Title

Highway Electrification And Automation Technologies - Regional Impacts Analysis Project: Executive Summary

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Highway Electrification and Automation Technologies -Regional Impacts Analysis Project: Executive Summary

Southern California Association of Governments (SCAG), California Partners for Advanced Transit and Highways (California PATH)

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Highway Electrification and Automation Technologies - Regional Impacts Analysis Project: Executive Summary

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Prepared for:

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Institute of Transportation Studies
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FOREWORD

A variety of organizations, too numerous to list on the report cover page, provided valuable service to this project and helped lead to its successful completion.

Phase I of the project was designed to compile required data and to make forecasts for the target study year, 2025, in the major areas of analysis, namely the transportation, utility, socioeconomic, and environmental sectors. Work was performed primarily by SCAG with technical support from Cambridge Systematics, Inc. and JHK & Associates. PATH provided management oversight, including handling administrative issues and documentation review. Systems Control Technology, Inc. a PATH contractor on a related project also provided input.

Phase II of the project consisted of the development of the advanced highway technology system scenarios. Work was performed primarily by PATH and SCAG. In addition, PATH provided management overview, including handling administrative issues and documentation review. Systems Control Technology, Inc. a PATH contractor on a related project also provided technical support.

Phase III of the project consisted of the derivation of the impacts analysis results for each of the two advanced highway technology scenarios. Work was performed primarily by PATH and SCAG. In addition, PATH provided management overview including handling administrative issues and documentation review. Systems Control Technology, Inc. a PATH contractor on a related project and the University of California at Davis also provided technical support.

A Project Advisory Group was formed at the beginning of the study to provide guidance regarding study goals/objectives, specific methodological approaches, schedule and milestone review, and overall project evaluation. The membership was comprised of individuals from academia, as well as the private and public sectors, with interest in the applications of advanced transportation technologies. The membership list is provided at the end of the report.

Funding for this project was provided by the United States Department of Transportation, Federal Highway Administration, the State of California, Business, Transportation, and Housing Agency, Department of Transportation and the Southern California Association of Governments.

EXECUTIVE SUMMARY

Applications of highway automation and roadway electrification were designed and evaluated for portions of the freeway system in the greater Los Angeles region. Highway automation technologies, such as longitudinal control systems and lateral guidance control devices, were studied to address traffic congestion. Roadway electrification was investigated to target air quality deterioration.

Regional impacts for these technologies *were* modeled for 2025 and compared with 2025 baseline (no technology) forecasts. For highway automation, mobility was the primary impact although the ramifications of this technology on air quality *were* also examined. Fossil fuel, air quality, utility, economic and environmental assessments were developed for the roadway electrification technology. Impacts results for the technology application depended on the specific design considerations imbedded in each technology scenario, i.e. market penetration, network size, technology issues, modeling capabilities.

Highway Automation

- Congestion mitigation, measured as the reduction in vehicle hours of delay and increased speed, occurred on both automated and mixed flow lanes, as well as arterials.
- Considerable mobility improvements were present on freeways and arterials in the immediate vicinity of the automated facility as well as throughout larger geographic areas.
- Some mobility deterioration was exhibited on existing freeway ramps when the automation technology was applied.
- Ramp mobility improvements are expected when additional ramps were included in the automation facility to accommodate automated vehicles.
- Enhancements to the current transportation model are needed to overcome limitations encountered in simulating the automation technology.
- A *review* of past and present research and demonstration opportunities was provided.
- Demonstration and/or development considerations analyzed were fundability, organizational feasibility, ease of implementation, constructionphasing, operational issues, social and political acceptance, and monitoring issues.

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Roadway Electrification

- **Sizeable** air quality improvement and petroleum usage reductions were predicted.

- Increased electricity demand associated with roadway powered electric vehicles was negligible for the specified market penetration. Natural gas was the primary electricity fuelstock in 2025.

- Evidence of electromagnetic field exposure with respect to powered roadway use suggested little need for environmental concern.

- Acoustic noise measurements for conventional vehicles traveling on the powered roadway were high enough to warrant further testing of lower roadway currents and higher frequencies.

- Baseline user cost comparisons of gasoline vehicles and RPEVs indicated that RPEVs may offer some economic advantage to users over the life of the vehicle if roadway infrastructure costs were subsidized.

- RPEV user costs varied by the largest amount when alternative roadway costs were considered.

- Retail electricity rates charged to RPEV users that enabled system revenues and costs to breakeven, increased as roadway expenses increased and decreased as system performance and/or system usage increased.

- **Costs,** revenues, and profits of the powered roadway system were most sensitive to alternative roadway costs and interest rates.

- Additional benefits of roadway electrification were identified as: increased revenues to the utilities, possible new employment opportunities in construction, and vehicle maintenance and servicing. A potential benefit also exists if efforts are successful in the areas of manufacturing and commercializing RPEVs (and Evs) in the SCAG region.

- Policies to implement an **RPEV** system necessitate coordinated planning and management efforts that address market penetration, continued technology development, and support service complements to capture maximum regional benefits.

- Four possible demonstration opportunitieswereidentified for: local arterials, a local activity center on an arterial, freeway high occupancy vehicle lanes, and freeway corridors.

- RPEV demonstration and/or development considerations analyzed included: fundability, organizational feasibility, ease of implementation, construction phasing, social and political acceptance, and monitoring issues.

- Ongoing RPEV research needs were identified for government, university, business, and other institutional entities.

- Enhancements to the current transportation model are needed to overcome limitations encountered in simulating the roadway electrification technology.

- Completion of impacts assessment occasionally depended on certain assumptions, some optimistic, while others conservative.

- Further impacts assessment research is warranted which should include to the maximum extent possible the most realistic assumption set as well as at the very least a more thorough sensitivity analysis relative to changes in market penetration.

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EXECUTIVE SUMMARY

Ob-iectives of the Study

The Highway Electrification and Automation Technologies Regional Impacts Analysis Project (HE&A) addressed the **transportation-related problems** of freeway congestion, air pollution, and dependence on fossil fuels in southern California. The impacts of **roadway electrification and highway automation** were investigated to determine to what extent these advanced technologies could alleviate these problems. For the highway electrification technology, utility, environmental, and economic impacts were also studied. The feasibility of implementing one or more demonstrations in the six-county SCAG region was additionally analyzed.

Project Support

Institutional support for the HE&A project was provided by Southern California Association of Governments (SCAG) and the Partners for Advanced Transit and Highways (PATH), Institute of Transportation Studies, University of California, Berkeley, and the California Department of Transportation (Caltrans). The project was financed in part through grants from: the U.S. Department of Transportation, Federal Highway Administration and Federal Transit Administration under; and contract funds awarded from the University of California, Berkeley.

Description of Advanced Technolocries

Roadway Electrification was represented as **a** transportation system composed of roadway powered electric vehicles (RPEVs) that derive power from electrical cables buried under surface roadways. An inductive coupling system that transfers electric power from the roadway to the vehicle was assumed to provide energy to charge, or recharge, **the RPEV's battery and/or** power its traction motor. Figure 1 depicts the roadway electrification concept.

The roadway electrification technological effort began with the Department of Energy's (DOE) Electric **and Hybrid** Vehicle Program in 1976. Since that time research efforts have been conducted at Lawrence Berkeley Laboratory, **Lawrence** Livermore National **Laboratory, and University** of **California**, Berkeley's Richmond Field **Station.** The Richmond Field testing has entailed both static and **dynamic evaluation.** All research **has** indicated the technical viability of the RPEV technology. Current application of the technology, **as part** of the Playa **Vista project in Los Angeles**, has been **investigated.**

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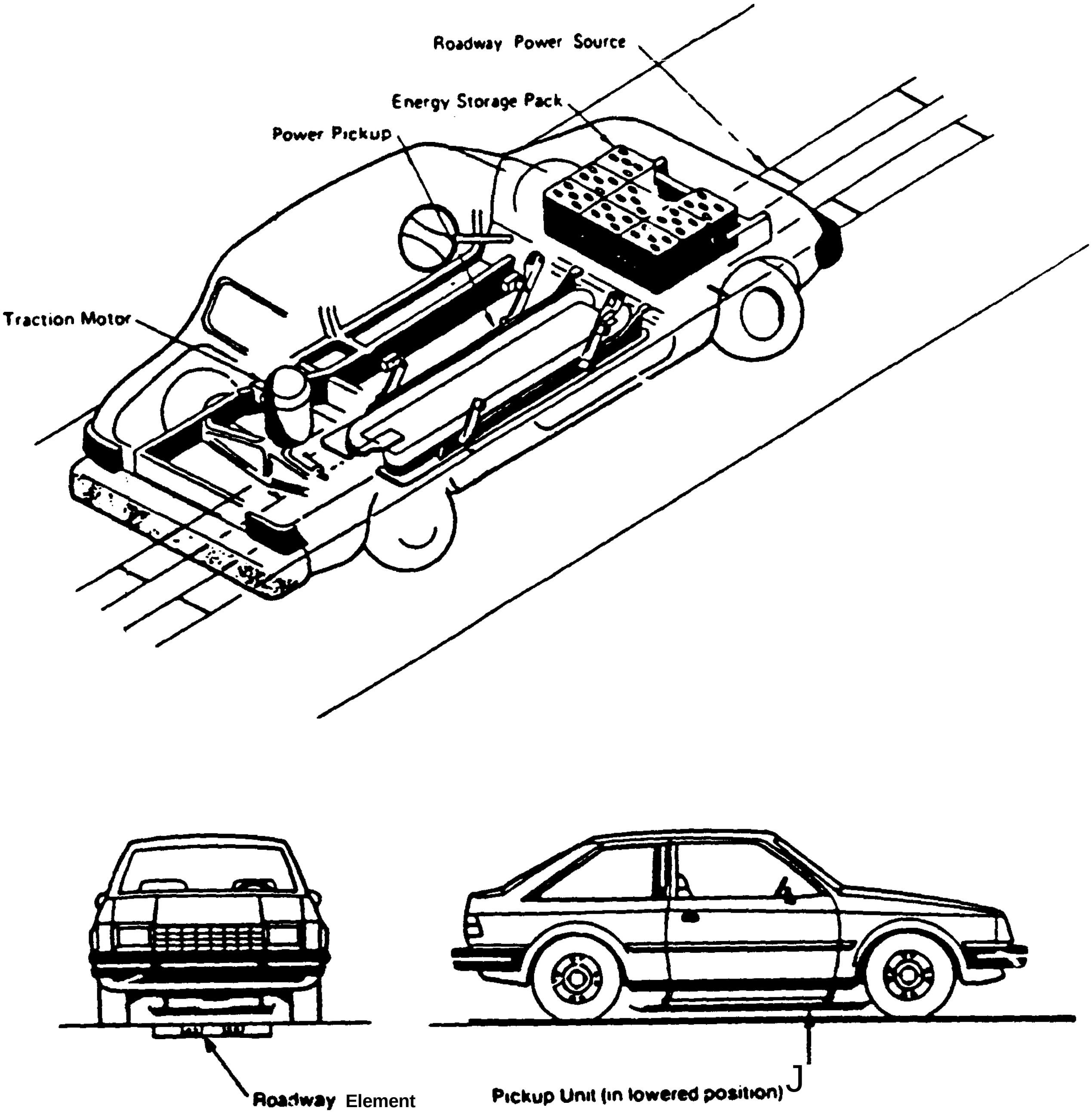

FIGURE 1 **TECHNICAL CONCEPT** FOR **ROADWAY** ELECTRIFICATION

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Highway Automation was identified as full system automation that included longitudinal control, lateral control and system management features. Longitudinal control devices included collision avoidance attributes that enable the vehicle to sense relative distance and velocity, such as radar obstacle detection, automatic braking, and other headway reduction technologies. Lateral control features, such as magnetic lane markers and automatic steering, that enhance capacity were additional components of the fully automated system. Speed control, signal control, electronic route guidance, automatic trip routing and scheduling, pre-trip electronic planning, and on-board navigation systems completed the menu of highway automation features. Figure 2 illustrates a technical concept for highway automation.

Highway automation has been under development since the late 1950s by public and private groups in the U.S. as well as internationally. Development of the technology is expected to continue throughout the 90s with deployment beginning in the early 2000s. Full system automation, such as that assumed in this study, should reach operational maturity by 2025. Current efforts to test longitudinal control devices are being conducted by PATH in the San Diego area during off-peak periods on the I-15 HOV facility when it is closed to the public.

Overview and Synthesis of the Executive Summary

The executive summary provides the 2025 baseline population, employment, transportation, utility, and emissions forecasts that were utilized for comparisons with the advanced technology scenarios. Next, aspects of the advanced technology system scenario development are reviewed, including technology issues pertaining to transportation system design, and system usage considerations. The advanced technology regional impacts analysis covers mobility, fossil fuel, utility, emissions, environmental and economic impacts developed for one or both of the technologies. Finally, demonstration opportunities identified for roadway electrification and highway automation are outlined.

Summary of Project Reports

The HE&A project was conducted in three phases, each culminating with a report of work completed. The Phase I Report summarized data assembly and the 2025 baseline, or no advanced technologies, forecasts of transportation demand, utility sector demand, and electric vehicle market penetration. Baseline mobile source emissions data associated with the 2025 transportation demand forecast were additionally reviewed.

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The Phase II Report developed the modeling frameworks for simulating implementation of the advanced technologies. This report presented the criteria utilized to select the specific

Figure 2 Technical Concept for Highway Automation

configurations for each advanced technology system. In addition, an evaluation of scenario development considerations, such as system costs, technological availability, fundability, organizational feasibility, ease of implementation, construction phasing, other operations issues, social and political acceptance, and monitoring concerns were discussed for each technology.

The Phase III Report presented the impacts analysis of the two final highway system designs for roadway electrification and highway automation. Modeling results for 2025 were detailed for mobility measurements, i.e. vehicle miles traveled (VMT), vehicle hours traveled (VHT), vehicle hours delay (VHD), and speed. Fossil fuel, utility, environmental and economic impacts were presented for roadway electrification. Air quality impacts were reported for roadway electrification and highway automation. The report concluded with a review of demonstration opportunities for both advanced technologies.

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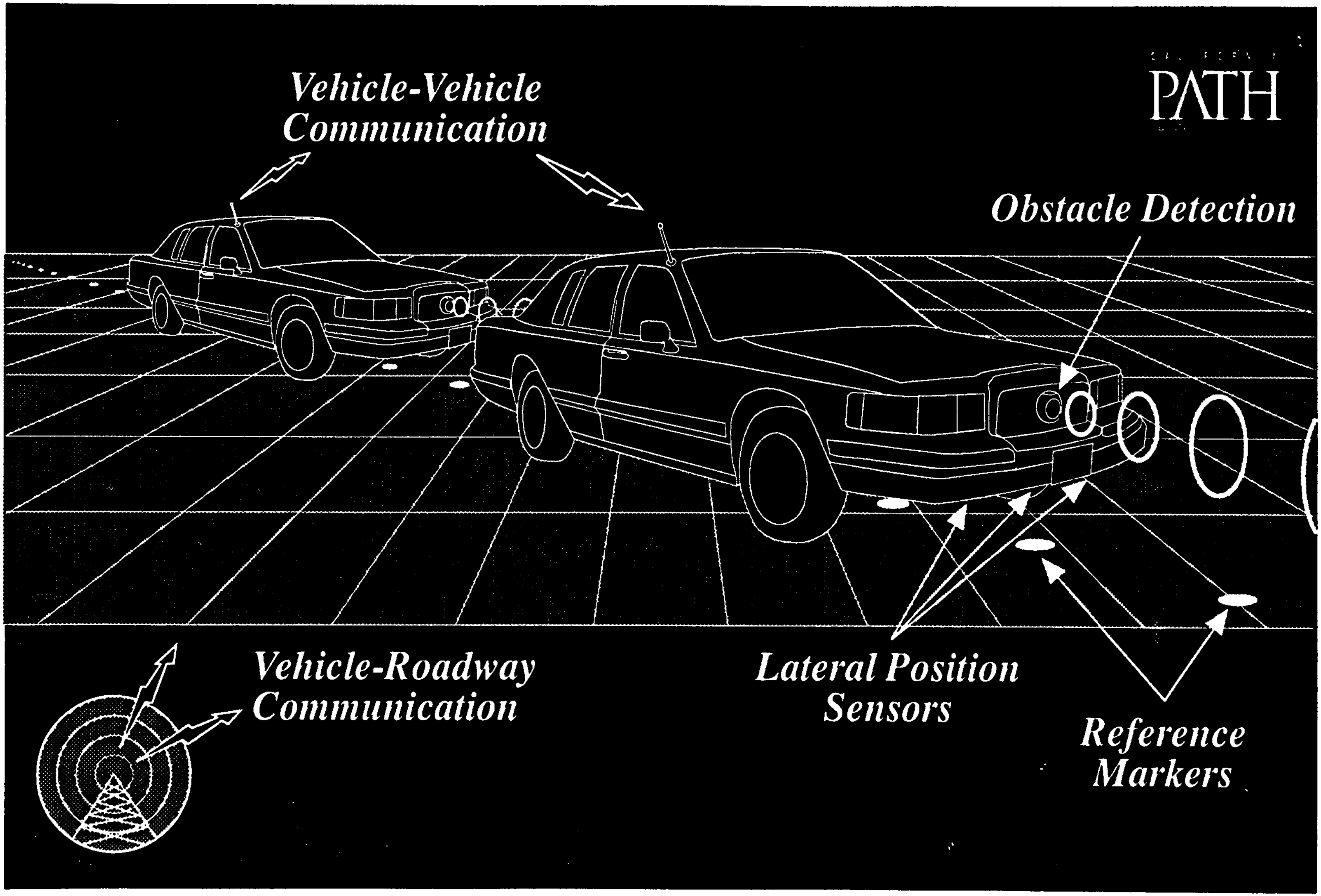

FIGURE 2 TECHNICAL CONCEPT FOR HIGHWAY AUTOMATION

I. SUMMARY OF 2025 BASELINE REGIONAL FORECASTS

Transportation Demand

The SCAG Regional Transportation Model System was employed to generate the baseline assessment of travel in 2025 for the SCAG region. For this study population and employment forecasts were developed for use in the transportation analysis. (See Table 1). Baseline estimates for total projected vehicle miles traveled (VMT) I vehicle hours traveled (VHT), and vehicle hours of delay (VHD) were determined as 415,672,000, 15,095,000 and 4,904,000 respectively. (See Table 2). Projected 2025 average speeds on all facilities and freeways were estimated to be 28 and 36 miles per hour respectively. (Table 3 provides the 2025 distribution of travel by time of day).

Comparing these 2025 baseline figures with those reported by SCAG in 1987, the following summary statistics are noteworthy:

- VMT are expected to increase by an average of 1.3% per year,
- VHT are projected to increase by an average of 1.7% per year,
- VHD are expected to grow by an average of 3.6% per year, and
- average speeds are projected to decrease from 33 mph for all facilities and 43 mph on freeways to 28 mph and 36 mph , respectively.

Overall, dramatic decreases in average speeds, and increases in VMT due to projected population growth, jobs-housing imbalances, and individual driver behavior, are expected in the SCAG region for 2025.

Utility Sector

A baseline forecast was developed for electricity requirements and capacity in the year 2025 for this study by Cambridge Systematics. The forecast was derived from information supplied by the California Energy Commission for the Southern California Edison (SCE) and the Los Angeles Department of Water and Power (LADWP) Planning Areas. A summary of the baseline forecast is provided in Table 4.

In the baseline forecast, traditional power sources from utility-owned capacity, i.e. nuclear, coal, oil and gas steam, combustion turbines, combined cycle, hydroelectric, and pumped storage, made

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TABLE 1

POPULATION AND EMPLOYMENT GROWTH BY COUNTRY
(in 000s)

COUNTRY	POPULATION* 1984	POPULATION* 2025	EMPLOYMENT* 1984	EMPLOYMENT* 2025
Imperial	102	154	37	75
Los Angeles	7,863	11,058	4,053	5,836
Orange	2,065	3,302	1,048	1,941
Riverside	758	2,185	247	752
San Bernardino	1,015	2,575	325	938
Ventura	580	1,032	213	416
Region	12,303	20,306	5,923	9,958

TABLE2

TRANSPORTATION INDICATORS (daily)

	1987	2025
VMT (000s)	243,339	415,672
VHT (000s)	7,454	15,095
VHD (000s)	1,136	4,904
Average Speed (mph)		
All Facilities	33	28
Freeways	43	36
Miles of congestion		
AM Peak	1,054	2,209
PM Peak	1,743	4,335

TABLE3

DISTRIBUTION OF TRAVEL BY TIME OF DAY (2025)
(millions)

	FREEWAYS Trips	FREEWAYS VMT	ALL FACILITIES Trips	
		27.2	5.4	53.2
A.M. Peak (6:30-6:00 a.m.)	3.4	56.0	12.6	113.5
Daily Totals	11.4	238.3	47.4	415.7

*These numbers represent a project planning forecast rather than an adopted agency policy forecast.

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TABLE 4

SUMMARY OF BASELINE FORECAST OF ELECTRICITY SUPPLY AND DEMAND (MW)

	SCE			LADWP			TOTAL REGION
	1988	2007	2025	1988	2007	2025	2025
Demand							
Total Capacity requirements	18,232	28,483	43,453	7,068	9,739	13,131	56584
Supply							
Traditional Utility-Owned Capacity	15,908	14,909	1,988	6,910	6,375	2.817	4.805
Nondeferrable Resources	400	2,992	8,799	0	149	208	9,007
Total Pending Resources	0	810	687	56	28	0	687
Total Imports	2,306	2,212	941	958	958	72	1,013
Total Other Dependable Capacity	2,529	4,367	8.001	118	141	2,968	10,969
Advanced Combined Cycle. Gas	0	0	23,037	0	0	7.066	30.103
Total Available Capacity	21,143	25,289	43,453	8,042	7.65 I	13,131	56,584
Surplus/D&it	2,911	-3,194	0	974	-2.088	0	0

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up a smaller percentage of total energy generating capacity in 2025 than in the previous years. This result was attributable to the phasing out of traditional power plants, and no further increases in traditional utility power plant construction. New capacity needs were assumed to be met by qualifying facilities, such as small power producers and cogenerators, and from non-traditional power sources, particularly advanced combined cycle gas power plants. The advanced combined cycle plants are favored since they are relatively clean, small, and easy to site.

Mobile Source Emissions

The baseline assessment of air quality for the year 2025 was determined by use of the Direct Travel Impacts Model (DTIM). DTIM computes the amounts of emissions from, and fuel utilized by motor vehicles based on Caltrans transportation modeling and California Air Resources Board (CARB) impact rates. The methodology contained in DTIM and its companion impact rate program, EMFAC7E, were employed, with modifications recommended by CARB for 2025, to calculate the baseline reactive organic gases (ROG), oxides of nitrogen (NOX), oxides of sulfur (SOX), carbon monoxide (CO), and particulate matter (PM10) emissions given in Table 5.

Comparing the 2025 baseline figures above with those reported by SCAG for 1987, the following summary statistics aggregated across all vehicle types indicate:

- emission reductions of 57.5%, 62.1%, and 35.3% for ROG, CO, and NOX, and
- increased SOX and PM10 emissions of 68.3% and 40.1%.

The emissions reduction for ROG, CO, and NOX were assumed to result from the impact of the air quality management plan which places stringent controls on the sources of air pollution, and fosters retirement of the older more polluting internal combustion engine vehicle fleet. Mobile source PM10 emissions are road gravel, dust, and oily residue forced up from the road surface by continuous vehicle movement, and are thus directly related to VMT. Mobile source SOX emissions were calculated as sulfur dioxide (SO2), since most sulfur in gasoline is converted into SO2 during gasoline combustion. Even with controls on the sulfur content of gasoline, the growth in VMT would lead to the indicated increase in SOX emissions.

Thus, while urban traffic congestion and air pollution are crucial issues in most metropolitan areas, the Southern California region presents a challenge to policymakers of acute proportions. The transportation demand and emissions forecasts have shown the ongoing

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TABLES
BASELINE DAILY EMISSIONS FOR SCAG REGION
(tons)

	1987 LDA	1987 LDT	1987 MDT	2025 LDA	2025 LDT	2025 MDT
Reactive Organic Gases (ROG)	454.09	98.10	31.13	184.70	48.85	14.21
Oxides of Nitrogen (Nox)	388.42	83.91	26.63	240.79	63.69	18.52
Carbon Monoxide	3,354.02	724.61	229.97	1,216.74	321.84	93.60
Oxides of Sulfur (Sox)	18.44	3.98	1.26	24.73	6.54	1.90
Particulate Matter (PM10)	23.33	5.04	1.60	37.61	9.95	2.89

Note:

LDA = Light Duty Auto
LDT = Light Duty Truck
MDT = Medium Duty Truck

Source:

Direct Travel Impacts Model - 1990
Southern California Association of Governments
Los Angeles, CA

need to develop remedies to curb these disamenities whether they be government regulation, infrastructure developments, and/or technological changes. The HE&A study investigated the latter option.

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II. ADVANCED TECHNOLOGY SYSTEM SCENARIO DEVELOPMENT

Technology Issues

The advanced technology system scenario development began with an identification of the special characteristics of each technology. This step was necessary given the system design implications of each technology.

For roadway electrification, the key technology consideration was vehicle range due to battery limitations. An analysis of RPEV market potential, that is, the number of trips that were possible depending on alternative vehicle battery ranges and extent of the electrified network, was performed. Since only unlinked trips were reported in the modeling process, derated battery ranges were studied. (For example, a derated battery range of 40 with a derating factor of two would correspond to 80 miles of travel without recharging). This work utilized 2025 AM-peak trip length distribution matrices for mileage traveled on and off a specified network. In general, it was determined that market potential was directly related to battery range and network size. The selection of a 40 mile derated range for this study enabled 97% or more of the AM-peak trips and more than 78% of the AM-peak VMT to be completed by RPEVs.

Roadway electrification did **not** require facility separation and special access and egress facilities from conventional mixed-flow traffic. While maintaining separate facilities could assist in linking electrified roadway costs to users, other mechanisms such as electronic toll collection devices could be utilized for this purpose.

For modeling purposes, highway automation was defined as vehicles traveling in fifteen vehicle average length platoons at approximately current free flow speed limits, i.e. 55 mph, on freeways. Automation research indicated that an average vehicle platoon size of fifteen vehicles traveling at 55 mph would allow lane capacity to be approximately 6,000 vehicles per lane per hour when longitudinal control automation features were utilized.

The highway automation technology was assumed to require lane separation to ensure maximum safety. This technology consideration was modeled in a manner similar to the current High Occupancy Vehicle (HOV) procedure. Special access and egress facilities were additionally modeled as part of the automated system design in one of the automation applications studied.

For highway automation the potential number of trips that could utilize the automation facility was assumed to consist of **all** trips greater than 4 miles in length. AM-peak trip distribution matrices for 2025 were utilized in this analysis.

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Transportation System Design

The HE&A study developed a modeling framework for evaluating the application of roadway electrification and highway automation to selected freeway lanes. The 2025 regional highway network provided a base network from which the electrified and automated network subsets **were** chosen. Selection of the freeway links for inclusion in the advanced technology network designs utilized the following criteria in order to address regional transportation **concerns:**

- potential mobility improvement -- baseline volume to capacity ratios (V/C) greater than one,
- potential congestion relief -- proximity to SCAG regional activity centers,
- potential air quality improvements -- proven correlations between congestion and emissions, and
- potential infrastructure advantages -- existing and/or planned HOV lanes.

AM-peak trip distribution data were analyzed employing alternative VMT market penetration and network size assumptions to guide selection of the specific configurations for the 2025 advanced technology scenarios. The methodologies which led to the choice of these scenarios incorporated the physical characteristics of each technology, and identification of the potential number of trips, and associated VMT, that could be serviced with each technology. The final freeway network configurations combined statistical data associated with the distribution of trips, and reviewer comments on the analysis.

System Usage Analysis

System usage analysis first evaluated the market potential number of trips, and corresponding VMT, that were possible with the advanced technology. In the RPEV scenario, the market potential was dependent on the assumed vehicle battery range and extent of the electrified network. For the automation scenario, it was assumed that all trips greater than 4.0 miles in length could utilize the automated facility.

Market penetration, that is, the percentage of potential trips, or VMT, that would actually **use** the advanced technology was studied next. Several market penetration and advanced technology network size combinations were investigated in the sensitivity analysis. A careful review of modeled output for these combinations led to selection of the specific market penetration for each technology scenario.

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The designated percentage of trips to be penetrated by the technology was chosen from a subset of the on- and off-freeway trip length combinations associated with the freeway network selected for each technology. Numerous trips of different origins and destinations were represented by each on- and off-freeway trip length combination. Those trips specified as RPEV or automation were randomly chosen from the trips classified in each origin-destination group per on- and off-freeway trip length combination. This method of trip selection was utilized in the assignment methodologies for both advanced technologies.

Scenario Descriptions

Highway Automation

Several design considerations were incorporated in the development of the chosen automation scenario. Table 6 summarizes the characteristics of the automated system. An ambitious network size coupled with a 45% market penetration was selected to allow sufficient development of the technology for evaluation purposes. Figure 3 depicts the 2025 automation scenario.

To ensure maximum safety, automated lanes were modeled as separate facilities throughout the analysis. That is, only trips designated as automated trips were permitted access to the specified automated lane/s. Non-automated trips, or trips performed by conventional vehicles, were allocated to mixed flow lanes in the trip allocation process. Automated vehicles traveling in 15 vehicle platoons at 55 mph were assumed to enable lane capacities to reach 6,000 vehicles per lane per hour. Automatic braking, headway keeping,automatic steering and communication systems were component features of the fully automated system.

The two automation scenarios developed in this analysis were referred to as:

Base Network Ramps = Automated vehicles merged with mixed flow facilities to enter or exit the automated facility, and

Additional Ramp Facilities = Automated vehicles utilized separate ramp facilities to enter or exit the automated facility.

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TABLE 6

HIGHWAY AUTOMATION SCENARIO DESCRIPTION

Network Size	**2,165 Lane Miles**
Market Penetration	**45% AM-Peak VMT** **24,268,500 VMT** **19.3% AM-Peak Trips** **1,047,699 Trips**
Technical Characteristics	**Automated Vehicles Travel in 15 Vehicle Platoons at 55 mph Enabling Lane Capacity to Reach 6,000 v/l/h** **Special Access and Egress Facilities Modeled** **Lane Separation Required**

The base network ramps scenario included only those ramps that could be utilized by traversing mixed flow lanes. The additional ramp facilities scenario incorporated additional ramp facilities to allow automated vehicles to separately exit the freeway to adjacent arterials. In selecting the merge points for automated and mixed flow traffic, attention was given to the location of concentrated activities, such as airports, business centers, major shopping developments, large sporting or entertainment complexes, etc. Merge points relative to such activity centers were designed to minimize travel inefficiencies, that is, to allow minimal interference of the facility configuration and the travel path of the automated trip. Such merge points occurred at approximately five mile intervals or less.

Modeling restrictions required loading automated and conventional trips separately from one another. Assigning the automated trips after the conventional trips was chosen as the trip loading procedure for the impact analysis after careful analysis of alternative trip assignments. This ordering process was assumed to be a more realistic representation of expected travel behavior since it attached a small time penalty to automated travel that would resulted from traversing congested conventional traffic in order to enter and exit the automated lanes. The highway automation trip assignment procedure is summarized in Table 7.

The modeling adjustments imbedded in the automation trip assignment procedure were necessary to accurately represent the unique characteristics of automated travel, i.e. the requirement that automated vehicles travel at 55 mph in lanes of hourly capacity of 6,000 vehicles. This method approximated the automation technology concept given current transportation modeling capabilities.

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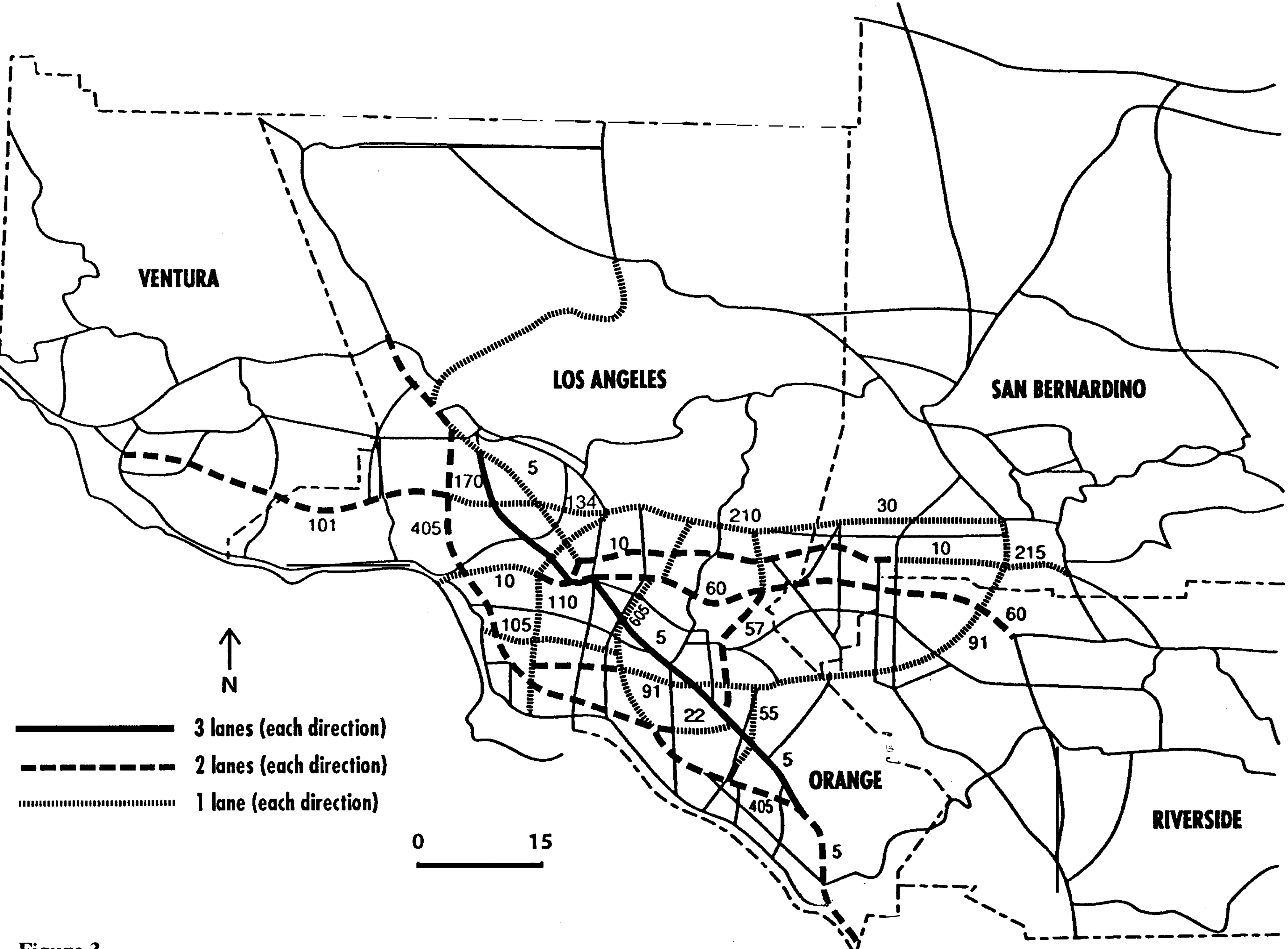

Figure 3
Automation Scenario
2025 Regional Highway Network

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TABLE7

HIGBWAY AUTOMATION TRIP ASSIGNMENT PROCEDURE

(1) Load Mixed Flow Trips

(2) Load Automated Trips

- **(a) 30% of Automated Trips Loaded with BPR Speed-Volume Relationship**

  Speed = Speed, / (1 + .15 (V/C)^4)

  where Speed,, = 55 mph

- **(b) Review Traffic Link Volumes. If A Link's**

  V/C > 1.00 then Speed = 1 mph

  v/c < 1.00 then Speed = 55 mph

- **(c) Load 10% of Remaining Automated Trips**

- **(d) Repeat (b) and (c) Until All Automated Trips Are Loaded**

As a result of the iterative assignment loading procedure used for automation scenarios, some links had V/C ratios above 1.00, though the excess was within tolerable limits. Speeds on all links of the automated network were maintained at 55 mph in each scenario. For the base network ramps scenario, 81.2% of the automated links had V/C ratios below 1.00, while the maximum V/C ratio was 1.19. The additional ramps scenario indicated that 77.5% of the automated links had V/C ratios less than 1.00 and 98.5 of the links had V/C ratios less than 1.20.

It is important to note that only a portion of each trip, whether completed by an automated or a conventional vehicle, was performed on the freeway. A portion of each trip occurred on arterials and ramps. For automated trips, an additional component of each trip was associated with traversing and traveling on mixed flow lanes of the freeway system. A review of the allocation of post-trip assignment VMT associated with the automated trips is given in Table 8. These results indicated the portion of automated trips performed on the automated facility, while remaining VMT for the automated vehicles driven in manual mode occurred on other highway facilities, i.e. mixed flow lanes, ramps and arterials.

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TABLE8

AUTOMATED POST-ASSIGNMENT TRIP ALLOCATION

	VMT (millions)	% OF SYSTEM VMT	% OF ASSIGNED VMT
Base Network Ramps	13.4 on automated network	25.6%	56.6
Additional Ramp Facilities	15.1 on automated network	28.9%	64.1%
Total Assigned	23.5	45.0%	
Total System	52.4	100.0%	

Roadway Electrification

Several alternative system designs were analyzed for the roadway electrification scenario. The final roadway electrification scenario consisted of a modest freeway network size and assumed a 15% AM-peak VMT market penetration. The selection of a modest network size was primarily influenced by the high facility construction costs. The market penetration was chosen to be consistent with the facility size as well as forecasts of electric vehicle market penetration. (See Phase I report for a review of EV market penetration forecasts). Table 9 summarizes the specific attributes of the chosen RPEV system. Figure 4 depicts the RPEV scenario that provides the basis for all subsequent impact analyses.

Lane capacity restrictions were not required for the roadway electrification technology although attention was given to designating an RPEV network that kept volume/capacity ratios as close as possible to that of the baseline scenario. Merge points for RPEV and mixed flow traffic were selected as in the automation scenario. Two RPEV scenario assignments were designed to analyze the impacts of separate and non-separate RPEV facilities:

RPEV Exclusive = Only RPEV trips travel on RPEV lanes, and

RPEV Non-Exclusive = All trips may travel on RPEV lanes.

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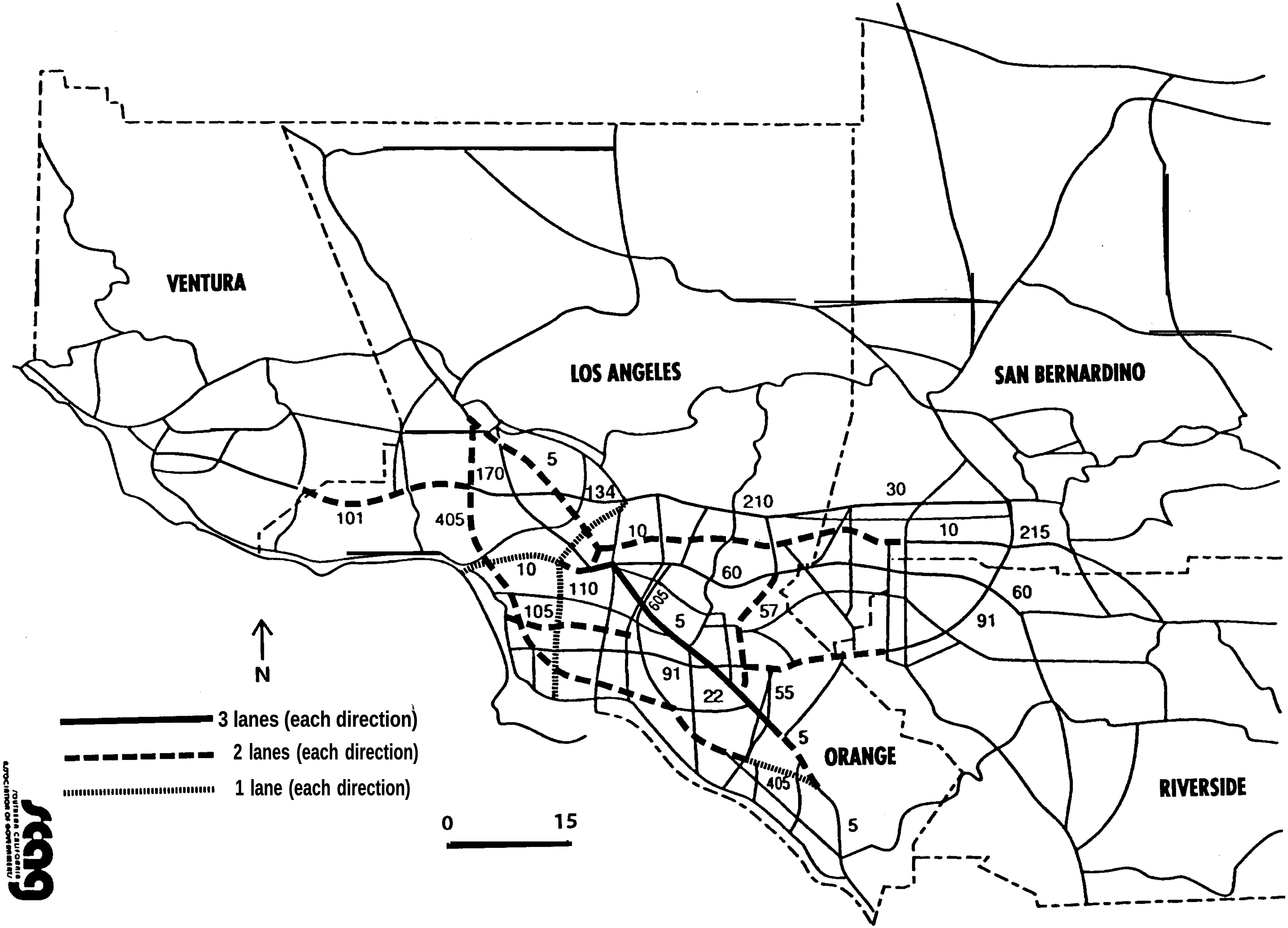

Figure 4
RPEV Scenario
2025 Regional Highway Network

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TABLE 9

ROADWAY ELECTRIFICATION SCENARIO DESCRIPTION

Network Size	**1,035 Lane Miles**
Market Penetration	**15% AM-Peak VMT** **6,632,400 VMT** **3.28% AM-Peak Trips** **173,410 Trips**
Technical Characteristics	**Derated Battery Range = 40 Miles** **No Lane Capacity Restriction** **No Special Access and Egress Facilities Required** **Lane Separation Designated but Not Required**

The RPEV trips were loaded separately from all other network trips due to modeling restrictions. The RPEV trips were assigned first and conventional vehicle trips second since analysis of alternative trip prioritization produced negligible differences in post-assignment results. This trip assignment decision was imbedded in the impact results for both RPEV scenarios.

The amount of vehicle miles traveled by the RPEVs on the RPEV lanes versus the VMT associated with travel on other facility types was recorded after completion of the trip assignment for use in the impact analysis. The results revealed that 2,903,749 VMT were associated with RPEV travel on the RPEV facility out of the total VMT attributed to RPEVs of 6,248,000, or 46.5% of all RPEV vehicle miles traveled. The division of RPEV vehicle miles traveled on and off the powered roadway had important implications for the regional impacts, i.e. electricity demand, fossil fuel usage, and roadway costs. The effect of RPEVs on air quality was computed with respect to <u>total</u> RPEV vehicle miles traveled since the RPEVs were zero emission vehicles.

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III. ADVANCED TECHNOLOGY REGIONAL IMPACTS ANALYSIS

The regional impacts for highway automation and roadway electrification were compared to the 2025 baseline forecasts. For highway automation, mobility impacts were the primary impact, although the ramifications of this technology on air quality were also reported. With respect to roadway electrification, fossil fuel, air quality, utility, economic, and environmental impacts were analyzed.

Mobility Impacts

Mobility results were compiled with respect to the highway automation technology for three scenarios -- baseline, automation base ramps, automation additional ramp facilities). Mobility was studied for several facility types -- automated lanes, mixed flow freeway lanes, major and minor arterials,and freeway ramps, and levels of aggregation -- automated freeway segment, or corridor, regional statistical area (RSA), county, region, or system. Figure 5 depicts the RSAs within the SCAG region.

The performance measures reported were VMT, VHT, VHD, and speed. Of these measures, VHD and speed were the appropriate indicators of congestion. Table 10 reports the average percentage change in VHD and speed for all three paired scenario comparisons -- baseline versus automation base ramp, baseline versus automation additional ramp facilities, automation base ramp versus automation additional ramp facilities -- at different levels of aggregation for different facility types.

Table 10 indicates changes in congestion levels on a per lane basis for the freeway segments, whereas the RSA and system results were aggregated over all lanes for a particular facility type. Note also that for both RSA and regional results, "FT1+FT7" refers to all freeway lanes contained within the specific area. The findings exhibited:

- an almost uniform congestion reduction at all levels of aggregation for each facility type, and paired scenario comparison, and
- increased congestion mitigation from automation base ramp to automation additional ramp facilities scenarios.

The latter result was expected since the additional ramp facilities scenario offered more access and egress opportunities to the automated vehicles. Table 10 also shows similar congestion

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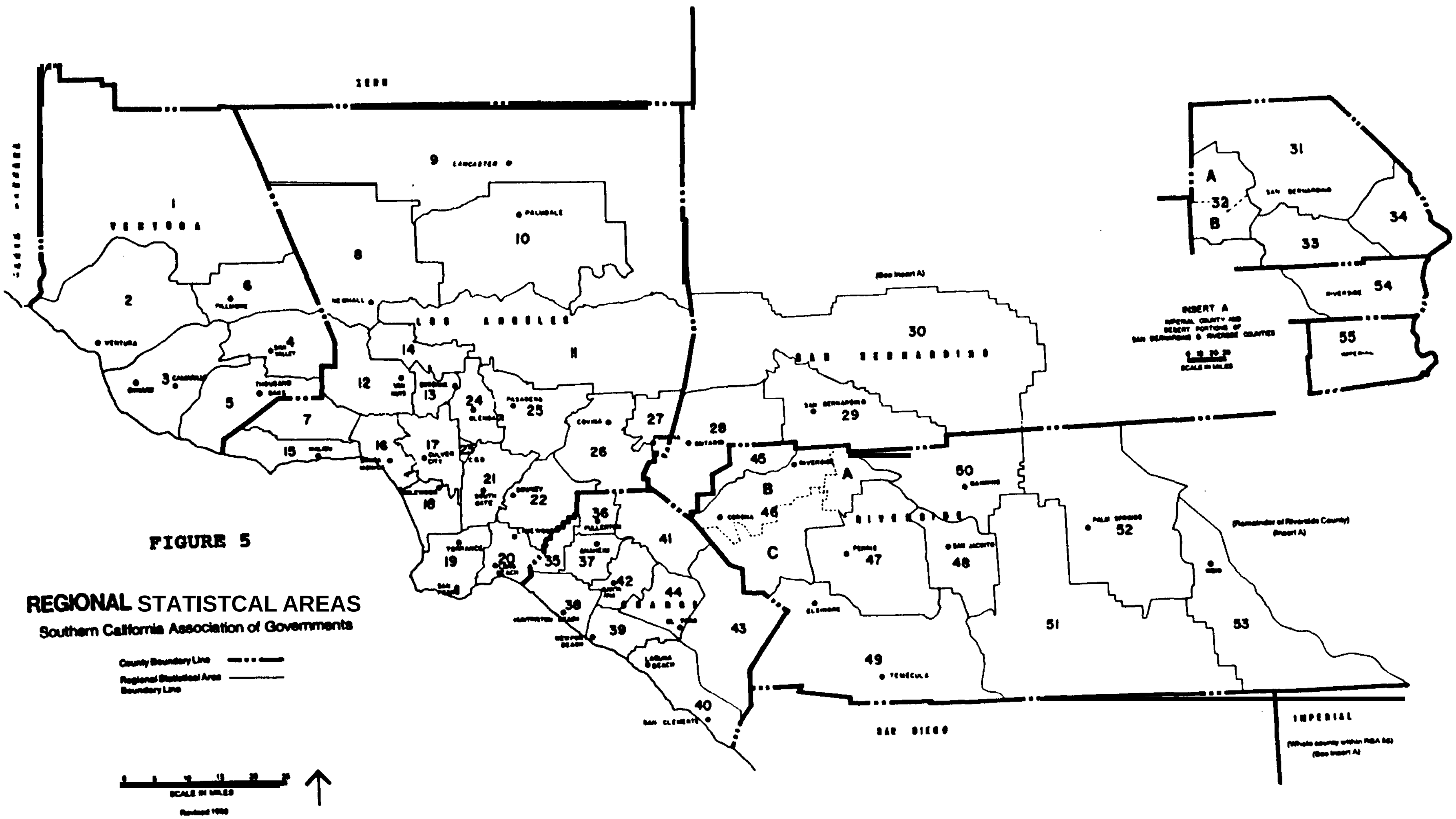

FIGURE 5

REGIONAL STATISTCAL AREAS

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TABLE 10 HIGHWAY AUTOMATION MOBILITY COMPARISONS
(Average Percentage Change)

	Baseline vs Base Ramps		Baseline vs Added Ramps		Base Ramp vs Added Ramps	
CC	VBD	SPEED	VHD	SPEED	VHD	SPEED
FT 1	-21.6	+13.1	-45.0	+28.0	-29.7	+13.3
FT 1 + FT 7	-50.5	+63.7	-64.3	+79.7	-29.7	+ 9.5
RSA	VHD	SPEED	VHD	SPEED	VBD	SPEED
FT 1 + FT 7	-39.6	+29.1	-54.5	+40.1	-25.3	+ 8.2
FT 3	-26.7	+ 4.4	-27.4	+ 4.7	- 1.9	+ 0.2
FT 4	-22.2	+ 7.1	-21.3	+ 6.4	+ 5.1	- 0.2
COUNTY	VHD	SPEED	VHD	SPEED	VHD	SPEED
FT 1 + FT 7	-47.0	+26.0	-59.0	+34.2	-23.0	+ 6.2
FT 3	-13.5	- 2.2	-14.0	- 1.7	- 0.6	+ 0.5
FT 4	-15.3	+ 8.7	-17.1	+ 8.5	- 1.0	-0.02
REGIONAL	VHD	SPEED	VHD	SPEED	VHD	SPEED
FT 1 + FT 7	-47.7	+35.6	-62.3	+47.5	-27.9	+ 8.8
FT 3	-22.9	+ 1.1	-23.6	+ 0.5	- 1.0	- 0.5
FT 4	-28.0	+10.0	-27.7	+10.0	+ 0.5	0.0
ALL FACILITIES	-33.8	+21.8	-40.2	+25.9	- 9.7	+ 3.4

NOTE:

FT 1 = Mixed flow lanes
FT 3 = Major arterials
FT 4 = Minor arterials
FT 7 = Automated lanes

CC = Individual Freeway Segment, e.g. I-10 or US-101, each designated by a construction code (CC) for modeling purposes
RSA = Regional Statistical Area

reduction results at the RSA and regional level. In addition, congestion mitigation effects were found on arterials. These findings suggested that vehicle trips were drawn to the automated freeway lane/s (as well as mixed flow lanes) from the arterials when trips equipped with automation technology enabled freeway mobility conditions to improve. That is, a larger portion of trips were capable of traveling faster on the automated freeway lanes, as well as on the mixed flow lanes, than in the baseline assignment. Fewer trips remained on the arterials when the option to travel with automation enhancements was present. In addition to the above percentage changes in VHD and speed over several levels of aggregation, Table 11 presents complete system results for all three scenarios and facility types for VMT, VHT, VHD, and speed. Table 11 shows the congestion mitigation effects of highway automation on a regional scale.

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Table 11
HIGHWAY AUTOMATION
2025 REGIONAL HIGHWAY NETWORK
(AM PEAK)

Complete System

		Automation Scenarios			
Baseline		Base Network Ramp Facilities*		Additional Ramp Facilities**	
FT	**VMT ('000s)**	**FT**	**VMT ('000s)**	**FT**	**VMT('000s)**
1	27,175	1	18,419	1	16,805
3	22,920	3	17,824	3	17,523
4	2,369	4	2,032	4	2,022
5	612	5	644	5	678
7	n.a.	7	13,402	7	15,063
2 Total	53,186	Total	52,431	Total	52,201
FT	**VHT ('000s)**	**FT**	**VHT ('000s)**	**FT**	**VHT('000s)**
1	940	1	568	1	475
3	1,262	3	971	3	957
4	182	4	142	4	142
5	31	5	32	5	34
7	n.a.	7	244	7	274
Total	2,415	Total	1,957	Total	1,882
FT	**VHD ('000s)**	**FT**	**VHD ('000s)**	**FT**	**VHD('000s)**
1	446	1	233	1	169
3	516	3	398	3	395
4	102	4	74	4	74
5	0	5	0	5	0
7	n.a.	7	0	7	0
Total	1,064	Total	706	*Total*	636
FT	**SPEED**	**FT**	**SPEED**	**FT**	**SPEED**
1	28.9	1	32.4	1	35.5
3	la.2	3	la.4	3	la.3
4	13.0	4	14.3	4	14.4
5	19.9	5	19.8	5	20.0
7	n.a.	7	55.0	7	55.0
Total	22.00	Total	26.77	Total	27.74

Note
FT1 = Mixed Flow Lanes
FT3 = Major Arterials
FT4 = Minor Arterials
FT5 = Ramps
FT7 = Automated Lanes

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In the HE&A's Phase III report, a more detailed analysis of automated freeway segment and RSA VHD data was performed to determine the statistical significance of these results. At the automated freeway corridor level of analysis, the per lane reductions in congestion for each of the three paired scenario comparisons were found to be statistically significant. At the more aggregated RSA level, findings for the two paired scenario comparisons (baseline versus automation) were also found to be statistically significant. Comparing the two automation scenarios produced mixed results. Congestion reduction results for total freeway travel were significant, while the findings were not found to be significant for arterial travel. The latter result was expected due to the level of aggregation (RSA) that could weaken the congestion benefits on arterials adjacent to the automated facility. For this reason further analysis was conducted to investigate the impacts of the automation scenarios on arterials and ramps in close proximity to the automated freeway.

Automation Sub-Area Assessment

The impacts of automation on facilities adjacent to the automated network were derived based on an assessment of six geographically diverse sub-areas of the SCAG region. The approximate locations of the sub-areas were: Claremont, El Toro, Los Angeles Central Business District (CBD), Long Beach, Riverside/San Bernardino, and the San Fernando Valley. Each sub-area covered approximately 100 square miles, with the exception of the Los Angeles CBD sub-area, which spans 25 square miles. Figure 6 depicts the chosen sub-areas.

Analysis of the mobility impacts began with compilation of V/C ratios for each arterial link located within approximately one mile of the automated facility. For each sub-area, the cumulative arterial link V/C ratio frequency distributions were derived and a comparison of these distributions was made across all scenarios -- baseline, automation base ramps, automation additional ramp facilities. All sub-areas, for any fixed V/C ratio showed a larger percentage of links in both automation distributions with V/C ratios below a given threshold compared to the baseline distribution. These results indicated that arterial travel was less congested when automation technology was applied than when it was not utilized. The degree of mobility improvement varied across sub-areas. In addition to the data on arterial V/C ratios, individual link traffic volumes were compiled for all three scenarios for arterial links and freeway on- and off-ramp links adjacent to the automated facility. For arterial links, the average percentage changes in both VHD and speed across scenarios for each sub-area were derived. For ramp links, the average percentage change in traffic volume across scenarios was derived. These results are presented in Tables 12 and 13 respectively.
The ranges in the average percentage reduction in VHD across sub-

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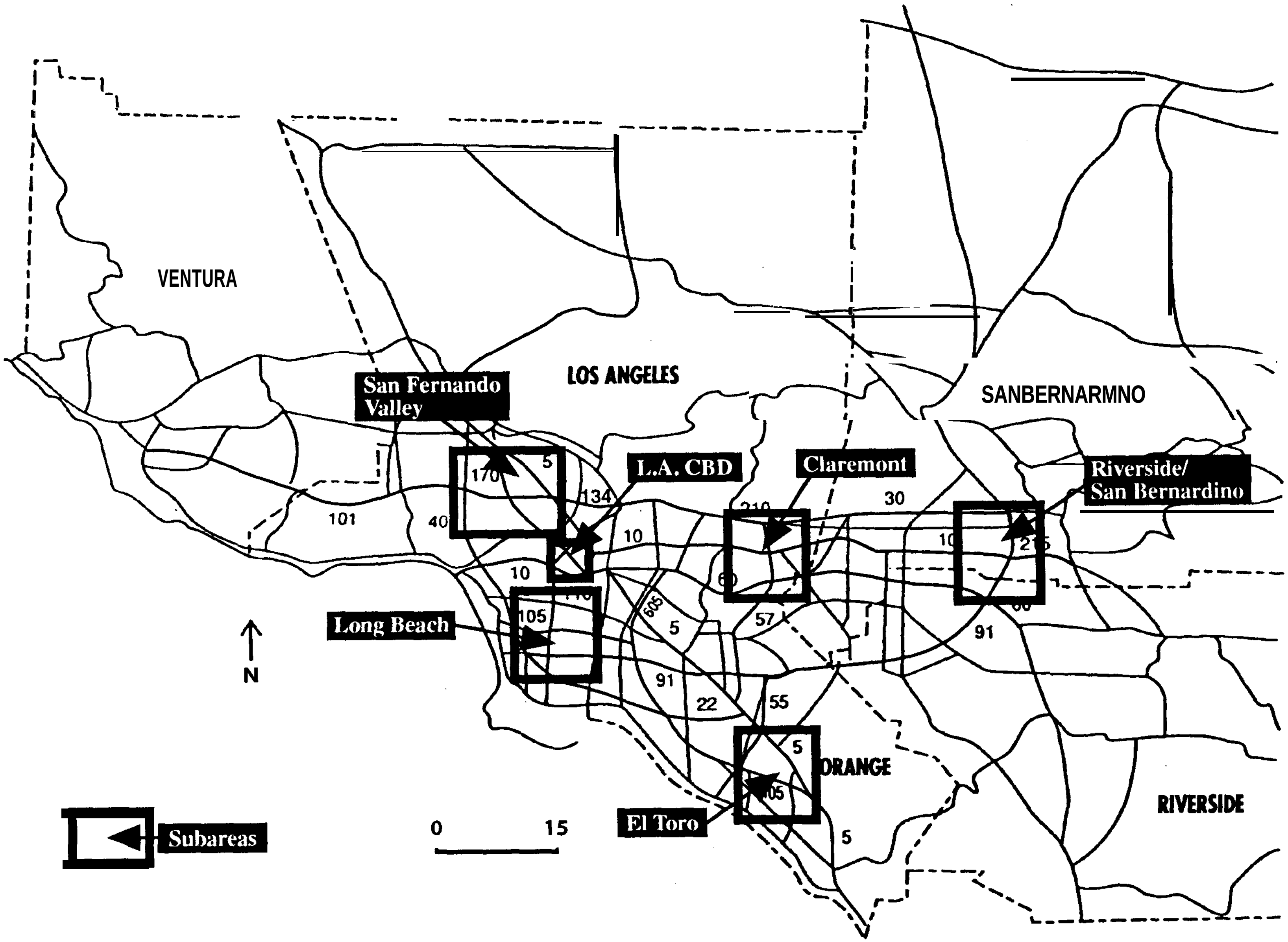

Figure 6
2025 Regional Highway Network

TABLE 12 HIGHWAY AUTOMATION ARTERIAL MOBILITY COMPARISONS
(Average Percentage Change)

ARTERIAL Sub-Area	Baseline vs Base Ramps		Baseline vs Added Ramps		Base Ramp vs Added Ramps	
	VHD	SPD	VHD	SPD	VHD	SPD
Claremont	-42.4	+ 2.2	-41.3	+ 2.2	- 2.0	0.0
El Toro	-34.7	+ 7.7	-31.3	+ 6.3	+ 5.3	-1.3
LACBD	-57.7	+ 1.6	-65.5	+ 2.1	-18.5	+0.5
Long Beach	-74.4	+ 4.3	-76.4	+ 4.3	- 7.6	0.0
Riverside/San Bernardino	-36.4	+ 1.0	-35.2	+ 1.0	- 2.0	0.0
San Fernando Valley	-57.9	+ 6.1	-60.5	+ 6.5	- 6.2	+0.4

TABLE 13 HIGHWAY AUTOMATION RAMP MOBILITY COMPARISONS
(Average Traffic Volume Percentage Change)

RAMPS Sub-Area	Baseline vs Base Ramps	Baseline vs Added Ramps	Base Ramp vs Added Ramps
Claremont	+ 5.3	+ 9.7	+ 4.2
El Toro	+ 5.5	+13.6	+ 7.6
LACBD	+32.8	+46.5	+10.4
Long Beach	+14.4	+19.9	+ 4.8
Riverside/San Bernardino	+20.5	+22.6	+ 1.7
San Fernando Valley	+ 9.6	+13.1	+ 3.3

areas on arterials, comparing the baseline to the automation base ramp scenario, and the baseline to the automation additional ramp facilities scenario, were approximately 35%-75%, and 30%-75%, respectively. The analogous ranges in the average percentage increase in speed were 1%-8%, and 1%-7%, respectively. The comparison of the two automation scenarios showed much less change in VHD and speed. The range in the average percentage change in VHD across sub-areas comparing the base ramp to additional ramp facilities scenario was -19% to +5%. The corresponding range in average percentage change in speed was approximately -1% to +1%. These results further supported the earlier conclusions that arterial travel was considerably less congested when automation technology was applied than when it is not.

A detailed analysis of arterial link volume data was performed to determine whether or not these results were statistically

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significant. (See Phase III Report). All sub-areas showed statistically significant reductions in arterial traffic volume. These results provided more conclusive evidence that neighboring arterial traffic decreased as a result of the attraction of traffic to the automated facility.

The ranges in the average percentage increase in traffic volumes on ramps across sub-areas, comparing the baseline to the automation base ramp scenario, and the baseline to the automation additional ramp facilities scenario, were 5%-33%, and 10%-47%, respectively. The range in the average percentage increase in traffic volume across sub-areas comparing the two automation scenarios was approximately 2%-10%. These results suggest that automated freeway ramps for the automation base ramp scenario were more congested than ramps in the baseline scenario. Baseline and automation base ramp scenarios contained the <u>same</u> number of ramps. However, for the additional ramp facilities scenario, while traffic volume increased, ramp congestion (VHD) decreased on a <u>reaional</u> basis relative the baseline since automated and non-automated vehicles utilized distinct sets of ramps.

A detailed analysis of ramp link volume data was performed to determine the statistical significance of these results. The findings indicated that the larger the percentage increases in traffic volume, the more likely the results were to be statistically significant. Although only half of the sub-areas showed statistically significant increases in traffic volume when standard statistical tests were applied, the general trend indicated that ramp traffic adjacent to automated facilities would become slightly more congested for the automated base ramp scenario.

<u>Fossil Fuel Energy Consumption</u>

The impacts of both roadway electrification scenarios on fossil fuel energy usage were derived. Petroleum, natural gas, and coal were the fossil fuel energy sources investigated. An analysis of petroleum usage alone was also performed because of its extensive usage in the U.S. transportation sector, and the dependence of the U.S. on foreign sources of oil. The analysis was performed for LDAs, LDTs, and an aggregation the two vehicle types. Results for <u>total</u> RPEV driving -- on <u>and</u> off the RPEV network, and on-network driving were derived for two time periods: AM-peak and daily.

Results showed that for each time period and scenario comparison -- baseline versus RPEV, differences in fossil fuel energy consumption associated with <u>total</u> RPEV travel versus on-network driving were negligible. This result was expected since the market penetration for both RPEV scenarios was small. The on-network RPEV fossil fuel usage was approximately half the total RPEV fossil fuel energy consumption.

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Petroleum Consumption

The baseline scenario vehicle fleet was assumed to entirely consist of gasoline internal combustion engine vehicles **(ICEVs).** Petroleum consumption for **ICEVs** was derived from two sources: gasoline consumption, and the use of petroleum-derived fuels in the early phases of the gasoline production cycle, i.e. gasoline, diesel, and fuel oil. Petroleum consumption for RPEVs was also derived from two sources: petroleum for electricity generation, and the use of petroleum products for processing other fuels, i.e. coal and natural gas.

For comparative purposes, all results were expressed in million Btu (mbtu). Results for the AM-peak period were characteristic of petroleum usage across all time periods and extent of RPEV network travel with only slight modifications. (See Table 14). The petroleum consumption savings in the AM-peak period for both **RPEV** scenarios **was** approximately 12%. Only very small differences existed between total and on-network RPEV petroleum consumption for a given vehicle type, and RPEV scenario since the market penetration for RPEVs was small. Daily petroleum consumption savings across RPEV scenarios and extent of **RPEV** traffic was approximately 15%.

Natural Gas Consumption

An assessment of fossil fuel primary energy consumption was performed in which petroleum and natural gas were the primary energy sources considered and the entire energy production process stream was analyzed. Other primary energy sources such as biomass were excluded from the analysis since they were not fossil fuels. This assessment was performed for both AM-peak and daily time periods, all scenarios, vehicle types, and extent of RPEV network travel. Based on the results of this analysis and the petroleum consumption previously discussed, natural gas usage was derived. AM-peak period results for both RPEV scenarios, major vehicle **types,** and on-. and off-network traffic are given in Table 15. These results were typical of primary energy consumption across other time periods and extent of RPEV network travel with only minor modifications.

Even though the RPEV market penetration was relatively small, 81% of electricity produced for the RPEVs was assumed to be derived from natural gas as the primary energy source, producing large increases in natural gas usage relative to the baseline. As in the case for petroleum consumption analysis, the relatively minor differences between scenarios for a given vehicle type, time period, and type of RPEV traffic were due to VMT differences between these two scenarios. The total increase in daily natural gas consumption aggregated over both vehicle types was 147,800 mbtu and 147,400 mbtu for the exclusive and non-exclusive scenarios

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TABLE 14

2025 ROADWAY ELECTRIFICATION

AN-PEAR PETROLEUM CONSUMPTION: ON- & OFF-NETWORK

PERCENTAGE CHANGE RELATIVE TO TBE BASELINE

	Exclusive RPEV	Non-Exclusive RPEV
LDA	-11.5	-11.7
LDT	-11.5	-11.7
Total	-11.5	-11.7

TABLE 15

2025 ROADWAY ELECTRIFICATION

AM-PEAK NATURAL GAS CONSUMPTION: ON- & OFF-NETWORK

PERCENTAGE CBANGE RELATIVE TO TRE BASELINE FOR TRANSPORTATION

	Exclusive RPEV	Non-Exclusive RPEV
LDA	+38.5	+38.3
LDT	+66.6	+66.5
Total	+45.8	+45.7

respectively. Total end use demand of natural gas for California in 2025 was estimated to be approximately 1,500 trillion btu (tbtu). The SCAG region proportion of this amount was about 50%, that is 750 tbtu, based on the region's population relative to the whole state. The average daily volume of natural gas demand in the SCAG region was thus 2.055 tbtu. For either of the RPEV scenarios, natural gas consumption increased 7.2% relative to the average daily end use for the SCAG region. Daily natural gas supply for the SCAG region in 2025 was forecast to be approximately 3.297 tbtu. Thus, while the increase in natural gas usage associated with the RPEV scenario is considerable relative to forecasted growth between 1990 and 2025, plentiful supplies of natural gas are projected for 2025.

Air Qualitv

Impacts of both roadway electrification and highway automation on air quality were derived and compared with 2025 baseline emissions. AM-peak period results were given for five pollutants: reactive organic gases (ROG), carbon monoxide (CO), nitrogen oxide (NOX),

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sulfur oxide (SOX), and particulate matter (PM)), for two major vehicle types -- LDAs and LDTs, and an aggregation of the two vehicle types. Baseline mobile source emissions were composed of cold and hot start, evaporative and running emissions. In addition, two stationary emission sources contributed to baseline emissions: refueling emissions consisting of evaporative emissions at fuel stations and bulk plants, and petroleum refinery emissions.

Roadway Electrification

Roadway electrification emissions were divided into a total RPEV travel case (on- and off-network), and an on-network travel case. RPEV emissions referred to the pollution produced by vehicles driving during the AM-peak period. Not all RPEV-related pollution was produced during the AM-peak since approximately 53% of the RPEV VMT was generated by off-network travel. It was assumed that all battery recharging, and consequently all off-network emissions, were produced overnight (10PM-6AM). Total emissions produced during the day by vehicles driving during the AM-peak period, and emissions generated during the AM-peak period were reported.

Total emissions generated in each roadway electrification scenario consisted of: (1) mobile source emissions generated by the ICEVs, (2) refinery and refueling emissions attributed to the ICEVs, and (3) stationary source emissions produced by power plants during the electricity generation process. ICEV mobile and stationary source emissions for the RPEV scenarios were derived as in the baseline scenario. Total in-basin power plant emissions (grams per kilowatt-hour) were first derived by pollutant and power plant type. Data required for this derivation consisted of the: (1) percentage breakdown of fuel feedstock sources for in-basin electricity generating power plants, (2) mix of power plants by type for each fuel feedstock source, (3) future emission reduction technologies utilized in each power plant type coupled with the percentage emission reduction for each pollutant, and (4) percentage of power plants by type employing these emission reduction technologies.

Natural gas was the only in-basin fuel feedstock source used in the derivation of power plant emission factors, generating 81% of SCAG region electricity in 2025. Gas power plants were further disaggregated into steam, turbine, combined cycle, and advanced combined cycle types. Fuel feedstock sources, i.e. wind and solar, were excluded from the analysis due to their negligible emissions. Biomass-fired powerplants were excluded (1) given their small contribution to electricity production (approximately 3%) and (2) the lack of sufficient data to describe biomass emission factors. Oil-fired power plants were excluded given their negligible contribution to electricity production. Coal-fired power plants were excluded from the analysis since no in-basin coal-fired power plants were projected for the year 2025, and the focus of this research was SCAG regional air quality.

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Power plant emissions were converted to grams per mile from kilowatts per mile for each vehicle type after accounting for all distribution losses between the power plant and the vehicle. Emissions were then aggregated across power plant types, for each vehicle type, power source (electrified roadway or onboard battery), and pollutant. For total RPEV travel, a weighted average of emissions was derived to reflect the on-network/off-mix of RPEV usage. Total emissions were derived by adding the stationary source emissions to ICEV emissions. Results for total RPEV traffic are presented in Table 16.

Results indicated a reduction in the total emissions for each roadway electrification scenario relative to the baseline. Percentage reductions overall varied between 7.1% and 14.9%. The relatively modest improvements in air quality were directly related to the small market penetration for the roadway electrification scenarios. The variation for a given pollutant and vehicle type across scenarios was small due to slight VMT differences for the two RPEV scenarios. These effects were smaller than the 15% of VMT and 15% gasoline swings because of the dependence of pollutants on the number of trips as well as VMT.

The contributions of power plant emissions to the total AM-peak emissions for both RPEV scenario were extremely small. The percentage contribution of power plant emissions varied between 0.1 and 0.6. Further investigation into the trade-off between increased RPEV market penetration and resulting power plant emissions and reduced ICEV emissions were favorable for the RPEV technology since the reduction in ICEV emissions offset increased RPEV-related emissions.

Automation

All vehicles were assumed to be ICEVs in the automation scenarios. The automated vehicles were, however, modeled to travel at 55 mph on the automated network. Total emissions for both automation scenarios disaggregated by vehicle type and emission type were derived by the same methodology as in the baseline case. Results are presented in Table 17.

With the exception of NOX, all emissions associated with automated travel indicated a reduction for each automation scenario relative to the baseline. Percentage reductions overall varied between 1% and 7.5%. There was a slight increase in NOX emissions of between 3.3% to 3.8%. The emission reductions for ROG, CO, SOX, and PM, and the increased NOX were attributable to the increase in speeds for the automated vehicles.

While almost all emission changes were favorable, the results did not reflect the long term consequences of automation on air quality.

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TABLE 16

2025 ROADWAY ELECTRIFICATION

AM-PEAK EMISSIONS: ON- & OFF-NETWORK

PERCENTAGE CHANGE RELATIVE TO TEE BASLEINE

	Exclusive		Non-Exclusive	
Pollutant	LDA	LDT	LDA	LDT
ROG	-5.3	-5.7	-5.5	-5.9
co	-6.2	-6.2	-6.4	-6.4
NOX	-7.8	-8.0	-7.7	-7.9
sox	-11.3	-10.9	-11.4	-10.9
PM	-10.2	-10.0	-10.0	-10.0

Note: LDA = Light Duty Auto
LDT = Light Duty Truck

TABLE 17

2025 HIGHWAY AUTOMATION

AM PEAR EMISSIONS PERCENTAGE CEANGE RELATIVE TO THE BASELINE

	Base Ramp Network		Additional Ramp Facilities	
Pollutant;	LDA	LDT	LDA	LDT
ROG	-5.0	-6.4	-5.9	-7.5
co	-3.4	-3.4	-4.0	-4.0
NOX	+3.3	+3.4	+3.7	+3.8
sox	-1.4	-1.2	-2.0	-1.6
PM	-1.2	-1.2	-1.8	-1.9

Note: L D A = Light Duty Auto
LDT = Light Duty Truck

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Over time, an induced increase in VMT could occur with concomitant increases in energy use and emissions as a consequence of *no* constraints on land development or of pricing individual travel below its marginal social cost. Highwa automation would provide tripmakers the option of living fu--her from employment locations without increased travel time due to the increased effective speeds attained on the automated network.

Utility Demand

The impact of roadway electrification on electricity usage was derived. The volume of RPEV trips remained constant across both RPEV scenarios. Additional demand for electricity usage resulting from roadway electrification was therefore the same for each scenario. Results were derived for the AM-peak, PM-peak, and daily time periods.

Total energy usage was determined as the product of vehicle energy consumption and RPEV VMT. Because vehicle energy consumption and VMT differed by vehicle type, estimates were made for each vehicle type individually, then aggregated together. All distribution, vehicle, and roadway energy losses were included in the calculation of vehicle energy consumption. Results were also derived for total RPEV travel and on-network RPEV travel.

Total electricity usage for the RPEV scenarios is depicted in Table 18. Electricity usage for on- and off-network travel refers to RPEV usage during those time periods rather than the production of electricity during those time periods. Usage listed as on-network indicates production of power during the specified time period.

The time of day electricity demand profile for the SCAG region was derived to provide a worst case day for analysis and planning purposes. This electricity profile was representative of historical usage for a peak usage day. In addition to baseline electricity demand profiles by time of day, travel distribution patterns were also required to develop an accurate account of the impact of roadway electrification on electricity service providers. There were two daily peak travel periods for the SCAG region: the AM-peak, 6 AM -8 AM, and the afternoon peak, 3:30 PM - 6:30 PM. Thus there was a daily overlap in travel and electricity demand peaks in the late afternoon, and a seasonal overlap in peaks during the summer months.

The SCAG region's time of day electricity demand profile for an average summer weekday in *2025* was derived from the current profile to reflect the ratio of the 2025 baseline peak hour estimate to the current peak hour estimate. The time of day electricity usage profile *for* on-RPEV network travel was derived from the daily on-RPEV network electricity demand, the hourly distribution of traffic on SCAG regional freeways, and the assumption that hourly energy

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TABLE 18

2025 ROADWAY ELECTRIFICATION

ELECTRICITY DEMAND (mwh)

RPEV USAGE

	ON- & OFF-NETWORK	ON-NETWORK
AM-PEAK	1,881	866
PM-PEAK	5,633	2,595
DAILY	19,264	8,879

demand for transportation was proportional to hourly traffic volume.

Finally, the time of day electricity usage profile for off-RPEV network travel was derived. It was assumed that all battery recharging occurred overnight, all vehicles *were* fully recharged in the morning, and all roadway power was utilized to drive the vehicle. It was further assumed that all overnight recharging occurred uniformly between the hours of 10 PM and 6 AM, and that all households recharged the same amount over an 8 hour period. The estimates of RPEV electricity demand are depicted in Table 18.

Total electricity demand in the SCAG region by time of day was calculated as the sum of electricity demand for the baseline and RPEV-related usage. (See Figure 7). The time of day electricity demand profile was dominated by the baseline distribution, although the electricity demand from roadway electrification followed a substantially different profile. This occurred since the additional amount of electricity used was relatively small for the RPEV scenario compared with the baseline. Peak hour demand shifted, however, from 2-3 PM to 3-4 PM. The additional utility demand associated with the RPEVs represented an increase of 1.0 percent *over* the baseline peak hour amount and an increase of 2.1% over total daily baseline electricity usage when aggregated over the entire day.

With a *larger* market penetration of RPEVs, the additional demand for electricity would increase. Table 19 presents the results of a sensitivity analysis that indicated the changes in peak hour electricity demand resulting from increases in daily market penetration of RPEVs.

While the potential of a 5% increase in peak hour demand would be possible and of concern, it would correspond to a regional RPEV VMT of approximately 55%. Based on the analysis performed in the development of the RPEV scenarios, a more likely and still

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FIGURE 7 ELECTRICITY USAGE COMPARISON

Baseline vs. RPEV Scenario

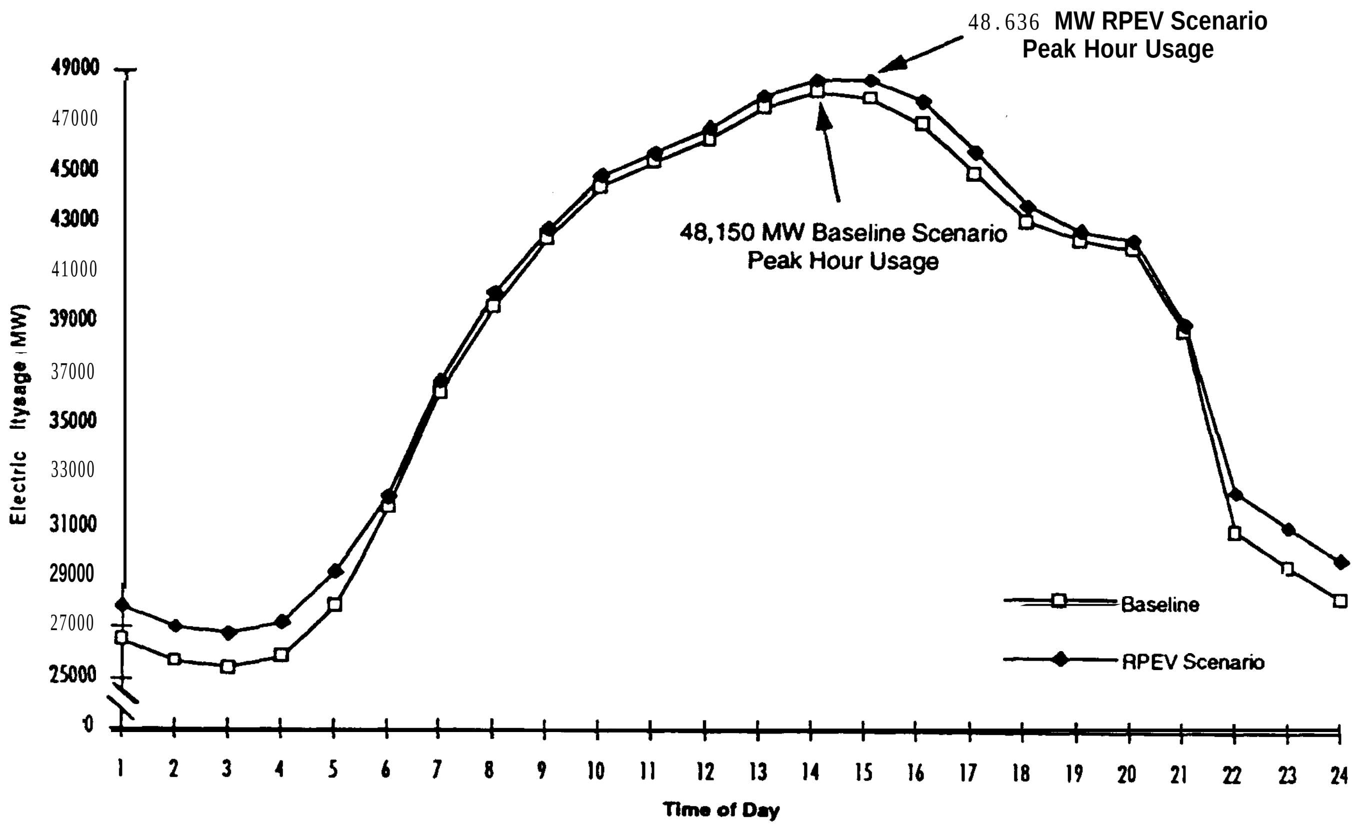

TABLE 19

IMPACT OF MARKET PENETRATION ON ELECTRICITY DEMAND

DAILY RPEV VMT PERCENTAGE	RPEV SCENARIO ELECTRICITY DEMAND INCREASE OVERBASELINE (PEAK HOUR)
15.4	1.0
20.0	1.5
30.0	2.4
40.0	3.4
50.0	4.3
60.0	5.3

conservative upper limit on market penetration would be about 40%. This corresponds to a 3.4% increase in the peak hour demand for electricity, again not negligible, yet a more modest increase.

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Environmental Issues

Three additional environmental issues were addressed with respect to the implementation of the roadway electrification technology: (1) the introduction of electromagnetic fields (EMF) in close proximity to the electrified lane centerline, (2) the potential hazardous waste associated with disposal of RPEV (as well as EV) batteries, and (3) the acoustic noise levels in vehicles traveling on the powered roadway.

EMF Exposure

RPEV operation entails the transfer of energy via an inductive coupling system (ICS) between the powered roadway and the vehicle. The ICS transfers power through a magnetic field. The magnetic field strength varies depending on roadway current and distance from the roadway centerline. Since EMF field strength is measured as the density of magnetic flux, attention to this issue was warranted in order to ascertain the environmental impact of the powered roadway.

Concerns that have arisen within the scientific community regarding possible health impairments due to long-term exposure to EMF have been heightened as the number of studies correlating cancer in humans and EMF exposure has increased. To adequately address these concerns, EMF measurements were studied from both static and dynamic testing of the PATH roadway powered bus and conventional vehicles on the Richmond Field Station test track.

Test results from the PATE bus and conventional vehicle powered roadway experiments indicated that in a unshielded situation, the magnetic flux density (the measure of EMF strength) was 300 milligauss (Mg), and 1.5 to 3.0 Mg for a shielded position for a 240 amp roadway. These measurements were taken at 40 inches above the roadway to approximate the EMF exposure at the driver's position in the vehicles. Shielded test findings indicated lower EMF exposure for the roadway powered vehicle since the magnetic field passes through the pick-up unit in an RPEV whereas it passes through the steel chassis in a conventional vehicle.

To put these powered roadway EMF readings in perspective, Figure 8 ranks several electrical appliances and power delivery by field strength and degree of EMF exposure (in Mg), including shielded and unshielded powered roadway cases. The RPEV estimates of EMF were also found to be significantly below the standards for EMF exposure set by the International Radiation Protection Association (IRPA) and the International Non-Ionizing Radiation Committee (INIRC). Thus, at this time evidence regarding EMF exposure with respect to the powered roadway suggests that there is little need for environmental concern.

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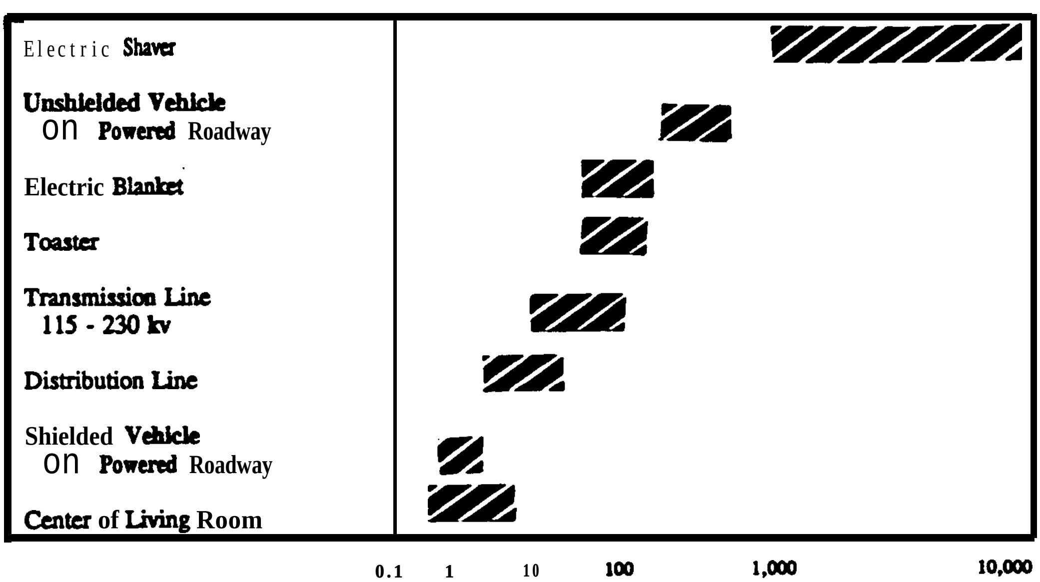
Battery Disposal

Whether lead acid or other batteries are utilized in RPEVs (as well as Evs), increased unrecycled battery disposal is likely to produce more impacts on the environment. The concern for water quality that would be jeopardized by the increased likelihood of battery leachate in groundwater supplies warrants attention for "cradle-to-grave" battery management. Similarly, incineration of lead waste products raises questions regarding air quality deterioration and associated health damages. Thus, directing public policy to reinforce behavior towards participation in currently established recycling efforts is necessary to offset the potential for increased hazardous waste from illegal disposal of batteries as the market for RPEV/Evs expands. For example, Federal support of smelter subsidies and mandated usage of recycled lead as well as legislation requiring retailers to assist in battery collection should be pursued.

Acoustic Noise

Since interior sound levels are an aesthetic concern to the driver of a vehicle, attention was given to analyze the acoustic noise of conventional vehicles and RPEVs under driving conditions on the Richmond Field Station test track. In tests conducted on the PATH roadway powered bus, the interior noise level was found to be 40-45 decibels. Conventional vehicles of different makes and sizes were

FIGURE 8 EMF EXPOSURE RANKED BY FIELD STRENGTH



Source: Morgan, et al, 1989. Ranges represent 95% confidence intervals.

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also examined for acoustic noise under test track driving conditions. For the conventional vehicles **40-70** decibel readings were experienced. To put this in perspective, a library has an acoustic noise level of approximately 35 decibels, an office - 65 decibels, a heavy truck - 90 decibels, a jack. hammer - 105 decibels, and a jet plane - 125 decibels. Experts consider noise levels of 135 decibels to be painful to the ear.

The acoustic noise measurements for conventional vehicles were considered high enough to warrant further testing of lower roadway currents and higher frequencies. The use of higher frequencies in the inductive coupling design would lower interior noise levels since it permits use of lower roadway currents, and humans are less sensitive to higher frequencies. Ongoing results of these new tests have been encouraging.

Economic Analysis

Economic analysis was derived for development and usage of the 2025 RPEV scenario. Two categories of costs pertained to the RPEV system: construction and operating expenses of the electrified roadway, or infrastructure, and life cycle costs to users of the facility. Supportive cost model analysis was utilized to crosscheck the infrastructure costs, and life cycle expenses associated with owning and operating a gasoline vehicle were also summarized. Gasoline vehicle costs and alternative infrastructure cost estimates were also furnished for comparative purposes.

Life Cycle User Cost Analysis

A disaggregated cost model was utilized to develop the life cycle personal vehicle costs. This work drew on a methodological framework developed by Nesbitt, Sperling, and Deluchi (NSD) with further modifications by SCAG and PATH. The RPEV and gasoline vehicle user costs included ownership components which were amortized over their respective lives, and operation and maintenance expenses. RPEV life cycle costs incorporated those costs associated with development and usage of the electrified roadway, i.e. roadway installation and maintenance. Personal vehicle allocation of the costs for the **RPEV** system were first derived for a one-mile portion of a fully built **RPEV** system with a vehicle population consistent with the RPEV scenario, and later modified to include the number of lane-miles contained in the RPEV scenario.

Table 20 lists the results of the life cycle RPEV and gasoline vehicle cost analysis. Gasoline vehicle user costs were slightly lower than those for **RPEVs,** 24.88 cents per mile compared to 25.64 cents per mile. Fuel cost for the gasoline vehicle was 4.14 cents per mile while total electricity cost for the RPEV was 1.68 cents per mile. The roadway electricity cost was composed of **.78** cents per mile of **on** roadway electricity cost, and **.90** cents per mile of

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TABLE 20 OUTPUTS FOR BASELINE GASOLINE AND RPEV USER COSTS

Gasoline Vehicle Outputs (cents/mile)

4.14	Gasoline
9.11	Vehicle
5.40	Insurance
3.46	Maintenance
0.20	Oil
0.45	Replacement tires
0.91	Parking and tolls
0.18	Registration
0.18	Inspection and maintenance
0.71	Gasoline tax
0.13	Accessories
24.88	TOTAL PRIVATE COST

RPEV Outputs (cents/mile)

1.68	Total electricity cost (46.5%,or .78* is on-roadway)
9.21	Initial vehicle cost
2.09	Batteries
6.00	Insurance
2.08	Maintenance
0.64	Replacement tires
.91	Parking and tolls
0.19	Registration
0.71	Fuel tax
0.13	Accessories
0.59	Cost for additional electric roadway maintenance *
1.41	Cost for electric roadway installation *
25.64	TOTAL PRIVATE COST

Note * = The sum of these three items is 2.78 ¢/mile which compares with 4.05 ¢/mile in the steady state cost model (SSM) and 6.17 ¢/mile in the regional economic cost model (REM). The revised private cost is 26.91 ¢/mile for the SSM and 29.03 ¢/mile for the REM.

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electricity cost associated with off roadway charging, i.e. at home, opportunity charging, since 46.5% of RPEV travel occurred on the powered roadway.

RPEV maintenance costs compared favorably with those of the gasoline vehicle. The gasoline vehicle user costs included a gasoline tax that was assumed to provide revenue for the development of and usage of the freeway facilities whereas the RPEV user costs covered costs explicitly related to roadway infrastructure maintenance and installation. For the RPEV, 2.00 cents per mile of the user costs represented the allocation of infrastructure expenses. Thus, the baseline user cost comparisons suggest that the RPEV may offer some economic advantage to users over the life of the vehicle especially if roadway infrastructure costs were subsidized similarly to highway developments provided for conventional gasoline vehicles.

The life cycle cost analysis was, however, deficient in several areas. It did not contain: a mechanism to allocate deficit expenses that would accrue during the early years of roadway construction, a precise market penetration growth profile, or a roadway construction schedule consistent with the RPEV scenario defined for the study. For these reasons further work was undertaken to address these crucial economic considerations.

RPEV System Cost Analysis

Three cost models were developed by Systems Control Technology, Inc. with input from SCAG and PATH to portray the relationship between costs and revenues associated with operation of the powered roadway. Each model built upon the previous model construction adding further refinements and detail while retaining adequate similarities with the previous models to provide easy validation.

The Steady State Model (SSM) was comparable with the NSD model in its treatment of roadway construction, energy, administration, operations, and maintenance expenses. It provided a one-mile reference model case for a fully built roadway that serviced the market penetration given in the RPEV scenario. Since the SSM did not incorporate financing considerations related to development and use of the system in previous time periods nor a market penetration growth profile, the Startup Transient Model (STM) was formed to add these points to the cost analysis. The RPEV Economic Model (REM) added a specific construction schedule for the RPEV scenario to the STM. The REM model is thus the most comprehensive approach for capturing the design and practical application of the RPEV scenario.

The REM produced a breakeven rate, an estimate of the retail energy price, for both annual and cumulative cost analyses. The cumulative cost analysis was, however, utilized for further cost

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sensitivity work since this cost perspective immersed the complete cost profile into.electricity rate determination. For example, for cumulative revenues and costs to break even in year 25 would require a breakeven rate that would guarantee that all previous deficit expenses associated with roadway construction would be zero, and cumulative revenues would equal cumulative costs. After year 25, given the breakeven rate charged to RPEV user, the powered roadway system would become profitable. This analysis thus focused on determining the costs to build and operate the electrified roadway with revenues derived from power purchased by RPEV users of the system.

Throughout the REM analysis of roadway construction costs, it was assumed that loans were used to finance these capital costs. Wholesale energy cost was calculated by multiplying the amount of energy sold by the wholesale energy rate, and adding a cost component to cover system distribution losses. Administration costs were assumed to be related to construction activity and the number of users. Table 21 summarizes the REM baseline model inputs while Table 22 lists the outputs for the baseline REM cumulative revenue and cost analysis. Figure 9 depicts the baseline REM cumulative revenue and cost profile over a 40 year period.

As indicated in Table 22 and Figure 9, the cumulative breakeven of all system revenues and costs occurs in year 25. In order for this to occur, a retail energy price, or breakeven rate, of $.294/kwh would be charged to users. At this rate, cumulative system revenues and costs equalled $7,552.8 million; in year 25. This figure included the full cost to build the 1,035 lane-miles of roadway with a market penetration of 28,737 v/l/d as specified in the RPEV scenario.

Important annual cost and revenue patterns imbedded in the cumulative cost results were: (1) the rapid increase in annual costs during the ten years of initial roadway construction, (2) lower annual costs after year 25 due to roadway replacement costs, which were assumed to be two-thirds of initial roadway construction expenses, and removal of the deficit interest expense associated with initial roadway construction, and (3) increased annual revenue until stabilization when market penetration was completed.

The wholesale price of energy was approximately one-third of the retail price of energy in the breakeven year with debt service and cumulative interest on the cumulative deficit representing nearly half of the retail energy price. The wholesale costs of energy represented an increasing proportion of the retail energy price over time while all other cost components' percentage contributions to the retail price of energy declined. This result was expected since all system costs other than energy were spread over a larger number of users over time.

The REM model produced a cumulative breakeven rate of $.294/kwh, or

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Table 21 Regional Economic Model inputs

Regional Economic Model	Scenario Baseline
	INPUT
Market Penetration	
4,000	Number of RPEV users in the initial year of market growth
6,000	Number of users per year until market saturation
3	Start year
26,737	Volume limit in vehicles/lane/day (or vehicle-miles/lane-mile/day)
Revenue	
0.294	Cumulative breakeven rate*
cost	
2.5M	Cost per lane-mile of roadway
1.67M	Replacement cost ($/lane-mile)
2.5	Administrative (% of debt + energy)
2.5	O&M (% of cumulative new roadway capital cost
$.07	Wholesale cost of energy ($/ kwh)
Vehicle Parameters	
0.21	Energy consumption of vehicle (kwh/mile)
75	System efficiency (%)
33.4	Average vehicle-miles per day on the system
Debt Service	
3.3%	Interest rate (real %/year)
25	Life of loan and life of roadway (years)
Miscellaneous	
25	Designated year for cumulative breakeven rate
9.95	Number of years for roadway construction
52	New system-miles per year (104 lane-miles)

*Output of model

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Table 22 Regional Economic Model Results

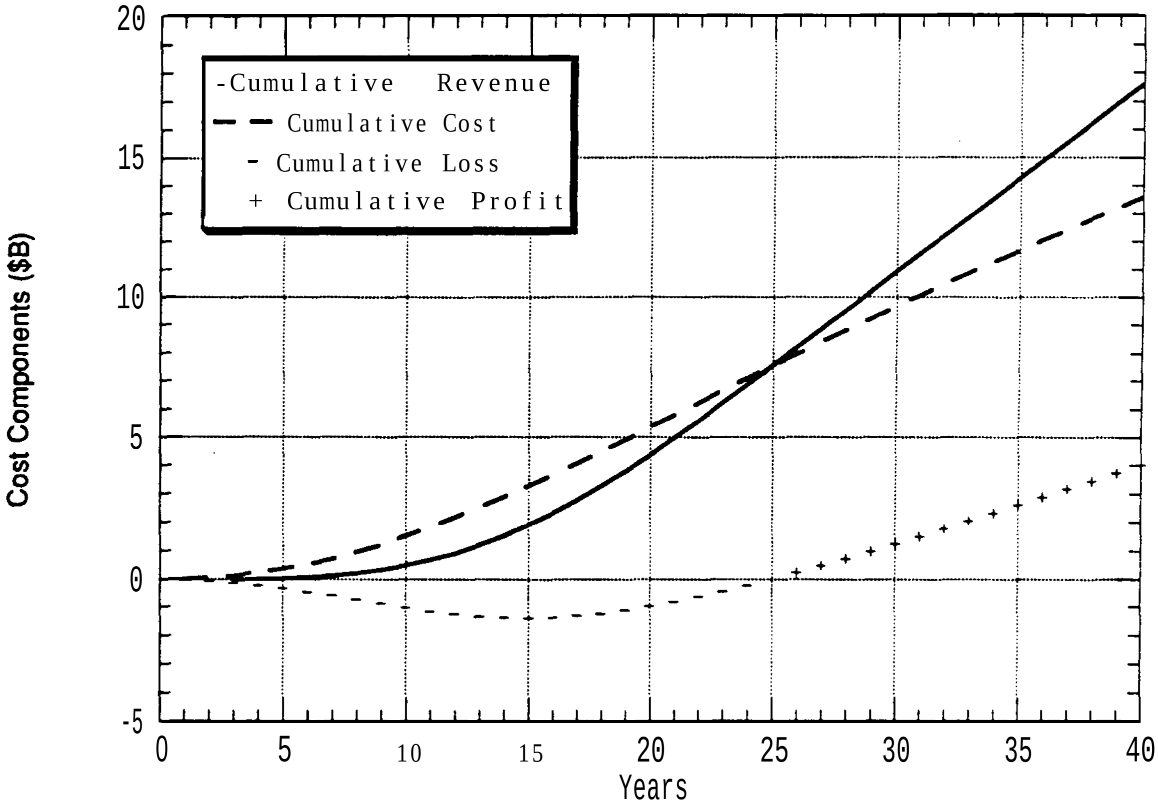
Regional Economic Model

Scenario: **Baseline**

OUTPUT

Cumulative	Year 16		Year 25		Year 40	
	M$	$/kwh	M$	$/kwh	M$	$/kwh
Cost Summary						
Debt service	1,766.1	0.226	3,148.3	0.123	4,914.4	0.087
Wholesale cost of energy	728.8	0.093	2,393.2	0.093	5,582.9	0.093
Operating expenses	806.1	0.103	1,464.4	0.057	2,558.4	0.042
Administrative	62.4	0.008	138.6	0.005	262.4	0.004
O & M	743.7	0.095	1,325.8	0.052	2,296.0	0.038
Interest on cumulative deficit	362.2	0.046	546.9	0.021	546.9	0.009
Total Cost	3,663.2	0.468	7,552.8	0.294	13,602.6	0.226
Revenue Summary						
Retail energy revenue	2,299.9	0.294	7,552.8	0.294	17,619.0	0.294
Total Revenue	2,299.9	0.294	7,552.8	0.294	17,619.0	0.294
Profit/Loss	-1,363.2		0		4,016.4	

FIGURE 9 RPEV ECONOMIC MODEL CUMULATIVE REVENUES AND COSTS



6.17 cents per mile. This retail energy rate was used to modify the NSD model's RPEV life cycle cost estimate for system users. For the REM model, roadway costs assumed in the analysis were higher than those found in the NSD model due to the cumulative cost analysis which included deficit financing and roadway construction timetable considerations. The revised baseline life cycle cost to the RPEV system user of 29.03 cents per mile incorporates these REM revisions.

In addition to the baseline REM and modified baseline life cycle cost estimates. cited previously, sensitivity analyses were completed with respect to changes in roadway costs, wholesale energy cost, roadway operating expenses, interest rates, energy consumption, system efficiency, and average vehicle-miles per day on the system. When possible user cost sensitivity analyses were additionally performed. Table 23 lists the previously stated sensitivity measures and identifies the baseline results with asterisks. All results were based on the requirement that cumulative costs and revenues would balance (breakeven) in year 25.

Table 23 demonstrates that the cumulative breakeven retail electricity rate generally increased as expense category sensitivity values increased, and decreased as sensitivity measures related to system performance and/or system usage increased. Increased system efficiency, however, reduced cumulative costs. Cumulative costs, revenues, and profits were found to be most

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Table 23 Regional Economic Model Results: Sensitivity Analysis

Sensitivity Measures	Cumulative Breakeven Rate (Year 25) $/kwh	OUTPUTS Cumulative Revenue = Cumulative costs (Year 25) M$	Cumulative Revenue (Year 40) M$	Cumulative costs (Year 40) M$	Cumulative Profit (Year 40) M$
Roadway Cost					
$O.OM	0.156	3,998.0	9,326.4	8,317.3	1,009.1
$1.5M	0.241	6,182.1	14,421.5	11,518.6	2,842.9
$2.5M*	0.294	7,552.8	17,618.8	13,602.6	4,016.3
$4.0M	0.376	9,646.3	22,502.5	16,725.8	5,776.7
$6.0M	0.492	12,613.3	29,424.0	21,197.6	8,226.4
Wholesale Energy Cost					
$0.05	0.267	6,851.9	15,984.0	11,967.6	4,016.3
$0.07'	0.294	7,552.8	17,618.8	13,602.6	4,016.3
$0.09	0.322	8,253.7	19,254.0	15,237.6	4,016.3
Operating Expenses					
1.0%	0.256	6,573.0	15,333.2	11,966.3	3,366.8
2.5%'	0.294	7,552.8	17,615.8	13,602.6	4,016.3
5.0%	0.358	9,185.9	21,428.6	16,329.7	5,099.0
Interest Rate					
3.3%*	0.294	7,552.8	17,615.8	13,602.6	4,016.3
6.6%	0.377	9,675.7	22,571.2	16,438.4	6,132.8
9.9%	0.481	12,340.8	28,788.3	19,914.0	8,874.2
Energy Consumption					
0.16	0.357	6,968.7	16,256.4	12,240.1	4,016.3
0.21'	0.294	7,552.8	17,615.8	13,602.6	4,016.3
0.26	0.256	8,136.9	18,981.4	14,965.1	4,016.3
System Efficiency					
65%	0.309	7,930.2	18,499.3	14,483.0	4,016.3
75%*	0.294	7,552.8	17,618.8	13,602.6	4,016.3
85%	0.283	7,264.2	16,945.7	12,929.3	4,016.3
Average Vehicle-Miles/Day on System					
33.4'	0.294	7,552.8	17,619.8	13,602.6	4,016.3
40	0.262	8,037.6	18,749.8	14,733.4	4,016.3
50	0.229	8,772.0	20,463.0	16,446.7	4,016.3

Note: ● = Baseline values

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sensitive to alternative roadway costs and interest rate measures. Table 24 translates the REM model's cumulative breakeven rate from $/kwh to cents per mile to enable calculation of RPEV life cycle user cost sensitivities. The results in Table 24 demonstrate that user costs vary by the greatest amount when alternative roadway costs are considered.

It is important to note that comparisons of the RPEV and gasoline vehicle user cost (24.88 cents per mile) relied on direct, or tangible, cost information only. Consideration of the external, or intangible, costs associated with operation of a gasoline vehicle, i.e. pollution costs corresponding to health, productivity, visibility, material, and other damages, were not factored into the calculations. The ability to calculate such externalities would increase the life cycle costs associated with conventional vehicles relative to RPEVs.

Regional Economic Impacts from RPEV System Application

The most significant regional economic impact associated with the RPEV scenario would be air quality improvements. Quantification of the impacts of this enhanced air quality would require quantification of the primary health benefits accompanying this improvement. In addition to health benefits, increased crop yields for produce that is sensitive to ozone damage, visibility improvements and the associated increased property values, reduced damage to livestock, and decreased deterioration of materials, would be further regional economic benefits associated with air quality improvement. Further benefits associated with the impact of improved environmental quality may exist in the labor market since areas that provide amenities are often migration attractors.

The benefits of reduced reliance on petroleum consumption to fuel the SCAG region's transportation system would be a second primary economic impact associated with the application of the RPEV technology. Other benefits, such as decreased production of greenhouse gases associated with petroleum fueled vehicles could also be experienced globally. At the regional level, it is also likely that reduced consumption of petroleum fuels could provide further environmental quality improvements to the area via decreased water pollution. Losses to regional economic sectors providing petroleum would occur due to reduced reliance on these fuel products.

The electricity demand associated with the RPEV scenario would provide increased revenues to the utilities. As a result the utility sector would experience income and job growth associated with the expansion of RPEV usage.

In the construction, maintenance and vehicle servicing sectors, it is unclear to what extent employmeat and income will change under the RPEV scenario. It is more likely that shifts in the

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TABLE 24 LIFECYCLE RPRV USER COST: SENSITIVITY ANALYSIS

Sensitivity Measures	Cumulative Breakeven Rate (Year 25) $/kwh	Cumulative Breakeven Rate (Year 25) t/mile	Lifecycle RPEV User cost (Year 25) C/mile
Roadway Cost			
$ 0.0m	0.156	3.28	26.14
$ 1.5m	0.241	5.06	27.92
$ 2.5m *	0.294	6.17	29.03
$ 4.0m	0.376	7.90	30.76
$ 6.0m	0.492	10.33	33.18
Wholesale Enerav Cost			
$ 0.05	0.267	5.61	28.21
0.07 *	0.294	6.17	29.03
0.09	0.322	6.76	29.79
Operatinq Expenses			
1.0%	0.256	5.38	28.25
2.5% *	0.294	6.17	29.03
5.0%	0.358	7.52	30.38
Interest Rate			
3.3% *	0.294	6.17	29.03
6.6%	0.377	7.92	33.07
9.9%	0.481	10.10	37.67
Svstem Efficiencv			
65.0%	0.309	6.49	29.34
75.0% *	0.294	6.17	29.03
85.0%	0.283	5.94	28.86

Note: * = Baseline Values

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distribution of jobs and income will occur as powered roadway construction and RPEV usage develop. Similarly, although maintenance and vehicle servicing are expected to be substantially reduced by the RPEV technology, workers may gain skills necessary to provide assistance to RPEV users, and/or acquire different positions as part of a newly created RPEV industry.

A potential benefit for the RPEV scenario exists if efforts are successful in the areas of manufacturing and commercializing RPEVs and Evs in the SCAG region. Such developments would necessitate provision of complete production systems that would integrate local industries, service centers, and training and research facilities toward building an industrial base for the emergence of this technology. Localization economies could be fostered by clustering firms within the RPEV industry in the SCAG region so as to capture scale economies in the production of intermediate inputs, labor market economies, and communication economies. Production and servicing of RPEVs within the region could generate local multiplied impacts on jobs and income as well as provide possible export multiplier impacts for the regional economy if market demand for the technology spread to other areas.

The ability of the Southern California region to attract Federal funding as well as new private capital outlays toward development of the RPEV system design would play an important part toward capturing many of the significant income and employment impacts within the region. Thus, the degree to which such outside funding is attracted to the project will thus assist in the success of improving regional economic growth. Clearly, the capability to design the proper incentives to stimulate increased RPEV/EV market penetration, to provide supportive public and industrial policies to assist technology development, and to build an integrated support structure for maintaining and servicing these new technologies, remain of tantamount importance in the overall determination of regional economic impacts.

Policy efforts. to implement an RPEV system thus necessitate coordinated planning and management efforts that address market penetration, continued technology development, and support service dimensions of system implementation simultaneously in order to capture maximum regional benefits. Mobilization of local collaborations consisting of industry, government, university, and other institutional participant expertise would thus be a first step toward system development.

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IV. DEMONSTRATION OPPORTUNITIES FOR ROADWAY ELECTRIFICATION AND HIGHWAY AUTOMATION

Demonstration Opportunities for Roadway Electrification

Public demonstration of the roadway electrification technology in the SCAG region needs to await the results of ongoing research at the Richmond Field Station and the proposed Playa Vista RPEV Test Facility in Los Angeles.

Recently, studies supported by Southern California Edison and the City of Los Angeles, Department of Water and Power at Richmond Field Station have resulted in a redesigned test vehicle, roadway inductor and power controller. The principal design changes involved increasing the roadway excitation frequency from 400 Hz to 8,500 Hz; reduction in roadway current from 1,200 amps to 240 amps; and, installation of field cancellation windings in the roadway inductor, to further reduce electro-magnetic field (EMF) strengths in the immediate vicinity. Results of these changes were that interior noise in the RPEV was reduced from about 70 DBA to 40 DBA, or less (hardly a perceptible level) and RPEV interior EMFs, which ranged from 20 milligauss to 300 milligauss with the old design, were reduced to 1 to 2 milligauss under the new design. Wayside EMFs at 50 ft from the centerline dropped to less than 1 milligauss. These levels are below those experienced in the typical home or work environment.

Work has been underway over the past few years on the establishment of an RPEV Test Facility at the Playa Vista site located west of the I 405 freeway and about two miles due north of Los Angeles International Airport. As currently envisioned, the initial phase at Playa Vista could begin in the Spring of 1993 with completion of the design and construction of the test facility. Plans call for testing RPEV equipped modified G-vans to start, with later testing to involve minivans, automobiles, multiple occupant vehicles (MOVs), and electric transit buses. Initial plans called for the installation of an electrified roadway test track, similar to the one at Richmond Field Station. Subsequent phases at Playa Vista will look at such issues as lateral guidance, energy storage, roadway design and construction, network analysis for demonstration, market penetration and other studies leading toward public demonstrations.

The following four applications have been identified for demonstrating the roadway electrification technologies:

- Local application on arterial(s) or local streets
- Local activity center on an arterial highway

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- Freeway high occupancy vehicle application
- Freeway setting (single or multiple segments) application

These four applications are further described below and depicted on Figure 10.

Local Application on Arterial(s) or Local Streets

Test Facility Demonstration -- This testing of different vehicle types would occur at the **Playa** Vista Test Facility, initially on a 1,000 **ft** roadway and later on an extended 2,000 ft roadway. Although no "public demonstration" is planned, the vehicles will be repeatedly demonstrated to visitors having an interest in the technology.

Playa Vista Demonstration -- The intent would be to put a permanent network on the permanent roadway system at the **Playa** Vista Site that might be 2 to 3 miles in extent. The vehicles for this demonstration would be second generation multiple occupant vehicles (MOVs), operating at low or moderate speeds. Testing of electronic coupling on up to three MOVs would also be done as part of this effort.

Local Activity **Center on an Arterial Highway**

Pilot Scale Demonstration -- This demonstration would occur on an arterial network in the vicinity of the **Playa** Vista site, bounded roughly by Sepulveda Blvd., Lincoln Blvd. and Santa Monica Blvd.. It would include private vehicles (autos and vans) and **MOVs.**

LAX Shuttle Bus Near-Term Demonstration -- This demonstration would encompass the area in the immediate vicinity of Los Angeles International Airport (LAX). It would be a traditional shuttle bus operation, utilizing full scaled buses, vans or possibly **MCVs.** The shuttle system would link together major airport activity centers (terminals, rental cars, hotels and long term parking lots).

Subregional Demonstration -- This demonstration would encompass about 50 square miles and perhaps 1 million people. It would span an area from Santa Monica and West Los Angeles on the north to El Segundo and Los Angeles International Airport on the south. This system would include arterials but also major freeways traversing the area (I 10 and I 405). It is envisioned that the network would have about 200 lane miles, built at a cost of about $500 million. It is assumed that the vehicles would be produced by major automobile manufacturers, and purchased by the public.

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Figure 10

ROADWAY ELECTRIFICATION DEMONSTRATION OPPORTUNITIES

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Freeway High Occupancy Vehicle Application

Busway Electrification Demonstration Project -- Opportunities for HOV applications of the RPEV technology were outlined by SCAG in a 1984 study. The networks chosen for HOV lane consideration still bear potential. They include: El Monte Busway (11.25 mi.) east-west facility, existing, parallel to San Bernardino Freeway (I-lo), two lanes in each direction: Santa Ana Guideway (30.3 mi.) southeasterly from downtown Los Angeles to Santa Ana, parallel to Santa Ana Freeway (I-5), one lane each way; and, Harbor Guideway (11.36 mi.) north-south from downtown Los Angeles to Route 91 in the vicinity of Gardena, parallel to the Harbor Freeway (I-105), one lane each way.

I-15 **San Diego Area HOV Demonstration** -- This opportunity, while not in the Los Angeles area proper, is near enough to provide close-by public visibility. An 8 mile section of reversible HOV lanes adjacent to I-15 in San Diego County is currently serving as an off-peak period test facility for the PATH program's lateral control vehicle following program. The HOV lanes could also be electrified and serve as a demonstration for the RPEV technology.

Near-Term HOV Demonstration -- Another possible near term HOV site would be along Route 91, east of the Harbor Freeway. This demonstration **could take place** prior to 2000 as is envisioned in the Playa Vista work scope.

Freeway Setting (Single or Multiple Segments) Application

Marina Freeway Demonstration Possibility -- Before a widescale freeway application is considered, the concept could be tested on **a 2 mile segment of the Marina Freeway** from Culver Boulevard to Slauson Avenue. This site, in close proximity to Playa Vista, could provide a good test facility for the RPEV freeway concept with minimal public disruption and maximum exposure.

Subregional Demonstration -- This is a combination demonstration, previously discussed under the arterial highway description. It includes major segments of I-10 and I-405 in the environs of the Playa Vista project.

Thin Regional Alternative -- An alternative to the subregional demonstration would be to install enough of the powered roadway so that a trip can be made anywhere in the region, for example one **lane in each direction on I-15 for 80 miles, and one lane** on I-10 over a similar distance.

Proposed Western National Transportation Research and Development Center -- A final possible test facility for

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freeway or any one of the other app.. cations would be at a proposed Western Transportation Researcn and Development Center to be built by the state somewhere in California. This would be an ideal location to test construction techniques as well.

RPEV Demonstration and/or Development Considerations

Fundability -- Funding for application of the RPEV technology must involve ongoing public/private sector cooperation. Construction funding for roadway inductor construction could be funded wholly or partly with governmental funds (federal, state or local). Electric utility revenue **based** funding could be used as well. Private funding could help supplement vehicle development for demonstration purposes.

Organizational Feasibility -- The key organizational questions that need to be addressed are: who would construct, own and operate the system; and, **can** an effective system be developed to capture the ongoing costs of operating and maintaining the system. Construction on the state highway system would be under the jurisdiction of Caltrans (State Highway Agency) or a given local jurisdiction if the demonstration occurred on local arterials. Alternatively the electric utility or another governmental agency could build and operate the facility.

Ease of Implementation -- An RPEV scenario may be harder to implement than a highway automation scenario. The one exception would be if the automation scenario included the construction of special access facilities (ramps or cross overs).

Construction Phasing -- A key question is how can the RPEV technology be implemented with minimal public disruption of the transportation network. Current techniques for the RPEV would require cutting out a segment of the roadway and replacing it with the inductors. Existing techniques to minimize disruption, like nighttime construction, could help to minimize this problem. Piggybacking RPEV construction with normal resurfacing would also be appropriate.

Social Acceptance -- Key questions of social acceptance of the RPEV technology may require acceptance of the electric vehicle by the driving public, and include:

- **Will the** electric vehicle (with RPEV modifications) be priced (including subsidies) to compete with the internal combustion vehicle?
- Will a publicly acceptable static charging system infrastructure be available?

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- Given that fleet electric vehicles will likely be the first types in widespread use, how will their experiences be translated to help facilitate personal electric vehicle use?

- Will the electric vehicle be effective for multi-vehicle families, and will they be able to overcome battery range limitations?

- Will acceptable electric vehicles be able to incorporate personal conveniences demanded by the driving public, like air conditioning?

Political Acceptance -- Local officials will need to see the benefits of the RPEV technology in relationship to other alternatives, including doing nothing. Regional and county transportation and air quality planning bodies should be utilized to help educate local officials and the general public on the benefits of the RPEV technology and the results of any public demonstrations.

Monitoring -- Demonstrations of the RPEV technology need to be based on an effective monitoring program. This program should be designed to collect transportation systems utilization data; socio-economic data; public acceptance levels; and, projected and actual capital and operating costs. Monitoring of pre and post demonstration conditions should also be a vital part of any monitoring program.

Ongoing RPEV Research Needs

The following ongoing RPEV research needs should be pursued at the governmental, university, transportation laboratory and private sector levels:

- Market Potential for RPEVs and Electric Vehicles in the Los Angeles Area

- Highway Network Analysis of Different RPEV Network Configurations, Market Penetration Assumptions, Battery Ranges and Alternative Spacings

- Manufacturing/Retrofit Feasibility and RPEV Market Integration

- Electricity Use and Cost Recovery (Vehicle/System)

- Roadway Inductor Construction, Installation and costs (Including Applications for Robotics Techniques)

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- Long Term Impacts of Highway Use on Roadway Inductor and Pavement Structure (Highway Test Segment)
- **RPEV** Opportunity Charging Possibilities (Intersections, Bus Bays, Parking Lots)
- Arterial Applications for RPEV Technology
- RPEV Bus vs. Battery Electric Bus vs. Electric Catenary Bus (Comparisons)
- Long and Short Term Electra-Magnetic Field and Electra-Magnetic Interference Effects (Vehicle/Wayside)
- Time-Staging and Deployment Studies in the Metropolitan Area
- Cost-Effectiveness of RPEV vs. Alternative Electric Vehicle and Hybrid Vehicle Assumptions
- Ongoing Testing and Refinement of the Inductor and Pickup Technologies.
- Ongoing Vehicle Applications **(Auto/Van/Bus/MOV/Truck)**

Demonstration Opportunities for Highway Automation

Highway Automation technologies are not as fully developed as RPEV technologies. Most work in testing these concepts has occurred in the laboratory at university or private sector research facilities. In recent years work in the United States **has** been discussed as part of a national public/private effort referred to as Mobility 2000. This group gave rise to a crystallization of research and demonstration planning for Intelligent Vehicle Highway Systems. Most recently, the work of Mobility 2000 has been expanded upon as a part of the national organization IVHS America. Moreover, the IVHS America Strategic Plan, published in May 1992, provides a guideline for development and deployment of IVHS in the U.S.

Mobility 2000 studies reveal that the type of automation technologies considered in the SCAG region study could be fully researched, tested and deployed by 2015. These include the essential elements of automatic lateral and longitudinal control, communications for control, automated traffic merging, automated obstacle avoidance and automated trip routing and scheduling.

Very little information is available on the cost of automation technologies. One study in 1980 estimated costs at about $2

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million per mile. Further research is needed on costing of automation technologies before practical demonstration planning and applications can and should occur.

A recent study on the social and institutional forces impacting on highway automation technologies points to the following driving forces for implementation, in order of priority:

- Increasing Traffic Congestion
- Desire for Improved Safety
- Motorists' Desire for Comfort and Convenience
- Public Demand for Travel Information
- Declining Cost of Technology and Operation
- Incremental Process Toward Development and Adoption of Advanced Systems
- Commuters' Preference for Highway Over Rail
- Novelty of the Technology
- Promise of Shorter Trip Times by Traveling on Designated Lanes

In the same study, the survey participants ranked the expected sociotechnical impacts of highway automation technologies:

- Reduced Congestion (positive)
- Improved Safety (positive)
- Increased Comfort and Convenience for the Motorist (positive)
- Increased Driver Acceptance of Automated Control (positive)
- Increased Automobile Commuting (negative)
- Smoother Traffic Flow on Toll Roads (positive)

Highway automation technologies are still in their relative infancy as is the readiness of the public to accept the full range of automating strategies being researched. Some tests are underway in the US and other countries. In California the only tests currently in operation involves experiments with longitudinal control on the I

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15 reversible lane in the San Diego area and with lateral control at the Richmond Field Station. No actual public demonstrations are underway in California at present or contemplated in the near future.

The crafting of demonstrations.of highway automation technologies needs to await the results of further research and development work. Until that time it is premature to move forward with any possible demonstrations within the southland. A possible future site in the Los Angeles area might be the El Monte Busway on I 10 between El Monte and downtown Los Angeles. This site has also been suggested as a demonstration possibility for the RPEV.

Automation Demonstration and/or Development Considerations

Fundability -- Significant funding is necessary to bring highway automation technologies to a point where public demonstrations are possible. The IVHS Strategic Plan estimated a need for approximately $1.57 billion for research and development costs through 2011. This estimate assumes an 80/20 percentage split for public/private contribution. The recent federal surface transportation legislation includes provisions for Intelligent Vehicle Highway Systems.

Organizational Feasibility -- Caltrans is the logical candidate to construct and operate automated highway facilities. Due to the strong communications interface, this function could be provided by a local or national telecommunications provider. Another approach to building and operating an automated facility would involve Caltrans leasing the facility to a regional organization similar to a Toll Highway Authority.

Ease of Implementation -- Implementation of automation technologies would in most instances be easier than for an RPEV network of similar scope. Construction would consist of the installation of magnetic markers in the roadway and communications linkages in the wayside. Physical barriers would be necessary to provide lane separation as would ingress and egress facilities.

Construction Phasing -- Since mixed flow traffic is excluded from automated lanes, an immediate reduction in the number of mixed flow lanes will occur. Phasing of construction would need to occur in a manner so that significant segments of the system would be operational and functional in a coordinated manner, to minimize user confusion.

Operational Issues -- Three major operational issues have been identified to date in implementing highway automation technologies:

- "Platoon" Functioning and Systems Integration (Variety of Issues Pertaining to System Operations)

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Legal/Institutional Barriers liability to system developers and operators when failures (crashes) occur.

Functioning of Operating Cost Recovery Systems (Integrated System Needed to Minimize Operations Problems)

Social Acceptance -- Highway automation is a largely untested phenomena in the public's eyes. The following are examples of major questions that need to be addressed by researchers prior to initiation of any large scale public demonstrations:

- Perceived Levels of Driver Inconvenience
- Change in Felt Level of Enjoyment in Driving, Versus a Sense of Riding in an Automated Vehicle.
- Ability of the Driver to Understand and Use the Automated Vehicle Control System
- Sense of Loss of Personal Freedom to "Do Your Own Thing" (Perception by Some of Traditional Automobile Driving)
- Vehicle Operator's Perceived Risk of Platoon Driving

Political Acceptance -- Political acceptance of highway automation may be a greater challenge than for RPEVs, because of its higher level of driver adaptation. Political acceptance will ultimately hinge upon public acceptance.

Monitoring -- The monitoring program necessary to effectively implement any highway automation demonstration or development effort should be similar in scope to that for the RPEV. One variation would be the need for a fully developed social acceptance component. Any monitoring program should focus both on evaluating system reliability as well as public acceptance.

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