Title

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I. INTRODUCTION

Major transportation problems confront both California and the U.S. Among them are traffic congestion, highway safety, reliance on petroleum-based liquid fuels, and environmental problems such as air quality, public health, acid rain and urban noise. To help solve these problems and provide better transportation service, the Program on Advanced Technology for the Highway (PATH) was established by the California Department of Transportation (Caltrans) in conjunction with the University of California Institute of Transportation Studies. The primary emphasis of PATH is to develop the technology and analyze the implications of automating and electrifying'highway transportation.

Automation of the highway promises to increase the traffic capacity of existing highways and to improve highway safety. Electrification promises. increased vehicle reliability and system performance because electric engines are more reliable (less frequency of failures) and have a faster and more certain dynamic response than internal combustion engines. More advanced forms of automation may require the use of electrified vehicles and roadways. Electrification of highways would decrease reliance on petroleum-based liquid fuels and would reduce urban air pollution.

The objective of this preliminary report is to explore the energy supply opportunities and implications of electrifying highways. An important assumption in this report is that the technology and general cost structure for generating and storing electricity does not change significantly in the future. In other words, we ignore the possible use of superconductive materials to store electricity during off-peak times, which, if feasible, would greatly reduce average electricity costs. A future report will examine the opportunities and implications of breakthroughs in superconductivity.

The report is organized as follows. First, the relationship between transportation and electricity demand patterns are investigated. These relationships are then explored for different regions of the country. With this background, we then identify the implications of electrifying highway transportation for the electricity industry, including an analysis of energy supply considerations.

II. ELECTRICITY DEMAND PATTERNS

How would the conversion of motor vehicles to electricity affect the electric utility industry? One may posit several very different scenarios. These scenarios would be sensitive to the type and efficiency of on-board and centralized electricity storage technologies that are deployed'and the sequence of steps that are followed in electrifying the highway network. These pathway scenarios are investigated in later reports. For now, a worst-case scenario based on an extrapolation of current consumption and traffic patterns are explored to determine the importance of developing and deploying various storage technologies and to determine the implications for alternative network electrification strategies.

In this section we examine hourly electricity demand by time of day and monthly electric consumption by season in current electricity-consuming sectors and compare them to daily and seasonal energy demand patterns in transportation.

Time-of-Day-Pattern

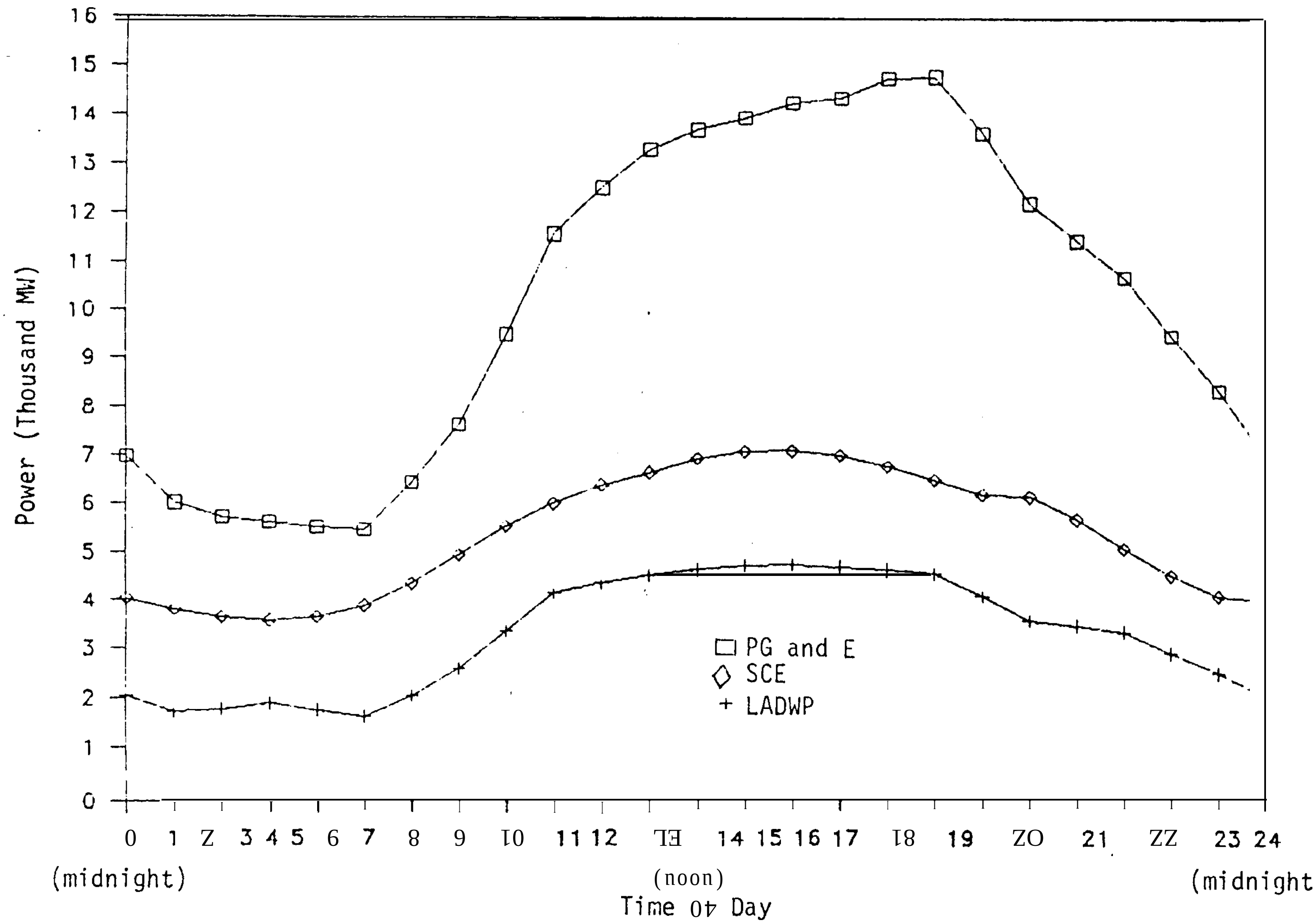
There are several utility planning areas in California. We chose the three largest companies, Pacific Gas and Electric (PG and E), Los Angeles Department of Water and Power (LADWP), and Southern California Edison (SCE) for the analysis.

Electric utilities generally have various types of facilities and resources for generating electricity. Oil and natural gas are generally burned to meet peak demands because combustion units using these fuels can be turned on and off more readily than other generating equipment; they are used mostly just during peak hours, however, because they are more expensive than other energy sources. Utilities would prefer customers to use more electricity during off-peak hours because this would flatten the peaks, allowing them to use less expensive "baseload" facilities and reducing the generating capacity the utility must build. The extent to which demand peaks in transportation coincide with demand peaks in. non-transportation electricity consumption determines how much additional capacity would be needed and what the associated costs would be.

Figure 1 shows that for the three utility planning areas peak hours of electricity use (during the peak days of electricity consumption in 1985) fell between 9:OD am and 6:00 pm. In the PG and E area, the peak occurred at 3:00 pm and the trough at 5:00 am. The peak was 171% higher than the trough. In the SCE service area, peak demand was at 2:00 pm and the trough at 3:00 am. The peak was 99% higher than the trough. In the LADWP service area, peak demand was at 2:00 pm and the trough at 5:00 am. The difference between the peak and the trough was 192%. The peak day in 1985 was July 9th in the PG and E area and August 30th in both the LADWP and SCE service areas (see Table 1).

Hourly electricity demand patterns during peak days, as presented in

Figure 1. Hourly Electric Demand During Peak Days in Three Utility Service Areas in California.



Note: Date of peak day in 1985 was July 9th in PG and E, and August 30th in SCE and LADWP.

Source: 1) Personal communication with Dr. Lex Baxter in Assessments Division of CEC, July, 1987.

2) SCE, <u>1985 Rate Group Load Studies</u> (Rosemead, California: Revenue Requirement Department of SCE, 1986).

Table 1. Date of Peak Days of Electricity Consumption in PG and E and SCE Service Areas

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
PG and E[1]	6-28	8-1	8-9	7-24	8-1	6-22	7-14	7-13	7-14	6-1
SCE[2]	8-30	9-7	9-25	9-11	7-30	8-21	9-2	9-12	9-5	8-30

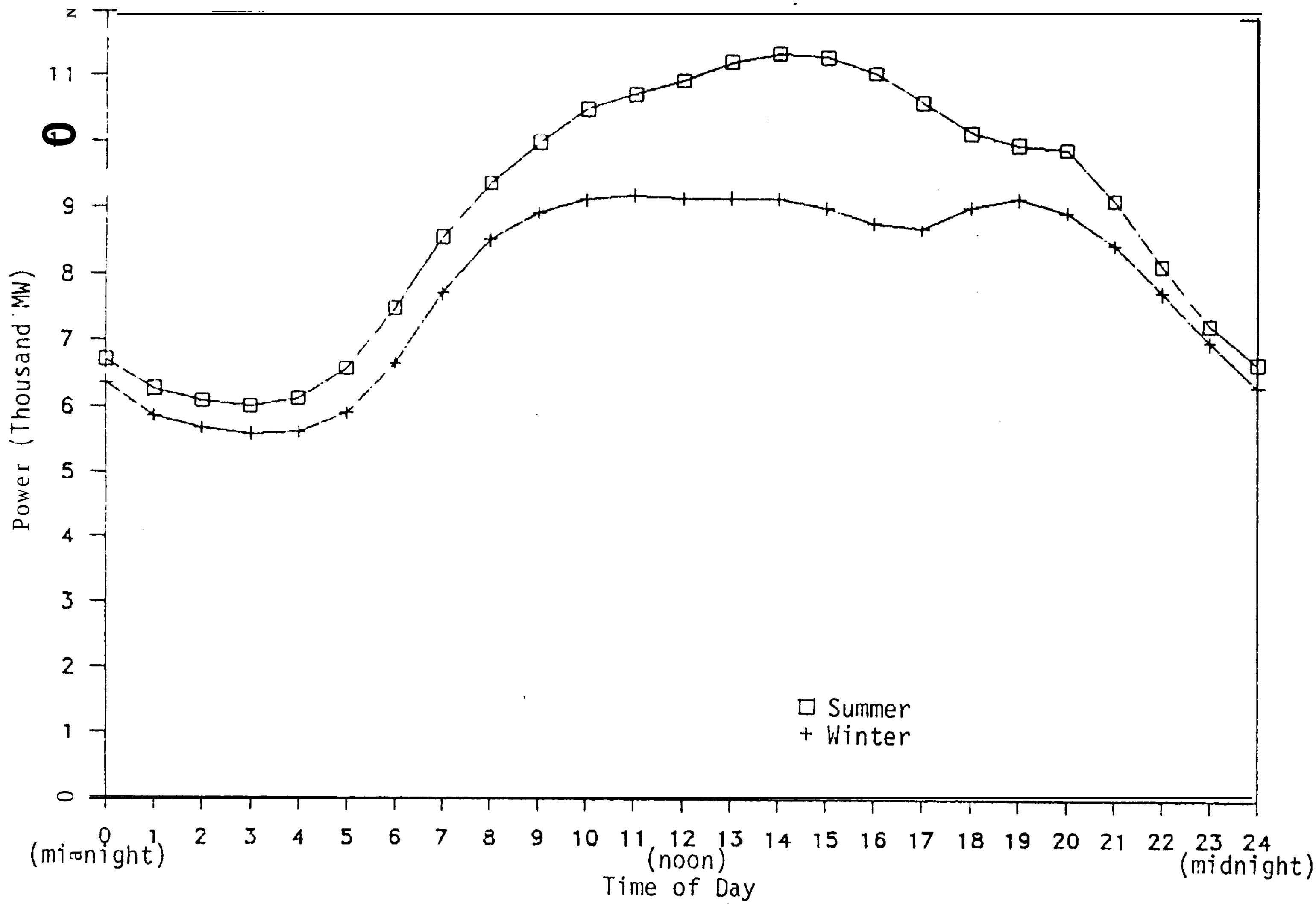
SOURCE: 1) Personal communication with Ms. Carol Betten in Department of Customer Accounting of PG and E, August 1987.

2) SCE, 1985 rate group load studies (Rosemead, California: Revenue Requirement Department of SCE, June 1986).

Figure 1, may be considered representative of consumption patterns on other weekdays. Average hourly electricity demand during weekdays is presented in Figure 2 for both the summer and winter seasons in the SCE service area. SCE defines the summer as June through September, and the winter as October through May. As can be seen, peak hours during summer weekdays occur at the same time as peak hours on the peak day. Further comparison of weekday patterns with peak day patterns is presented in Table 2. The peak demand on the peak day and on summer weekdays occur at the same time. The lowest demand in the peak day and on the weekday also occur almost at the same time. The difference between the peak demand and the lowest demand on average weekdays is somewhat smaller than the difference on the peak day (Table 2).

During winter, peak hours on weekdays are between 9:00 am and 8:00 pm (Fig. 2). Note that there is a small dip in hourly electricity demand between 3:00 pm and 6:00 pm. Peak demand is lower and the electricity demand curve is flatter during the winter than during the summer. The difference between the peak and the trough is about 64% of the trough. Also peak demand in the winter is 2,200 megawatt less than in the summer. This means that hourly electricity demand on summer days is the critical factor for electrifying transportation. Also, we know that the hourly electricity demand on peak days is, indeed, represen-tative of hourly electricity demand in other summer days. And thus, we may use peak day's electricity demand as a worst-case day in our

Figure 2. Average Hourly Electric Demand During Summer and Winter Weekdays in SCE Service Area.



Source: SCE, <u>1985 Rate Group Load Studies</u> (Rosemead, California: Revenue Requirement Department of SCE, 1986).

Table 2. Comparison of Hourly Electric Demand Between Summer Weekday and the Peak Day in SCE Service Area (1985)

	Peak Demand		Lowest Demand		Difference (% of Lowest Demand)
	Time of day	Power(MW)	Time of day	Power(MW)	
Peak day	2:00 pm	14,300	4:00 am	7200	99.4%
Average Weekday (Summer)	2:00 pm	11,300	3:00 am	6000	88.0%

SOURCE: SCE, 1985 Rate Group Load Studies (Rosemead, California: Revenue Requirement Department of CEC, June 1986).

pumping (AG and P); large power (LP); and resale sector. The domestic sector includes residential customers; the LSMP sector includes small commercial and industrial customers under 500 kw; the AG and P sector includes general agricultural and water and sewage pumping customers; the LP sector includes large commercial and industrial customers over 500 kw; and the resale sector includes other utilities and municipalities which purchase power wholesale for distribution to their own customers (1).

California's climate results in high electricity usage by the domestic, LSMP, agriculture and pumping (AG and P), and large power (LP) sectors during the summer (see Table 3). In the SCE service areas, AG and P has the largest difference of electricity consumption between winter and summer months, but the LSMP sector is the main contributor to the large aggregate differences between winter and summer months, because the LSMP sector accounts for over 40% of total electricity consumption in the SCE system. The LP sector has the smallest difference of the four sectors, although it accounts for about 55% of total electric consumption.

Table 4 indicates that for the entire state, 10% more electricity is consumed during summer months than winter months. Figure 3 shows that more electricity is consumed during summer months than during winter months in the SCE service area, which is similar to the pattern of the entire state. The peak electricity consumption occurs in July and the lowest electricity consumption in February. The difference of electricity consumption between July and February is 37% of the electricity consumption in February.

Monthly electricity consumption in northern California coastal areas

Table 3. Monthly Electricity Consumption by Sector in Winter and Summer in SCE Service Area (mwh)

	Domestic	LSMP	AG and P	IP	Total
January (Winter)	1,544,928	1,437,263	83,996	1,615,241	2,681,428
August (Summer)	1,772,214	1,828,683	240 , 986	1,816, 10d	5,657,987
Difference (% of January's consumption)	14.7	ZT.Z	186.9	12.4	20.9

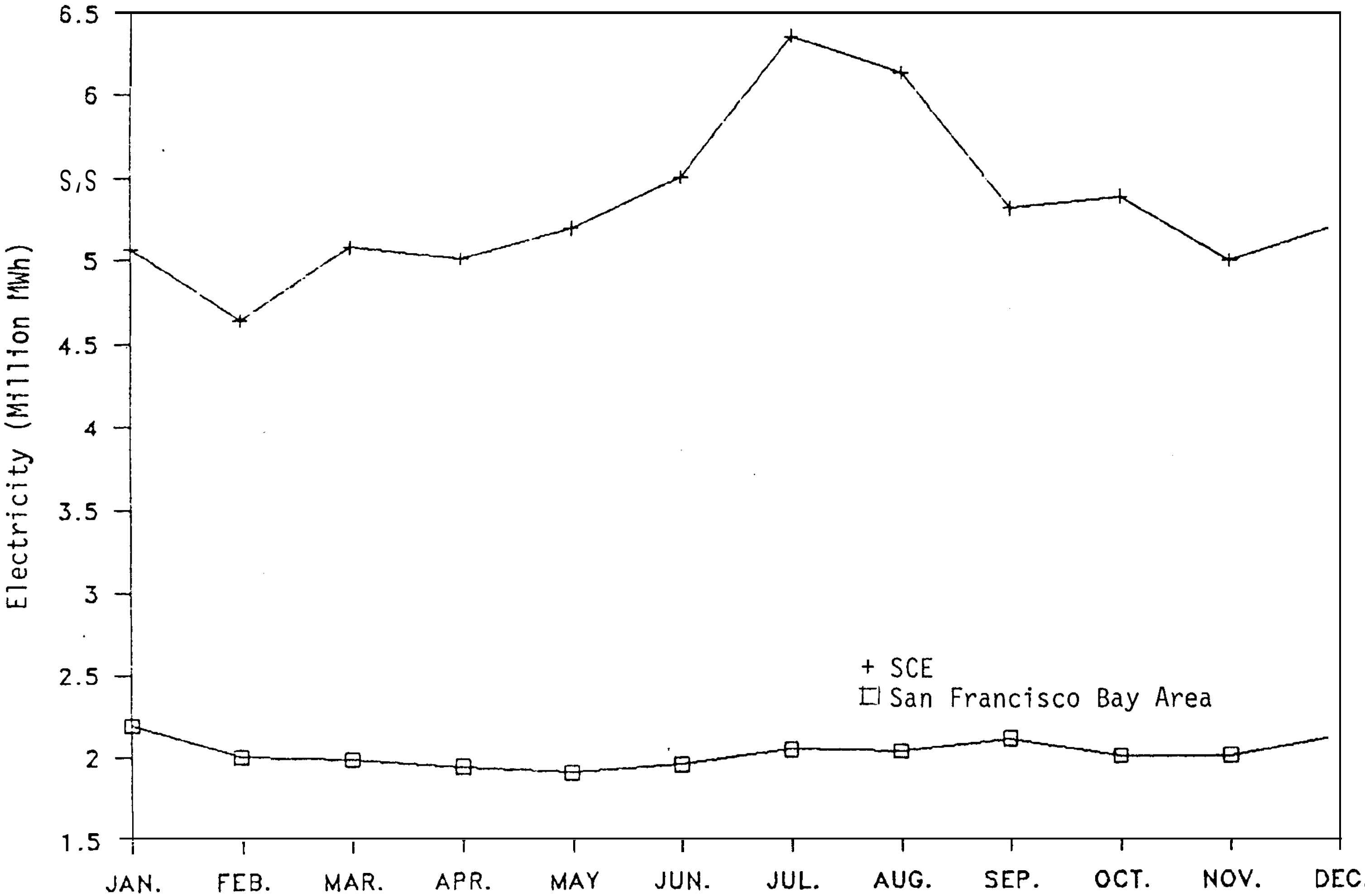
SOURCE: SCE, 1985 Rate Group Load Studies (Rosemead, California: Revenue Requirement Department of SCE, June 1986).

Table 4. Electricity Sales by Month in California (1985, million kwh)

Month	Electricity Sale
January	14,699
February	14,118
March	13,974
April	13,882
May	14,285
June	14,822
July	16,776
August	16,032
September	16,032
October	14,777
November	14,770
December	14,773
Total	179,139

SOURCE: EIA, Electric Power Monthly (Washington, D.C.: GPO), 1985 issues.

Figure 3. Monthly Electricity Consumption in SCE Service Area and San Francisco Bay Area.



Note: The data for SCE is that of 1985, and the data for San Francisco Bay Area is that of 1986.

Source: 1) SCE, 1985 Rate Group Load Studies (Rosemead, California: Revenue Requirement Department of SCE, 1986).

2) Personal Communication with Ms. Donna J. Fuller in Customer Accounting Department of PG and E, July, 1987.

is different, however, from the pattern in the rest of the state. Peak monthly electricity consumption occurs during winter months in these areas (see Figure 3). Peak monthly electricity consumption occurs during January in these areas, and the lowest levels occur during May. The difference in electricity consumption between these two months is 15% of May's consumption, which is relatively small compared with the differences in the SCE Service area. The reason for these different electricity consumption patterns are lower space cooling and agricultural pumping along the northern coast during the summer.

Although peak monthly electricity consumption in the San Francisco Bay area occurs during the winter, monthly peak electricity consumption for the entire PG and E service area is still during the summer because large parts of the PG and E service area are in the San Joaquin Valley where it is very hot in the summer and where large amounts of electricity are used during the summer for agricultural pumping.

From the data in Figures 1 and 2, two conclusion can be drawn. First, peak electricity demand in most of California occurs during the summer, the result of mild winters and hot summers. This is further evidenced by Table 1. During the summer, space cooling in the residential and commercial sectors uses large amounts of electricity in Southern California, and agricultural pumping and space cooling use large quantities of electricity in central California.

A second conclusion is that peak hours are roughly between 9:00 am and 6:00 pm in the state with PG and E having the steepest peak.

III. TRAFFIC DISTRIBUTION PATTERNS

Electricity cannot be stored as easily as fossil fuels, If peak traffic patterns overlap with peak non-transportation electricity demand, then electricity suppliers must increase their generating capacity to handle the extra demand. If peaks do not overlap, then the cost to electric utilities of supplying energy for motor vehicles is modest because little or no additional capacity (capital cost) would be needed. As will be shown, there is a daily overlap in peaks around 4:00 pm to 5:30 pm in the afternoon and seasonal overlaps in peaks during summer months. Traffic patterns on freeways, surface streets of city centers, and bus transit systems are examined below.

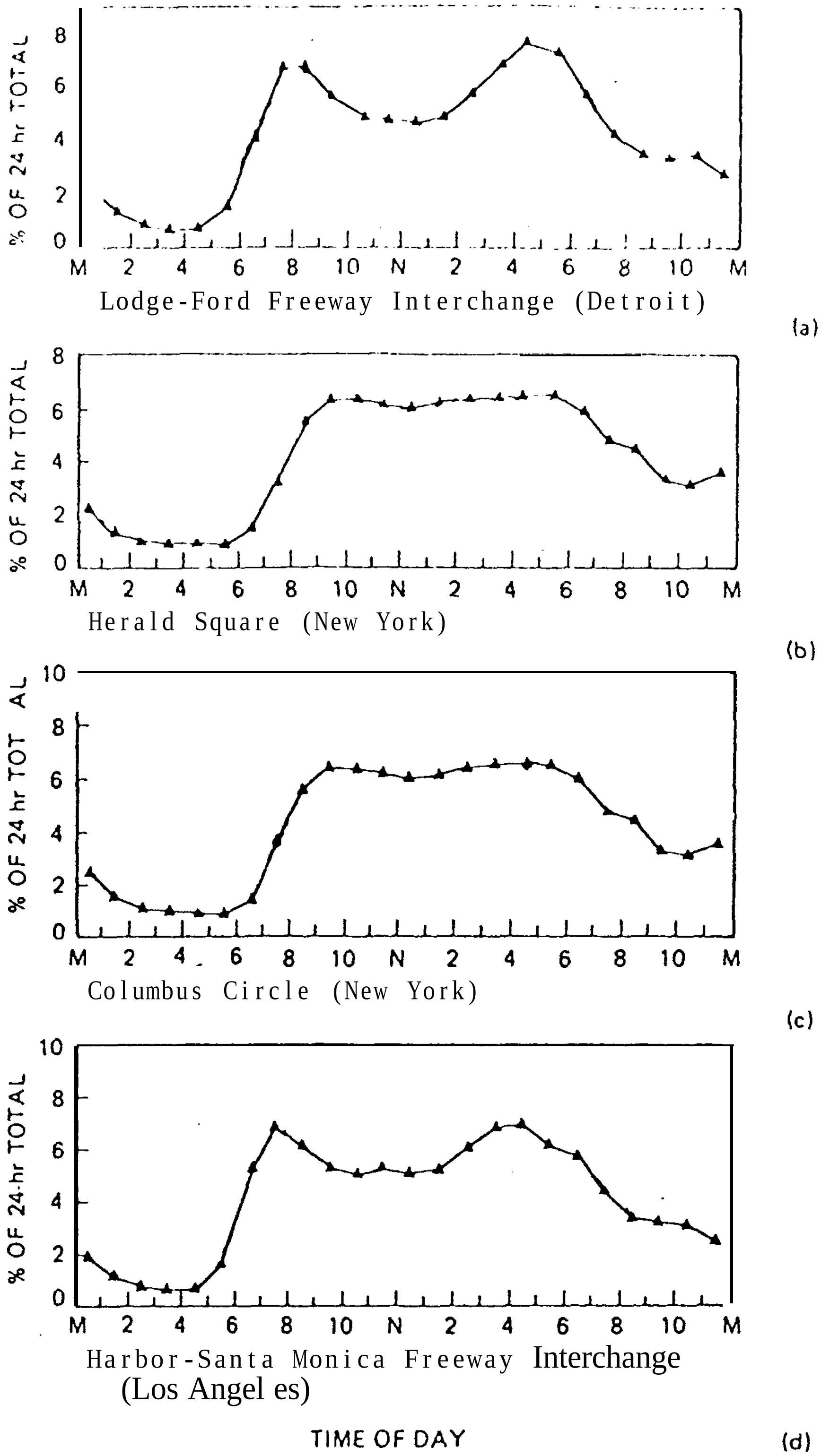
Hourly Traffic Distribution Patterns

The hourly distribution of traffic volume is highly correlated with hourly motor vehicle energy consumption. Since data on hourly energy consumption in transportation are not available, hourly traffic volume is used as an indicator of hourly energy consumption in transportation.

Figure 4 shows relative traffic volumes over time of day on freeways in Detroit (Figure 4a) and Los Angeles (Figure 4d) and in downtown areas of New York (Figure 4b,4c). There are two daily peak traffic periods on freeways. One is between roughly 7:00 am and 9:00 am, and another between 3:00 pm and 6:00 pm. As shown, the hourly traffic distributions on freeways in and near Detroit and Los Angeles are similar, even though these two cities have a very different economic and socioeconomic composition and very different land use patterns. This suggests that temporal traffic patterns on freeways are relatively uniform in major metropolitan areas of the U.S.

The hourly traffic distribution patterns in downtown areas are different from those on freeways. Curves in Figures 4b and 4c [redacted] show the hourly traffic distribution on surface streets in two different loca-

Figure 4. Hourly Distribution of Traffic in Freeways and Downtown Areas.



Source: Horowitz, J.L., Air Quality Analysis for Urban Transportation Planning (Cambridge, Massach.: The MIT Press, 1982), P42.

tions in downtown New York. These two graphs suggest that a flatter peak occurs for a longer period in dense city centers than on freeways.

Urban transit systems in the U.S. have two peak periods, similar to freeways, as indicated by the system in Albany, New York represented in Figure 5. The morning peak period of buses in service in Albany was between 6:00 am and 10:00 am, and the afternoon peak period was between 2:00 pm and 6:00 pm. Weekday peaks are much greater than weekend peaks. To accomodate demand during morning rush hours in Albany, over 140 vehicles are required. The base requirement for midday periods is only 68 vehicles (2).

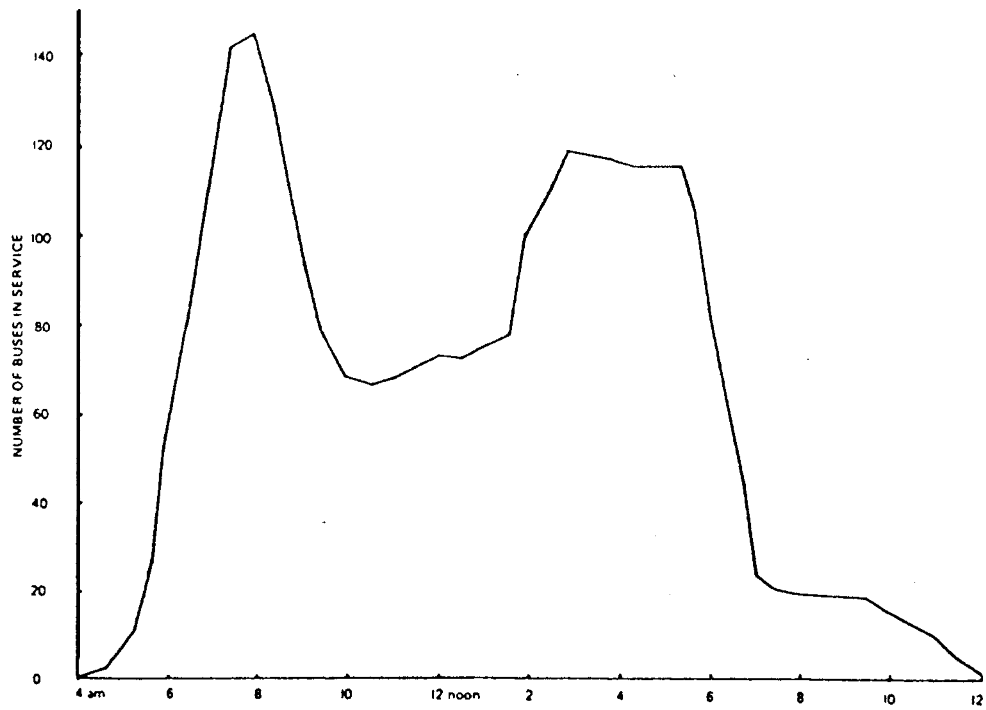
Figure 6 further explains hourly traffic distribution patterns. Trips are categorized by purpose in this graph. School and work trips are the primary contributors to the two-peak traffic distribution patterns on freeways, and personal business and shopping mainly contribute to the flatter hourly traffic distribution pattern in downtown areas.

Monthly Traffic Distribution Patterns

Gasoline and diesel fuel currently account for virtually all energy consumed by highway transportation, gasoline accounting for 86% of the total and diesel fuel for almost 14%(3). Since gasoline is such a large percentage of the total, we use gasoline sales by month to represent the monthly distributions of energy consumption in transportation. Figure 7 shows monthly motor vehicle gasoline sales (excluding aviation gasoline) in California in 1985 and 1986. Total gasoline sales in 1985 and 1986 were 11.7 billion gallons and 12.2 billion gallons, respectively .

The lowest gasoline sales in both years were recorded in February, while peak gasoline sales were in August. Figure 8 indicates that the

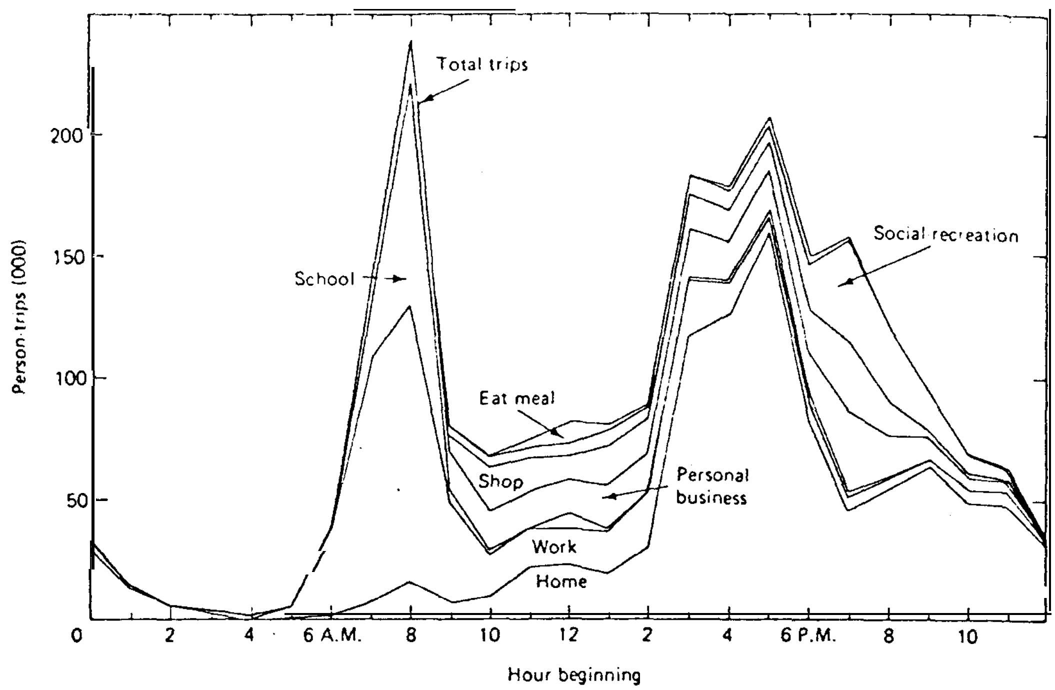
Figure 5. Bus Requirement by Time of Day in Albany, New York.



Time of Day

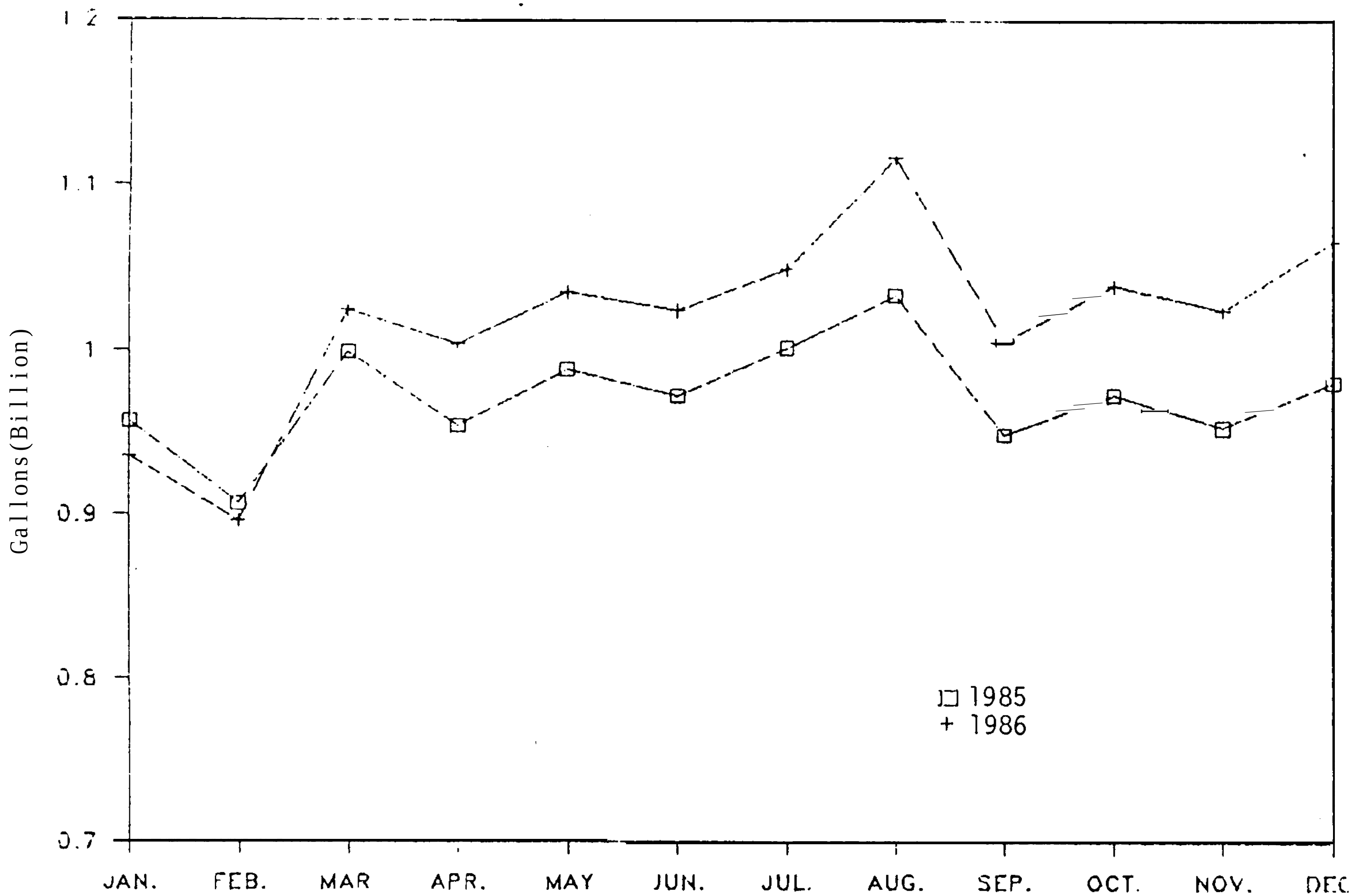
Source: Reilly, John M., "Transit Costs during peak and off-peak hours," Transportation Research Record, No. 625, 1977, p. 23.

Figure 6. Hourly Distribution of Person-trips by Trip Purpose.



Source: Papacostas, C.S., Fundamentals of Transportation Engineering (Englewood. Cliffs, New Jersey: Prentice-Hall, Inc., 1987), p. 248.

Figure 7. Monthly Motor Vehicle Gasoline Sales in California.



Source: Caltrans, Travel and Related Factors in California, Annual Summary, 1986, published by Division of Transportation Planning of Caltrans, 1987.

fewest vehicle miles traveled (VMT) in California occur in January and the greatest in August. Thus, it may be concluded that total highway energy consumption in California is lowest in the January-February time period and highest during late summer.

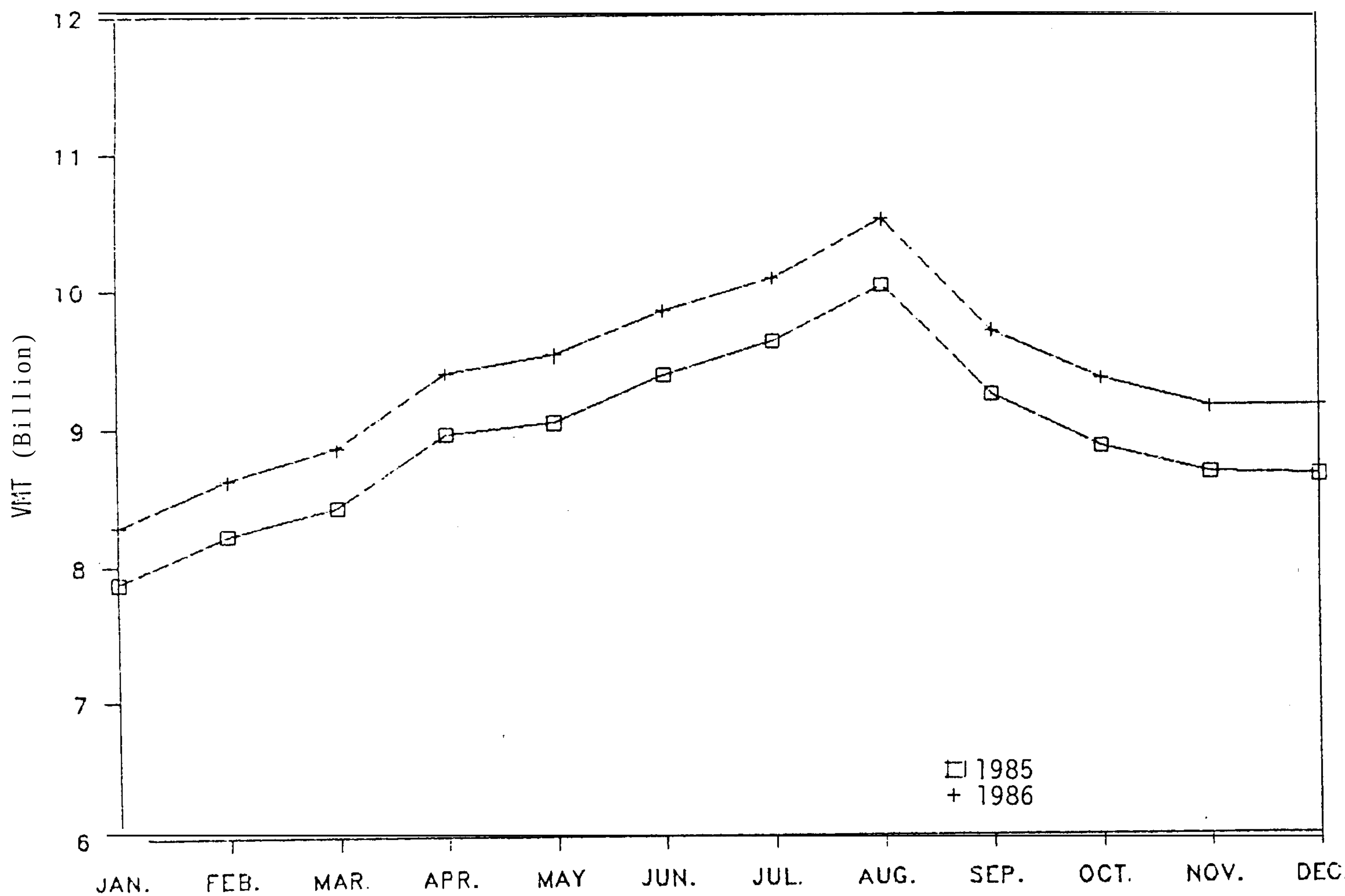
IV. TEMPORAL COMPARISON OF CURRENT ELECTRICITY AND TRAFFIC PATTERNS IN CALIFORNIA

The analysis of hourly electricity demand showed that peak hours are between 9:00 am and 6:00 pm during the summer in California. The peak day and peak months of electricity use occur in the summer in the major service areas. Hourly electricity demand patterns are likely to be fairly stable into the foreseeable future because fuel switching to or from electricity is not likely and because weather and daily activity patterns are fairly stable. Of course, it is difficult to foresee changes that might take place 20 or more years into the future.

It was shown in the previous section that there are two daily traffic peaks while peak hours of electricity demand in California are between 9:00 am and 6:00 pm, with the peak usually between about 2:00-5:00 pm. As suggested by Figure 9, most of the morning transportation peak, but little of the afternoon peak, could be served with existing electricity-generating capacity. Since the seasonal electricity consumption peaks, as shown in Figure 3, are in July and August, and because motor vehicle traffic (and therefore energy consumption) also peaks during that same time, more electricity-generating capacity would be needed in the summer than other times to serve electrified highways. Quantitative estimates of the electricity needed to electrify various parts of the highway system are presented in Section VI.

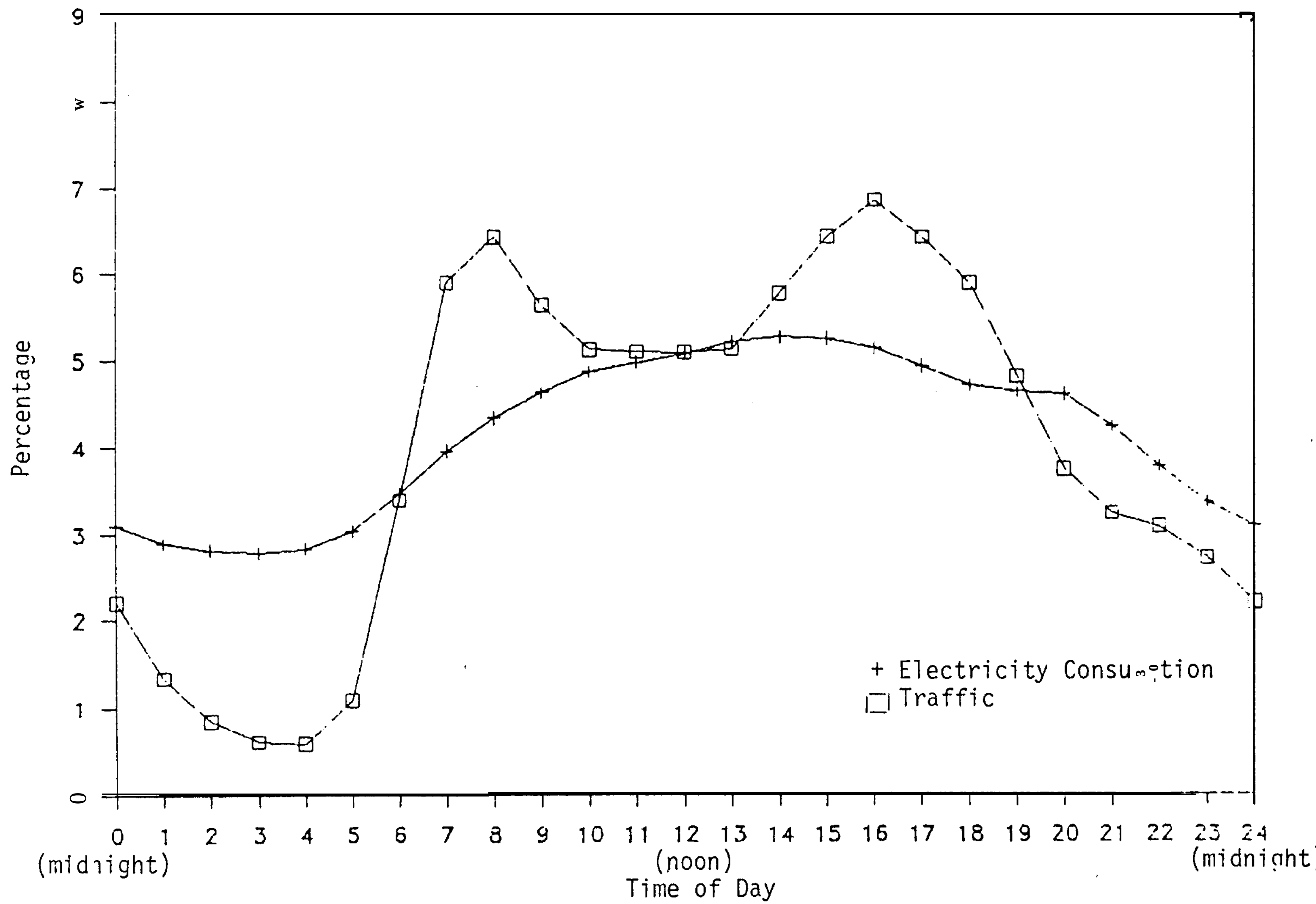
Since the cost of adding new capacity and the cost of providing new

Figure 8. Highway Vehicle Miles Traveled in California.



Source: Caltrans, Travel and Related Factors in California, Annual Summary 1986, Published by Division of Transportation Planning of Caltrans, 1987.

Figure 9 Hourly Electricity Demand vs Hourly Distribution of Traffic Volume in Southern California.



Source: 1) SCE, 1985 <u>Rate Group Load Studies</u> (Rosemead, California: Revenue Requirement Department, 1986).
2) Horowitz, J.L., <u>Air Quality Analysis for Urban Transportation Planning</u> (Cambridge, Mass.: The MIT Press, 1982), p. 42.

peaking capacity is currently considerably higher than average electricity generation costs, the cost of serving transportation demand with current technology and current institutional patterns would result in increases in electricity costs. So one of the critical strategic factors in electrifying highways is determining how to minimize this electricity supply problem. One approach is to identify market niches in which electrification is particularly attractive and where overlap with non-transportation peaks is minimal. One such niche might be urban transit operations.

As shown later, very small amounts of energy are consumed by urban transit systems. Some urban systems, including all urban rail transit operations, are already powered with electricity. It would be possible to electrify urban bus routes with little or no increase in utilities' electricity-generating capacity.

Highway electrification in city center areas may be another early opportunity. Hourly traffic in these areas is much more evenly distributed from 8:00 am and 6:00 pm. These flatter peaks and their relatively modest energy demands would be more acceptable to electricity suppliers than highly peaked traffic. Electrification of downtown streets would be attractive also because it would reduce noise and air pollution.

V. DIFFERENCES IN ELECTRICITY AND TRAFFIC PATTERNS BETWEEN CALIFORNIA AND OTHER STATES

California's climate and economy is very different from that of many other states in the country. As a result, electricity consumption patterns are also very different. These differences suggest that the opportunities and implications for electrifying highways vary from one region to another.

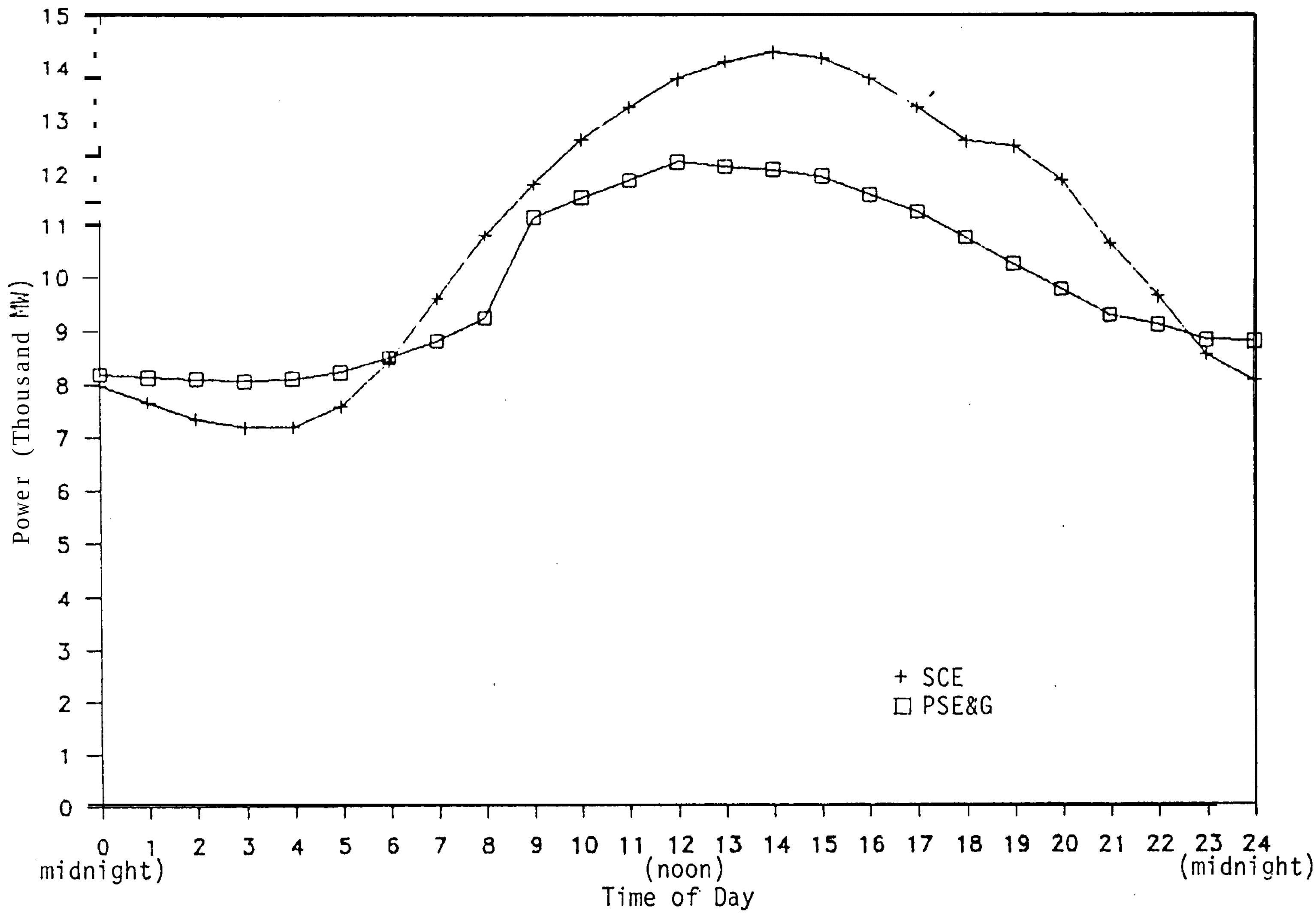
Average hourly electricity demand in California and New Jersey is compared in Figure 10. Electricity peaks occur at roughly the same time of day, but the peaks are more exaggerated in California.

The effect of climatic differences are most dramatically illustrated by comparisons of monthly electricity consumption patterns (Figure 11). In northern and northeastern states, such as Illinois and New York, electricity consumption is fairly constant from month to month. In southern and western states, such as Texas and California, more electricity is consumed during summer months, and less electricity during the spring from March to May. The difference in electricity consumption between the high and low month is large for the sunbelt states.

Traffic distribution patterns, on the other hand, are more similar across states. Figure 4 showed that the hourly traffic distribution on freeways near Los Angeles is about the same as on freeways near Detroit. In both cases, morning rush hours occur between about 6:30 am and 9:00 am and afternoon rush hours between about 3:30 pm and 6:00 pm. Likewise, monthly traffic distribution patterns are similar, with peaking during summer months (see Figure 12). The summer peaks are more accentuated in colder regions such as New York and Illinois than in California, where temperatures are more moderate.

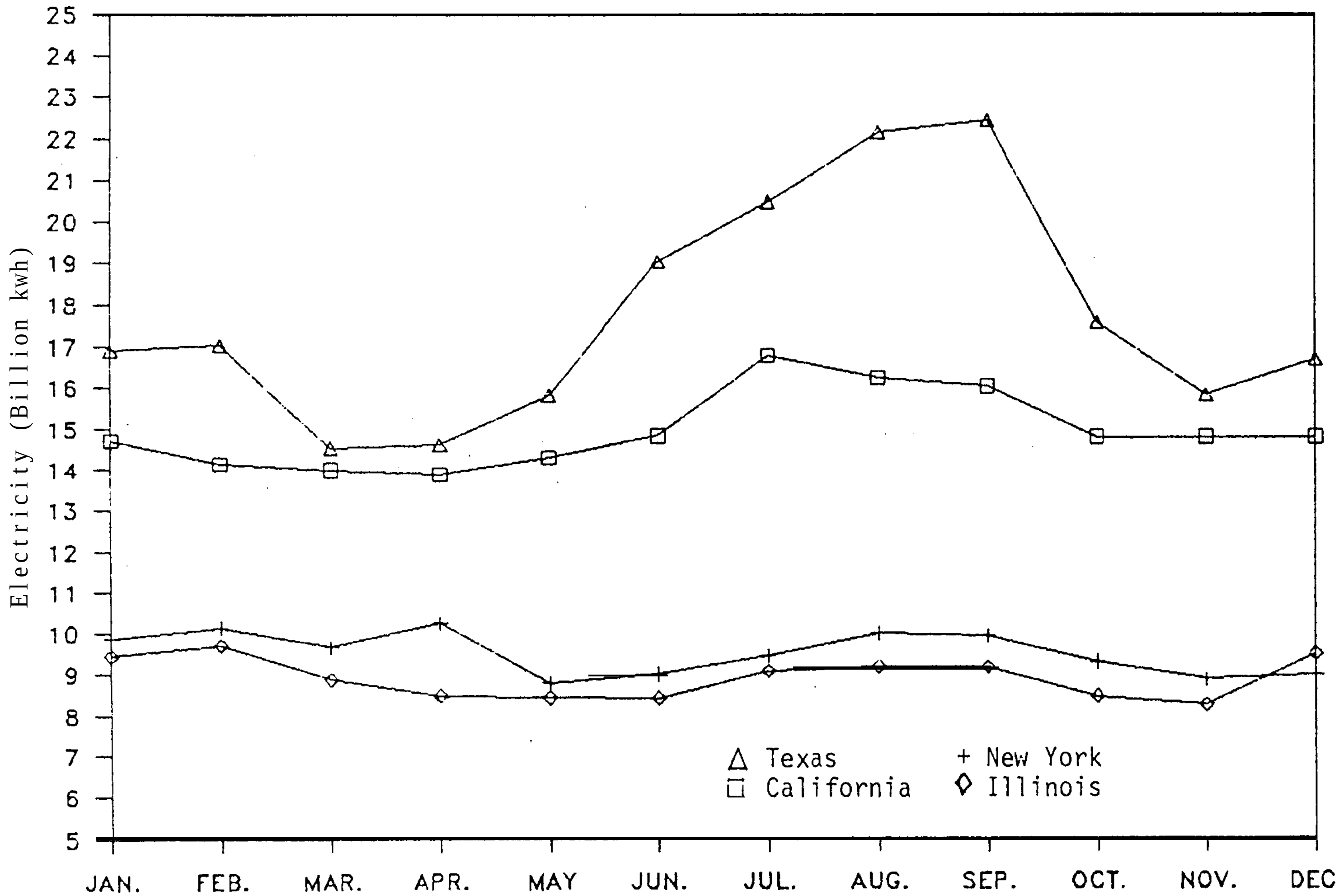
The similarity in transportation demand patterns across geographical regions suggests that electrifying motor vehicles will have similar effects on electricity supply in those different areas. While current electricity demand patterns are quite different across the country, highway electrification would not accentuate these differences any more

Figure 10. Hourly Electric Demand in PSE&G (New Jersey) vs. SCE Service Area



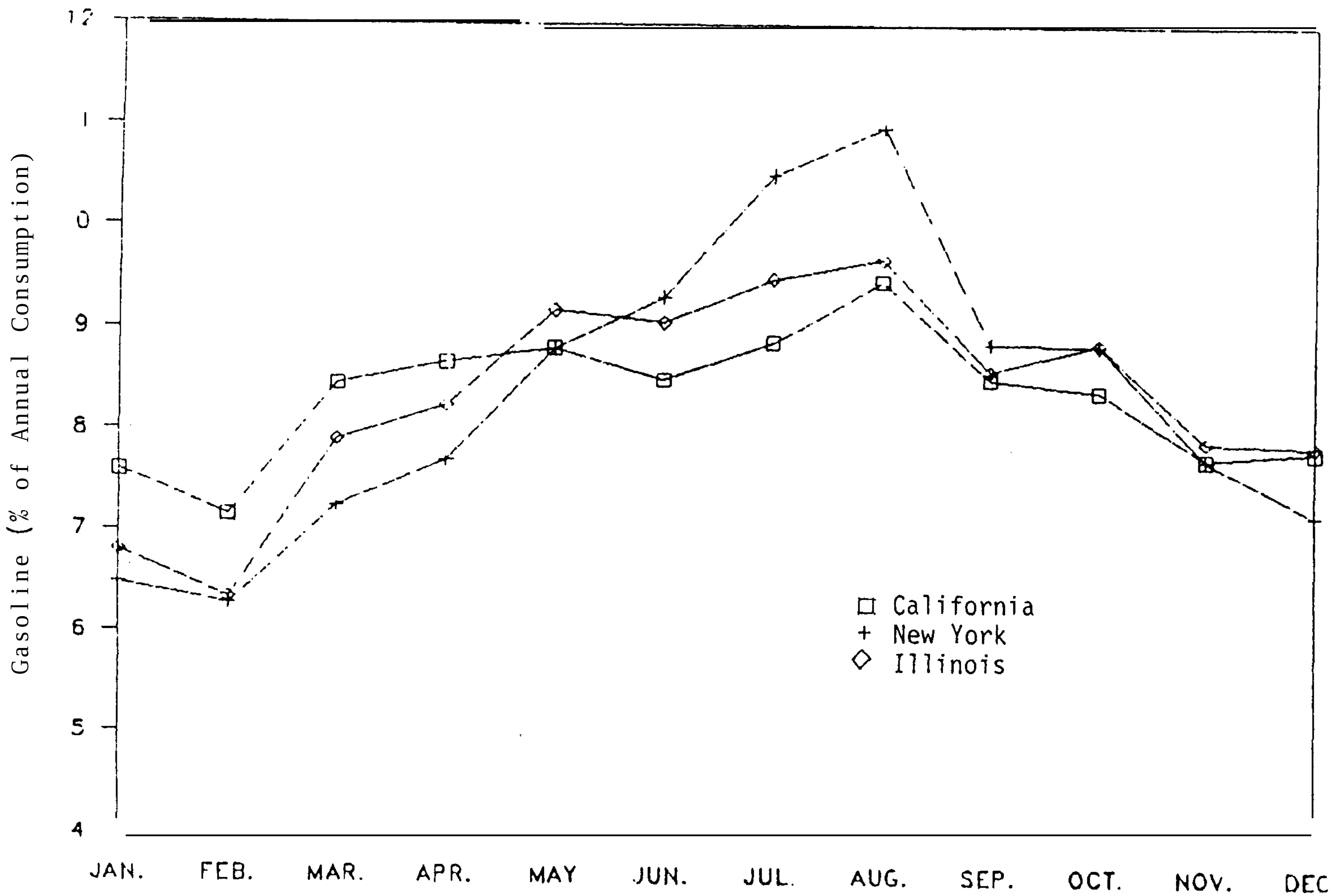
Source: 1) SCE, <u>1985 Rate Group Load Studies</u> (Rosemead, California; Revenue Requirement Department of SCE, 1986)
2) Toulukdar, S., etc., <u>Load Management</u> (New York: IEEE Press, 1987), p. 133.

Figure 11. Monthly Electricity Consumption in 4 States in 1985.



Source: EIA, Electric Power Monthly (Washington D.C., GPO), 1985 issues.

Figure 12. Percentage of Highway Gasoline Consumption by Month in 3 States (1985).



Source: U.S. Department of Transportation, Highway Statistics 1985 (Washington, D.C.: GPO, 1986), P. 9. Gasoline Consumption in 1985 was 11,221 million gallons in California, 5,691 million gallons in New York, and 4,660 million gallons in Illinois.

in California than elsewhere.

VI. ELECTRICITY CONSUMPTION IMPLICATIONS OF HIGHWAY ELECTRIFICATION

Electrifying highway transportation would dramatically increase demand for electricity. Assuming no major improvements in electricity storage technology, an analysis is conducted here of energy use by different segments of the highway transportation system. By comparing the energy efficiency of internal combustion engine (ICE) vehicles with roadway-powered electric vehicles (EVs), we can estimate the electricity consumption of roadway-powered EVs. Then we can compare current electricity consumption. with the quantity of electricity that would be consumed by electrifying highway vehicles. The analysis follows.

Since we have observed that peak electricity and transportation fuel demand in California are during weekdays in August, we use an August weekday 'to analyze the worst-case scenario for electricity supply. Because transportation energy demand data are most accurate on the state level, the analysis is conducted at that level.

Electricity Demand in Current Electricity-Consuming Sectors

Hourly distribution of electricity demand at the state level is not available. However, since hourly distribution of electricity demand in the SCE service area is available, and since electricity demand in the SCE service areas accounts for 36.4% of California's total electricity demand (4), we estimate the state's hourly electricity demand by dividing SCE's hourly demand by 0.364. SCE's hourly electricity consumption figures exclude the transmission loss from power plants to customers, which represents about 10% of electricity demand (5); thus electricity consumption is divided by 0.90. These calculations of total hourly electricity consumption in the state are shown in Table 5.

Energy Demand Associated With Highway Electrification

Highway gasoline consumption in August of 1986 was estimated as 1,072 million gallons, which is equivalent to 1.339×10^{14} Btu (6). Diesel fuel sales to highway vehicles were 14.4% of total gasoline sales in California in 1986. Thus, diesel consumption in August 1986 was about $1.339 \times 10^{14} \times 0.144 = 1.928 \times 10^{13}$ Btu (7). Total fuel consumption by highway vehicles in August 1986 was therefore 1.532×10^{14} Btu. The daily fuel consumption in August of 1986 was $1.532 \times 10^{14} \div 31 = 4.942 \times 10^{12}$ Btu.

ICE vehicles have-an energy efficiency of about 12% (8). Electric vehicles with batteries have an energy efficiency of about 52% (9). The energy efficiency of roadway-powered electric vehicles would be somewhat higher because electricity loss from batteries to controller in the EVs with batteries is avoided in roadway-powered EVs. We estimate the energy efficiency at 58% (10). The energy efficiency of roadway-powered EVs is about 4.8 times the energy efficiency of ICE vehicles.

By electrifying highways, 1.0296×10^{12} Btu of electricity (4.942×10^{12} Btu /4.8), which is equivalent to 3.018×10^{5} MWH, would have been needed to operate all motor vehicles in California in a day of August 1986 on electrified roadways.

To calculate total daily electricity that would be consumed in transportation, we estimate that electricity lost between the powered roads and the vehicles would be about 5% of electricity consumption (11). We assume that the transmission loss from power plants to powered roads is 10% of electricity demand. Thus the total daily electricity demand at power plant sites for transportation is 3.018×10^{5} mwh $\div$

Table 5. Hourly Electricity Demand in the SCE Service Area and California (MW)

Time of day	SCE service area	California (Including transmission loss)
1:00	6267	19130
2	6087	18583
3	6015	18361
4	6128	18706
5	6588	20110
6	7515	22940
7	8588	26215
8	9404	28706
9	10028	30616
10	10529	32140
11	10760	32845
12 (noon)	10976	33504
13	11275	34417
14	11410	34829
15	11356	34664
16	11113	33922
17	10662	32541
18	10204	31148
19	10027	30607
20	9961	30406
21	9194	28065
22	7308	22308
24 (midnight)	6707	20473

Note : Estimates are for an average summer weekday in 1985.

$0.95 \div 0.9 = 3.5298 \times 10^5$ Mwh/day.

The hourly distribution of traffic on Los Angeles freeways (Figure 4d) were converted into percentages of traffic volume which in turn were converted into hourly electricity consumption estimates, assuming that hourly energy demand in transportation is proportional to hourly traffic volume. The results are presented in Table 6. If the entire highway transportation system were electrified, the amount of electric capacity shown in Table 6 would be needed for transportation. Total electricity demand in California for both current electricity-consuming sectors and highway transportation would be the sum of electricity demand in Tables 5 and 6, as summarized in Figure 13. The electricity consumption curve in Figure 13 has peaks in the morning and afternoon due to transportation peaking patterns. Peak demand including highway electrification would be 58,000 MW, which occurs at 4:00 pm in the afternoon, representing a 66% increase over the current peak of 35,000 MW.

It is unlikely that the entire highway system would ever be electrified. A more realistic perspective is to examine the energy requirements of different segments of the system. Consider, for instance, public transit, which is electrified relatively easily due to its centralization and intensive operation on specified routes. If all buses were electrified, electricity demand would increase by less than 1%.

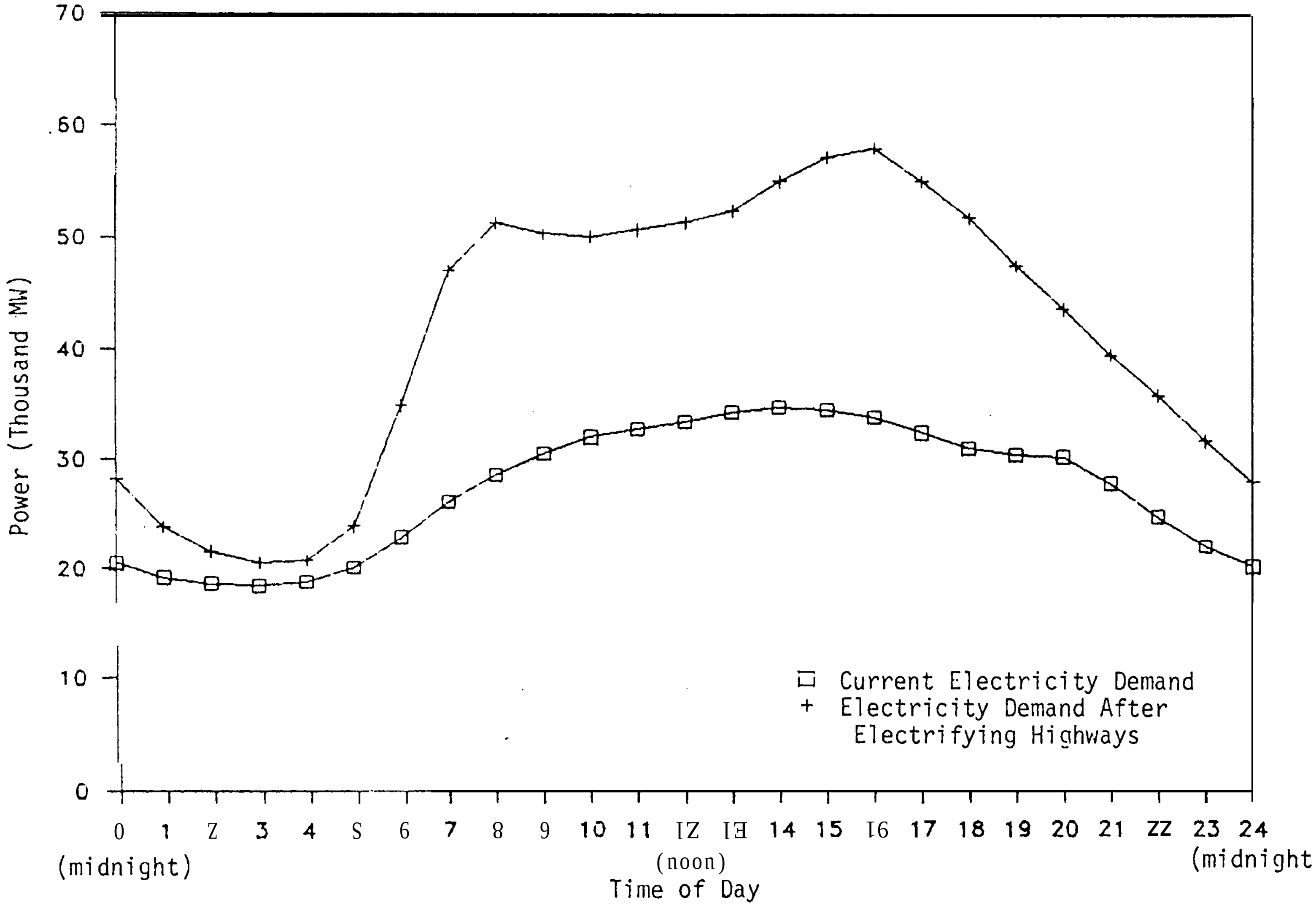
Two 'other possible market niches are fleet vehicles and carpools/vanpools. Each of these could be significant. Fleet vehicles are attractive because many of the vehicles are maintained at a central garage. Equipment purchase and maintenance is centralized and supported by a few mechanics who could be specially trained for electric vehicles.

Table 6. Electricity Demand for 100% Highway Electrification in California

Time of day	Traffic volume %	Electric demand (MW)
1	1.3441	4744
2	0.8484	2995
3	0.6096	2152
4	0.5847	2064
5	1.0947	3864
6	3.4011	12005
7	5.9003	20827
8	6.4317	22703
9	5.6367	19896
10	5.1197	18072
11	5.0947	17983
12	5.0912	17971
13	5.1304	18109
14	5.7682	20361
15	6.4281	22690
16	6.8522	24187
17	6.4206	22663
18	5.8827	20765
19	4.8092	16976
20	3.7580	13269
21	3.2407	11439
22	3.0875	10896
23	2.7204	9602
24	2.2035	7778

Note: The traffic pattern on freeways near Los Angeles is used to calculate these percentages. See text.

Figure 13. The Impact of Electrifying Highways on Electric Capacity in California.



Vehicles in fleets of ten or more vehicles account for about 18% of highway gasoline consumption in the U.S. (12). Many of these vehicles are not stationed in centralized facilities, however, and most do not follow fixed routes.

Carpools and vanpools are an attractive niche because for institutional reasons they could be accepted onto designated electrified HOV (high occupancy vehicles) lanes along with buses.

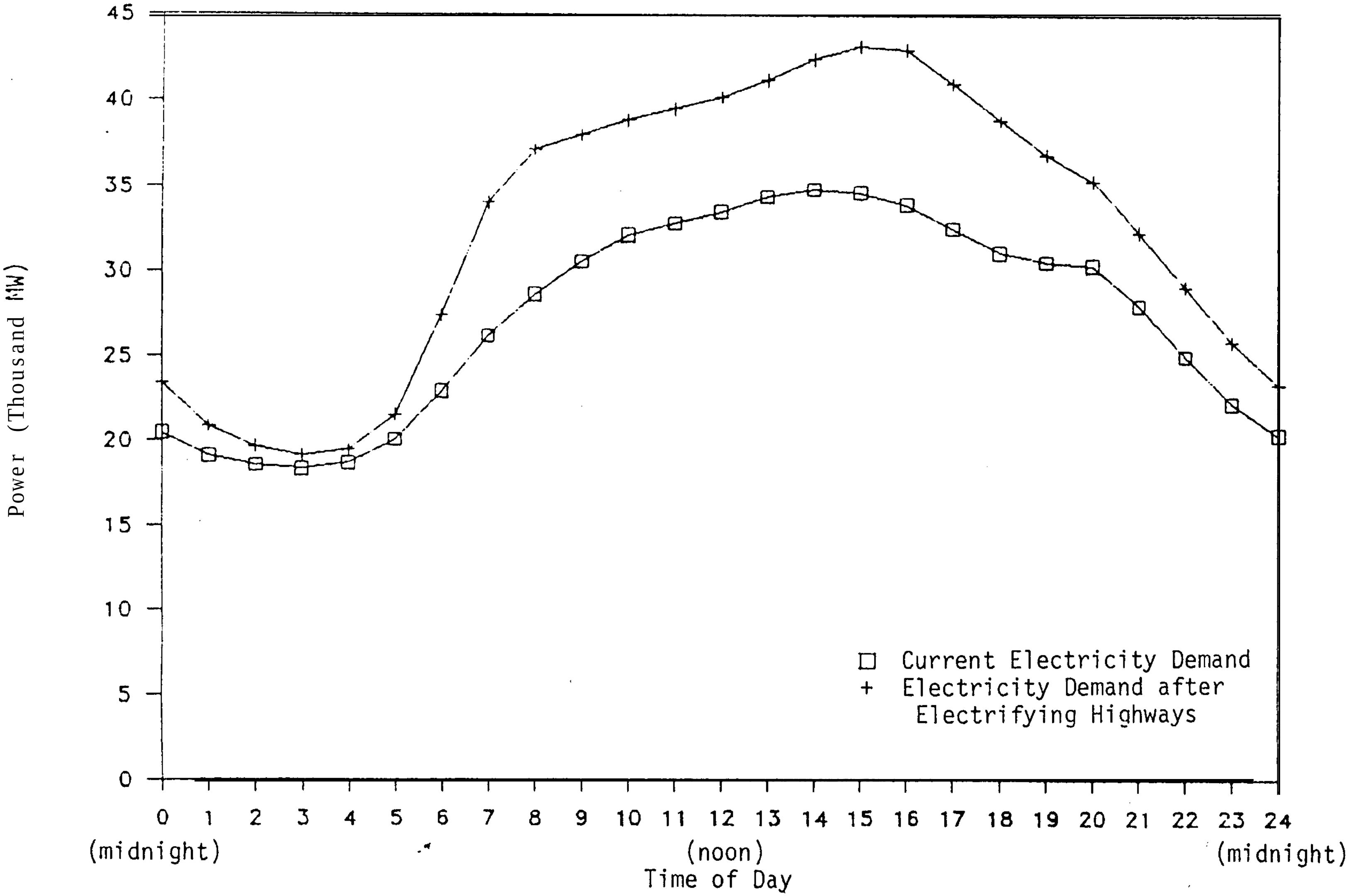
The size of these two market niches depends on many factors; considerable analysis is needed to specify how many of these vehicles could be electrified and under what conditions. For now, we simply observe that each niche could be several percent of highway energy use and leave more specific analysis to subsequent studies.

In general, though, the highway market is not easily segmented into market niches because household vehicles constitute the great majority of all vehicles and the household vehicle market is relatively homogeneous. Household vehicles usually serve as multipurpose vehicles. As vehicle ownership rates and vehicle specialization continue to increase, this homogeneity will diminish. For instance, a future niche might be specialized vehicles used only for commuting to work.

In any case, to electrify all cars and light trucks in one step would need a large increase in electricity demand. For illustrative purposes, assume 50% of cars and light trucks are electrified, accounting for 37.5% of total energy demand in highway transportation (13). The effect on total electricity demand would be as shown in Figure 14. Peak demand would be 43,000 MW at 3:00 pm, 23% more than current peak electricity consumption.

If all cars and light trucks, accounting for 75% of total energy

Figure 14. The Impact of Electrifying 50% of Cars and Trucks on Electric Capacity in California.



demand in transportation, were electrified the peak demand would be 52,000 MW, representing a 49% increase in peak electricity demand.

Aggregate Electricity Consumption

Electrification of transportation would require not only an increase in electric capacity (mw), but also an increase in electricity production (mwh). An analysis of total electricity production will help provide insight into the quantity of energy resources that would be needed for generating electricity. Of course, this energy does not necessarily represent an increment in total energy use since the energy used for electrified vehicles replaces gasoline and diesel fuel. Indeed, total energy demand for transportation would decrease because electric vehicles are more efficient than ICEs.

Total annual electricity consumption for electrifying highway transportation in California would be 1.025×10^8 mwh (14). The California Energy Commission forecasts annual electricity consumption in California to be 2.0316×10^8 mwh electricity in 1990 (excluding electrified transportation) (15). Electrifying the entire highway transportation system would therefore increase annual electricity consumption by 50.5%. Utilities would have to produce 3.0557×10^8 Mwh of electricity to meet annual electricity demand in California. If only public transit were electrified, an additional 1.025×10^6 Mwh of electricity would be needed, only a 0.5% increase in annual electricity production (16). If 50% of cars and light trucks were electrified, 3.844×10^7 mwh electricity would be needed, which leads to a 18.9% increase in annual electricity production. If all cars and light trucks were electrified, 7.688×10^7 mwh electricity would be needed, and this leads to a 37.8% increase in annual electricity comsumption. The above impacts of electrifying different components of the highway market transportation on electricity demand and consumption is summarized in Table 7.

Table 7. Electricity Generating Capacity and Production Requirements for Electrifying Motor Vehicles

	Instantaneous Peak Demand		Annual Consumption	
	MW (10^3)	Increase (%)	Mwh (10^8)	Increase (%)
Current Consumption	35	--	2.0316	--
Urban Bus Transit	35.13	0.5	2.0419	0.5
50% of Cars/ Light Trucks	43	22.9	2.416	18.7
All Cars and Trucks	52	48.6	2.8304	37.8
All highway vehicles	58	65.7	3.0557	50.5

Table 7 shows that the increase in electricity generating capacity required to electrify transportation is greater than the increase in electricity production.

VII. CONCLUSIONS

Without major breakthroughs in electricity storage technology, the electrification of highway vehicles will require major increases in electricity-generating capacity. With or without breakthroughs, it will be necessary to generate much more electricity. In rough terms, electrifying all highway vehicles would require about 66% more generating capacity and 50% more electricity production.

In general, transportation energy demand tends to exhibit sharper peaking patterns than current electricity demand patterns. More to the point, transportation peaks coincide with current electricity peaks during late afternoon. Electrification strategies should be sought which mitigate the magnitude of this overlapping peak. One strategy might include a time-of-day pricing structure that encourages drivers to draw energy from their batteries instead of the roadway during parts of the afternoon peak hours.

In practice, highway electricity consumption will increase at a slow pace, even if large segments of the road network were to be electrified at once. That is because of the slow turnover of motor vehicles. (Retrofitting existing vehicles is not likely to be feasible.) The average life of a car is over 10 years and for a light truck, over 14 years. Thus, the impact on electric utilities will be felt gradually.

In this report, we have just touched upon a few of the important issues associated with highway electrification. Future research should address the following questions and issues:

1. Efficiency and cost of future electricity storage technology, especially involving superconductivity. Improved storage could be handled on-board the vehicles or as part of the electricity-generating system.
2. Demand for electrified vehicles. Who would be willing to purchase a roadway-powered electric vehicle and under what conditions? What incentives could be offered? What market niches exist and how large are they?
3. Energy supply. Does the substitution of electricity for petroleum (gasoline and diesel fuel) create opportunities to use cheaper or more abundant resources? Is electricity a more efficient and less costly use of resources than liquid and gaseous fuels? What are the implications of electrification in the U.S. for world energy

markets? Is the energy 'issue ultimately an energy management question because the same type and quantity of resources would be used whether the end-state fuel is a liquid or electricity?

4. Impacts on electric utilities. How would large new capacity additions to the existing system be made? While it is difficult to do this type of long range forecast, at least a qualitative assessment should be conducted. What are the cost implications for the consumer and utility?

5. Environmental impacts. What would be the air quality effects--for urban areas where vehicle use will be concentrated and rural areas where much of the electricity will be generated? How large will the noise reduction benefits be? What would the impact be on the "greenhouse" effect?

6. How could or should the transition proceed? How can different groups of vehicle owners and users be attracted to electrification? Vehicle fleets? Buses? Urban commute cars? How would a highway segmentation strategy proceed in which selected lanes and freeways might be incrementally electrified? How would a spatial segmentation strategy proceed in which entire regions are targetted?

7. How could highway electrification enhance the prospects and attractiveness of highway automation? What reliability improvements could be expected? How would it facilitate the incorporation of electronic equipment on vehicles and in and along highways?

Notes and References

1. SCE, 1985 Rate Group Load Studies (Rosemead, California: Revenue Requirement Department of SCE, June 1986), Preface, p. 2.

2. Reilly, J.M., "Transit costs during peak and off-peak hours," Transportation Research Record, No. 625, 1977, p. 22-26.

3. CEC , California Transportation Energy Demand: 1984-2004. Staff Report, P300-85-002 of CEC publications, p. 4.

4. CEC, 1986 Electricity Report, P106-87-001 of CEC publications, p. 2-6.

5. Collins, M.M., W.F. Hamilton, and W.M. Carriere, "Impacts of electric vehicles on electric power generation," General Research Corporation, CR-l-983, prepared for Electric Power Research Institute, p. 24.

6. Total gasoline sale in August of 1986 was 1,117 million gallons, the highway gasoline sale was 96% of total gasoline sale in 1986. So highway gasoline sale in August of 1986 was 1,117 x 0.96 = 1,072 million gallons. For these figures, see California Department of Transportation (Caltrans), Travel and Related Factors in California, Annual Summary, 1986, published by Division of Transportation Planning of Caltrans. The higher heating value of gasoline is 124,952 Btu per gallon, and that of diesel is 138,690 Btu per gallon, personal communication with Mr. Gareth Occhiuzzo in Technology Assessments Project Office of CEC, August 1986.

7. Ibid. Total gasoline sale in 1986 was 12,229 million gallons, which is equivalent to 1.528 x 10^{15} Btu, and total diesel sale was 1,590 million gallons, which is equivalent to 2,205 x 10^{14} Btu. The diesel sale was 2.205 x $10^{14}/1.528 \times 10^{15}$ = 14.4% of gasoline sale.

8. Abdel-Aal, H.K., "Future fuels for motor vehicles: hydrogen vs. methanol," in Hydrogen Energy Progress IV, proceedings of the World Hydrogen Energy Conference IV, Pasadena, California, 13-17 June, 1982, edited by T.J. Vezirog W., W.D. van Vorst, and J.H. Kelly (New York: Pergamon Press, 1982), P. 1107. From the figures in this reference, energy efficiency for ICE vehicles is calculated as 12%. Also, In Lovins, Amory B., et al., Least-cost Energy: Solving the CO2 Problem (Andover, Massachusetts: Brick House Publishing Company, 1981), P. 43, the overall energy efficiency is cited as 10-15%. In OTA, Increased Automobile Fuel Efficiency and Synthetic Fuels (Washington, D.C.: OTA, 1982), P. 109. The energy efficiency is described as 12-13%.

9. Unnewehr, L.E., Electric Vehicle Technology (New York: John Wiley and Sons, 1982), P. 42. The energy efficiency of electric vehicles with battery is 52% (excluding battery recharge).

10. Ibid.; it is estimated that energy efficiency from battery to controller is 90%. So the energy efficiency for powered-road electric vehicles can be 52% ÷ 0.9 = 58%.

11. Shaladover, S.E., "The roadway powered electric transit vehicle - progress and prospects," Systems Control Technology, Inc. (forthcoming), P. 2.

12. Fleet vehicles consume about 1.2 million b/d of gasoline in the U.S. See Sperling, D., New Transportation Fuels: A Strategic Approach to Technological Change (Berkeley, California: UC Press, forthcoming). The annual total gasoline consumption in highways is about 103,607 million gallons in the U.S., which is equivalent to 6.76 b/d of gasoline. See U.S. Department of Transportation, Federal Highway Administration, Highway Statistics 1985 (Washington, D.C.: GPO, 1986), p. 9. So fleet vehicles consume 2.1/6.76 = 18% of highway gasoline consumption.

13. See Note 3, P10.

14. Total gasoline and diesel sales in 1986 were 1.749 x 1015 Btu (see Note 7). The highway gasoline and diesel consumption was $1.749 \times 10^{15} \times 0.96 = 1.679 \times 10^{15}$ Btu (See Note 6). Electrifying highways would need 1.679×10^{15} Btu $\div 4.8 = 3.497 \times 10^{14}$ Btu of Electricity. (See the text), which is equivalent to 1.025×10^{8} mwh.

15. See Note 4, p. 2-6.

16. Public transit consumes 1% of total energy consumption in transportation. See Note 3, p. 2.