EPA-460/3-74-020-a

OCTOBER 1974

IMPACT OF FUTURE USE OF ELECTRIC CARS IN THE LOS ANGELES REGION: VOLUME I - EXECUTIVE SUMMARY AND TECHNICAL REPORT

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-a

IMPACT OF FUTURE USE OF ELECTRIC CARS IN THE LOS ANGELES REGION: VOLUME I - EXECUTIVE SUMMARY AND TECHNICAL REPORT

by

W. F. Hamilton

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 Programs
Alternative 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 22161.

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. Aproval 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-a

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.

CONTENTS

CONTENTS (Cont.)

ILLUSTRATIONS

ILLUSTRATIONS (Cont.)

TABLES

TABLES (Cont.)

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.

1 EXECUTIVE SUMMARY

The scope of this study was limited to battery-electric cars in the years 1980-2000. The study's focus was on California's South Coast Air Basin, an area of some 10,000 square miles (25,000 square kilometers) bounded by mountains and ocean; this area includes greater Los Angeles and had 1970 populations of 10 million people and over 5 million cars. The study's emphasis was on environmental, energy, and socioeconomic impacts of electric car use rather than on vehicle technology and design.

As a starting point for impact calculation, future electric cars were briefly characterized. Four representative battery technologies were considered, with the basic capabilities shown in Fig. 1.1. Lead-acid battery characteristics were projected from those of high-performance electric vehicle batteries which have already been tested in electric cars. Characteristics of advanced batteries were taken from achievements and goals of development programs at Gould, Inc., Energy Development Associates, Inc., and Argonne National Laboratory.

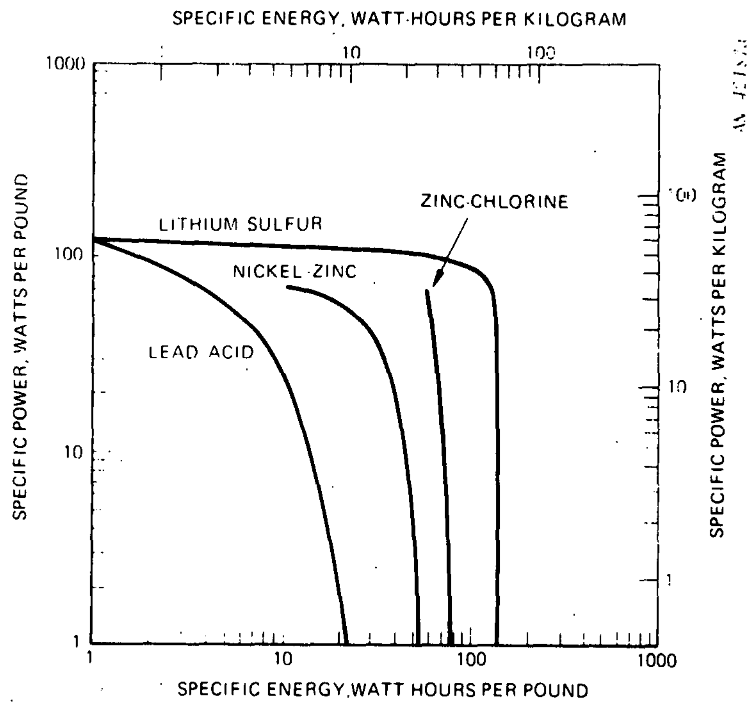


Figure 1.1. Assumed Battery Capabilities

A computer program was developed to model battery discharge according to Fig. 1.1 while meeting power requirements of electric cars for urban driving. The SAE Metropolitan Area Driving Cycle for electric cars was used in this program; it calls for a stop each mile (1.6 km), an average speed of 24 mph (39 km/hr), and an energy requirement per mile very near that of the US Federal driving cycle used in official measurement of auto exhaust emissions and fuel economy.

After a parametric analysis, the specific car ranges of Table 1.1 were selected for the impact analysis. The electric cars were efficient four-passenger subcompacts with performance slightly below that of current low-performance conventional subcompacts; they were capable of accelerating from 0 to 40 mph (65 km/hr) in 10 seconds, and of cruising on a freeway at 60 mph (100 km/hr). At a constant 30 mph on a level road, car ranges would be over twice those shown for urban driving; in hilly terrain or near the end of battery life, however, they could be significantly less than in Table 1.1.

TABLE 1.1

CHARACTERISTICS OF ELECTRIC CARS

(For Urban Use)

Availability, Year	1978	1980	1985	1990
Battery Type	lead-acid	nickel-zinc	zinc-chlorine	lithium-sulfur
Test Weight, lb (with 450 lb payload)	3,975	3,530	2,950	2,655
kg	1,803	1,602	1,338	1,204
Urban Driving Range, mi	54	144	145	139
km	87	232	233	224
Recharge Energy Requirement, kW·hr/mi	0.79	0.51	0.41	0.45
kW·hr/km	0.49	0.32	0.25	0.28
Cost (less battery), 1973 dollars	2,977	2,945	2,891	2,795

Characteristics of batteries used in the electric cars are shown in Table 1.2. The lifetimes shown assume urban driving of about 30 mi/day (48 km/day). For the lead-acid battery, the projected range of lifetimes is based on current experience; the longer life projection is optimistic. For the nickel-zinc and zinc-chlorine batteries, the indicated lifetimes assume that developers' goals for lifetimes of 400 and 500 deep discharges, respectively, will be achieved, and that life with partial discharges will be increased in inverse proportion to discharge depth. For the lithium-sulfur battery, which must be maintained at a very high temperature, the indicated lifetime range is assumed to be independent of use. Cost and life characteristics for the zinc-chlorine and lithium-sulfur batteries are relatively uncertain, and the figures in Table 1.2 are quite optimistic.

The electric car ranges of Table 1.1 were selected after a new analysis of Los Angeles travel data which had been collected in an extensive 1967 survey. Figure 1.2 shows the resultant distribution of driving distances on the survey day for drivers with cars exclusively available to them. Most present Los Angeles drivers and virtually all future Los Angeles drivers fall in this category. The distribution of Fig. 1.2 was

---

TABLE 1.2

CHARACTERISTICS OF ELECTRIC CAR BATTERIES

(For Urban Car Use)

Battery Type	lead-acid	nickel-zinc	zinc-chlorine	lithium-sulfur
Weight, lb	1,500	1,090	570	300
kg	681	495	259	136
Energy Density, W·hr/lb	13	44	70	126
W·hr/kg	27.8	96	157	276
Energy Efficiency, Percent	46	66	70	62
Life, Years	1.3-3.4	5.8	7.3	3-5
Cost, 1973 Dollars	1,200	2,930	600	600

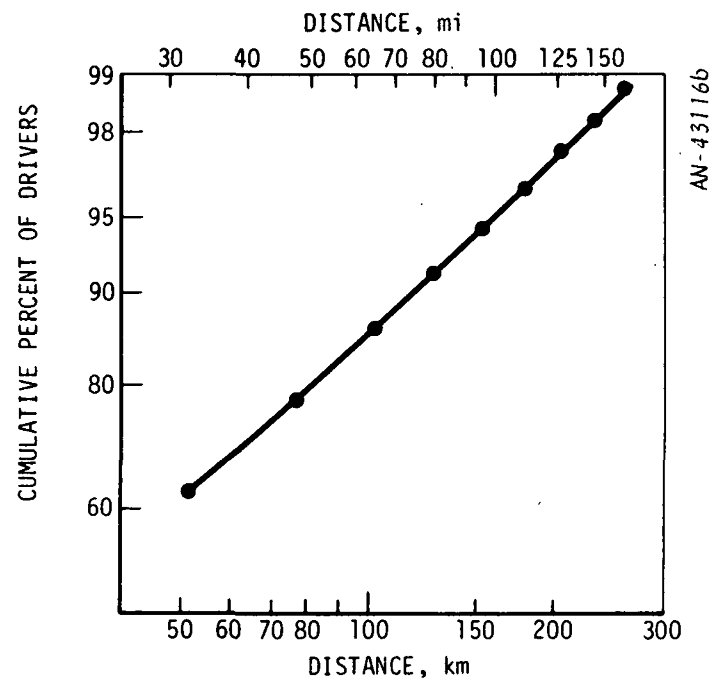


Figure 1.2. Distribution of Daily Driver Travel in the Los Angeles Area

derived from about 130,000 separate trips made by 30,000 drivers at 22,000 representative households. It shows that cars of Table 1.2 with 145-mile (230-km) range would be inadequate on only 2% of urban driving days. The car with 54-mile (87-km) range, however, would be inadequate on about 1 driving day out of 6, a frequency considered unacceptable. As a secondary car in a two-car household, however, where longer trips were accomplished by the primary car, even this car could be adequate on over 97% of driving days. Average daily car travel in Los Angeles is no greater than the national average, which has been growing quite slowly since the 1930s, and little future change is expected. The average in Fig. 1.2, 28.5 mi (45 km), is projected to increase only 6% by the year 2000.

Simple overnight recharging, rather than a system of battery exchange and recharge stations, was assumed. Overnight recharging would be easiest arranged at single-family houses with off-street parking. There will be about one million such households in Los Angeles in 1980 having at least one secondary car. Thus, as shown in Table 1.3, the shorter-range electric car would be applicable to the functions of one million cars in 1980, or 17% of all cars in the Air Basin; but these secondary cars would be driven less than the average car and would account for a smaller proportion of area travel. The longer-range electric cars could generally replace automobiles where overnight recharge facilities will be available. In 1990, 3.1 million automobiles in the Air Basin are expected to be parked off-street at single-family houses, where recharging would be most easily arranged. In 2000, recharge facilities might be available at all of the 5.6 million off-street parking places projected at Los Angeles residences. These are the bases for the corresponding applicability projections in Table 1.3.

Provision of certain battery materials for the numbers of cars indicated in Table 1.3 could perturb US metals markets. The nickel required for extensive regional use of nickel-zinc battery cars would require significant increases in US nickel imports. The lithium for wide use of lithium-sulfur batteries would require a major expansion in US production facilities, but this is not a serious problem: US reserves are adequate, and current production is modest.

TABLE 1.3

APPLICABILITY OF ELECTRIC CARS IN THE SOUTH COAST AIR BASIN

	1980	1990	2000
Cars, millions	1.0	3.1	5.6
Percent of all area cars	17	46	74
Daily travel, millions of mi	18	90	169
millions of km	29	145	272
Percent of all auto travel	11	46	74

Sources of recharge energy for electric cars were investigated through projection of future electric power production and consumption in the Los Angeles area. The result, which is subject to major uncertainties, is shown in Fig. 1.3. The peak demand is anticipated on hot August afternoons, but even on the peak day, demand is expected to fall dramatically in the late evening hours in the absence of car battery recharging. About 85 million kilowatt-hours, the shaded area in Fig. 1.3, would be available during the night of the peak 1990 day--more than enough to recharge the 3.1 million electric cars of Table 1.3.

Future peak power production is expected to grow at about 4-1/2% per year per capita in Los Angeles, and most of the new capacity is expected to be nuclear. Since the use of existing oil-fired plants in the Air Basin will be more expensive and cause air pollution, Fig. 1.3 assumes that oil-fired facilities will be used primarily for meeting peak loads,

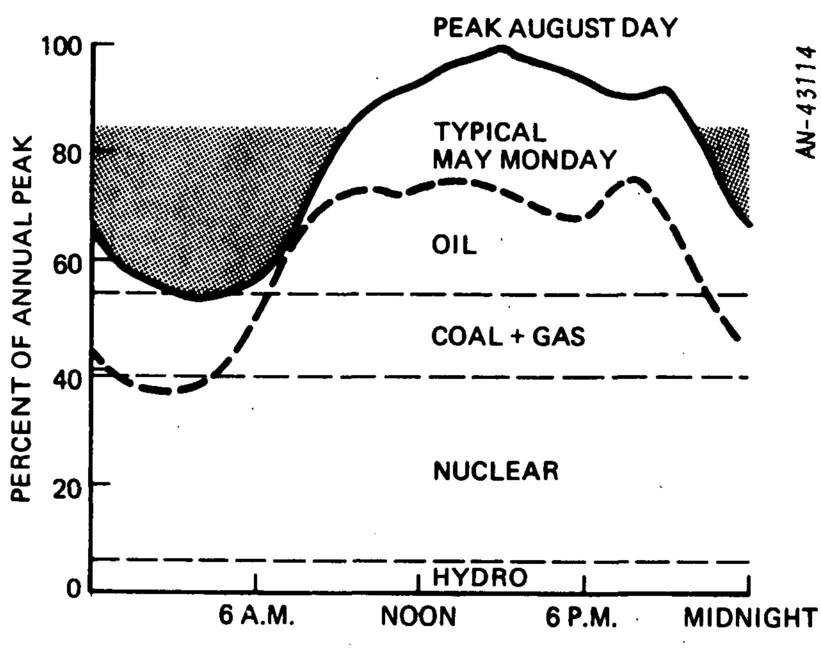


Figure 1.3. 1990 Electric Power Production and Consumption in the South Coast Air Basin

and so would be shut down in the late evening unless electric car recharging were in progress. On the peak day, petroleum would thus be the fuel for electric car travel. On low-demand days, however, such as the May Monday of Fig. 1.3, coal, gas, and nuclear fuel could provide recharge power. On an annual average basis, 46 percent usage of the efficient advanced-battery cars could enable a reduction in automotive petroleum usage of 28-35%, but only if nuclear power plants are built at the high rates planned by electric utilities serving the Los Angeles area.

The petroleum fuel consumption of the electric cars of Table 3.1 and internal-combustion-engine (ICE) cars are shown in Fig. 1.4. The thermal efficiency of electric power generation is assumed to be 36% and the efficiency of electric power transmission to be 91%, in line with utility projections for the Los Angeles region. All recharge energy is assumed in this efficiency comparison to be provided by oil-fired facilities. As the dashed line of Fig. 1.4 indicates, the fuel consumption of

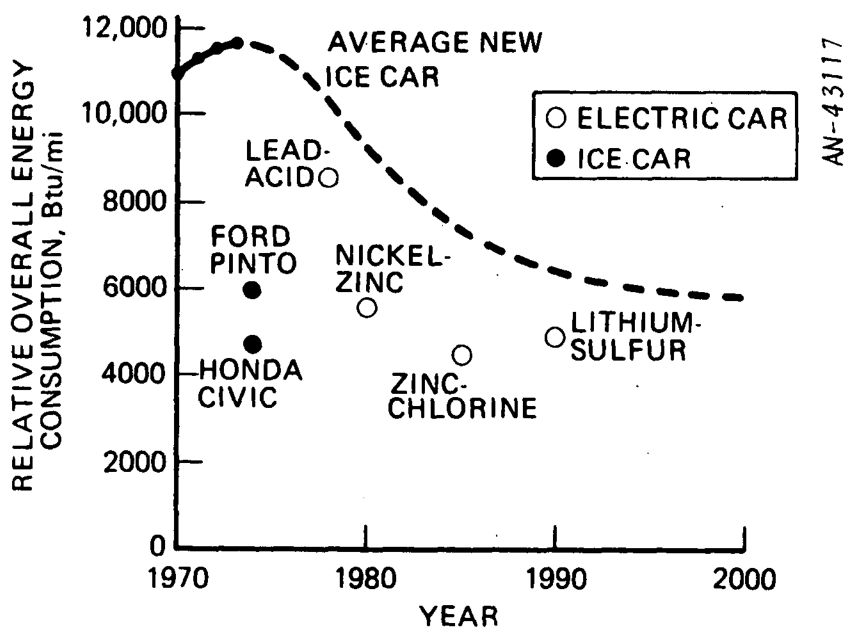


Figure 1.4. Auto Fuel Consumption

average ICE cars in Los Angeles is expected to improve by 50% in this century, in line with legislation now being considered by the Federal government. The improvement would be achieved partly through improved technology and partly through a substantial reduction in average car weight from its present level of 3,500 lb (1,600 kg). Fuel consumptions of ICE cars in Fig. 1.4 include a refinery energy penalty of 10%.

Despite the major improvement projected for the average ICE car, Fig. 1.4 shows that the electric cars promise further reductions in total energy consumption--as compared with the average ICE car. They offer little or no energy saving, however, as compared with existing ICE subcompacts of comparable size (and superior performance).

Electric cars can be nearly pollution-free. But as shown in Fig. 1.5, the 90% reductions of conventional auto exhaust emissions required by existing legislation in this decade will dramatically reduce total vehicular

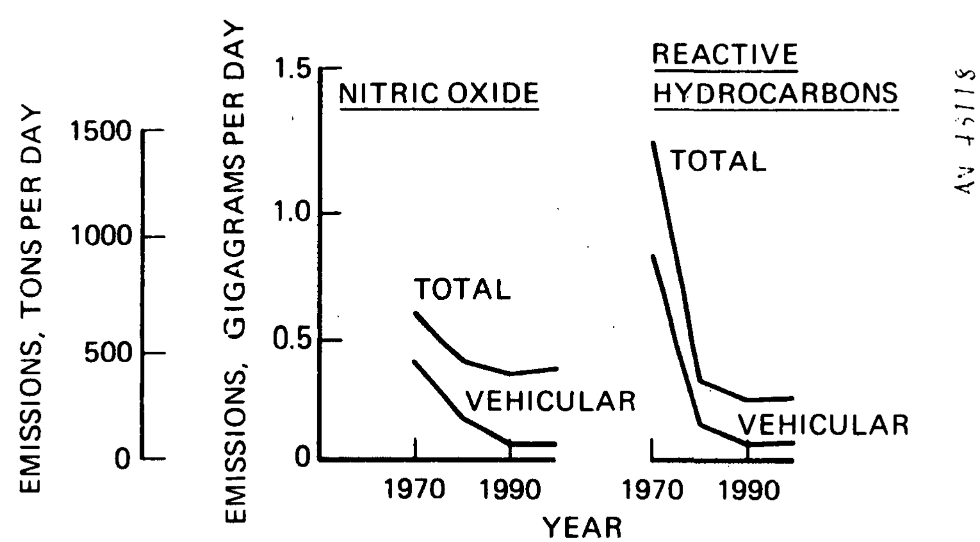


Figure 1.5. Projected Emissions of Air Pollutants Without Electric Car Use, South Coast Air Basin

emissions of air pollutants, and make cars a minor rather than major contributor to total projected emissions. Under these circumstances, air pollution will no longer be a critical problem in Los Angeles, and even extensive electric car use will have little further effect.

Table 1.4 shows worst-case air pollution projected for 1990 in relation to Federal air quality standards and 1970 measurements in Los Angeles. Concentrations of secondary pollutants (ozone and NO_2) were estimated by applying a photochemical-smog simulation to detailed forecasts of emissions. Concentrations of the other pollutants were assumed to decrease in direct proportion to the emissions. The 1990 baseline projection (no electric cars) in Table 1.4 shows major improvements in air quality, after which even very high usage of electric cars will reduce secondary pollutant concentrations relatively little, and will actually raise sulfur dioxide (SO_2) concentrations due to power plant emissions. The projected SO_2 levels assume only the use of low-sulfur fuel in power plants; if stack scrubbers were added, SO_2 levels with or without electric

TABLE 1.4

PROJECTED WORST-CASE AIR POLLUTION, SOUTH COAST AIR BASIN

Pollutant	Measure		US Standard	1970 Actual	1990 Baseline	1990 Change for 80% Electric Car Use
	Units	Period				
Ozone	pphm*	1 hr	8	62	15	-10%
NO_2	pphm	1 hr	--†	43	10	-14%
CO	ppm**	1 hr	35	54	7	-26%
SO_2	pphm	1 yr	3.0	2.6	4.1	+14%
Particulates	$\mu g/m^3$	24 hr	260	357	437	-21%

*Parts per hundred million.

**Parts per million.

†No hourly standard is established. The annual average concentration standard is 5 pphm; the 1970 actual annual average was 6.3 pphm.

cars would be well within Federal air quality standards. The impacts of electric cars shown in Table 1.4 would not be changed much by a two-year delay in imposing final auto emission standards or by relaxation of the nitrogen-oxides emission standard from 0.4 to 2 grams per mile.

The overall costs of electric car operation are projected in Table 1.5, together with costs of a conventional ICE subcompact automobile. The life of the conventional car is 100,000 mi (161,000 km) and 10 years; its initial cost is $2,270, its fuel economy is 30 mpg (0.078 liters per km), and it utilizes air pollution control devices with a significant initial and recurring cost. The electric cars are assumed to last for 12 years and 120,000 mi (193,000 km). Their higher initial costs (see Table 1.1)

TABLE 1.5

LIFE-CYCLE CAR COSTS

1973 cents per mile

	Conventional ICE Subcompact	Electric Cars			
		Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur
Depreciation					
Vehicle	2.3	2.5	2.5	2.4	2.3
Battery	0	3.5-9.2	5.1	0.8	1.2-2.0
Upkeep	2.4	1.5	1.2	1.2	1.2
Fuel	1.9	1.5	1.0	0.8	0.9
Pollution Control	0.9	0	0	0	0
Financing	1.6	2.5	3.7	2.2	2.2
Taxes, Insurance Parking, etc.	4.3	4.5	4.5	4.5	4.5
Total	13	16-22	18	12	12-13

are more than offset by longer life, lower maintenance, and reduced fuel costs. For the lead-acid and nickel-zinc battery cars, however, high battery depreciation costs make overall costs 22 to 66% higher than those of the conventional subcompact, or about equal to those of standard-size ICE cars. The much smaller depreciation costs projected for the zinc-chlorine and lithium-sulfur battery cars remain to be verified in practice.

The higher costs of the nearer-term electric cars would significantly reduce consumer income available for non-transportation expenditures. With 100% electric car use, 30,000-40,000 service station jobs would disappear, along with some 10,000-20,000 jobs in automobile service, parts, and sales businesses. The total job loss would be only partly compensated by increased employment in battery manufacturing. Overall, however, only about one percent of the regional labor force would be affected, over a period of years.

In conclusion, it appears that future electric cars could replace many Los Angeles automobiles with little sacrifice of urban mobility. Electric power facilities already planned for the Los Angeles region would be adequate for their nighttime recharge, and high levels of use in the Los Angeles region would pose problems of materials availability only in the case of nickel-zinc battery cars. Air quality improvements due to electric car use would be relatively minor in importance. Total energy saving would be modest, but potential reductions in regional automotive petroleum consumption are substantial, and could be the most important benefit of electric car use. Until battery depreciation costs are significantly reduced, electric car life-cycle costs would be high compared with ICE subcompacts.

CONCLUSIONS

1. Electric car range and performance can be adequate for substantial urban use. Even limited-range lead-acid battery cars could replace a million second cars in the Los Angeles area in 1980 (17% of all area cars) with little sacrifice in typical daily driving patterns. Electric cars utilizing advanced batteries such as nickel-zinc, zinc-chlorine, or lithium-sulfur batteries could have sufficient daily range for general urban use without serious travel restriction. Electric cars could perform the functions of 45-75% of Los Angeles cars in 1990-2000, depending on the fraction of off-street parking places equipped with electric outlets for overnight recharging.

2. Adequate electric power and material resources will be available for electric car use in Los Angeles. Available late-night capacity of electric utilities serving the Los Angeles region will be adequate for electric car recharge unless planned facilities are not constructed. No likely usage of lead-acid or zinc-chlorine battery cars in the Los Angeles region will significantly perturb US demand for key materials; demand for nickel and lithium, however, would be substantially increased by extensive regional use of nickel-zinc and lithium-sulfur battery cars.

3. Air quality benefits obtained by electric car use in the Los Angeles region are projected to be minor. By the time any significant level of electric car use could be obtained, the projected improvement in combustion-powered car emissions will have significantly reduced car emissions as a factor in overall regional air pollution. The modest reductions in regional oxidant, carbon monoxide, and particulate concentrations due to electric car use will probably be accompanied by moderate increases in sulfur dioxide concentrations re-

sulting from increased electric power plant emissions within the Los Angeles region due to electric car recharging.

4. Energy benefits of electric car use can be significant. Advancing battery technology should keep electric cars moderately more energy-efficient, where petroleum is the basic fuel, than the average ICE car; but electric cars would be little or no more efficient than ICE subcompacts which offered equal accommodations and performance. An increasing number of electric cars in Los Angeles could be recharged from coal or nuclear power, according to current facilities planning of utilities serving the region; thus by 1990 electric car use of 40% could reduce regional automotive petroleum use by 26-33% if these plans materialize.

5. Regional economic impacts of substantial electric car use would be moderate. Electric car use will entail shifts in Los Angeles regional transportation employment from automotive support, principally service stations, to battery manufacturing; but at most only about one percent of the regional labor force would be directly affected and this would be accomplished over a long time period. The life-cycle costs of lead-acid and nickel-zinc battery cars will be near those of standard-size ICE cars and significantly higher than those of ICE subcompacts; to the extent that they replace subcompacts, these electric cars will reduce consumer resources available for non-transportation expenditures. The zinc-chlorine and lithium-sulfur battery cars, however, may actually have lower life-cycle costs than ICE subcompacts if the ambitious cost and life goals of the respective battery developers are achieved.

6. The free-market level of electric car usage appears most desirable in the Los Angeles region. The principal externalities to free-market auto transactions are air quality and

energy; but air quality in Los Angeles will be little affected by choices of electric rather than ICE cars, and petroleum savings will only be large if nuclear power plants planned for Los Angeles are built, an uncertain prospect at present. Without assurance of nuclear electric power, there seems to be insufficient justification for market intervention to ensure extensive regional use of electric cars.

7. Battery technology and specifically battery depreciation costs are the principal technological determinants of electric car desirability. The energy storage capability of even the lead-acid battery is adequate for significant urban use in the Los Angeles region, and the higher energy densities of advanced batteries are ample for more general use. Higher energy densities, however, will do little to make electric cars desirable and beneficial unless they are achieved with depreciation costs considerably less than those of the lead-acid batteries. Long life and low initial cost are thus vital objectives for battery research.

8. National use of electric cars would differ in important respects from regional use in Los Angeles. Materials markets and reserves would be seriously impacted by any of the battery types considered here, since twenty times as many electric cars would be involved. Petroleum savings could be larger, however, since electric utilities nationally are far less dependent on petroleum than in the Los Angeles region. If coal is used in the future to make synthetic gasoline, the amount of coal required for this purpose would be up to twice as much as would be required if the coal were burned directly in an advanced cycle electric generating plant and the electricity used in advanced battery cars.

2 CHARACTERIZATION OF FUTURE ELECTRIC CARS

2.1 APPROACH

The starting point for calculating impacts of electric cars is a quantitative description of their functional characteristics, such as performance, accommodations, range between recharges, energy consumption, materials requirements, and so on. The objective of this car characterization is simply to develop such descriptions for alternative future electric cars on a consistent basis. It is in no sense an exercise in detailed, innovative, or definitive design.

The electric cars characterized here are intended to be as useful as they can be made, but not to compete feature by feature with prospective ICE cars. Storage battery cars are not likely to achieve the range, acceleration, speed, and low cost of ICE cars simultaneously; some compromise is necessary. The best compromise will maximize the utility of the electric car in serving actual travel needs, rather than compete with ICE cars in particular characteristics such as acceleration or top speed.

Given the present battery technology, it is clear that range between recharges is critical for electric car utility. Without adequate range for a typical day's collection of urban trips, other virtues such as high acceleration and top speed, excellent accommodations and amenities, or low cost will be of limited value. Accordingly, after minimum performance requirements are established, driving range is given high priority and treated as a basic parameter in this electric car characterization. Range is initially analyzed parametrically as a function of car and battery weight. Then particular ranges for different battery technologies are selected to be compatible with reasonable battery costs and representative daily travel ranges.

2.2 PERFORMANCE REQUIREMENTS

Both present and prospective electric car batteries are relatively heavy for their energy storage capacity. With present technology, as much as 500 pounds of battery may be required to provide the mechanical energy obtainable from a single gallon of gasoline, despite the low efficiency of the gasoline engine relative to the electric motor. The battery equivalent of even a 10-gallon tank of gasoline will be prohibitively heavy until improved battery technology becomes available.

In consequence, energy efficiency and minimization of energy storage requirements are far more important in electric cars than in ICE cars. For these reasons, practical electric cars are usually conceived as subcompacts of relatively low performance.

Performance requirements were set in this characterization at minimal levels for maintaining traffic flow. Average accelerations of 5 mph per second from 0 to 30 mph, and 4 mph per second from 0 to 40 mph, were selected to ensure adequate traffic volumes through signalized intersections. This is at the low end of the performance spectrum spanned by current conventional subcompacts--a bit less than that of the Pinto or Vega, but about equal to that of the common VW Beetle. A top speed of 65 mph was chosen to enable freeway cruising at moderate speeds with an acceleration reserve for on-ramps and minor grades.

Safety in accord with prospective Federal motor vehicle standards is taken as a fundamental requirement for these electric cars. Accommodations for four passengers are assumed, to ensure general utility for family, social, and recreational trips as well as work and business trips. A modest heater capability appropriate to the mild Los Angeles winters is assumed to be provided from waste heat given up by the propulsion motor and its controller. No air conditioning is assumed, because its relatively high energy demand could significantly reduce range between recharges. Moreover, in 1973 only a minority (30%) of subcompacts sold in the US were equipped with air conditioning.

2.3 BATTERY CHARACTERISTICS

Because future battery technology is the critical issue in electric car capability and cost, a brief survey of the field was made. From it four representative future batteries for electric cars were characterized approximately as in Table 2.1. There are, of course, other promising battery types; but their prospects are encompassed in the range spanned by the entries in Table 2.1.

The prospective energy storage of these batteries is further described in Fig. 2.1 for different power levels, which correspond to different rates of discharge. Particularly in the case of lead-acid batteries, single figures for energy density such as those offered in Table 2.1 can only be rough approximations because of their dependence on discharge rate. In calculating ranges in this characterization, the curves of Fig. 2.1 rather than the particular energy densities (and associated efficiencies) of Table 2.1 were employed.

The lead-acid battery specific energy projected for 1978 is based on developmental batteries which have actually been operated in electric cars. All are of the golf-cart type, which offers relatively high energy density at high discharge rates with a life of several hundred deep discharge cycles. In these respects the electric car batteries represent a compromise between long-life industrial traction batteries and high-energy starting-lighting-ignition batteries for automotive use. While their projected specific energy can probably be achieved, the simultaneous achievement of the higher cycle life in Table 2.1 is quite uncertain; accordingly, the indicated range of lifetimes has been carried through the impact analysis.

The nickel-zinc battery characteristics in Table 2.1 are based on recent results and objectives of a development program at Gould, Inc. The potential performance of the nickel-zinc couple with aqueous potassium hydroxide electrolyte has long been recognized, but cycle life

TABLE 2.1

SUMMARY PROJECTION OF BATTERY CHARACTERISTICS

(Source: Task Report 1, Table 5.1)

	Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur
Specific Energy,[*] W•hr/lb	13	44	70	140
W•hr/kg	29	96	155	310
OEM Cost Per Unit of Capacity, $/kW•hr	20-25	25-35	10-15	15
Life, Deep-Discharge Cycles	250-750	200-400	500-1,000	3-5 years
Energy Efficiency,[*] Percent	46	66	70[**]	62[†]
Availability	1978	1980	1985	1990

[*] Assumes discharge in urban driving and overnight recharge.

[**] Includes allowance for electrolyte circulation pumps and for refrigeration required during charging.

[†] Includes allowance for heater to maintain battery operating temperature.

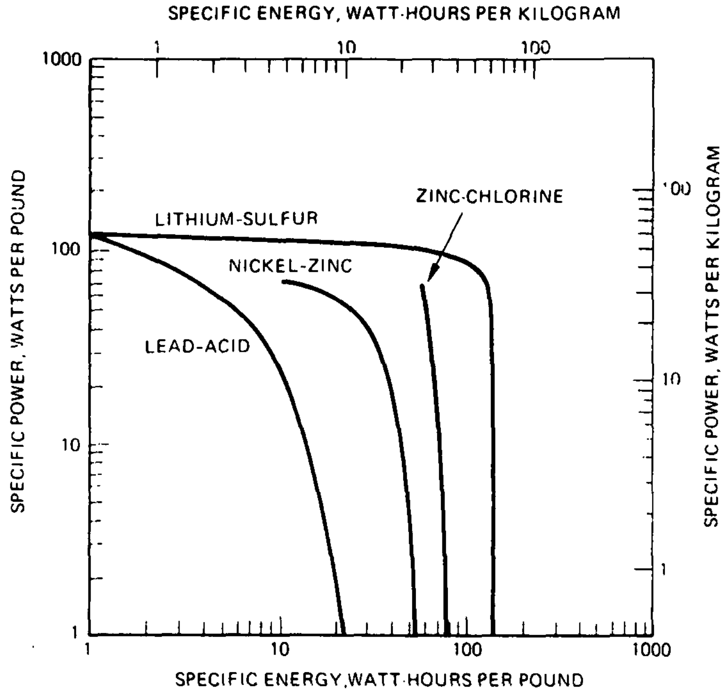


Figure 2.1. Assumed Battery Capabilities (Source: Task Report 1, Fig. 5.15)

problems have heretofore prevented applications. The cycle life shown in Table 2.1 is a projection based on current laboratory results for deep discharges. As discharge depth is decreased, cycle life is expected to increase in inverse proportion; i.e., the total energy delivered by the battery during its life is expected to be independent of cycle depth.

The zinc-chlorine battery characteristics in Table 2.1 are based upon objectives of a five-year development program being conducted by Energy Development Associates, Inc. To allow for unforeseen problems, availability is here projected in 1985. This battery might more informatively be described as an energy system, since it utilizes a chlorine hydrate store separate from the electrode stack and includes pumps for electrolyte circulation and a refrigerator for forming the chlorine hydrate.

The lithium-sulfur battery characteristics in Table 2.1 are derived from a recent development program at Argonne National Laboratory. They refer to a high-performance, high-temperature battery with molten lithium and sulfur electrodes, rather than a less-ambitious battery with solid lithium alloy and metal-sulfide electrodes which is the current focus of development. This battery, unlike the others, has never been operated in any electric vehicle; it is in a much earlier stage of development, and consequently its commercial availability, even by the distant date projected in Table 2.1, is relatively uncertain. The molten salt electrolyte must be operated at temperatures near 375°C, which gives rise to very difficult problems of corrosion and dissolution. Moreover, a heater is required except during periods of battery discharge and charge when internal energy losses are sufficient to maintain the required temperature; at an estimated 3 kilowatt-hours per day, heater energy is a significant factor in the overall energy efficiency, which otherwise would be near 80% in Table 2.1. As with the zinc-chlorine system, the cycle life of Table 2.1 is a goal yet to be corroborated by laboratory results.

2.4 PARAMETRIC RANGE ANALYSIS

With the electric car performance requirements and battery characteristics of Secs. 2.2 and 2.3, driving range between recharges was estimated as a function of battery weight to show a range of reasonable possibilities for each battery type. Ranges were evaluated by a computer simulation consisting of a road load model and an elementary battery discharge model. The road load model calculated power and energy requirements for each time increment in an urban driving cycle. The battery discharge model estimated the fraction of the battery capacity used in meeting each time increment's power and energy requirement, by reference to the curves of Fig. 2.1.

The SAE Metropolitan Area Driving Cycle shown in Fig. 2.2 was used for the range calculations. Comparisons showed that it gave results within a few percent of those obtained for the much more complicated

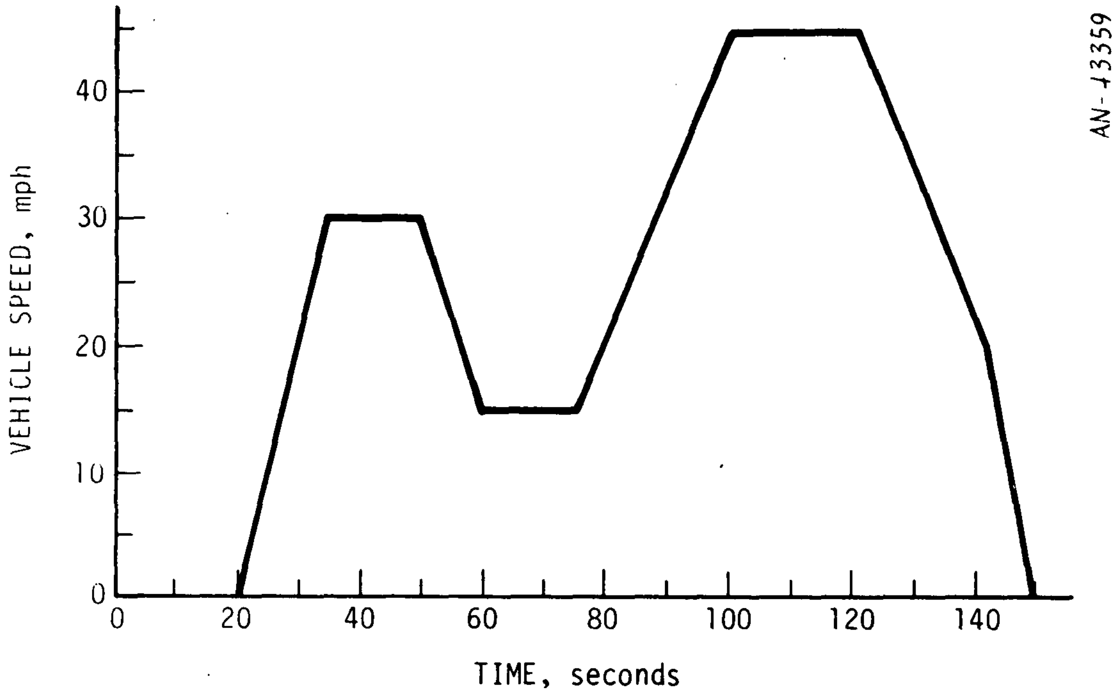


Figure 2.2. SAE Metropolitan Area Driving Cycle (SAE J-227)

Federal driving cycle. Additional comparisons showed that the computer model could reasonably reproduce actual measurements of electric auto ranges on these SAE and Federal driving cycles.

The basic parametric results produced by the computer model are shown in Fig. 2.3. In obtaining these results, the frontal area of the electric car was taken to be 22 square feet. Its aerodynamic drag coefficient was taken as 0.4, midway between the value of 0.3 achieved by the VW Karmann Ghia and the values of 0.5 to 0.6 typical of US passenger cars. Special low-loss tires were assumed, with 42% of the rolling resistance of conventional bias-ply tires. A DC series traction motor and thyristor controller were assumed, with power adequate to meet the performance requirements described in Sec. 2.2. Average electrical efficiency (from controller input to motor output) was taken as 80%, and average mechanical efficiency (from motor output to rear wheels) as 90%. A two-speed automatic transmission, which raises motor speed and efficiency at low road speeds, is implicit in these figures.

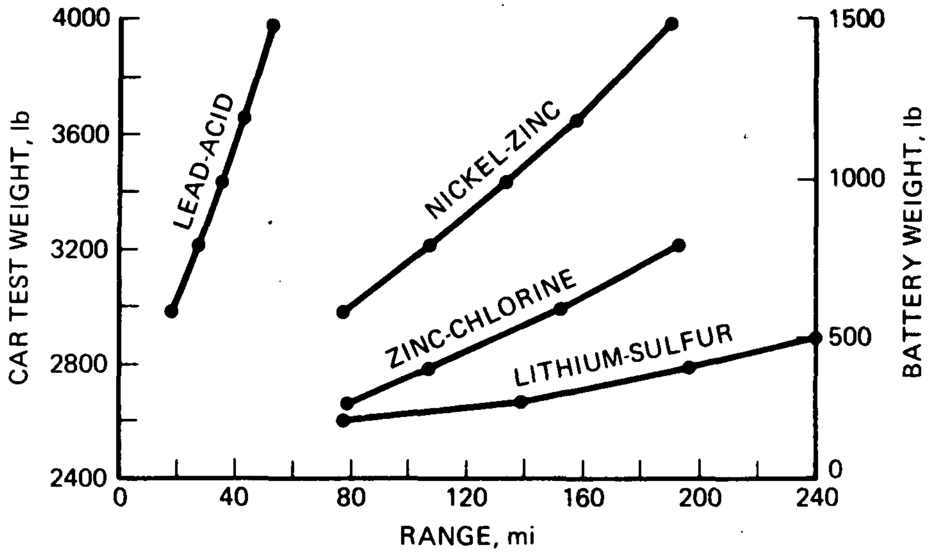


Figure 2.3. Urban Driving Range of Future Four-Passenger Electric Cars (SAE Metropolitan Area Driving Cycle) (Source: Task Report 1, Fig. 6.2)

The longer ranges in Fig. 2.3 may be conservative, since lengthy urban trips will probably involve less stopping and starting than the SAE driving cycle of Fig. 2.2. The ranges of these cars on level ground at steady moderate speeds are more than twice those shown.

Battery life is commonly considered to be ended when capacity has dropped to 60% of its initial value. Thus the range capability of Fig. 2.3 would decrease substantially with battery age. The lead-acid and nickel-zinc batteries are somewhat temperature-sensitive; at 32°F, the range of the lead-acid car may be reduced by about 30% of that shown.

2.5 CAR CHARACTERISTICS

A preliminary calculation showed that depreciation costs for lead-acid batteries might range up to six cents per mile with increasing range capability and battery weight, even with optimistic battery life assumptions. Thus it can be expensive to buy range capability which is seldom needed. Preliminary car usage data showed that a 55-mile daily range was generally adequate for second-car applications, while 140-mile daily range was sufficient for most urban driving. Accordingly, these were selected as characteristic ranges for the lead-acid car and the advanced-battery cars, respectively. After these selections and after completion of car characterization, detailed car cost and usage analyses were performed, as described in Secs. 7 and 8.

The characteristics of cars with the selected ranges are summarized in Table 2.2. In addition to weights from Fig. 2.3, they show energy consumption rates measured at the battery charger input and at the motor controller input. Controller inputs were derived directly from the computer road load model; battery charger inputs were estimated by several methods, each assuming a high charger efficiency of 97%. For the zinc-chlorine and lithium-sulfur batteries, the overall charge-discharge efficiency goals stated by the developers were utilized. For the lead-acid battery an overnight charging efficiency of 83% was deduced from typical recharging recommendations; an equal efficiency was assumed for the nickel-zinc battery; and for both, energy to be replaced was assumed to be that withdrawable from the battery at a low rate of discharge--although in practice something less would be required, depending on how high the actual discharge rate was.

Though they are based on simple and approximate calculations, the range and energy consumption estimates do not appear unreasonable in the light of experience to date. Table 2.3 presents results of energy consumption tests on several electric cars, both as reported and normalized per pound of test weight. In comparison, the energy consumption of the lead-acid battery car characterized here appears a bit low at a constant 30 mph and a bit high in urban driving. Urban driving is the important case for impact analysis; here the characterization's energy use estimate is only 10% above the range reported for the Sundancer, the only car of Table 2.3 tested on the SAE driving cycle used in the characterization. It is noteworthy that the Sundancer and the lead-acid car characterization

TABLE 2.2

SUMMARY PROJECTION OF ELECTRIC CAR CHARACTERISTICS

(Source: Task Report 1, Tables 7.1 and 8.1, Fig. 6.3)

Battery Type	Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur
Test Weight,* lb	3,975	3,530	2,950	2,655
kg	1,803	1,602	1,338	1,204
Battery Weight, lb	1,500	1,090	570	300
kg	681	495	259	136
Urban Driving Range,** mi	54	144	145	139
km	87	232	233	224
Range at 30 mph, mi	183	375	309	317
km	295	604	497	510
Overall Energy Use**,†				
kW•hr per mi	0.79	0.51	0.41	0.45
kW•hr per km	0.49	0.32	0.25	0.28
Battery Energy Output**				
kW•hr per mi	0.35	0.33	0.28	0.27
kW•hr per km	0.22	0.21	0.17	0.17

*Includes 450-lb payload.

**SAE Metropolitan Area Driving Cycle.

†From power lines. Assumes 97% battery charger efficiency and overnight recharge; includes allowances for pumping and refrigeration in the zinc-chlorine system, and for heating in the lithium-sulfur system.

TABLE 2.3

COMPARATIVE ENERGY USAGE OF LEAD-ACID BATTERY CARS

(Source: Task Report 1, Table 8.2)

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

*SAE Metropolitan Area Driving Cycle (J 227).

are similar in key respects: both have DC traction motors with chopper controllers, two-speed transmissions, and high-efficiency tires; and both have high-performance batteries constituting 38% of car test weight. In range tests, 50-55 mi on the SAE Metropolitan Cycle of Fig. 2.2 was reported for the Sundancer, bracketing the 54-mile simulation result in Table 2.2.

Battery energy outputs per mile in Table 2.2 are equivalent to average battery power outputs of 6.5 to 8.4 kW. At the estimated average efficiency of 80%, 1.2 to 1.7 kW of heat would be available from the motor and controller, enough to maintain comfortable interior temperatures even on overcast days with 40-50° ambient temperatures. In Los Angeles, the average minimum daily temperature in January, the coldest month of the year, is 45°.

Allowances for accessory power are not included in the figures of Table 2.2, but with the exception of air conditioning, accessory power consumption would be relatively low. Lights, windshield wipers, blowers, and radio would require only about 225 W total, less than 3% of the average battery output power implicit in Table 2.2. Power steering and brakes together would consume even less; they would be especially desirable for the heavier lead-acid and nickel-zinc battery cars. Air conditioning, on the other hand, would require about 1.3 kW, or 15-20% of average battery output power for propulsion; driving range would thereby be reduced by 25% or more from the figures of Table 2.2.

The zinc-chlorine and lithium-sulfur batteries for cars in Table 2.2 are relatively light; their size could be readily increased to allow air conditioning, improved accommodations, higher performance, and extended range between recharges. At the other extreme, such changes would be much more costly in the lead-acid battery car, where battery weight is high and capabilities marginal to begin with.

The cars characterized in Table 2.2 are conceived as subcompacts, with performance at the low end of the current subcompact ICE car market. With lead-acid batteries, the car might be sized and arranged as suggested in the sketch of Fig. 2.4, which allows adequate crush distance for occupant protection to high standards. The zinc-chlorine and lithium-sulfur batteries are each a single package rather than a collection of modular units as sketched; they might be placed ahead of the car occupants, or (with change of occupant position) under the front seat. Cases for such batteries would protect against accidental release of battery materials, and could be designed to contribute energy absorption capabilities as well in a crash.

The materials required by the cars of Table 2.2 differ from those of conventional cars primarily because of the batteries. Table 2.4 summarizes battery material requirements.

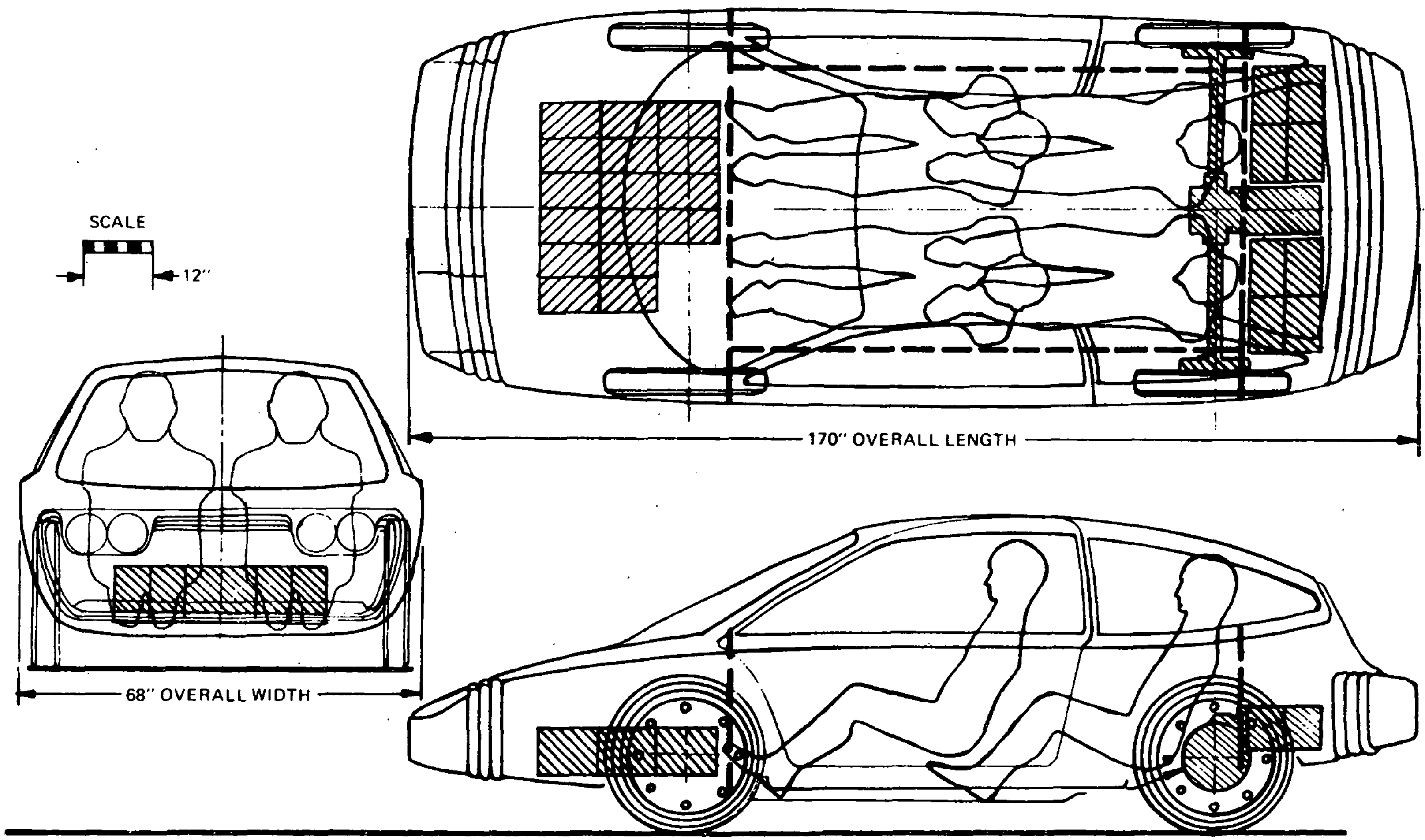


Figure 2.4. Four-Passenger Electric Car Concept (Source: Task Report 1, Fig. 3.8)

TABLE 2.4

BATTERY MATERIAL WEIGHTS

(Source: Task Report 1, Table 8.3)

	Pounds Per Car
	Lead-Acid Battery
Lead	481
Lead Oxide	489
Antimony	24
Electrolyte	426
Polypropylene	56
Filled Polyethylene	20
Epoxy	4
Total Weight	1,500
	Nickel-Zinc Battery
Nickel	362
Zinc Oxide	328
Potassium Hydroxide	109
Electrolyte	96
Polypropylene Oxide	64
Plastic Separators	33
Band and Terminals (Copper or Nickel)	11
Miscellaneous	87
Total Weight	1,090
	Zinc-Chlorine Battery
Zinc	64
Chlorine	69
Water	200
Titanium	34
Frames, Electrodes, Mountings	34
Heat Exchanger (Titanium and Coolant)	17
Support Structure	17
Miscellaneous	135
Total Weight	570
	Lithium-Sulfur Battery
Lithium	17
Sulfur	66
Electrolyte	63
Porous Graphite	23
Porous Stainless Steel	29
Stainless Steel Housing	61
Aluminum Casing	7
Thermal Insulation	16
Insulation, Connectors, Misc.	18
Total Weight	300

Much smaller electric cars were also characterized in this study. Intended only for neighborhood travel, they seated two passengers and offered neither the acceleration nor speed desirable for freeway use. In curb weight, they ranged from 1/2 to 2/3 that of the four-passenger cars, with similarly reduced energy consumption and battery depreciation costs. Because these cars offered so much less capability than conventional cars now in use, and were so sharply limited in passenger capacity and performance, no clear area of applicability emerged for them in the analyses of automobile usage patterns discussed in Sec. 8. Accordingly, they were not carried through the impact analysis, and are not considered further here.

3 BASELINE POPULATION AND TRANSPORTATION PROJECTIONS

The "baseline" projections used in this study outline the prospects for the Los Angeles region in the absence of electric cars, providing a benchmark relative to which the impacts of future electric car use may be measured. These baselines are often crucial in importance. If, for example, high air quality is already to be assured through other means, further pollution reductions due to electric cars may be minor in both amount and importance; or if nuclear energy is to supplant petroleum as the major source of electricity in Los Angeles, then petroleum savings due to electric car use may be greatly increased.

This section presents the baseline regional population and transportation projections. The air quality, energy, and economic baselines are described subsequently in Secs. 4, 5, and 7, each with its associated analysis of electric car impacts.

3.1 BASIS OF THE PROJECTIONS

The study area, California's South Coast Air Basin, is outlined in Fig. 3.1. A region of roughly 10,000 square miles, it is bounded by the Pacific Ocean and by inland mountains, accommodates a population approaching 10 million persons, and includes greater Los Angeles.

Baseline regional projections in this study rest on two basic assumptions: first, that population growth in the region will be moderate, considerably less than in the past; and second, that environmental and economic progress will be balanced without systematic subordination of either one to the other. At the present time, a much-reduced rate of population growth is already a matter of record, but the long-term balance of economic and environmental priorities remains to be fully established.

The baseline projections in this study further assume that there will be no dramatic technological breakthroughs, such as practical solar-electric power generation, or high-capacity personal rapid transit and dual-mode transportation systems. Though worthy of consideration elsewhere, such developments are beyond the scope of this analysis.

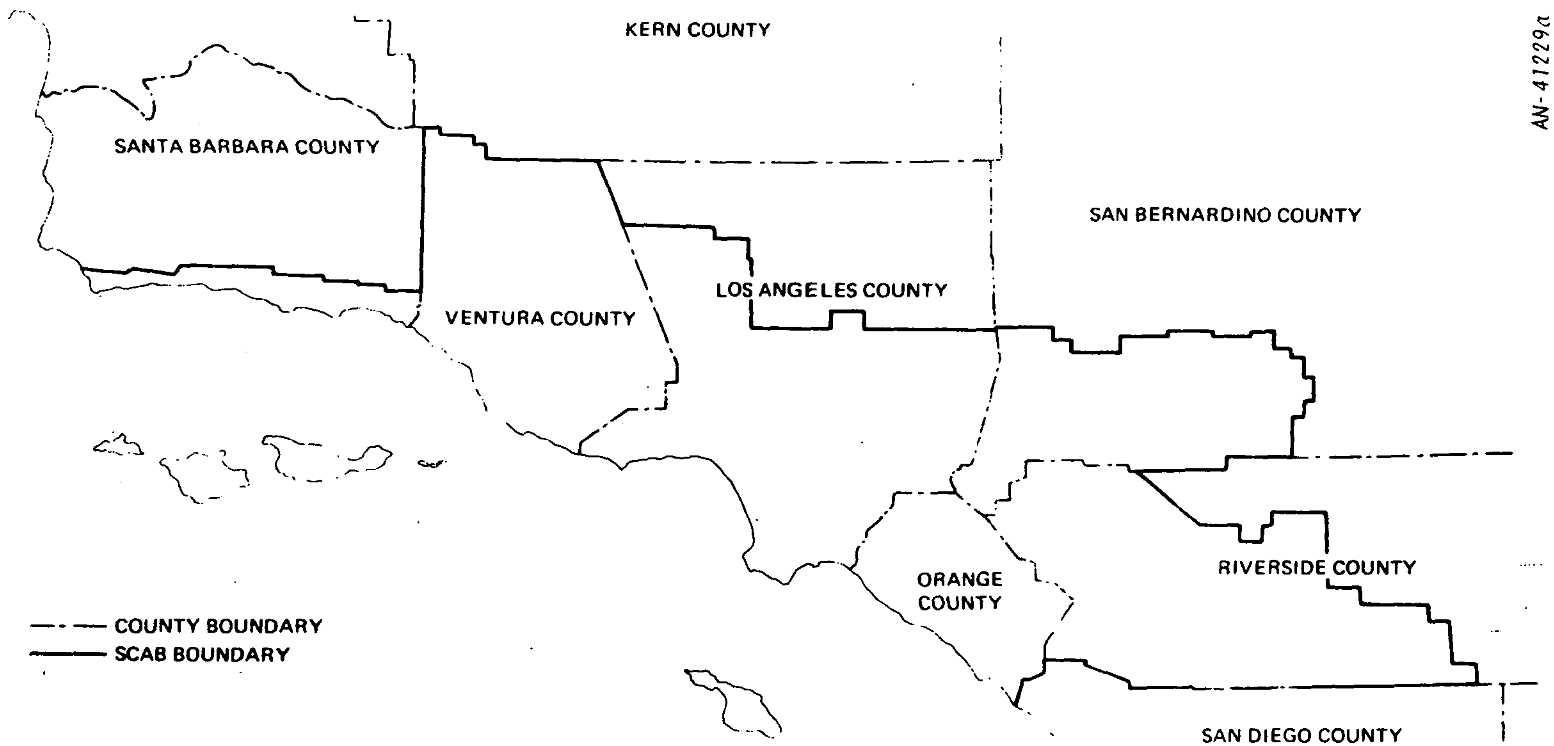


Figure 3.1. California's South Coast Air Basin (Source: Task Report 2, Fig. 1.1)

3.2 POPULATION BASELINE

The population projections shown in Fig. 3.2 were developed for the South Coast Air Basin from county-by-county projections of the California Department of Finance and the Southern California Association of Governments. In years past, the Series D projection (which included substantial net immigration) was generally accepted for the region. Recently, however, an end to net immigration and a continued decline in regional birth rates has led the agencies concerned to move towards the Series E projection in Fig. 3.2, which was accordingly adopted in this study. It assumes zero net migration and a completed fertility rate of 2.1, conditions leading eventually to population stabilization: the growth implicit in this Series E projection is only 0.8% per year for the period 1970-2000. Even lower growth is conceivable: during the

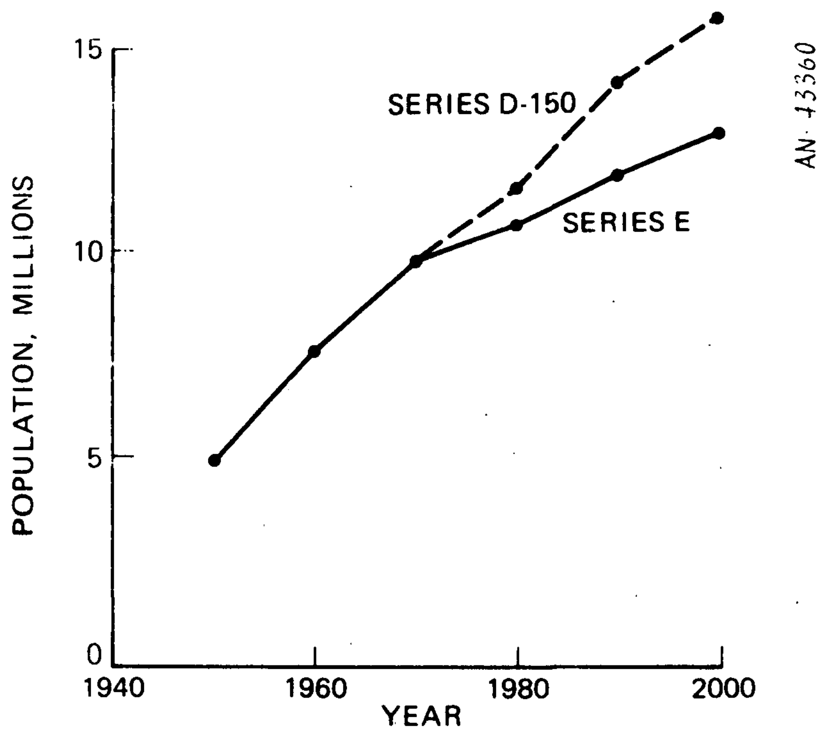


Figure 3.2. Population of the South Coast Air Basin (Source: Task Report 1, Tables 2.1, 2.3, 3.1)

early 70's, the population of Los Angeles County actually declined, and current birth statistics are following an even lower trend line, Series F.

3.3 TRANSPORTATION BASELINE

As in other cities across the nation, freeway construction in Los Angeles has slowed considerably from its pace in the 50's and 60's. Though almost half the officially planned and adopted freeway network for the Air Basin had been completed in 1972, present indications are that only a small fraction of the remainder will be built. Nonetheless, it appears that freeway route mileage in the Basin will continue to grow somewhat faster than the population, at an annual rate of about 1-1/2%. Moreover, freeway capacity should expand even faster as lanes are added along existing routes.

Continued growth in automobile ownership rates is projected for the Air Basin, as shown in Fig. 3.3. The region has historically had more automobiles per capita than the United States or even the rest of California. The future growth projected in Fig. 3.3 follows projections based on detailed regression analyses involving household size, type, and income which were developed at the Los Angeles Regional Transportation Study (LARTS).

The usage of individual automobiles has been relatively stable for many years. In the United States as a whole (except during the war years), average annual mileage per car has taken three decades to increase from 9,000 to 10,000. California auto usage in recent years has been below the national average. Future usage growth in line with the national trend shown in Fig. 3.4 is projected for this study.

Table 3.1 presents baseline auto projections for the South Coast Air Basin. These projections were developed by combining the population, auto ownership, and auto usage projections of Figs. 3.2-3.4, and adding figures on trip frequency, trip speed, and freeway usage developed by LARTS through detailed network modeling.

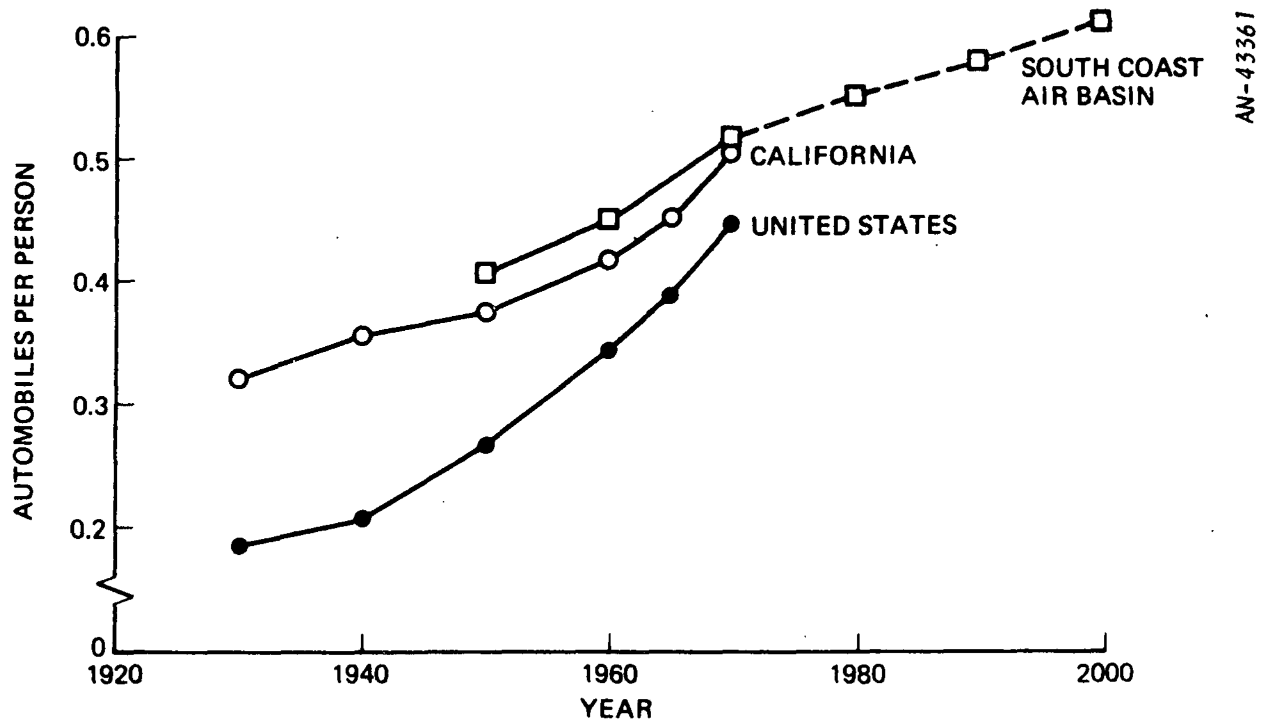


Figure 3.3. Automobiles per Person
(Source: Task Report 3, Fig. 4.1)

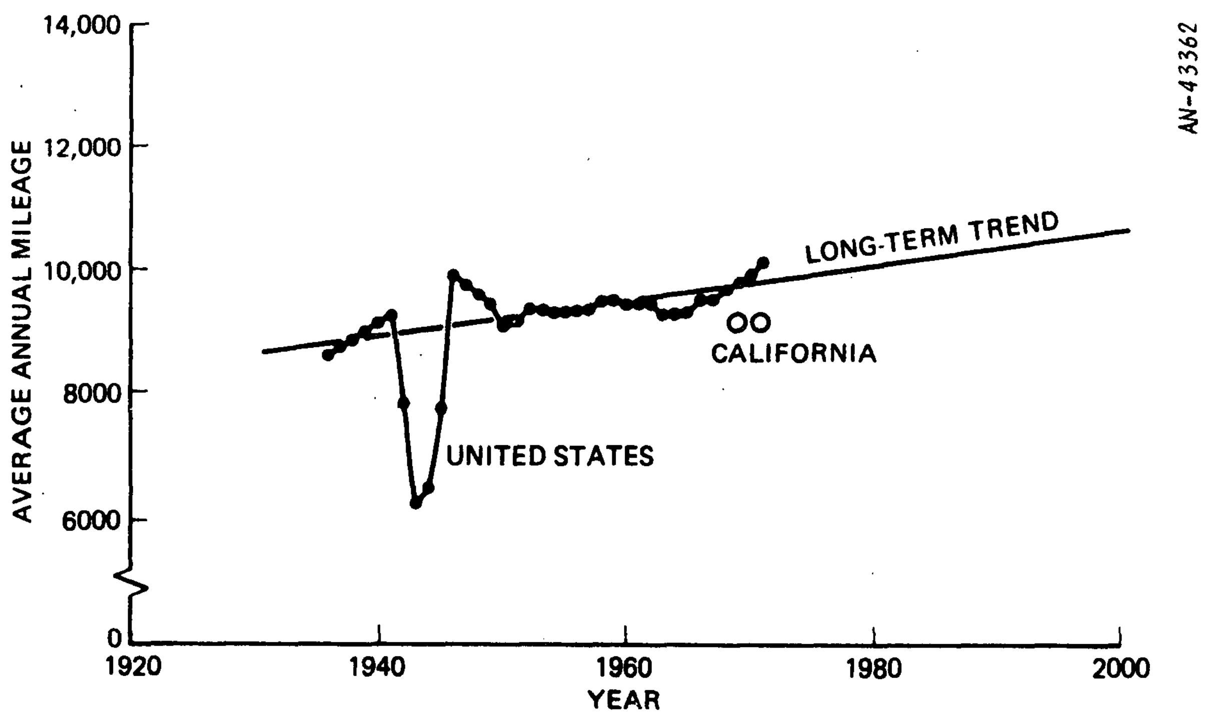


Figure 3.4. Average Annual Passenger Car Mileage
(Source: Task Report 3, Fig. 5.2)

TABLE 3.1

BASELINE AUTO TRAVEL PROJECTIONS, SOUTH COAST AIR BASIN
(Source: Task Report 3, Table 5.5)

	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

Despite ambitious regional plans and a prospective multi-billion-dollar investment in new facilities and equipment, public transit will apparently play only a minor role in future regional travel. A system recommended in 1973, combining 140 miles of grade-separated rapid transit with an expanded fleet of 2740 buses, was expected to divert only 2.4% of motorists in its service area to rapid transit in the year 1990.

Overall, the outlook in Table 3.1 is for relative stability: little change in average auto usage, or travel speeds, or congestion levels, and only moderate growth in total regional automobile travel. More rapid growth in regional population and auto ownership would have relatively little effect on electric car impacts. Rapid growth in average automobile usage, however, could significantly increase daily driving ranges relative to practical capabilities of nearer-term electric cars, thus reducing their applicability. Though the stability of the usage trend in Fig. 3.4

makes this seem unlikely, regression analysis at LARTS has led in the past to projections far above the 1990 daily mileage in Table 3.1.

Future auto energy consumption is projected as shown in Fig. 3.5. Although auto fuel economy has been declining for many years, as indicated by DOT data for cars on the road and EPA data for new cars, the projection anticipates major improvements: 50% by 1984 and 100% by the end of the century. Powerful economic and political forces have already begun a movement in this direction; and though the gasoline "crisis" of early 1974 has eased, these forces remain at work: petroleum reserves are dwindling, prices remain much higher than in previous years, international payments deficits accumulate rapidly, and the US desires independence of politically-inspired embargoes by oil-producing nations. The projection of Fig. 3.5 is in line with a legislative request to Congress planned in early 1974 by EPA (circle 1 in Fig. 3.5), and with the goal of legislation actually

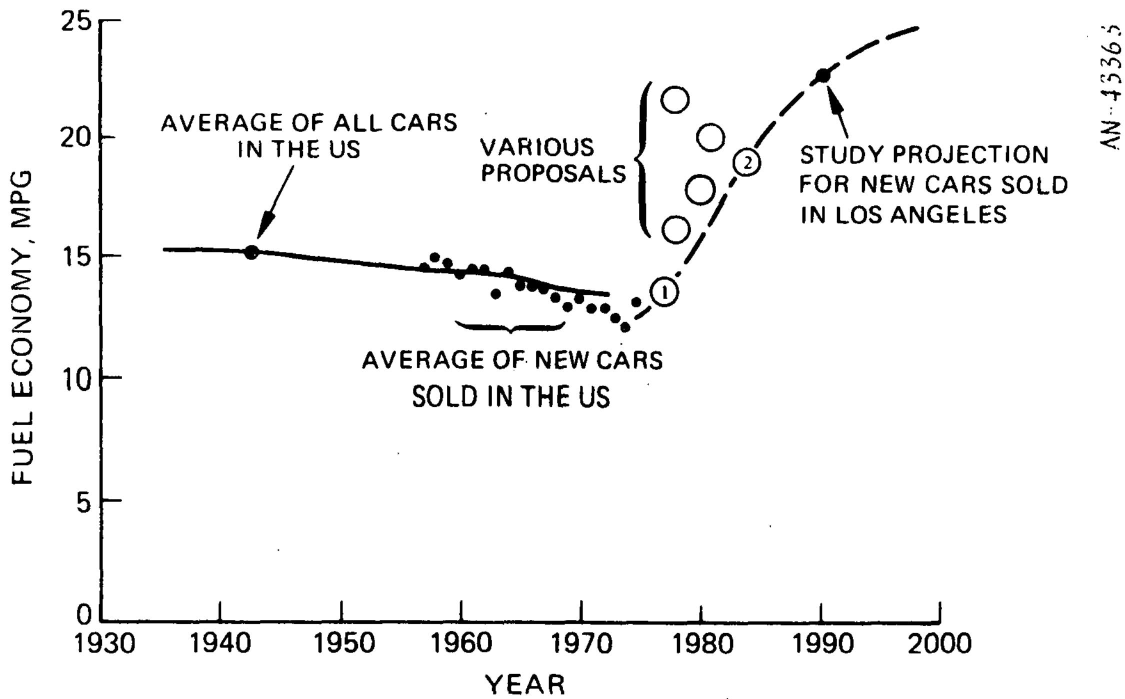


Figure 3.5. Automobile Fuel Economy (Source: Task Report 3, Fig. 7.4)

passed in December, 1973, by the US Senate (S.2176) to encourage auto fuel economy (Circle 2 in Fig. 3.5). Though this projection represents a dramatic reversal of past trends, it remains less ambitious than other legislative goals and technology-development goals advanced during 1973 (unnumbered circles in Fig. 3.5). Part of the projected economy increase may be attributed to a continuation of the trend to smaller cars, in which Los Angeles has led the nation for many years. In 1972, 45% of the automobiles sold in the area were compacts and subcompacts; by 1990, this proportion is projected to rise to 65%, mostly subcompacts. The remainder of the economy improvement will require more efficient power trains and weight reductions within each auto size class. If the projection is realized, total gasoline consumption in the South Coast Air Basin will decline by almost 1/4 during the remainder of this century, despite the increase in travel shown in Table 3.1.

The projection of Fig. 3.5, though clearly within technological reach, is relatively optimistic. The data points in Fig. 3.5 for 1974 and 1975 cars, which became available after the projection was made, are encouraging evidence that the anticipated economy upturn has begun, but it may nevertheless fall far short of the projection. In that case, the savings of energy and petroleum due to electric car use could be substantially increased in both magnitude and importance.

4 AIR QUALITY IMPACTS

4.1 BACKGROUND AND ASSUMPTIONS

In this study of electric car impacts, the largest single analytic effort was devoted to air quality. There were several reasons for this emphasis. First, air quality has been an important problem in the Los Angeles area for over thirty years. Second, Los Angeles air pollution has been primarily vehicular in origin: in 1970, almost 100% of carbon monoxide emissions and about two-thirds of reactive hydrocarbons and nitrogen oxides emissions were from motor vehicles. Third, the use of electric cars instead of conventional cars drastically alters automotive air pollutant emissions.

The quantitative impacts of electric car use on air pollution will depend strongly on the extent to which pollution from conventional automobiles is controlled. California legislation to limit automotive emissions first took effect in 1963; Federal legislation followed in 1968. With the Clean Air Act of 1970, the Federal government moved towards a 90% reduction of automotive pollutant emissions relative to 1970 by the year 1977. As Table 4.1 shows, the major part of this reduction is to take effect progressively from 1974 to 1977--and California, in recognition of its particular air quality problems, is to lead the rest of the nation in the tightening of controls.

Though the scheduled emissions standards of Table 4.1 remain effective as of this writing, legislation is being proposed and developed to delay and relax the final steps in the schedule. It is thus quite possible that the imposition of the 1976 requirements will be delayed two years, and that the final reduction of nitrogen oxides emissions from 2.0 to 0.4 grams per mile will be delayed indefinitely.

In developing baseline projections of air quality for this study, it was assumed that the emissions standards of Table 4.1 would be applied,

TABLE 4.1

EXHAUST EMISSION STANDARDS FOR LIGHT-DUTY VEHICLES

(Source: Task Report 7, Table A.3)

	Emission Standards, grams per mile		
	Hydrocarbons	Carbon Monoxide	Nitrogen Oxides
1974 Federal	3.4	39	3.0
California	3.2	39	2.0
1975 Federal	1.5	15	3.1
California	0.9	9.0	2.0
1976 Federal	0.41	3.4	2.0
California	0.41	3.4	2.0
1977 Federal	0.41	3.4	0.40
California	0.41	3.4	0.40

as existing law requires. In recognition of the possibility of future revisions, however, projections for an alternative baseline in 1980 were also developed. This case, in which standards are delayed and relaxed as discussed above, is called "1980D" in the following pages.

The Clean Air Act of 1970 has led not only to emissions standards, but to the air quality standards summarized in Table 4.2. At present, Federal law requires compliance with these standards in Los Angeles by 1977. Since it has appeared unlikely that the scheduled reduction of pollutant emissions from both vehicular and stationary sources would be sufficient to reach compliance, stringent transportation controls are being developed for application in the Los Angeles region. But just as relaxation of emission standards is possible, so also are delays and revisions in air quality standards and related controls.

TABLE 4.2

NATIONAL AMBIENT AIR QUALITY STANDARDS

(Source: Task Report 6, Table 7.1)

Pollutant	Level Not to Exceed: Primary	Level Not to Exceed: Secondary	
Sulfur Dioxide	80 μg/m^3 (0.03 ppm)	60 μg/m^3 (0.02 ppm)	(a)
	365 μg/m^3 (0.14 ppm)	260 μg/m^3 (0.1 ppm)	(b)
Particulate Matter	75 μg/m^3	60 μg/m^3	(c)
	260 μg/m^3	150 μg/m^3	(b)
Carbon Monoxide	10 mg/m^3 (9 ppm)	Same	(d)
	40 mg/m^3 (35 ppm)		(e)
Photochemical Oxidants	160 μg/m^3 (0.08 ppm)	Same	(e)
Hydrocarbons	160 μg/m^3 (0.24 ppm)	Same	(f)
Nitrogen Oxides	100 μg/m^3 (0.05 ppm)	Same	(a)

(a) Annual arithmetic mean.

(b) Maximum 24-hr concentration not to be exceeded more than once a year.

(c) Annual geometric mean.

(d) Maximum eight-hour concentration not to be exceeded more than once a year.

(e) Maximum one-hour concentration not to be exceeded more than once a year.

(f) Maximum three-hour concentration (6-9 AM) not to be exceeded more than once a year.

Because transportation controls assuring compliance in 1977 with the air quality standards would be very severe, the baseline projections of this study have assumed that such strict controls will not be imposed (see Sec. 4.4), and consequently that the air quality standards will not necessarily be met as presently scheduled. In the absence of such controls, vehicular emissions and air pollution levels would be higher than otherwise, and both the size and the desirability of reductions due to electric cars would be enhanced.

4.2 METHODS AND OBJECTIVES

In accord with initial planning for an efficient and effective analysis, this study addressed air pollution in three steps: emissions projections, photochemistry simulations, and simple "rollback" calculations.

The emissions projections show prospective air pollutant emissions in considerable spatial, temporal, and chemical detail, both with and without the use of electric cars. The changes in total emissions by themselves indicate what electric cars can do. But they do not tell the whole story: besides changing total emissions, electric cars will shift emissions from streets and freeways to power plants and from daytime to nighttime, and will also alter the mixture of pollutants emitted. The net effect on air quality depends significantly on the interaction of all these changes in the photochemical diffusion processes through which "secondary" pollutants appear. Most important among secondary pollutants are the oxidants of Table 4.2. Photochemical oxidants have been a serious problem in Los Angeles, repeatedly reaching concentrations triggering local health alerts.

To investigate the effects of the detailed emissions changes on secondary photochemical pollutants, a computer simulation developed at General Research Corporation for the Los Angeles area, DIFKIN, was employed. The basic operation of DIFKIN is illustrated schematically in Fig. 4.1.

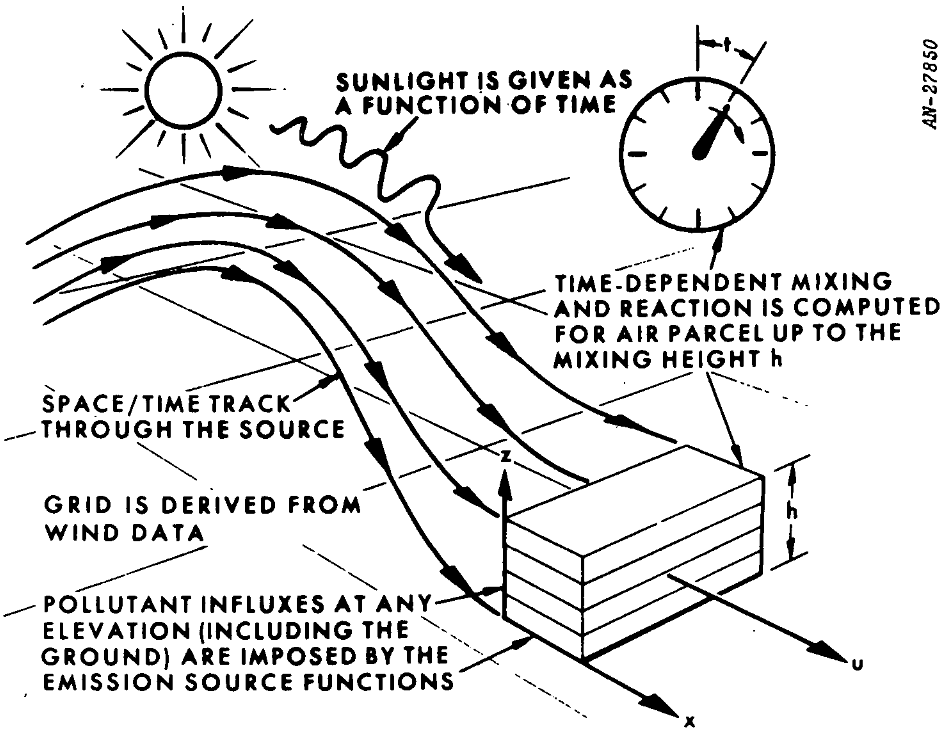


Figure 4.1. Schematic GRC Photochemical Diffusion Model for Air Quality Simulation (Source: Task Report 6, Fig. 3.1)

As a check on the DIFKIN results and to estimate primary pollutant concentrations not computed by the simulation, projections were also made by means of "linear rollback" calculations. In these calculations, changes in pollutant levels are simply assumed to be proportional to changes in aggregate daily emissions. Largely because simulations are difficult to operate and validate, rollback has been widely accepted as an analytic tool despite its evident theoretical limitations.

The basic objective of the air pollution analysis has been to determine changes in air quality due to future electric car use. The importance of a given change depends, however, on the absolute level of air quality at which it is effective. Thus a secondary objective has necessarily been to forecast absolute air quality levels in the absence of electric car use. Though such forecasts are admittedly contentious, they are essential to electric car impact assessment.

4.3 POLLUTANT EMISSIONS

Detailed projections of pollutant emissions were made for the heavily populated subarea of the South Coast Air Basin shown in Fig. 4.2, hereafter referred to as "Los Angeles and Environs." Vehicular and distributed stationary sources were aggregated by a system of 2 × 2 mile grid squares. Future vehicle movements and emission factors for streets and freeways, treated separately, were developed from the emission standards of Table 4.1 and the detailed travel forecasts of the Los Angeles Regional Transportation Study, adjusted for this study's population and transportation baselines (see Sec. 3). Distributed stationary sources (such as gasoline marketing and dry cleaning) were developed from land use plans of the Southern California Association of Governments. Finally, point-source emissions from power plants were derived from the baseline electric energy projection of Sec. 5, while those of oil refineries were projected in accord with actual facilities plans. The projections detail,

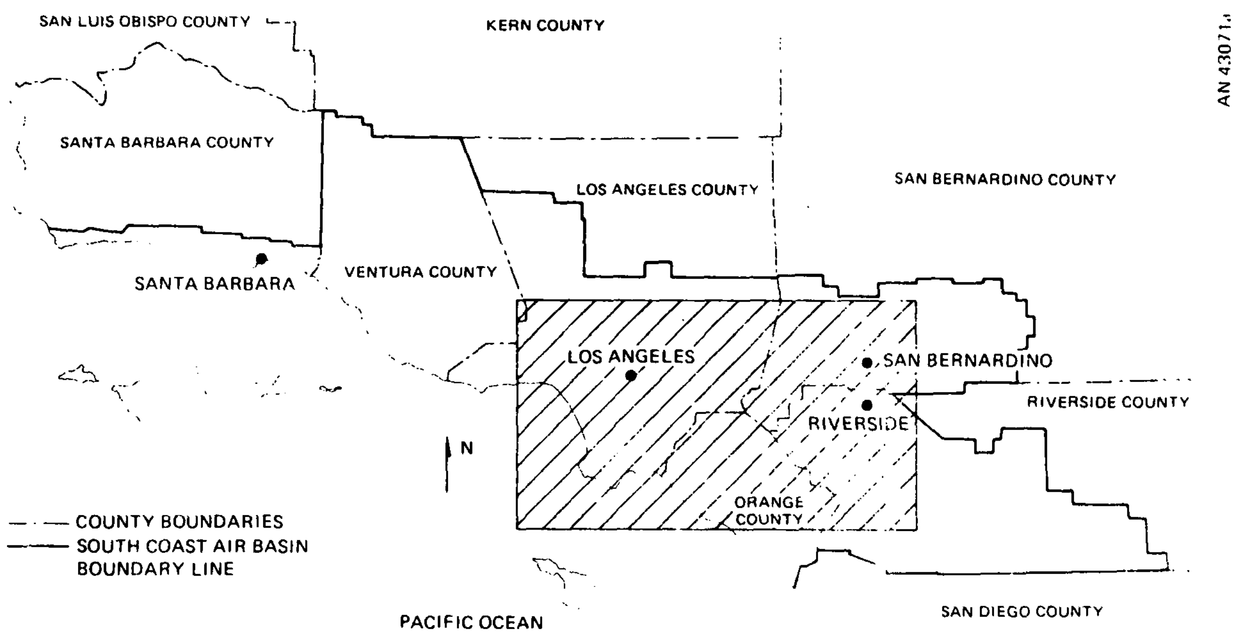


Figure 4.2. "Los Angeles and Environs", the Heavily Populated Subarea of the South Coast Air Basin Selected for Air Quality Analyses (Source: Task Report 7, Fig. A.2)

for each grid square, the hour-by-hour emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen, as required by the DIFKIN simulation. Sulfur dioxide and particulate emissions were only projected on an aggregate basis, as required for rollback calculations. Except as noted below, the projections apply to the average work day; emissions are typically less on weekends.

Table 4.3 summarizes the emissions by source projected for 1980, 1990, and 2000 in the absence of electric car use, and the actual 1970-71 emissions, for direct comparison.

In the case where auto emissions standards are delayed and relaxed, baseline projections for 1980 with and without the delay are shown in Table 4.4 for the most important vehicular emissions.

The projections of vehicular emissions in Table 4.3 were based on emissions measurements in the Federal Driving Cycle by model year, assuming for future years compliance with the standards of Table 4.1. These emissions were weighted by three factors: first, a deterioration factor accounting for the loss in effectiveness of emission controls with vehicle mileage; second, the fraction of daily vehicle miles contributed by vehicles according to their ages and use; third, a speed correction factor for speeds other than the driving cycle average speed. In general, all these factors are functions of vehicle model year.

5% of total vehicle miles traveled are assumed to be contributed by heavy-duty vehicles (over 6000 pounds). This figure is subject to some uncertainty, and varies significantly with locale. Because emissions standards for heavy-duty vehicles are less stringent than for automobiles, they contribute a disproportionate amount of the total vehicular emissions, as detailed in Table 4.5.

TABLE 4.3

BASELINE POLLUTANT EMISSIONS FOR LOS ANGELES AND ENVIRONS

(Source: Task Report 7, Tables 2.4-2.6 and C.1)

Four entries for each source and type are 1970-71 actual emissions, and projections for 1980, 1990, and 2000, in that order.

	Emissions, tons per day				
	Nitrogen Oxides	Hydrocarbons	Carbon Monoxide	Sulfur Dioxide	Particulates
Vehicular	455.0	918.4	9,719.7	20.2	82.2
	181.5	160.3	2,202.8	22.4	91.2
	75.5	72.3	1,084.2	24.4	99.2
	80.6	77.1	1,152.1	26.4	107.5
Stationary Area Sources	77.5	472.3	---	178.0	88.3
	106.0	160.7	---	195.3	96.9
	140.8	160.7	---	213.1	105.7
	181.1	160.7	---	227.7	112.9
Power Plants	78.6	---	---	175.0	7.5
	113.3	---	---	362.0	12.6
	116.2	---	---	372.0	12.9
	98.1	---	---	315.0	10.9
Oil Refineries	44.6	30.8	---	55.4	10.1
	48.8	33.7	---	60.6	11.0
	53.7	37.1	---	66.7	12.2
	57.6	29.8	---	71.5	13.0
Totals	655.7	1,421.6	9,719.7	428.6	188.1
	449.6	354.7	2,202.8	640.3	211.7
	386.2	270.1	1,084.2	676.2	230.0
	417.4	277.6	1,152.1	640.6	244.3

TABLE 4.4

1980 BASELINE VEHICULAR EMISSIONS FOR LOS ANGELES AND ENVIRONS WITH AND WITHOUT DELAYS IN IMPLEMENTING AUTO EMISSION CONTROLS

(Tons/Day)

(Source: Task Report 7, Table 2.7)

	Nitrogen Oxides	Hydrocarbons	Carbon Monoxide
With Delay	300.6	168.5	2,328.2
Without Delay	181.5	160.3	2,202.8

TABLE 4.5

PERCENTAGE CONTRIBUTION OF HEAVY-DUTY VEHICLES TO VEHICULAR AND TOTAL BASELINE EMISSIONS FOR LOS ANGELES AND ENVIRONS

(Source: Task Report 7, Table 2.9)

	Nitrogen Oxides		Hydrocarbons		Carbon Monoxide		Sulfur Dioxide		Particulates	
	Vehicular	Total	Vehicular	Total	Vehicular	Total	Vehicular	Total	Vehicular	Total
1980	18	7	23	10	31	31	9	0.3	8	3
1990	31	6	33	9	67	67	9	0.3	8	3
2000	31	6	33	9	67	67	9	0.4	8	3
1980D	11	6	22	10	29	29	9	0.3	8	3

The projections of power plant emissions in Table 4.3, principally nitric oxide and sulfur dioxide, assume no breakthroughs in emission control. The sulfur dioxide emissions are based simply on the use of 0.5% low-sulfur crude, without stack scrubbers. An increasing fraction of electric power for Los Angeles and environs is expected to be generated outside the air basin, and increasingly by nuclear power stations. In consequence, although total electricity consumption is projected to grow, the power generation that contributes air pollution in the air basin is projected to remain relatively constant. As shown in Fig. 4.3, the peak capacity of oil-fired power plants in the area is expected to increase modestly, but load factors will decrease as nuclear power becomes available to meet base demands.

For comparison with these baseline projections, emissions were also projected for selected levels of electric car use. Upper-bound usage levels were chosen, in order to show the maximum possible effects of electric cars on pollutant emissions and the resultant air quality. Usage levels of 20% in 1980, 80% in 1990, and 100% in 2000 were actually employed. Because they were selected and analysis begun before the results of the usage analysis of Sec. 8 were available, these figures are somewhat higher than the upper bounds estimated there.

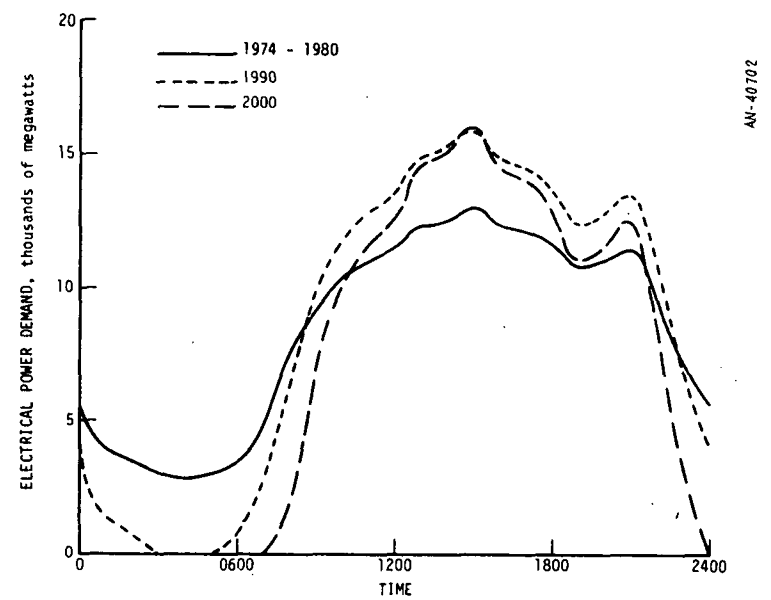


Figure 4.3. Projected Baseline Diurnal Power Demand on Oil-Fired Power Plants in Los Angeles and Environs for Peak Demand Month (August) (Source: Task Report 6, Fig. 5.2)

Projected emissions with upper-bound electric car use are shown in Figs. 4.4-4.8, together with the baseline emissions already presented in Table 4.3. In each figure, vehicular contributions to the total are indicated (for carbon monoxide, total and vehicular contributions are equal), and where appropriate, power plant emissions are also separately indicated. These figures show that electric cars will change total emissions relatively little, even at very high levels of use, primarily because of the relative future importance of emissions from stationary sources and heavy-duty vehicles after the cleanup of conventional automotive emissions now in progress.

Figure 4.9 shows similar projections for nitrogen oxides emissions, assuming a delay of two years in effecting the final reduction of auto emissions standards in Table 4.1, and assuming that the nitrogen oxides emission standard will remain at 2 grams per mile rather than reach 0.4 grams per mile. In this circumstance, total nitrogen oxides emissions would remain much higher, and the potential reductions due to electric cars are more significant.

In Figs. 4.4-4.8, overnight recharging of electric cars is implicit. On the day of peak annual demand, most of the recharging power will be generated in the Air Basin; this is shown in Fig. 4.10, which is to be compared with Fig. 4.3, the baseline case without electric cars. On the average day, however, an increasing fraction of recharge power will come from new power plants planned for construction outside the Basin; as a result, extra oil-fired generation in the Basin will be much less than shown in Fig. 4.10. The peak demand day typically occurs during the late-summer smog season. For worst-case analyses, then, the emission rates from power plants corresponding to Fig. 4.10 are used. For addressing average annual pollution levels, as is appropriate for sulfur dioxide and particulates, the lower average annual emissions due to electric car recharge are used.

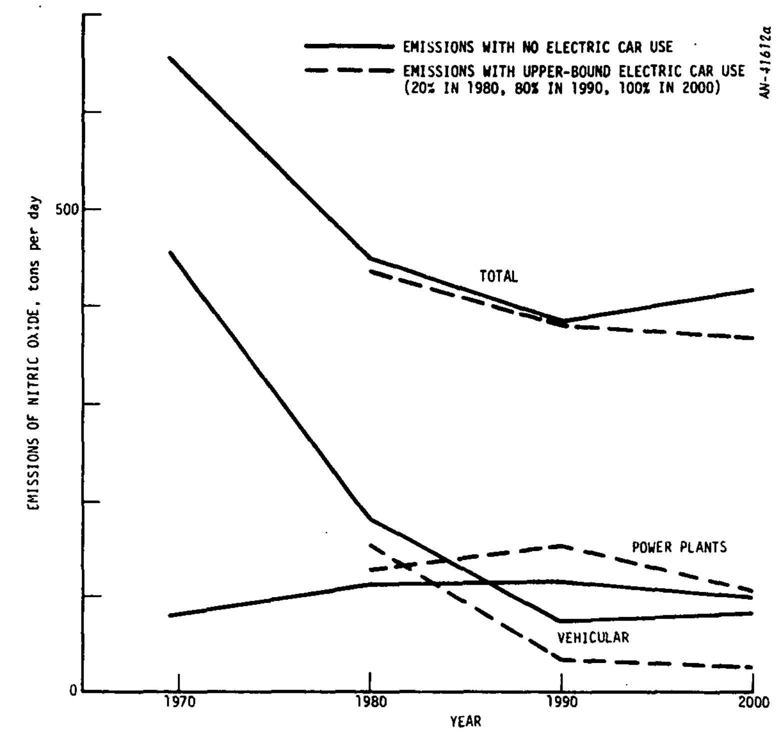


Figure 4.4. Projected Nitric Oxide Emissions (for Los Angeles and Environs, Without Delay of Emission Controls) (Source: Task Report 7, Fig. 3.2)

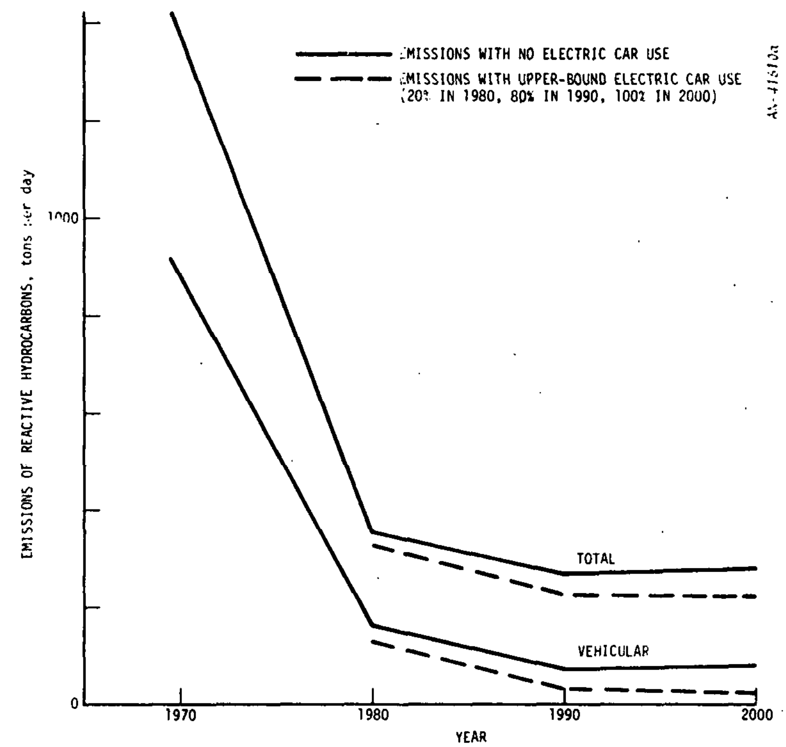


Figure 4.5. Projected Reactive Hydrocarbon Emissions (Source: Task Report 7, Fig. 3.3)

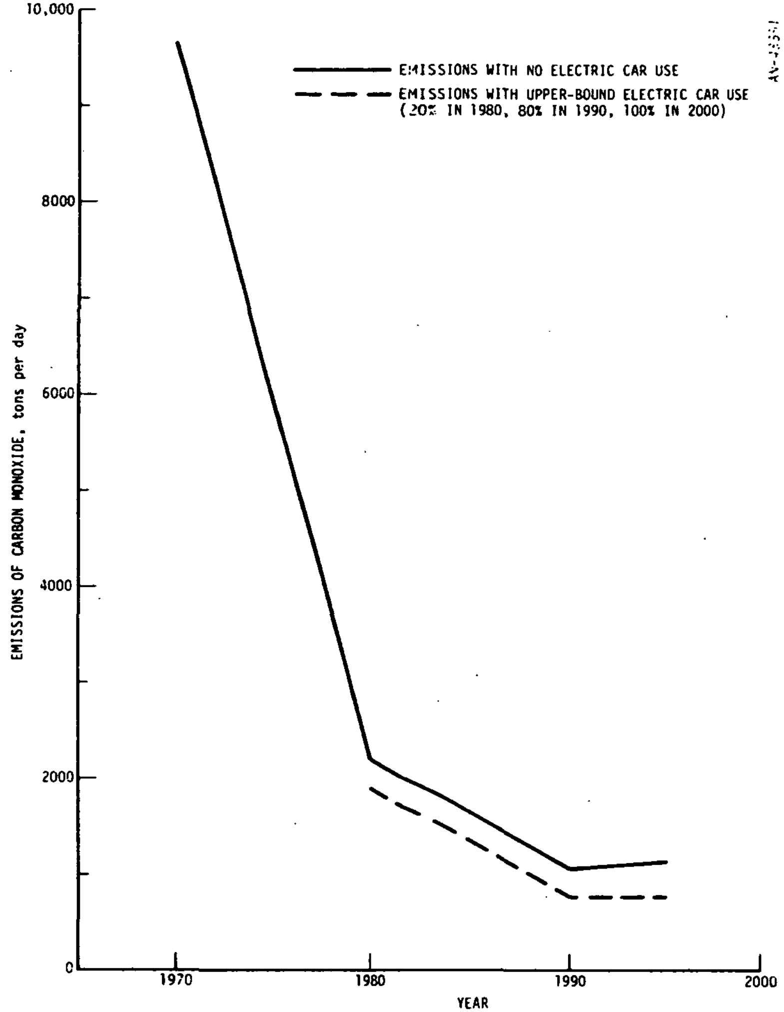


Figure 4.6. Projected Carbon Monoxide Emissions (Source: Task Report 7, Fig. 3.4)

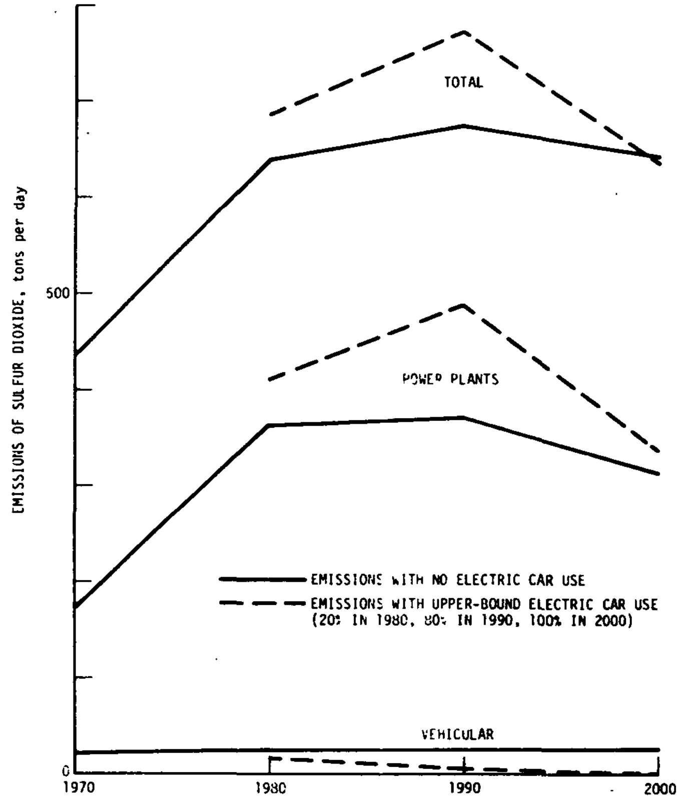


Figure 4.7. Projected Sulfur Dioxide Emissions (Source: Task Report 7, Fig. 3.5)

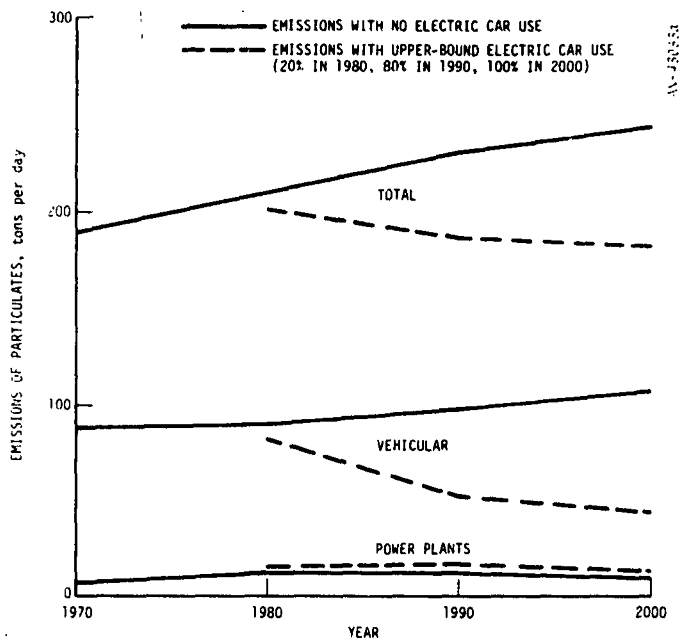


Figure 4.8. Projected Particulate Emissions (Source: Task Report 7, Fig. 3.6)

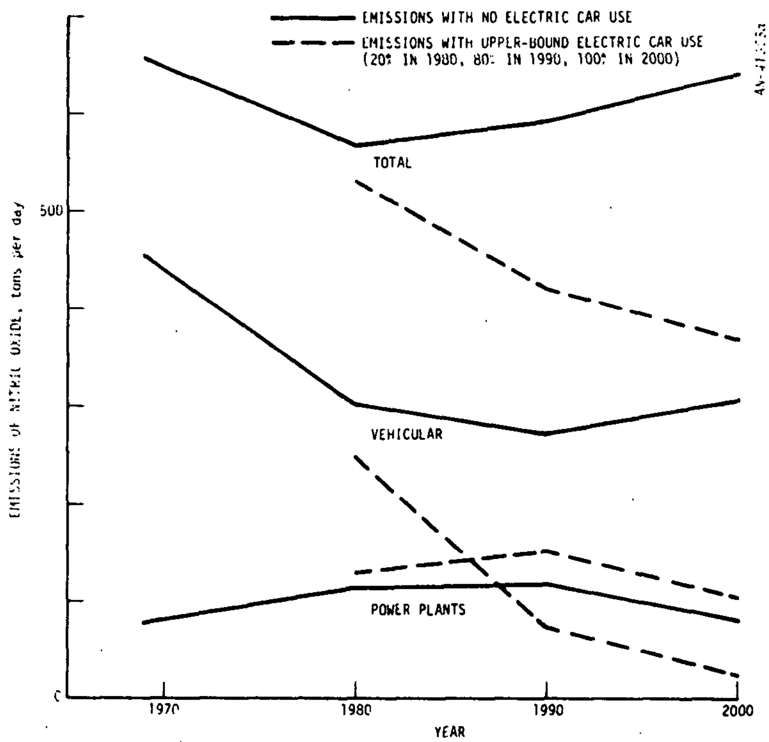


Figure 4.9. Projected Nitric Oxide Emissions (for Los Angeles and Environs, Delay of Emission Controls) (Source: Task Report 7, Fig. 3.7)

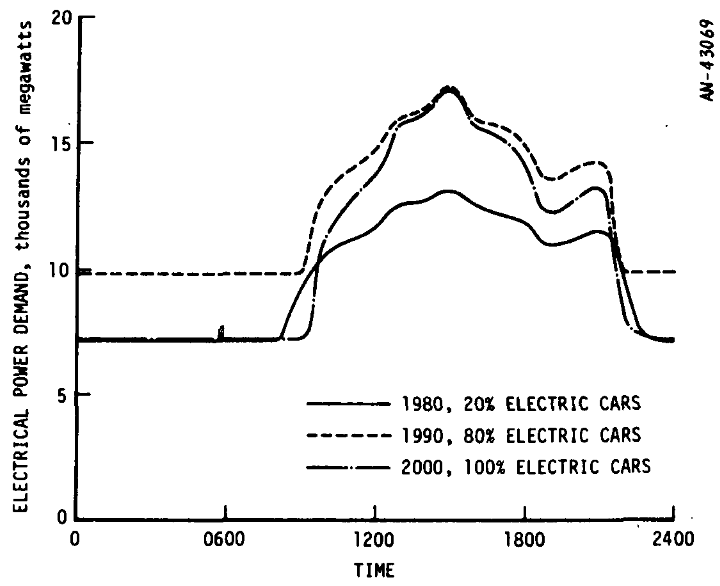


Figure 4.10. Projected Diurnal Power Demand on Oil-Fired Power Plants in Los Angeles and Environs for Peak Demand Month (August) (Source: Task Report 7, Fig. 3.1)

4.4 AIR QUALITY

The Federal air quality standards of Table 4.2 rely on a worst-case approach: they state for each pollutant a level allowable anywhere in the region only once annually, except for nitrogen oxides, for which only a maximum annual mean is established. To project corresponding future levels of air pollution, it is thus necessary to select the worst locations in the Air Basin for the various pollutants, and to establish for them representative meteorological conditions under which worst-case concentrations will arise.

These selections were made by a review of historical pollution records at measurement stations spanning the Air Basin, as shown in Fig. 4.11. The records show that conditions for smog in 1969 and 1970 were about the same, as summarized in Table 4.6. 1970 pollution maxima were used as the basis for rollback calculations, a convenience since 1970 is the reference year for Federal automotive emission reductions. For the

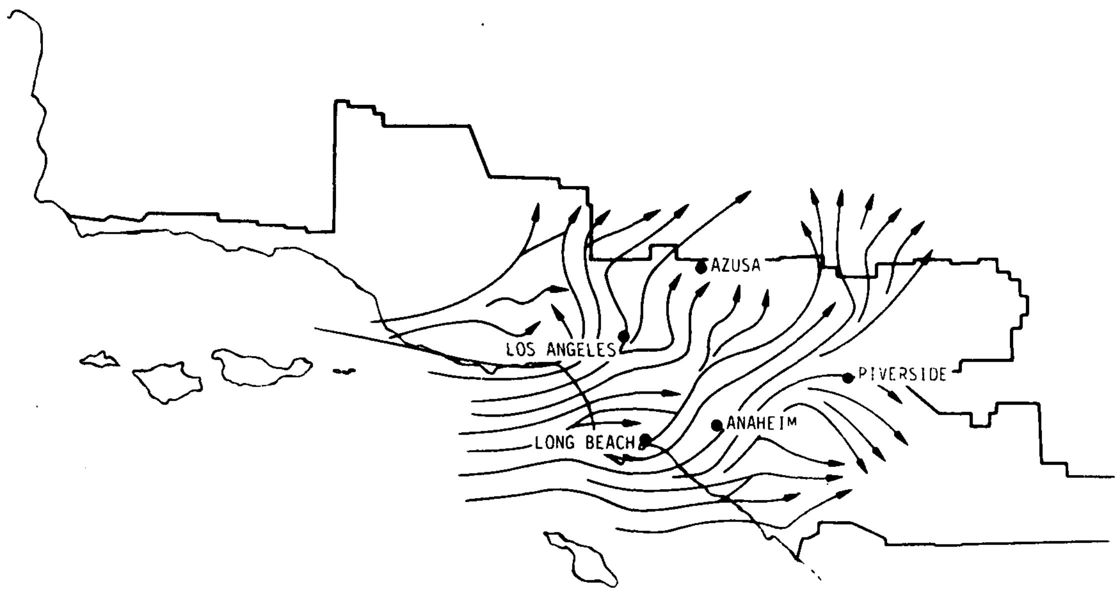


Figure 4.11. Typical Autumn Afternoon Airflow and Critical Sites in the South Coast Air Basin (Source: Task Report 6, Fig. 3.2)

TABLE 4.6

AUGUST-OCTOBER SMOG STATISTICS FOR 1969 AND 1970

(Source: Task Report 6, Table 3.1)

	1969	1970
Number of alerts	4	5
Number of days with eye irritation	65	57
Number of days on which oxidant > 0.1 ppm hourly average*	88	84
Number of days on which $NO_2 \geq 0.25$ ppm hourly average*	41	40
Number of days on which CO $\geq$ 10 ppm for 12 hours*	50	52

*California state standard in force in 1970.

air quality simulations, meteorological conditions observed in the smog episode of late September 1969 were used, primarily because the available data is unusually extensive and had previously been used in the calibration and validation of the DIFKIN model.

Baseline worst-case pollutant concentrations are summarized in Table 4.7. In the case of secondary pollutants (ozone and nitrogen dioxide), both DIFKIN and rollback results are presented; they compare favorably, differing principally as would be expected because of changes in emissions mixes not accounted for in rollback. Both methods lead to the same conclusion: major decreases in secondary pollutants may be expected in future years. In the case of ozone, the Federal standard will nonetheless be exceeded on the worst-case day and probably several other days, but this is to be compared with excesses recorded during over 1500 hours at Riverside in 1970. No worst-case hourly or daily average is prescribed in Federal air quality standards for nitrogen dioxide, but the 1970 hourly maxima of Table 4.7 were accompanied by annual means about equal (in the worst Basin locations) to the standard. Thus the baseline projections of Table 4.7, representing a fourfold reduction in hourly maxima, suggest that the standard will be met. In contrast, the sulfur dioxide and particulate standards do not appear likely to be met.

Pollutant reductions due to upper-bound usage of electric cars are shown in Table 4.8. As in the case of emissions reductions, the low leverage of the electric cars--except for carbon monoxide--is apparent. Overall, the introduction of electric cars is likely to bring about a relatively small further change beyond that already in prospect due to improving control of conventional automobile emissions. In no case will the upper-bound usage of electric cars bring excessive pollutant concentrations of the baseline into compliance with Federal standards. In the case of sulfur dioxide, on the contrary, high electric car use moderately aggravates the already excessive pollutant concentrations in prospect. These concentrations appear in relatively small areas downwind of fossil-fuel power plants in the Basin; they may be reduced to acceptable levels when stack scrubbers are brought into use, as seems possible in the 1980s.

TABLE 4.7

BASELINE POLLUTANT CONCENTRATIONS, SOUTH COAST AIR BASIN

(Source: Task Report 7, Tables 3.9, 3.11, 3.14)

Pollutant	Measure		Federal Standard	1970 Maximum	Projections				Location
	Units	Period			1980	1990	2000	1980D	
Ozone	pphm	1 hour	8	62	16*	15*	15*	12*	Riverside
					16	13	13	17	
NO_2	pphm	1 hour	---	43	12*	10*	11*	13*	Azusa/Anaheim
					14	13	14	17	
CO	ppm	1 hour	35	54	13	7	7	14	Lennox
SO_2	pphm	1 year	3.0	2.6	3.9	4.1	3.9	3.9	Reseda
Particulates	$\mu g/m^3$	24 hours	260	357	402	437	464	402	Anaheim

*DIFKIN simulation result; other projections from linear rollback.

TABLE 4.8

CHANGE IN POLLUTANT CONCENTRATIONS DUE TO ELECTRIC CAR USE, SOUTH COAST AIR BASIN

(Source: Task Report 7, Tables 3.10, 3.12, 3.15)

Year	Percent Electric Car Use	Ratio of Pollutants With and Without Electric Cars				
		Ozone*	NO_2*	CO**	SO_2**	Particulates**
1980	20	0.99/0.94	0.92/0.97	0.86	1.07	0.96
1990	80	0.90/0.88	0.86/0.99	0.74	1.14	0.79
2000	100	0.87/0.84	0.88/0.88	0.67	1.07	0.80
1980D	20	1.04/0.94	0.92/0.93	0.86	1.07	0.96

*(DIFKIN result)/(Rollback result).

**Rollback result.

Because Los Angeles is atypical in its meteorology and photochemistry, the air quality projections of Tables 4.7 and 4.8 are inapplicable to most other large US urban areas. The emissions projections, however, exhibit an underlying condition for air quality which may be expected elsewhere: rapid reductions in both the overall quantity of air pollutant emissions and the relative importance of automotive emissions. These are simply the developing impacts of the Clean Air Act of 1970, which adopted as a national goal the elimination of 90% of conventional automobile emissions by 1977.

5 ENERGY IMPACTS

5.1 BACKGROUND

Because future energy supply and demand has been repeatedly analyzed in recent years, existing studies and projections were relied upon here as much as possible. The 1972 report on the US energy outlook by the National Petroleum Council was employed as background. Recent studies of the California situation by Stanford Research Institute (SRI) and the RAND Corporation supplied the regional setting. Detailed projections and plans by the electric utilities serving the South Coast Air Basin provided local detail.

The future energy situation assumed in the baseline projections resembles the second of four alternatives detailed by the National Petroleum Council. It is characterized by rapid future growth in nuclear power generation, oil importation near present levels through the 1970s, and eventual independence of oil importation in the late 1980s. As noted in Sec. 2, the baseline transportation projections of this study include rising automobile efficiency and consequent moderation in gasoline consumption. Reasonably stable gasoline prices are assumed, in the range of 50¢ to 80¢ per gallon (in 1973 dollars, including taxes). This assumption, of course, is very uncertain, since world oil prices are now set by an international cartel.

5.2 ELECTRIC ENERGY BASELINE

In line with RAND, SRI, and utility forecasts of baseline growth in per capita energy consumption, Fig. 5.1 shows the electric energy consumption baseline projected for the South Coast Air Basin. The growth rate, about 4-1/2% per year, is considerably less than in the past, but the total increase projected from 1970 to 2000 is nevertheless about 300%.

The baseline electrical generating capacity is projected in Fig. 5.2. In the near term, it follows the facilities plans of Air Basin utilities:

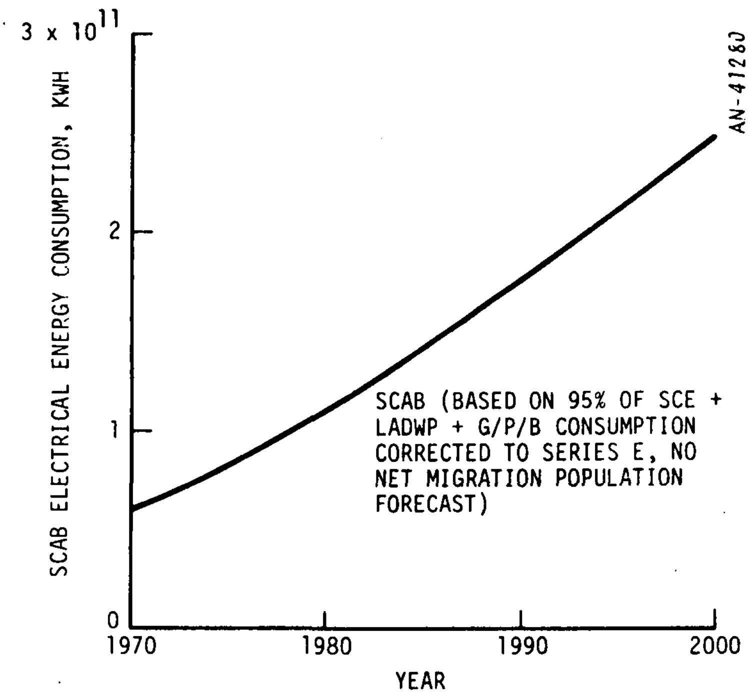


Figure 5.1. Projected Baseline Energy Consumption, South Coast Air Basin (Source: Task Report 5, Fig. 3.8)

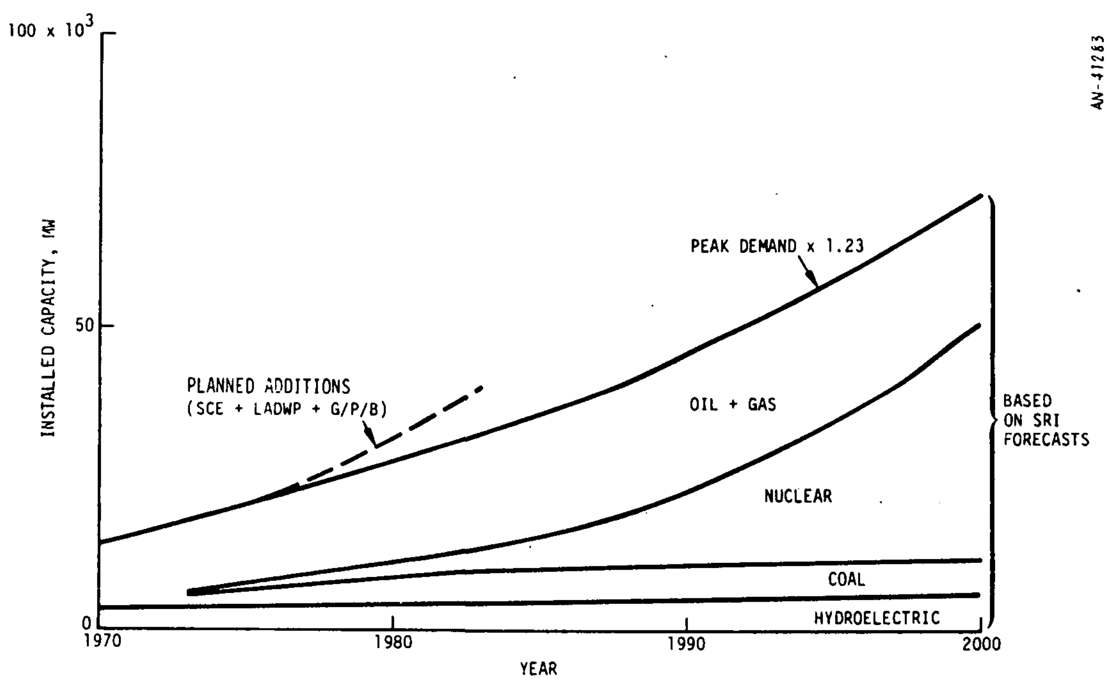


Figure 5.2. Projected Electrical Generating Capacity, South Coast Air Basin (Source: Task Report 5, Fig. 3.11)

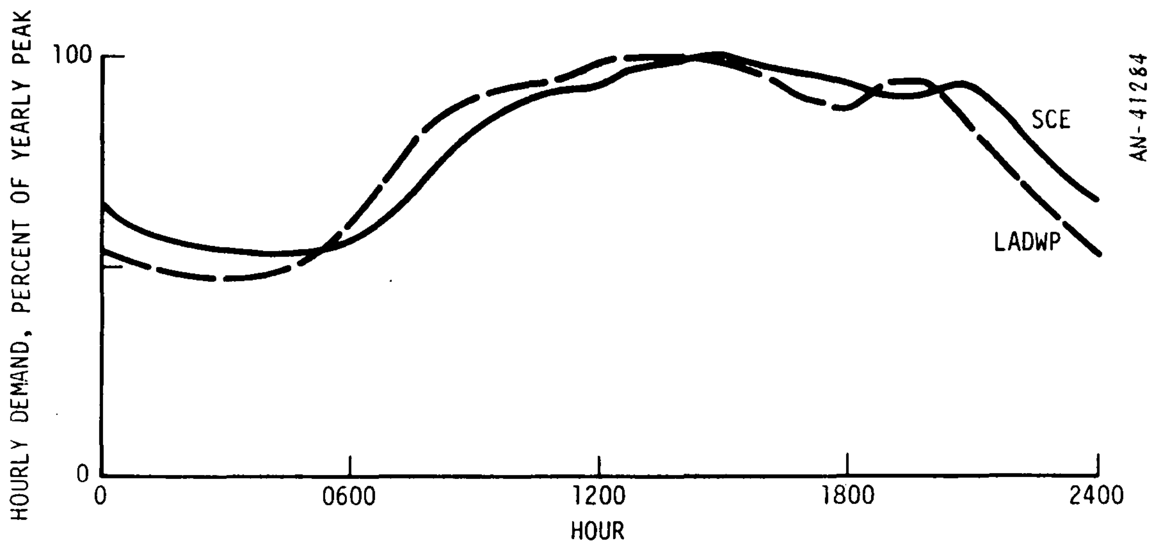
Southern California Edison (SCE), Los Angeles Department of Water and Power (LADWP), and the Municipal Utilities of Glendale, Burbank, and Pasadena (G/B/P). After 1978, however, these plans (though now lagging behind schedule) call for faster growth than is needed to meet the demand forecast of Fig. 5.1. Accordingly, the projection for later years in Fig. 5.2 is simply taken as 1.23 times the peak demand projection. The factor 1.23 allows 18.6% reserve capacity at peak load, a figure projected by SRI as appropriate for scheduled maintenance and a margin of safety.

Figure 5.3 shows recent hourly demand profiles for SCE and LADWP, which provide around 95% of the Air Basin's electricity. They are in reasonable agreement, both peaking with air conditioner demand on summer afternoons; even on the peak day, demand drops to about half the afternoon maximum after midnight.

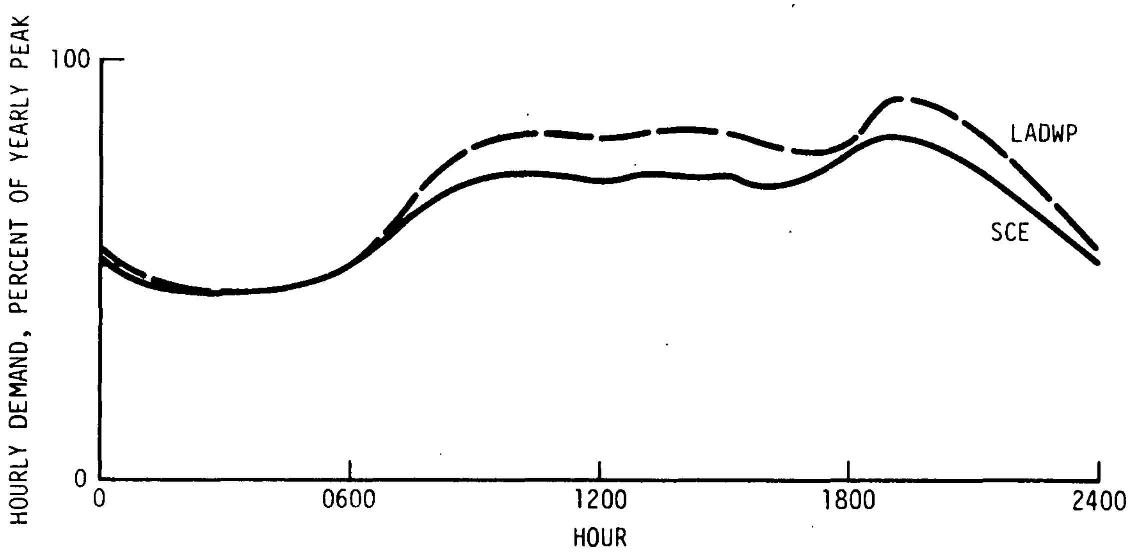
Baseline projections of peak-day and average-day supply and demand profiles for electric power in the South Coast Air Basin are shown in Fig. 5.4. These projections assume the overall demand growth of Fig. 5.1, the daily fluctuation of Fig. 5.3, and the availability of power from different sources of Fig. 5.2. They further assume that base loads will be taken over by future nuclear and coal power stations, leaving the higher-cost oil-fired power generation to be used increasingly for meeting peak loads.

All these assumptions are uncertain at best. The overall energy situation, and the particular future of electric power generation for Southern California, are both areas in which alternatives are under intense debate and future courses of action have not yet clearly emerged.

The demand fluctuations of Fig. 5.3 may be inapplicable in the future for several reasons. On the one hand, changed rate structures to encourage off-peak use or to discourage peak use could flatten the profile substantially. On the other hand, rising rates may decrease overall

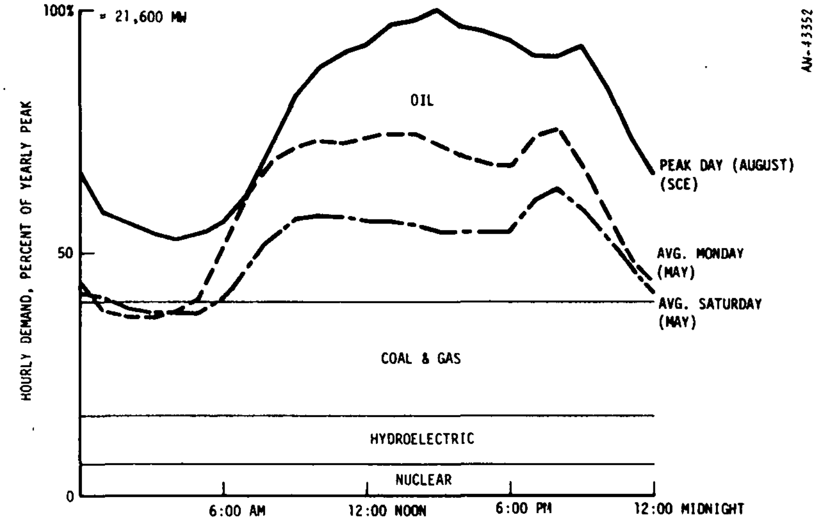


a) Typical Peak Month

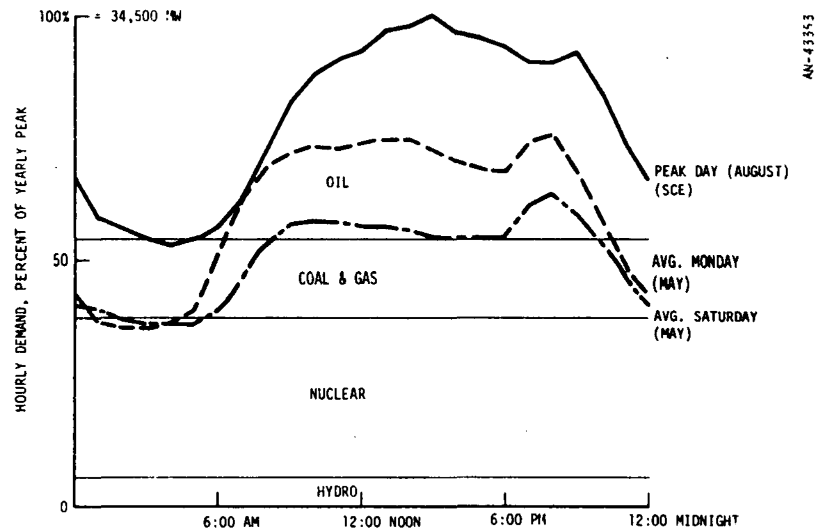


b) Typical Off-Peak Month

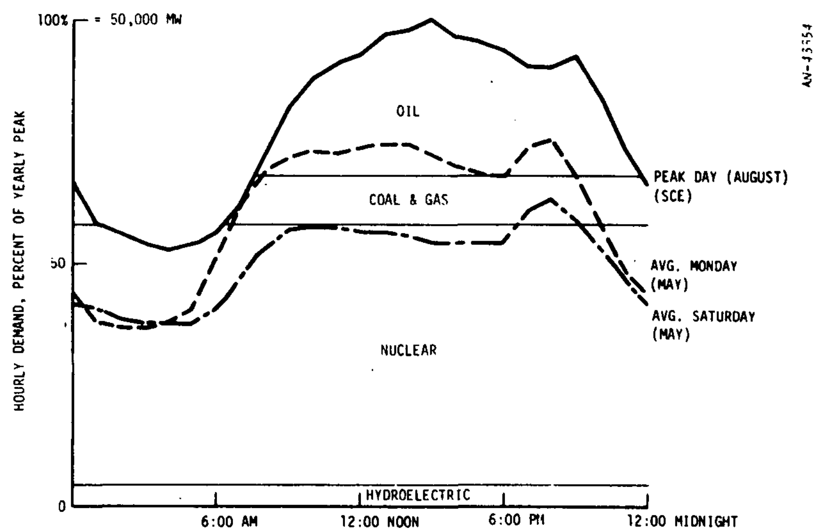
Figure 5.3. Variation in Hourly Electric Power Demand, 1973 (Source: Task Report 5, Fig. 3.12)



a) 1980



b) 1990



c) 2000

Figure 5.4. Profile of Hourly Electric Power Demands with Projected Supply, South Coast Air Basin (Source: Task Report 5, Fig. 3.13)

consumption without much depressing peak demands, as for air conditioning on very hot afternoons, and consequently exaggerate the daily variation in demand.

On the supply side in Fig. 5.4, there are also important uncertainties. The plans of regional utilities to build nuclear plants have not yet received all necessary permits and approvals, and intense debate over public safety and environmental pollution continues. Systematic conversion of oil-fired plants to coal could be required as a matter of national policy. Finally, if electric storage batteries are sufficiently improved, energy stored during early morning hours could be used to meet peak demands of the afternoon; substantially less generating capacity would then suffice, allowing the construction of less new capacity, whether nuclear or other, or earlier retirement of existing oil-fired facilities, or some combination of the two.

Given the projections of Figs. 5.4, considerable reserve capacity will be available even on the peak-demand day during the early morning hours. This capacity could be used for electric car recharge; if it were, oil would be the additional fuel principally consumed on the peak day in 1980 and 1990. The capacity potentially available for electric car recharge is shown in Fig. 5.5. The unused generating capacity is assumed to be as shown in Fig. 5.4, with recharge done late at night and in the early morning hours, and total demand including recharging limited to 85% of the annual peak so as to provide for necessary maintenance. On the average day rather than the peak day, much more power would be available. Also shown in Fig. 5.5 are the recharge requirements for 100% electric car use, given the baseline auto mileage projections of Sec. 3 and each of the per-mile electric car energy requirements of Sec. 2.

Even at rapid rates of electric car introduction, as will be discussed in Sec. 8, it appears unlikely that the required recharge power would exceed the available generating capacity projected, even for the peak day of the year. Thus generating capacity for recharge poses no limitations

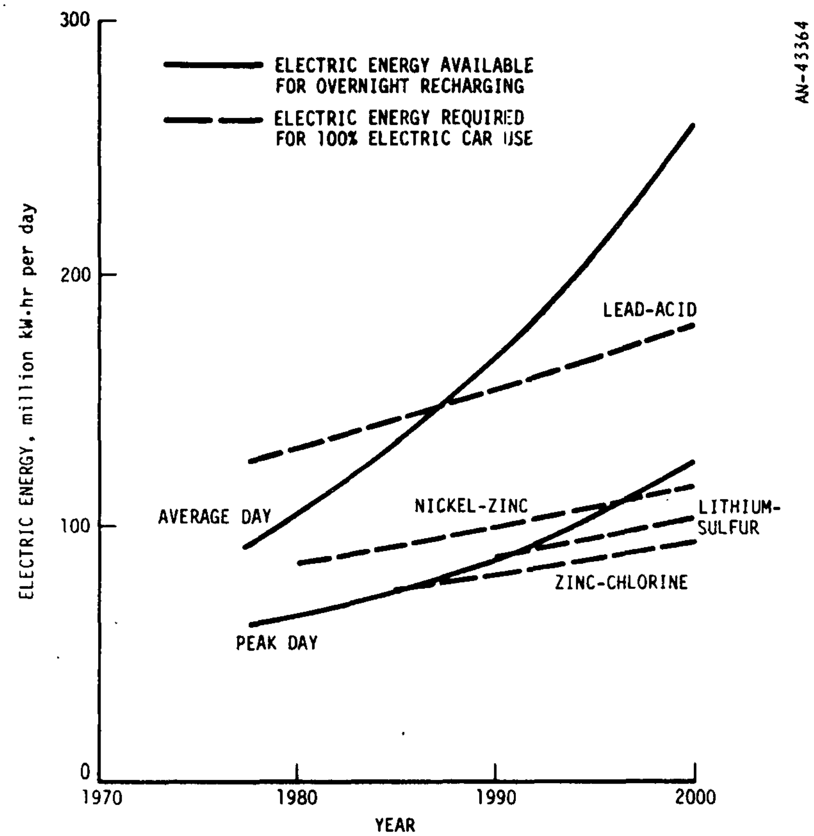


Figure 5.5. Projected Electric Car Recharge Energy, South Coast Air Basin (Sources: See Text)

on electric car use--unless, of course, baseline electric energy projections are not fulfilled. This might come about if advocates of reduced growth, environmental protection, neighborhood preservation, or nuclear safety prevail in legislative and judicial proceedings over utility plant expansion. It might also come about if rapid advances in battery technology permit utilities to store substantial quantities of electricity economically, allowing sizing of their generating facilities for average rather than peak loads. In this instance utilities might be expected to build additional new facilities only as required to serve electric cars (unless restrained by the forces just noted); if these new facilities were nuclear, then electric car use even on the peak day would not require petroleum fuels.

5.3 ENERGY IMPACTS

The energy consumption of prospective conventional and electric cars in the South Coast Air Basin is shown in Fig. 5.6. The average ICE car is expected to become much more efficient in its fuel usage, as discussed in Sec. 3. Energy usage for ICE cars in Fig. 5.6 includes a 10% penalty for refining energy in excess of that required in the production of power plant fuels from crude oil. Energy usages for electric cars in Fig. 5.6 assume a power plant efficiency of 36% (9500 Btu/kWh), and 91% transmission efficiency, as projected by SCE.

Overall, advancing battery technology promises to keep electric cars a bit ahead of the advancing efficiency of the average ICE car. It must be noted, however, that the electric cars are all low-performance subcompacts, in contrast to the larger "average" ICE car. In comparison with ICE subcompacts, as represented by the current Pinto and Honda in Fig. 5.6, the lead-acid battery car is relatively inefficient, and the advanced battery cars offer modest improvements which may well be matched by engineering progress in ICE subcompacts. The Pinto was the best selling subcompact in the Los Angeles region in 1973; the Honda led all subcompacts in fuel economy as measured by EPA for 1974 models.

In comparison with the average ICE car of Fig. 5.6, electric cars would offer some saving in petroleum use even if recharging were entirely dependent on petroleum-fired electric power generation. Under the baseline projections of this study, however, energy sources other than petroleum will become available for at least a portion of overnight recharging on the average day, as shown in Fig. 5.4. In consequence, usage of electric cars instead of average ICE cars would reduce petroleum consumption considerably more than Fig. 5.6 alone would imply. This is illustrated in Fig. 5.7, which shows savings in petroleum use for automotive travel as a function of percentage auto travel by electric cars, for each electric car characterized in Sec. 2. The "typical" weekday of Fig. 5.7 is a composite of typical weekdays for all 12 months of the year; thus the

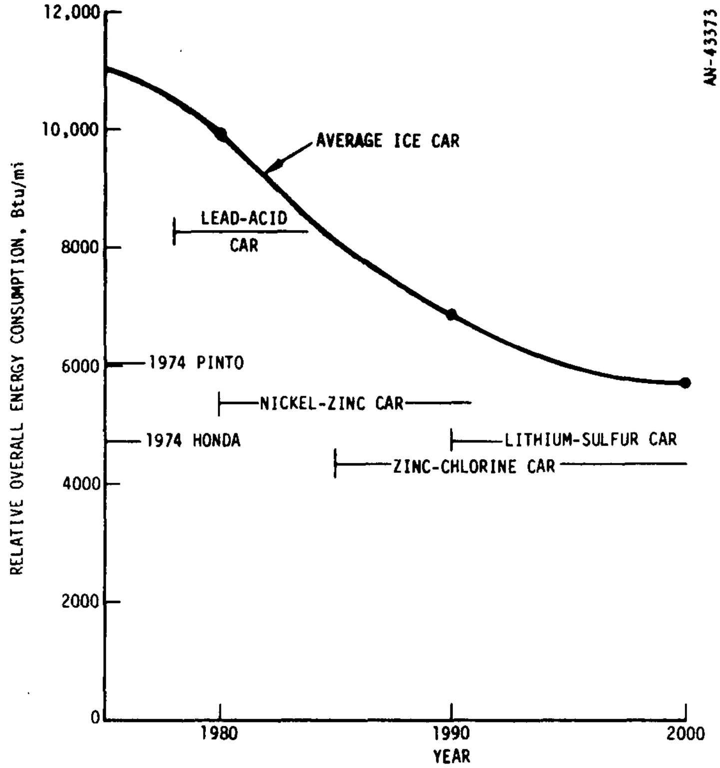


Figure 5.6. Comparative Auto Energy Consumption (Sources: Task Report 8, Tables 2.1 and 2.2; EPA 1974 Fuel Economy Measurements)

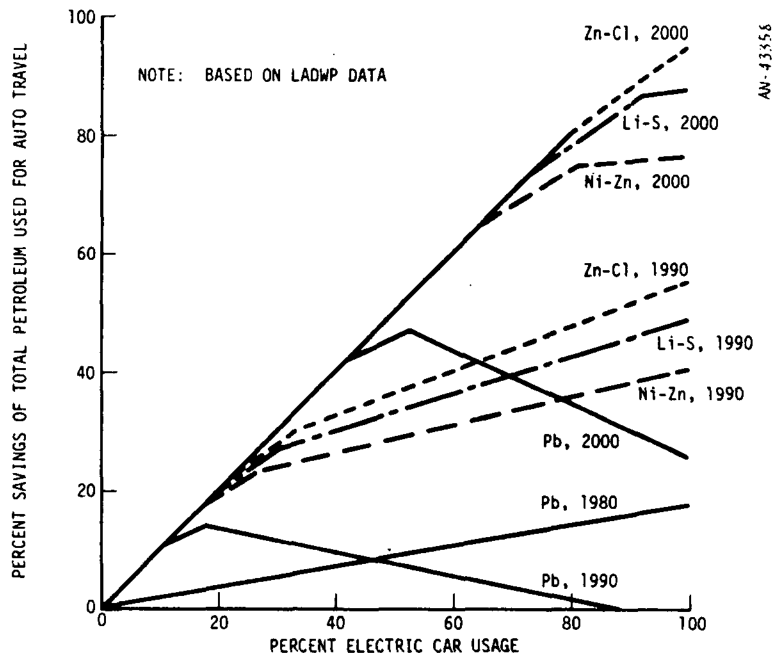
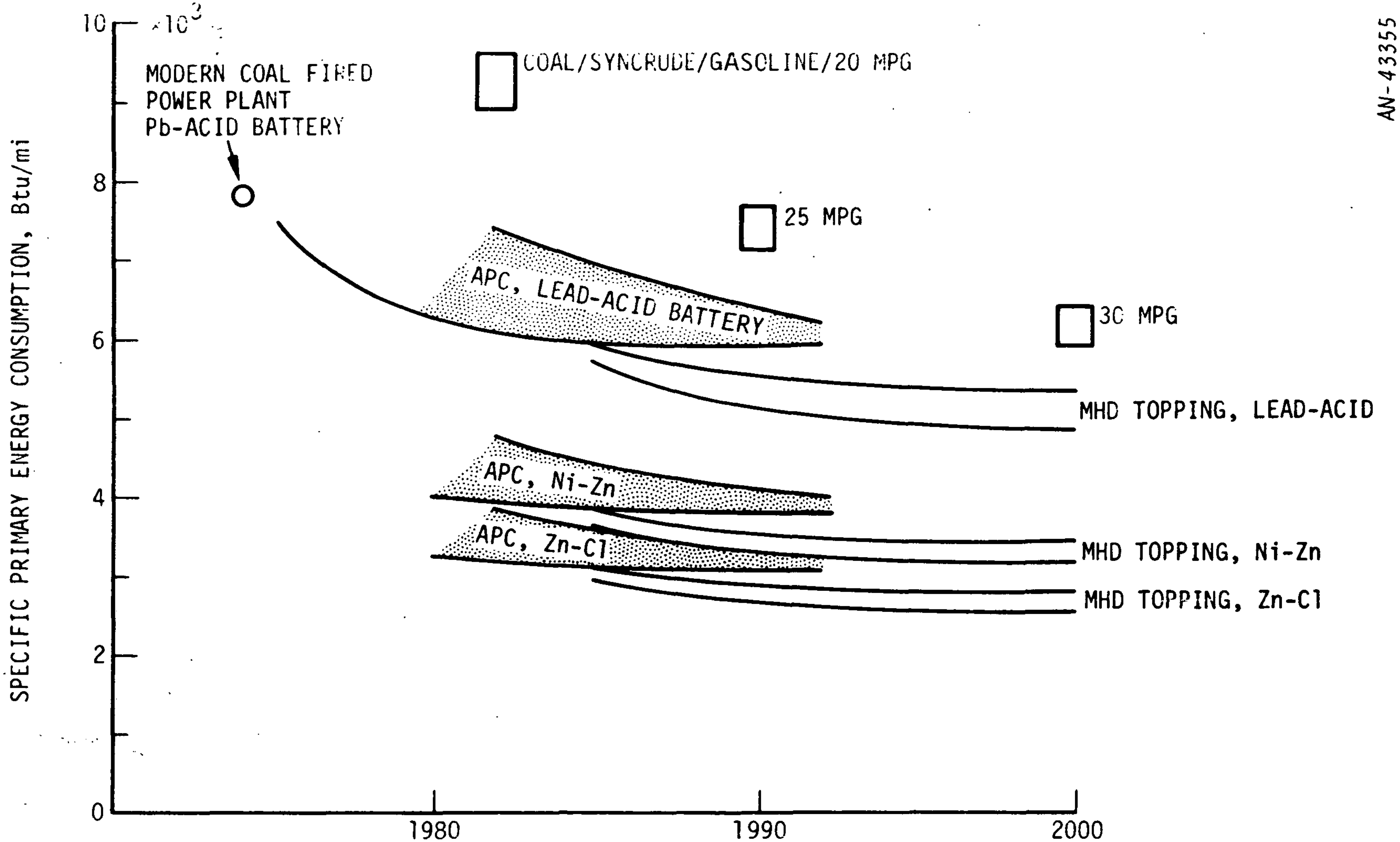


Figure 5.7. Petroleum Savings as a Function of Electric Car Usage, South Coast Air Basin (Source: Task Report 8, Fig. 2.7)

savings it shows in petroleum use are approximately those which could be achieved during a full year of electric car use. In general, low usage of electric cars can be almost entirely accomplished with recharge from nuclear power in 1990, so that initial petroleum savings are proportional to electric car use. At higher levels, where oil-fired recharge power is required, electric cars produce further saving on account of their greater overall fuel economy (compared to the "average" ICE car), but the rate of increase with electric car use is much less rapid.

At very high levels of use, electric cars must replace average ICE cars, as assumed throughout in Fig. 5.7. At low levels of use, however, electric cars might replace only subcompacts, in which case petroleum savings would be much less. On the other hand, the baseline projection of fuel economy for the average ICE car could prove overoptimistic, in which case savings due to electric car use could be significantly increased at every usage level.

In the baseline projections, relatively little additional generation of electric power from coal is included. Much-increased dependence on coal, however, is an important possibility in the US, not just for electric power generation, but also for production of synthetic crude oil and gasoline for automotive propulsion. In both these applications, important technological advances are likely: production of gasoline from coal itself is a significant technological innovation, while Advanced Power Cycles are being developed for improved efficiency of coal use in electric power generation. Some of these prospects are illustrated in Fig. 5.8, which compares the energy content of coal which would be required in various future years for automotive transportation by ICE cars and electric cars. While there are many uncertainties, it appears that as much as 50% less coal could be required in future years to propel electric rather than ICE cars.



APC = COAL/GAS/BRAYTON/RANKINE
MHD TOPPING = COAL/MHD/RANKINE

Figure 5.8. Comparison of Alternative Uses of Coal for Automotive Transportation (Source: Task Report 8, Fig. 2.1)

6 RESOURCE IMPACTS

Requirements of copper, steel, plastics, and other common materials for the electric cars of Sec. 2, without batteries, are modest in relation to overall US demand. At present auto sales rates in the South Coast Air Basin, for example, 100% substitution of the electric cars of Sec. 2 for conventional new cars would increase US copper demand less than 1%. The batteries of the electric cars, however, require various less-common materials; the amounts necessary could potentially impact US markets substantially, or even exceed domestic reserves.

Table 6.1 summarizes the resource impacts of key battery materials for maintaining large numbers of cars in the Los Angeles region. As indications of material availability, Table 6.1 shows US primary production and demand in 1968 and as projected to the year 2000, both from US Bureau of Mines data published in 1970. Electric car requirements are stated in terms of annual need for maintaining a given level of electric car usage, as opposed to building up the electric car population and its battery material inventory. Finally, significant impacts are noted, where they occur, for possible usage of electric cars both in the South Coast Air Basin and nationwide.

Comparison of the production and demand columns of Table 6.1 to the annual requirement column shows the prospective overall level of market impact, and the extent to which imports, foreign dependence, and foreign payments would be involved. Where electric car requirements are a small fraction of US primary production--that is, production exclusive of recycling--imports would be unnecessary. Where the electric car requirements are large compared to US primary demand, the major impact would probably be to increase imports. In the particular case of titanium, present production of titanium metal is near zero, and US demand is quite small. Production of and demand for titanium compounds, however, is very much larger. Table 6.1 shows the titanium content of such compounds, on the assumption that extraction of the metal could and would be undertaken to fulfill electric car demand.

TABLE 6.1

BATTERY MATERIAL PRODUCTION AND CONSUMPTION

(Source: Task Report 8, Table 3.5)

Battery Type	Material	Quantities, Thousands of Tons per Year: US Primary Production 1968	US Primary Production 2000 (Range)	US Primary Demand 1968	US Primary Demand 2000 (Range)	Annual Electric Car Consumption,* South Coast Air Basin	Percent Electric Car Use Assumed, for Future Year	Significant Impact**: South Coast Air Basin Implementation	Significant Impact**: Nationwide** Implementation
Lead-Acid	Lead	354	520-1,120	880	1,300-2,800	22	17%, 1980		X
	Antimony	1.9	2.5-4.8	21.1	28-52	0.6	17%, 1980		X
Nickel-Zinc	Nickel	15	36-52	160	382-550	29	46%, 1990		X
	Zinc	529	786-1,500	1,406	2,040-4,000	20	46%, 1990		
Zinc-Chlorine	Zinc	529	786-1,500	1,406	2,040-4,000	12	100%, 2000		
	Titanium (Metal)	305 (0)	670-1,610 (0)	440 (13)	960-2,160 (62-234)	9.5	100%, 2000		X††
	Chlorine	8,400	26,400-43,900	8,400	26,400-43,900	130†	100%, 2000		
Lithium-Sulfur	Lithium	2.9	9.4-14.4	2.6	8.7-13.1	3.2	100%, 2000	X††	X††
	Graphite	3.0	4.0-4.7	60	80-135	50†	100%, 2000	X	X
	Sulfur	11,000	28,000-45,000	10,000	26,000-41,500	128†	100%, 2000		

*Assume constant electric car population, 2-year battery life, and 90% material recycling. This does not include inventory buildup in cars on the road.

**Significant impacts are assumed wherever annual materials requirements exceed 20% of US primary demand for that year, as determined by linear interpolation between the 1968 demand and the midpoint of the range projected for 2000. National requirements for materials are assumed to be 20 times those for the South Coast Air Basin.

†No recycling assumed for this material.

††Electric car requirements for these materials would impact on production capacity for metallic forms.

The annual requirement column of Table 6.1 assumes the usage of electric cars tabulated in the adjacent column, with two-year battery life and 90% recycling of battery materials. A two-year life is relatively brief, even for lead-acid batteries, and tends if anything to overestimate the amount of battery material to be replaced each year. 90% recycling is the figure currently indicated for lead (in lead-acid battery data from the Battery Council International), and may also lead to overstatement of material requirements. The batteries required by the electric cars described in Sec. 2 are much more valuable than conventional auto batteries as salvage; recycling rates would tend to increase as a result. Again, the effect is to make the annual requirement of Table 6.1 conservatively large.

The maximum likely usage of lead-acid electric cars, as shown in Sec. 8, is for 17% of Los Angeles area travel in 1980. The resultant lead and antimony requirements are well under 10% of 1968 US primary demand, and hence not deemed likely to produce significant impacts. Nationwide, however, a 17% population of such cars would require 20 times the quantities of materials in Table 6.1; and this would clearly impact the metal market significantly.

Though nickel is a relatively scarce material, nickel for nickel-zinc batteries would not significantly impact the national market if electric car usage in Los Angeles reached the 46% level in 1990, the maximum foreseen in Sec. 8; but at 100% usage it would approach the significance threshold adopted in Table 6.1. The US is highly dependent on nickel imports; at $2 a pound, 29,000 tons of nickel imported per year would cost over a hundred million dollars and alter the US balance of payments accordingly.

The material requirements of the zinc-chlorine battery are relatively moderate, even for 100% usage in the Los Angeles area. For national implementation at the 100% level, however, the titanium (compound) market would be significantly perturbed.

The lithium required for lithium-sulfur batteries could impact national markets significantly, even for electric car usage only in Los Angeles. The present production of lithium is quite low, apparently because demand is low, and it is interesting to note that the US has been an exporter of the metal. Because production is quite small, it could probably be expanded to cope with electric car needs for Los Angeles, but national needs would be much more difficult. The US demand for graphite could be nearly doubled by demands for these batteries in the Los Angeles area alone. Graphite, however, is relatively inexpensive (around 10¢ a pound, in comparison with some $10 a pound for lithium), and world production would probably expand rapidly to meet such a demand increase.

Given the two-year battery life and 90% recycling of Table 6.1, the annual requirement listed is 5% of the total material inventory in battery cars. A buildup of this inventory over twenty years would annually require as much as the tabulated maintenance requirements in Table 6.1. Thus, to arrive at the steady-state conditions discussed so far would increase the tabulated requirements over a twenty-year period by a factor rising from one to two.

Another view of the materials inventories required in electric car batteries is presented in Table 6.2. This table shows US and world reserves, according to Bureau of Mines estimates, for important battery materials, and also the inventories of battery materials required for electrification of all Los Angeles automobiles and all US automobiles. Generally, world reserves are large in comparison with tabulated requirements for the Los Angeles region. For full national use of electric cars, however, even world reserves would be seriously impacted: "rolling" inventories of lead, antimony, lithium, nickel, and zinc in such electric car usage would amount to between 22 and 72% of tabulated world reserves.

TABLE 6.2

MATERIAL RESERVES AND REQUIREMENTS

(Source: Task Report 8, Table 3.6)

	Estimated Reserves, Thousands of Short Tons		Maximum Inventory Required for 100% Electric Car Use in 2000	
	US	World	South Coast Air Basin	United States*
Lead	39,000	99,000	3,550	71,000
Antimony	110	4,000	91	1,820
Nickel	900	>75,000	1,360	27,200
Zinc	78,000	90,000	1,000**	20,000**
Titanium	25,250	160,000	188	3,760
Lithium	5,254	6,036	64	1,280
Graphite	600	∿100,000	106	2,120

*Assumes national requirement is 20 times that of South Coast Air Basin alone.

**Determined by nickel-zinc battery car; requirements for zinc-chlorine battery are about 24% of these amounts.

Generally, of course, it must be recognized that reserves are calculated on the basis of known deposits from which materials may be extracted at specified prices, usually near those prevalent at the time of the estimate. New discoveries of mineral deposits, new production technology, and increases in materials prices can all cause reserve estimates to increase significantly. Recent major increases in nickel prices, for example, have made extraction from laterite deposits profitable, warranting major additions to the reserves shown in Table 6.2.

7 ECONOMIC IMPACTS

7.1 IMPACT ON TRANSPORTATION CONSUMERS

For the consumer, the electric car will be important in its direct impacts on the costs of automotive travel. Prospective costs for the electric cars characterized in Sec. 2 are summarized in Table 7.1, together with baseline cost projections for both subcompact and standard ICE cars.

Table 7.1 generally follows the format of the annual DOT publication Cost of Operating an Automobile, from which the ICE costs were primarily derived. To this format, in the last two lines of Table 7.1, are appended financing charges and total costs which include them. Financing charges were computed as though purchase costs of cars and propulsion batteries were amortized in equal payments throughout their lifetimes, at a 10% annual rate of interest. This rate is a compromise between the higher interest charges customary in auto financing, and the lower interest income that consumers forego on the equity they have in a car. The financing charge is necessary to reflect the considerably higher average investment which consumers must eventually support in electric cars.

For the ICE cars of Table 7.1, recent DOT figures are modified in two respects. First, additional initial and recurrent costs of antipollution devices are added in accord with estimates developed by the Environmental Protection Agency. Second, gasoline and oil prices are adjusted upward to the range of 50-80¢ per gallon for gasoline, as is projected to prevail (in 1973 dollars) through the study period. It should be noted that the DOT fuel economy figures were not modified; thus the major improvements projected in Fig. 3.5 are not reflected in Table 7.1. For the average Los Angeles car, these improvements could reduce fuel costs by about two-thirds of a cent per mile in the year 2000.

For the electric cars of Table 7.1, a 20% longer life was assumed than used by DOT for ICE cars. Considering the probable long life of

TABLE 7.1

PROJECTED LIFE-CYCLE CAR COSTS

1973 Dollars

(Source: Task Report 9, Tables 2.1, 2.3, 2.4)

Cost Item	ICE Cars*		Battery-Electric Cars**			
	Subcompact	Standard	Lead-Acid	Nickel-Zinc	Zinc-Chlorine	Lithium-Sulfur
Depreciation						
Basic Vehicle	$2,270	$4,817	$2,977	$ 2,945	$ 2,891	$ 2,795
Propulsion Battery and Replacements	0	0	4,200-10,982	6,125	993	1,440-2,400
Repairs and Maintenance	1,953	2,362	1,200	900	900	900
Replacement Tires	344	440	527	451	451	451
Accessories	57	57	69	69	69	69
Pollution Control	860	930	0	0	0	0
Gasoline and Oil***	2,004-3,484	3,097-5,395	0	0	0	0
Electricity	0	0	1,800	1,163	935	1,026
Insurance	1,376	1,485	1,782	1,782	1,782	1,782
Garaging, Parking, Tolls, Etc.	1,990	1,990	2,388	2,388	2,388	2,388
Taxes	805	1,299	1,248	1,241	1,241	1,241
Financing Charge†	1,591	3,200	3,009-3,225	4,462	2,640	2,580-2,628
TOTAL	13,250-14,730	19,677-21,975	19,200-26,498	21,609	14,290	14,672-15,680
Total Average Cost per Mile	.133-.147	.197-.220	.16-.218	.180	.119	.122-.131

*10-year, 100,000-mile life.

**12-year, 120,000-mile life.

***At gasoline prices per gallon of $.40-.70 (not including $.10 tax), with corresponding range for oil; 21.4 and 13.6 miles/gallon were assumed.

†Assumes amortization of car and propulsion battery purchase prices over respective lifetimes at 10% interest charges.

the electric car's motor and controller, and the enhanced car body life likely in the gentle climate of Los Angeles, even longer lifetimes are possible. The 20% increase of Table 7.1 assumes that lifetime will be limited by interior and exterior wear and tear, by technological obsolescence, and by style changes, which in combination will eventually lead consumers to prefer purchasing new cars to repairing and refurbishing old ones.

Electricity costs for electric car recharging were assumed to be 1.9¢ per kilowatt-hour in Table 7.1, near the average marginal rate for large residential users in a recent year. Higher rates may be coming, but their effects on total costs would be minor, since electricity amounts to less than 10% of the total electric car costs per mile in Table 7.1. Road user taxes in current amounts are assumed for both electric and ICE cars; they are included in a separate tax account rather than in fuel costs.

Like fuel costs, repair and maintenance costs for electric cars are expected to be substantially less per mile than for gasoline cars, as will be discussed in more detail in Sec. 7.2. For the next decade, however, total electric car costs promise to be near the cost of standard-size ICE cars, and substantially higher than for ICE subcompacts. This is a consequence of the large prospective depreciation and financing costs of lead-acid and nickel-zinc batteries.

In accord with Sec. 2, the high-energy lead-acid battery pack is expected to last roughly 1.3 to 3.4 years in automotive use. At a retail price of 80¢ a pound (including a 10% allowance for turn-in of the old battery), the battery pack will cost about $1,200 to replace. Even at the high usage of 10,000 miles per year, the resultant depreciation charges range from 3.5¢ to 9¢ per mile. As noted previously, the longer life and lower cost are probably optimistic.

Because of its more expensive materials and higher capability, the nickel-zinc battery pack will cost about $2,930 (or even more, if recent increases in nickel prices persist). At a life of 400 full discharges or proportionately more partial discharges (as described in Sec. 2), the total depreciation cost for this battery pack is near that of the longer-lived lead-acid battery pack in Table 7.1.

If the goals of their developers are met, the zinc-chlorine and lithium-sulfur batteries will relieve the depreciation cost problem and make electric subcompacts cost-competitive with ICE subcompacts. The developers expect an initial cost of only $600 for these batteries, which are considerably lighter than the lead-acid and nickel-zinc batteries. Life targets are 500 deep cycles and 3-5 years, respectively; but the likelihood of meeting these ambitious targets remains to be established by laboratory and in-the-field vehicular tests.

Average car costs in the Los Angeles area are between those of the standards and subcompacts of Table 7.1, and are expected to move lower as the proportion of subcompacts in the auto population increases to a projected maximum of 45% by 1990. Table 7.2 shows extra total costs of electric cars relative to these average ICE car costs, which are necessarily the proper basis for comparison if electric car usage levels are very high. At lower levels of electric car use, where primarily subcompacts would be replaced, extra total costs could be higher, as is also shown in Table 7.2.

7.2 IMPACTS ON TRANSPORTATION SUPPLIERS

<u>Baseline Projections</u>. The importance of auto-related economic activity in the South Coast Air Basin in 1971 is indicated in Table 7.3. About 3.5% of the area's economy is directly involved in supplying and supporting automotive transportation, but a larger fraction of the area's businesses are involved because of the large number of gasoline stations.

TABLE 7.2

EXTRA LIFE-CYCLE COSTS OF ELECTRIC CARS

(Source: Task Report 9, Table 2.5)

Electric Car Battery Type	Extra Life-Cycle Cost Per Mile* Relative to Average Los Angeles ICE Car	Relative to Los Angeles ICE Subcompact
Lead-Acid	1% to 37%	20% to 63%
Nickel-Zinc	13%	35%
Zinc-Chlorine	-25%	-11%
Lithium-Sulfur	-15% to -21%	-2% to -8%

*Assumes gasoline at 50¢ per gallon including tax in 1973 dollars.

Baseline total regional employment was projected for the study period as summarized in Table 7.4. Baseline activity in each of the industrial classifications of Table 7.3 was separately projected from historical trends. The auto-related employment thus determined is also shown in Table 7.4, as a percentage of total employment. This percentage grows slowly, primarily because of higher-than-average rates of employment growth in the auto distribution, supply, and repair sectors.

The employment in industries likely to be impacted by electric cars is relatively small. At under 4% of the total for the South Coast Air Basin, it stands well below current regional unemployment. Even if Los Angeles shifted entirely to electric cars in a period as short as ten years, the annual impact on regional employment would be very small. Within the individual industries of Table 7.3, however, electric car use would make major changes. As shown in Table 7.5, activity in several of these industries is highly dependent on the needs of automotive internal-combustion engine systems (including radiator, exhaust, fuel, and ignition subsystems)--needs unlikely to be paralleled in automotive electric motor

TABLE 7.3

RELATIVE IMPORTANCE OF AUTO-RELATED ACTIVITY, SOUTH COAST AIR BASIN (1971)

(Source: Task Report 4, Table 4.2)

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

TABLE 7.4

BASELINE PROJECTIONS OF TOTAL AND AUTO-RELATED EMPLOYMENT, SOUTH COAST AIR BASIN

(Source: Task Report 4, Tables 2.1, 4.5-4.7)

Year	Total Projected Employment	Projected Auto-Related Employment, Percent of Total
1980	4,335,000	3.7%
1990	4,579,000	3.9%
2000	5,025,000	4.0%

TABLE 7.5

CURRENT PERCENT DEPENDENCE OF AUTO SUPPORT INDUSTRIES ON THE INTERNAL COMBUSTION ENGINE SYSTEM

(Source: Task Report 9, Tables 3.3, 3.5, 3.6)

Service Stations	91%
Auto Parts and Supplies	44%
Auto Repairs and Service	72%

systems. In battery manufacturing, however, the situation is reversed. These cases are discussed individually, in order of importance of employment impacts, in the remainder of this section. Section 7.3 discusses the collective impacts.

Impacts on the Petroleum Distribution Industry. According to recent figures for the South Coast Air Basin, over 82% of service station sales are concentrated in gasoline and oil. After allowance for additional ICE-related sales of parts and labor, only an estimated 9.2% of sales would remain if all ICE automobiles were replaced by electric cars. For lead-acid battery cars, the reduction is partly offset by new requirements for periodic inspection and addition of water to the individual cells of the batteries. 50% of motorists were assumed to service these batteries themselves, to save the expense and time of visiting a service station; nevertheless, the prospective reduction in baseline employment for wholesale and retail petroleum distribution is 71%, assuming 100% usage of lead-acid electric cars. Other battery cars utilize battery systems for which maintenance will be largely or entirely eliminated; the consequent impacts are even greater than for lead-acid battery cars.

Impacts on the Battery Manufacturing Industry. Because battery production can be economical on a relatively modest scale and because battery materials will be largely recycled, local manufacturing of batteries is projected for electric cars in the Los Angeles region. With high levels of electric car use, much of the decrease in service station employment will be compensated by an increase in battery manufacturing employment. Of the battery candidates, only lead-acid batteries are now in production; hence the estimates of employment requirements for manufacture of advanced batteries, which here were based on discussions with battery developers, are at best relatively uncertain. Moreover, battery production rates (and manufacturing employment) for a given level of electric car use will depend on battery lifetimes, which are also uncertain.

Impacts on the Automotive Aftermarket and Repair Industry. Elimination of ICE propulsion would eliminate 44% of current sales of automotive aftermarket items, according to Table 7.5. To the remaining sales would then be added sales of replacement batteries for electric cars, which differ for each battery type depending on its prospective frequency of replacement. Except for the short-lived lead-acid batteries, however, battery sales to electric cars would be less frequent than for the ICE cars they replaced. Each battery would, of course, be a much larger unit at a much higher price for the electric cars; but a much lower percentage markup and ratio of sales effort per sales dollar is expected.

Recent reports of frequencies of ICE car services, labor involved per service, and the resultant distribution of service labor indicate that over 50% of labor hours are involved in ICE engine overhaul and tuneup alone. In total, removal of the ICE system would eliminate about 72% of car service hours. Added service requirements of the electric power train are expected to be minimal: annual inspection of the controller and motor, with motor brush replacement as necessary. Battery service for electric cars was previously assumed to be performed at service stations, and is not included here.

7.3 OVERALL ECONOMIC IMPACT

Table 7.6 aggregates the impacts that were discussed individually in Sec. 7.2, plus small additional impacts expected in the new car sales industry. In every case, substantial reductions in total regional employment are the direct result of the assumed 100% usage of electric cars. Reductions in total area personal income are relatively less, however,

TABLE 7.6

DIRECT EFFECTS ON LOCAL IMPACTED INDUSTRY DUE TO 100% ELECTRIC CAR USE IN THE SOUTH COAST AIR BASIN

(Source: Task Report 9, Table 4.1)

Year	Electric Car Battery Type	Total Direct Effects on Impacted Industries: As Percent of Total Area Employment	As Percent of Area Personal Income
1980	Lead-Acid	-0.22 to -0.79	-0.23 to +0.14
1990	Lead-Acid	-0.17 to -0.74	-0.20 to +0.15
	Nickel-Zinc	-0.88	-0.18
	Zinc-Chlorine	-1.20	-0.36
2000	Zinc-Chlorine	-1.21	-0.31
	Lithium-Sulfur	-1.15 to -1.25	-0.27 to -0.31

largely due to a shift in employment from low-pay service station jobs to higher-pay battery manufacturing jobs, as shown in Table 7.7. In the case of the shortest-life lead-acid battery, regional personal income would actually increase due to this effect.

Although auto manufacturing activity in the South Coast Air Basin is almost entirely assembly, which would presumably continue with little change even though electric propulsion replaced ICE propulsion, outside the area there would be impacts felt due to wide use of electric cars in Los Angeles. These impacts would come about through reduction of ICE manufacturing and a corresponding increase in electric motor and control manufacturing. The ICE manufacturing reduction would be small compared to annual national fluctuations in the automotive business, however, and consequently minor in impact. The national impacts on electric motor and control manufacturing would range downward from 3.3% and must also be regarded as minor.

In the employment changes of Table 7.7, individuals losing service station jobs who could find new employment in battery manufacturing would benefit through a major increase in earnings. Such cases could be few,

---

TABLE 7.7

STRUCTURE OF EMPLOYMENT CHANGES IN THE SOUTH COAST AIR BASIN DUE TO 100% ELECTRIC CAR USE, 1990

(Source: Task Report 9, Table 4.2)

	Petroleum Distribution	Battery Manufacturing	Auto Parts and Service	Auto Sales
Electric Car Type:				
Lead-Acid	-32,400	14,800 to 39,200	-14,900 to -11,400	-3,450
Nickel-Zinc	-41,500	20,600	-15,800	-3,450
Zinc-Chlorine	-41,500	6,600	-16,800	-3,450
Lithium-Sulfur	-41,500	4,600 to 8,100	-18,600 to -14,600	-3,450

however, because many service station jobs require minimal skills and are often held by those unqualified for more demanding employment elsewhere.

Beyond the direct effects of Table 7.7, secondary and tertiary impacts on regional economic activity may be expected. For 100% use of lead-acid or nickel-zinc battery cars, total regional expenditure for auto transportation would increase significantly, while regional labor inputs to supply this transportation would generally decrease. The difference would be made up by expanded regional imports from the rest of the nation, with a corresponding reduction in regional funds available for purchase and import of other needed commodities and services. Such reductions tend to depress regional payrolls. Conversely, reduced regional expenditures for zinc-chlorine and lithium-sulfur battery cars could increase funds available for extra-regional purchases and thus tend to expand regional economic activity.

8 USAGE ANALYSIS

8.1 APPROACH

The competitive disadvantages of electric cars in the auto market-place have long held their sales and usage to negligible levels. Air pollution and energy considerations external to free-market transactions, however, suggest that much higher electric car use might be beneficial overall in future years. In this section, specific higher levels of electric car sales and use are hypothesized, so that the desirability of the net impacts may be subsequently evaluated.

First, daily driving patterns in Los Angeles are analyzed to develop basic needed data: the extent to which limited-range cars are applicable to drivers' actual travel. Next a lower bound on future electric car use is developed by projecting free-market sales, and an upper bound is postulated from production lead-time considerations. Then intermediate usage levels are hypothesized as possible public policy goals, and measures required to achieve them are considered. Finally, specific schedules for introducing alternative electric cars are postulated, so that the net benefits of alternative future levels of use may be evaluated in Sec. 9.

In this analysis, as throughout this report, overnight recharging of electric car batteries is assumed. This assumption is important to usage for two reasons: first, because it implies that daily driving must be limited to the range between recharges; and second, because it also implies that availability of residential recharging facilities will be a prerequisite for electric car use.

To circumvent the range limitations of electric cars implicit in overnight recharging, systems of service stations are sometimes suggested to make available interchangeable battery packs. Such stations would maintain large inventories of battery packs on recharge, substituting fully charged for discharged packs with results equivalent to refilling the gasoline tanks of conventional cars. In any large-scale, long-term usage of electric cars with very limited range, such institutional arrangements would surely develop to supplement overnight recharging, despite the considerable associated cost. In this study, however, such prospects are not considered further, simply because improved technology, improved range capability, and therefore reduced need for battery exchange appear less than ten years away. Within that limited time, the wide development of a battery exchange system seems unlikely.

Overnight recharging of electric car batteries requires considerable amounts of electricity. At the energy consumption rates of Table 2.2, recharge energy for the average day's driving of 30 miles will range from about 12 to 24 kWh. Corresponding average recharge power levels during 8 hours are 1.5 to 3 kW. Initial recharge rates may be twice the average rates, however, so 3 to 6 kW may initially be desirable; on days of more than average driving, further increases in charging power will be required. In comparison, the standard 110-V, 15 amp AC outlet delivers 1.65 kW maximum. Evidently, then, 220-volt circuits capable of delivering 5 to 10 kW will be required for overnight recharge, and electric cars will be unattractive or infeasible for those who cannot conveniently arrange such electrical service at their car's overnight parking place.

8.2 APPLICABILITY OF LIMITED-RANGE ELECTRIC CARS

The lead-acid battery car of Sec. 2 is capable of some 55 miles of urban driving between recharges, considerably more than the 30 miles driven each day by the average urban motorist. Nevertheless, the electric car is not necessarily adequate for the average motorist, because he will occasionally wish to drive further than its range capability--even if the capability is increased far above 55 miles. The adequacy and applicability of the electric car must consequently be measured in terms of the fraction of days on which its range would probably satisfy typical driving requirements.

In this study, an electric car range adequate for 95% of urban driving days was employed as the criterion of electric car applicability. Less than a 5% sacrifice in desired urban travel is implied by this criterion, since even on problem days the electric car could provide at least a part of the desired mileage. Interurban travel is assumed here to be made by other means.

Though urban driver travel has been repeatedly surveyed in origin-destination studies across the nation, the basic analytic unit has been the single trip. This unit, unfortunately, is inadequate for the present purpose. To determine the probability that the average driver will wish to drive more than a specified range on an average day, the distribution of total trip mileages for driving days must be determined. To do so, computer tapes were obtained from the Los Angeles Regional Transportation Study detailing 197,000 trips described at 33,000 households (a 1% sample) in the 1967 origin-destination survey. A special processing program then computed and totaled mileages of trips reported by each surveyed driver for the survey day, and from these whole-day mileages developed distributions of daily driver travel.

The resultant distributions of urban travel distance on the survey day are shown in Fig. 8.1, together with the ranges selected for lead-acid and advanced battery cars. Among drivers with cars available on the survey day--that is, drivers from households reporting as many available vehicles as drivers--83% drove less than the range of the lead-acid battery cars, while 98.4% drove less than the range of the advanced battery cars. Where a single car served the needs of two drivers, the corresponding figures were lower: 55% and 95%. Since the survey disclosed that 88% of drivers had cars available, and in future years even higher automobile ownership is predicted, the upper distribution of Fig. 8.1 has been taken to define electric car applicability, rather than the more demanding lower distribution for single cars serving two drivers.

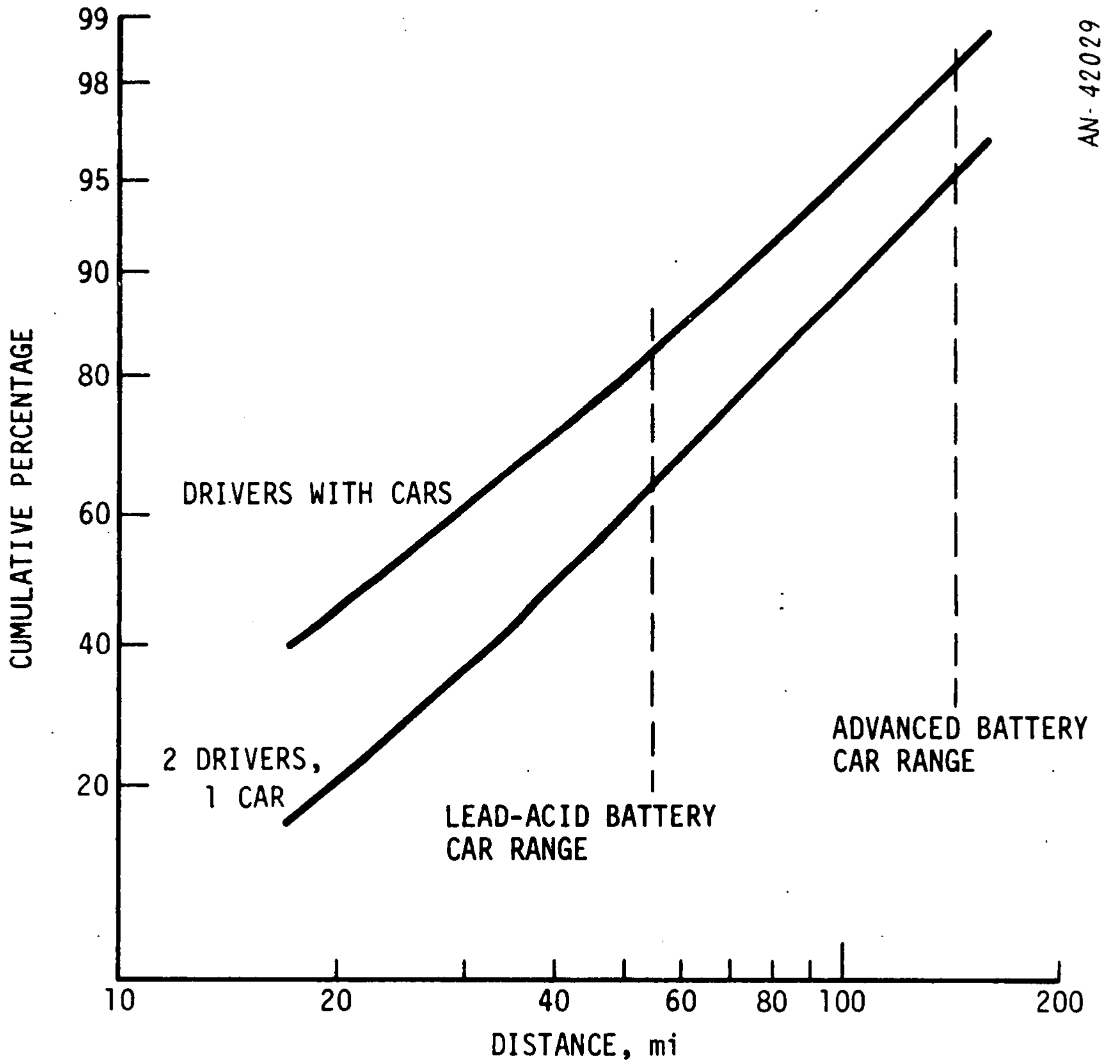


Figure 8.1. Adjusted Distributions of Daily Travel, Los Angeles Region, 1967 (Source: Task Report 10, Fig. 4.2)

Though the advanced battery-car range is generally applicable to drivers' needs by the criterion of this study (even for cars shared by two drivers), the lead-acid battery car is not. It could be satisfactory, however, in restricted circumstances. Figure 8.2 shows daily driving range distributions for secondary drivers in multicar households, computed from the basic results of Fig. 8.1 under the assumption that separate travel of individual drivers in households is uncorrelated (i.e., that two drivers in a household will not tend to plan separate long trips for the same days). The figure shows that the lead-acid battery car would be applicable to 96.6% of secondary-driver days in two-car households, where the secondary driver is defined as that driver traveling least on the given day.

For electric cars to be useful, overnight recharging facilities must be made available. This will generally require a 220-volt electric outlet near the car's parking place. Such outlets are not always feasible: according to the 1967 survey, only 74% of Los Angeles area cars had off-street overnight parking available. Furthermore, some of this off-street parking was in apartment lots or garages in which electric installations would be more difficult to arrange than at single-family houses, where the householder is in control and often has both 220-volt service and a private garage.

89% of single-family housing units reported having off-street parking in the survey, and were assumed to be able to provide recharge facilities for electric cars in 1980. 1,136,000 single-family households in the Los Angeles area are expected to have more than one car by 1980; at 89% of these, or 1,011,000 households, the lead-acid electric car might reasonably replace a conventional secondary car. In 1990, advanced battery cars with sufficient range for general use might reasonably replace all cars having off-street parking at single-family housing units. Of 4,188,000 cars expected at single-family housing units, at least 74%, or 3,099,000, should have off-street parking. By 2000, when electric cars might be in more general use, recharge provisions might be assumed available at off-street parking of all residences, that is, for 74% of all cars in the region, or 5,624,000 cars.

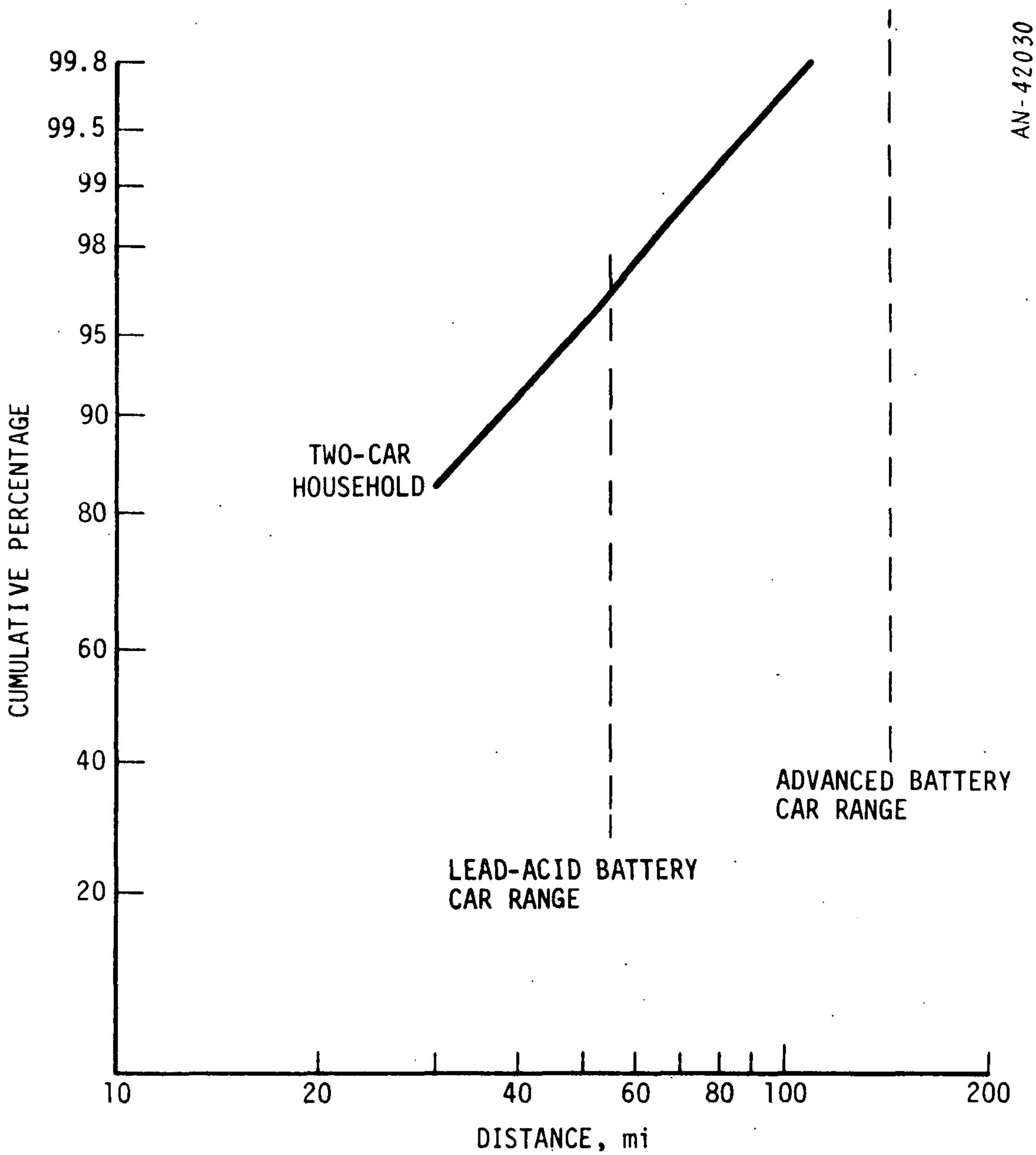


Figure 8.2. Probability of Daily Driving Less than a Given Distance for Secondary Drivers with Cars (Source: Task Report 10, Fig. 5.1)

These projections of candidates for electric car replacement in future years are shown in Table 8.1. For 1980, the candidates constitute 17% of all cars but account for only 11% of daily vehicle miles. This arises in the limited daily range and usage of secondary cars, which would be driven only 6400 miles per year rather than the usual 10,000 miles.

The numbers of candidate cars in Table 8.1 are plainly impressive. Even with the limited 55-mile range assumed for electric cars with lead-acid battery technology, over a million conventional cars could be replaced in the Los Angeles region with very little sacrifice of daily urban travel. Since driving in Los Angeles appears similar to that elsewhere in the nation, prospects are that electric cars could find comparably wide application on a national basis.

TABLE 8.1

CANDIDATES FOR ELECTRIC CAR REPLACEMENT, SOUTH COAST AIR BASIN
Source: Task Report 10, Table 5.4

	1980	1990	2000
Cars, thousands	1,011	3,099	5,624
Percent of Total	17	46	74
Daily Vehicle Miles, millions	18	90	169
Percent of Total	11	46	74

8.3 ALTERNATIVE USAGE LEVELS

Prospective free-market sales and use of electric cars place a lower bound on their usage and consequent impact. Recent electric car market studies based on consumer interviews, for example, projected that only 1 to 2% of national car sales would be captured by electric cars in 1980.*

*See Task Report 10, Sec. 6.3.

In a free-market projection for the Los Angeles region undertaken for this study, a review of price, performance, and market share data for subcompact ICE car sales in the Los Angeles area disclosed no useful quantitative relationships for projecting electric car sales. Instead, the data show that wide differences in market shares of competing conventional cars are occasioned by differences in price, performance, and style which are insignificant in comparison with the differences between ICE and electric cars. In short, there is no basis in current market share data for quantitative forecasting of electric car sales. On the other hand, the data do not show that electric cars cannot sell well: an ICE car with novel propulsion (the Mazda) captured a substantial market share despite a significantly higher price, and low-performance cars such as Volkswagen successfully competed despite power-to-weight ratios as low as those of the electric cars characterized in Sec. 2.

Since quantitative projection methods for electric car sales forecasts were not developed in this study, a qualitative approach was necessary. From qualitative consideration of the factors noted above, and from published electric car market surveys, the free-market sales of electric cars characterized in Sec. 2 were estimated by assuming capture rates of 5%, 10%, and 15% of sales to replace candidate cars for 1980, 1990, and 2000 in Table 8.1. The resultant electric car sales range from under 1% of the Los Angeles regional market in 1980 to 11.1% in 2000. The resultant regional populations of electric cars are at most a few percent. Thus the free-market case places a lower bound on electric car use which is small enough to promise little area-wide impact.

An upper bound on prospective electric car use, assuming that high usage levels were to be urgently fostered by public policy, is basically set by manufacturing lead times and acceptable scrappage rates for existing cars. Because transportation controls proposed for the Los Angeles area to assure compliance with the Clean Air Act of 1970 include drastic gasoline rationing, a high degree of urgency is implicit in public policy and hence seems appropriate in setting an upper bound on electric car use. Accordingly, the upper bound projection for electric car population is based on assumptions of an immediate decision to proceed (in 1975), a three-year lead time to production in 1978, and a production quantity to support sales amounting to 80% of projected sales for conventional cars in the Los Angeles region.

Figure 8.3 shows upper and lower bound electric car populations in future years which would result from the bounding sales projections. It also shows total regional car population (the baseline projection), and two intermediate electric car populations which could be adopted as public policy goals. The "high use" policy projection assumes auto market shares for electric cars proportional to the candidate percentages in the second

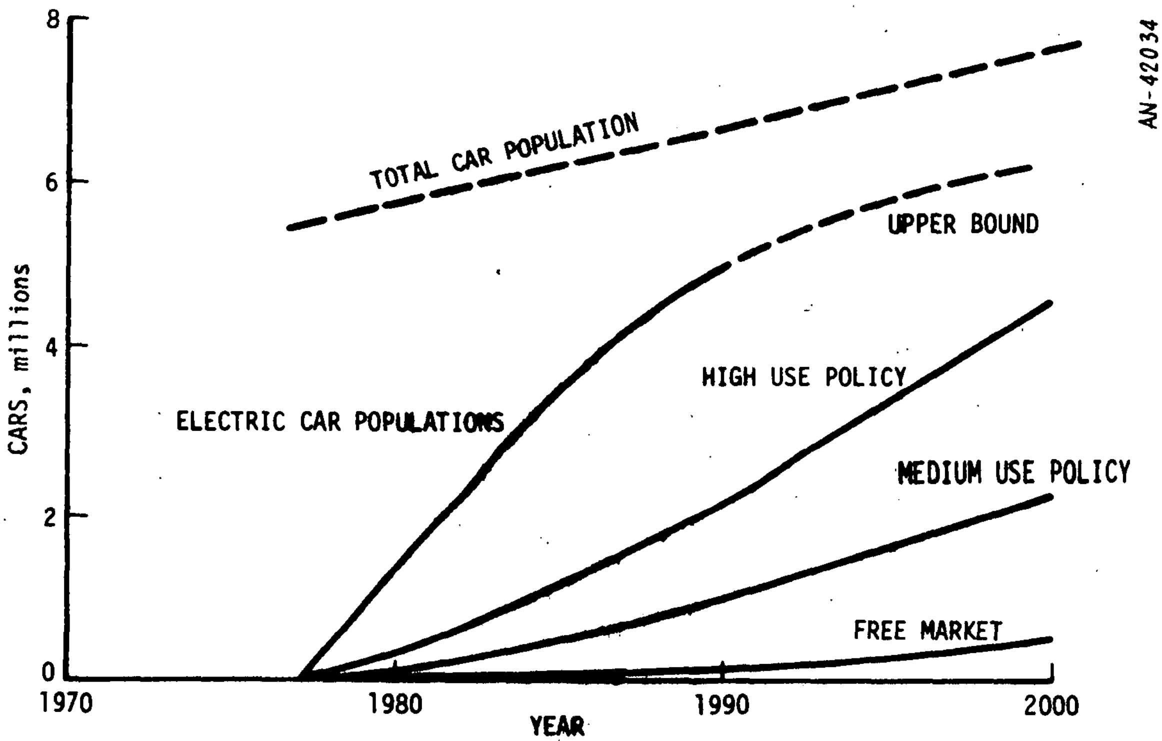


Figure 8.3. Alternative Electric Car Population Projections, South Coast Air Basin (Source: Task Report 10, Fig. 8.1)

line of Table 8.1, with linear interpolation between tabulated values, and sales beginning in 1978. The "moderate use" policy assumes electric car market shares half those for "high use."

On the one hand, the hypothetical policy goals of Fig. 8.3 are very high: they presume major changes in a major sector of the economy which are very unlikely under free-market conditions and consequently would require powerful legislation to be achieved. On the other hand, they are relatively low so far as auto impacts are concerned: even in 1990 they lead to electric car populations of less than 1 in 3, with correspondingly low leverage for the electric cars in changing regional conditions dependent on the automobile.

The probable difficulty in achieving high levels of electric car use may be appraised in terms of the relative costs of electric cars. Table 8.2 summarizes the extra initial and life costs of electric cars relative to competitive ICE subcompacts. Most of the initial cost differential is attributable to the battery; through battery leasing, this difference could be shifted to operating costs, so that the remaining extra initial cost might not be a substantial buyer deterrent, given the probable longer life and reduced maintenance of the electric car. The life cost differentials remain as shown, however, and for the lead-acid and nickel-zinc batteries they are high.

Table 8.2 shows these extra life costs both per mile and per 30-mile day, for which about a gallon of gasoline would be required to fuel the competitive ICE subcompact. If a gasoline tax were instituted to discourage the ICE subcompact by eliminating its cost advantage relative to lead-acid and nickel-zinc battery cars, per-gallon gasoline taxes of $0.81-2.55 would be required, as Table 8.2 indicates. Because of the additional performance disadvantages and range limitations of the electric cars, an even greater tax might actually be necessary to ensure their use. Any such taxes would be very painful and would inappropriately discourage total auto travel, so per-day subsidies of the electric cars

TABLE 8.2

EXTRA COSTS OF ELECTRIC CARS

Source: Task Report 10, Tables 8.2, 8.3, 8.4

	Extra Initial Cost*		Extra Life-Cycle Cost*	
Car Battery Type	Without Battery	With Battery	¢ Per Mile	$ Per 30-mile Day
Lead-Acid				
Best Life	$707	$1907	2.7¢	$ .81
Worst Life	707	1907	8.5	2.55
Nickel-Zinc	675	3615	4.7	1.41
Zinc-Chlorine	621	1221	-1.4	-.42
Lithium-Sulfur				
Best Life	525	1125	-1.1	-.33
Worst Life	525	1125	-.2	-.06

*In 1973 dollars, relative to ICE subcompact at $2270 initial cost and 13.3¢/mi operating cost (for 10,000 mi/yr and gasoline price of $.50 per gallon including taxes).

in like amounts could be preferable. In either case, heroic measures appear required to ensure substantial use of the higher-cost electric cars.

For the remaining battery cars of Table 8.2, lower total operating costs than those of conventional ICE subcompacts are indicated. Because of range and performance disadvantages, however, some sort of subsidy or differential taxation would probably be required to bring these cars into general use. Moreover, it should be noted that the cost differentials of Table 8.2 could disappear, or be reversed, if the cycle-life goals of the battery developers are not met.

To serve as a basis for overall impact evaluations and to permit clean differentiation between basic battery technologies, simple schedules were postulated for introduction of individual types of electric cars, in quantities which would permit achievement of the policy use levels of Fig. 8.3 through combinations of individual schedules. These schedules are shown in Table 8.3.

TABLE 8.3

BASIC SCHEDULES FOR ELECTRIC CAR INTRODUCTION
Source: Task Report 10, Table 8.5

Target Year	Use Policy	Elec. Car Pop. Target	Battery Type	Sales Period	Approx. Avg. Market Share
1980	High	5%	Lead-acid	1978-80	16%
1990	Moderate	15%	Lead-acid	1978-90	16%
			Nickel-zinc	1980-90	17%
			Zinc-chlorine	1985-90	30%
	High	30%	Nickel-zinc	1980-90	35%
2000	Moderate	30%	Zinc-chlorine	1990-2000	35%
			Lithium-sulfur	1990-2000	35%
	High	60%	Zinc-chlorine	1990-2000	70%
			Lithium-sulfur	1990-2000	70%

9 EVALUATION OF ALTERNATIVE USAGE LEVELS

In this section, the individual impacts analyzed in Secs. 4-7 are evaluated and summarized for the particular levels of electric car use hypothesized in Sec. 8. The impact valuations are then assessed in relative importance, so that the most desirable future levels of electric car use may be selected.

Table 9.1 summarizes the major quantitative impacts of the hypothesized levels of electric car use on air pollution, energy, and the economic situation in the Los Angeles region. It also includes subjective assessments of impacts on national markets for requisite battery materials, and the prospective degree of intervention required in the free market to bring about the indicated electric car use.

The air pollutants included in Table 9.1 (oxidant and sulfur dioxide) are the most important in the Los Angeles region among those for which national air quality standards have been promulgated: in the baseline case of this study, their concentrations are projected to remain in excess of the national standards even after expected major reductions. Ozone concentration changes in Table 9.1 were obtained from Table 4.8 for the given levels of use by simple linear interpolation. SO_2 concentration changes in Table 9.1 are expected to be near zero because the indicated usage levels require almost no petroleum-fired recharge, as Fig. 5.7 indicates, in every case but one. The exception, 30% usage of nickel-zinc battery cars in 1990, requires only about 10% of the petroleum-fired recharge energy implicit in the 80% usage level for 1990 of Table 4.8; accordingly, Table 9.1 shows a change in SO_2 level for this case which is only 10% of the figure in Table 4.8.

The petroleum use figures in Table 9.1 were taken from Fig. 5.7. Except for the lead-acid battery car cases and the case of 30% nickel-zinc battery car use in 1990, very little recharge power is expected to be generated by petroleum-fired power plants, so that the savings in automotive petroleum use are nearly equal to the fractional electric car use.

TABLE 9.1

IMPACTS OF ALTERNATIVE LEVELS OF USE OF ELECTRIC CARS IN THE LOS ANGELES REGION

(Sources: Tables 4.8, 6.1, 7.2, 7.6, 8.3; Fig. 5.7)

Situation			Percentage Changes in Regional Baselines					Implementation Problems	
Year	Electric Car Use, Percent	Battery Type	Air Pollutant Worst-Case Concentrations: Ozone	Air Pollutant Worst-Case Concentrations: SO_2	Auto Travel Petroleum Use	Auto Travel Cost	Direct Employment	Providing Incentives	Providing Resources
1980	5	Lead-Acid	0.0	.0	- 1	0.0 to 1.9	-0.01 to -0.04	Major	Minor
1990	15	Lead-Acid	-1.9	.0	-13	0.2 to 5.6	-0.03 to -0.11	Major	Minor
	15	Nickel-Zinc	-1.9	.0	-15	2.0	-0.13	Major	Minor
	15	Zinc-Chlorine	-1.9	.0	-15	-3.8	-0.18	Minor	Minor
	30	Nickel-Zinc	-3.8	1.4	-25	3.9	-0.26	Major	Moderate
2000	30	Zinc-Chlorine	-3.9	.0	-30	-7.5	-0.36	Minor	Minor
	30	Lithium-Sulfur	-3.9	.0	-30	-4.5 to -6.3	-0.34 to -0.38	Minor	Moderate
	60	Zinc-Chlorine	-7.8	.0	-60	-15.0	-0.73	Moderate	Minor
	60	Lithium-Sulfur	-7.8	.0	-60	-9.0 to -12.6	-0.69 to -0.75	Moderate	Moderate

These figures in Table 9.1 assume that electric cars replace average cars in Los Angeles; if electric cars instead replaced subcompacts, savings would be reduced correspondingly.

The auto travel costs in Table 9.1 were obtained by linear extrapolation from the relative costs of Table 7.2. It should be noted that cost changes are shown relative to the total for all auto travel, including both conventional and electric cars, again under the assumption that electrics replace average conventional cars. Depending on the methods used to encourage electric car use, cost increases or decreases may be spread over all auto travelers, or concentrated on electric car users. At the lower usage levels, it is possible for electric cars to replace only subcompacts, in which case the cost increases in Table 9.1 would be larger, and the cost decreases smaller.

The changes in regional transportation employment in Table 9.1 were obtained by linear interpolation for each usage level and year in Table 7.6. Employment changes overall are small relative to normal unemployment, and would develop slowly over periods of 5 to 10 years.

The evaluations of resource problems in Table 9.1 follow the judgments presented in Table 6.1. Impacts on US demand would be minor except in the case of high nickel-zinc battery car usage, where moderate increases in US imports would result, and in the case of the lithium-sulfur battery cars, where major expansion of facilities for production of lithium metal would be required.

Finally, the incentives problems noted in Table 9.1 were judged according to the extra dollar cost of particular electric cars, the extent to which their daily range is limited, and the level of use assumed. Where high costs and low daily ranges are involved and high levels of use are sought, implementation incentives pose more difficult problems.

Overall, loss of auto capability is probably the most important impact of electric cars not shown directly in Table 9.1. This loss--measured in terms of low acceleration, limited range, and small capacity relative to what conventional automobiles offer--would reduce opportunities now available to auto travelers more than it would actually curtail travel itself; opportunities, however, are often important considerations in consumer decisions and in benefits which must be imputed to resultant selections.

The most important potential benefit of electric car use shown in Table 9.1 is reduced petroleum consumption. The most important costs of electric car use are loss of auto capability and the expense, inequities, and rigidities of government intervention in free markets necessary to bring about the indicated levels of use. Both these costs are subsumed in the incentives problems assessments of Table 9.1, as are the extra dollar costs of lead-acid and nickel-zinc battery cars, which are also important.

Relative to these impacts, reductions in air pollution due to electric car use are unimportant. Even at the highest levels of use in Table 9.1, reductions in ozone concentration are small, and are not adequate to reach compliance with Federal standards. Impacts on employment are similarly small: the affected fractions of regional employment are much less than typical regional unemployment; furthermore, these impacts would appear gradually over a period of years. Materials resources for regional application could be provided with relatively little difficulty, and consequently pose no major barrier to implementation.

In this light, the basic issue in selecting the most desirable level of electric car use is whether the potential petroleum savings would justify the associated sacrifice of auto function and government intervention in the auto market. Behind this issue are major uncertainties, among which the most important is the extent to which nuclear and coal-fired electric power plants will actually be built in Los Angeles. The petroleum savings shown in Table 9.1 assume that regional utilities will construct major new nuclear plants, but as yet the necessary approvals for construction of such plants have not been issued. In fact, there is intense debate over the overall desirability of nuclear power, and its resolution is not yet clear. If nuclear plants are not constructed for Los Angeles, and if electric cars were then recharged from oil-fired power plants, the petroleum savings in Table 9.1 would be reduced by factors of 3 and 4 or more.

Moreover, the significance of any given level of petroleum saving is also uncertain, because it will depend greatly on future US dependence on foreign oil sources. In the baseline projections of this study, independence of foreign sources was projected for the late 1980s, partly due to improved fuel economy of conventional automobiles, partly due to much-increased use of nuclear electric power. To the extent that this independence is thus achieved, additional petroleum savings due to electric car use may not hold the same significance.

Given these uncertainties in both the magnitude and significance of petroleum savings in Table 9.1, the benefits of future electric car use do not now appear to warrant the loss of auto capability and the market intervention problems involved. Accordingly, it seems preferable to accept the free-market level of electric car use for the Los Angeles area until important net benefits can be confidently foreseen for higher levels of use.

Among the individual cases of Table 9.1, those involving lead-acid battery car use seem least desirable. In 1980, impacts are trivial and the costs of attaining them considerable. In 1990, potential energy savings could be significant, but costs would remain high. Use of nickel-zinc battery cars in 1990 would be much preferable: energy savings would be greater, dollar costs no more unfavorable, and auto capability much less impaired due to the much greater daily driving range. Use of the zinc-chlorine and lithium-sulfur battery cars would be better still, largely due to lower anticipated costs. Of these two cars, the zinc-chlorine battery car appears preferable for its lower energy consumption and costs; but these estimates are uncertain, and the lithium-sulfur battery's projected higher energy density offers greater driving range and performance potential.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-460/3-74-020-a	2.	3. RECIPIENT'S ACCESSION NO. PB 238-877/AS
4. TITLE AND SUBTITLE Impact of Future Use of Electric Cars in The Los Angeles Region: Volume I-Executive Summary and Technical Report		5. REPORT DATE October 1974
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) W.F. Hamilton		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 elecric 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 17-74 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 113
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE $5.25

EPA Form 2220-1 (9-73)