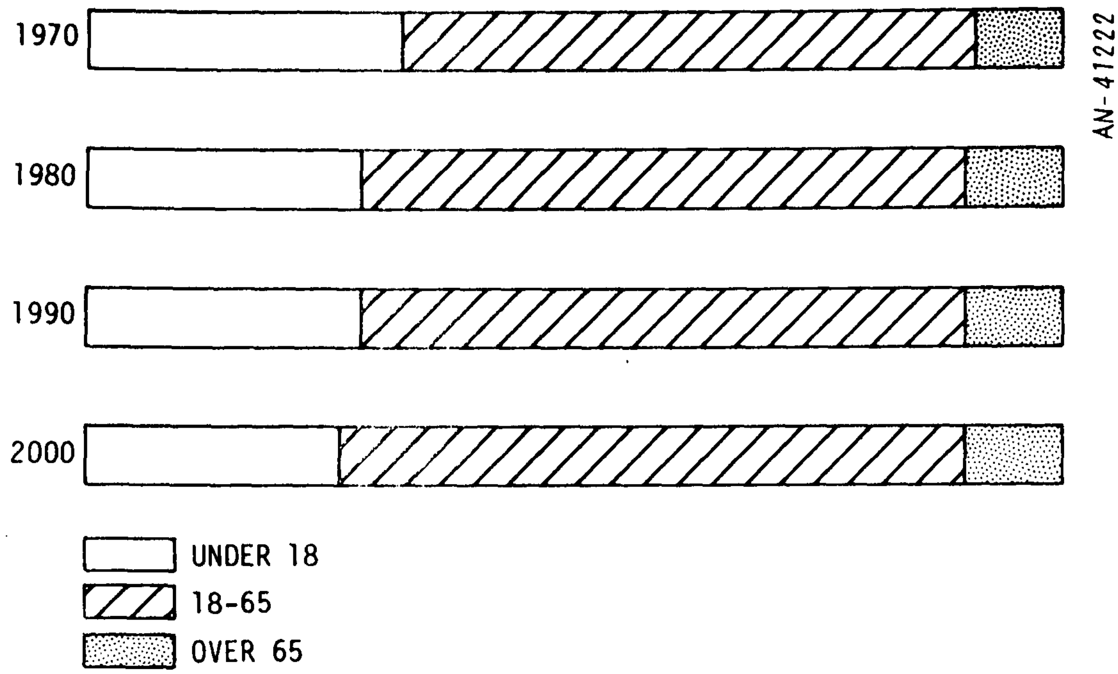


Figure 2.3. Age Distribution Profile, Los Angeles County

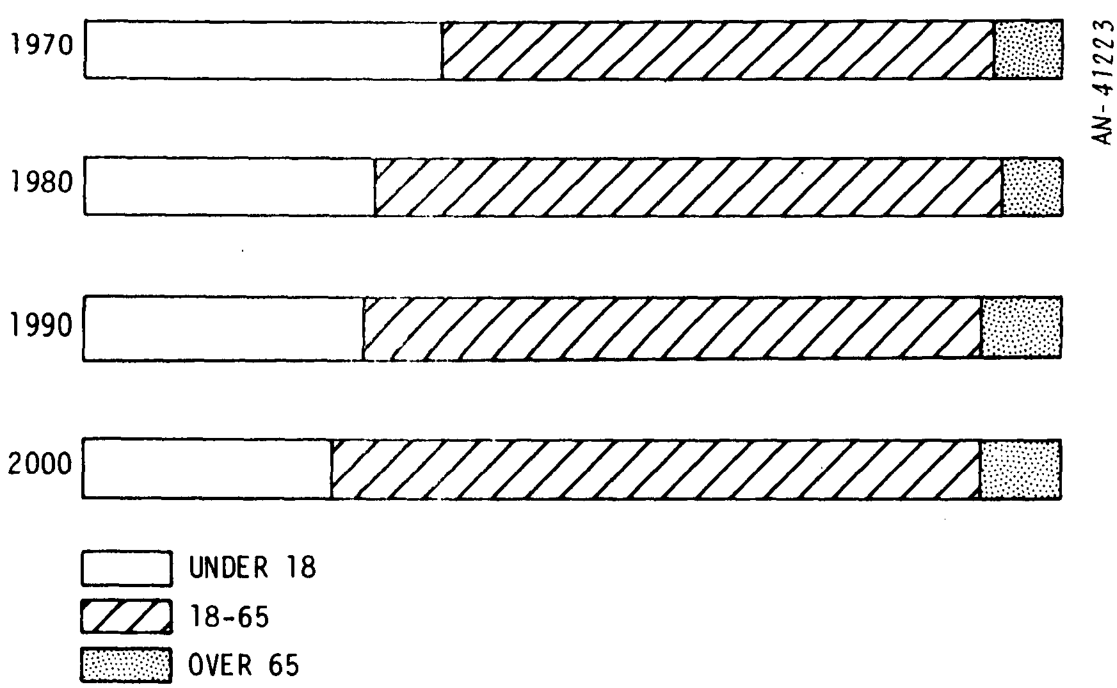


Figure 2.4. Age Distribution Profile, Orange County

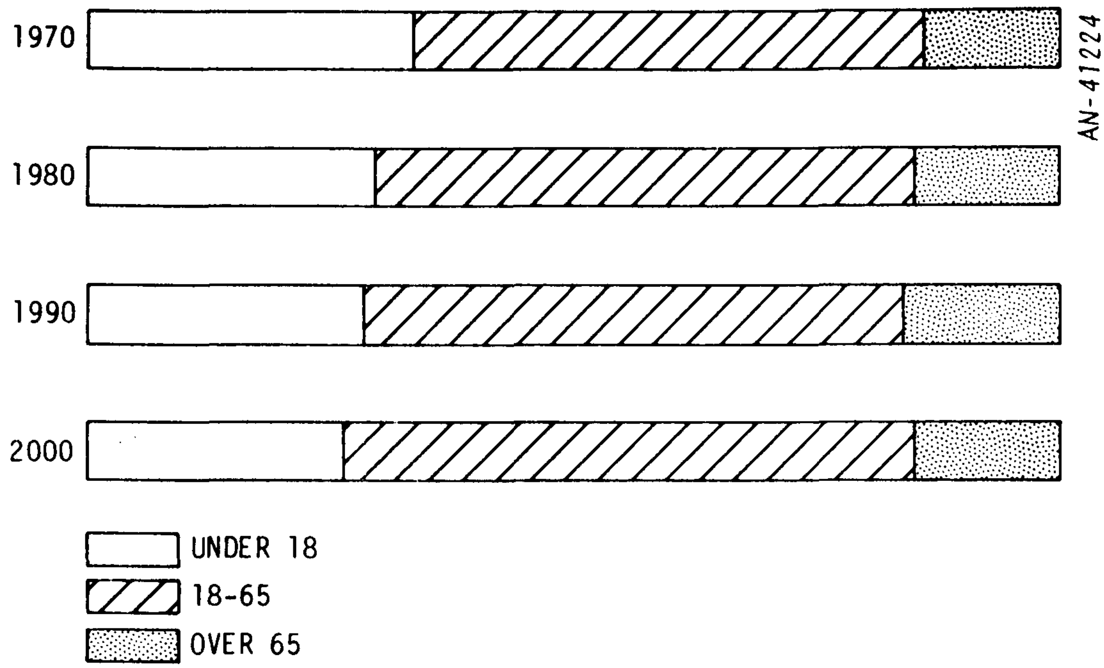


Figure 2.5. Age Distribution Profile, Riverside County

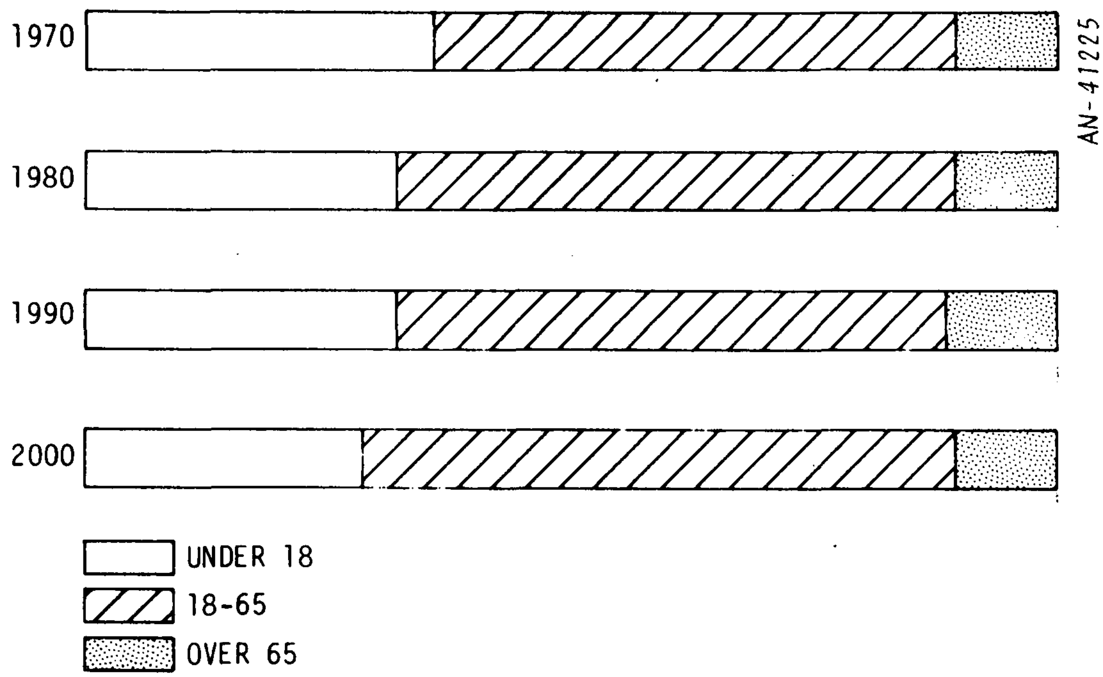


Figure 2.6. Age Distribution Profile, San Bernardino County

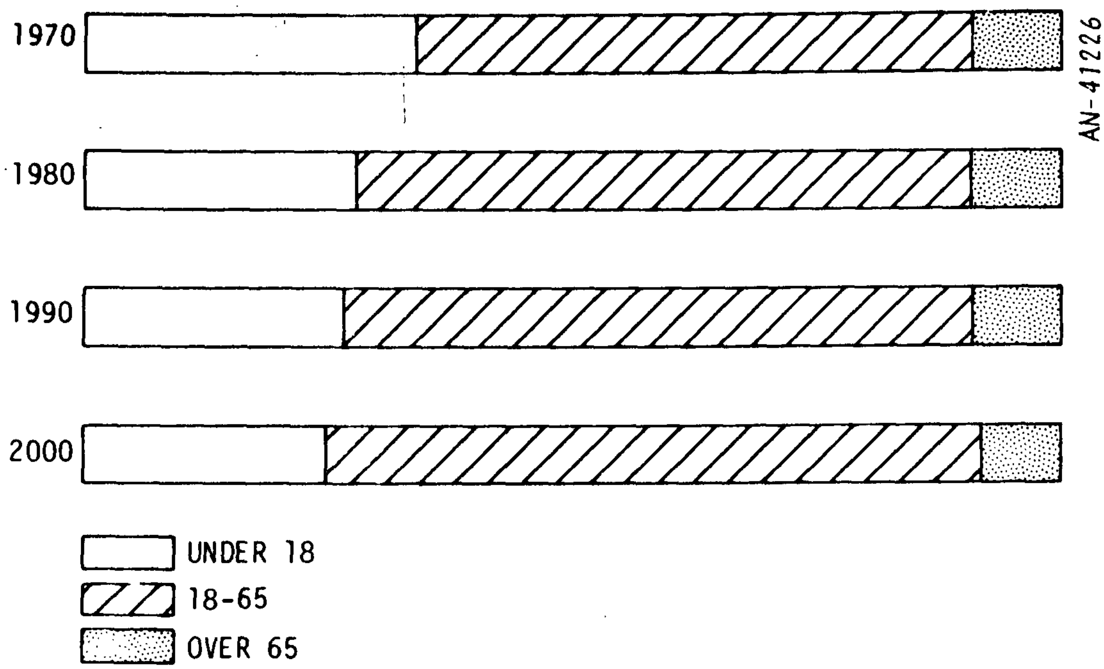


Figure 2.7. Age Distribution Profile, Santa Barbara County

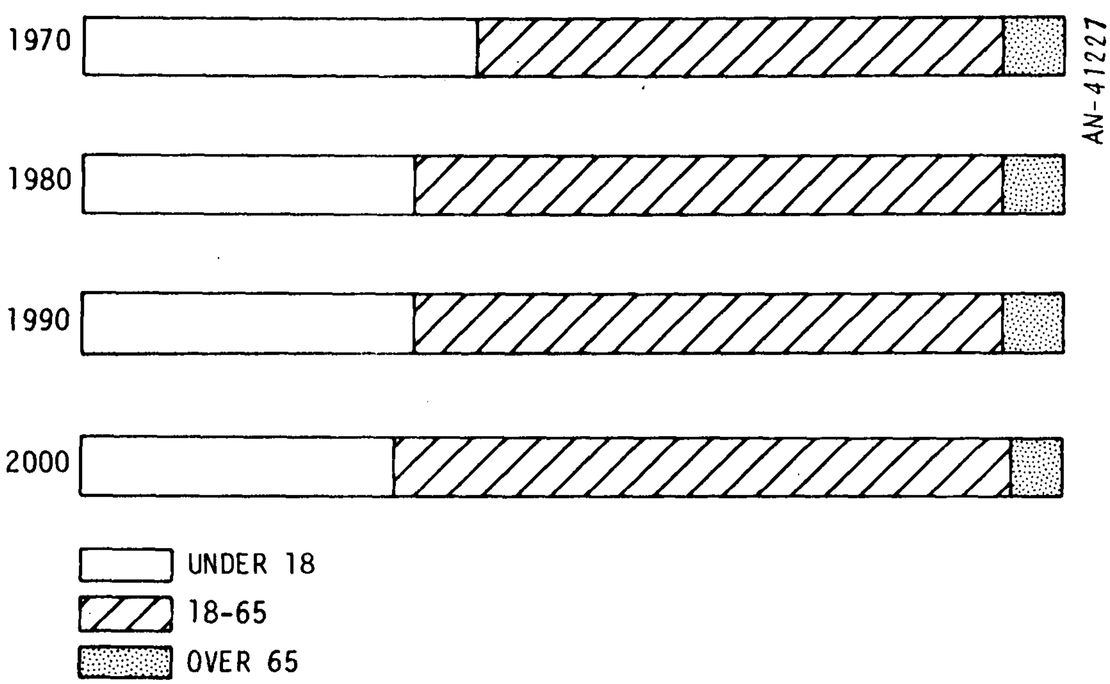


Figure 2.8. Age Distribution Profile, Ventura County

3 ALTERNATIVE POPULATION FORECASTS

Currently available forecasts were obtained from various State, County, and private agencies. The most complete of these data have been scaled down to fit the study area and are tabulated in Table 3.1 and graphed in Figs. 3.1-3.6. They represent different assumptions about future growth and include Department of Finance Series D-150 and Series E-0, SCAG combination D/E and D-dispersed, Southern California Edison, and individual county forecasts.

The DOF Series D-150 assumes 2.45 births per woman and net annual state migration of 150,000. Series E-0, as described earlier, projects 2.1 births per woman and zero state migration.

SCAG D-Dispersed modifies DOF Series D projections to locate population in the suburbs rather than the central city. This concept includes:

- Establishment of new towns and employment centers in outlying areas, linked to the rest of the region by high-speed ground transportation
- Limited protection of agricultural areas
- Development of the Palmdale Intercontinental Airport
- Protection of coastline and mountain areas
- Improvement of air and water quality
- Some central city renewal, maintaining the same net density

As illustrated in the following charts, the SCAG D dispersed projection is lower than the DOF Series D in Los Angeles, Orange, and Ventura Counties and higher in Riverside and San Bernardino Counties. SCAG D/E is the same as the projection being used in this study (Table 2.3), since it incorporates Series D for areas outside the Air Basin and Series E for areas inside.

Southern California Edison projections include the assumptions that the average birth rate is approaching Series E and that net annual migration will reach 100,000 for the State per year by 1980 and remain at that rate thereafter. SCE develops projections for whole counties by extrapolating from projections of the portion of the county in its service area.

Wells Fargo projections are much closer to Series E than to Series D. These projections, available only for 1980, differ from the others in that their projections for Los Angeles, and Ventura are much lower, while Riverside, Orange, Santa Barbara, and San Bernardino are higher.

TABLE 3.1

ALTERNATIVE POPULATION FORECASTS

Year	County	DOF Series D-150	SCAG D Dispersed	Southern California Edison	DOF Series E	County
	Los Angeles	7,500,[illegible]	7,302,430	7,281,400	7,215,753	---
1	Orange	1,926,[illegible]	1,843,800	1,937,500	1,774,000	1,905,057
9	Riverside	[illegible]	559,711	398,088	370,467	439,531
8	San Bernardino	[illegible]	910,227	661,080	635,780	690,560
0	Santa Barbara	191,9[illegible]	---	188,400	173,562	191,943
	Ventura	[illegible]	541,220	535,000	488,400	799,500
TOTAL		11,[illegible]	---	11,001,468	10,657,962	---
	Los Angeles	8,49[illegible]	6,071,839	8,009,540	7,530,288	7,546,000
1	Orange	2,445,300	2,565,680	2,372,600	2,122,500	2,240,386
9	Riverside	522,864	864,079	464,832	409,576	550,670
9	San Bernardino	894,264	1,097,981	787,080	730,128	894,264
0	Santa Barbara	239,997	---	230,040	208,020	241,331
	Ventura	902,100	789,820	770,000	618,500	799,500
TOTAL		13,494,861	---	12,634,092	11,619,012	12,272,151
	Los Angeles	9,433,098	6,815,061	---	7,767,251	---
2	Orange	2,907,200	2,615,220	---	2,408,300	2,560,386
0	Riverside	631,[illegible]	1,139,040	---	437,371	641,282
0	San Bernardino	1,1[illegible]	1,411,808	---	812,260	1,104,150
0	Santa Barbara	283,[illegible]	---	---	233,340	281,306
	Ventura	1,241,[illegible]	1,093,500	---	741,000	1,027,600
TOTAL		15,600,693	---	---	12,399,522	---

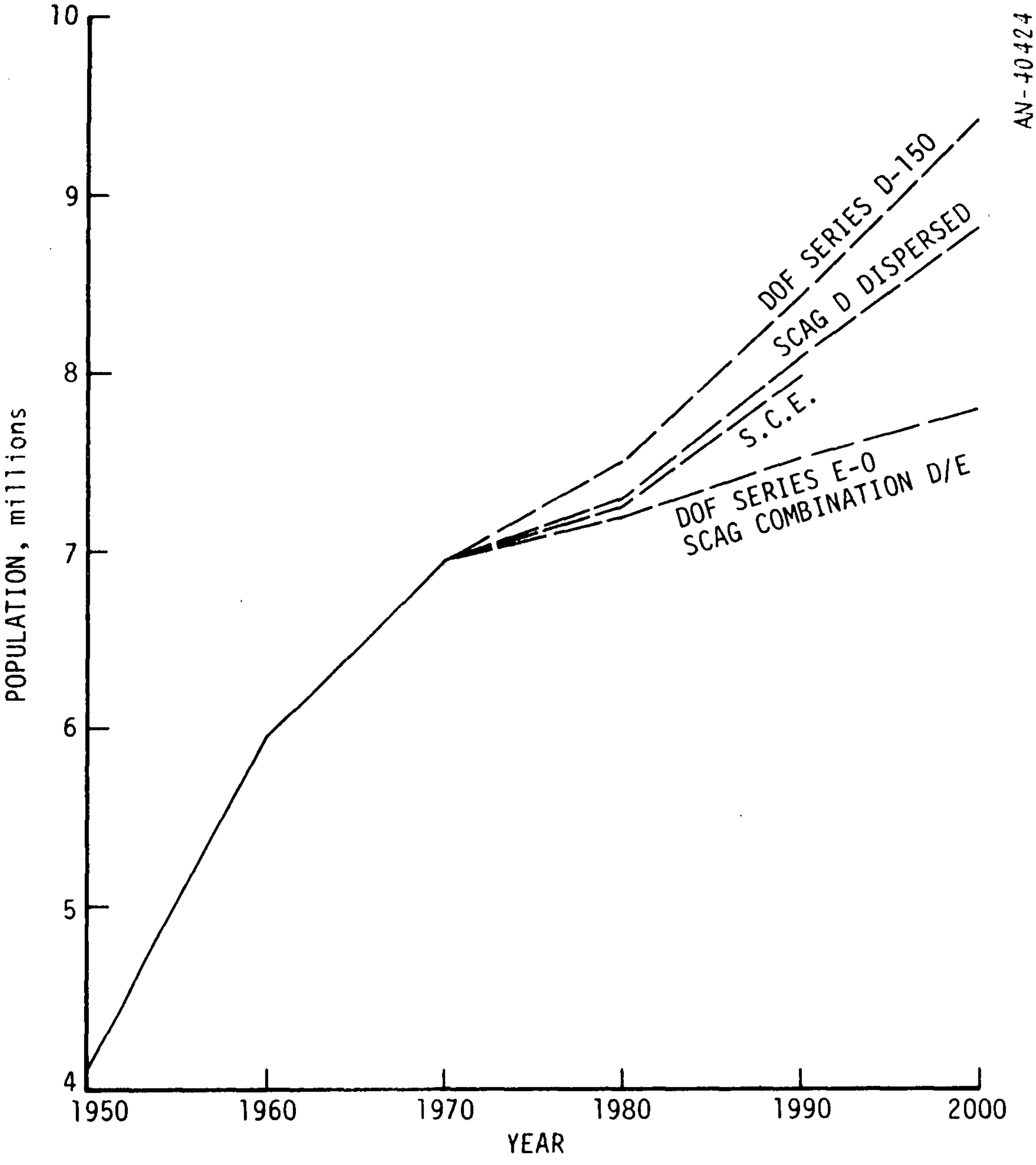


Figure 3.1. Alternative Population Projections, Los Angeles County

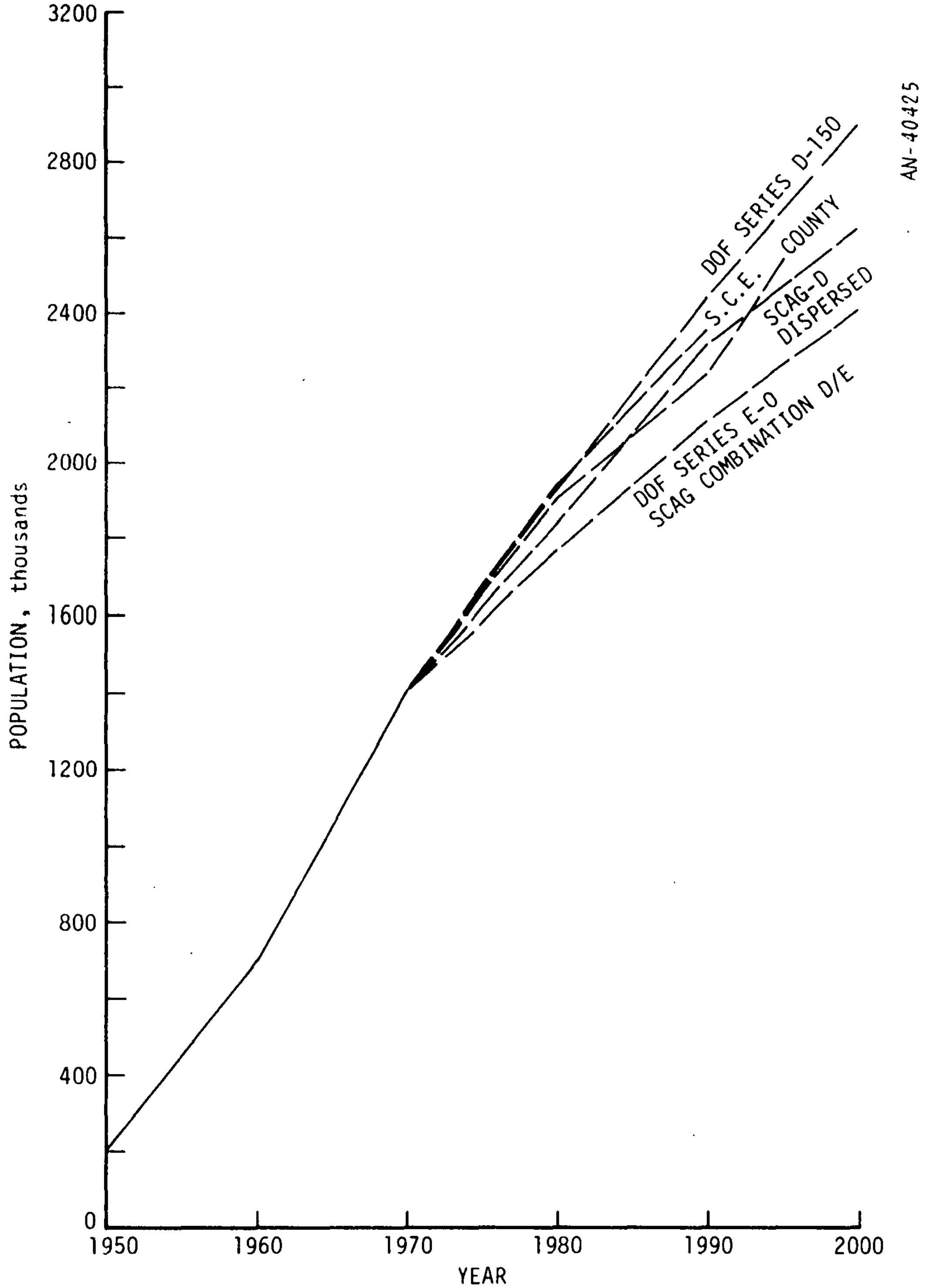


Figure 3.2. Alternative Population Projections, Orange County

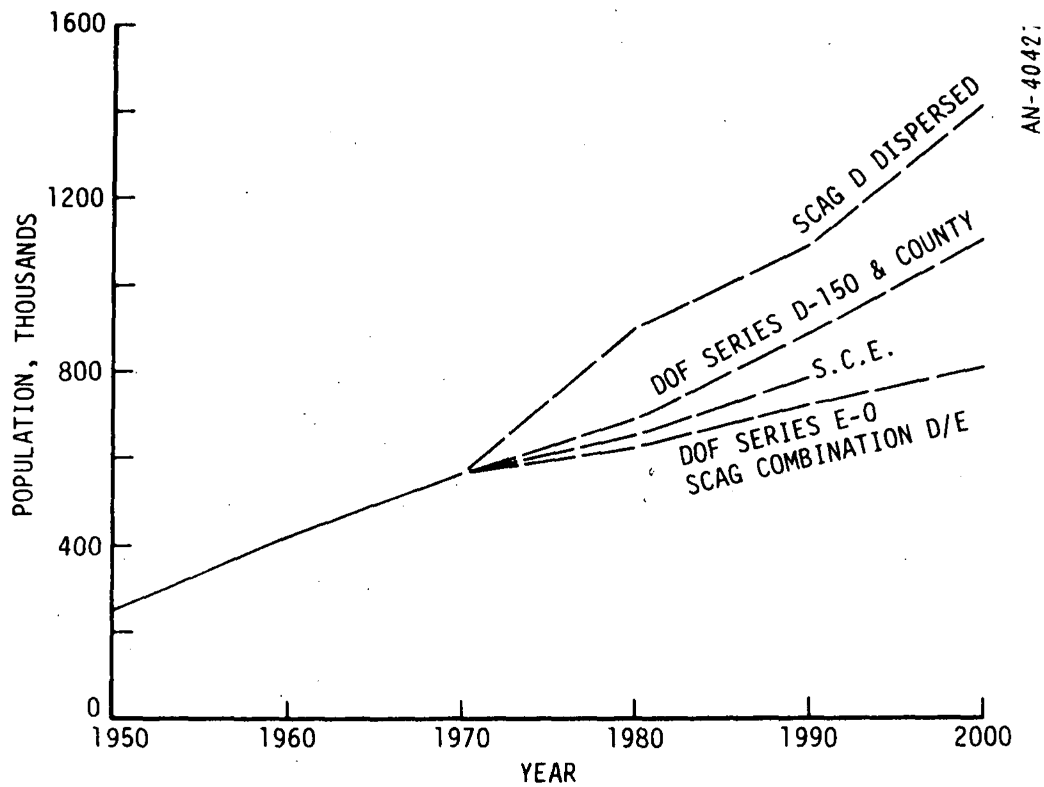


Figure 3.3. Alternative Population Projections, Riverside County

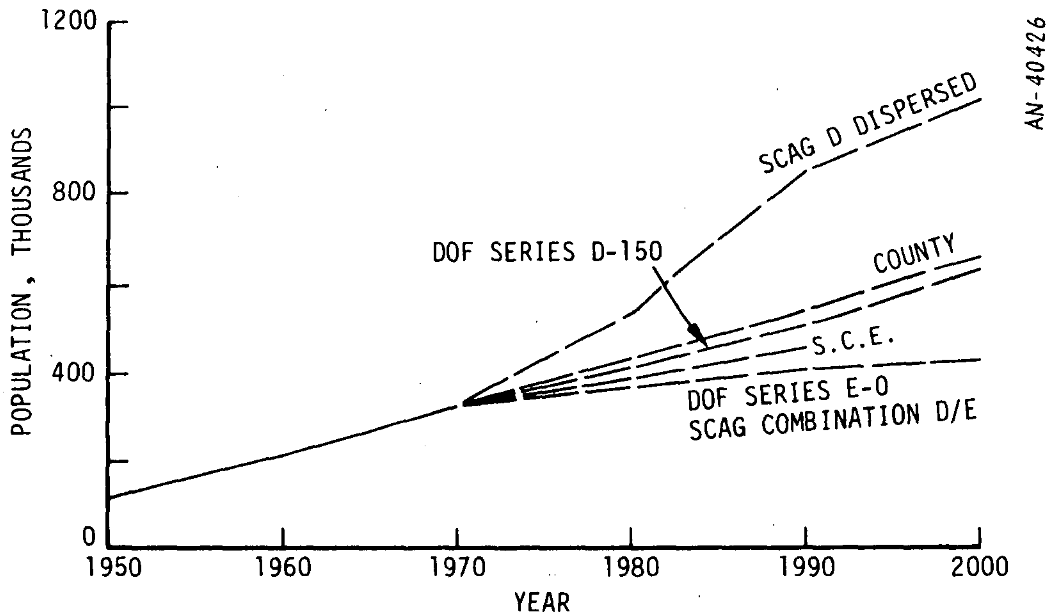


Figure 3.4. Alternative Population Projections, San Bernardino County

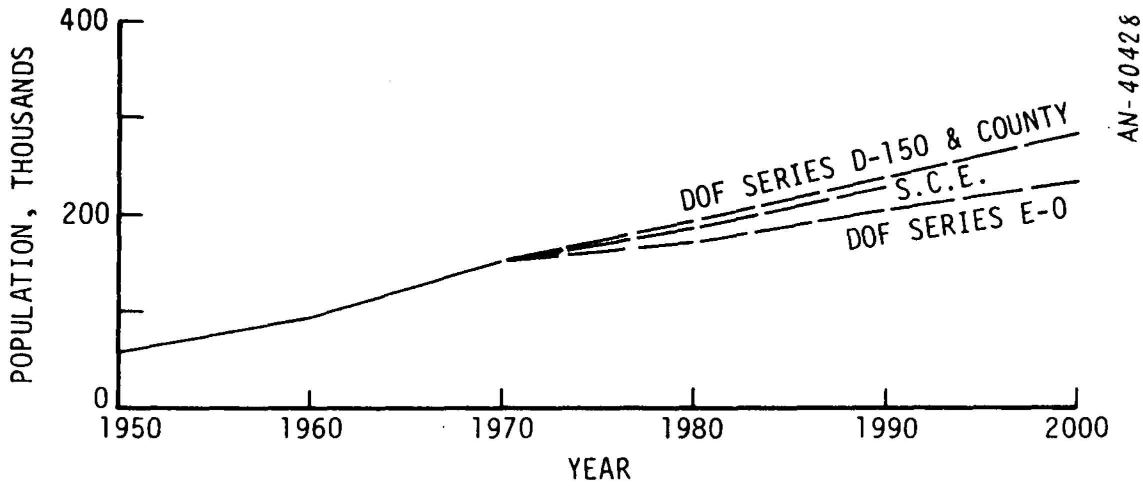


Figure 3.5. Alternative Population Projections, Santa Barbara County

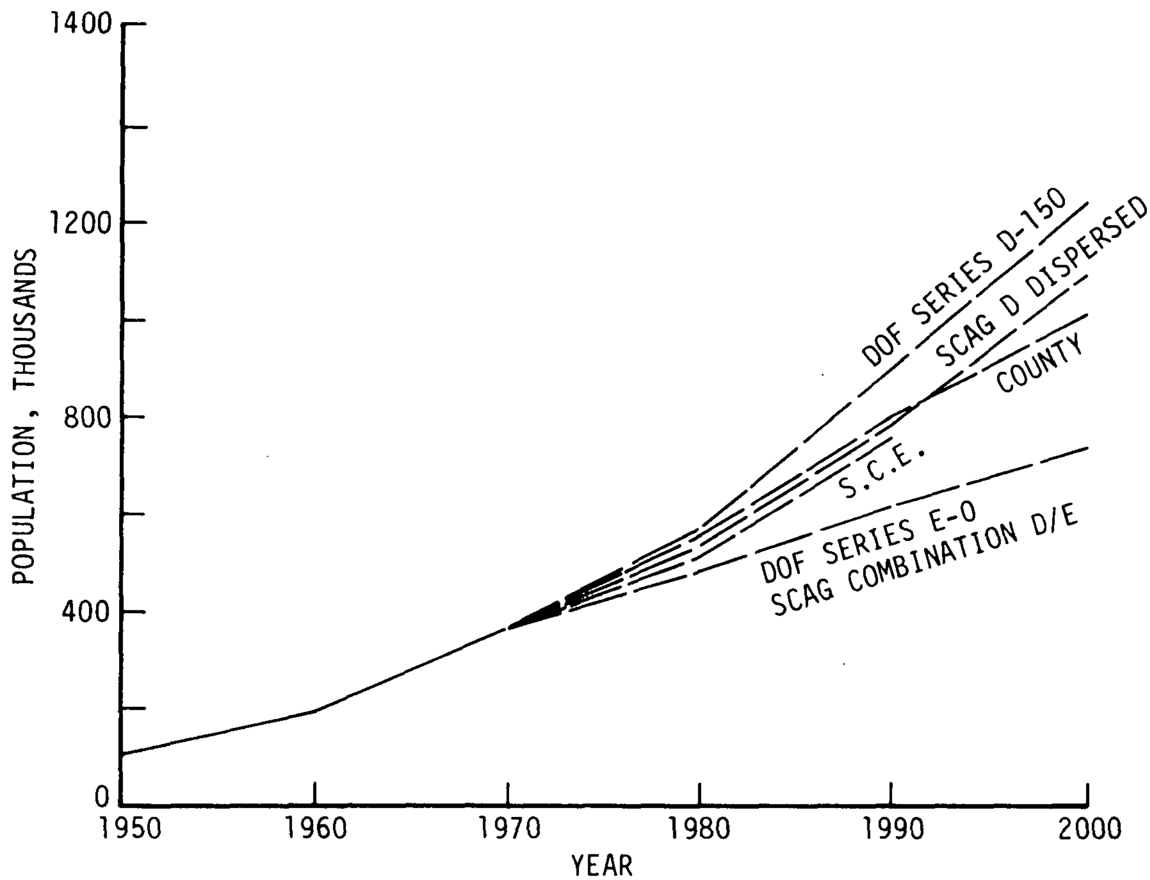


Figure 3.6. Alternative Population Projections, Ventura County

APPENDIX A

TOTAL POPULATION FOR 1970 TO 2000 BY REGIONAL STATISTICAL AREA

RSA Number	RSA NAME	1970	1980	1990	2000
1	LOSPDRS	375	375	375	375
2	OJAIVEN	112,165	141,824	182,154	234,290
3	OXNCAMR	136,540	173,145	209,961	240,643
4	MRPSIMI	67,756	84,320	100,318	112,553
5	THSOAKS	51,542	79,220	111,354	129,699
6	FILPIRU	10,229	12,515	17,324	26,450
7	CALABAS	18,935	27,065	35,261	37,964
8	NEWHALL	47,242	66,584	85,360	92,579
9	LANCAST	51,446	69,301	86,713	93,932
10	PALMDAL	31,429	41,046	50,606	54,817
11	S G MTS	2,013	2,013	2,013	2,013
12	SW SFV	539,935	553,720	577,276	591,410
13	BURBANK	264,922	266,607	275,146	289,280
14	SANFERN	267,158	281,544	295,884	301,595
15	MALIBU	11,709	13,098	14,462	15,868
16	SMONICA	304,300	321,563	338,288	358,141
17	WCENTRL	934,831	981,753	1,038,425	1,066,997
18	SO BAY	531,138	541,652	555,992	573,634
19	PALVRDS	413,510	427,295	440,948	447,362
20	L BEACH	435,416	451,783	467,831	485,473
21	ECENTRL	828,311	843,190	867,433	896,005
22	NOR-WHI	592,502	610,948	632,796	654,454
23	LA CBD	90,416	94,781	98,874	100,280
24	GLENDAL	412,626	429,889	446,614	460,748
25	WSANGAB	667,492	684,755	706,260	720,394
26	ESANGAB	441,043	458,306	478,446	492,580
27	POMONA	149,654	161,360	175,013	182,232
28	WESTEND	233,386	264,631	305,295	339,883
29	EASTEND	312,097	352,072	403,571	444,277
30	MTS-SB	20,374	21,467	22,812	24,515
31	BAKER	9,700	10,596	11,941	13,644
32	BARSTOW	76,701	81,559	86,722	90,128
33	TWPALMS	24,103	26,586	29,167	32,573
34	NEEDLES	5,872	6,266	6,884	7,689
35	J-BUPK	160,903	176,275	190,212	207,057
36	A-FULTN	170,787	200,249	228,133	244,978
37	H-ANAHM	307,729	329,456	357,340	391,123
38	I-N CST	240,377	273,603	302,881	319,726
39	F-C CST	161,253	238,721	315,396	365,829
40	D-S CST	38,834	79,500	114,353	131,198
41	B-CANYN	34,390	57,103	75,221	92,066
42	G-S ANA	266,278	308,333	354,336	404,769
43	C-TRABU	18,306	47,768	79,834	113,617
44	E-TORO	21,529	59,721	101,543	135,326
45	JURUPA	37,095	40,169	41,641	42,641
46	RVRSIDE	221,619	249,593	278,263	298,819
47	PERRIS	22,564	25,343	27,453	29,461
48	HEMET	34,368	39,423	43,643	45,651
49	MURRIET	12,001	13,292	15,078	16,578
50	PASS	26,852	28,438	30,646	32,146
51	IDYWILD	3,048	3,640	4,484	4,984
52	PALM SP	48,586	56,225	63,390	67,203
53	COACHEL	38,411	41,880	44,510	46,010
54	CHUCKAW	16,397	17,490	19,078	20,070
55	IMPERAL	74,492	79,951	85,555	88,063
	SCAG	10,052,689	10,949,000	11,930,500	12,711,792

REFERENCES

1. California Population 1971, California Department of Finance, May 1972; with accompanying undated computer printouts entitled Civilian Population.

2. Population Growth Analysis, Southern California Association of Governments, April 5, 1973.

3. Progress Report: Growth Forecast Revision, Southern California Association of Governments, September 12, 1973.

4. System Forecasts 1973-1995, Southern California Edison, February 1973.

5. Moving Ahead, Wells Fargo Looks at Southern California, Wells Fargo Bank, June 1973.

6. LARTS Annual Report, 1971/72, Los Angeles Regional Transportation Study, July 1972.

7. 1973 Forecast, United California Bank, November 10, 1972.

8. The Southern California Report, Security Pacific National Bank, March 1970.

9. Annual Report, 1971, Southern California Association of Governments, April 1971.

10. Regional Development Guide, Southern California Association of Governments, April 1972.

11. Projected Population Growth, Los Angeles Regional County Planning Commission, February 9, 1973.

TASK REPORT 3

TRANSPORTATION PROJECTIONS
FOR THE LOS ANGELES REGION, 1980-2000

W.F. Hamilton

G.M. Houser

SUMMARY

Transportation projections are developed for California's South Coast Air Basin, which includes greater Los Angles, based on existing analyses and forecasts and the assumption that there will be no dramatic changes in existing trends such as would result from stringent gasoline rationing. The projections foresee much slower growth of the freeway system, from 677 route miles in 1972 to 885 miles in 1990, but no significant diversion of area travel to public transit. Auto ownership is projected to increase from 0.52 to 0.61 cars per person from 1970 to 2000, with total autos increasing from 5 to 7.6 million. Daily vehicle mileage will rise slightly more than proportionately, reaching 168 million miles in 1980 and 228 million miles in 2000, with a slight increase in the fraction of miles driven on freeways. The average auto will be driven 10,600 miles per year, or 30 miles per day, by 2000, only 9 percent more than at present. By 1985, compact and subcompact autos are projected to capture two-thirds of the new car market, four times the share of standard autos, and average new-car fuel economy will increase 50 percent by 1984 and 100 percent by 2000. Total auto fuel consumption in the Air Basin is consequently projected to decrease slowly until the late 1990's.

CONTENTS

ILLUSTRATIONS

Illustrations (Cont.)

TABLES

1 INTRODUCTION

This is the second in a series of reports projecting baseline conditions (in the absence of electric cars) for use in a study of the impacts of future electric car use. It follows assumptions and data presented in the first report of the series, Task Report 2, Population Projections for the Los Angeles Region, 1980-2000.

The basic source of transportation information for the projection of this baseline is the Los Angeles Regional Transportation Study (LARTS). A continuing effort, LARTS has developed the definitive transportation data base for the region, and is currently in the process of modeling the future on this basis.

LARTS was established in January 1960 to deal with the transportation planning of the greater Los Angeles area, a region of some 9,000 square miles comprising 122 cities and parts of five Southern California counties. The LARTS study area is shown in Fig. 1.1, along with the South Coast Air Basin. The Basin and the LARTS region are nearly coincident; they differ primarily in that the Air Basin includes the Santa Barbara area and a sparsely populated portion of Riverside County, but does not include the Lancaster/Palmdale environs of Los Angeles County north of the San Gabriel Mountains. Well over 90 percent of the combined population is included in both of them.

LARTS began its studies and analyses in 1960 with the compilation of data from various sources. This included a home interview survey at a small number of dwellings (2,700 in all), a larger postcard questionnaire with 300,000 responses, a land use survey, material from the 1960 census, and others. In the effort to make maximum use of existing data, ". . . sampling of travel characteristics was minimized." The LARTS Base Year Report 1960 is the definitive initial presentation of the regional transportation situation.

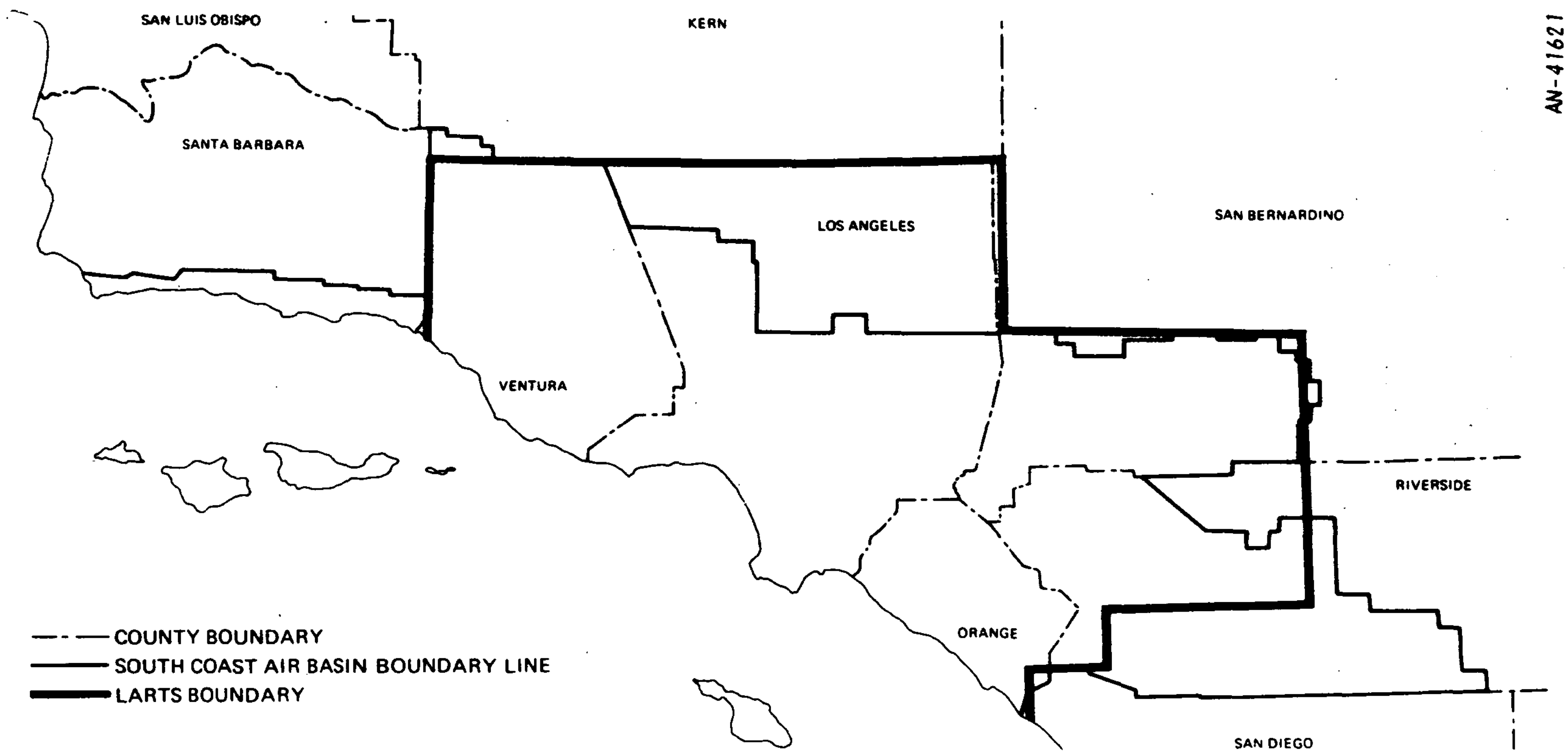


Figure 1.1. The LARTS Study Area

In 1967, LARTS greatly extended and improved its data base with a home interview survey of over 30,000 dwelling units. The results of this survey have been published as LARTS Base Year Report: 1967 Origin-Destination Survey. In many respects, they may be compared directly with the results of previous years, as in Table 1.1.

The 1967 survey is particularly useful for forecasts because it reflects an increased scope for LARTS. In the years since 1960, the Southern California Association of Governments (SCAG) had been founded as the review agent for comprehensive planning in the greater Los Angeles area. LARTS became the technical study arm of the transportation arm of SCAG, and as such became more involved with overall regional planning problems, as opposed to automobile transportation alone.

LARTS is presently engaged in developing transportation plans for 1990, together with detailed forecasts describing their prospective performance and cost. Only interim results are now available, however, since both plans and analyses remain in a state of flux. Substantial reasons for this state of flux may well be found in two major changes appearing in Los Angeles since work began on the 1967 survey. These changes are virtual cessation of population growth, and unprecedented popular concern for maintenance or improvement of environmental quality.

LARTS has been most cooperative in supplying working papers, reports, advice, and commentary in support of the development of baseline transportation projections reported here. It must be emphasized, nevertheless, that these projections are the responsibility of the authors.

The objective of this report is to draw together baseline projections for transportation systems of Los Angeles, with emphasis on characteristics particularly relevant to the impact of electric car usage and utility. It begins with a consideration of the basic facilities for the future: freeways available and their distribution among households of the

TABLE 1.1

SUMMARY RESULTS, LARTS BASE YEAR REPORTS

		1960	1967
Study Area, square miles		9,000	9,000
Population		7,597,000	9,008,400
Automobiles		3,437,000	3,930,200
Trucks		409,000	391,500
Weekday Person Trips		--	22,189,500
Weekday Driver Trips		12,261,164	15,773,538
Weekday Bus Passenger Trips		700,000	490,900
Weekday Freeway Vehicle Miles*		20,273,640	--
Weekday Total Vehicle Miles**		88,078,391	--
Housing Units		2,644,000	3,078,200
Apartment Units		568,000	986,400
Percent Units With:	No Car	16.7	14.7
	One Car	51.8	48.5
	Two Cars	27.4	30.8
	More Than Two Cars	4.1	6.0
Median Household Income, dollars per year		6,900	7,818
Median Age		30.6	27.8

*Computed; "counted or estimated" figures within 10 percent.

**Computed.

Basin. It then considers future travel characteristics, with particular concern for trends in automobile movement and daily usage of automobiles. Finally, it addresses the probable mix of different kinds of automobiles in the future automobile population, and projects on this basis their requirements for gasoline.

2 FREEWAYS

As the data in Table 1.1 makes clear, the Los Angeles region is highly automobile-oriented. The modal split--the fraction of trips taken by public transit--was only 3 percent in 1967, after many years of decline.

Though the majority of automotive trips have been and will continue to be made in the street system of the region, the freeway network plays an increasingly important role in both personal and vehicle movement. Los Angeles has, in fact, long been generally regarded as the stereotype of the "freeway city." The freeway system was inaugurated in 1940 with the opening of the Arroyo Seco Parkway (now the Pasadena Freeway), a six-mile, six-lane, six-million-dollar harbinger of the future. Subsequent expansion brought the total freeway system in the South Coast Air Basin to 677 route miles, as broken down by county in Table 2.1 and mapped in Fig. 2.1. In 1959, the California State Legislature had designated almost 1,600 miles of route in the LARTS area as part of the California Freeway and Expressway System. In recent years, however, public sentiment has come to favor much less freeway construction. In consequence, it now seems unlikely that a substantial portion of as-yet-incomplete segments of this System will be brought to freeway or expressway standards in this century.

Present network modeling at LARTS assumes that only about 200 miles of freeway route will be added in the SCAB area by 1990.* This mileage includes completion of the Foothill Freeway traversing the region from west to east, construction of the Century Freeway from the ocean to Interstate 605, construction of a missing segment of Interstate 15 on a north-south alignment through the eastern part of the Basin, and completion of a number of smaller segments.

Whether much of this additional route will actually be completed is open to speculation. At the moment, major parts of the addition--the Century Freeway, for example--are embroiled in litigation, the results of which cannot be confidently predicted.

*SCAB - South Coast Air Basin.

TABLE 2.1

FREEWAY ROUTE MILEAGE
IN THE SOUTH COAST AIR BASIN

County	Freeway Miles 1972	Freeway Miles 1990	Increase, Percent	Annual Growth Rate, Percent
Los Angeles	349	419	20	1.0
Orange	109	124	14	.7
Ventura	75	105	40	1.9
San Bernardino	68	114	68	2.9
Riverside	46	81	76	3.2
Santa Barbara	30	42	40	2.4
SCAB Total	677	885	31	1.5

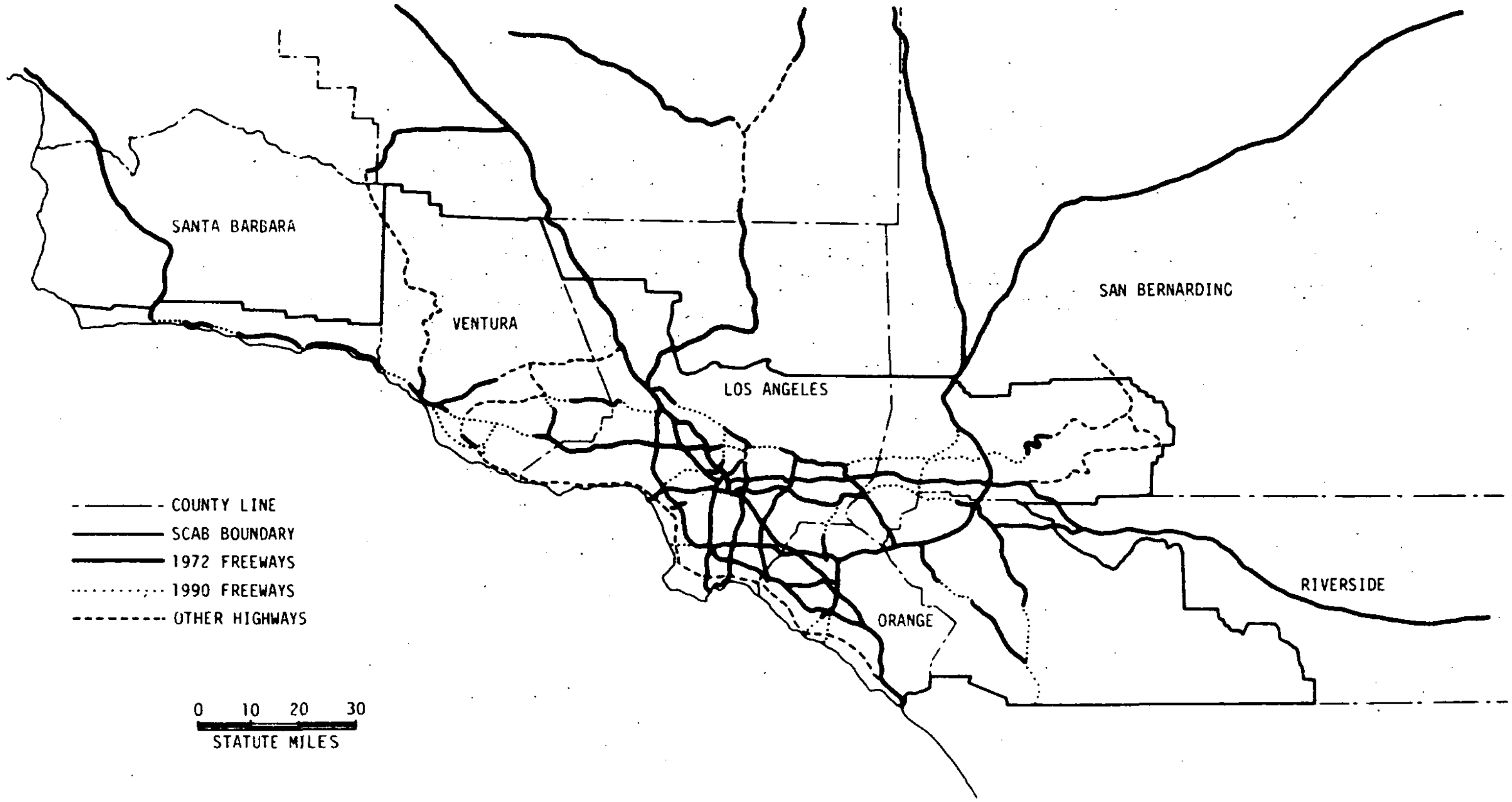


Figure 2.1. Freeway Routes in the South Coast Air Basin

Nevertheless, we have assumed that additional freeways modeled for 1990 by LARTS will be completed by that year. This represents, after all, a major reduction in planned route additions from that contemplated only a few years ago. The location of this additional route is shown in Fig. 2.1, and tabulated by County for the SCAB area in Table 2.1.

It is noteworthy, in Table 2.1, that the result of these prospective route additions is an average annual growth rate of 1.5 percent for freeway mileage in the SCAB. This amounts to a growth more rapid than that for the SCAB population, which is forecasted to grow at an average rate of 0.8 percent in the same period. On a county basis, rate of population growth in these projections exceeds rate of freeway route mileage growth only in Orange County, where relatively rapid population growth (1.3 percent per year) is in prospect, but only minor freeway additions are expected.

Route mileage, of course, is only one indicator of freeway availability. Probably more significant is total lane mileage, but current and prospective lane mileages for the SCAB are not conveniently available. Continuing expansion in number of lanes over existing freeway routes is, however, in progress now and contemplated for the future.

Overall, then, it appears that freeway capacity in the Air Basin will expand somewhat more rapidly than population during the remainder of this century.

3 RAPID TRANSIT

Though transit presently accounts for a very small portion of travel in the South Coast Air Basin, this was not always the case. Street cars and inter-urban electric railways provided comprehensive service to transit patrons before World War I. Their routes extended from San Bernardino to Santa Monica, and from the top of Mount Lowe to Balboa Bay, comprising twice as many route miles as the freeway system of the 1960s.

But the electric street railways could not provide service competitive with the automobile, and as automobile popularity grew, the trolley cars were additionally penalized by increasing numbers of at-grade crossings. By 1967, only motor coaches were providing transit service in the area to only 3 percent of total trips taken.

Private transit companies were consolidated in 1958, when the Los Angeles Metropolitan Transit Authority acquired and joined the separate systems into a single bus system. The MTA was subsequently transferred, in 1964, into the Southern California Rapid Transit District, which was created to raise funds from property or sales taxes to finance a rapid transit system. In 1968, an 89-mile, $2.5 billion rail rapid transit system was submitted to the voters. It received 45 percent of the vote, whereas 60 percent was required for approval.

Additional sources of funds have subsequently been developed in both state and federal government, and a new plan for rapid transit has been prepared. This plan was published in July 1973, in a volume titled Rapid Transit for Los Angeles: Summary Report of Consultants' Recommendations. Major points of this recommendation are summarized in Table 3.1, while the recommended route system is shown in Fig. 3.1.

The current recommendation is for a system including 116 route miles of generic "mass rapid transit," plus 24 miles of exclusive busways. The mass rapid transit routes are to be served by vehicles operated in

TABLE 3.1

SUMMARY OF THE 1973 RAPID TRANSIT RECOMMENDATION FOR LOS ANGELES

Mass Rapid Transit	
Route System	116 mi
Stations	62
Line Capacity	24,000 pass./hr (seated)
Maximum Speed	80 mph
Exclusive Busways	
Route System	24 mi
Line Capacity	10,000 pass./hr
Maximum Speed	60 mph
Surface Bus System	2,740 buses
Costs	
Capital Cost	
1972 Prices	$3.5 billion
Over 12-year Acquisition	6.6 billion
Annual Operating Cost	
Rapid Transit	$226 million
Surface Busses	285 million
Annual User Charges (fares)	$237 million
Estimated 1990 Patronage	
Weekday Rapid Transit Riders	1.05 million
Weekday Surface Bus Riders	0.875 million
Peak One-way Volume	40,000 pass./hr

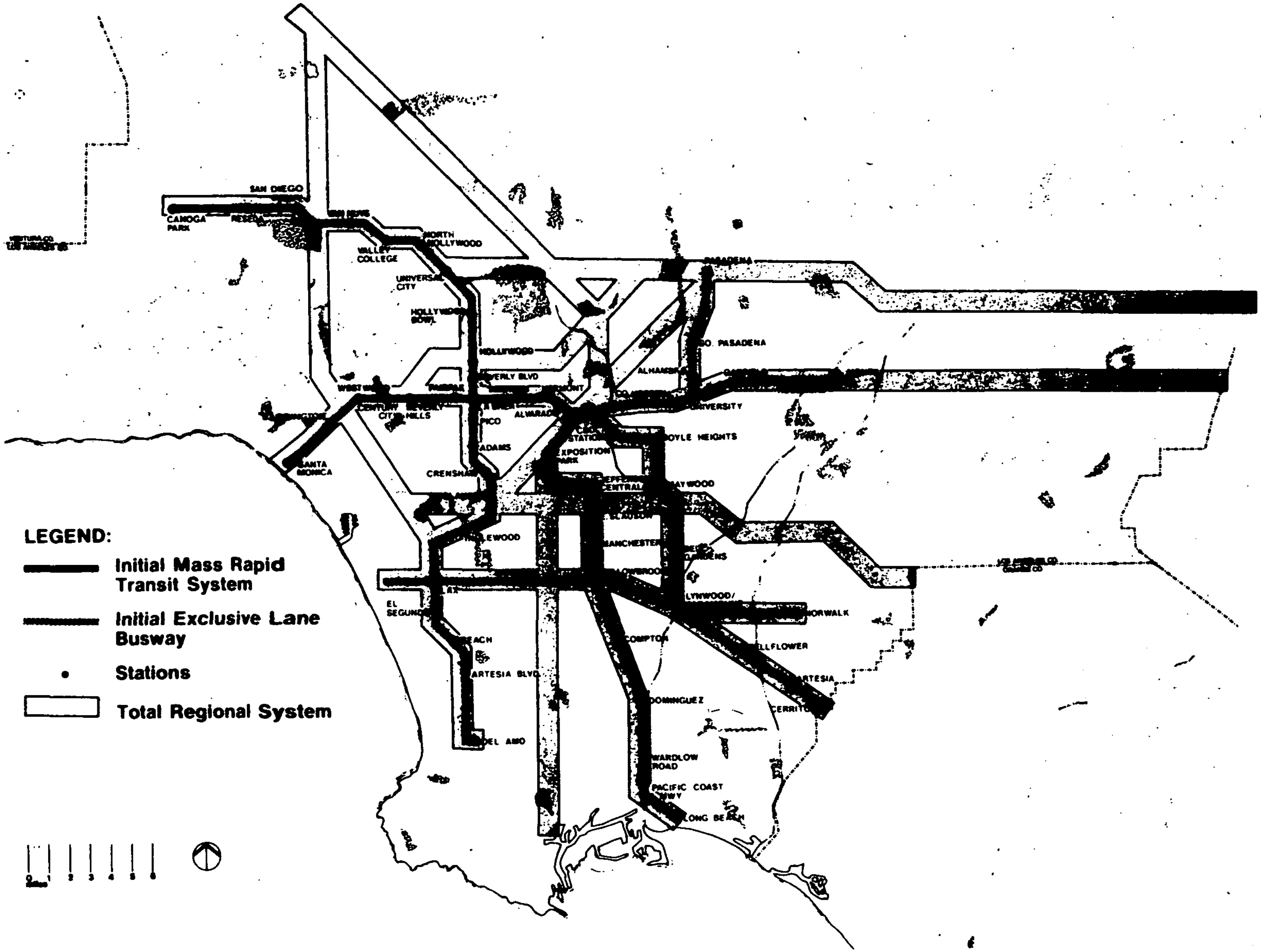


Figure 3.1. Los Angeles Rapid Transit--Proposed Routes

trains, like the BART system in the San Francisco Bay area, but their design has not been "finalized."

The rapid transit system of Fig. 3.1 serves Los Angeles County only. Patronage estimates for this area were made in conjunction with overall LARTS forecasts and modeling of 1990 trip production and automobile usage. In 1990, LARTS forecasts 29.7 million daily trips for Los Angeles County, of which all but a small portion are south of the San Gabriel Mountains, in the area served by the recommended transit system. Thus the estimated 1990 rapid transit patronage of 1.05 million represents a rapid transit modal split of only 3.5 percent. An additional 0.875 million riders per day are expected on the bus system, leading to a 6.5 percent modal split for the total transit system. This must be regarded as a high estimate, since a good many of the bus passengers are using the bus to gain access to the rapid transit system, and thus are being counted twice in the 6.5 percent figure.

The diversion of travelers from auto to the recommended rapid transit is relatively small overall: 2.4 percent of all automobile travelers in Los Angeles County. For trips to and from the Central Business District of Los Angeles, however, the diversion rate is over ten times higher. Such key areas, however, do not always play a role of increasing prominence in Los Angeles: the number of persons visiting the central business district in a day, has actually declined overall during the last 50 years, despite concurrent growth in total regional population from slightly over one million persons to nearly ten million persons.

Final planning of the recommended transit system proposal is now in progress, with the prospect that it will be submitted to Los Angeles County voters in November 1974, for approval of necessary local taxes. Whatever the election outcome, it seems unlikely that any mass rapid transit more expensive and effective than that of the current recommendation will be built in Los Angeles by 1990. Thus the patronage estimates of the recommendation are unlikely to be exceeded, and in consequence we may conclude that for purposes of this study, baseline transit use will be under 6 percent of total trips and consequently must be regarded as negligible in its impact on overall automobile movement. Only in the event of dramatic changes explicitly excluded from the baseline, such as stringent gasoline rationing, is it likely that rapid transit would serve as much as 10 percent of Los Angeles' daily travel.

4 AUTO AVAILABILITY

The automobile population for the Los Angeles region has been forecast for 1990 by the Los Angeles Regional Transportation Study. The forecast is documented in LARTS Technical Work Paper No. 1: Trip Generation Analysis Report, September 1, 1971. Additional detail is available in computer tabulations provided by LARTS.

The LARTS 1990 projections are based on extensive data gained in the 1967 home interview survey. They employed multiple linear regression in order to project automobile availability as an intermediate step in projecting future trips.

Projections for electric car impact analysis have been developed simply by extension of the LARTS results to the geographical area of the South Coast Air Basin, with adjustment for the different population projection adopted in the impact study.

The basic result taken from LARTS is the number of automobiles per person in the Los Angeles region. Since LARTS projected specifically to the year 1990 alone, figures for 1980 and 2000 were obtained by linear extrapolation, using 1972 actual automobile registrations, plus the population projections of this study. The result is shown in Fig. 4.1, which presents comparable automobile availability rates for California and for the US. Evidently, the projection calls for a leveling off in automobiles available per person, and the implication of past trends is that the high availability rates of the South Coast Air Basin will eventually be equalled in California and the US, which have demonstrated more rapid rates of growth since 1950. Automobile ownership rates for portions of the South Coast Air Basin by county are tabulated in Table 4.1.

The automobile availability data of Fig. 4.1 and Table 4.1 was combined with the population projections of this study to arrive at projections of total automobile population in the South Coast Air Basin. This total and its breakdown by county, is shown in Fig. 4.2 and tabulated in Table 4.2.

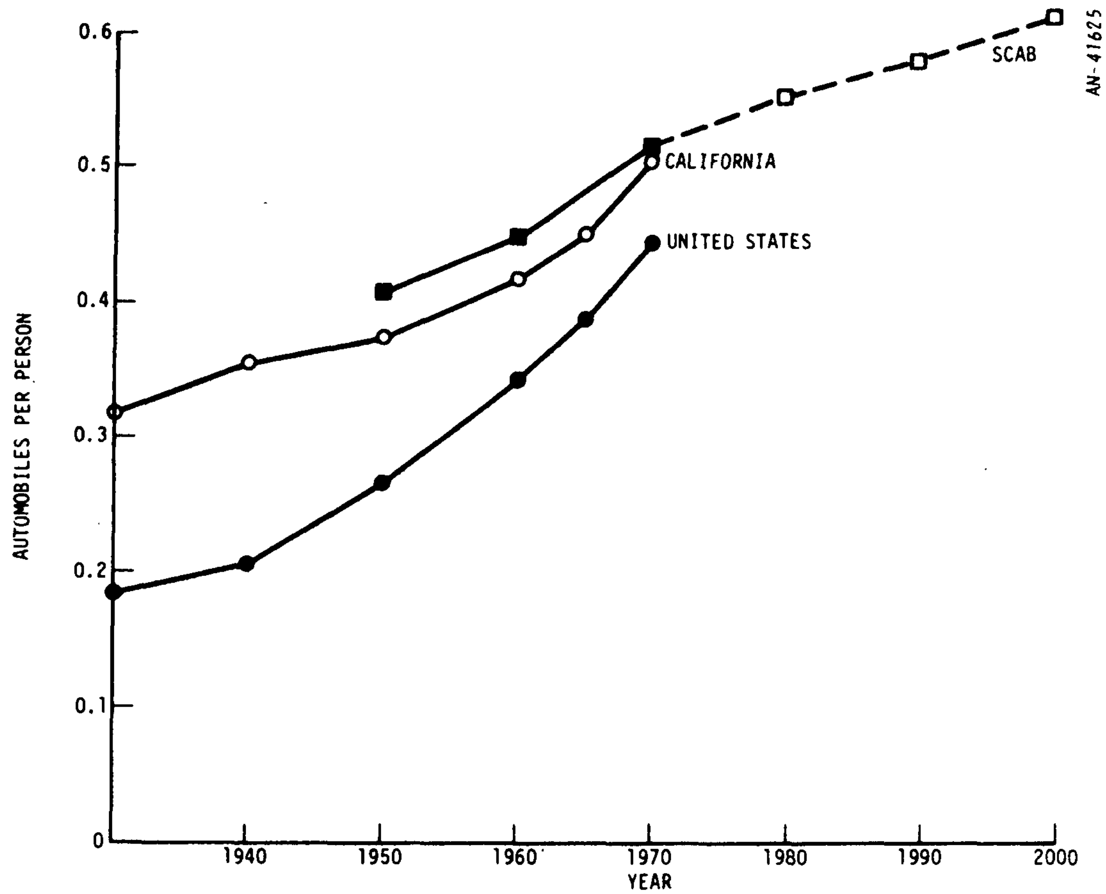


Figure 4.1. Basic Automobile Availability

TABLE 4.1

AUTOMOBILES PER PERSON, SOUTH COAST AIR BASIN

	Actual			Projected		
County	1950	1960	1970	1980	1990	2000
Los Angeles	.41	.459	.522	.559	.59	.63
Orange	.431	.440	.527	.547	.565	.584
Riverside	.386	.411	.495	.525	.558	.588
San Bernardino	.368	.407	.48	.53	.56	.60
Santa Barbara	.417	.44	.51	.538	.568	.592
Ventura	.366	.386	.481	.51	.538	.565
SCAB Total	.409	.451	.519	.551	.579	.613

Since the LARTS projections are based on detailed data about past and future residences, it is possible to break down the automobile population not only according to geographical area, but according to type of dwelling and automobiles available per household. This is done, for the LARTS area, in Tables 4.3 and 4.4. Since the SCAB area differs only in minor respects from that of LARTS, the percentages in these Tables from the LARTS area may be applied directly to the SCAB area with reasonable accuracy.

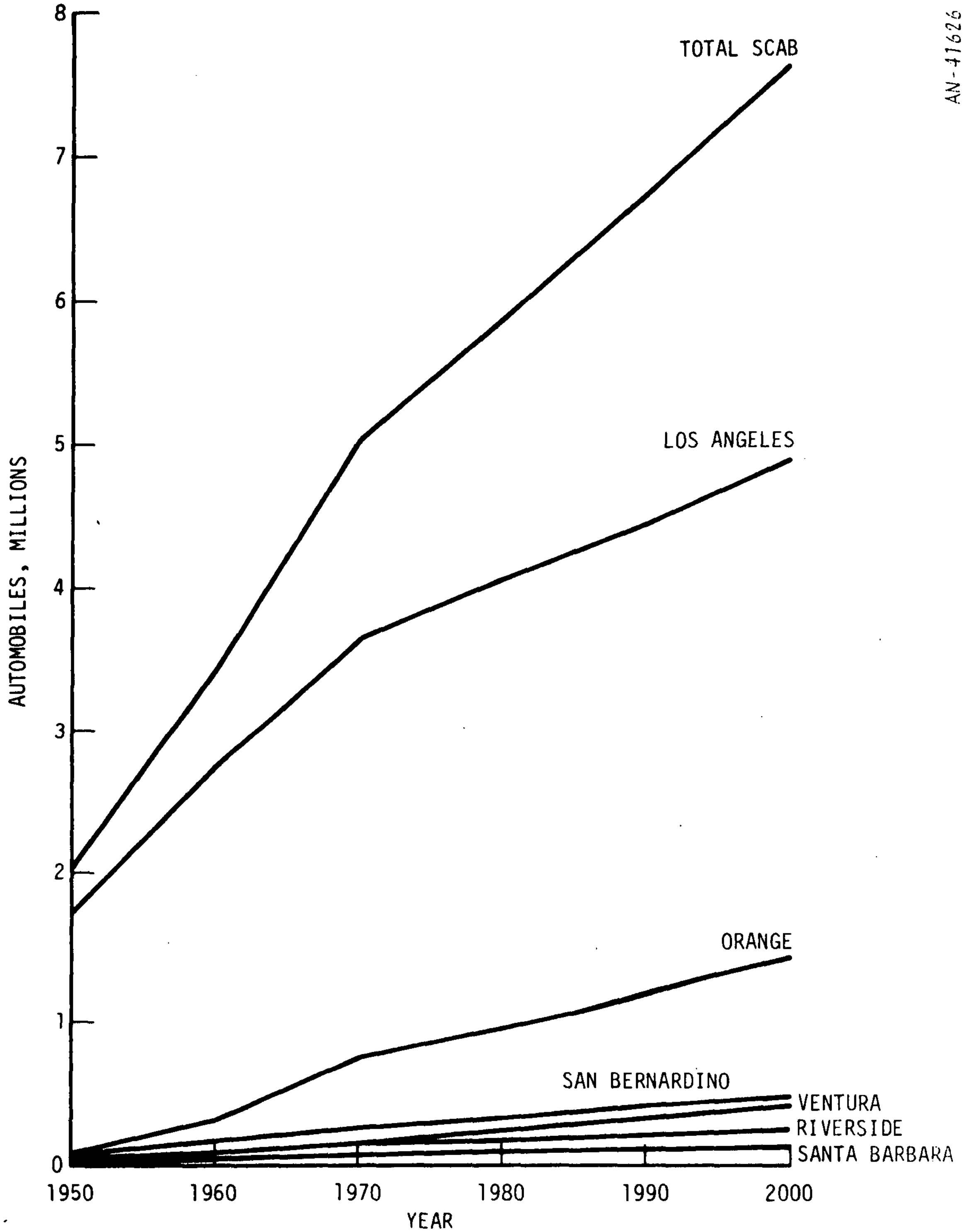


Figure 4.2. Automobile Population in the South Coast Air Basin

TABLE 4.2

AUTOMOBILE POPULATION OF THE SOUTH COAST AIR BASIN

County	Actual* 1950	1960	1970	Projected 1980	1990	2000
Los Angeles	1,705,694	2,747,570	3,626,450	4,033,605	4,442,869	4,893,368
Orange	93,106	309,392	748,217	970,378	1,199,212	1,406,447
San Bernardino	91,342	172,391	265,492	339,726	411,312	486,940
Santa Barbara	26,180	41,171	78,975	93,425	118,155	138,137
Riverside	47,442	88,508	160,523	194,495	228,543	257,174
Ventura	41,930	76,852	180,746	249,084	332,753	418,665
Total SCAB Area	2,005,694	3,435,884	5,060,403	5,880,713	6,732,844	7,600,731
10-year annual growth rate, percent		5.5	3.9	1.5	1.3	1.2

*Source: California Department of Motor Vehicles

TABLE 4.3

AUTOMOBILES AVAILABLE BY DWELLING UNIT TYPE
(In thousands)

County	1967			1990		
	Single	Mult.	Total	Single	Mult.	Total
Los Angeles	2,091	1,064	3,155	2,833	1,978	4,811
Orange	453	165	619	823	504	1,327
Ventura	125	32	158	343	141	484
San Bernardino	204	36	240	399	107	506
Riverside	125	25	150	231	79	310
Total	2,998	1,322	4,322	4,629	2,809	7,438
Percent	69	31	100	62	38	100

Source: LARTS Interim Model Runs, Tabs 400260-4, 400504-7, 400603

TABLE 4.4

AUTOS AVAILABLE BY HOUSEHOLD CAR OWNERSHIP CLASS
(In thousands)

County	1967		1990	
	1 car	2+ cars	1 car	2+ cars
Los Angeles	957	2,198	1,353	3,458
Orange	132	487	308	1,019
Ventura	36	122	106	378
San Bernardino	63	177	105	401
Riverside	43	107	76	234
Total	1,231	3,091	1,948	5,490
Percent	28	72	26	74

Source: LARTS Interim Model Runs, Tabs 400260-4, 400504-7, 400603

5 TRAVEL CHARACTERISTICS

Eventually, definitive travel forecasts for the Los Angeles area will be produced by LARTS. At the moment, travel forecasting is not complete, but interim data is available. From this data, detailed by computer models which regenerate 1967 conditions and forecast 1990 conditions, travel characteristics for 1980, 1990, and 2000 must be developed for electric car impact analysis. Results of the first step in computer modeling, projections of household characteristics and automobile availability, have been summarized already, as in Tables 4.3 and 4.4. The next modeling step utilizes these results to estimate trip production. The results of separate trip production model runs for 1967 and 1990 appear in Table 5.1.

Comparison of the 1967 and 1990 model output in Table 5.1 shows a tremendous growth in daily person trips and vehicle trips--over 100 percent. During the same time, the population increase in these models is only 50 percent. The difference is accounted for by major increases in daily trips per vehicle and daily trips per person.

Considerable data on the source of the vehicle trips in Table 5.1 is available from interim LARTS computer tabulations, as summarized in Table 5.2. The 1990 LARTS projections in Table 5.2 for person-trips rather than vehicle-trips; for comparability with the 1967 data, they have been scaled by the average vehicle occupancy of the area in 1967, 1,407 persons per vehicle. The absolute figures in the table apply, of course, to the LARTS area and to its 1990 population forecast, both of which differ from those used in this study. Nevertheless, because of the great similarities between the two situations, the percentage distributions at the bottom of Table 5.2 may be applied in this study with reasonable confidence. They show, for example, that in 1967 and 1990 over two-thirds of all vehicle trips will originate at dwelling units having two or more cars and that the fraction of such trips originating from multiple-unit dwellings will increase from 25 to 31 percent between 1967 and 1990.

TABLE 5.1

COMPARISON OF TRIP PRODUCTION MODEL RUNS, LARTS

	1967	1990
Population	9,019,184	13,446,007
Vehicles	4,479,000	7,437,000
Person Trips Per Day	22,272,000	48,554,752
Vehicle Trips Per Day	15,583,000	34,509,000
Vehicle Trips Per Day		
Per Vehicle	3.5	4.6
Per Person	1.7	2.6
Vehicles Per Person	.50	.55
Person Trips Per Day Per Person	2.5	3.6
Trips Per Vehicle At		
1 car households	3.9	5.2
2+ car households	3.5	4.3

Source: LARTS Interim Model Runs,
Tabs 400260-4, 400504-7, 400603

TABLE 5.2

DAILY VEHICLE TRIPS BY ORIGINATING HOUSEHOLD TYPES
(In thousands)

COUNTY	DWELLING UNIT TYPE	1967 1 car	1967 2+ cars	1967 total	1990 1 car	1990 2+ cars	1990 total
Los Angeles	single	2,167	5,367	7,534	3,725	9,239	12,964
	multiple	1,496	2,032	3,528	3,009	4,543	7,552
Orange	single	343	1,382	1,725	966	3,203	4,169
	multiple	202	421	623	776	1,533	2,309
Ventura	single	119	375	494	450	1,363	1,813
	multiple	34	111	145	180	692	872
San Bernardino	single	231	594	825	527	1,599	2,126
	multiple	50	85	135	134	309	443
Riverside	single	141	308	449	308	792	1,100
	multiple	33	54	87	102	241	343
Totals	single	3,001	8,026	11,027	5,776	16,196	22,172
	multiple	1,815	2,703	4,518	4,201	7,318	11,519
	overall	4,816	10,729	15,545	10,177	23,514	33,691
Totals, percent	single	62	75	71	59	69	66
	multiple	38	25	29	41	31	34
	all	31	69	100	30	70	100

Source: LARTS Interim model runs, Tabs 400260-4, 400504-7 400603. 1990 tabulations of person trips reduced by factor of 1.407 to approximate vehicle trips.

The next step in travel modeling is to distribute the trips of Table 5.1 and 5.2 by application of a gravity model, i.e., to determine where on the map the various trips go. In the course of this process, distributions of trip times by trip are necessarily produced. The results for several trip types in 1990 are shown in Fig. 5.1, along with a summary of home-to-work trips observed in the 1967 origin-destination survey. For 1990, as may be expected, it may be seen that work trips are generally substantially longer than the average of all trips, and that shopping trips are substantially shorter. That the 1967 work trips are longer in time than the 1990 work trips is probably the consequence of a different definition. The discrepancy, an almost-constant eight minutes regardless of total trip time, may be due to a portal-to-portal definition of trip time in the survey, which would include parking and walking times.

It is noteworthy that trips in the Los Angeles area are not substantially longer in duration than elsewhere in the nation. According to the 1963 Census of Transportation, 77 percent of all workers traveled less than 35 minutes to work, as compared to 76 percent from the 1967 Los Angeles O-D survey.[1]

Once trips have been distributed by the gravity model, they are assigned to specific routes in a detailed network model of the transportation system. The results of the assignment process, summarized in Table 5.3, show a great deal about the travel distances and speeds associated with different categories of trips. They also show what portion of trips and travel miles are on city streets as opposed to freeways.

Though these are interim model results, they suggest that vehicular travel conditions in Los Angeles are not to change greatly by 1990. The speeds in Table 5.3 change relatively little during this period, reflecting the prospect envisioned previously in this report that roadway capacity will keep up with travel demand, so that congestion levels will remain about as they are now.

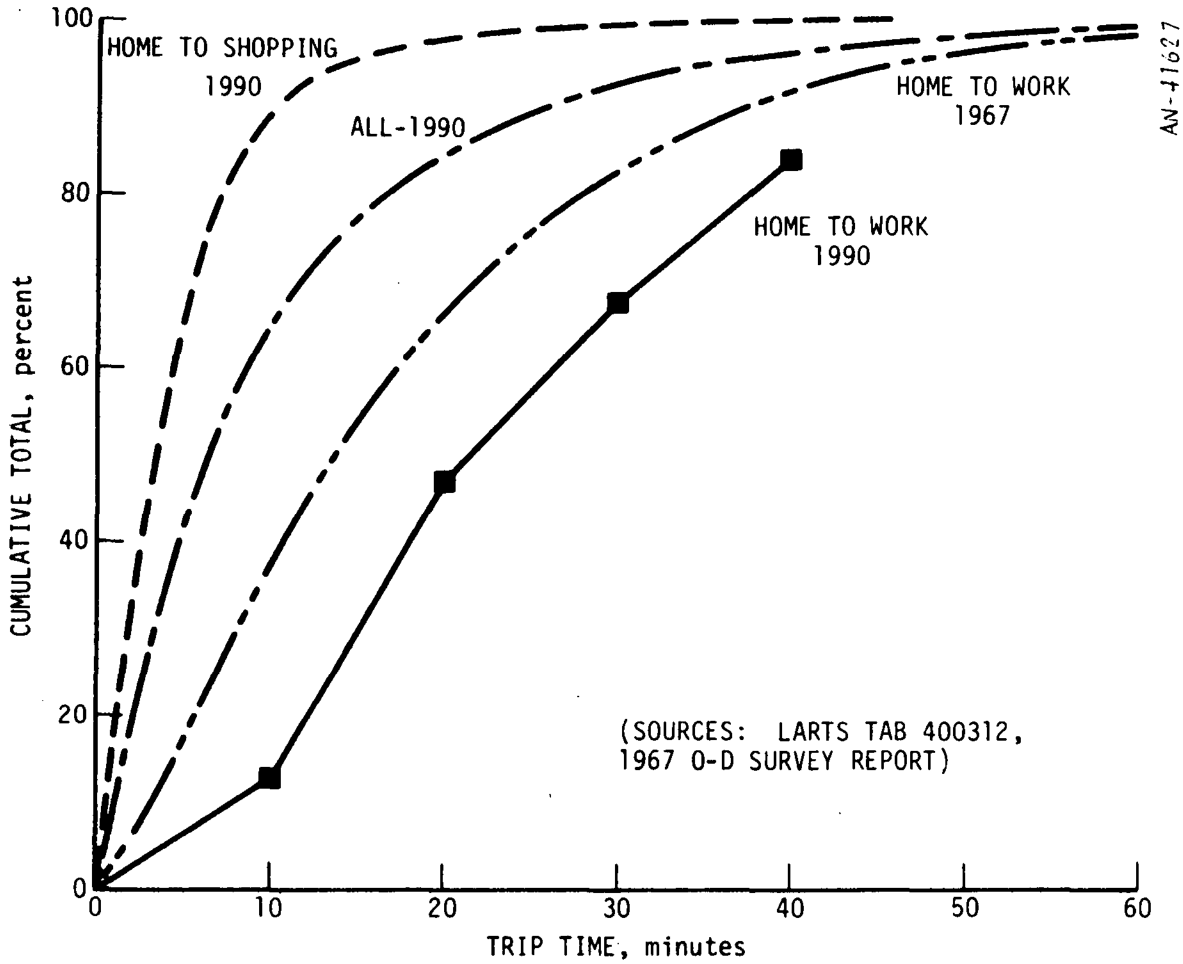


Figure 5.1. Distribution of Trip Times

TABLE 5.3

COMPARISON OF NETWORK MODEL RUNS - LARTS

TRIP TYPE CHARACTERISTICS	1967 MODEL RESULT BY TRIP TYPE				1990 MODEL RESULT BY TRIP TYPE			
	Home-Work	All Work	Non-Work	All Internal	Home-Work	All Work	Non-Work	All Internal
Vehicle Trips, Thousands	4,151	5,977	14,287	20,264	6,689	9,890	23,642	33,532
Percent	20	29*	71	100	20	29	71	100
Avg. Distance, Miles	8.9	8.3	4.7	5.8	10.8	10.2	6.1	7.3
Avg. Speed, mph	28.1	28.0	34.3	32.4	29.7	29.5	34.7	33.2
Streets	24.1	24.0	29.1	27.6	24.7	24.5	28.6	27.4
Freeway	36.9	36.9	54.4	49.2	36.5	36.5	46.0	43.2
Freeway Use Trips								
Percent of Total	37.7	36.0	21.0	25.5	40.1	38.5	25.3	29.2
Avg. Distance, mi.	15.4	15.3	14.1	14.9	19.7	19.5	19.7	19.6
Fwy. Distance, mi.	10.4	10.3	9.7	10.1	15.6	15.5	16.0	15.7
Street Distance, mi.	5.0	5.0	4.4	4.8	4.1	3.9	3.7	3.8
Freeway Vehicle Miles, percent	41	41	32	36	53	52	46	49

Source: LARTS Network Model Runs, Tabs 601978, 601979, 450268, 450269

*includes home-to-work

It should be noted that the total number of vehicle trips shown for 1967 in Table 5.3 is much greater than that from the 1967 survey reported in Table 1.1. It is also much greater than the total shown in Table 5.1, which comes from a trip production model closely approximating the survey result. The reason for this discrepancy is that the survey and model results were scaled up by approximately one-third in the network run, primarily to give screen line volumes in accord with traffic counts made at the time of the 1967 survey. This is clearly a major adjustment, leaving the various 1967 survey and model results in some doubt; under-reporting of travel in the survey is the most likely explanation.

To proceed with travel forecasting for electric car impact analysis, it is necessary to select either the 1967 description of Table 5.1 or that of Table 5.3 as a basis for viewing growth projected for 1990. It is most conservative to assume that the network results of Table 5.3 are more realistic than those which would result with the smaller number of trips of Table 5.1. This assumption minimizes the projected increase in vehicle movement within the LARTS area between 1967 and 1990. Nevertheless, as Table 5.4 demonstrates, the implications of the comparison of network runs is that there will be substantial increases in individual vehicle usage and in travel by individuals.

The consequences of these increases would be considerable, both in contribution of conventional automobiles to air pollution, and in the utility of electric vehicles for the increased number of longer trips on the average day. It appears, however, that though the increases may be implied by the LARTS multiple regression analyses, they are not suggested by other past experience. Figure 5.2 displays the long-term national trend in annual automobile use, as reported in Highway Statistics, the annual publication of the Federal Highway Administration. Also shown in Fig. 5.2 are recent figures for California, and the figures implicit in the LARTS 1967 and 1990 network model runs. Three points are immediately evident in Fig. 5.2:

TABLE 5.4

IMPLICATIONS OF TRIP PRODUCTION AND NETWORK MODEL RUNS - LARTS

WEEKDAY TRAVEL CHARACTERISTIC	1967	1990	Percent Increase
Total Vehicle-Miles, Thousands*	123,503	262,828	113
Total Vehicle-Minutes, Thousands*	231,392	476,009	106
Total Vehicle-Trips, Thousands*	20,399	33,932	66
Vehicles, Thousands**	4,479	7,437	66
Persons, Thousands**	9,019	13,446	49
Miles Per Vehicle	27.6	35.3	28
Minutes Per Vehicle	51.7	64.0	24
Trips Per Vehicle	4.6	4.6	0
Miles Per Person	13.7	19.5	67
Minutes Per Person	25.7	35.4	38
Trips Per Person	2.3	2.5	10
Miles Per Trip	6.1	7.7	26
Minutes Per Trip	11.3	14.0	24

*Source: Network Tabs 601978-9, 450268-9

**Source: Trip Production Tabs 400260-4, 400504-7, 400603

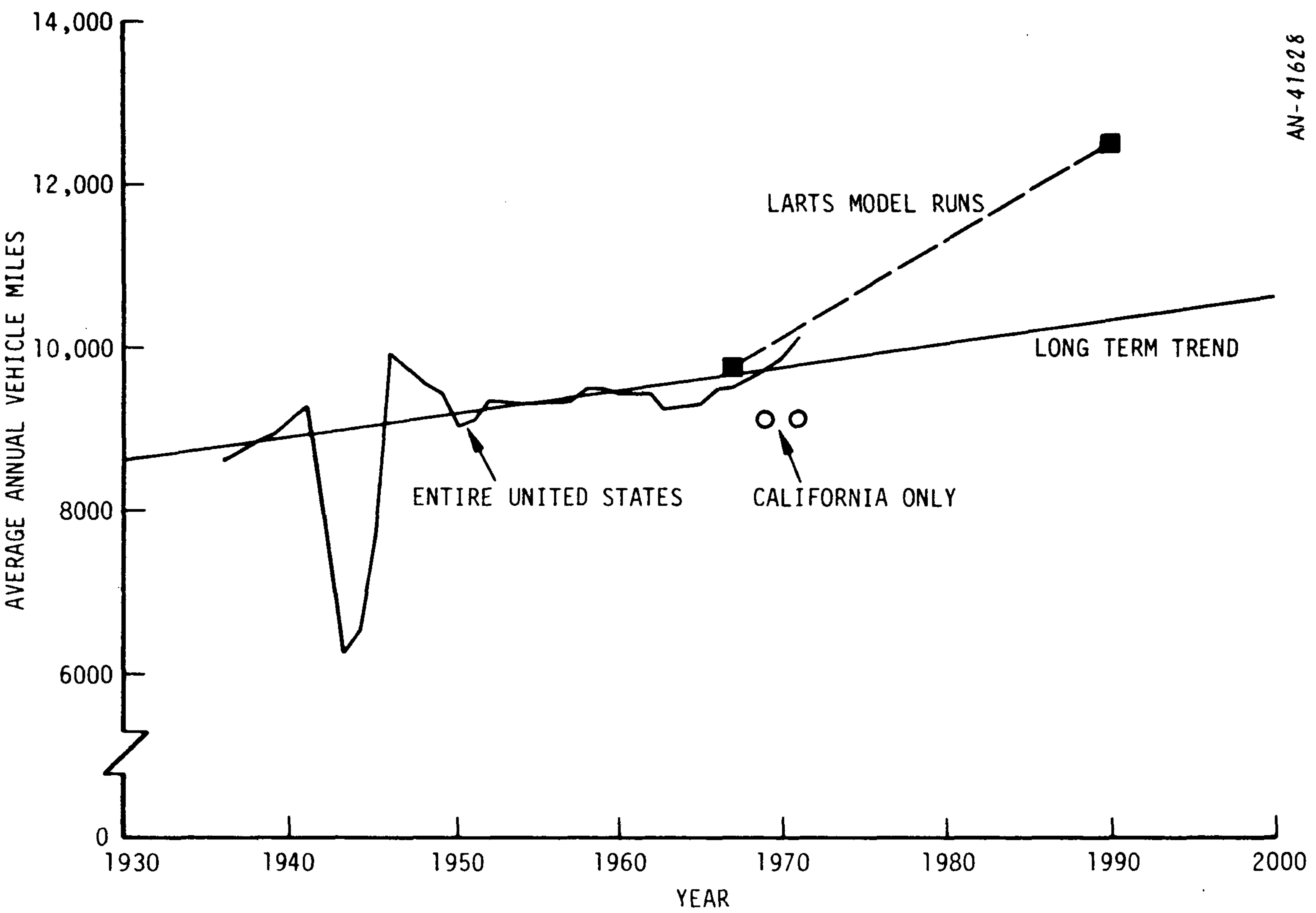


Figure 5.2 Average Annual Passenger Car Mileage Versus Time

- Except for dislocations due to World War II, national average automobile mileage per year has risen very slowly over the past 35 years. From 1940 to 1970, the total increase in annual automobile mileage was less than 10 percent.
- In recent years, California automobiles have been driven less, on the average, than those in the nation as a whole.
- The LARTS models envision a very rapid growth in Los Angeles automobile usage, at a rate over three times that of the long-term national trend.

It is true, of course, that for the last eight years, automobile use nationally has grown as rapidly as the LARTS projections. In view of the thirty preceding years of much lower growth, however, together with the depressing effects of fuel shortages and environmental controls, we believe that continued growth according to the LARTS models is unrealistic.

Accordingly, we have adopted the projections shown in Table 5.5, which are much closer to the national trend. The basis for these projections is the national trend of Fig. 5.2, which leads immediately to the daily vehicle mile projections. The daily trips per vehicle follow immediately from Table 5.4. The total daily vehicle miles follow from the daily averages and the automobile population projections of Table 4.1. The daily minutes of use per vehicle follows from the average speed in the LARTS 1990 model run.

The percentage of vehicle miles on freeways is less easily derived. Since the number of trips per vehicle is being held constant, the average trip in 1990 according to the baseline projection will be only slightly longer than in 1967. Thus the model run increase in trip distance, a disproportionate portion of which is by freeway, is inappropriate. The baseline projection of Table 5.5 assumes a much lesser growth rate of freeway use, equal to the rate of growth in the average trip distance.

TABLE 5.5

BASELINE AUTO TRAVEL PROJECTIONS
SOUTH COAST AIR BASIN

	1980	1990	2000
Daily Vehicle Miles, millions	167	196	228
Percent on Freeways	39	42	45
Percent on Streets	61	58	55
Daily Miles Per Vehicle	28.3	29.2	30.0
Daily Trips Per Vehicle	4.6	4.6	4.6
Daily Minutes Per Vehicle	53	54.7	56.2
Miles Per Trip	6.15	6.35	6.52
Minutes Per Trip	11.5	11.9	12.2
Average Speed, mph	32.0	32.0	32.0

6 AUTO AGE AND CLASS

In Sec. 4, the total number of automobiles for the South Coast Air Basin was projected from area population and forecast automobile ownership rates. The result is shown in Fig. 4.2. Important changes are in progress in the automobile population, however, as emission control and safety requirements are being introduced, and as buyer preference shifts from the larger to the smaller classes of automobiles. The projections developed in this section describe the changing future mix of automobiles by age and class, providing the necessary basis for projecting future overall emissions and fuel consumption, and for changes in them as increasing numbers of electric cars are introduced.

6.1 AUTO AGE DISTRIBUTION AND SALES

Survival rates for US automobiles from several different model years are shown in Fig. 6.1. These rates, drawn from actual registration data, are vital in translating market share and sales trend data into total auto population characteristics at any single time. But the rates of Fig. 6.1 are not immediately applicable to the South Coast Air Basin, for two reasons. First, they are obviously erroneous in showing number of survivors for 1962 and 1959 models to be larger after two years of use than after one. Second, they are drawn from data for the entire US which on the average involve higher levels of use, more difficult environmental conditions, and consequently shorter life than in Southern California. The first of these difficulties may be removed by a minor adjustment of the questionable curves of Fig. 6.1, as suggested by the 1967 model curve; but the second is not so simply handled.

When the average car lasts longer, as in California, lower sales are required relative to a given automobile population in order to maintain that population constant by replacing scrapped cars. This illustrated in Fig. 6.2, which shows the proportion of new car registrations to total car population for the US and for California alone.

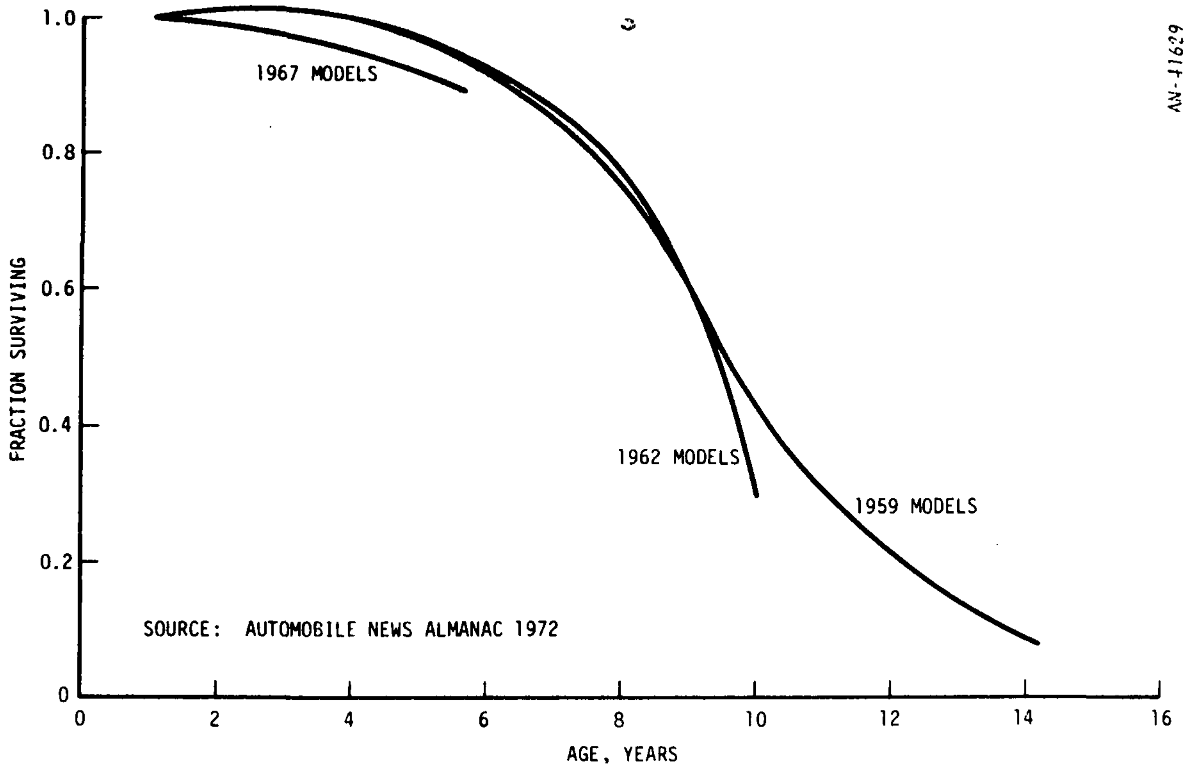


Figure 6.1. Survival Rates for US Autos

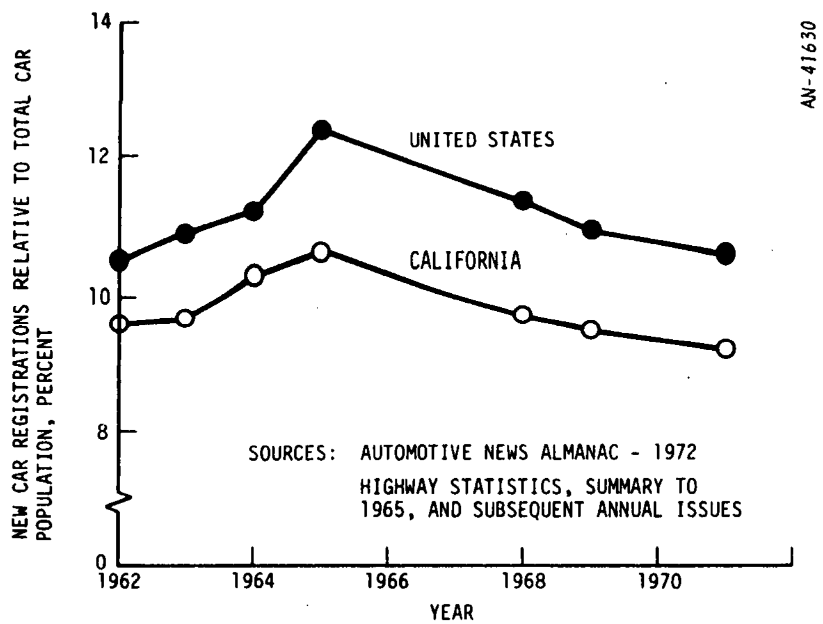


Figure 6.2. Relation of New Car Registrations to Total Car Population

There is an additional factor, of course, in the relation of registrations to population: the rate of growth of car population. Independent of the longevity of automobiles, a rapid growth rate requires higher new car additions to the population than a lower growth rate. During the latter part of the period illustrated in Fig. 6.2, however, the growth rates for California and US populations were almost equal. Accordingly, the difference between the two curves of the figure is a significant indicator of longer automobile life in California.

The sales rates relative to car population in Fig. 6.2 for recent years range from 14 to 17 percent higher in the US than in California. If anything, these figures underestimate the difference between California and the US, because in previous years California did grow faster than the nation in automobile population, and consequently may require replacement of relatively fewer elderly cars than does the US generally. Accordingly, we have assumed a difference of 18 percent for adjustment of national survival times.

Figure 6.3 shows the adopted projection for automobile survival rates in both the US and the South Coast Air Basin. The US rates were obtained by replotting average data from Fig. 6.1. The California rates in Fig. 6.3 follow immediately from the assumption that California automobiles survive 18 percent longer than US automobiles in general.

The adequacy and accuracy of this assumption rests on its simultaneous compatibility with actual sales rates of automobiles in California and with the projections of automobile population for the South Coast Air Basin appearing in Table 4.2. These projections are independent, of course, since they were derived from the LARTS forecasts of automobile availability in Table 4.1, together with the population forecasts of this impact study.

Automobile sales for the South Coast Air Basin are shown in Fig. 6.4. Actual sales data for the Air Basin were not available, so estimates

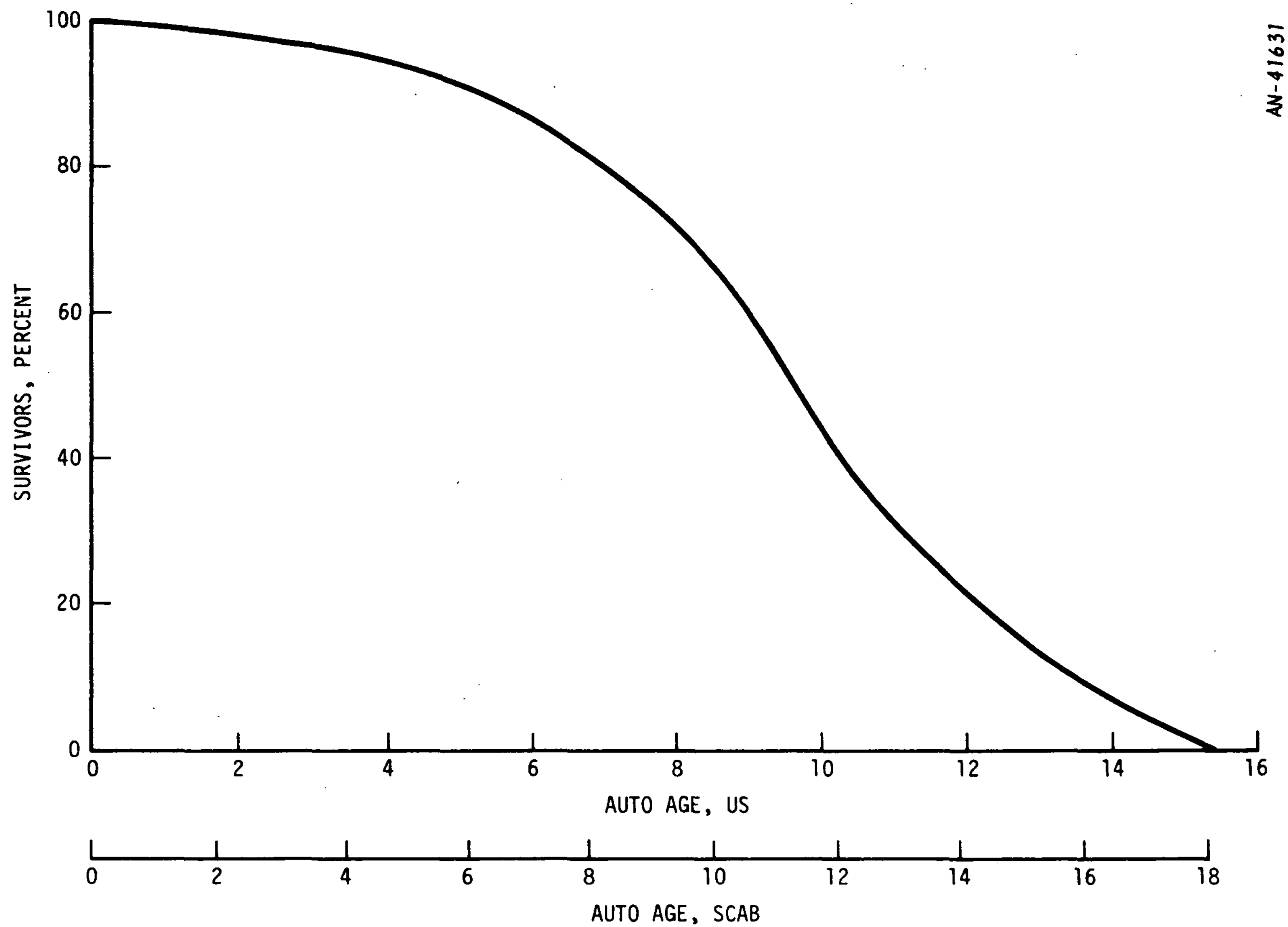


Figure 6.3. Projected Automobile Survival Rates

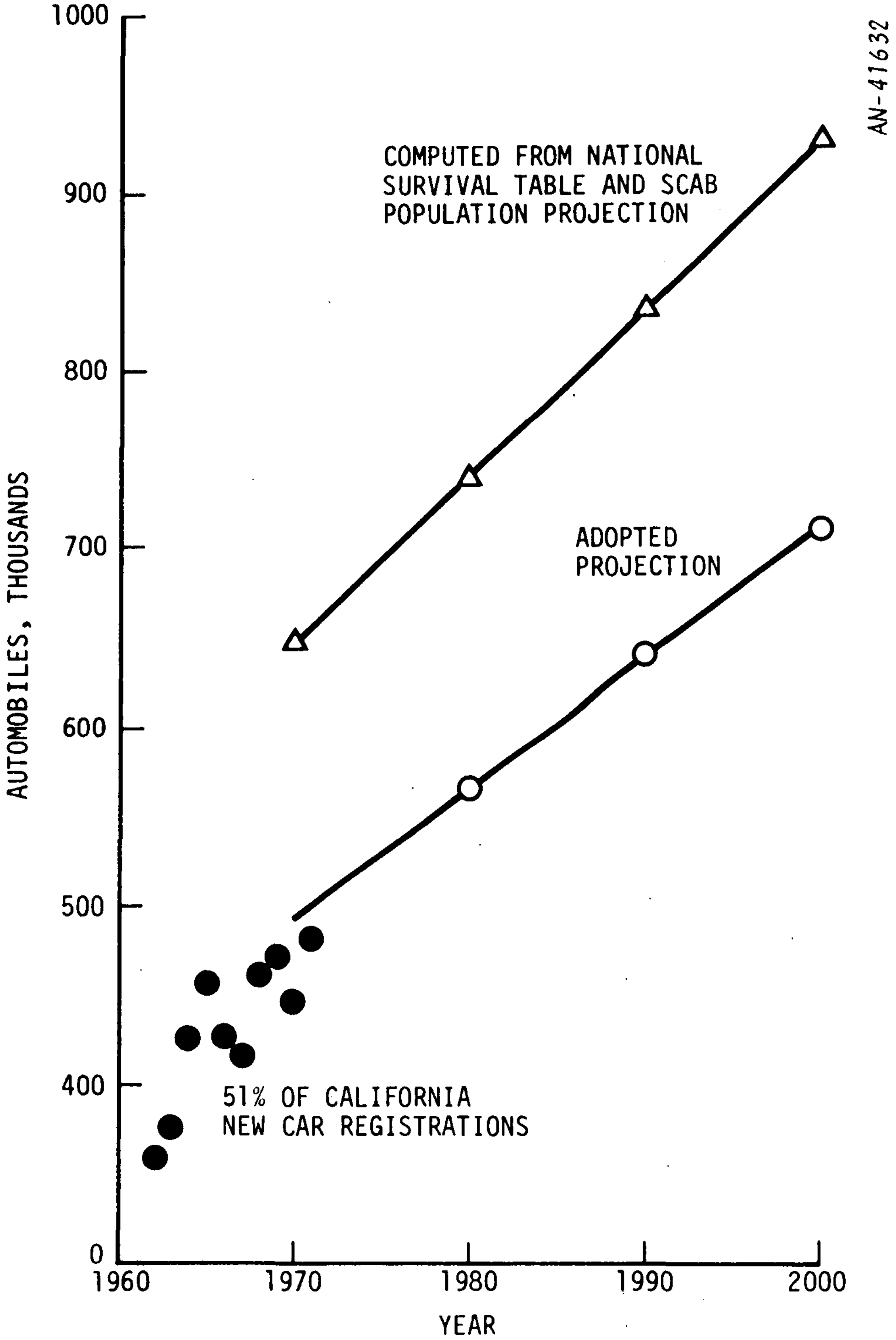


Figure 6.4. Annual Automobile Sales, South Coast Air Basin

were obtained by taking 51 percent of total car new car registrations in California, as shown. In 1970, 51 percent of all automobiles in California were in the Air Basin.

The upper line on Fig. 6.4 shows a computed automobile sales rate necessary to support the independent population projection of Table 4.2, assuming survival rates according to the US curve of Fig. 6.3. Computation of this sales rate is described in the appendix. It is obviously much higher than past sales in Fig. 6.4, further substantiating the observation that California automobiles last considerably longer than automobiles in the entire US. Accordingly, another projection method is needed.

The adopted projection of Fig. 6.4 was based on estimated SCAB sales in preceding years and estimated future sales to meet the SCAB auto population forecast of Table 4.2. When combined with the California survival rate of Fig. 6.3, it results in a total automobile population which is in excellent agreement with the independent projection; a comparison appears in Table 6.1. As described in the next section, this population projection has been used in converting market share percentages by automobile class into total population percentages by class. The projection of Table 4.2, however, remains basic, so resultant population percentages are applicable to the left-hand population totals of Table 6.1 rather than those on the right.

The sales projections of Fig. 6.4 and the California survival rates of Fig. 6.3 may be combined to determine the distribution of SCAB automobiles according to age. This is done, on a percentage basis, in Table 6.2, and plotted in Fig. 6.5. In Table 6.2, only relative sales rates are required, since only percentage distributions are sought. The relative sales figures are increased uniformly from a nominal value of one for the sales year of the oldest car in the population, at the percentage rate implicit in Fig. 6.4.

TABLE 6.1

COMPARISON OF AUTO POPULATION PROJECTIONS FOR THE SOUTH COAST AIR BASIN

Year	Computed from Auto Availability and Population Projection	Computed from Auto Survival and Sales Projections	Discrepancy
1980	5,880	6,046	2.0%
1990	6,733	6,955	3.2%
2000	7,600	7,740	1.8%

TABLE 6.2

DISTRIBUTION OF VEHICLES WITH AGE, SOUTH COAST AIR BASIN

Vehicle Age	Relative Sales	Survival Rate	Survivors	Percent of Total	Cumulative Percent
1	1.772	0.990	1.754	10.9	10.9
2	1.724	.985	1.698	10.6	21.5
3	1.676	.970	1.626	10.1	31.6
4	1.628	.952	1.550	9.7	41.3
5	1.580	.935	1.477	9.2	50.5
6	1.531	.909	1.392	8.7	59.2
7	1.483	.87	1.290	8.0	67.2
8	1.435	.82	1.177	7.3	74.5
9	1.386	.759	1.016	6.3	80.8
10	1.338	.668	.894	5.6	86.4
11	1.290	.551	.711	4.4	90.8
12	1.241	.428	.531	3.3	94.1
13	1.193	.319	.381	2.3	96.4
14	1.145	.22	.252	1.6	98.0
15	1.097	.149	.163	1.0	99.0
16	1.048	.09	.094	.6	99.6
17	1.0	.04	.04	.2	99.8
		Total:	16.046		

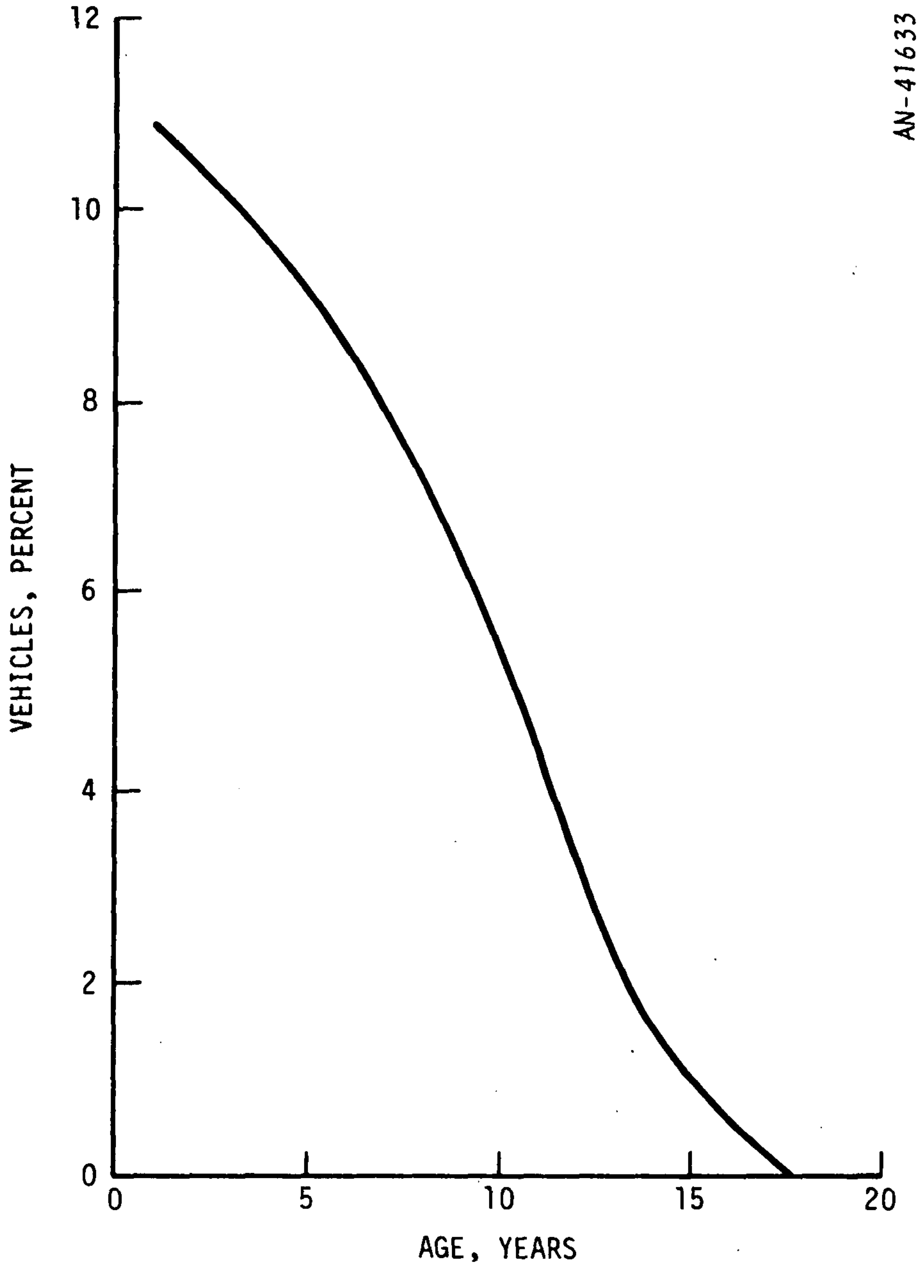


Figure 6.5. Distribution of Vehicles with Age, South Coast Air Basin

The distribution of vehicles with age (Fig. 6.5) was compared with a standard distribution used in California. This distribution appears in a California air quality manual and is in general use in determining emissions factors in a given year appropriate to a realistic mix of vehicle ages.[2] The standard distribution is so nearly identical to that of Fig. 6.5 that it is not practical to plot them separately on the same figure. Thus the adopted sales projection and survival rates seem fully corroborated.

6.2 AUTO MARKET SHARES AND POPULATIONS BY CLASS

There has been a drastic shift in the last 15 years in the nature of automobiles sold in the US. In 1958, 90 percent of the US auto market was taken by standard-size automobiles. But by 1972, in the bellwether Los Angeles area, sales of standard cars had precipitously declined to 25 percent of the market and they have continued to slide subsequently. Projection of this trend into the future is important partly to establish the baseline auto world on which electric cars will impact, and partly to show the kind of market in which electric cars must compete.

Figure 6.6 presents actual and projected shares of the US auto market by class. Though definitions of the classes seem to change with time, they may be described in recent years as follows:

Class	Price	Weight, pounds	Cylinders
Subcompact	<$2285	up to 2,600	four
Compact	<$2800	2,601-3,200	six (with eight-cycle options)
Intermediates	<$3498	3,201-4,000	six and eight
Standard	<$3500	4,001 and up	eight
Specialty	"Sports" models encompassing entire range.		

At the left of Fig. 6.6 are actual market shares. Those for 1964 through 1972 were taken directly from annual issues of Automotive News Almanac; earlier data from the same sources were supplied by Dr. Joseph

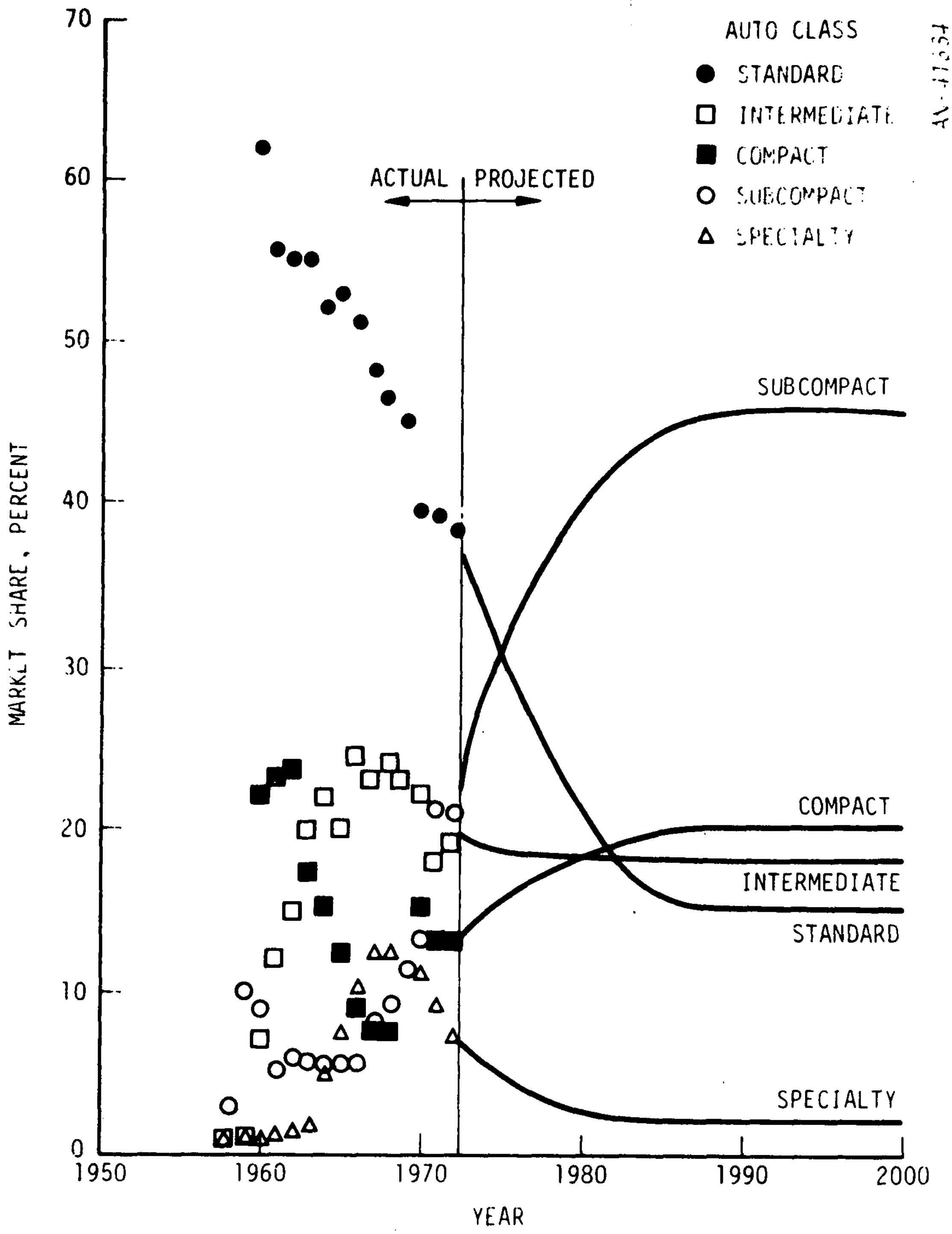


Figure 6.6. US Auto Market Share by Class

Meltzer of the Aerospace Corporation. The rapid decline in popularity of the standard automobile is evident in Fig. 6.6, as is the very rapid rise of subcompact popularity.

The market share projections at the right of Fig. 6.6 are basically extrapolations of the existing trends. But trend extrapolation, if carried too far, leads to market shares below zero or over 100 percent, so some limitation or reversal of trend must be introduced. The limitations appearing in Fig. 6.6 are necessarily subjective assumptions, since detailed forecasts are beyond the scope of this study. They reflect the following major prospects:

- That dwindling supplies of fuel and rising prices will increasingly favor smaller, more economical automobiles
- That stringent exhaust emission controls and noise emission controls will make "muscle" cars more difficult and less rewarding to produce and operate
- That automotive safety requirements will increasingly encourage smaller cars

In the past, of course, there has been some talk of elimination of smaller cars in the interests of improved safety. At present, however, national emphasis in automotive safety research is moving rapidly towards the problem of smaller cars, both because the public has demonstrated increasing desire for small cars, and because the national energy situation could be much improved with lighter, more efficient automobiles. There is an inherent safety problem when large and small cars mingle, as at present on US streets and freeways. But the mix is shifting; and whereas it might once have seemed sensible to eliminate a few hazardous little cars, it may soon seem much more desirable to eliminate a few menacing large cars.

The projections of Fig. 6.6 approach ultimate values which are foreseeable now in view of the above considerations and existing trends. In the further future, of course, other problems, issues, and trends will doubtless develop which will further alter market shares. It is not possible, however, to delve into such prospects within the scope of this study. In consequence, the market shares are projected at a constant level after 1985.

Because historical data for market shares in the South Coast Air Basin are not readily available, projections for the Basin must be developed from the national situation of Fig. 6.6. This was accomplished as shown in Fig. 6.7, simply by extrapolating from existing actual market shares for 1972 to the same ultimate market shares of Fig. 6.6.

Looking to 1985 and beyond, when further shifts in market share cannot be anticipated by this study, there is no solid ground for assuming different market shares in Los Angeles and the nation. The underlying assumption in Fig. 6.7 is that the SCAB auto market has been perhaps five years ahead of the national trend of Fig. 6.6, but is eventually going to go no further than elsewhere in the nation.

Given the sales projections of Fig. 6.4 for the South Coast Air Basin, the market shares of Fig. 6.5, and the survival rates of Fig. 6.3, it is possible to project the mix of autos in the Basin for future study years. The result is shown in Fig. 6.8. Some further assumptions, however, are necessary, since as Table 6.2 shows, 20 percent of automobiles in 1980 California will be pre-1972 models, for which market shares are not presented in Fig. 6.7. To obtain necessary estimates, the extrapolations of Fig. 6.7 were simply continued backward several years. This is not necessarily an accurate procedure but since it only affects a minor fraction of the total vehicle population in 1980, the expense of obtaining additional regional data seemed unjustified.

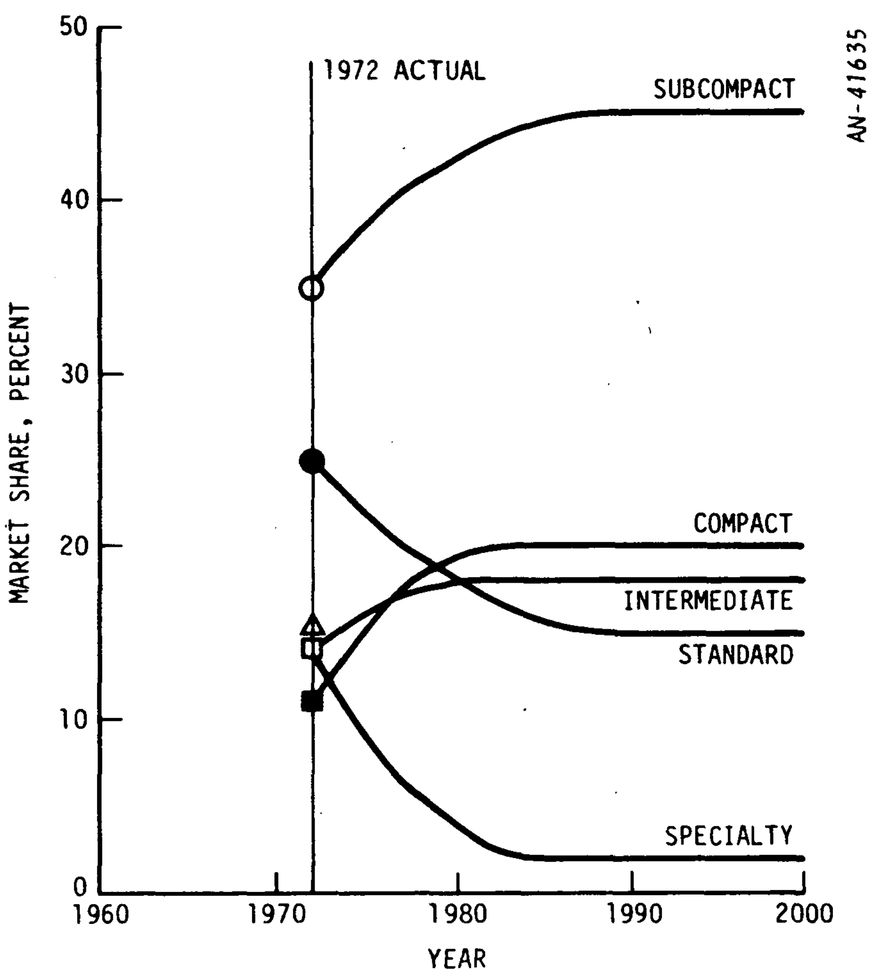


Figure 6.7. Projected Auto Market Share by Class for the South Coast Air Basin

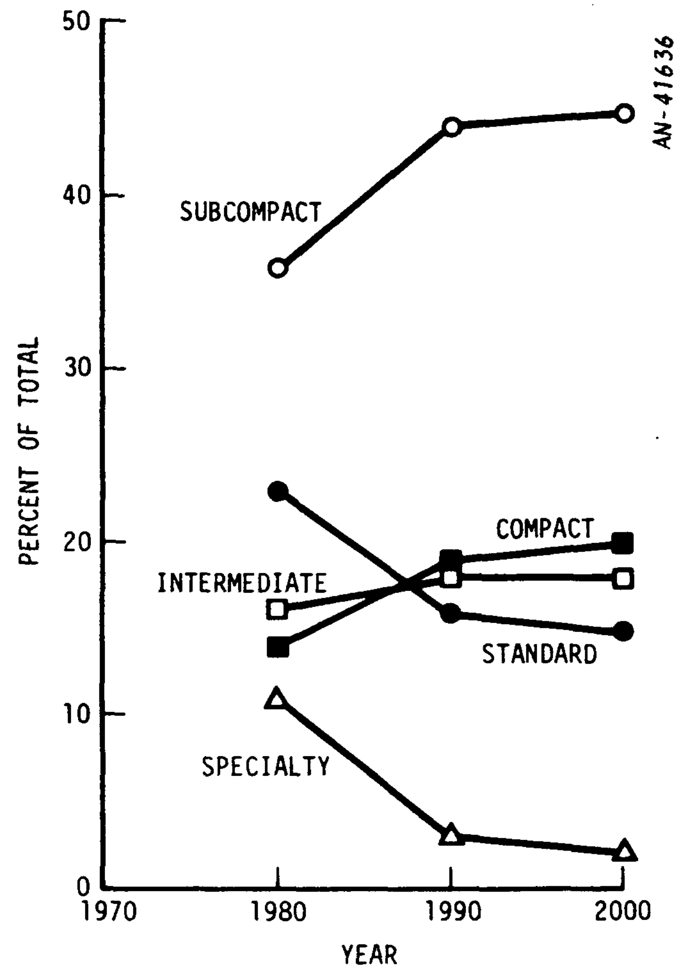


Figure 6.8. Projected Auto Population Share by Class for the South Coast Air Basin

7 AUTO FUEL CONSUMPTION

In the first approximation, fuel requirements for automobiles have been proportional to vehicle weight. According to a summary from the Motor Vehicles Manufacturers' Association,[3] horsepower required to meet road load and acceleration is given by

$$\text{Horsepower required} = K_1WV + K_2DAeV^3 + K_3VWC$$

where K_1, K_2, and K_3 are constants

W is car weight

V is car speed

D is vehicle drag coefficient

A is frontal area of the car

e is air density

C is acceleration rate

Where speeds are not excessive and stops are frequent, the first and last terms of this expression dominate required energy production in a given driving cycle, and both are directly proportional to vehicle weight. Weight correlation with fuel economy is shown by an EPA study of dynamometer tests of automobiles of various model years on the Federal Driving Cycles.[4]

The general trend to increased average weights for major classes of automobiles is shown in Fig. 7.1. This trend has not been compensated fully by shifts in market preference towards the compacts. Moreover, there have been automobile efficiency sacrifices due to increased use of air conditioning and to pollutant emission controls. In consequence, fuel economy persistently declined until the 1975 model year, as Fig. 7.2 shows. Points in Fig. 7.2 are based on EPA measurements of fuel economy by market year on the Federal Driving Cycle, weighted for the sales mix of each year since 1958.[5]

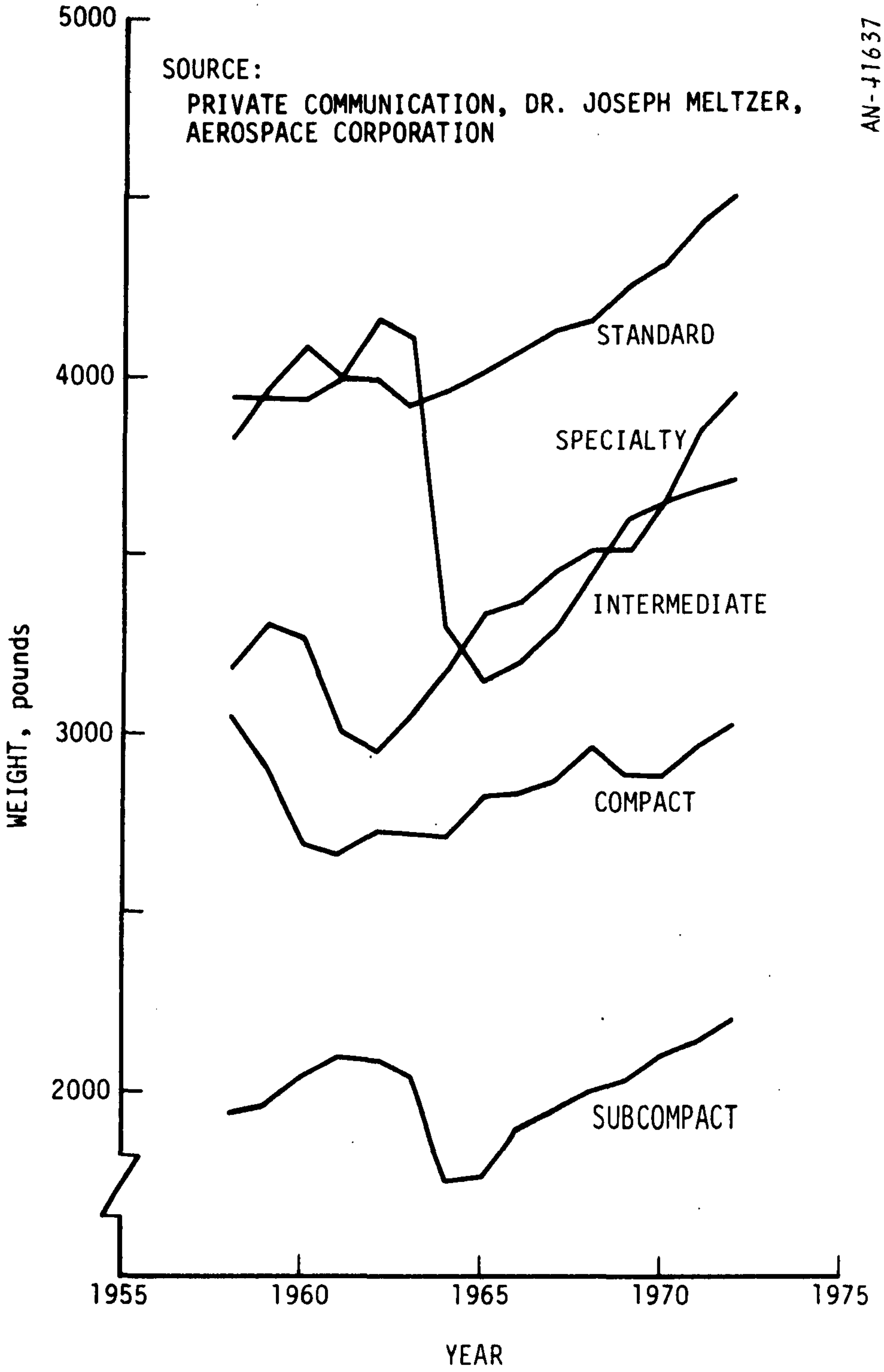


Figure 7.1. Automobile Weight by Class

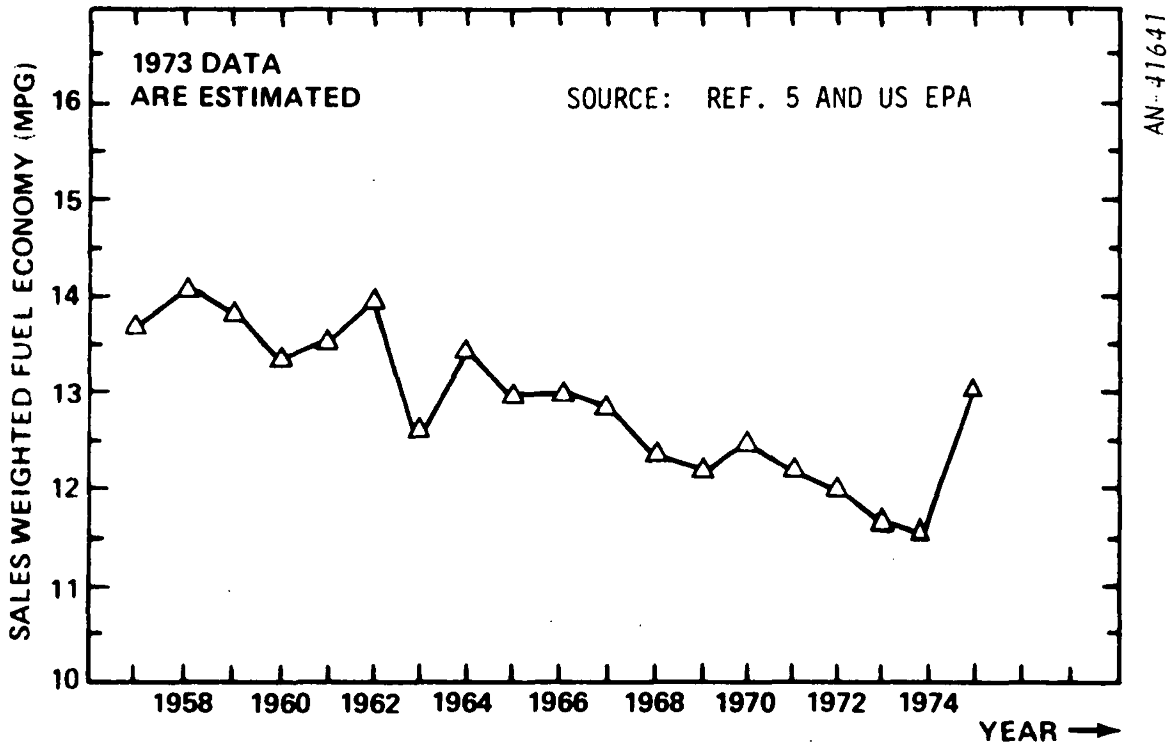


Figure 7.2. Sales Weighted Fuel Economy Versus Model Year

Fuel economy for new cars is not the same as for all cars on the road in a given year, nor is fuel economy in the Federal Cycle identical with average fuel economy in actual use. Figure 7.3 shows national average fuel economy as reported by DOT from automobile miles driven and gallons of fuel consumed, in comparison with fuel economy calculated for the actual mix of cars on the road based on Federal Emission Cycle measurements.[5] The national average mileage is consistently about 6 percent higher than that calculated from Federal Emission Cycle measurements.

For future electric cars, it is important to estimate gasoline mileage for conventional cars which the electric may replace. This is not easily done, however, partly due to the current spate of gasoline shortages and price increases, partly due to pending legislation which may directly influence fuel economy, and partly due to research programs intended to make major improvements in auto efficiency.

A joint DOT/EPA program initiated in 1973 has as its objective a 30-percent decrease in fuel consumption (equivalent to a 43-percent increase in fuel economy), suitable for mass production automobiles of 1980. The objective is particularly impressive because it is sought without sacrifice in performance, appearance, available space, safety standards, emission standards, and noise standards, and without undue increase in cost.[6]

Legislation is currently being formulated which will deal directly with automobile fuel economy. To date, proposals have included setting of standards and imposition of taxes and penalties, in addition to further supporting research. The EPA Administrator was reported to favor Congressional action for a minimum new-car average of 13.5 miles per gallon by 1977, with increases to follow in subsequent years.[7] A bill introduced in the House of Representatives by Charles Vanik of Ohio would impose taxes up to $770 on the purchase of automobiles providing less than 20 miles per gallon in 1981.[8] A bill introduced by Senator Hollings called for a standard of fuel economy effective in 1978 designed to achieve a

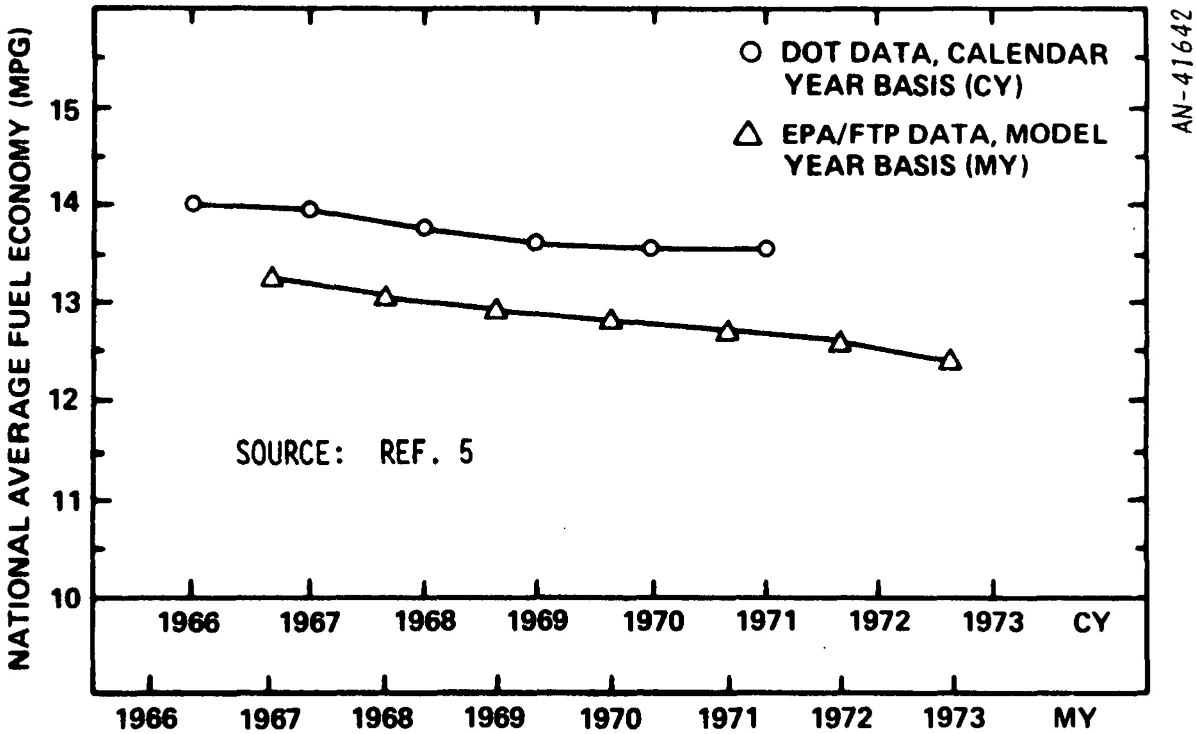


Figure 7.3. National Average Fuel Economy Versus Calendar Year

25-percent increase relative to model year 1972 automobiles, coupled with a graduated fee paid at the time of vehicle purchase which reaches zero only for vehicles achieving fuel economy 35-percent better than the standard (69 percent better than 1972 autos). A bill subsequently passed by the Senate adopts as an objective a 50-percent increase in fuel economy for 1984 automobiles.[9]

In the longer term, there seems little doubt that even greater fuel economy can be achieved. The Mercedes 1973 diesel automobile, for example, delivered 85 percent better fuel economy in EPA tests than the corresponding gasoline-fueled Mercedes car of similar test weight, appearance, and accommodations (there are, of course, differences between the two cars in acceleration, top speed, maintenance requirements, and so on).[5] As an alternative to more efficient power plants, automobile size may be simply reduced. The 1974 Honda automobile, for example, delivered 29.1 miles per gallon in EPA tests on the Federal Driving Cycle, well over 100 percent better than the fuel economy of the average automobile in 1974.[10]

The various economic, legislative, and technological factors which will determine future automobile fuel consumption have obviously not yet stabilized. Nevertheless, a nominal projection is required for purposes of this study. The various considerations noted above and this nominal projection are illustrated in Fig. 7.4.

The dashed line in Fig. 7.4, the projection adopted for the study, assumes that a 50-percent increase in fuel economy of the average new car will be achieved by 1984, and that subsequent improvements at a slower rate will yield a 100-percent overall improvement by the year 2000. This is in line with the proposal of the EPA Administrator and the current Senate bill (Circles 1 and 2 in Fig. 7.4), and relatively less optimistic than either the standards and incentives proposed by Representative Vanik and Senator Hollings (Circles 3 and 4 in the figure), or the DOT/EPA research program goal (Circle 5).

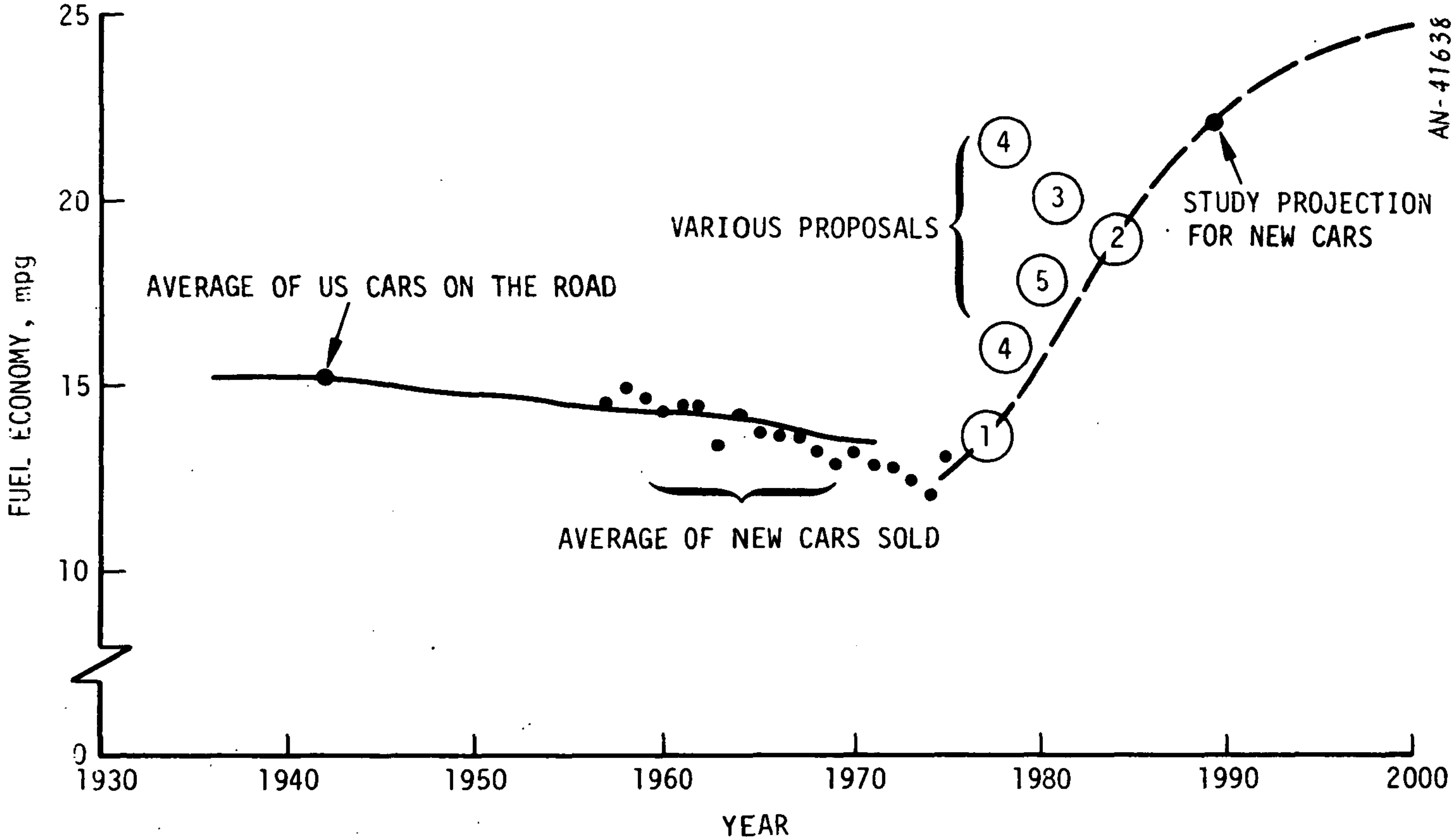


Figure 7.4. Projected Auto Fuel Economy

Also shown in Fig. 7.4, for reference, are the national average fuel economics reported annually in Highway Statistics by DOT, and the sales-weighted model year gasoline mileages of Fig. 7.2 (adjusted upward 6 percent for comparability with the DOT figures, as Fig. 7.3 shows to be appropriate). In comparison with their history of persistent decline, the nominal projection of the study obviously constitutes a dramatic switch to rapid improvement in gasoline mileage. As such, it seems relatively optimistic, even though it falls considerably below at least some current research objectives and legislative proposals.

Though the fuel economy projection of Fig. 7.4 is national in scope, it may be applied without modification to the Los Angeles area, because average fuel economy in California, and presumably in Southern California, apparently differs very little from the national figure. From data in the 1971 edition of Highway Statistics, for example, California vehicles travel 118 billion miles on 9.817 billion gallons of fuel, for an overall average of 12.02 miles per gallon. On the same basis, US vehicles travel 1,186 billion miles on 97.5 billion gallons of fuel for an average of 12.16 miles per gallon. Trucks and diesel fuel are included, so these values are somewhat lower than for passenger cars, but they are directly comparable since truck activity in California is in proportion to that nationally. (10.7 percent of California motor vehicles are trucks, versus 11.0 percent nationally; California's use of special vehicular fuels--diesel, propane, etc.--is 6.7 percent of its total fuel use, versus 7.8 percent nationally.) Thus the overall conclusion must be that California autos get about the same gasoline mileage as autos nationally.

The projection of Fig. 7.4 does not specify what combination of weight decrease and propulsive efficiency increase will be adopted to achieve the indicated overall increase in fuel economy. Figures 6.6 and 6.7 of course, already envision a considerable further swing to the subcompact and compact class of autos, but class weights themselves are continually changing so this cannot serve as a ready basis for further projections. If individual class weights stayed fixed at the most recent levels shown in Fig. 7.3, and if fuel usage remained proportional to car weight, then the increasing numbers of compact cars would reduce average car weight and increase average miles per gallon by only 10 percent, much less than the 100 percent projected for 2000 in Fig. 7.4. Prospects are that there will be not only a significant improvement in mechanical efficiency, but significant reductions in class weights as well, quite possibly with some sacrifice in accommodations and performance. Thus as the conventional auto becomes progressively more desirable on energy grounds, it is likely to compromise in some of these other areas.

The fuel economy projection of Fig. 7.4 is for future new cars. To estimate average fuel economy for all cars operated in the South Coast Air Basin, it is necessary to average together the different fuel uses of each different model year likely to be on the road in a given year, weighted according to probable usage. Table 7.1 presents the necessary usage data, together with the age distribution of cars on the road shown in Fig. 6.5. The overall result of the averaging process is shown in Fig. 7.5. The rise in average auto fuel economy here is delayed considerably relative to that of Fig. 7.4 on account of the sizeable admixture of older, less economical cars.

As shown in Fig. 5.2, the average annual usage of automobiles is trending slowly upward. Moreover, the number of automobiles in the South Coast Air Basin is expected to increase considerably, as shown in Table 4.2. In combination with projected average fuel economy of Fig. 7.5, these factors result in total annual auto fuel usage for the Basin as shown in Fig. 7.6. Total fuel use has been rising rapidly, but is being arrested now by the trend to smaller cars, and is projected to be turned around by projected rapid improvement in average auto economy. By the end of the century, however, when projected rates of fuel economy increase are dropping, total fuel use will tend to rise again as more cars are added to the total Basin auto population.

TABLE 7.1

AUTOMOBILE USAGE VERSUS AGE, CALIFORNIA

AGE, YEARS	PERCENT OF ALL CARS	PERCENT OF ALL AUTO MILES
1	10.8	19.9
2	10.5	16.7
3	10.2	13.7
4	9.8	11.5
5	9.3	9.5
6	8.8	7.5
7	8.1	5.2
8	7.2	4.4
9	6.2	3.4
10	5.1	2.6
11 and up	13.0	5.6

Source: Air Quality Manual, Vol. II, "Motor Vehicle Emission Factors for Estimates of Highway Impact and Air Quality," FHWA-RD-72-34, Federal Highway Administration, Washington, D.C., April 1972.

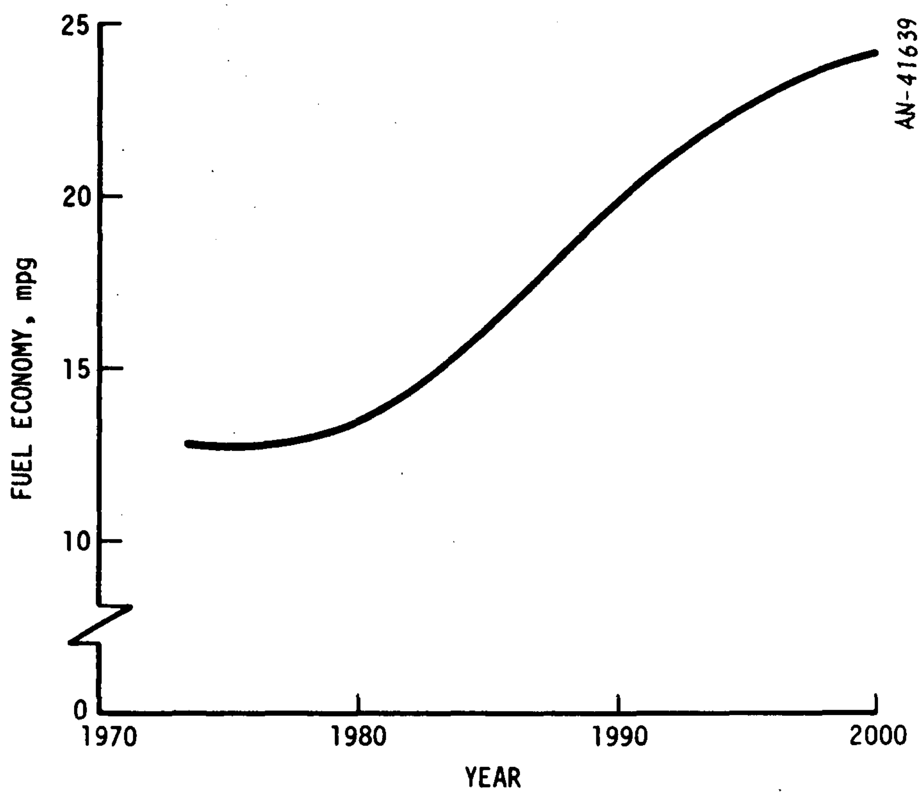


Figure 7.5. Projected Average Auto Fuel Economy for the South Coast Air Basin

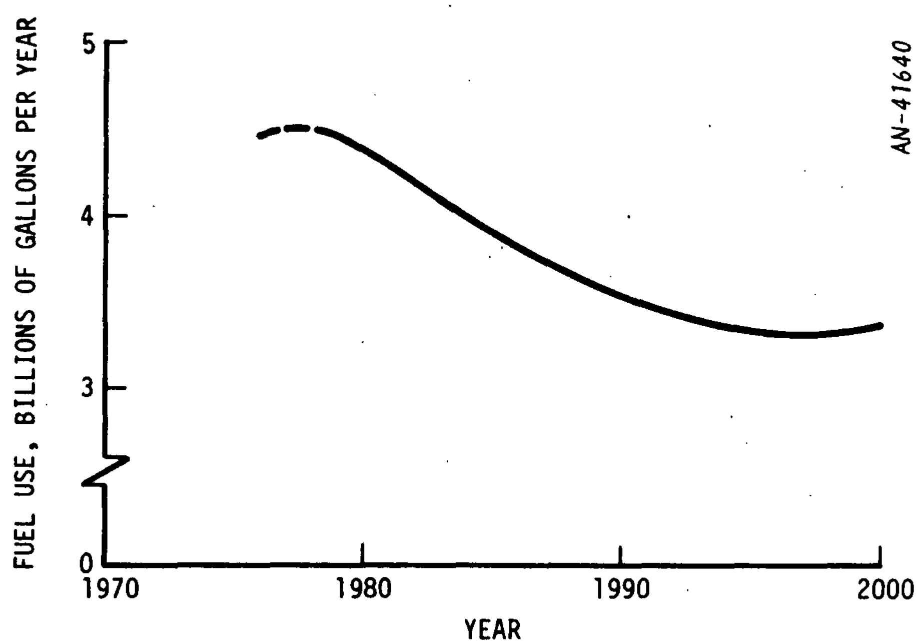


Figure 7.6. Projected Total Auto Fuel Use for the South Coast Air Basin

APPENDIX

AUTO SALES PROJECTION BASED ON NATIONAL SURVIVAL TABLES

The projected auto population of the South Coast Air Basin is shown in Fig. 4.2. To forecast sales necessary to support this growth, we must determine, at each sales year, what number of the previous year's autos in use will be scrapped. This can be readily accomplished with satisfactory accuracy by assuming a constant auto sales growth per year, and using the auto survival rates of Table A-1. Table A-1 is derived from Fig. 6.3, which shows actual national survival rates for several auto model years.

We adopt the following nomenclature:

S_n = sales in model year

s_k = fraction of any model year sales surviving after k years of use

P_n = auto population surviving at year n from previous year's sales

g = annual sales growth factor

Then we have

$$P_n = s_1 S_{n-1} + s_2 S_{n-2} + s_3 S_{n-3} \; . \; . \; . \; = \sum_k s_k S_{n-k}$$

But because $S_n = gS_{n-1}$, This can be rewritten as

$$P_n = \left(s_1 g^{n-1} + s_2 g^{n-2} + s_3 g^{n-3} \; . \; . \; . \right) S_o = S_o \sum_k s_k g^{n-k}$$

TABLE A-1

AUTOMOBILE SURVIVAL FACTORS

Age	Survival Factor
0	1.00
1	.99
2	.98
3	.963
4	.94
5	.915
6	.87
7	.81
8	.73
9	.60
10	.46
11	.32
12	.21
13	.13
14	.07
15	0.0

The previous year's auto population may be written as

$$P_{n-1} = S_o \sum s_k g^{n-k-1} = S_o g^{-1} \sum s_k g^{n-k}$$

So the annual growth factor for auto population is simply g , as is to be expected.

With the survival rates of Table A-1, the value of S_o corresponding to a given P_n and g can be found by substitution in the above. This enables forecasting sales rates required to support the SCAB auto population projections of Fig. 4.2. These are reproduced, with annual growth factors, in Table A-2. Since the rate is not quite constant, different calculations of S_o may be made with the growth year taken at the beginning of each coming decade, with results plotted in Fig. 6.4.

TABLE A-2

AUTO POPULATION ANNUAL GROWTH FACTORS
SOUTH COAST AIR BASIN

Year	Auto Population	Annual Growth Factor
1950	2,005,000	1.055
1960	3,435,000	1.039
1970	5,060,000	1.015
1980	5,880,000	1.013
1990	6,732,000	1.012
2000	7,600,000	

REFERENCES

1. Statistical Abstract of the United States - 1967, US Department of Commerce, Washington, D.C.

2. J. L. Beaton, et al., Air Quality Manual, Vol. II, "Motor Vehicle Emission Factors for Estimates of Highway Impact on Air Quality," Federal Highway Administration Report FHWA-RD-72-34, US Department of Transportation, Washington, D.C., April 1972.

3. Automobile Fuel Economy, The Motor Vehicle Manufacturers' Association of the United States, Detroit, Michigan, 21 September 1973.

4. Fuel Economy and Emission Control, US Environmental Protection Agency, Office of Water Programs, Mobile Source Pollution Control Program, November 1972.

5. A Report on Automobile Fuel Economy, Office of Air and Water Programs, US Environmental Protection Agency, October 1973.

6. A Study of Technological Improvements in Automobile Fuel Consumption 2nd Bi-Monthly Progress Review Presentation, Arthur D. Little, Inc., Cambridge, Mass., 30 October 1973.

7. The Wall Street Journal, 17 January 1974.

8. Automotive Research and Development and Fuel Economy, Hearings before the Senate Commerce Committee, Serial 93-41, US Government Printing Office, Washington, D.C.

9. "National Fuels and Energy Conservation Act of 1973," S.2176, 93rd Congress, 1st Session, 10 December 1973.

10. "Gas Mileage Data for 1974 Cars," released to the press 18 September 1973, by Russell E. Train, Administrator, US Environmental Protection Agency, Washington, D.C.

TASK REPORT 4

ECONOMIC PROJECTIONS
FOR THE LOS ANGELES REGION, 1980-2000

J. Eisenhut

ABSTRACT

Business activity in the South Coast Air Basin (Greater Los Angeles) is examined to determine what industry sectors might be affected if electric cars are used in the area. There are 16 industry sectors comprising 3.4 percent of the area's employment and 3.6 percent of the area's payroll. The industries are grouped in the general areas of vehicle and vehicle parts manufacturing, petroleum distribution, and the sales and repair of automobiles. Historical trends in the employment, payroll, and number of these firms are extrapolated to the year 2000. These extrapolations are a basis for Task Report 9 (Vol. 3) which shows the relative magnitude of changes induced by various levels of electric car use.

CONTENTS

ILLUSTRATIONS

TABLES

Tables (Cont.)

1 INTRODUCTION

This is the third in a series of reports projecting baseline conditions (in the absence of electric cars) for use in a study of the impacts of future electric car use. It follows assumptions and data presented in the first report of the series, Task Report 2, Population Projections for the Los Angeles Region, 1980-2000.

This economic baseline projection is organized into three sections. Section 2 lists employment levels in the South Coast Air Basin. Section 3 details total personal income and discusses the regional product. The area's business establishments, employment, and payroll which are subject to electric car production and use are listed in Sec. 4. The detail behind the development of Sec. 4 is available in the appendixes.

In drawing on existing forecasts, the baseline economic projections set forth in Secs. 2 and 3 take population as one primary variable. Population projections were developed from official sources in Task Report 2. These projections are used in adjusting other projections and forecasts, which generally were based on varying population forecasts. In addition, factors based on the population projections are used to allocate appropriate fractions of whole-county data to those county portions included in the South Coast Air Basin (SCAB).

2 SOUTH COAST AREA EMPLOYMENT

A Department of Commerce study[1] was the source of past and projected employment data. The study presented economic activity for all states and Standard Metropolitan Statistical Areas (SMSAs) by decade intervals from 1950 through 2000. Included were projections of population, employment, and personal income, the latter projection being used in Sec. 3. Population projections in the Commerce Study were based upon the high growth assumptions of Series C, and consequently it was necessary to adjust them according to the population projections presented in Task Report 2. Also the data, which is organized by SMSAs, was adjusted to conform to the SCAB boundaries. The results of this exercise are shown in Table 2.1.

The historical employment trends in Ref. 1 were based on employment covered by Unemployment Insurance and then adjusted to include all civilian employment. The projected trends assume an unemployment rate of 4 percent, and regional employment to population ratios moving toward the national average. While a 4 percent unemployment rate is probably optimistic, it is consistent with the rate for the first half of 1973, and

---

TABLE 2.1

SOUTH COAST AREA EMPLOYMENT (Thousands)[1]

	1950	1959	1970	1980	1990	2000
Los Angeles	1,612	2,394	3,147	3,175	3,162	3,340
Orange	78	254	475	585	743	915
Riverside and San Bernardino	126	230	274	364	411	449
Santa Barbara	25	37	60	65	77	91
Ventura	43	74	115	146	186	230
SCAB Total	1,884	2,989	4,071	4,335	4,579	5,025

it conforms to the announced employment goals of the federal government. A South Coast Association of Governments study projected an employment figure about 15 percent higher for the year 2000. This study simply assumed a constant employment to population ratio, however, failing to account for industry or national trends as did Ref. 1.

3 TOTAL PERSONAL INCOME

To present a more meaningful comparison of trends in personal income, all dollar values have been adjusted to 1972 dollars. Presenting "constant" rather than "current" dollars enables one to compare growth patterns exclusive of inflationary effects. Normal practice calls for the use of the consumer price index as a price deflator to show the constant buying power of personal income. We, however, are specifically concerned with the effects of cost variations of private transportation and the impacts of these variations upon personal and business income. Thus, the Private Transportation Index will be used throughout this report as the price deflator utilized in calculating the "constant" or 1972 purchasing power of any dollar amounts. The makeup of this index is approximately one-third auto purchases, one-third auto services, and one-third petroleum and parts cost. This makeup avoids any bias which might be caused by a rapid increase in price of any one sector. Table 3.1 contains unpublished Consumer Price Indices for Transportation for Los Angeles-Orange Counties. Figures 3.1 and 3.2 further present this data.

We have used Ref. 1 as the source of projected personal income data. The data is scaled to conform to our projected SCAB population. In addition, the values which were presented in current dollars were deflated to constant 1972 dollars with the use of the Private Transportation Price Index. Table 3.2 shows actual and projected average personal income, and Table 3.3 shows actual and projected total personal income. The source of the actual personal income data is an unpublished document from the Bureau of Economic Analysis.

Personal income is defined to include income from all sources including labor, proprietors, and property income and transfer payments, but excludes personal contributions for social security insurance. Total personal income (Table 3.3) is related to Gross Regional Product (GRP) and is a reasonable surrogate for use as an indicator of regional economic activity. Total personal income differs from GRP in that it includes

TABLE 3.1

CONSUMER PRICE INDICES, LOS ANGELES-ORANGE COUNTIES

	Transportation	Private Transportation	Public Transportation
1950	54.5	58.4	38.0
1951	56.9	61.5	38.0
1952	62.7	66.2	46.8
1953	65.2	68.5	50.5
1954	64.6	67.2	52.6
1955	64.2	66.2	54.9
1956	65.2	67.4	55.8
1957	67.9	70.4	56.9
1958	69.6	72.0	59.1
1959	73.2	76.1	59.7
1960	73.6	75.2	67.6
1961	76.0	76.1	79.0
1962	78.7	78.7	81.3
1963	78.7	78.7	81.2
1964	81.7	81.8	81.2
1965	83.5	83.7	81.4
1966	83.4	84.0	82.1
1967	85.0	85.0	86.1
1968	87.7	87.6	90.2
1969	90.1	90.1	91.5
1970	93.2	93.2	94.4
1971	97.7	97.8	97.3
1972	100.0	100.0	100.0

Source: Bureau of Labor Statistics, unpublished data.

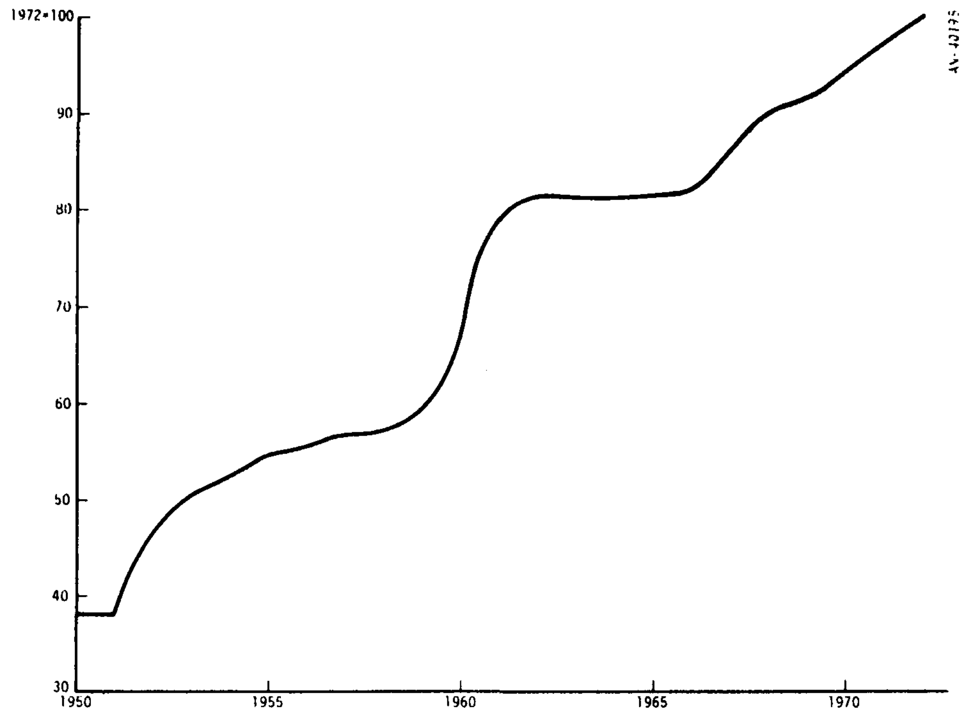


Figure 3.1. Consumer Price Index for Public Transportation in Los Angeles (1972=100)

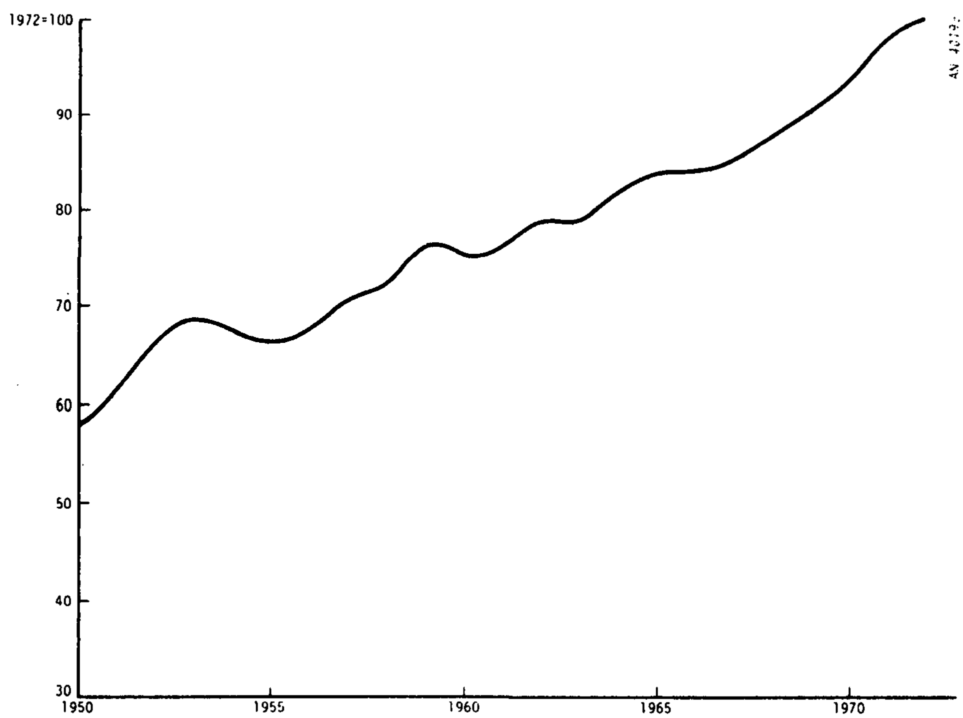


Figure 3.2. Consumer Price Index for Private Transportation in Los Angeles (1972=100)

TABLE 3.2

AVERAGE PERSONAL INCOME (1972 dollars)

	Actual*			Projected[1]		
	1950	1959	1970	1980	1990	2000
Los Angeles	3,159	3,880	5,196	7,069	8,838	11,678
Orange	2,572	3,450	4,326	5,987	7,669	10,294
Riverside and San Bernardino	2,299	2,871	3,496	5,000	6,582	9,079
Santa Barbara	3,267	3,468	3,680	5,055	6,719	9,374
Ventura	2,602	3,103	3,153	4,601	6,104	8,481

*Bureau of Economic Research, Total Personal Income, Table 5.0.

TABLE 3.3

TOTAL PERSONAL INCOME (1972 $ millions)

	Actual*			Projected[1]		
	1950	1962	1970	1980	1990	2000
Los Angeles	13,826	25,181	36,258	51,006	66,551	90,706
Orange	690	3,017	6,101	10,621	16,273	24,789
Riverside and San Bernardino	897	2,022	3,225	5,049	7,471	11,330
Santa Barbara	217	427	634	909	1,398	2,184
Ventura	317	713	1,405	2,245	3,772	6,284
SCAB Total	15,947	31,360	47,623	69,830	95,465	135,293

*Bureau of Economic Analysis, Total Personal Income, Table 5.0.

transfer payments and does not include retained corporate profits and corporate taxes. This difference does not inhibit its usefulness as an economic indicator.[2]

4 BUSINESS IMPACTS

This section examines the business sectors which may be impacted by lead-acid battery car production or use. For the impacted sectors, data are presented on employment, payroll, and number of firms, and are examined to show the relative importance of the industry within the basin. Various hypotheses are utilized in projecting the data through 2000. It should be re-emphasized that these projections are largely simple extensions of existing trends and are made to provide a basis for Task Report 9, which shows the magnitude of the changes induced by electric car use.

Table 4.1 shows the results of a thorough search of all industry classification descriptions.[3] This search included all Standard Industrial Classification (SIC) groupings. The detail available at the four-digit SIC level groups can be distinguished by a very specific type of activity. Not all automotive-related industries were selected, only those where there was a possibility of some electric car impacts. Note that electrical manufacturing sectors, not necessarily automobile-related, were included because they would be impacted by the regional manufacture or assembly of electric cars. Also included are lead mining and manufacturing, on a national scale only, because of the possible increased demand for lead-acid batteries should electric cars become plentiful. Among those industries omitted were those relating to the supply of material for projected but undeveloped battery types (e.g., lithium-sulfur). The SIC listings which cover the processing of these materials contains too many other materials to be useful.

For each of these industries, SCAB data were obtained on employment, payroll, and number of firms for several years. <u>County Business Patterns</u> (CBP)[4] was used as the data source because it contains this data on a four-digit SIC level. The data is based on Unemployment Insurance coverage data and thus has some gaps in self-employment and government employment. These gaps affect the total employment figures, but not the SICs in which

TABLE 4.1

BUSINESSES SUBJECT TO ELECTRIC CAR IMPACTS[3]

Standard Industrial Classification (SIC)	Description
1031	Lead and Zinc Ore Mining
3332	Lead Smelting and Refining
3621	Electrical Motors and Generators Manufacturing
3622	Electrical Industrial Controls Manufacturing
3691	Storage Battery Manufacturing
3717	Motor Vehicle and Motor Vehicle Parts Manufacturing
4911	Electric Services
5012	Motor Vehicle - Wholesale Distribution
5013	Automotive Parts - Wholesale Distribution
5014	Tires - Wholesale Distribution
5092	Petroleum - Wholesale Distribution
5511	New and Used Car Dealers
5521	Used Car Dealers
5531	Auto Supply Stores
5541	Service Stations
7534	Tire Retreading Shops
7538	Automotive Repair Shops
7539	Specialized Auto Repair Shops

we are interested. Also, CBP is the only general, long-term data available for four-digit SIC levels. The data were adjusted to the boundaries of the SCAB and to 1972 dollars. The resulting tables are contained in Appendixes A and B. Lead Mining and Refining is not included in the appendixes because there is no activity in the SCAB. These are included in national data shown further along in Table 4.4. Electric Services, which are affected by electric car use, was not included in the CBP due to confidentiality. Data for 1972 was obtained through surveys of the two major electrical utilities.

Table 4.2 shows these industries grouped together into related clusters, and the relative importance of each cluster to the basin's economy. Some clusters are more susceptible to electric car impacts than others. For example, petroleum sales, which are 1 percent of SCAB's employment and 4.1 percent of its business units, would obviously be affected by electric car usage. It is not so apparent that Vehicle Distribution and sales would be affected as, of course, cars would still be sold. Table 4.3 shows the SCAB employment data obtained from the CBP. As mentioned, CBP is not all-inclusive and thus there is some disparity with the employment as listed in Table 2.1. Since Table 2.1 better represents total employment (e.g., includes government, self-employment, and agriculture), it was used in calculating the relative importance of battery car related employment. The payroll calculations are based on the average salary implicit in Table 4.3 but scaled to total employment.

For additional reference, Table 4.4 shows the nation-wide activity of the manufacturing concerns. The impacts upon refining and manufacturing are less geographically restricted than are the impacts upon service and trade industries. Employment in the three electrical manufacturing industries considered is 3 percent of the US electrical manufacturing employment, and SCAB auto manufacturing employment is 3 percent of US auto manufacturing employment.

TABLE 4.2

RELATIVE IMPORTANCE OF AUTO-RELATED ACTIVITY

(SCAB 1971)

	Employment	Percent of Area Total Employment	Payroll, $ million	Percent of Area Total Payroll	Number of Firms	Percent of Area Firms
Vehicle & Parts Mfg. (SIC 3717)	19,210	0.5	233.5	0.7	62	0.0
Petroleum--Wholesale & Retail Sales (SIC 5092 & 5541)	39,703	1.0	192.7	0.6	6,694	4.1
Auto Parts & Supplies (SIC 5013, 5014, & 5531)	22,606	0.6	175.4	0.6	1,938	1.2
Auto Repair (SIC 7534, 7538, & 7539)	9,448	0.2	65.0	0.2	2,444	1.5
Vehicle Distribution (SIC 5012)	5,606	0.1	57.2	0.2	147	0.1
Vehicle Sales (SIC 5511 & 5521)	37,679	0.9	362.2	1.2	1,182	0.7
Battery & Motor Mfg. (SIC 3621, 3622, & 3691)	4,910	0.1	44.5	0.1	65	0.1
		3.4		3.6		7.7

TABLE 4.3

TOTAL* 1971 EMPLOYMENT, PAYROLL, AND NUMBER OF FIRMS[4]

	Employment	Payroll, $ million	Firms
Los Angeles	2,326,207	18,482.5	123,760
Orange	336,344	2,482.5	19,595
Riverside	63,340	401.6	5,100
San Bernardino	102,298	700.0	7,836
Santa Barbara	36,233	250.6	2,816
Ventura	98,609	403.3	4,843
SCAB Total	2,963,031	22,720.5	163,950

*Data excludes government and self-employed persons.

TABLE 4.4

TOTAL US ACTIVITY OF SELECTED INDUSTRIES (1971)

SIC	Employment[4]	SCAB Employment as % of US	Payroll[4] (1972 $M)	SCAB Payroll as % of US	Firms[4]
1031 (Lead Mining)	9,412	0	79.3	0	94
3332 (Lead Smelting)	3,672	0	31.8	0	24
3621 (Motor Manuf.)	93,064	3.0	767.3	3.3	396
3622 (Electrical Controls Manuf.)	47,941	3.0	407.4	3.3	536
3691 (Battery Manuf.)	20,432	3.0	182.4	3.3	221
3717 (Automobile Manuf.)	746,929	3.0	7,976.0	3.0	1,945

The historical data gathered in Appendixes A and B were extended throughout the year 2000. Tables 4.5-4.7 summarize the results of these extrapolations to the years 1980, 1990, and 2000. These projections are used in Task Report 9 which deals with the variations in economic trends caused by electric car usage.

Since these projections are used to show the relative importance of changes in automobile-related activity in the SCAB, the ratio of historical industry sector data to SCAB automobile population levels was determined.* Using least squares regression techniques, some curve (linear or power) was fit and this ratio was extrapolated. Then, again using the auto population projections found in this study,** the ratio was reconverted to an absolute level of anticipated business activity. Thus these economic projections are consistent with the level of automobile activity anticipated elsewhere in this study. Appendix C contains the curves used in these baseline projections as well as a discussion of data limitations and a brief rationale for each of the industry projections.

Electrical manufacturing (SIC 3621 and 3622) is the exception to this trend extrapolation and are not shown in Appendix C. Neither of these activities is directly related to current automobile activity. In addition, activity in these industries is more dependent on national trends than are the other more regional service industries. Thus projections for these industries were simply taken from a Department of Commerce publication.[5]

A check for reasonableness was made by taking the average salary in 1972 (Table A.9) and in 2000 (Table 4.7) and computing the annual compound

---

*The transportation projections arrived at in Task Report 3 showed that the number of miles per car per year is fairly constant and thus number of cars is also a reasonable indicator of total miles driven.

**The pertinent projections from Task Report 3 are reproduced in Appendix C.

TABLE 4.5

PROJECTED ECONOMIC ACTIVITY SUBJECT TO ELECTRIC CAR IMPACT (1980)

SIC	Employment	Payroll, 1972 $ millions	Number of Firms
3621 (Motor Manuf.)	3,314	30.0	48
3622 (Electrical Controls Manuf.)	2,484	22.3	44
3691 (Battery Manuf.)	2,235	24.1	22
3717 (Automobile Manuf.)	21,090	339.2	223
5012 (Wholesale Vehicle Dist.)	10,000	105.8	162
5013 (Wholesale Parts Dist.)	15,289	129.4	1,000
5014 (Wholesale Tire Dist.)	2,646	22.6	182
5092 (Wholesale Petroleum Dist.)	3,646	45.3	270
5511 & 5521 (Retail Vehicle Sales)	41,164	394.0	1,058
5531 (Auto Supply Stores)	8,820	70.5	1,058
5541 (Service Stations)	39,400	182.3	6,175
7534 (Tire Retreading Shops)	470	2.9	41
7538 & 7539 (Auto Repair Shops)	10,584	80.5	2,470

TABLE 4.6

PROJECTED ECONOMIC ACTIVITY SUBJECT TO ELECTRIC CAR IMPACT (1990)

SIC	Employment	Payroll, 1972 $ millions	Number of Firms
3621 (Motor Manuf.)	3,512	31.8	51
3622 (Electrical Controls Manuf.)	2,732	24.5	48
3691 (Battery Manuf.)	2,895	34.3	22
3717 (Automobile Manuf.	21,568	399.4	289
5012 (Wholesale Vehicle Dist.)	15,485	168.3	153
5013 (Wholesale Parts Dist.)	18,851	175.0	1,009
5014 (Wholesale Tire Dist.)	3,366	28.2	222
5092 (Wholesale Petroleum Dist.)	3,366	57.9	309
5511 & 5521 (Retail Vehicle Sales)	40,397	424.1	942
5531 (Auto Supply Stores)	10,166	85.5	1,212
5541 (Service Stations)	43,090	208.7	5,386
7534 (Tire Retreading Shops)	451	2.7	27
7538 & 7539) (Auto Repair Shops)	12,793	104.4	2,558

TABLE 4.7

PROJECTED ECONOMIC ACTIVITY SUBJECT TO ELECTRIC CAR IMPACT (2000)

SIC	Employment	Payroll, 1972 $ millions	Number of Firms
3621 (Motor Manuf.)	3,723	33.7	54
3622 (Electrical Controls Manuf.)	3,005	27.0	53
3691 (Battery Manuf.)	3,800	45.6	22
3717 (Automobile Manuf.)	21,300	511.2	364
5012 (Wholesale Vehicle Dist.)	22,800	250.8	137
5013 (Wholesale Parts Dist.)	22,422	224.2	988
5014 [illegible] Dist.)	4,560	35.7	258
5092 (Wholesale Petroleum Dist.)	3,420	64.6	350
5511 & 5521 (Retail Vehicle Sales)	41,800	455.0	798
5531 (Auto Supply Stores)	11,550	104.9	1,368
5541 (Service Stations)	46,360	237.1	4,560
7534 (Tire Retreading Shops)	456	2.3	23
7538 & 7539 (Auto Repair Shops)	15,200	129.2	2,584

growth rate for each industry. The rates ranged from plus three to minus one, and the mode was about one. The highest rate, for motor vehicle manufacturing, was 0.4% below the 3.6% annual productivity gains for that industry sector over the past 13 years.[6] Other unpublished, non-releasable productivity data obtained from the Bureau of Labor Statistics showed projected salary gains trailed productivity gains by about half. This seems reasonable when noting that the service sector is less heavily unionized than is motor vehicle manufacturing. The annual compound salary increase, in 1972 dollars, is 2% for the total activity projected.

APPENDIX A

EMPLOYMENT AND PAYROLL DATA

TABLE A.1

INDUSTRIAL CLASSIFICATION LISTING[3]

Standard Industrial Classification (SIC)	Description
3621	Electrical Motors and Generators Manufacturing
3622	Electrical Industrial Controls Manufacturing
3691	Storage Battery Manufacturing
3717	Motor Vehicle and Motor Vehicle Parts Manufacturing
5012	Motor Vehicle--Wholesale Distribution
5013	Automotive Parts--Wholesale Distribution
5014	Tires--Wholesale Distribution
5092	Petroleum--Wholesale Distribution
5511	New and Used Car Dealers
5521	Used Car Dealers
5531	Auto Supply Stores
5541	Service Stations
7534	Tire Retreading Shops
7538	Automotive Repair Shops
7539	Specialized Auto Repair Shops

TABLE A.2

1951 EMPLOYMENT AND PAYROLL* SUBJECT TO ELECTRIC CAR IMPACT

	Los Angeles		Orange		Riverside		San Bernardino		Santa Barbara		Ventura		SCAB Total	
SIC	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M
5511	19,066	140.8	1,116	7.3	495	2.9	856	5.9	345	2.1	579	3.6	22,457	162.6
5521	1,658	10.0	19	0.2	27	0.2	48	0.2	19	0.2	26	0.2	1,797	11.0
5531	3,581	18.9	202	1.0	63	0.3	165	0.8	60	0.3	67	0.3	4,138	21.6
5541	13,657	50.9	648	2.1	362	1.3	684	2.4	241	0.8	251	0.8	15,543	58.3

*Normalized to 1972 dollars.

TABLE A.3

1956 EMPLOYMENT AND PAYROLL* SUBJECT TO ELECTRIC CAR IMPACT

	Los Angeles		Orange		Riverside		San Bernardino		Santa Barbara		Ventura		SCAB Total	
SIC	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M
5511	23,948	193.2	1,662	12.0	536	5.3	916	8.9	357	2.4	784	5.2	28,203	227.0
5521	2,133	13.5	109	0.6	34	0.1	128	0.7	19	0.1	55	0.3	2,478	15.3
5531	2,624	23.4	176	1.0	76	0.4	214	1.2	62	0.3	97	0.6	3,244	26.9
5541	18,946	79.8	1,381	5.6	616	2.4	1,278	5.2	278	1.0	438	1.6	22,937	95.6

*Normalized to 1972 dollars.

TABLE A.4

1962 EMPLOYMENT AND PAYROLL* SUBJECT TO ELECTRIC CAR IMPACT

	Los Angeles		Orange		Riverside		San Bernardino		Santa Barbara		Ventura		SCAB Total	
SIC	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M
3621	2,559	19.7	891	7.5	---	---	---	---	---	---	---	---	3,450	27.2
3622	451	2.8	---	---	---	---	---	---	---	---	---	---	451	2.8
3691	687	5.0	---	---	---	---	---	---	---	---	---	---	687	5.0
3717	16,180	139.0	---	---	---	---	---	---	---	---	---	---	16,180	139.0
5012	2,065	16.9	---	---	---	---	---	---	---	---	---	---	2,065	16.9
5013	7,726	54.8	352	2.4	89	0.5	255	1.5	33	0.3	92	0.6	8,547	60.1
5014	1,527	13.3	---	---	---	---	---	---	---	---	---	---	1,527	13.3
5092	3,583	28.8	219	2.0	79	0.5	149	1.0	26	0.3	48	0.1	4,104	32.7
5511	21,837	188.1	2,505	21.3	833	6.5	1,301	10.2	400	3.3	783	5.8	27,659	235.2
5521	2,220	15.6	171	1.0	67	0.4	113	0.6	22	0.1	76	0.5	2,669	18.2
5531	4,076	26.3	407	2.7	147	0.8	240	1.4	74	0.5	117	0.8	5,061	32.5
5541	20,024	93.8	2,343	9.9	806	3.3	1,668	6.4	400	1.5	706	2.7	25,947	117.6
7534	500	3.3	---	---	---	---	76	0.5	---	---	---	---	576	3.8
7538	4,066	25.8	389	2.5	144	0.8	275	1.5	67	0.4	78	4.2	5,019	35.2
7539	1,238	7.9	123	1.4	28	0.1	35	0.1	---	---	31	0.1	1,424	9.6

*Normalized to 1972 dollars.

TABLE A.5

1965 EMPLOYMENT AND PAYROLL* SUBJECT TO ELECTRIC CAR IMPACT

	Los Angeles		Orange		Riverside		San Bernardino		Santa Barbara		Ventura		SCAB Total	
SIC	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M
3621	2,276	17.0	996	8.4	---	---	---	---	---	---	---	---	3,272	25.4
3622	945	6.7	---	---	---	---	---	---	---	---	---	---	945	6.7
3691	611	4.9	482	4.1	---	---	---	---	---	---	---	---	1,093	9.0
3717	17,086	150.0	294	2.9	---	---	---	---	---	---	---	---	17,380	152.9
5012	2,973	30.0	205	1.9	---	---	---	---	---	---	---	---	3,178	31.9
5013	8,379	61.1	618	4.3	267	1.6	---	---	52	0.3	---	---	9,316	67.3
5014	1,349	10.5	---	---	---	---	---	---	---	---	---	---	1,349	10.5
5092	3,162	27.1	202	1.6	65	0.4	213	1.5	55	0.5	73	0.6	3,770	31.7
7534	470	3.4	---	---	---	---	57	0.3	---	---	---	---	527	3.7
7538	3,989	24.5	519	3.2	185	1.0	340	1.9	73	0.4	119	0.8	5,225	31.8
7539	1,483	9.5	136	0.9	96	0.3	57	0.3	19	0.1	20	0.1	1,811	11.2

*Normalized to 1972 dollars.

TABLE A.6

1967 EMPLOYMENT AND PAYROLL* SUBJECT TO ELECTRIC CAR IMPACT

SIC	Los Angeles Employment	Los Angeles $M	Orange Employment	Orange $M	Riverside Employment	Riverside $M	San Bernardino Employment	San Bernardino $M	Santa Barbara Employment	Santa Barbara $M	Ventura Employment	Ventura $M	SCAB Total Employment	SCAB Total $M
3621	2,856	24.1	1,557	13.4	---	---	---	---	---	---	---	---	4,413	37.5
3622	2,427	19.6	---	---	---	---	---	---	---	---	---	---	2,427	19.6
3691	1,079	9.1	654	5.8	---	---	---	---	---	---	---	---	1,733	14.9
3717	17,698	149.8	---	---	---	---	---	---	---	---	---	---	17,698	149.8
5012	3,321	30.9	278	2.7	---	---	93	0.8	---	---	---	---	3,692	34.4
5013	8,898	68.0	617	4.1	263	1.6	373	2.6	50	0.4	114	0.8	10,315	77.5
5014	1,257	10.5	97	0.7	---	---	---	---	---	---	---	---	1,354	11.2
5092	3,340	30.2	257	2.6	78	0.5	256	2.1	51	0.5	88	0.7	4,079	36.6
5511	27,060	252.0	3,717	36.7	1,147	9.4	1,867	15.3	581	4.7	988	8.0	35,360	326.1
5521	1,584	11.9	169	1.1	58	0.2	140	0.7	---	---	109	0.7	2,060	14.6
5531	5,244	37.5	607	4.4	261	1.6	311	1.9	86	0.6	203	1.3	6,712	47.3
5541	24,117	110.8	4,510	20.0	1,225	4.7	2,165	8.2	637	2.1	1,160	4.4	33,814	150.2
7534	461	3.4	37	0.2	---	---	53	0.4	---	---	---	---	551	4.0
7538	3,739	24.8	523	3.5	208	1.3	310	1.9	88	0.5	112	0.8	4,980	32.8
7539	1,378	9.6	174	1.3	30	0.2	73	0.5	23	0.1	13	0.1	1,691	11.8

*Normalized to 1972 dollars.

TABLE A.7

1969 EMPLOYMENT AND PAYROLL* SUBJECT TO ELECTRIC CAR IMPACT

	Los Angeles		Orange		Riverside		San Bernardino		Santa Barbara		Ventura		SCAB Total	
SIC	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M
3621	2,747	26.5	1,270	11.8	---	---	---	---	---	---	---	---	4,017	38.3
3622	2,303	20.2	---	---	---	---	---	---	---	---	---	---	2,303	20.2
3691	683	5.7	905	7.8	---	---	---	---	---	---	---	---	1,588	13.5
3717	18,612	170.6	266	2.4	---	---	96	0.8	---	---	---	---	18,974	173.8
5012	4,303	42.3	367	4.4	---	---	94	0.7	---	---	---	---	4,764	47.4
5013	10,804	85.4	714	5.1	345	2.1	445	3.2	62	0.4	169	1.1	12,539	97.3
5014	2,170	19.1	100	0.7	---	---	---	---	---	---	---	---	2,270	19.8
5092	3,391	32.5	---	---	82	0.5	217	1.9	137	1.2	81	0.4	3,908	36.5
7534	483	3.6	---	---	---	---	---	---	---	---	---	---	483	3.6
7538	4,156	28.4	616	4.1	170	1.0	330	2.0	92	0.7	130	0.5	5,494	36.7
7539	2,540	18.8	314	2.4	61	0.4	93	0.6	28	0.2	41	0.2	3,077	22.6

*Normalized to 1972 dollars.

TABLE A.8

1971 EMPLOYMENT AND PAYROLL* SUBJECT TO ELECTRIC CAR IMPACT

	Los Angeles		Orange		Riverside		San Bernardino		Santa Barbara		Ventura		SCAB Total	
SIC	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M
3621	1,992	18.1	1,026	9.3	---	---	---	---	109	0.9	---	---	3,127	28.3
3622	1,577	14.4	681	5.9	---	---	---	---	---	---	---	---	2,258	20.3
3691	615	5.3	1,018	9.7	---	---	150	1.2	---	---	---	---	1,783	16.2
3717	18,328	225.6	680	6.0	---	---	202	1.9	---	---	---	---	19,210	233.5
5012	5,090	52.3	314	3.3	102	0.8	100	0.8	---	---	---	---	5,606	57.2
5013	10,231	81.3	825	5.7	391	2.4	441	3.3	61	0.5	170	1.2	12,119	94.4
5014	1,931	17.5	87	0.7	---	---	---	---	---	---	---	---	2,018	18.2
5092	3,699	35.7	289	2.3	66	0.4	239	2.2	61	0.5	141	1.0	4,495	42.1
5511	25,889	254.7	5,143	51.4	1,310	11.8	1,980	17.4	559	5.1	1,271	11.0	36,152	351.4
5521	1,250	9.0	135	0.9	---	---	68	0.5	---	---	74	0.4	1,527	10.8
5531	6,096	46.2	1,214	8.6	338	2.4	454	3.0	140	0.9	227	1.7	8,469	62.8
5541	23,964	105.4	5,860	24.7	1,325	5.1	2,185	8.4	677	2.4	1,197	4.6	35,208	150.6
7534	465	3.4	45	0.3	---	---	---	---	---	---	---	---	510	3.7
7538	3,928	27.2	681	4.7	232	1.3	354	2.2	92	0.2	143	0.8	5,430	36.4
7539	2,824	20.4	382	2.8	94	0.5	117	0.7	37	0.2	54	0.3	3,508	24.9

*Normalized to 1972 dollars.

TABLE A.9

1972 EMPLOYMENT AND PAYROLL* SUBJECT TO ELECTRIC CAR IMPACT

	Los Angeles		Orange		Riverside		San Bernardino		Santa Barbara		Ventura		SCAB Total	
SIC	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M	Employment	$M
3621	1,960	18.1	961	9.5	---	---	---	---	---	---	---	---	2,921	27.6
3622	1,466	13.4	769	6.2	---	---	---	---	---	---	---	---	2,235	19.6
3691	604	5.8	941	9.5	---	---	---	---	---	---	---	---	1,545	15.3
3717	16,331	161.6	519	3.7	---	---	---	---	---	---	---	---	16,850	165.3
4911**	21,867	232.0	1,395	15.4	301	3.0	1,146	11.4	76	0.8	666	7.0	25,454	269.6
5012	5,763	60.6	295	3.7	---	---	108	0.9	---	---	---	---	6,166	65.2
5013	10,300	85.5	998	7.7	383	2.4	522	3.7	72	0.5	189	1.4	12,464	101.5
5014	1,895	18.3	101	0.8	---	---	---	---	---	---	---	---	1,996	19.1
5092	3,460	35.7	332	2.9	60	0.4	277	2.4	70	0.6	116	0.9	4,315	42.9
5511	26,358	271.6	5,446	58.2	1,389	12.9	1,914	17.8	583	5.5	1,330	12.6	37,020	378.6
5521	1,285	10.3	198	1.4	37	0.2	119	0.8	32	0.2	49	0.4	1,720	13.3
5531	6,058	47.7	1,189	8.6	359	2.6	483	3.1	142	1.0	293	2.2	8,524	65.2
5541	24,941	109.8	6,197	24.4	1,314	5.3	2,020	8.1	674	2.4	1,250	4.8	36,396	154.8
7534	425	3.2	51	0.4	---	---	---	---	---	---	---	---	476	3.6
7538	4,019	28.7	823	6.1	207	1.3	348	2.1	113	0.7	122	0.8	5,632	39.7
7539	2,945	22.6	493	3.6	88	0.4	118	0.8	40	2.4	69	0.4	3,753	30.2

*Normalized to 1972 dollars.

**Employment data was provided by Southern California Edison and the Los Angeles Department of Water and Power (for power only). Salary was estimated to be proportional to the salary of the total utilities sector.

APPENDIX B

NUMBER OF FIRMS SUBJECT TO ELECTRIC CAR IMPACTS

TABLE B.1

INDUSTRIAL CLASSIFICATION LISTING[3]

Standard Industrial Classification (SIC)	Description
3621	Electrical Motors and Generators Manufacturing
3622	Electrical Industrial Controls Manufacturing
3691	Storage Battery Manufacturing
3717	Motor Vehicle and Motor Vehicle Parts Manufacturing
5012	Motor Vehicle--Wholesale Distribution
5013	Automotive Parts--Wholesale Distribution
5014	Tires--Wholesale Distribution
5092	Petroleum--Wholesale Distribution
5511	New and Used Car Dealers
5521	Used Car Dealers
5531	Auto Supply Stores
5541	Service Stations
7534	Tire Retreading Shops
7538	Automotive Repair Shops
7539	Specialized Auto Repair Shops

TABLE B.2

NUMBER OF FIRMS SUBJECT TO ELECTRIC CAR IMPACT (1951)

SIC	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura	SCAB Total
5511	604	66	39	62	24	47	847
5521	275	5	5	14	1	5	305
5531	371	30	12	24	8	11	456
5541	3337	210	124	224	78	101	4074

NUMBER OF FIRMS SUBJECT TO ELECTRIC CAR IMPACT (1956)

SIC	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura	SCAB Total
5511	595	72	40	65	19	47	838
5521	509	29	8	39	17	14	616
5531	355	29	13	34	8	11	450
5541	4083	392	185	351	84	130	5225

TABLE B.3

NUMBER OF FIRMS SUBJECT TO ELECTRIC CAR IMPACT (1962)

SIC	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura	SCAB Total
3621	30	7	---	---	---	---	37
3622	23	---	---	---	---	---	23
3691	25	2	---	---	---	---	27
3717	51	---	1	---	---	---	52
5012	118	6	---	---	---	---	124
5013	672	36	10	31	7	10	766
5014	74	---	---	---	---	---	74
5092	97	23	24	26	10	19	199
5511	576	88	42	50	15	41	812
5521	485	54	13	38	8	15	613
5531	442	78	26	41	13	20	620
5541	4568	622	219	445	107	176	6137
7534	88	---	---	15	---	---	103
7538	1203	129	46	107	23	28	1536
7539	309	29	8	13	---	11	370

TABLE B.4

NUMBER OF FIRMS SUBJECT TO ELECTRIC CAR IMPACT (1965)

SIC	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura	SCAB Total
3621	31	11	---	---	---	---	42
3622	34	---	---	---	---	---	34
3691	18	4	---	---	---	---	22
3717	151	7	4	---	---	---	162
5012	150	14	---	---	---	---	164
5013	791	75	14	---	9	15	904
5014	79	---	---	---	---	---	79
5092	74	28	23	31	11	20	187
7534	92	---	---	9	---	---	101
7538	1200	164	54	115	29	45	1607
7539	416	50	8	18	10	13	515

TABLE B.5

NUMBER OF FIRMS SUBJECT TO ELECTRIC CAR IMPACT (1967)

SIC	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura	SCAB Total
3621	35	10	---	---	---	---	45
3622	42	---	---	---	---	---	42
3691	17	4	---	---	---	---	21
3717	175	---	---	---	---	---	175
5012	126	12	---	4	---	---	142
5013	760	82	19	43	7	15	926
5014	80	14	---	---	---	---	94
5092	67	24	21	26	12	22	172
5511	574	96	43	61	18	40	832
5521	343	64	13	33	---	15	468
5531	493	91	33	56	13	31	717
5541	4596	888	291	476	129	244	6624
7534	75	11	---	8	---	---	94
7538	1064	163	50	100	28	38	1443
7539	415	65	11	17	8	11	517

TABLE B.6

NUMBER OF FIRMS SUBJECT TO ELECTRIC CAR IMPACT (1969)

SIC	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura	SCAB Total
3621	35	8	---	---	2	---	45
3622	26	---	---	---	---	---	26
3691	15	5	---	2	---	---	22
3717	179	14	---	4	---	---	197
5012	130	16	---	5	---	5	156
5013	778	82	20	54	8	25	967
5014	125	16	---	---	---	---	141
5092	141	28	23	29	15	22	258
7534	58	---	---	---	---	---	58
7538	1100	166	50	100	26	45	1487
7539	628	101	23	32	15	20	819

TABLE B.7

NUMBER OF FIRMS SUBJECT TO ELECTRIC CAR IMPACT (1971)

SIC	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura	SCAB Total
3621	34	8	---	---	2	---	44
3622	30	11	---	---	---	---	41
3691	14	6	---	1	---	---	21
3717	34	22	---	6	---	---	62
5012	125	13	4	5	---	---	147
5013	771	92	22	51	9	26	971
5014	121	15	---	---	---	---	136
5092	137	31	21	27	13	25	254
5511	560	123	43	62	19	43	850
5521	257	36	---	27	---	12	332
5531	520	143	40	74	14	40	831
5541	4334	952	282	476	139	257	6440
7534	55	10	---	---	---	---	65
7538	1069	183	56	104	28	44	1484
7539	671	118	33	38	14	21	895

TABLE B.8

NUMBER OF FIRMS SUBJECT TO ELECTRIC CAR IMPACT (1972)

SIC	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura	SCAB Total
3621	33	9	---	---	3	---	45
3622	29	11	---	---	---	---	40
3691	14	6	---	---	2	---	22
3717	177	18	4	2	---	---	201
5012	127	12	6	4	---	---	149
5013	749	99	24	51	11	26	960
5014	121	15	---	---	---	---	136
5092	134	32	18	25	12	21	242
5511	568	132	44	61	20	41	866
5521	247	39	7	33	7	12	345
5531	551	138	40	78	14	45	1211
5541	4229	969	278	460	138	258	6332
7534	48	11	---	---	---	---	59
7538	1074	199	60	107	32	42	1514
7539	667	120	31	37	17	22	894

APPENDIX C

BASELINE PROJECTIONS FOR IMPACTED INDUSTRY SECTORS

The following is a brief rationale for most of the curve fits. This documentation deals with topics such as the industry relationship to the automobile industry, business characteristics (selling or manufacturing), and growth patterns. In many of these, the reader should recall that miles per year per car is fairly constant overtime. Thus the number of autos (Table C.1 and Fig. C.1)* is a reasonable indicator when looking at a service or auto usage connected industry, as it is a substitute for total miles.

The data used in these projections are given at the four-digit SIC level of detail. Data are not available at finer detail except through area survey. While a four-digit SIC code is narrowly defined there are inclusions which are not germane to this study. For example, tire stores may feature an expanding array of spare parts and repair services not related to tires. This would result in distorted employment projections. These data deficiencies are not a severe limitation on the outcome of the projections.

C.1 SIC 3691 (STORAGE BATTERY--FIG. C.2)

A spokesman for the Lead Industries Association indicated that batteries are generally manufactured in the region where they are solid, as lead is less bulky to ship than are batteries. Thus this is a good indicator of the regional activity. The projected payroll trend is curved because the straight line projection gave an unreasonably high annual average salary increase. The curves for employment and number of firms were both excellent statistical fits.

---

*Figures and tables for this appendix are given following the text.

C.2 SIC 3717 (AUTOMOBILE MANUFACTURING--FIG. C.3)

Here, payroll and employment are best related to the number of new autos. The number of firms is more stable, and is related to the total auto population. The first two curves are the best statistical fit and the employment curve is adjusted upward slightly as it approaches zero. The steep increase in payroll is plausible given the strength of the UAW, and the annual average salary increase here closely approximates the historical productivity growth of auto manufacturing.

C.3 SIC 5012 (VEHICLE DISTRIBUTION--FIG. C.4)

The statistical fit here is excellent. It is reasonable that the number of firms per auto should be decreasing, indicating a higher volume per distributor, while employment per auto is fairly constant.

C.4 SIC 5013 (PARTS DISTRIBUTION--FIG. C.5)

Again, there is a good statistical fit. It is reasonable to assume a higher volume per firm.

C.5 SIC 5014 (TIRE DISTRIBUTION--FIG. C.6)

The statistical fit here for payroll is poor. The curve was drawn with a slightly flatter slope than the statistical fit indicated. It seems reasonable that employment should climb slightly as tire stores become less specialized and sell more tire related items. Also, it seems reasonable that a recent increase in tire competition and in the number of high volume company stores should cause a drop in firms per auto.

C.6 SIC 5092 (PETROLEUM DISTRIBUTION--FIG. C.7)

The statistical fit here for payroll and number of firms is poor. However, they seem reasonable when considering that the service area of a bulk plant distributor is controlled by the major oil companies.

C.7 SIC 5511 AND 5521 (CAR DEALERS--FIG. C.8)

The statistical fit is good for employment and number of firms; less so for payroll. The decline here in number of firms, and to a lesser extent, payroll, should not be contrasted with the situation in motor vehicle distribution. Motor vehicle distributors are franchised wholesalers while car dealers include used car dealers; a less stable industry.

C.8 SIC 5531 (AUTO SUPPLY STORES--FIG. C.9)

The statistical fit here is only fair but acceptable without any adjustment of the curves.

C.9 SIC 5541 (SERVICE STATIONS--FIG. C.10)

The fit for payroll and employment is fair. Due to the small average employment of service stations, it is reasonable that employment should decline with the number of stations.

C.10 SIC 7534 (TIRE RETREADING--FIG. C.11)

Curves were found with a good statistical fit for all three indicators. The number of firms, however, was projected to reach zero and so that curve was redrawn in a less statistically sound but more logical form.

C.11 SIC 7538 AND 7539 (AUTO REPAIR SHOPS--FIG. C.12)

The statistical fit here is only fair, but it seems reasonable that shops should increase both in volume and in employment as cars become increasingly complex. These two SIC categories were combined as they are related and the statistical fit is better when they are combined. Increasing employment is a logical result of the increasing complexity of cars.

TABLE C.1

AUTOMOBILE POPULATION OF THE SOUTH COAST AIR BASIN

County	Actual* 1950	Actual* 1960	Actual* 1970	Projected 1980	Projected 1990	Projected 2000
Los Angeles	1,705,694	2,747,570	3,626,450	4,033,605	4,442,869	4,893,368
Orange	93,106	309,392	748,217	970,378	1,199,212	1,406,447
San Bernardino	91,342	172,391	265,492	339,726	411,312	486,940
Santa Barbara	26,180	41,171	78,975	93,425	118,155	138,137
Riverside	47,442	88,508	160,523	194,495	228,543	257,174
Ventura	41,930	76,852	180,746	249,084	332,753	418,665
Total SCAB Area	2,005,694	3,435,884	5,060,403	5,880,713	6,732,844	7,600,731
10-Year Annual Growth Rate, Percent		5.5	3.9	1.5	1.3	1.2

*Source: California Department of Motor Vehicles.

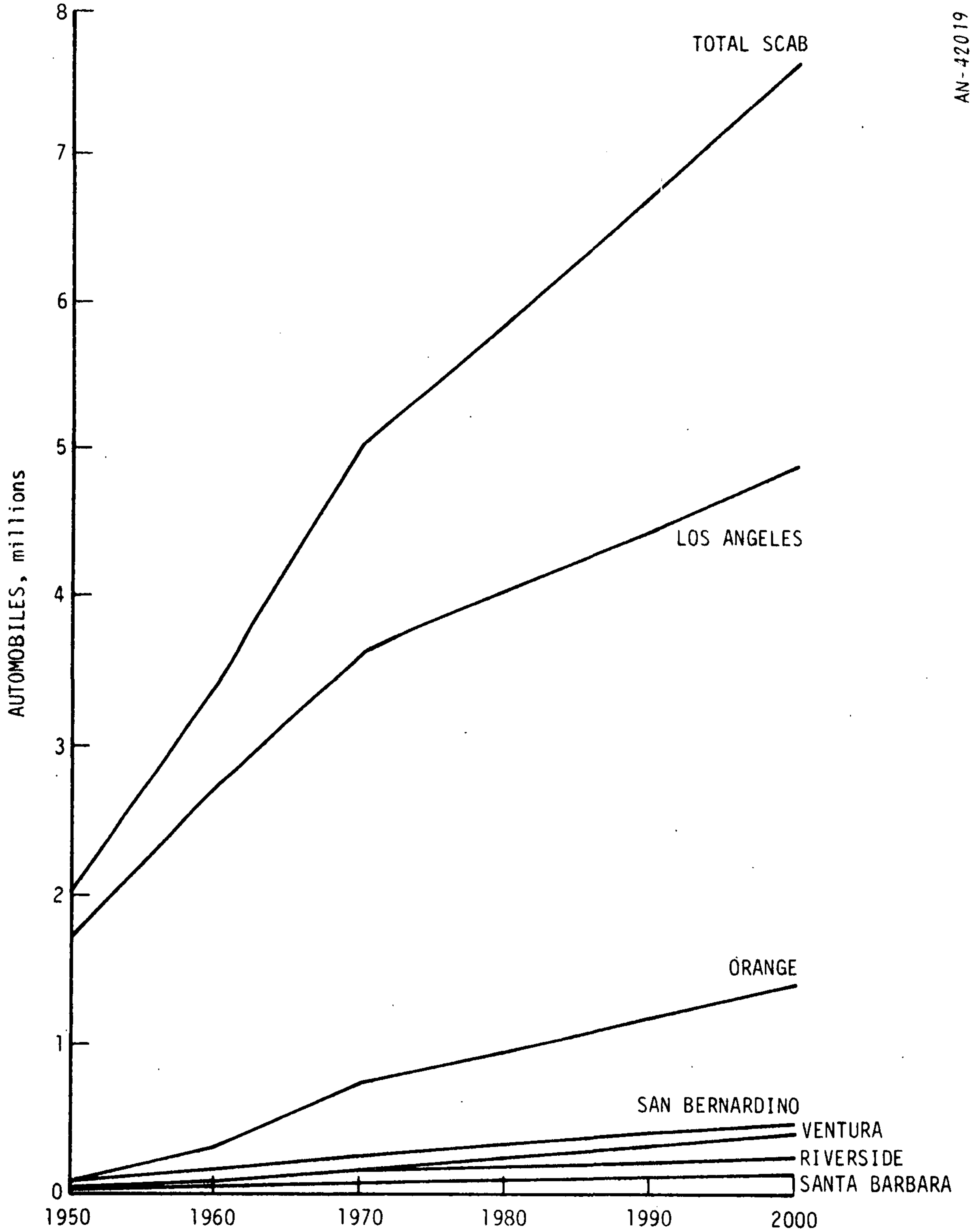


Figure C.1. Automobile Population in the South Coast Air Basin, by County

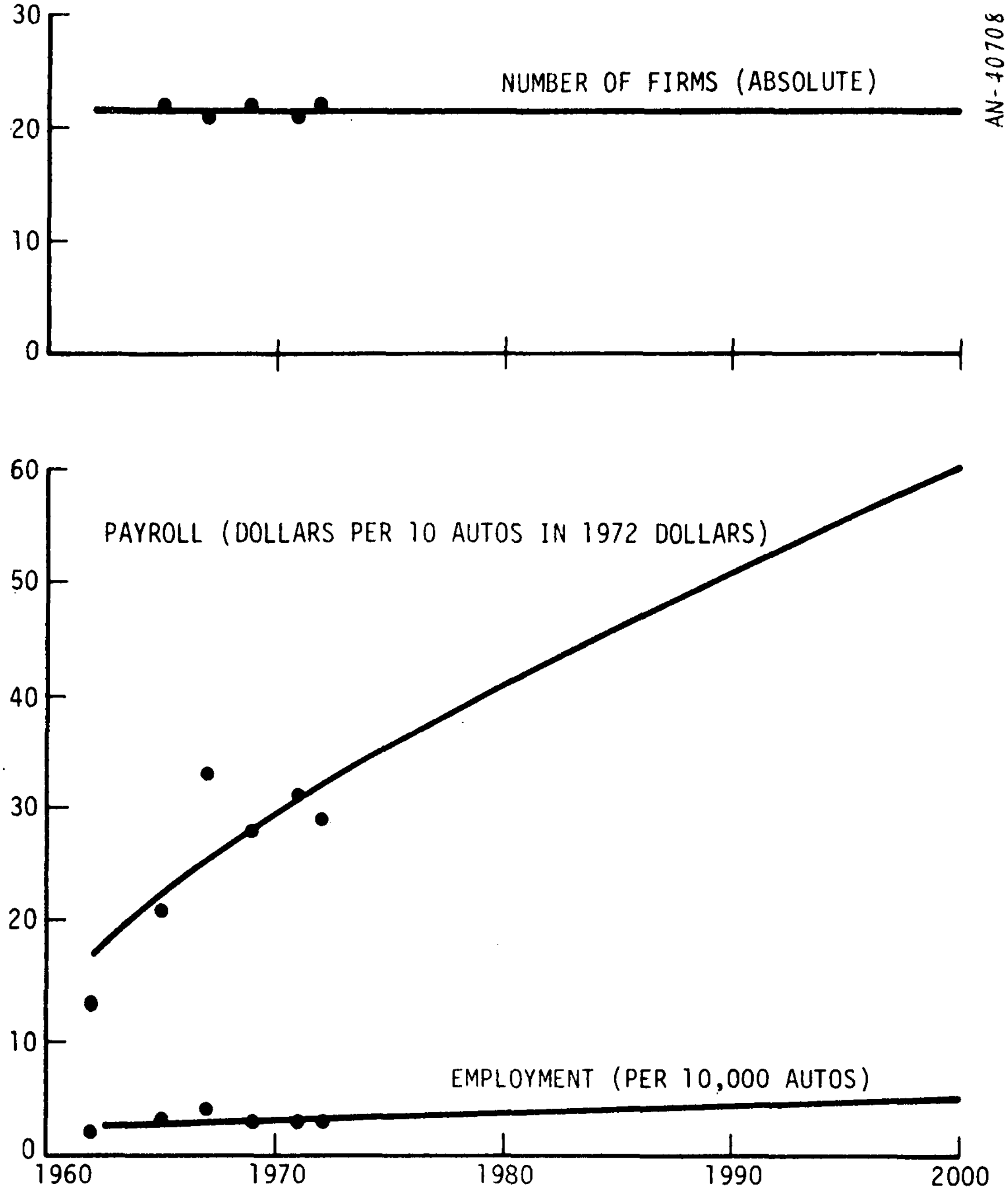


Figure C.2. SIC 3691: Storage Battery Manufacturing

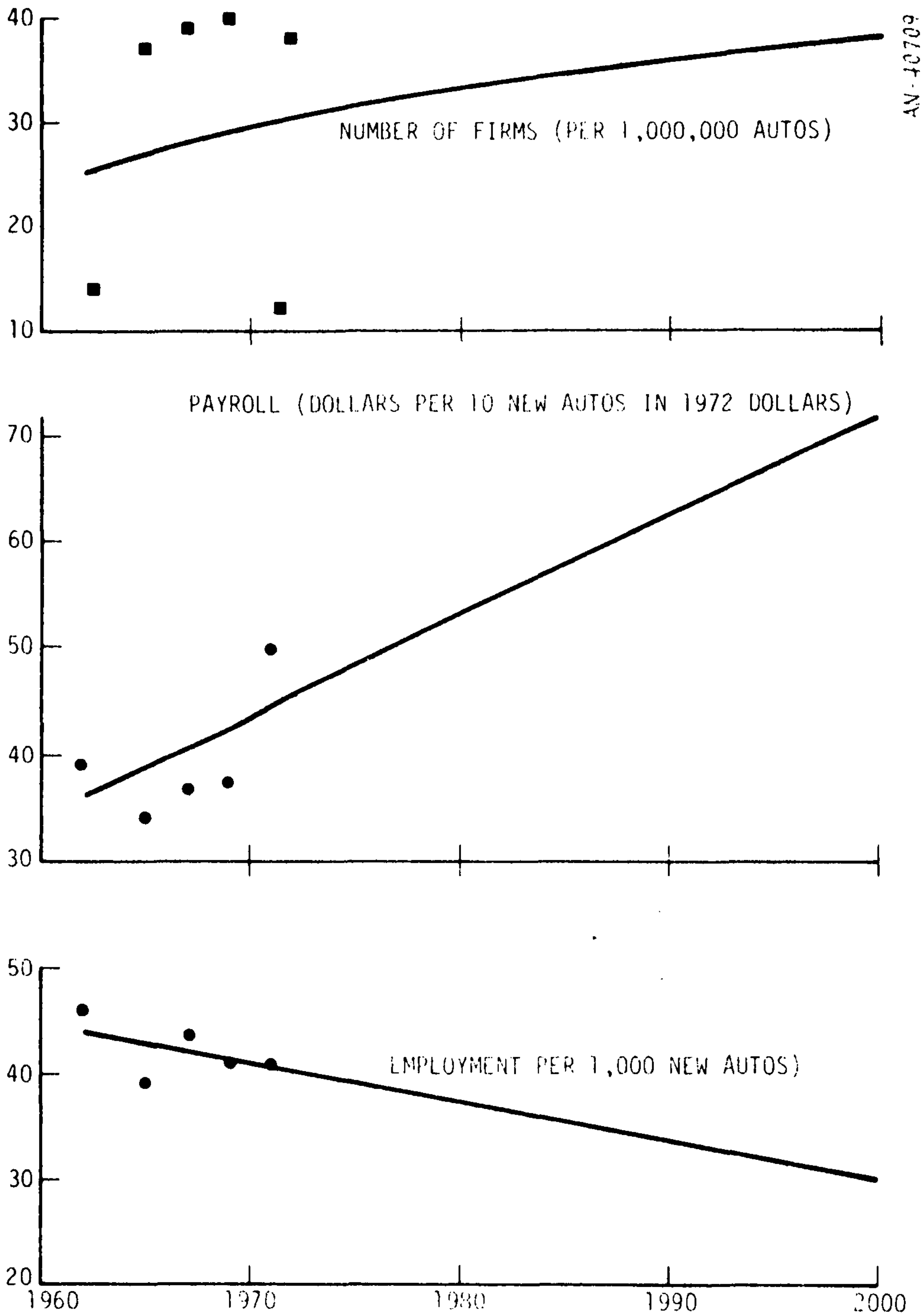


Figure C.3. SIC 3717: Motor Vehicle and Motor Vehicle Parts Manufacturing

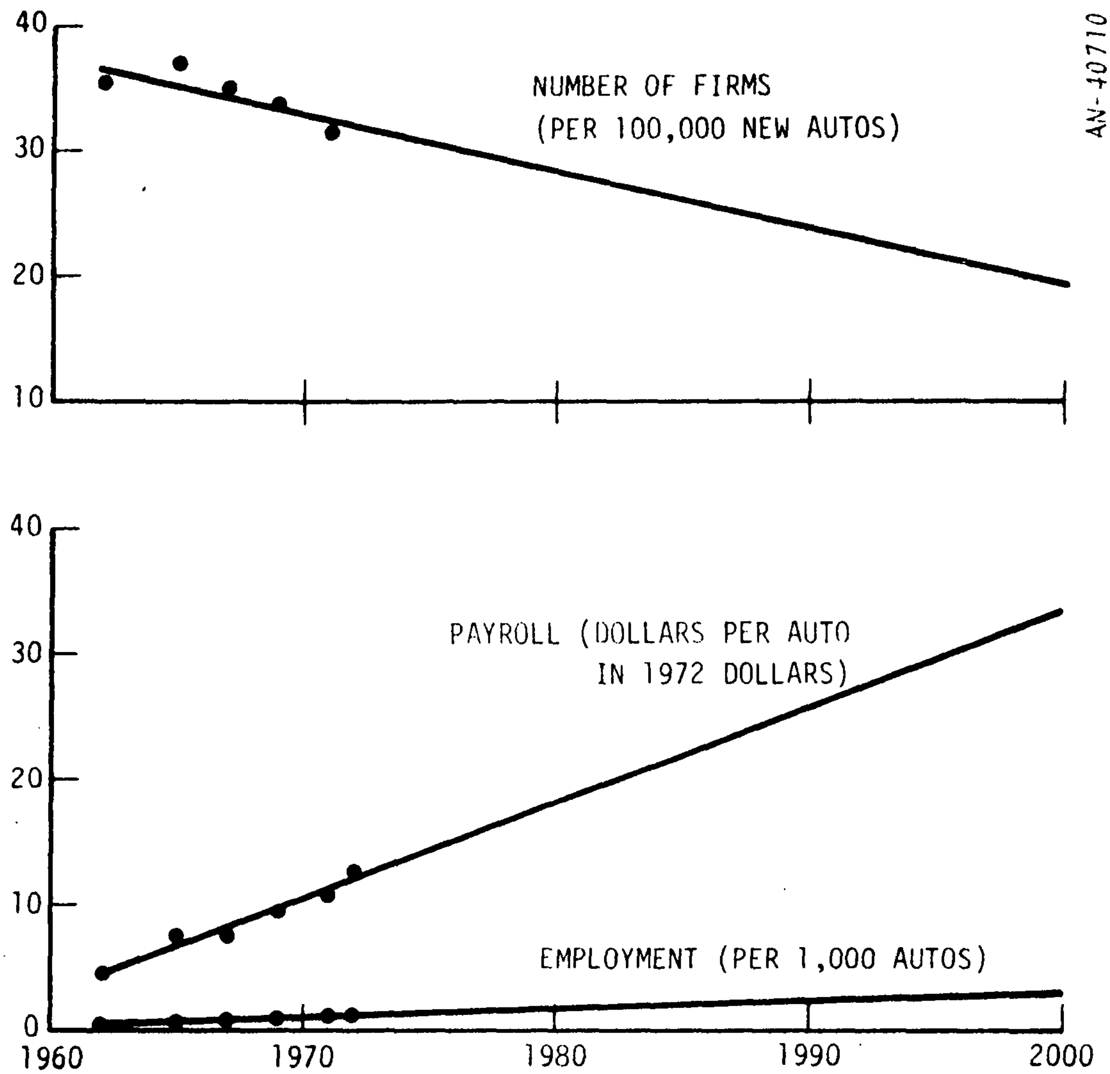


Figure C.4. SIC 5012: Motor Vehicle Distribution

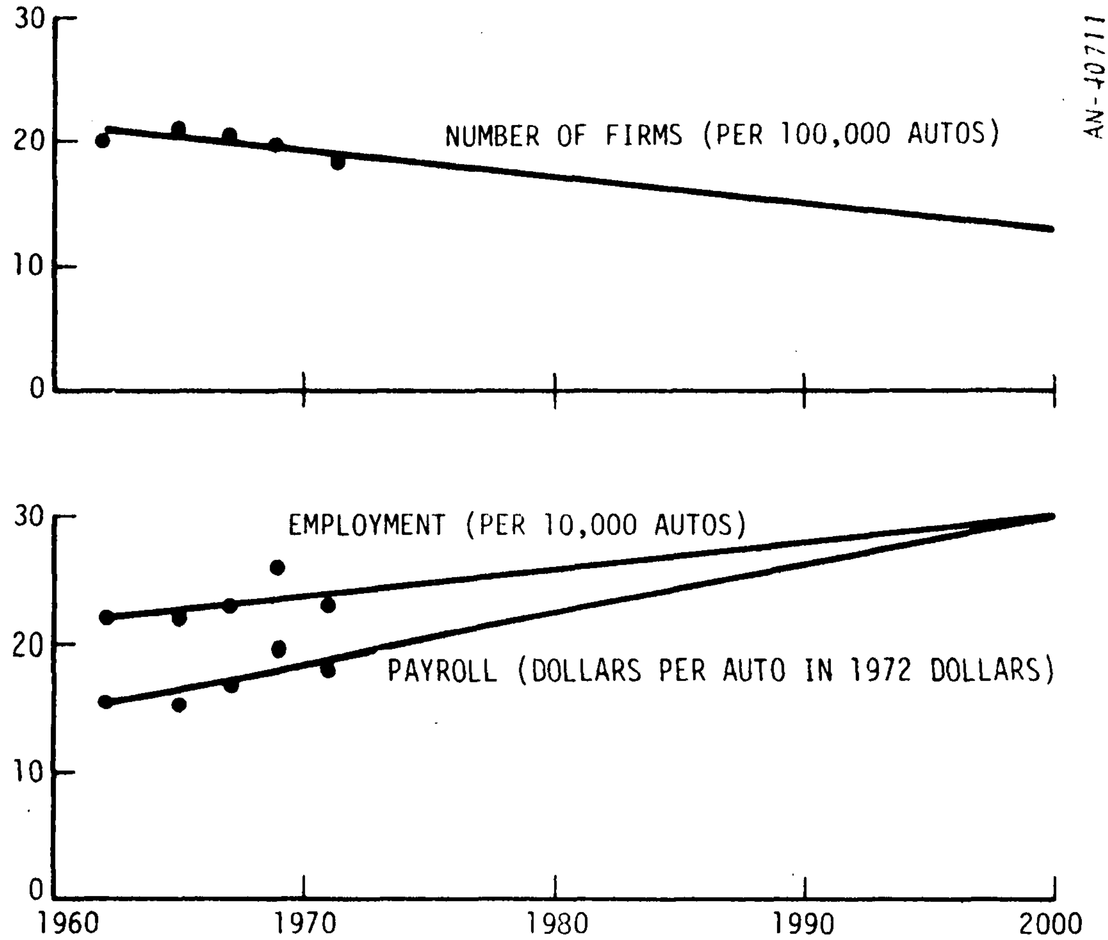


Figure C.5. SIC 5013: Automotive Parts Distribution

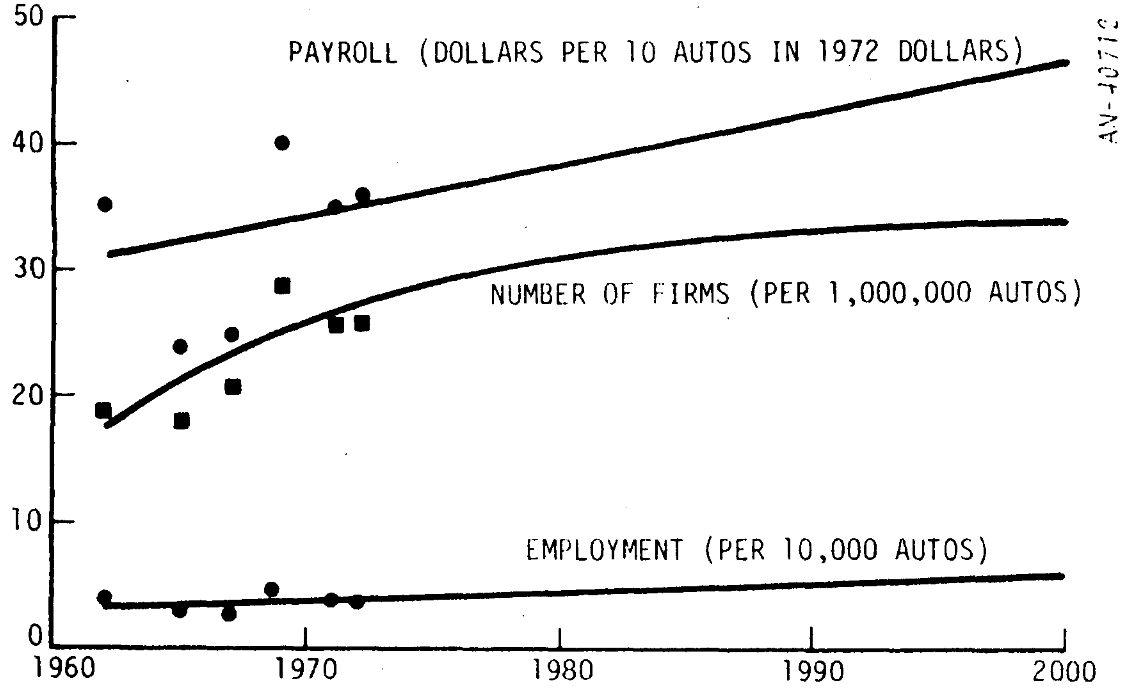


Figure C.6. SIC 5014: Tire Distribution

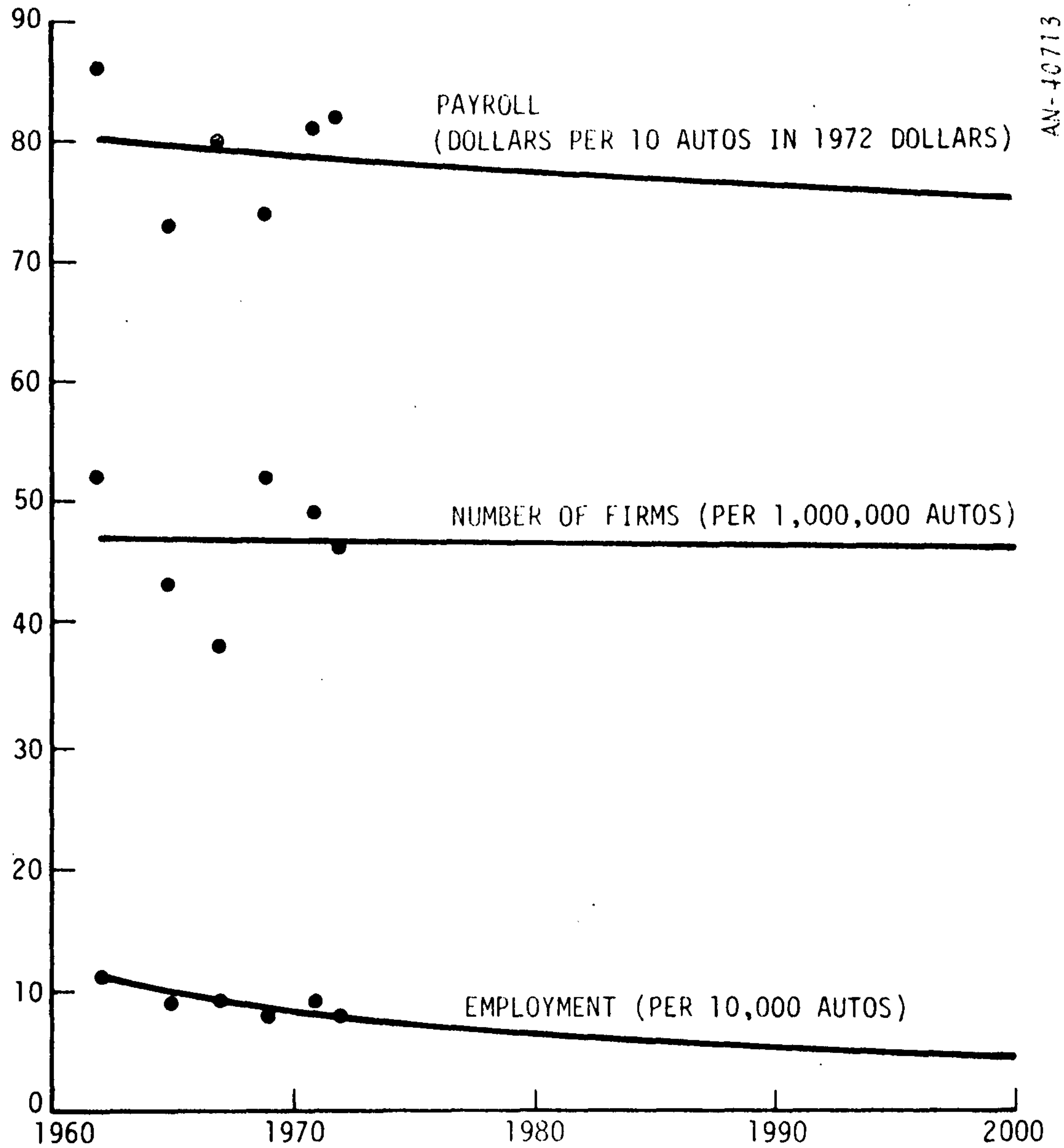


Figure C.7. SIC 5092: Petroleum Distribution

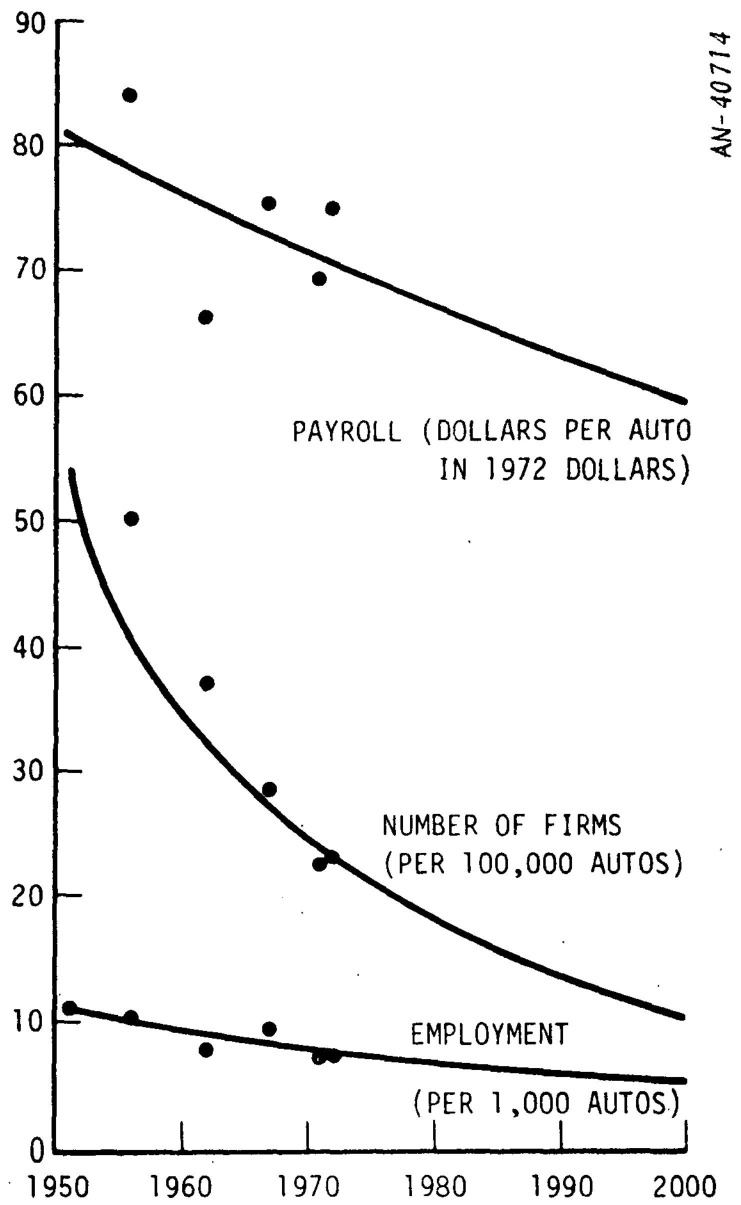


Figure C.8. SIC 5511 and 5521: Car Dealers

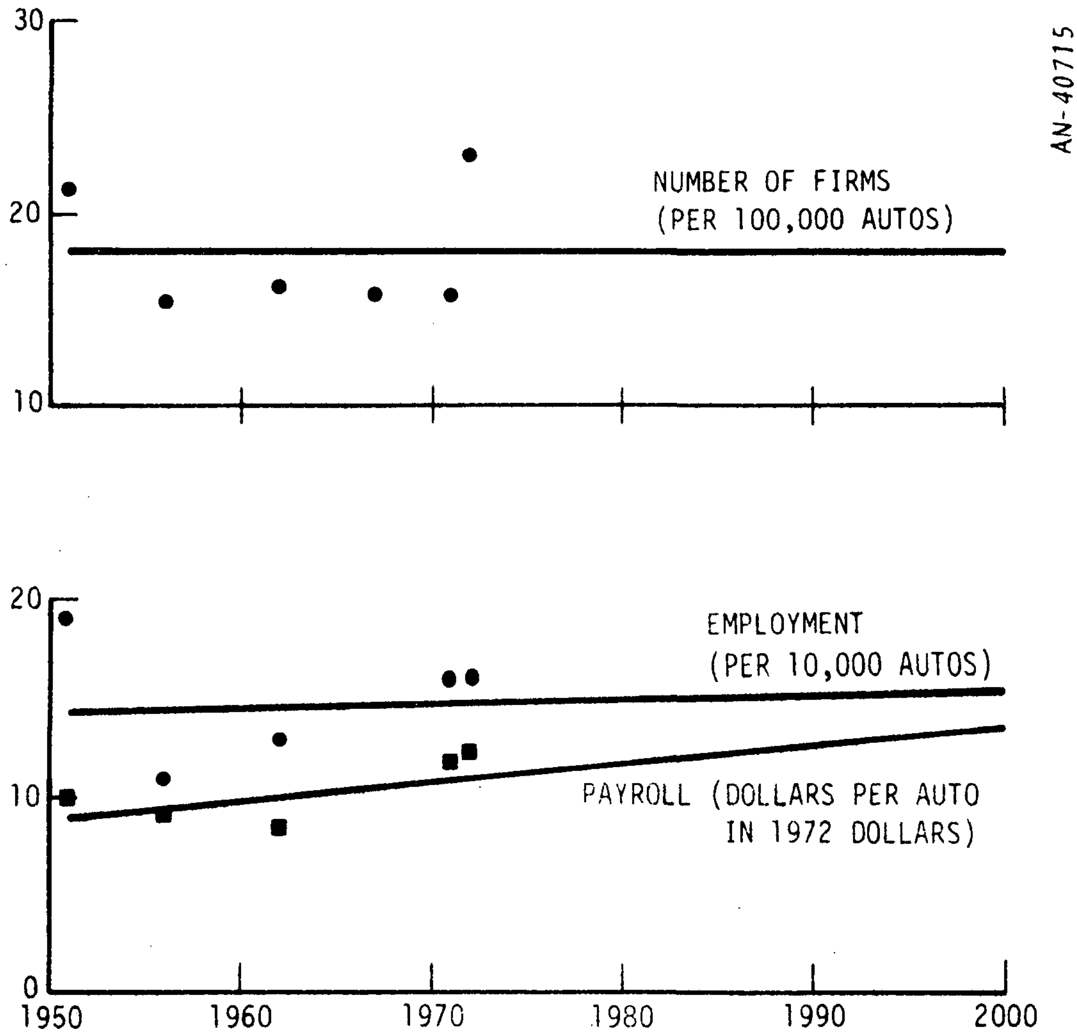


Figure C.9. SIC 5531: Auto Supply Stores

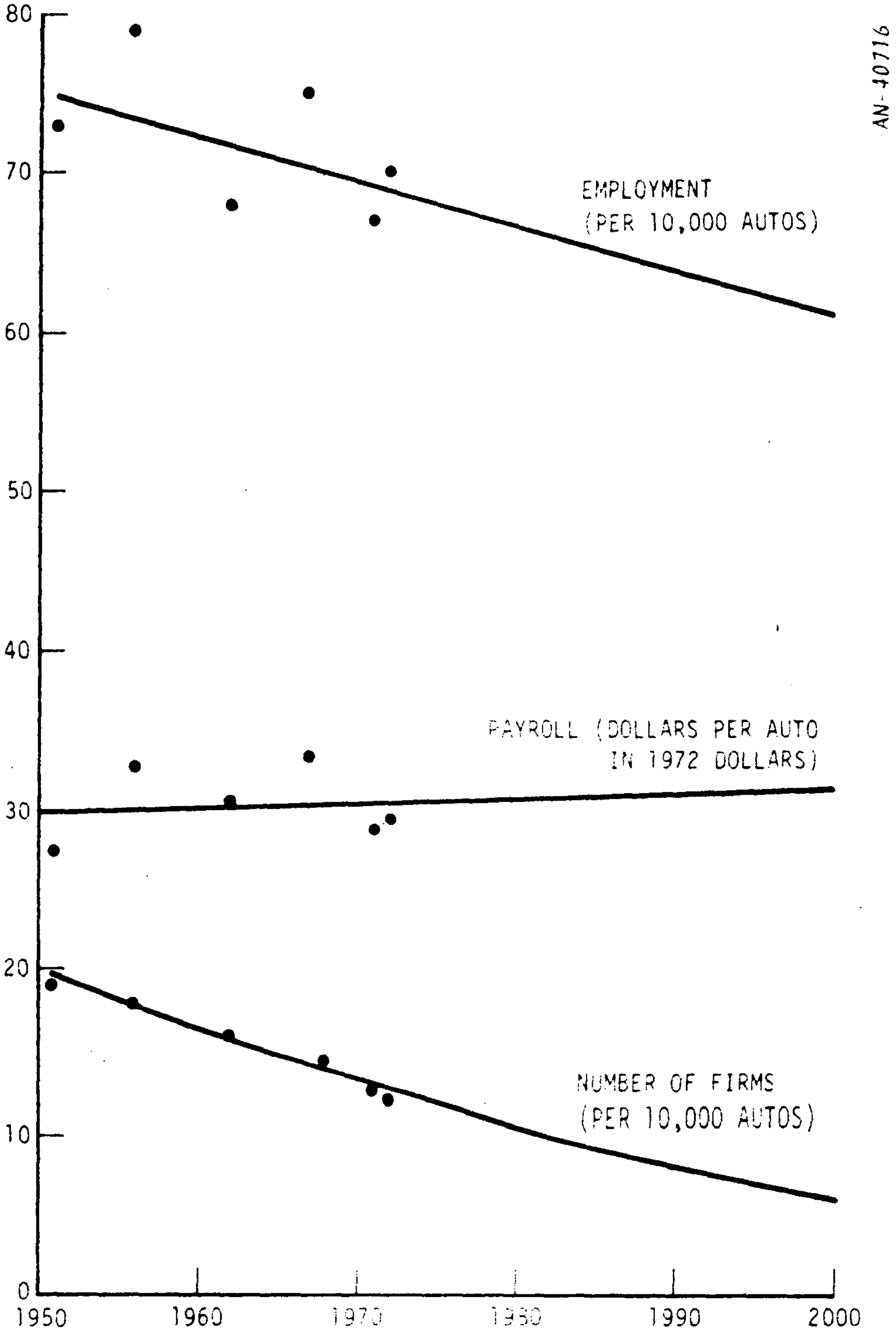


Figure C.10. SIC 5541: Service Stations

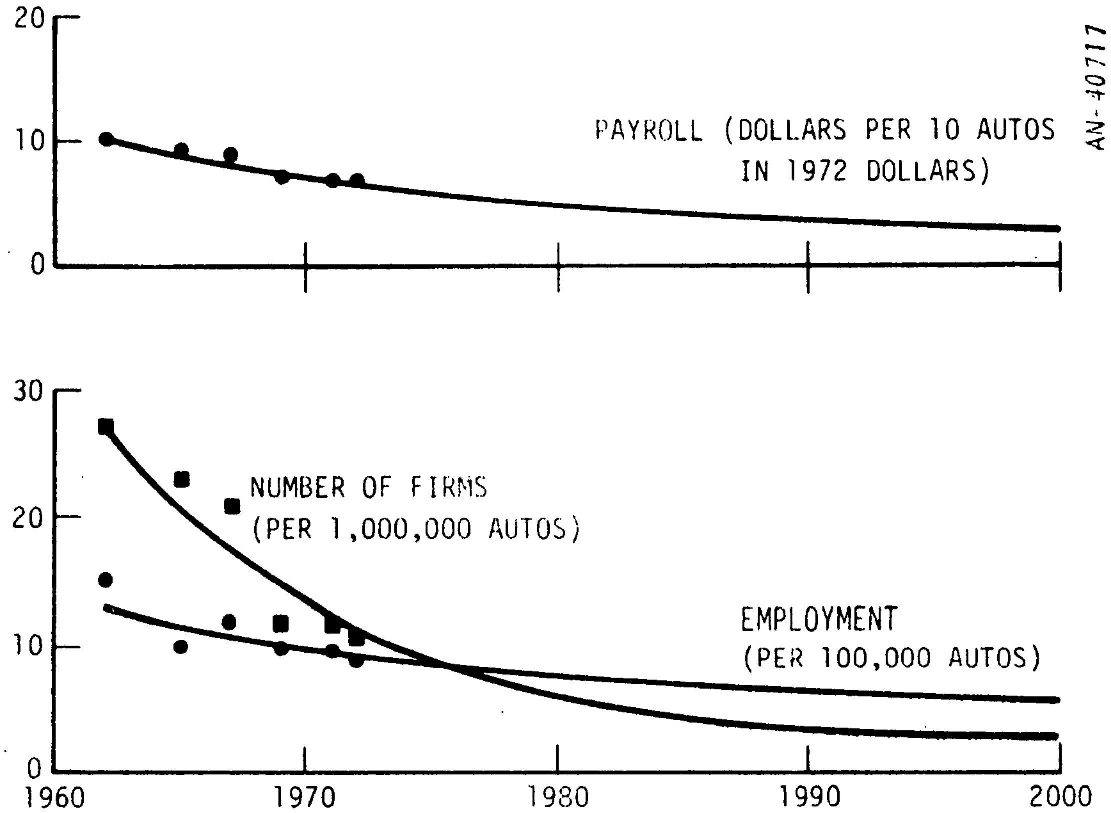


Figure C.11. SIC 7534: Tire Retreading Shops

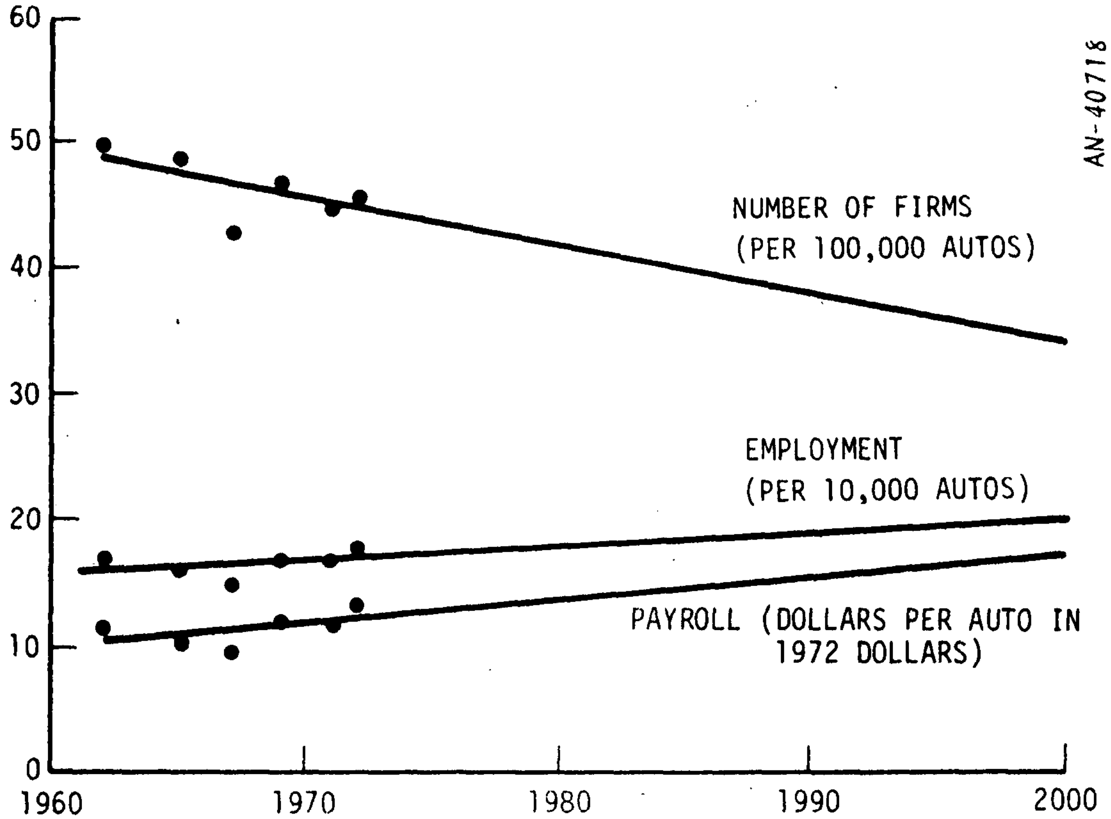


Figure C.12. SIC 7538 and 7539: Auto Repair Shops

REFERENCES

1. OBERS Projections: Economic Activity in the U.S., U.S. Department of Commerce, Bureau of Economic Analysis, Washington, D.C., 1972.

2. H. Noarse, Regional Economics, McGraw-Hill, 1968.

3. Standard Industrial Classification Manual, Office of Management and Budget, 1972.

4. County Business Patterns, California Department of Commerce, 1951, 1957, 1962, 1965, 1967, 1969, and 1972.

5. U.S. Industrial Outlook 1971, U.S. Department of Commerce, 1971.

6. Indices of Output Per Man-Hour: Selected Industries, 1947-1970, Bureau of Labor Statistics Bulletin 1962, 1971.

TASK REPORT 5

ELECTRIC ENERGY PROJECTIONS
FOR THE LOS ANGELES REGION, 1980-2000

A.R. Sjovold

ABSTRACT

Electric energy consumption in Southern California and the South Coast Air Basin is expected to grow at slower rates in the future than have been experienced in the past. Per capita consumption is expected to grow at an average annual rate of 4.3 percent. Adding the 0.5 percent-per-year expected population growth rate (which is lower than earlier projections), overall electric consumption is expected to grow at an average annual rate of 4.8 percent. Much electric energy in the South Coast Air Basin will be generated by fossil-fueled power plants--primarily fuel oils--until the year 2000 when nuclear fission powered facilities should constitute a significant fraction of total generating capacity. The growth in electric energy consumption will probably be accompanied by rising prices, the net rise depending on basic fuel scarcities and whatever inflation persists.

Available off-peak generating capacity within the South Coast Air Basin should be ample now and in the future to recharge in excess of a million electric cars daily, and so additional generating capacity will probably not be required. However, off-peak generation will during peak demand seasons most likely be associated with the burning of additional fuel oil in the older plants within the basin; the newer out-of-basin fossil plants and nuclear plants will be base-loaded but will provide some of the off-peak recharge energy during off-peak seasons.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Cont.)

TABLES

1 INTRODUCTION

This is the fourth in a series of reports projecting baseline conditions (in the absence of electric cars) for use in a study of the impacts of future electric car use. It follows assumptions and data presented in the first report of the series, Task Report 2, Population Projections for the Los Angeles Region, 1980-2000.

A significant shift from gasoline to electrically powered cars may cause an equally significant impact upon the patterns of energy consumption. To adequately assess the significance of such an impact it is first necessary to establish a set of baseline conditions regarding energy supply and demand that would exist if electric cars are not introduced.

Although the primary focus of the study is the South Coast Air Basin, the future patterns of energy supply and demand in the Air Basin will be influenced by overall energy policies pursued at the National level. The presently forecast shortages in domestic crude oil and natural gas supplies are causing a fundamental reassessment of the Nation's energy supply and demand functions. Accordingly, we first focus our attention on the National energy forecasts to determine the overall constraints and conditions within which the Air Basin regional supply and demand relationships are resolved. Additionally, these constraints and conditions include considerations of the technologic and economic limitations attendant to the development of environmentally clean energy sources.

In this paper we establish both National and South Coast Air Basin energy forecasts with compatible fundamental assumptions regarding population growth.

2 FORECASTS OF TOTAL US ENERGY SUPPLY AND DEMAND

There is at present a considerable focus on forecasting the future energy needs of the nation. It appears that for the next few years, the US may have to rely to a significant degree on foreign sources of crude oil to fuel our economy. A greater reliance on imported sources arouses concern about its dependability and would undoubtedly entail undue consequences with regard to our overall diplomatic strength in the world and our balance of payments in world trade. This reliance on foreign sources was not foreseen even as late as 1964 based on authoritative forecasts[1] made at that time. It is only within the last decade that a trend toward an increasing rate of energy consumption has brought us to the present state of our energy supply problems.

Thus, there is some evidence that we should view such long term forecasts with some caution as to their absolute accuracies. However, for the study of electric car impacts, our need is for a representative energy forecast to establish a baseline from which to measure impacts on energy supply and demand. Consequently, small inaccuracies or perturbations in the forecast conditions should not unduly affect the relative accuracies of estimated impacts.

There have been several recent analyses of our current problems and our expectations regarding future energy supplies and demands. One of the most recent and more thorough efforts was reported in "U. S. Energy Outlook" prepared by a special committee of the National Petroleum Council in December 1972.[2] Another equally comprehensive effort was the analysis by the Inter Technology Corporation for the National Science Foundation reported in November 1971.[3] Still other analyses have contributed insights to particular aspects or reduced scopes of the problem such as the analysis by Stanford Research Institute (SRI) on "Meeting California's Energy Requirements, 1975-2000"[4] and the Rand Corporation on California's future electric supply and demand.[5] For the purpose of establishing a National baseline energy forecast we have relied most strongly on the report by the National Petroleum Council (NPC).[2]

2.1 FORECAST OF US ENERGY DEMAND

One of the initial steps of the NPC analysis was to forecast in some detail the demand for energy for the year 1985 with an additional but less detailed forecast for the year 2000. Figure 2.1 presents the NPC predictions of future energy demand for the three alternatives labeled "high," "intermediate," and "low." Their forecasts are based on the following four variables which they deemed to be the most significant long range determinants of energy demand: (1) economic activity as characterized by GNP, (2) cost of energy (including cost-induced efficiency improvements), (3) population and (4) environmental controls. The three cases then are the result of a set of high and low projections for each of the four variables with the intermediate case representing something in between. With regard to the population variable, the three cases are associated with official US Census series projections C, D, and E as noted in the figure. The energy demand forecasts assume that there will be no substantial changes in the living habits of the US population and do not anticipate reduced energy consumption because of supply limitations or political decisions to regulate or allocate energy consumption.* In general, the forecasts assume that growth in economic

*The NPC forecast did not foresee the "crises" spawned by the Mid-East conflict, although in overview it warned of the potential for such a condition. It is difficult to assess the impact of the Mid-East spawned oil embargo on the US level of demand in the year 1985, the focus of the NPC forecast. The embargo may affect several of the assumptions underlying the NPC forecast. First, we should note that the embargo has forced almost instant fuel rationing in various degrees throughout the free world. Since unilateral responses by the impacted nations to make themselves independent of such actions will take several years to implement, a sustained embargo would necessarily force a rationing condition for some time which most likely will result in long-lived modifications to energy consumption habits. Second, we should note that the embargo disrupted the energy supply and demand relationships throughout the World with the net effect of increasing the posted prices of crude oil in international trade. Thus, the future prices (or costs) of energy may take a different path than forecast by the NPC. Third, to the degree that immediate reductions in the availability of energy may affect the growth in the National economy there may result a delay or deferment in the GNP growth rate envisioned by the NPC.

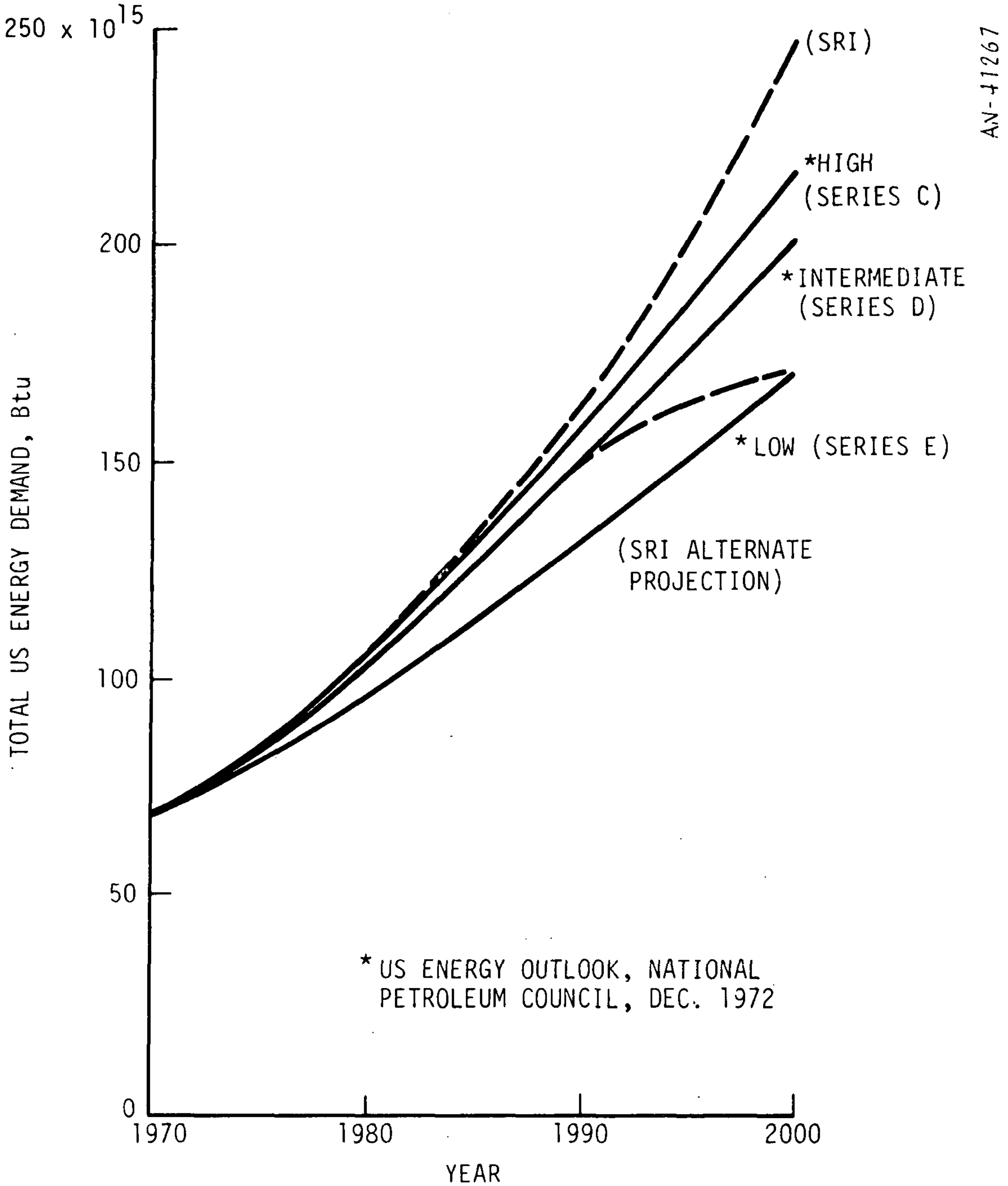


Figure 2.1. Projected U.S. Total Energy Demand

activity, and achievement of social goals such as full employment would be seriously impeded if energy consumption were arbitrarily curtailed.

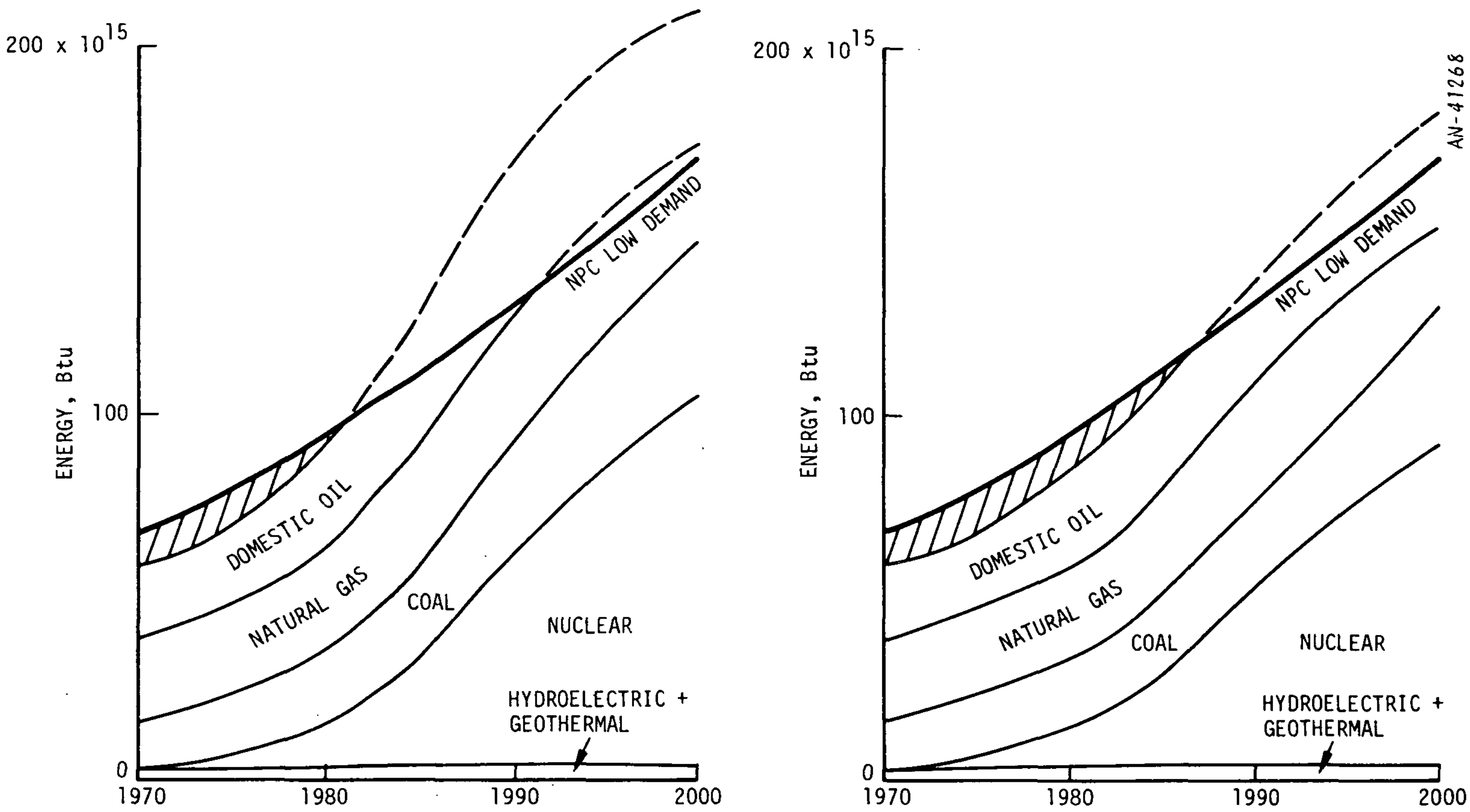
Figure 2.1 also presents two alternative forecasts made by Stanford Research Institute (SRI) pursuant to their study of California's energy supply and demand problems. The high curve by SRI assumes that energy consumption will expand at a constant 4.5 percent per year to the end of the century. The low curve has made allowance for a lower growth in population plus allowances for the costs of environmental cleanup. SRI believes that the low projection should prove to be the more realistic projection.

Consistent with our analysis of population growth, we have chosen the "low" demand case derived by the NPC study as the baseline for the US. This is supported to some degree, by the analyses of SRI except that they are somewhat different in the near term.

2.2 FORECAST OF US ENERGY SUPPLIES

Four scenarios for the development of future domestic energy supplies were explored in the NPC study. The four cases ranged from a level where the maximum economically feasible expansion of future energy sources was anticipated to the case represented by a continuation of present policies. The four cases are depicted in Figs. 2.2(a-d) which represent correspondingly the maximum expansion down to the lowest expansion. Superimposed on each figure is the low-demand case from Fig. 2.1. The cross hatched regions represent the shortfall in domestic supplies and it is assumed that this deficiency will be met by imported energy sources, primarily foreign crude oil.

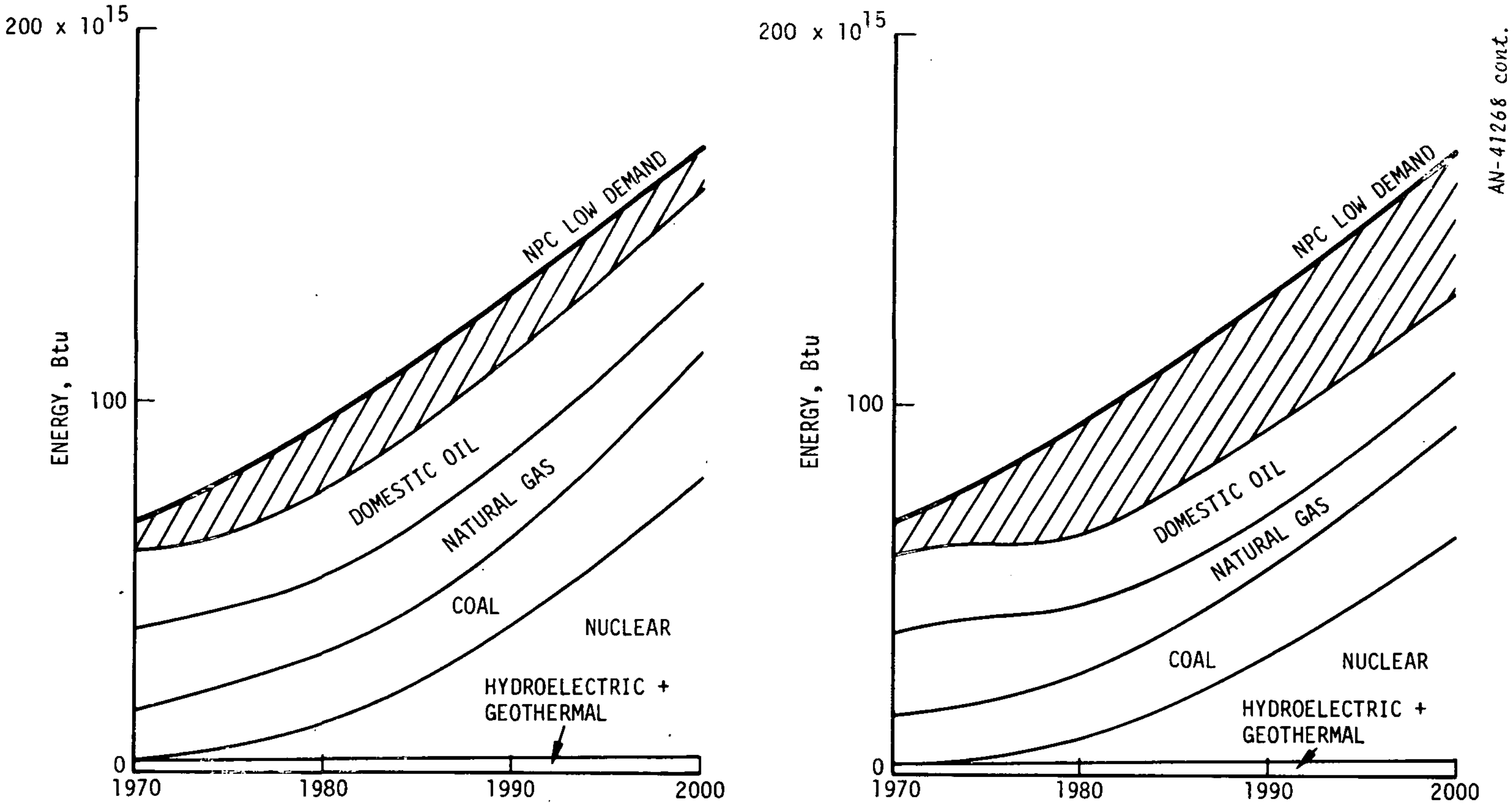
The four cases were developed by analyzing the current state of consumption relative to proven reserves, current prices, and a range of economic incentives by which production of each of the primary energy



a. NPC Case I

b. NPC Case II

Figure 2.2. Projected Primary Energy Supply for Total U.S. Compared With Projected Demand (Ref. 2)



c. NPC Case III

d. NPC Case IV

Figure 2.2(Cont.)

sources could be stimulated. The forecasts are all tempered with judgments reflecting the physical constraints on resource availability.

In all cases, nuclear power is forecast to become the major source of primary energy by the year 2000. Natural gas reserves are particularly low and there seems to be agreement among most energy observers[2,3] that it is presently underpriced. A significant increase in natural gas prices is anticipated which should stimulate the discovery of new reserves; however, the new reserves will not be instrumental in alleviating the near term shortages. If new incentives for gas exploration are not advanced (Case IV), then gas will decline relatively and absolutely as a significant primary energy source. In any case, gas supplies are not expected to expand greatly and in terms of its user priorities will be reserved mainly for residential uses and little used in fueling electric power generation in the future. In all four cases, new energy forms or sources such as coal gassification or exploitation of oil shales are expected to add very little to total energy supply through 1985; by the year 2000 shale oil is expected to provide between 2 and 3 percent of total US energy with coal gassification expected to contribute 5 percent.

A significant difference among the four cases of supply is in the quantities of oil and gas supplies and their sensitivities to prices. For example, in 1985 there is almost a 2-to-1 difference in the sum of oil and gas supplies between Cases I and IV (oil + gas = 69×10^{15} Btu for Case I and 38×10^{15} Btu for Case IV). Table 2.1 presents the estimated future prices of gas and oil for each case deemed adequate to call forth the necessary exploration and drilling activity to produce the corresponding level of supply. These estimates of supply are the result of careful calculations by the NPC of economic equilibrium conditions and it is significant to note that the NPC estimates that a 27-percent difference in oil prices between Cases I and IV will result in a 330-percent difference in the corresponding drilling rates. This difference in exploration activity is responsible for the 2-to-1 difference in oil and gas supply between Cases I and IV.

TABLE 2.1

AVERAGE REQUIRED "PRICES" FOR OIL AND GAS
(1970 CONSTANT DOLLARS)

	Oil ($/BBL.)		Gas (¢/MCF)	
Case I	3.18	6.69	17.1	43.6
Case II	3.18	6.18	17.1	39.8
Case III	3.18	6.60	17.1	53.0*
Case IV	3.18	5.28	17.1	38.7
	1970	1985	1970	1985

*If prices for gas discovered prior to 1971 were held at current levels, new gas would cost over 75¢/MCF

If we examine the four cases of supply as contrasted with forecast demand in Figs. 2.2(a-d), we find that they present a wide range of impacts on the necessary imports of fuels. Case I sets into motion a set of conditions that begins to sharply overshoot forecast demand by 1982; oil imports are minimized. Case II represents a more measured response to the near term shortage without result in sharp overshoot; required oil imports are not much greater than for Case I. Cases III and IV fail to solve both the near term and long term energy supply problems and commit the nation to a significant steady or even increasing reliance on foreign sources. Accordingly, we have chosen Case II supply conditions as most in accord with recently stated national energy policy for a steady expansion of energy supply while minimizing the risks of relying too heavily on imported sources. Case II also promises to return the Nation to a condition of self-sufficiency in energy by the year 1986. Case II also assumes that a quicker solution is found to problems in fabricating and installing nuclear power plants than is presently available.

2.3 POWER PLANT EFFICIENCY TRENDS

Because all four cases of energy supply forecast a heavy reliance on nuclear energy, which is programmed solely for electric energy production, an important factor in overall energy balances is the thermal efficiency with which basic energy sources are converted to electric energy, including both nuclear and fossil fuel sources. Among the factors involved in the design of a new plant affecting its design efficiency are the magnitude of the increased capital investment necessary to build more efficient equipment, the annual fueling and maintenance costs and, of course, the existing level of technology. Figure 2.3 shows the historical trend in average thermal efficiency of fossil fueled electric power generation in the United States.[6] The figure shows that in the decade between 1951 and 1961 there was a steady increase in the overall thermal efficiency which has since remained relatively constant for the past decade near the 1961 level. Although the major fraction of power generation through this period has been by conventional fossil-steam plants, the period from about 1965 to the present has witnessed a rapid rate of increase in installed new capacity with nuclear and internal combustion (IC) source facilities.[6] Both nuclear and IC facilities operate at significantly lower efficiencies than conventional steam plants. New plants listed under fossil fuel fired capacity include IC sources which tend to offset any gains in efficiency in new conventional steam plants. Furthermore, the shift to nuclear plants reduces the requirement to build new and more efficient conventional steam plants thereby helping to account for the slow rate of improvement in average fossil fuel plant efficiency evidenced in the decade 1961 to 1971.

Beyond 1971, the efficiency of fossil fuel plants is expected to further improve as new technology is incorporated in the mix of generation capacity. Table 2.2[2] shows a 1972 projection of the expected efficiencies for the most promising new technologies in power generation for selected years and the time they are projected to become available. The effect of these new technologies on the expected future trend of overall average generation efficiency of fossil fuel plants in the US is depicted in

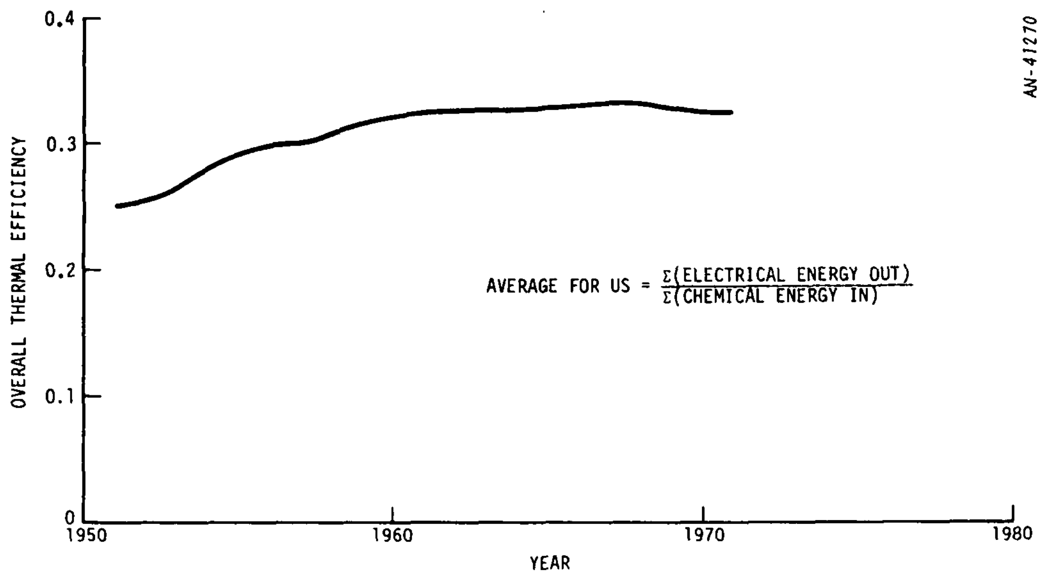


Figure 2.3. Historical Trend of Overall Thermal Efficiency of Power Generation by Fossil Fuel Plants[6]

TABLE 2.2

ESTIMATES ON AVAILABILITY OF COMMERCIAL TECHNOLOGY FOR ENERGY CONVERSION[2]

	Electrical Thermal Efficiency (Percent)	When Available
Stand-Alone MHD	20-25	1980
MHD-Topped Power Plant	50-52	1985
MHD-Topped Power Plant	55-60	1995
Fuel Cells Using Reformed Methane	40-45	1976
Combined Cycle* Using Clean Fossil Fuels	40	1972
Combined Cycle* Using Clean Fossil Fuels	45	1978
Combined Cycle* Using Clean Fossil Fuels	48	1985
Fixed-Bed Gassification of Coal and Combined Cycle*	40	1975
Fixed-Bed Gassification of Coal and Combined Cycle*	45	1978
Fluid-Bed Gassification of Coal and Combined Cycle*	40	1982
Fluid-Bed Gassification of Coal and Combined Cycle*	45	1988
Fluid-Bed Gassification of Coal and Combined Cycle*	48	1992
Fluid-Bed Combustion Coal or Residual Oil--Rankine Cycle	38-41	1980
Thermionic Topping Fossel-Fuel Power Plants	45	1985
Gas Turbine-Brayton Cycle (Clean Fossil Fuels)	28	1972
Gas Turbine-Brayton Cycle (Clean Fossil Fuels)	34	1978
Gas Turbine-Brayton Cycle (Clean Fossil Fuels)	38	1985

*Brayton-Rankine

Fig. 2.4[2] which indicates an overall improvement of 8 percent by the year 1990 when compared to present efficiency. Also shown are the expected efficiency trends for each year for newly installed conventional fossil fuel plants, the best available combined cycle plants, and the average of the cumulative capacity of installed combined cycle plants. The indicated improvement in efficiency averaged over all fossil fuel plants implies that a significant fraction of new, more efficient fossil plants will be installed either as net additions or replacement of old plants. This situation is expected to occur in conjunction with the very rapid buildup in nuclear plant capacity.

Among the factors that might affect this forecast trend in overall generation efficiency of fossil fuel plants is a significant departure from the forecast fossil fuel costs. Several possibilities present themselves. Extremely costly fossil fuels will focus a great deal of attention on generation efficiency. Improvements in overall efficiencies beyond that forecast in Fig. 2.4 would require a greater installation rate of new, more efficient plants such as the combined cycle plants. This result could in turn occur only if older plant were written off at a faster rate with a corresponding increase in the rate of capital investment in new plants or if the additional new plant capacity were to supplant some of the increase forecast for nuclear generation capacity. Since it is expected that nuclear plant overall energy costs will already be less than fossil fuel plants, the latter result is not likely. An additional possibility, if fossil fuel costs should be higher than forecast, would be a reduction in the expansion of new fossil fuel generation capacity to be made up by an even greater expansion in nuclear capacity. Although there will be an incentive to move in this direction any significant increase in the planned expansion of nuclear plant must contend with many other factors that are not yet clearly resolved. These include, environmental factors of radioactive waste disposal, emergency core cooling processes, and nuclear plant siting, and economic factors dealing primarily with the capital intensiveness of

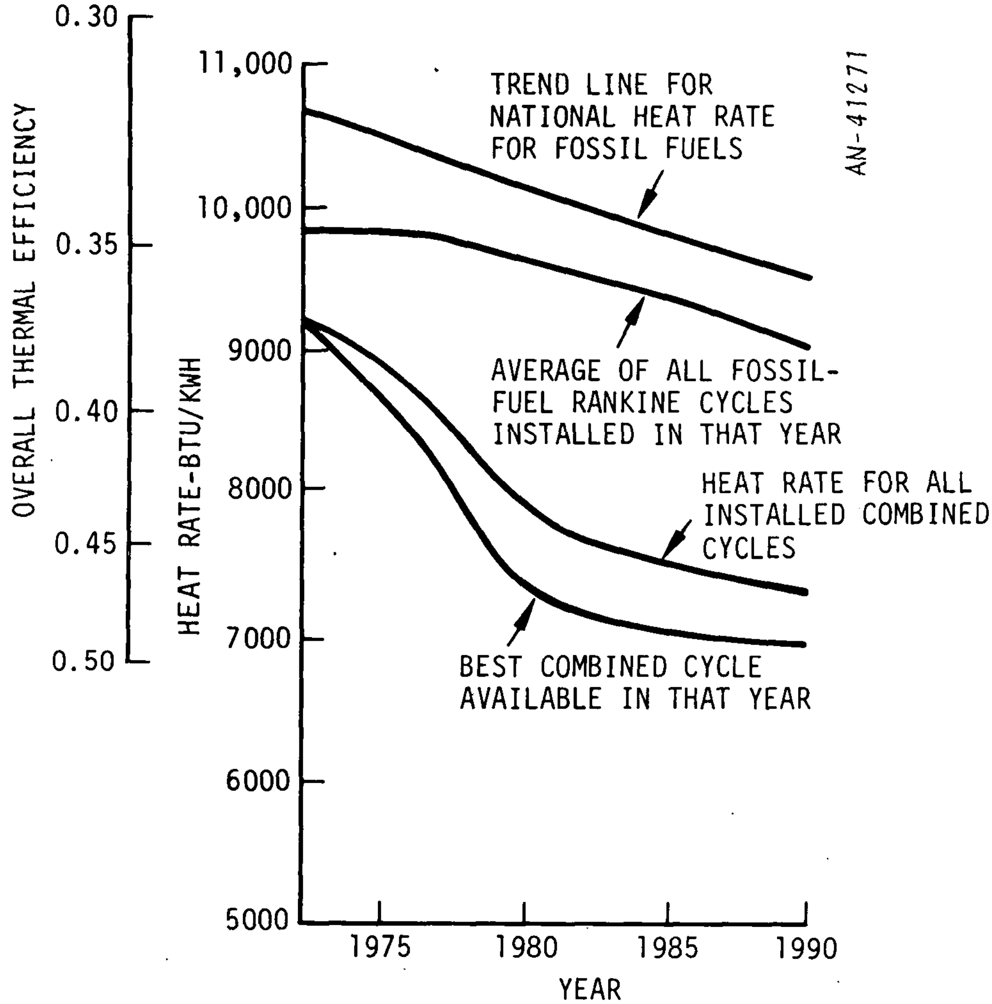


Figure 2.4. Estimated Trends for Efficiency of Electric Power Generation from Fossil Fuels, 1972-1990[2]

nuclear plants. Regarding this latter factor, a commitment to more nuclear plants in response to high fossil fuel costs would undoubtedly be based on beliefs that such high fuel costs would prevail for a long time, at least for a significant fraction of the typical economic life of a nuclear plant.

2.4 ESTIMATED FUTURE PRICES OF ENERGY SOURCES

A primary focus of the NPC analyses was the determination of the economic incentives in terms of future market prices necessary to stimulate an expansion of a particular energy source. The estimated future average prices of primary fuels corresponding to Case II supply conditions are depicted in Fig. 2.5.* These are basic prices in constant 1970 dollars for conditions at the wellhead or the mine and so do not include costs for cleaning the fuels such as desulfurization costs.

---

*We have assumed a uniform increase in basic energy prices between 1970 and 1985. A result of the Arab oil embargo has been to cause profound changes in the posted prices and actual market prices of crude oil in international trade. A news release on January 1, 1974[7] announced the following posted prices:

Indonesia	$10.80/bbl
Libya	18.76
Nigeria	14.69
Bolivia	16.00
Venezuela	14.08

Market prices typically run about 70 percent of posted prices except that "buy back" oil (oil actually owned by the producing country) is nearer the posted price (94 percent in the case of Saudi Arabia). It is not clear what the magnitude of these international prices will be on domestic crude oil prices or how long such elevated prices will persist. If they should prevail for any length of time, there will undoubtedly result such a significant and rapid increase in exploration activity that over supply and eventual price depression would occur and we would expect the NPC equilibrium price estimates for 1985 to remain reasonably valid. However, we would also expect the unforeseen rapid rise to stimulate competition of alternative technologies such as synthetic crude oil and gas production from shale oil and coal much earlier than anticipated by the NPC. Thus, the fractions of total US supply in the future from these sources may be slightly greater than anticipated by the NPC. However, the NPC estimates that under non-emergency conditions the maximum feasible rate of shale oil production in 1985 would be 750,000 bbls/day compared to the 400,000 bbls/day assumed for Case II (these amounts are 1.4 and 0.8 percent respectively of total 1985 US energy supply).

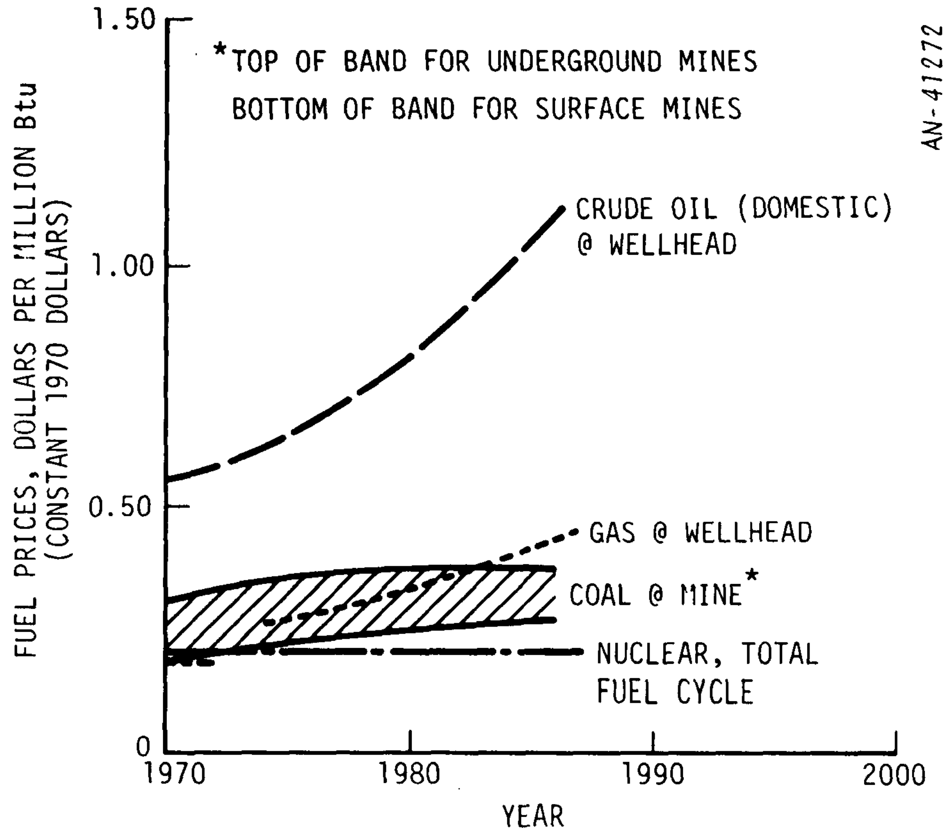


Figure 2.5. Projected Average Prices of Primary Energy Sources, Case II Conditions

Examining Fig. 2.5, we find that crude oil is expected to double by 1985 reaching approximately $1.05 per million Btu or approximately $6.00 per barrel. The average price of natural gas, our cleanest energy source environmentally, is still significantly underpriced relative to crude oil. However, it is expected that new discoveries would require prices of $0.78 to $0.72 per million Btu according to the NPC analysis.

The prices shown for nuclear fuel are somewhat deceptive in that this primary source is destined entirely for electric power production and requires a higher proportion of capital costs than for ordinary fossil fuel fired plants. SRI has estimated a 1980 "break even" price of fossil fuels in competition with nuclear fuels for power generation at $0.42 per million Btu,[4] of which $0.20 is estimated for the nuclear fuel cycle. Thus, the forecast prices of crude oil would certainly allow a favorable competition for the expansion of nuclear fuel sources. However, present prices set by the AEC for separative work in enriching uranium are based on extremely cheap electrical energy. It is anticipated that future requirements for separative work will require additional gaseous diffusion plants. These may be provided within the private sector and in that case could double the present cost of a separative work unit according to a recent analysis.[8] A doubling of enrichment services would raise the total nuclear fuel cycle costs from $0.20 to $0.26 per million Btu, but would still allow nuclear power to maintain its competitive position.

2.5 CLEAN POWER GENERATION TECHNOLOGY

By the year 2000, it is expected that nuclear energy will have assumed the major fraction of the burden of electrical power generation. However, in the intervening time span great reliance will be based on fossil fuels for energizing steam-electric power plants. As natural gas availability for power generation becomes reduced, the fossil fuel burden will fall most heavily on fuel oils and coal. Many of the available oil and coal sources contain excessive sulfur and could not be burned directly without violating air quality standards or adding cleanup equipment.

In the near term the use of coal for power generation will depend on the success with which the development of stack gas sulfur removal technology is met. In a recent report,[9] the results of a poll of experts by the Delphi Technique concerning the expectations for sulfur dioxide removal technology were published and are here reproduced in Table 2.3. Six categories of sulfur oxide removal equipment were considered: lime/limestone scrubbing, sodium sulfite-bisulfite scrubbing, catalytic oxidation, double alkali scrubbing, magnesia scrubbing, and others. Essentially, the panel was asked when they thought each of these processes would reach demonstrated reliability (one year operation) of 10, 50, and 90 percent of time on-stream. The results at the end of the second round shown in the table indicate the panel considered lime/limestone scrubbing and magnesia scrubbing the processes likely to be available first and double alkali scrubbing the one that would be demonstrated last.

Furthermore, although the poll results indicate that it will be 3 or 4 years before we can expect confident sulfur dioxide removal techniques, we can reasonably assume that by 1980 sulfur dioxide removal from stack gases should not be a problem. Further corroboration is evidenced by the present activity in installation of SO_2 removal equipment as shown in Table 2.4.[2]

In the longer term, other technologies will likely become available as means to cleaning up coal. Coal gasification can be thought of as a clean up technology. However, the practical application of this technology involves more than an alternative cleanup method; it allows the energy of the coal to be transformed to a more transportable commodity and thus its advantage may be in exploiting the more remote coal fields in the Western United States.

TABLE 2.3

POLL OF EXPERTS ON SO_2 REMOVAL TECHNOLOGY

Process	On-Stream Factor	Year Anticipated
Lime/Limestone Scrubbing	10%	1973
	50	1975
	90	1976
Double Alkali Scrubbing	10	1975
	50	1976
	90	1978
Magnesia Scrubbing	10	1973
	50	1974
	90	1976
Sodium Sulfite-Bisulfite	10	1974
Scrubbing with By-product	50	1975
Recovery	90	1976
Catalytic Oxidation	10	1973
	50	1974
	90	1977

TABLE 2.4

SULFUR DIOXIDE REMOVAL SYSTEMS AT US STEAM-ELECTRIC PLANTS[2*]

Power Station	Unit Size (MW)	Designer SO_2 System	New or Retrofit	Scheduled Start-Up	Anticipated Efficiency SO_2 Removal
Limestone Scrubbing:					
1. Union Electric Co., Meramec No. 2**	140	Combustion Engineer	R	September 1968	Operated at 73% Efficiency During EPA Test
2. Kansas Power & Light, Lawrence Station No. 4	125	Combustion Engineer	R	December 1968	Operated at 73% Efficiency During EPA Test
3. Kansas Power & Light, Lawrence Station No. 5	430	Combustion Engineer	N	December 1971	Will Start 65% & Be Upgraded to 83%
4. Kansas City Power & Light, Hawthorne Station No. 3	100	Combustion Engineer	R	Late 1972	Guaranteed 70%
5. Kansas City Power & Light, Hawthorne Station No. 4	100	Combustion Engineer	R	Late 1972	Guaranteed 70%
6. Kansas City Power & Light, Lacygue Station	800	Babcock & Wilcox	N	Late 1972	80% as Target
7. Detroit Edison Co., St. Clair Station No. 3	180	Peabody	R	Late 1972	90% as Target
8. Detroit Edison Co., River Rouge Station No. 1	265	Peabody	R	Late 1972	90% as Target
9. Commonwealth Edison Co., Will County Station No. 1	175	Babcock & Wilcox	R	February 1972	Guaranteed 80%
10. Northern States Power Co., Sherburne County Station Minu. No. 1	700	Combustion Engineer	N	1976	
11. Arizona Public Service, Chella Station Co.	115	Research Cottrell	R	December 1973	
12. Tennessee Valley Authority, Widow's Creek Station No. 8	550	Undecided	R	1974-1975	
13. Duquesne Light Co., Phillips Station	100	Chemico	R	March 1973	Guaranteed 80%
14. Louisville Gas & Electric Co., Paddy's Run Station	70	Combustion Engineer	R	Mid-Late 1972	Guaranteed 80%
15. City of Key West, Stock Island†	37	Zurn	N	Early 1972	Guaranteed 85% Removal
16. Union Electric Co., Meramec No. 1	125	Combustion Engineer	R	Spring 1973	80% as Target
Sodium Hydroxide Scrubbing Installation:					
1. Nevada Power Co., Reed Gardner Station	250	Combustion Equipment Associates	R	1973	Guaranteed 90% SO_2 While Burning 1%S Coal
Magnesium Oxide Scrubbing Installations:					
1. Boston Edison Co., Mystic Station No. 6	150	Chemico	R	February 1972	90% Target
2. Potomac Electric Power, Dickerson No. 3	195	Chemico	R	Early 1974	90%
Catalytic Oxidation:					
1. Illinois Power, Wood River††	100	Monsanto	R	June 1972	Guaranteed 85% SO_2 Removal

*Federal Register, Vol. 37, No. 55 (March 21, 1972), p. 5768, updated.

**Now abandoned.

†Oil-fired plants (remainder are coal-fired).

††Partial EPA funding.

The cost of stack gas cleanup of coal fired plants can vary significantly depending primarily on whether the cleanup equipment is part of a new installation or retrofitted to an existing one.

Domestic and foreign crude oils are expected to supply a significant fraction of the energy for power generation. Crude oils can vary significantly in their sulfur content and 65 percent of the current level of domestic supply has 0.5 percent or less sulfur content.[10] However, much of the crude supply is fed to refineries which are operated to yield a high percentage of jet, gasoline and distillate fuels which leaves most of the sulfur burden with the residual fuel oils, the main source of all heating oils for power stations. Presently, the free world refineries produce 27.8 percent of their output as residual fuel oil whereas the US refineries only produce 6.8 percent of their output as residual fuel oil.[10] Table 2.5 presents a breakdown of the sulfur content of the current supply of residual fuel oil by region of the country. It is to be noted that the Pacific Coast supplies are predominantly high sulfur content oils.

The average sulfur content of all imported oil in 1971 was in the range of 2.4 to 2.6 percent. There may exist some opportunities to allocate low-sulfur oils directly to fuel power plants, but due to blendings that occur in our crude oil distribution systems, the benefits of low sulfur sources are not always preserved. Thus, it appears that most fuel oils will have to undergo desulfurization before they can be utilized in the clean generation of power. It has been estimated that the additional cost of desulfurizing a barrel of oil will be approximately $0.90 for the case of hydrodesulfurization based on planned operations in Venezuela.* The premium prices now being paid for low-sulfur oil (up to $18.00 per barrel)[7] would make desulfurization at this price economically feasible. Assuming that desulfurization equipment can be constructed with sufficient capability, we foresee that low sulfur oil should be in ready supply by 1980 and beyond.

---

*This is the price in Venezuela. The energy requirement for the desulfurization process could not be readily determined.

TABLE 2.5

US RESIDUAL FUEL OIL SULFUR CONTENT[10]

(Current supply in thousands of barrels per day)

	Sulfur Content, percent					
	<.7	.7-1.0	1.0-1.5	1.5-2.0	2.0-3.0	>3.0
East Coast	-	2.5	-	6.0	42.9	-
Gulf States	9.1	13.0	42.0	11.0	25.6	6.0
Central States	24.0	35.4	52.8	0.5	69.9	5.8
Pacific Coast	5.4	22.3	14.2	67.3	18.1	11.8

In the longer term it is expected that the developing technologies of coal gasification and the manufacture of synthetic crude oil will be able to produce clean sources from high sulfur content feed stocks.

3 BASELINE ENERGY FORECASTS FOR SOUTHERN CALIFORNIA AND THE SOUTH COAST AIR BASIN

Efforts similar to that of the National Petroleum Council have recently been made in studying the energy supply and demand relationships for California. Noteworthy are the studies by Rand Corporation[5] and the Stanford Research Institute (SRI).[4] The public utilities in the State also have made many planning and forecast studies which have become input to many of these studies. To develop forecasts of future energy supply and demand for the South Coast Air Basin, we have relied most heavily on the SRI study* and the planning studies made by the Southern California Edison Company (SCE)[11,12] and the Los Angeles Department of Water and Power (LADWP).[13]

The SRI study, in addition to forecasting overall California energy needs, presented results by Northern and Southern divisions of the State. The Southern division was chosen as that area composed of the service areas of SCE, LADWP, the San Diego Gas and Electric Company, the Imperial Irrigation District and the small municipal power systems of Glendale, Pasadena, and Burbank (G/P/B). With minor corrections the SCE, LADWP, and G/P/B composite service area is almost congruent with the South Coast Air Basin and comprises about 70 percent of SRI's Southern California division.

While SRI made quite detailed comprehensive forecasts of energy supply and demand, the detailed planning forecasts of the utilities were concerned with sources of electric power supply for only the next ten years.

---

*The Rand Corporation study was found less useful to our study since it dealt solely with electric power demand forecasts. The assessment of electric car impact on energy resources will require careful consideration of the substitutability of basic energy resources and the Rand study did not couch their analyses of demand within a total energy supply and demand for California, whereas the SRI study did. Furthermore, the SRI study conveniently divided the State into Northern and Southern halves which helped us in our task of developing a South Coast Air Basin forecast. Nonetheless, comparisons with the Rand forecasts are offered where appropriate.

Consequently, we have put together the forecast data from SRI, SCE, and LADWP to help establish a picture of the future energy needs of the South Coast Air Basin.

3.1 ENERGY SUPPLY AND DEMAND IN SOUTHERN CALIFORNIA

Figure 3.1 presents the SRI forecast of primary energy supply and demand for the Southern California region while Table 3.1 shows the relative fractions of supply from each energy source in percent. Consistent with the National picture, natural gas is expected to first decline absolutely and then recover to a steady level of supply equal to its 1970 level. Nuclear energy is not expected to be a significant source until the late 1980s. The energy source labeled coal represents the contribution expected from the plants either completed or under construction in the Nevada desert and the four-corners region of the Southwest. Throughout the period of interest, oil is expected to be the major energy source.

TABLE 3.1

SOUTHERN CALIFORNIA ENERGY DEMAND[4]

(In percent by source)

	1970	1980	1990	2000
Oil	55.	65.1	58.8	46.
Gas	41.	22.4	19.1	15.8
Nuclear	.8	3.3	13.4	31.5
Coal*	1.5	7.1	6.6	4.8
Other	1.7	2.1	2.1	1.9

*The SRI figures have been modified to account for Southern California energy consumption from the Four-Corners coal fired plants.

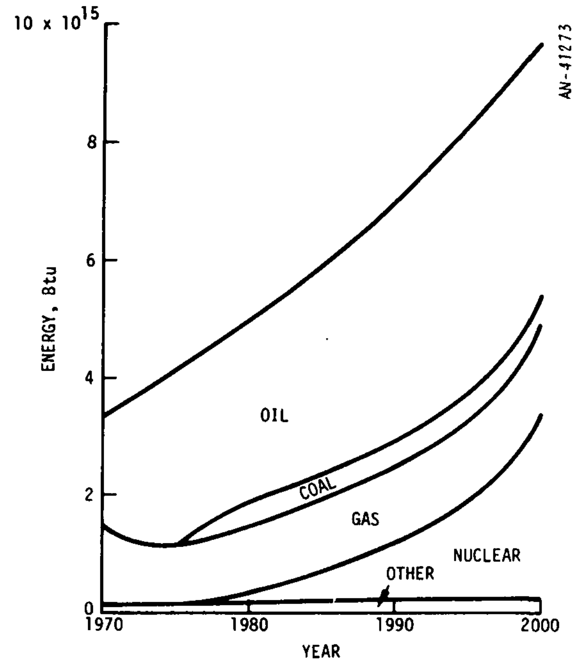


Figure 3.1. Primary Energy Supply and Demand, Southern California (SRI)

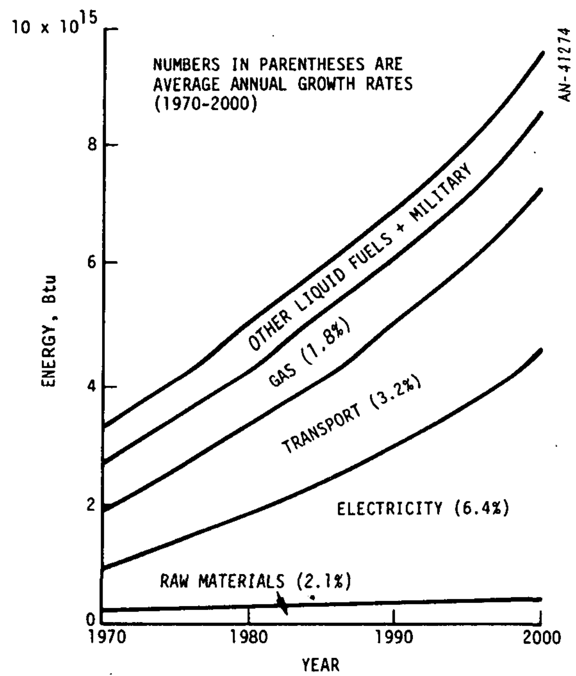


Figure 3.2. Energy Demand by end uses, Southern California (SRI)

Figure 3.2 shows, for the same region, SRI's estimates of how the energy demand will appear in terms of end uses with corresponding average annual growth rates for the period 1970 to 2000. "Gas" in this context is meant to represent the end use of gas for residential, commercial, and industrial uses. Transport demand represents mostly trucks, autos, and aircraft and is expected to grow moderately. Demand for energy to generate electricity is expected to grow rapidly through the year 2000.

Comparing Figs. 3.1 and 3.2, we note that the demand for energy to generate electricity everywhere exceeds the available nuclear supply. Furthermore, end uses of gas (present policy is to accord first priority to residential needs) will leave little gas available for fueling power plants. Thus, the energy demand for power generation will require significant amounts of oil in addition to the contribution of the coal fired plants.

Figure 3.3 presents SRI's estimates of how the annual electrical energy supply (in KWH electrical) will be consumed by major customer classes; industrial, commercial, and residential. All three classes are expected to grow at nearly equal rates (6.1 percent through 1985 and 4.7 percent thereafter) and represent nearly equal fractions of the total consumption.*

Comparing SRI's year 2000 forecast for California (Fig. 3.3 is for Southern California only) with the Rand forecast, we find that the SRI estimate for electric energy production is $651. \times 10^9$ KWH in the year 2000 while the Rand estimate for their base case is 747×10^9 KWH in the year 2000. However, the Rand calculation assumes a population for California at that time of 33.54×10^6, while SRI has estimated 27.525×10^6. If we scale the Rand electric energy production estimate by the population

*The Rand report estimates electrical demand annual growth rates for all of California over the period of 1970 to 2000 of: industrial 4.0 percent, commercial 7.5 percent, and residential 4.4 percent for their base case conditions.

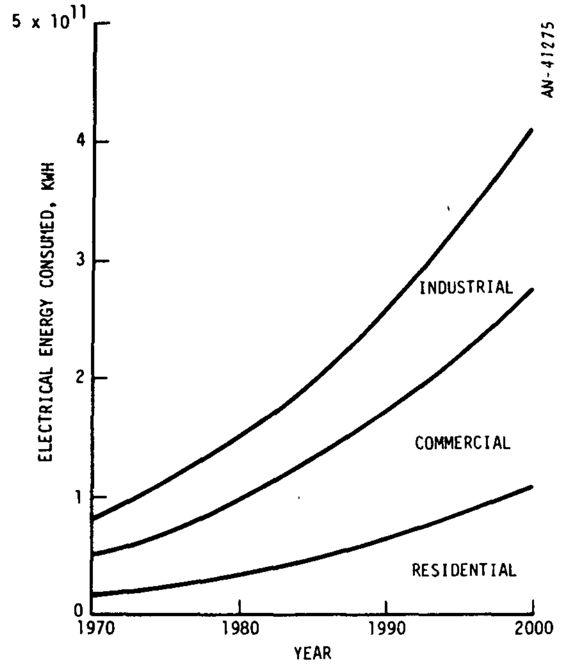


Figure 3.3. Electrical Energy Consumption, Southern California by Users (SRI)

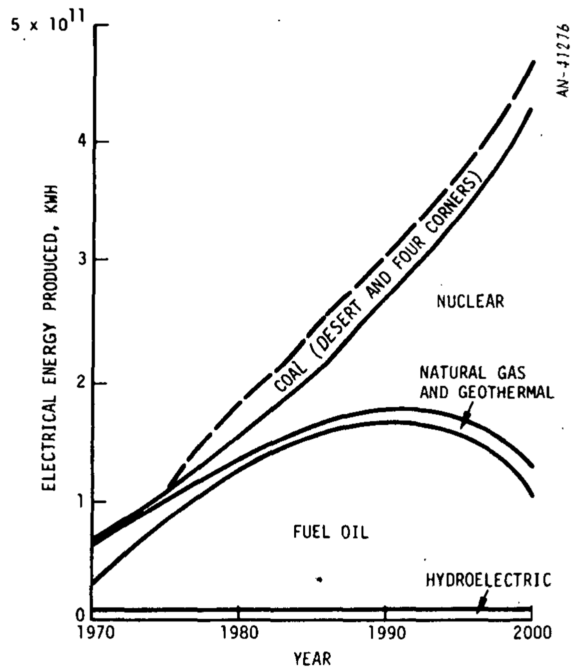


Figure 3.4. Electrical Energy Production, Southern California by Energy Sources (SRI)

ratio (27.5/33.5), the Rand value would be 612×10^9 KWH or within 7 percent of the SRI value. Under varying assumptions of lower growth rates and increased electricity prices, Rand forecasted considerable reductions in electric power demand relative to their base case. However, the Rand study assumed that feasible alternative energy sources could be utilized at lower cost than would be entailed under increased electricity prices. The present situation is one where prices of other basic energy sources are rapidly increasing. Thus, substitutions of sources as envisioned by Rand may not materialize as readily.

Figure 3.4 depicts how the annual electrical energy consumption is to be met in terms of the primary energy sources fueling the power plants. The contributions of each primary energy source have been calculated with due consideration of the varying efficiencies attendant to the various conversion processes and the likelihood that the sources will be either base loaded or peak loaded. These SRI estimates dealt strictly with energy production that occurs within Southern California to which we have added the expected amount to be derived from the coal fired plants. Thus, the total production shown is more than the consumption (Fig. 3.3); however, the Southern California region has in the past been the beneficiary of excess power capability from Northern California and the Bonneville Power Administration which they expect to repay in the future which may account for the excess production. It should also be noted that hydro-electric, gas, and geothermal sources are not expected to figure significantly in year 2000 power sources.

3.2 ELECTRICAL ENERGY AND POWER IN THE SOUTH COAST AIR BASIN

Figure 3.5 presents a comparison of electircal energy consumption forecasts between the sum of SCE[11] and LADWP[13] and the SRI Southern California total less a constant percentage fraction representing San Diego Gas and Electric and the Imperial Irrigation District. As noted on the figure, we estimate that the South Coast Air Basin represents about 95 percent of the aggregate service area of SCE, LADWP, and G/P/B.

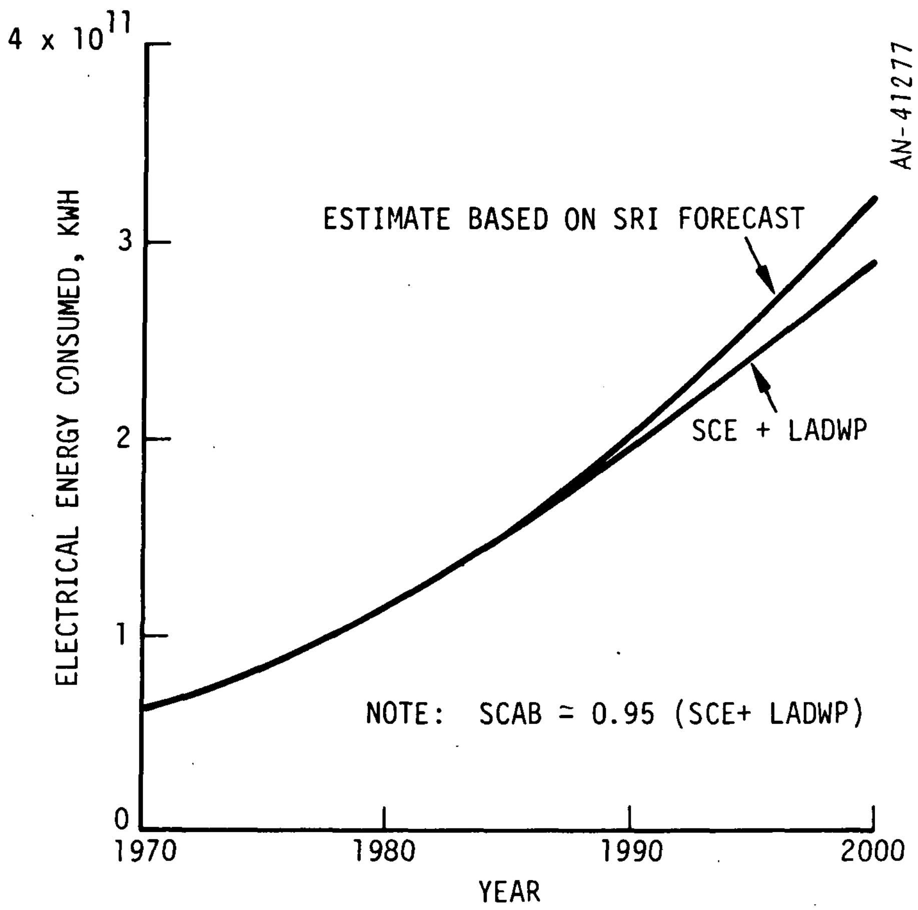


Figure 3.5. SCE and LADWP Electrical Energy Consumption

The SCE forecast is based on a population growth represented by Series E fertility and a steady net migration of 100,000 to the State of California in 1980 and thereafter. SRI's forecast assumes an average annual Statewide growth of 250,000 people per year which in effect produces very nearly the same population forecast as Series E fertility and 100,000 net migration. The LADWP did not state the underlying assumptions of their population forecasts, but since their service area is primarily the incorporated limits of the City of Los Angeles, there is little expectation of any radical growth patterns developing. Figure 3.5 indicates fair agreement between SRI and Utility forecasts; consequently, the Southern California overview of energy supply and demand presented in the few previous figures fairly depicts the situation we may expect for the South Coast Air Basin (recall that the South Coast Air Basin represents close to 70 percent of the SRI Southern California region).

The growth in per capita electrical demand (in annual KWH per person) imputed by dividing for each year overall consumption by population was calculated from the SRI, SCE and Rand forecasts and compared as shown in Fig. 3.6.

Figure 3.7 presents the forecast of peak demand in MW as determined from the forecasts of SCE, LADWP and an allowance estimated for G/P/B. Also shown is an estimate based on the SRI Southern California forecast which is in good agreement with the utility forecasts. The curves indicate a five-fold increase in peak demand between 1970 and 2000.

Because the fundamental assumption for population growth for this study is based on a Series E fertility and no net migration to or from the South Coast Air Basin, the energy consumption curve of Fig. 3.5 and the peak demand curve of Fig. 3.7 have been rescaled to reflect these study assumptions. The results are depicted in Figs. 3.8 and 3.9 for electrical energy consumption and peak demand respectively. Also, the factor of 95 percent representing the fraction of SCE, LADWP and G/P/B service area

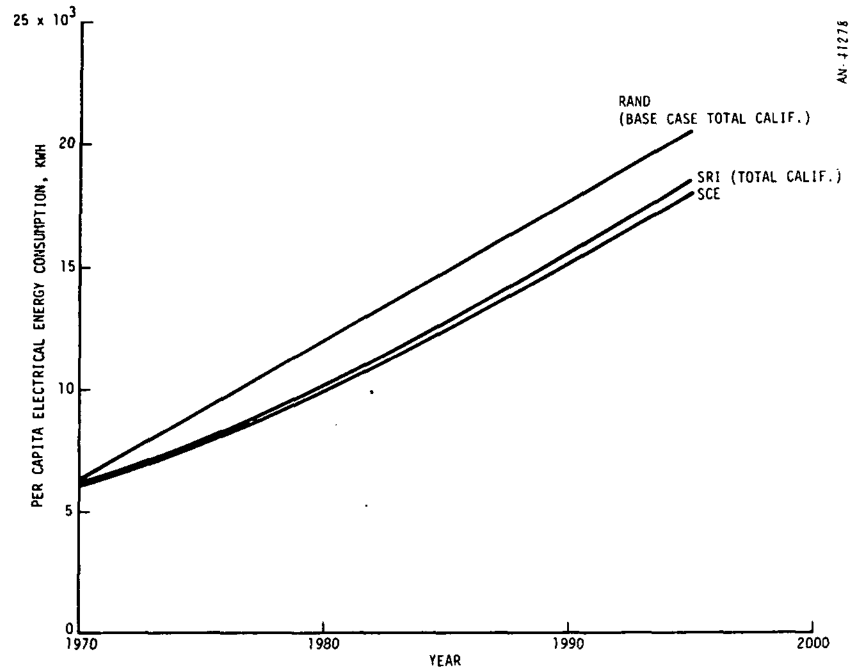


Figure 3.6. Per Capita Consumption of Electrical Energy SRI Total California and SCE

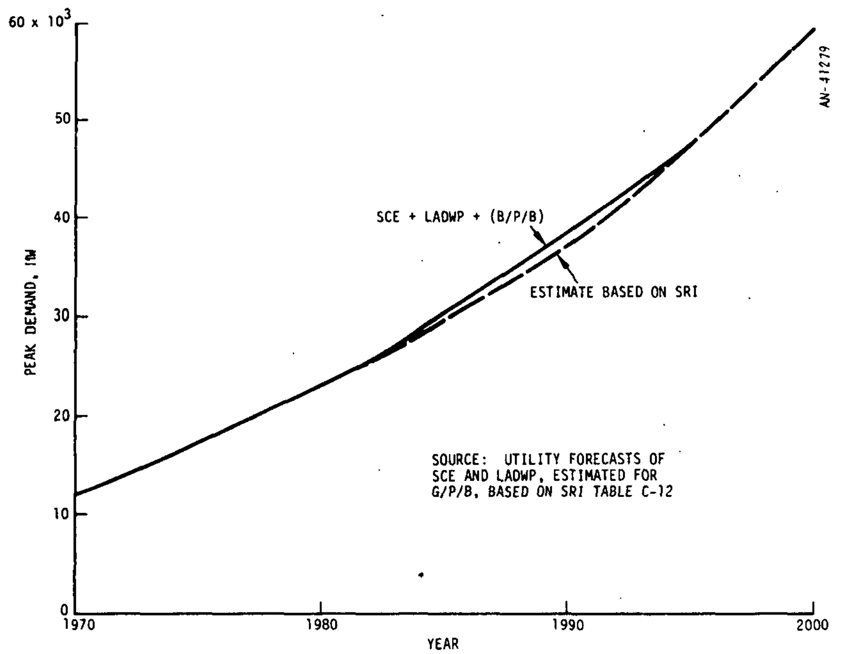


Figure 3.7. Peak Demand, MW, SCE and LADWP and (G/P/B)

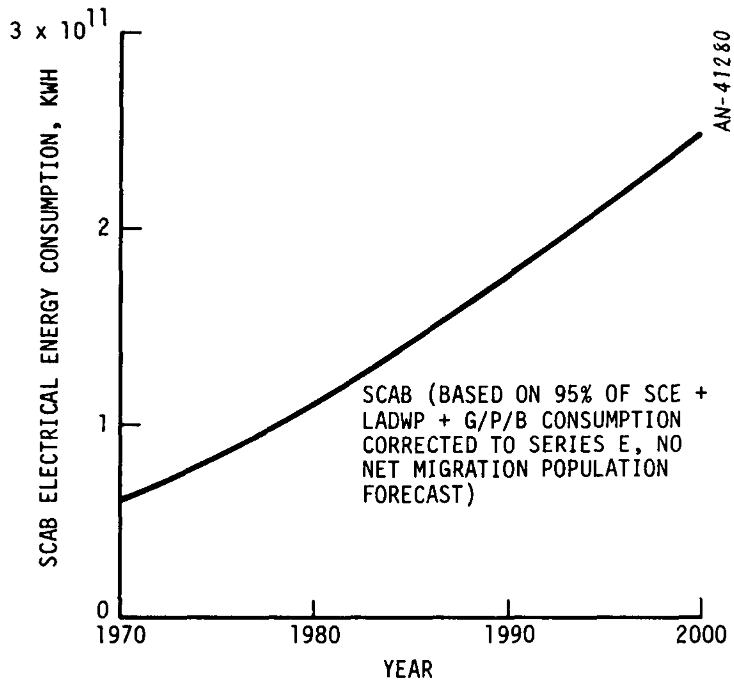


Figure 3.8. Forecast Energy Consumption in the South Coast Air Basin

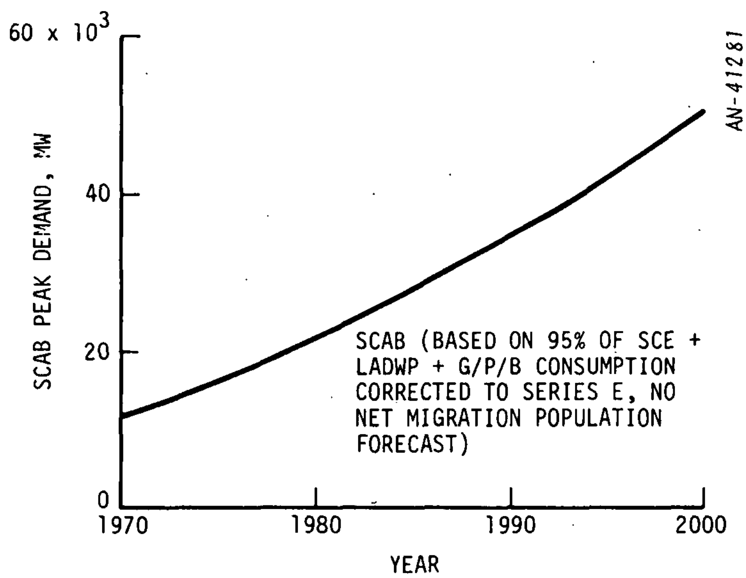


Figure 3.9. Forecast Peak Demand in the South Coast Air Basin

within the South Coast Air Basin has been included. The net result is to decrease the values of each curve by about 15 percent in the year 2000 with lesser changes in the intervening years.

3.2.1 Forecast Power Capabilities for South Coast Air Basin

The necessary increases in power generation facilities have been carefully planned by the utilities out to the next ten years. This planning data for SCE and LADWP have been combined (with the assumption that the existing generation capabilities of G/P/B remain constant) to develop an estimate of the expected sources of power generation for the next ten years. The results of this exercise are shown in Fig. 3.10 (not corrected to SCAB growth). Also shown is the forecast peak demand of Fig. 3.7 multiplied by 1.23* to allow for reserve capacity. As previously noted, nuclear power does not figure significantly in the near term sources. There is some expansion in coal fired sources representing the phasing of additional generating units as they become available at the existing remote sites. The growth in hydro-electric capability represents mostly the addition of pumped storage facilities and capabilities due to integration of facilities with the State Water Project. The remaining major fraction of generation capability is represented by facilities fired by oil (or gas when it is available). The category "Other" represents primarily firm purchase from northern sources.

Beyond the next ten years we have relied upon the SRI forecasts for Southern California generation capability. These estimates have been coupled with the utility planning data to derive a composite forecast for generation capability of the SCE, LADWP, and G/P/B service area (not corrected to SCAB growth) to the year 2000 as shown in Fig. 3.11. Again, we have bounded the total capacity requirement by scaling the peak demand of Fig. 3.7 by a factor of 1.23. By the year 2000, nuclear energy is

---

*SRI[4] assumes that power generation facilities will run with a reserve capacity of 18.6 percent. This factor gives good agreement with the Rand model which scales capacity from electric energy consumption assuming 30 percent for maintenance, outage, and contingency.

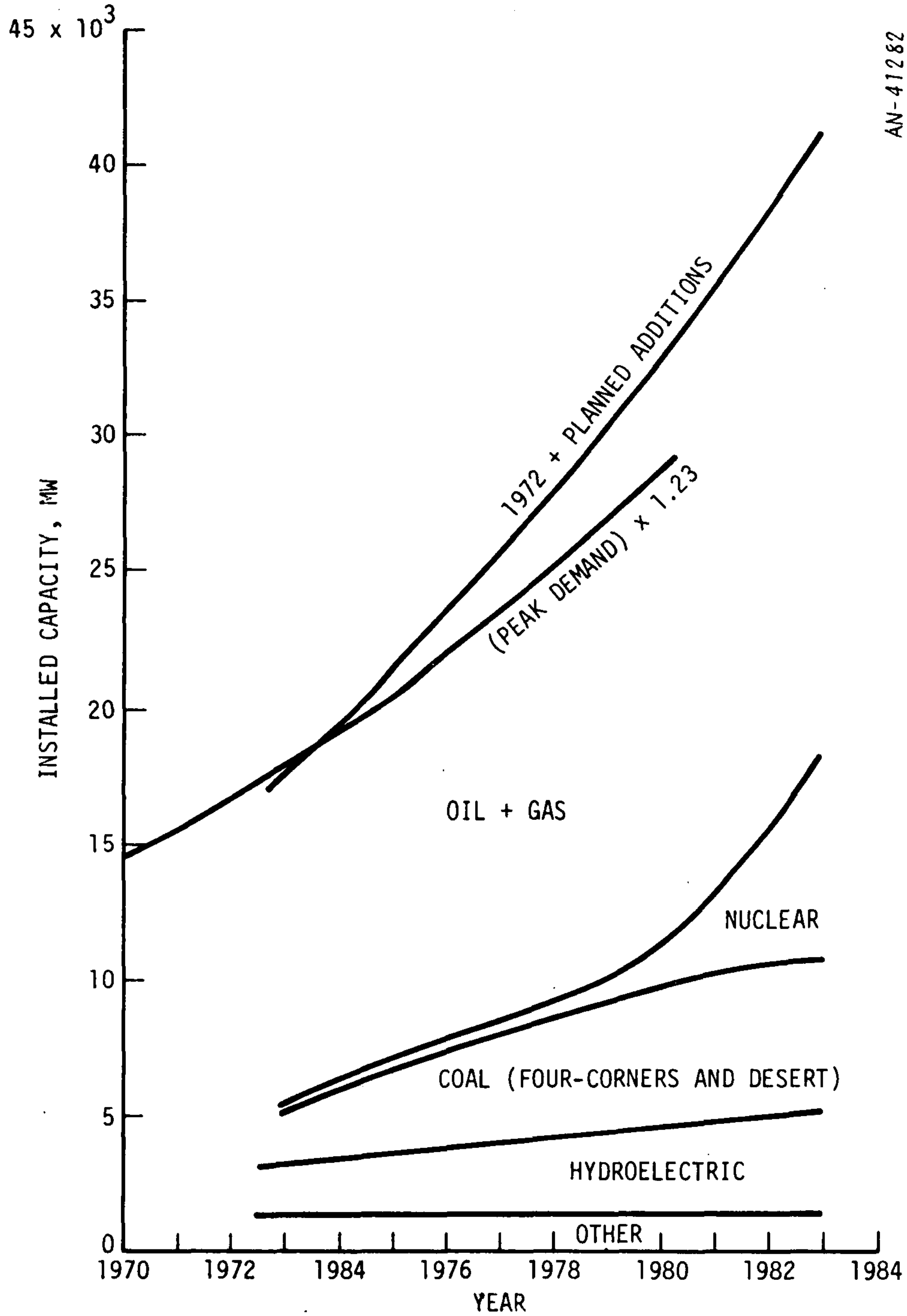


Figure 3.10. Power Capability, SCE Plus LADWP and (Glendale/Burbank/Pasadena)

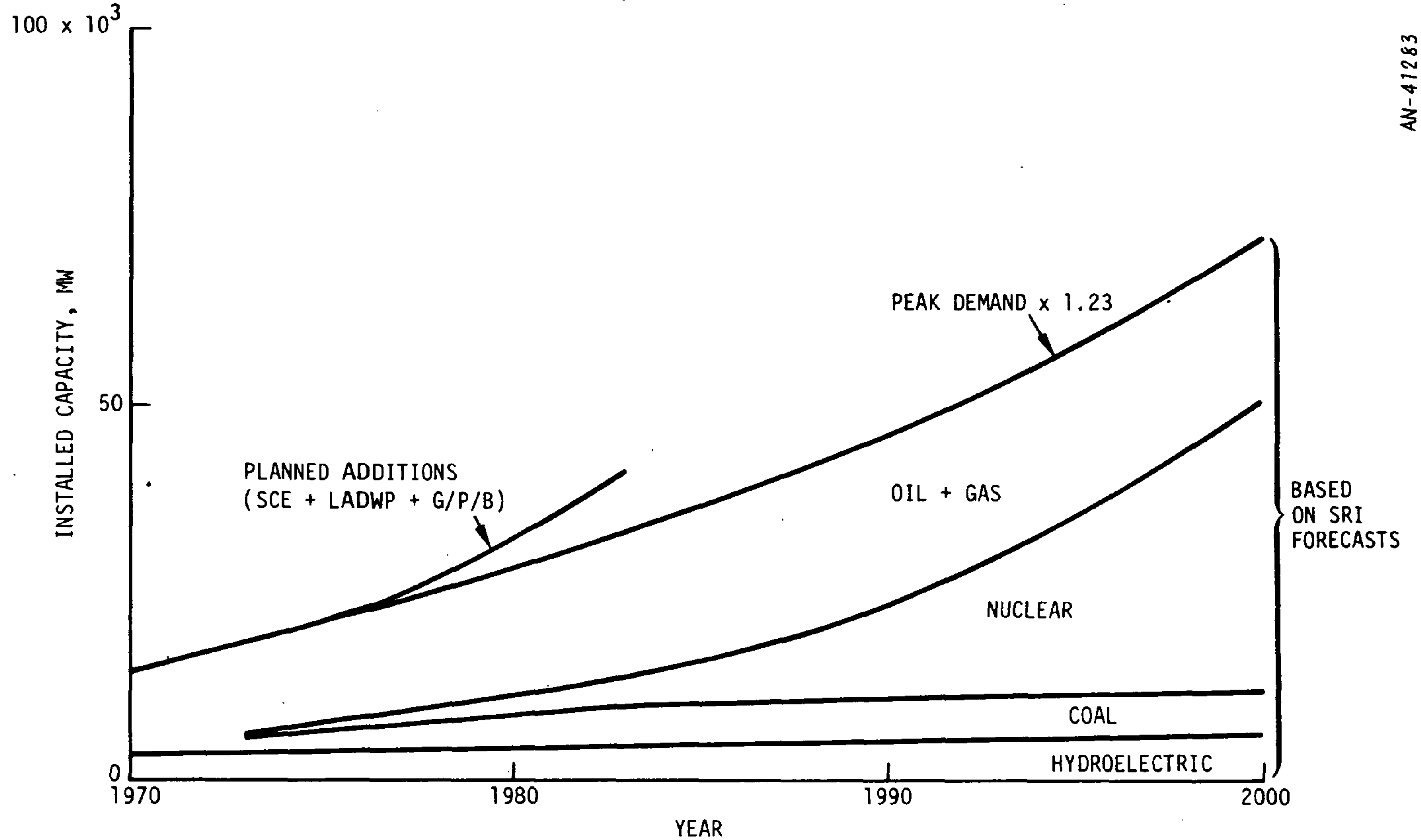


Figure 3.11. Power Capability, SCE Plus LADWP and (Glendale/Burbank/Pasadena)

expected to provide the major fraction of electrical generation capacity. In terms of electrical energy production (annual KWH) nuclear sources will be even more significant since they are expected to be base loaded. Because of the uncertainty in future gas supplies and the consumer priorities accorded them, gas is not expected to be a significant fuel source. Thus oil fired plants continue as significant power sources throughout the forecast period.

The implied expansion in fossil fueled generation capacity in the Air Basin involves no new power plant sites. Instead the new capacity is to be derived by either providing additional generating units at existing sites or by retrofitting existing plants with combined cycle capability.

As is apparent in Fig. 3.11, the planned additions based on the SCE and LADWP planning studies produce a faster expansion than may be necessary when compared to the scaled (× 1.23) peak demand forecast. We would assume that the difference may be accounted for in allowances for schedule shippage plus the fact that there is likely to be a buildup in the utilization of new plant after it first comes on line. Also, overall transmission losses may increase slightly due to increased utilization of the remote coal fired plants.

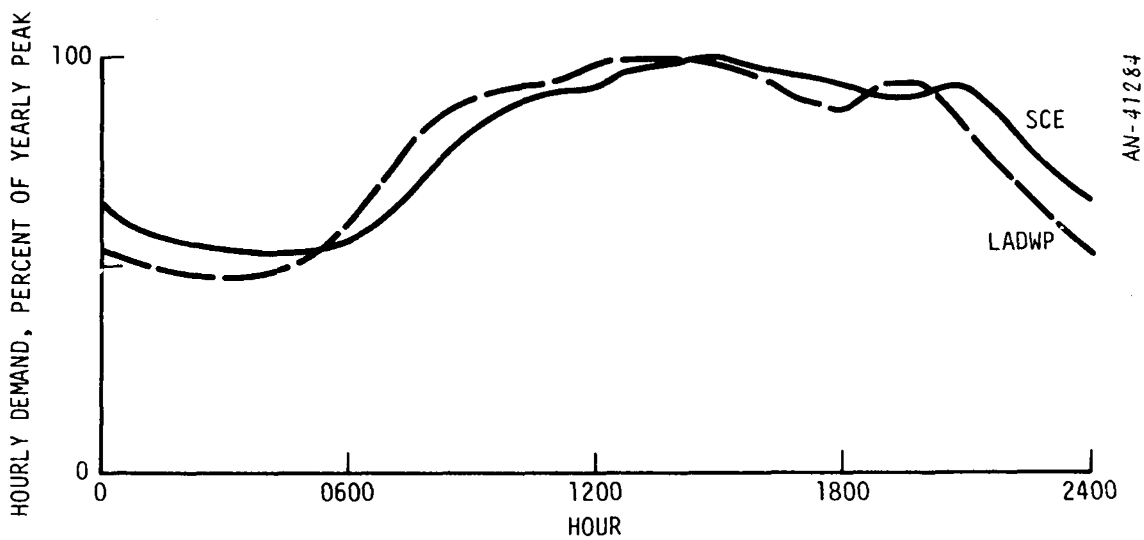
3.2.2 Hourly Power Demand Profiles

Of significant importance to the feasibility of electric car use and its ultimate public acceptance is the ease or difficulty with which it can be re-energized. A battery powered vehicle will have to be recharged daily and it is anticipated that one feasible recharge routine would rely on the potential power availability during the typical early morning off-peak hours. Depending on the amount of ordinarily unused off-peak energy available for a given level of electric car use, there may or may not exist a requirement for additional power generation facilities. The capability to readily use this potential off-peak energy depends further on details of the electric power service for individual households.

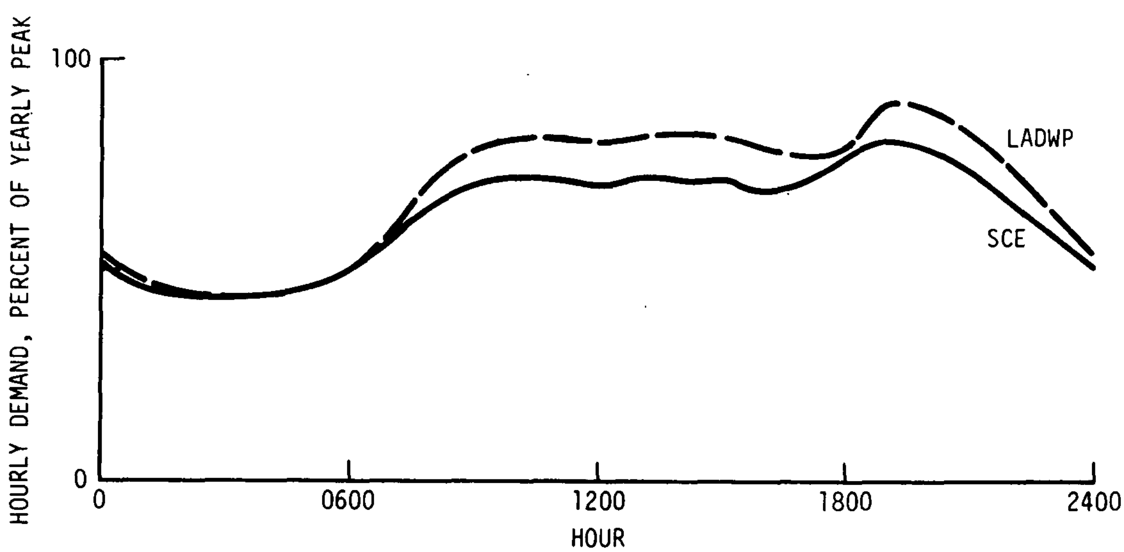
To determine the likely potential for available off-peak power for the purposes of electric car re-charge, we first examined the typical hourly demand profiles experienced by SCE and LADWP. Figure 3.12a presents the power demands by hour of the day in terms of the percent of the yearly peak demand which occurs typically sometime in August. Figure 3.12a is the peak demand case for August while Fig. 3.12b depicts the case for April, a typical off-peak month. The hourly demand profiles for SCE and LADWP compare favorably and we have arbitrarily chosen the SCE profile for the month of August as representative of the situation to be expected in the future. (Utility planning detail is insufficient to allow one to deduce likely shifts in future hourly demand profiles.)

The SCE peak month profile of hourly demand (Fig. 3.12a) has been scaled by the forecast peak demand for SCAB (Fig. 3.9) for the selected years 1980, 1990, and 2000. For each of these years we have also scaled the projected power capability curves of Fig. 3.11 to show how this hourly demand will be met. The results are shown in Figs. 3.13(a-c) for the three years 1980, 1990, and 2000, respectively. In each case, we sought to determine which of the available power sources would provide the base loads (used continuously with allowances only for maintenance and contingencies) and which would be associated with the peak loads. We also show in Fig. 3.13 hourly profiles for an average Monday and an average Saturday for an off-peak month, May, as experienced by LADWP.

Nuclear power generation is economically most efficient when utilized for base loads and present utility planning is based on that criterion. Although in the past many hydro-electric plants were economically justified on the basis of meeting peak needs, it does represent a clean energy source and under present constraints will probably

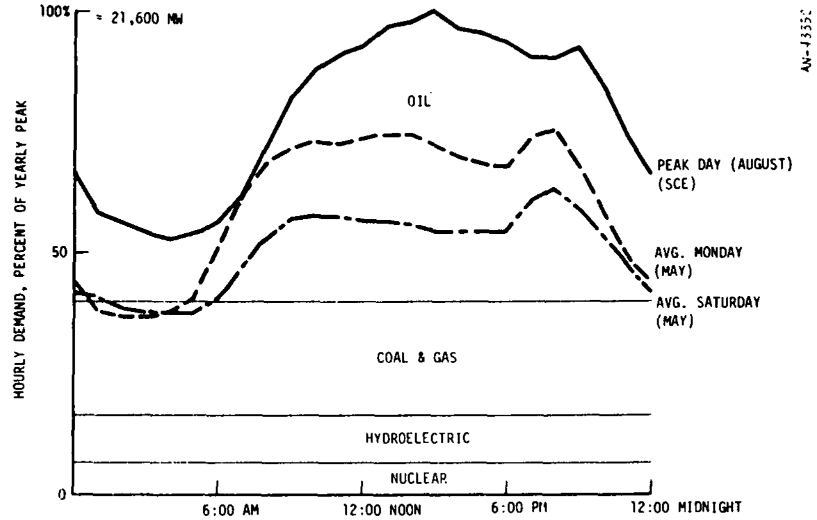


a. Peak Day in Peak Month

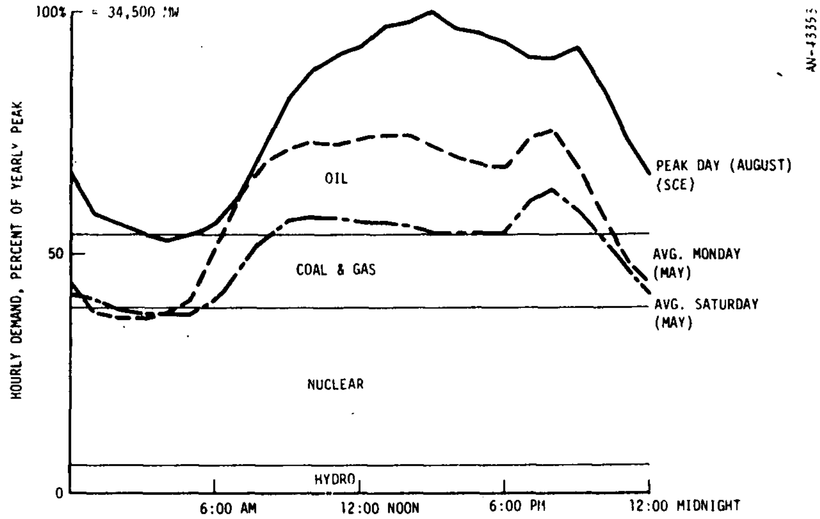


b. Typical Day in Off-Peak Month

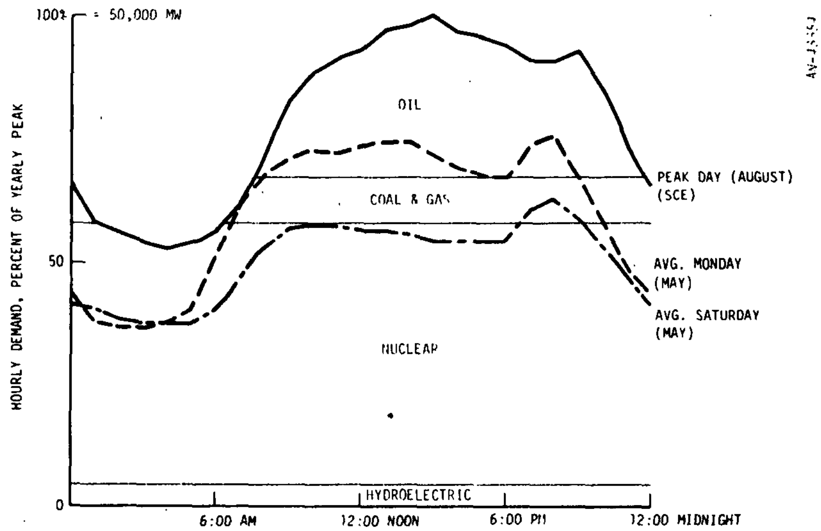
Figure 3.12. Hourly Demand, 1973



a) 1980



b) 1990



c) 2000

Figure 3.13. Profile of Hourly Demands with Projected Supply, South Coast Air Basin

be used for other than just peak loading.* Gas, as one of our cleanest sources, will be used as available. Coal, which in our case represents power stations in Nevada and the Four Corners, will likely be preferred to oil burning in the Air Basin provided the coal stations can meet the air quality standards of their respective states. All oil burning represents the fueling of power plants within the Air Basin and it seems likely that in meeting air quality standards the burning of oil would be minimized. Furthermore, oil will be the most expensive energy source.

This general assessment is corroborated in a recent paper[14] by Eugene N. Cramer of SCE wherein he indicated that newer fossil fueled and nuclear plants will be base loaded with older fossil fueled plants next to be brought on line with gas turbine operations last to be used in meeting peak demands. For the Los Angeles region, newer fossil fueled plants are really represented by the coal plants in the desert and at the Four-Corners region of the Southwest. Older fossil fueled plants are primarily those in the Los Angeles Basin.

Although in the very near term, prior to 1980, there may be some problems with sufficient supplies of low sulfur oils, we have previously noted that by 1980 de-sulfurized fuel oils should be available.

Overall generation efficiency for plants in the South Coast Air Basin is expected to remain constant at around 36 percent to 1983. Detailed planning data for Southern California Edison[12] indicates that approximately 1669 megawatts of combined cycle capacity will be installed by that time. Although the combined cycle capability is expected to

---

*It is difficult to accurately estimate just how much hydro-electric generation will be allocated to peak demands. Total hydro capacity includes power dams in the Sierra Nevada mountains, with variable water conditions throughout the year, and pumped storage capabilities as part of the State water project. The depiction of constant generation throughout the day may be over simplified, but because of the minor contribution of hydro in the future this simplification does not unduly impact the analysis.

operate at generally higher efficiencies, there will not be enough of it to significantly change the overall efficiency for SCE's operation. Beyond 1983, our baseline forecast shows little change in the generating capacity of fossil fuel plant (depicted by oil, gas and coal in Fig. 3.11) with most of the projected increase in demand to be served by nuclear power plants. Thus, except for modernizing and adding combined cycle capacity to older plant, we expect little change in the overall generating efficiency of fossil fuel plants out to the year 2000. Furthermore, since combined cycle efficiency will be better than conventional steam plants and fossil fuel costs will be a significant factor in overall generating costs, we would expect combined cycle plants to be brought on-line in serving peak demands before conventional steam plants. The last component of generating capacity to be used in peak demands will be isolated gas turbines and other internal combustion powered generators owing to their poorer thermal efficiencies.

Figures 3.13(a-c) indicate that oil will most likely be used to satisfy peak demands except for low demand days in low demand seasons (e.g., a typical Saturday in May). If the available capacity during normal off-peak periods is to be used to recharge electric cars, the sources to be used at any given time will vary between low and high demand seasons and with the changing proportions in the mix of sources over the forecast period. In 1980 additional off-peak generation for recharging electric cars will come from oil-fired plants throughout most of the entire year. By 1990 substantial off-peak generation can come from coal- and gas-fired plants during low demand seasons, but during the peak seasons, off-peak generation will come largely from oil-fired plants. By the year 2000, there will be sufficient nuclear capacity such that it can provide additional off-peak generation during low demand seasons and a very slight amount in the peak season. Otherwise substantial off-peak generation in the peak season will be met first with coal and gas and finally oil if needed.

The advent of significant electric car usage utilizing the early morning periods for recharge may virtually eliminate the distinction between peak and off-peak demands. Such a condition could conceivably alter utility planning considerations with respect to how and when individual power plants are used. A less pronounced off-peak period could economically justify a greater utilization of nuclear plants. Since the forecast nuclear capacity is already planned to be base loaded additional nuclear plants would have to be constructed. This, in turn, would imply that presently existing technical and environmental problems be speedily resolved, significant increases occur in the requirement of capital investment rates, and a faster than normal write-off of older facilities be pursued. Although such an expansion of nuclear power, in conjunction with electric car use may significantly relieve air pollution, there would likely be attendant additional dollar costs due to the greater rate of expansion of capital costs.

4 AVAILABILITY OF ELECTRIC POWER AND ENERGY FOR ELECTRIC CARS

The total additional potential energy production per day, due to utilizing off-peak capacity, will depend on many factors such as required downtime for routine maintenance and reserve for repairs. Presently, the utilities recognize August as the month of greatest demands and they tend to schedule maintenance periods around the peak demand month. For example, SCE estimates that, for adverse water conditions, the margin of available capacity over peak demand (month of August) may be as low as 13 percent.

We have made calculations based on the Figs. 3.13(a-c) of the potential electrical energy available during the off-peak period assuming that generation facilities could be run at 85 percent of peak demand. The results of this calculation are presented in Fig. 4.1 which shows daily off-peak kilowatt-hours that potentially could be used for electric car recharge for each year of the forecast

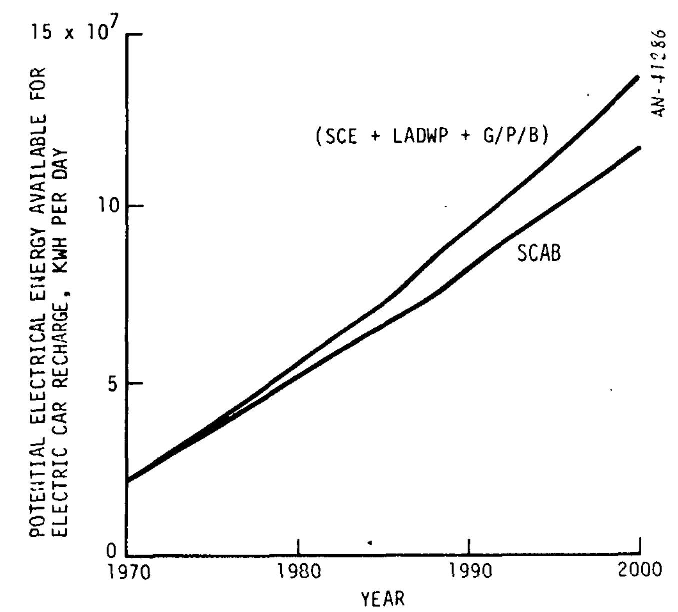


Figure 4.1. Potential Electrical Energy Available for Electric Car Recharge

period. The curve is based on the peak demand forecast scaled to the South Coast Air Basin study region (see Fig. 3.9).

The magnitude of the available off-peak energy indicated in Fig. 4.1 is quite significant. Electric cars may be expected to achieve energy consumption rates of 0.4 to 1.0 KWH (at the point of recharge) per mile of travel.[15] Thus, a 10-KWH expenditure, for example, may produce 10 to 25 miles of travel. The 1980 recharge capability from Fig. 4.1 is pproximately 50×10^6 KWH per day which could allow as many as 5×10^6 cars a 10-KWH recharge. All electric losses for recharge must of course be accounted for and our assumption of an 85 percent off-peak load may be too generous. Nonetheless, the calculation indicates that there is the recharge potential to accommodate on the order of a million or so electric cars in the Air Basin without requiring additional generation facilities.

The ability of individual householders to conveniently recharge an electric car may depend on the characteristics of the electric service provided the homes. Most modern garages of single family residences will have at least one convenience outlet on a 15-ampere, 110-volt circuit and under some circumstances may have outlets on circuits of greater capacity such as for a dryer or large power tools.* Assuming that at least 1.2 kW could be delivered over an 8-hour period from an ordinary convenience outlet, approximately 10 KWH of recharge (no allowance has been made for recharge losses) could be obtained which as we have already noted, can represent a significant daily mileage.

However, there are many apartment complexes that may have no garages at all while apartments in general have fewer garage spaces provided than apartment dwellers have cars. Of those apartments with garages, many are neither required to have nor are built with convenience outlets.

---

*Although the National Electrical Code, 1968, does not require garages of single family dwelling units to have such outlets, it does require that a special branch circuit be installed for a laundry machine, which quite often is located in the garage in the Los Angeles region.

According to data published in 1965 for the Nation as a whole by the Department of Housing and Urban Development,[16] 45 percent of homes of less than $9,000 value had garages, with corresponding percentages of 66 percent and 78 percent for homes of $15,000 and $20,000 (or greater) value, respectively. New homes constructed in that year had significantly fewer garages and a greater proportion of carports. It is probably even less likely that carports as compared to garages would have convenience outlets.

New residential construction, both nationally and in Southern California, has shifted predominantly to multi-family structures.[17,18] Garage facilities in Southern California communities for multi-family units may consist of detached car stalls or simply paved parking areas. Consequently, such new construction may have little or no built-in capability for electric car recharge and if desired, would have to be supplied on a retro-fit basis. Apartment complexes without garages or stalls may in practice preclude the utilization of electric cars unless economically feasible recharge systems could be provided on a retro-fit basis.

Although population is forecast to grow more slowly through the next several decades, the rate of formation of new households will remain at generally higher rates of growth than the population itself. According to the SCE forecast,[11] they expect to increase the number of residential customers by a factor of 1.65 between 1970 and 1995. Thus, a significant fraction of future customers will be housed in residential units yet to be built. Without the introduction of electric cars, we foresee no conditions that will necessitate a fundamental change in the building and electrical codes that would be inherently useful to electric cars.

A signicant shift to elecrric cars with routine recharging during the present off-peak period may cause utilities to readjust price schedules for various users especially with respect to peak and off-peak rates.

However, in the absence of foreseeable shifts in demand the present trend is not to alter the basic structure of the price schedules. Indeed, the SRI study believes that the fact that rate structures allow large users to pay lower average unit costs than small users is a phenomenon existing literally in every sector of our economy and consequently they foresee no marked changes in this phenomenon that are likely to occur. On the other hand, the SRI study does foresee a steady but slow rise in energy costs throughout the forecast period. Figure 4.2 presents curves showing the SRI forecast for future prices of conventional fuels for power plants in units of dollars per million Btu's assuming 3 percent per year inflation. For reference in the figure, a curve of the wellhead price of crude oil in constant 1970 dollars from the NPC study is also shown. The circled point shown for the year 1971 is the average cost of all conventional fuels sold to California generating plants.[6] Based on these forecast prices for fuels in combination with the expected costs for nuclear generated power, SRI forecast the retail prices of electrical energy in cents per KWH out to the year 2000.* Figure 4.3 presents these forecasts for residential and industrial users which are the highest and lowest prices of the large consumers respectively. Again, the 1971 average price for all users is shown by a solid dot.[6]

Since the SRI forecasts on fuel costs are not in basic disagreement with the NPC forecasts, we have chosen to use their derived electrical energy price forecasts for our baseline condition.

---

*Due to the current high prices of imported oil that electric utilities must pay to fill our their fuel requirements, the average cost of electricity in California is rising rapidly and under Public Utility Commission rules these costs can fairly easily be passed on to the customer. Should international oil prices stabilize in the future as expected by the NPC appraisal, we would expect utility rates to accurately reflect that condition as well which correspond to the estimates presented in Figs. 4.2 and 4.3.

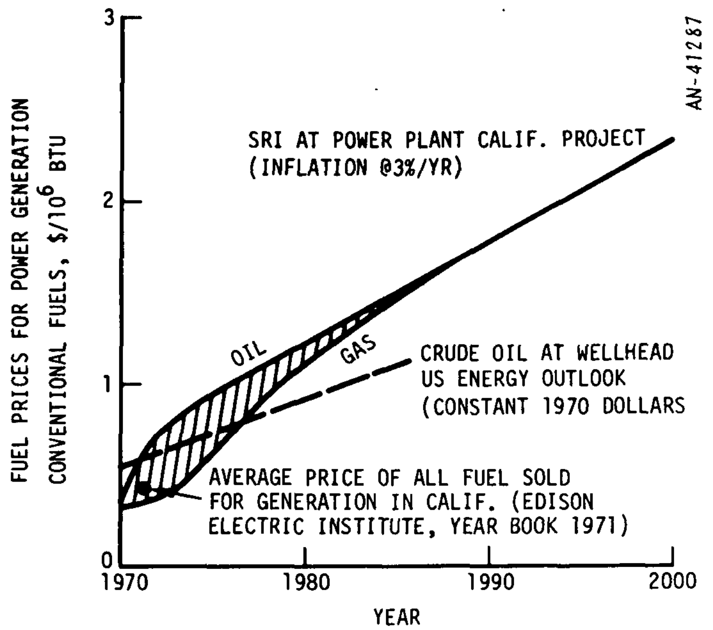


Figure 4.2. Forecast of Power Plant Fuel Prices

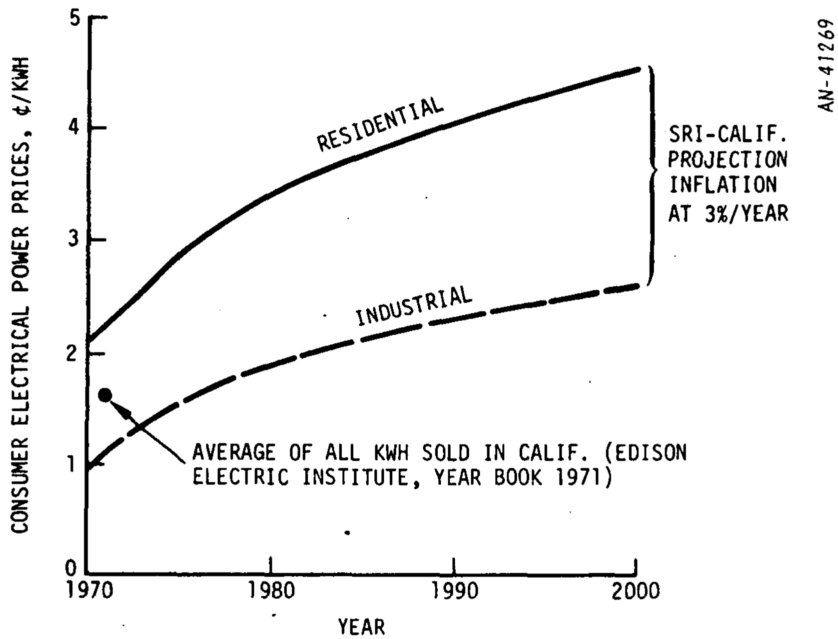


Figure 4.3. Forecast of Electrical Energy Consumer Prices

REFERENCES

1. Energy R&D and National Progress, prepared for the Interdepartmental Energy Study by the Energy Study Group under the direction of Ali Bulent Cambel, June 1964.

2. US Energy Outlook, A report of the National Petroleum Council's Committee on the US Energy Outlook, December 1972.

3. The US Energy Problem, Inter Technology Corporation, Report C 645, November 1971. (prepared for the National Science Foundation).

4. Meeting California's Energy Requirements, 1974-2000, Stanford Research Institute, May 1973.

5. California's Electricity Quandry: Estimating Future Demand, Rand, September 1972.

6. Edison Electric Institute Statistical Yearbook of the Electric Utility Industry for 1971, Edison Electric Institute, October, 1972.

7. Los Angeles Times, January 1, 1974

8. Stephen R. Boyle, The Dollar and Energy Economics of the Gaseous Diffusion Enrichment Process, General Research Corporation, IM-1784, March 1973.

9. Weekly Energy Report, Vol. 1, No. 27, August 13, 1973.

10. Study of the Future Supply of Low Sulfur Oil for Electrical Utilities, Hitman Associates Inc., February 1972.

11. System Forecasts, 1973-1995, Southern California Edison Company, February 1973.

12. Assorted Planning Documents of the Southern California Edison Company, transmitted privately to GRC, October 1, 1973.

13. Assorted Planning Documents of the Los Angeles Department of Water and Power, transmitted privately to GRC, September 14, 1973.

14. Eugene N. Cramer, Advanced Batteries and Energy Storage, proceedings of Advances in Battery Technology Symposium, Electrochemical Society, Inc., December 1, 1972.

15. The Automobile and Air Pollution: A Program for Progress, Part II, US Department of Commerce, December 1967.

16. Annual Report, 1965, US Department of Housing and Urban Development.

17. US Statistical Abstract, 1972.

18. Monthly Report of Building Permit Activity in the Cities and Counties of California, Security Pacific Bank, August, 1972 through June 1973.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-460/3-74-020-b	2.	3. RECIPIENT'S ACCESSION NO. PB 238 878/AS
4. TITLE AND SUBTITLE Impact of Future Use of Electric Cars in The Los Angeles Region: Volume II -Task Reports on Electric Car Characterization and Baseline Projections		5. REPORT DATE October 1974 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) W.F. Hamilton, J.C. Eisenhut, G.M. Houser and A.R. Sjovold		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS General Research Corp. P.O. Box 3587 Santa Barbara, California 93105		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-01-2103
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air and Waste Management Office of Mobile Source Air Pollution Control Alternative Automotive Power Systems Div. Ann Arbor, Michigan 48105		13. TYPE OF REPORT AND PERIOD COVERED Final Report 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Impacts of the use of electric cars in the Los Angeles region in 1980-2000 were projected for four-passenger subcompact electric cars using lead-acid and advanced batteries, with urban driving ranges of about 55 and 140 miles, respectively. Data from Los Angeles travel surveys shows that such cars could replace 17 to 74 percent of future Los Angeles autos with little sacrifice of urban driving. Adequate raw materials and night-time recharging power should be available for such use in the Los Angeles region. Air quality improvements due to the electric cars would be minor because conventional automobile emissions are being drastically reduced. The electric cars would save little energy overall, as compared to conventional subcompacts, but would save a considerable amount of petroleum if they were recharged from the nuclear power plants that are planned. The electric subcompacts would be 20-60% more expensive overall than conventional subcompacts until battery development significantly reduces battery depreciation costs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Electric Vehicles Air Pollution Batteries Conservation		13 B

18. DISTRIBUTION STATEMENT Release unlimited	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 358
	20. SECURITY CLASS (This page) Unclassified	22. PRICE $9.50

EPA Form 2220-1 (9-73)