# THE GROWING DEMAND FOR ENERGY

R. D. Doctor

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## INTRODUCTION

My talk today is about energy, especially one form of energy--electricity. I will try to give you some idea of how we use energy, how much we use and how we forecast our future energy requirements. I think we should begin by defining what we mean by energy.

In physics, energy is defined as the capacity to do work. This capacity is a crucial ingredient of our daily lives--but one we have come to take for granted. Energy has always been with us--from long before the days that primitive man walked the earth. In modern times, no less than in primeval times, it has been a major factor in the physical and cultural evolution of all species--not just man. The energy of the sun, the energy of the oceans as tidal and wave actions, the energy of the air through wind and rain and lightning, all these are common manifestations of energy that are ever present and that man has not yet learned to control--at least not economically. There are other forms or sources of energy that are just as familiar to us--coal, oil, natural gas, nuclear energy--forms that man _has_ brought under control--or perhaps I should say forms that we _think_ we control.

## AGGREGATE PATTERNS OF ENERGY CONSUMPTION

Let's begin by describing how much energy we use and how we use it.

Figure 1 shows U.S. trends in fuel consumption since the end of World War II. Now, don't be concerned about the units in the figure; the important points are the growth and composition of our energy use. We see that petroleum products and natural gas clearly dominate the market, and the present role of electricity in the national energy picture is surprisingly small.

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What else does this graph say to us? Well, one other very important point is how fast our energy demands are growing. Over the past decade, the compound growth rate has been 4 percent per year. This means that we have been doubling our energy needs every 18 years.

There's another way to examine how our energy use has grown. Let's look at the per capita use of energy in the U.S. (Fig. 2). Primitive man used only the energy his body could generate--about 2000 kilo calories per day. That, by the way, in very rough terms is about the amount of energy required to keep a single 100-watt light bulb lit for 24 hours. As man progressed through various cultural stages, he came to depend more and more on non-human sources of energy until today's technological man--that's us--is responsible for more than 230,000 kilo calories per day per person--over 100 times the amount of energy our primitive ancestors were able to use.

Now this is a huge amount of energy. It's as if each of us had at our disposal almost 300 other people working full time. But even more dramatic is the rate at which the U.S. per capita energy consumption is growing (Fig. 3). In the 1950's, the per capita growth rate was only 0.8 percent. By the 1960's, the growth rate had more than tripled to 2.7 percent.

There are two basic factors that account for this tremendous growth rate: greater numbers of people and increasing affluence due to economic growth (Fig. 3). Our population has increased from 143 million to about 205 million since 1947 (an average rate of about 1.5 percent per year).

But the increasing number of people is quite a bit less important than the growth in the economy that has taken place--measured by GNP. The GNP per capita is often used as a measure of affluence in the nation. We can extend this concept to energy use per capita.

The per capita consumption of energy currently is increasing some 2-1/2 times faster than the population. This means that population growth alone cannot explain our increased energy needs. We can ask then, what are we doing with all this energy? How do we use it?

## Where the Energy Goes

In Fig. 4, we see the distribution of the fossil fuels (by far the major forms of energy today) to the four major user groups. Industry, you see, accounts for about 1/3 of our fuel consumption, while our direct residential use accounts for only 1/5 of the total. The electric utilities, however, also use 1/5 of the fuels consumed each year. They in turn provide energy in the form of electricity to industry and to our homes. As we see in Fig. 5, over half of our national consumption of electricity is in our homes and commercial establishments. Industry consumes about 45 percent of the total.

## The Electricity Dilemma

It is important to notice again the exponential character of these curves. Total electricity consumption in the U.S. is currently growing at a rate of 6.9 percent. This means that if we are to meet this accelerating consumption, then every 10.2 years we must double our capacity to generate electricity. The efforts of the electric utility industry and their suppliers to meet these growing demands are behind many of the environmental confrontations that have been so much in the headlines during the past few years.

Let us consider just one of the environmental problems connected with the proliferation of electrical power plants--the siting problem. The question of where to put these plants is critical, especially to the electric utilities. One characteristic of current power plants is that they require large quantities of water for cooling purposes. Because of these cooling requirements, the power companies argue that the most logical and economic location for their new plants is near a large body of water. In California, the preferred location for power plants--from the utilities' point of view, is along the Pacific Coast. Professor Charles Washburn at Sacramento State College in California has taken FPC estimates of the power capacity required in

California 50 years from now--in the year 2020--and located all of the required new plants on the California coast (Fig. 6). He then shows that there will be a 1000 MW power plant every 2 miles along the entire coastline. If you want to think big and make them 6000 MW sites--far larger than any yet built--they will still be only 12 miles apart. Although this absurd situation results from the simplifying assumption that all new plants will be at coastal sites, it illustrates the magnitude of the problem.

And remember, this is only one of the problems that makes up our electricity dilemma. I won't go into those problems in any more detail because other speakers at this conference will be covering them. It is interesting and useful, however, to speculate on some of the solutions to these problems. It has been suggested recently by many learned and knowledgeable people that ultimately the solutions will involve developing non-polluting (or at least hardly polluting) methods for supplying the gargantuan amounts of electricity that not only the U.S., but that the world will require over the next century. Power from controlled fusion processes and solar power have been mentioned as prominent possibilities for the future. The difficulty is that the year 2000 may well be upon us before these sources can even begin to supply a significant part of our multiplying electricity needs. In addition, even if we can supply our electricity needs in some non-polluting way, we still are faced with the problem of disposing of the energy that we have generated and then have either wasted or used. Climatologists tell us that ultimately that energy might bring about significant changes in weather patterns--particularly near our urban areas.

So we still are left with that exponential increase in demand for energy--particularly electricity. And that brings us to one of the basic themes of this conference. How can we limit our voracious appetite for electricity? I don't believe that the demand curve (Fig. 7) can continue its ever increasing upward slope for much longer--or more precisely, that the supply can continue to satisfy demand. There are a lot of pressures developing--scarcities of resources, real and valid environmental concerns, and our basic inability to finance and build the needed facilities fast enough. These pressures are going to cause some bending over of that curve. If the economic laws of the marketplace are invoked, this might well result in severe dislocations of the economy, brownouts, critical energy supply shortages, greatly increased prices, and so on, before natural adjustments can take place. It would appear prudent to start considering rational voluntary and even governmental steps that might be taken to slow down the growth rate in demand--steps that might allow a less traumatic readjustment of our uses of energy. Please note that I am not advocating a decrease in the level of energy consumption--no return to candles and caves--only a decrease in the slope of the curve. There are a number of ways we can do this--there have been suggestions for changing the rate structures, taxation, rationing, regulations to improve the efficiency of use, and so on. Which options would be most effective, and which would cause the least undesirable side effects, remain to be studied and are being studied. But to do that kind of evaluation, we must have a much better understanding of what we are going to be using energy for. We are only now beginning to gain that understanding.

Now in the few minutes I have remaining, I'd like to give you an overview of how we use electricity.

Let's begin with per capita consumption of electricity on a nationwide basis. This we see is obtained by dividing total consumption by population (Fig. 7). Thus, average per capita consumption is about 7640 kwh/capita and is growing much faster than the total curve. This means simply that our accelerating use of electricity is due not so much to population increases as it is to the fact that each of us is constantly expanding our individual use of electricity.

Of course, as individuals, we don't consume all that electricity directly. Rather, we use only about 35 percent of that total directly in our homes. The remainder, over 65 percent of the total, we use indirectly through our purchases from commerce and industry of various goods and services (Fig. 8).

Which industries are the major consumers of electricity? When we look at the data, we find that only six of the 25 major manufacturing and mining industries consume 64 percent of the purchased electricity used by industry. By far, the largest consuming group is the primary metals industry, which all by itself accounts for almost a quarter of total industrial consumption. The chemical group is not far behind. Two major industries, aluminum and iron and steel, within the primary metals group, account for 39 percent and 28 percent, respectively, of the group total. The iron and steel and aluminum industries, then, consume about 16 percent of industrial purchases of electricity and account for 7 percent of total national electricity sales. These are significant amounts of electricity. These figures tell us that if we are going to reduce our growth rate of electricity consumption over the next 20-30 years, we must re-examine how we use the products of industry, particularly the products of the primary metals and chemical industries. We must re-examine how energy--and electricity in particular--is used by those industries and what technologies and operating practices might be introduced to encourage their more efficient use of energy.

## Residential Uses of Electricity

Let us turn now to the residential sector. How do we use electricity in our homes? First, let us put residential electricity use in perspective (Fig. 9). Electricity, of course, is not the only energy source we use at home. In fact, on a nationwide basis, it is not even the major source. In 1969, it accounted for only 17 percent of the combined residential-commercial energy consumption in the nation. Natural gas and petroleum, with almost 80 percent of the total, clearly dominate the residential-commercial market. Yet electricity *is* in the spotlight--and I believe rightly so. Because it is becoming evident that supplies of gas and oil are severely limited, and because electricity's share of the energy market is growing so rapidly, I believe it is proper and rational to analyze and critique our uses of electricity.

With this in mind, let's take a look at Fig. 10. We see that, by far, the major use of electricity is for home heating (if our homes are electrically heated). Surprisingly, the electric water heater is in second place. Other major users are electric ranges, freezers and refrigerator-freezer combinations, and, of course, air conditioning. Note that this is for a single room air conditioner. Whole house, central air conditioning, although somewhat more efficient, uses proportionally more electricity.

Notice also that the miscellaneous categories have grown significantly since 1948. This is a reflection of the great increase in the number of small electric appliances available, none of which by themselves uses much electricity.

## Forecasting Future Electricity Consumption

What can we do with this information? The numbers are interesting, but how can we use them to help solve our problems? One way these numbers and others like them can be used is in providing insight and data for forecasting future energy and electricity requirements. It is essential to do this well if we are to avoid the unpleasant and even destructive consequences of poor planning. This challenge is well illustrated by Ezra Mishan in his book, *The Costs of Economic Growth*. He said:

> The younger generation will be facing the future with honesty only when it brings itself to face the strain of thinking through the consequences, tangible and intangible, certain and speculative, of the current drift into the future, and in doing so, recognizes that . . . on many issues painful choices have to be made. . . .

At Rand, and at several other research institutions around the country, we are trying to identify some of these "consequences" and "painful choices." We have begun by trying to understand and improve the forecasting process. Much of the information that I'll be presenting now is drawn from the work of two Rand analysts, C. C. Mow and W. E. Mooz. They are engaged in developing improved forecasting techniques using California as a case study and data base.

Forecasting methods can be classified according to their time domain--immediate, short, intermediate or long term--and they can be classified according to whether they are based on extrapolation or correlation techniques. We are concerned mainly with the intermediate and long term and with both extrapolation and correlation methods.

Figure 11 shows California's aggregate electricity consumption over the past 25 years. The indicated growth rate over the 1960's is $8\frac{1}{2}$ percent, which means a doubling of electricity consumption every $8\frac{1}{2}$ years. The data are plotted in two ways. Figure 11a shows the typical exponential rise in use. Figure 11b shows the same data plotted on semi-log paper. Notice that when plotted in this way the data form a straight line. Using this graph, it is particularly easy to guess future consumption, for all we have to do is extend the line into the future. This method is called extrapolation. It assumes, implicitly, that future growth will be a continuation of past growth, that whatever factors have affected past history will continue operating in the same way in the future. Not surprisingly, extrapolation techniques have produced acceptable results, perhaps because of inherent social inertia, the long time required for large changes to be felt in society.

Another forecasting technique--correlation--seeks to relate electrical loads to the determinants of use, to selected factors associated with the loads (e.g., population, disposable income, prices, etc.). From an analytical point of view, this method is more satisfying because it provides some insight into the causes of past growth and helps us to understand the factors that might cause future growth. The problem is that correlation techniques require considerable amounts of data--information that is not always available. As a result, even when using correlation methods, we are often forced to estimate the values of the correlation variables by extrapolation techniques. Still, if we are to understand the nature of growth in electricity use, we must use and try to refine our correlation methods.

In California, Southern California Edison, which is one of the more sophisticated forecasters among the nation's utilities, uses a combination of extrapolation and correlation methods. Within their sales area, domestic consumption is estimated by combining data of per capita consumption and per capita income with forecasts of population growth and household incomes. Similarly, total industrial electricity sales are obtained by plotting industrial electrical energy consumption vs GNP, extrapolating the curve into the future and then forecasting GNP. A slightly different correlation method is employed by the Los Angeles Department of Water and Power. They divide their territory into 230 four square mile areas, analyze land uses within each area and correlate electricity consumption to these land use patterns. Results of these correlative methods have been quite satisfactory, at least so far. Most utilities throughout the country, however, depend strictly on simple extrapolation techniques.

At Rand, one of our efforts involves building a deterministic model for California based for the most part on correlation methods (Fig. 12). The model will estimate domestic consumption by multiplying consumption per household times the number of households. Each of these factors, in turn, is determined by several other factors such as the type of appliances in each household, income per household, rate of household formation, etc. Other consuming sectors are treated similarly.

Dr. Kent Anderson, one of our economists, has used a simplified version of this model to estimate minimum and maximum growth rates in electricity consumption to the year 2000. Some of his preliminary results are shown in Fig. 13. Residential use is based on a 68 percent population growth between now and the year 2000. Growth in consumption in other sectors is based on growth of the Gross State Product per capita which in turn is assumed to be 1 percent to 2 percent. (It was 1.9 percent in the 1950's and 1.7 percent from 1961-70.)

We see that in Dr. Anderson's hypothetical minimum case, electricity use would still be some 2-1/2 times the present use. We see also that there is a considerable and significant spread between the hypothetical minimum and maximum. Obviously, more refined estimates are required.

Mooz and Mow at Rand have been developing a model to estimate future electricity requirements for California. Let me illustrate with some of their initial results for the residential sector.

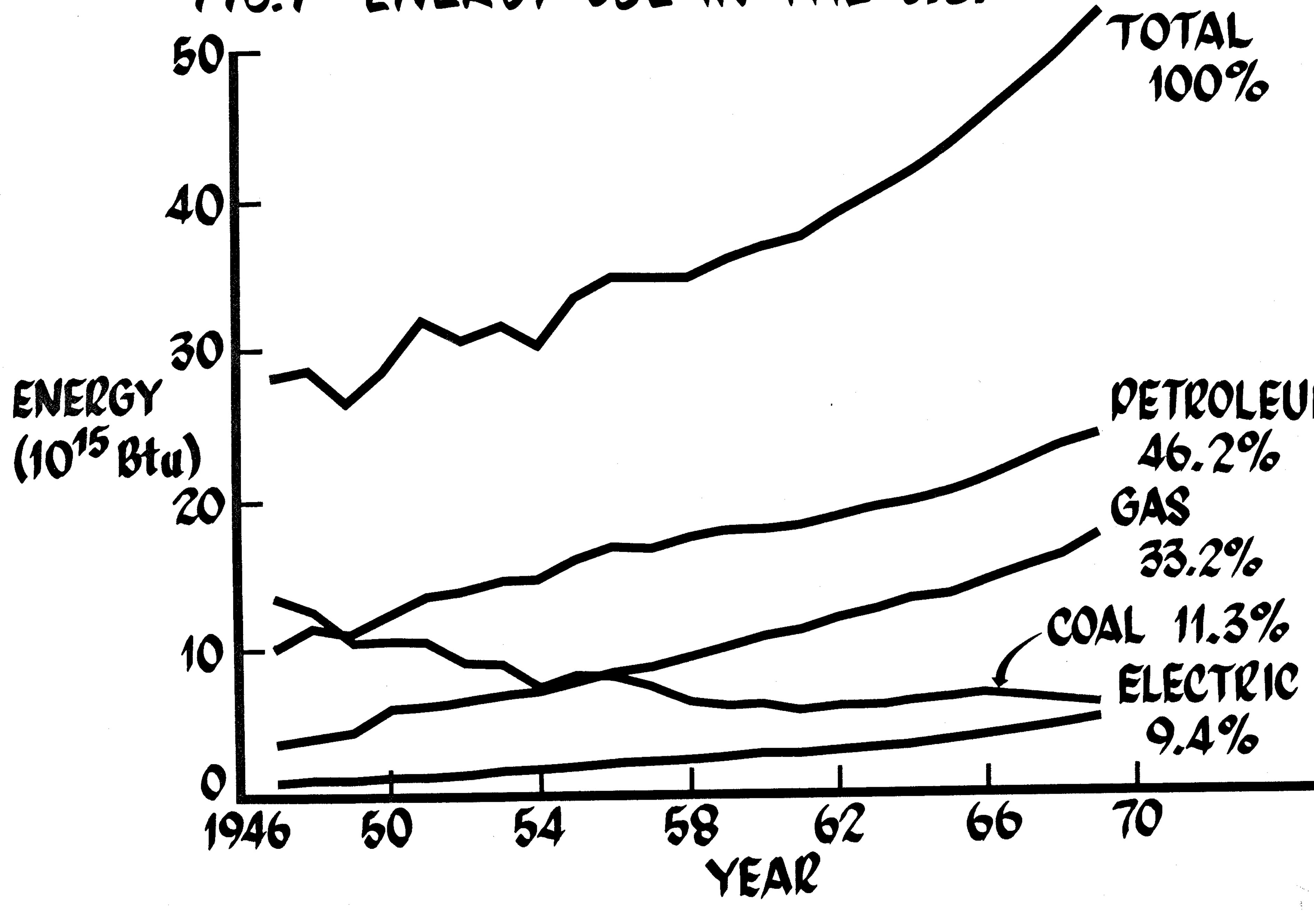
They have examined historical energy consumption and saturation data for various electrical appliances in the home (saturation refers to the fraction of households having at least one of each appliance). Based on these data, they have derived equations that describe changes in saturation and in energy use for each appliance as a function of time. Figure 14 shows typical equations for saturation of electric appliances. These equations, along with equations describing changes of energy use per appliance over time, allow them to calculate the amount of electricity that would be consumed by an average household. Results for Southern California Edison's service area are shown in Fig. 15 for 1970. (Actual 1970 consumption is within 2 percent of the results from their model.)

This model, of course, does not yet include two other very important variables--electricity price and household income. These will be incorporated as our analysis progresses.

Our task at Rand, and the task of many other researchers over the next several years, is to make the needed refinements in these forecasts. In the process, we are developing scenarios of potential alternative futures. That is, we are attempting to describe several future environments in terms of the variables that determine energy--and electricity--consumption.

If we are successful, then we will have a powerful analytical tool in hand that will be useful for analyzing the possible consequences of our planning decisions before these decisions are implemented. Or, to paraphrase the eloquent words of Professor Mishan, We are just beginning to face the strain of thinking through the consequences, tangible and intangible, certain and speculative, of our actions.

FIG. 1—ENERGY USE IN THE U.S.



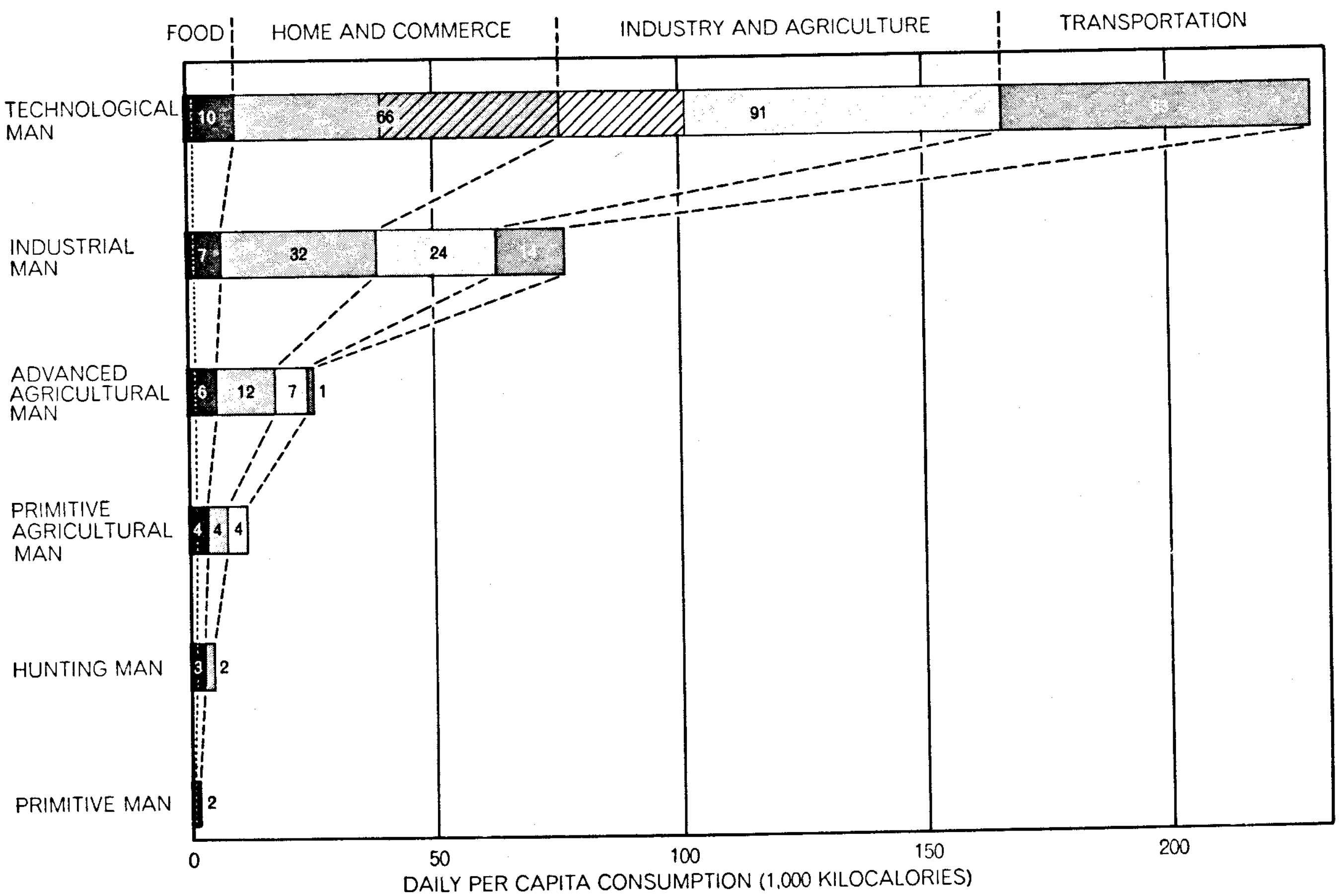
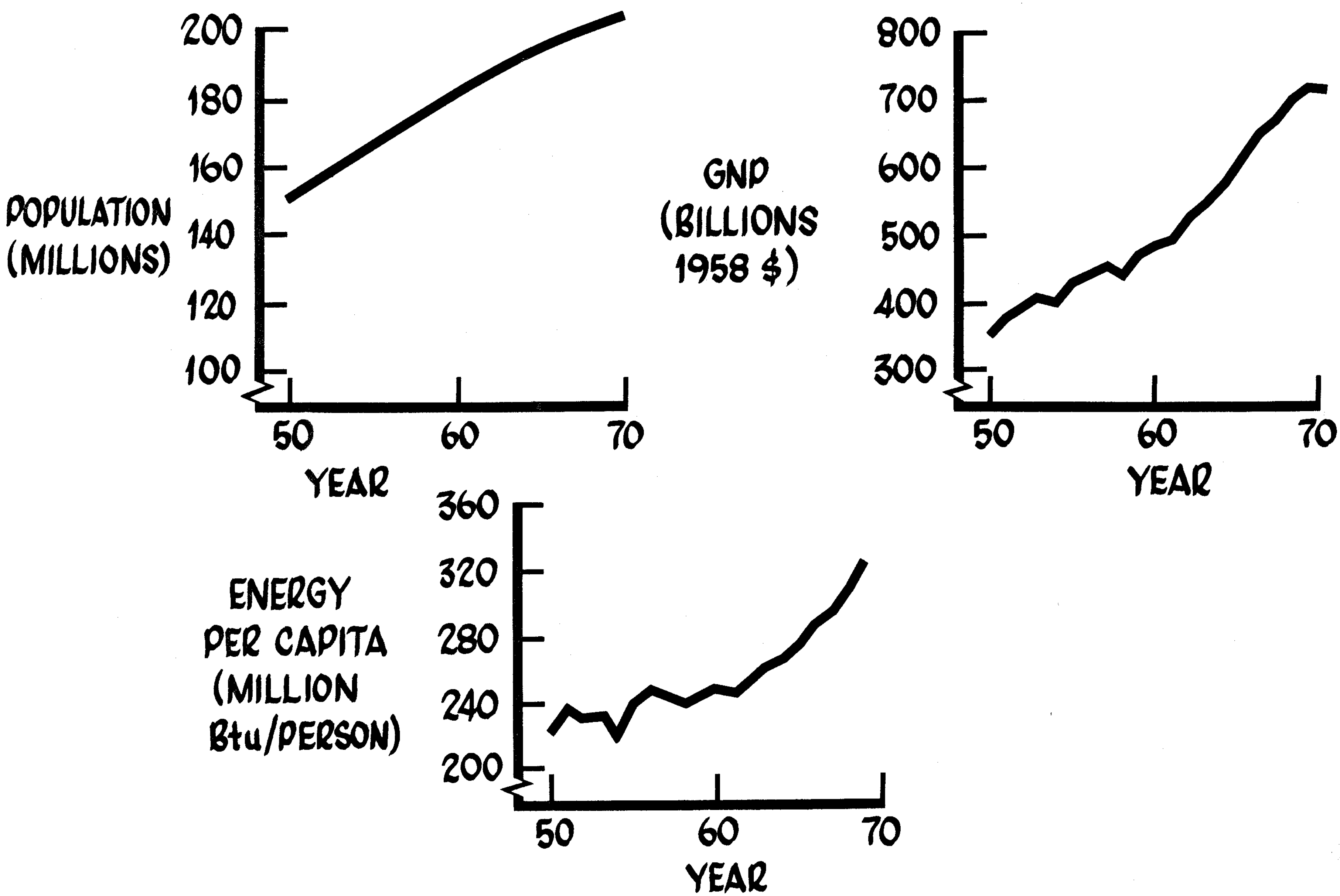



**Fig.2 — Scientific American daily per capita use; prim. man to technological man**

Source: Scientific American Sept. 1971, Earl Cook
"The flows of energy in an industrial society"

# FIG. 3 — GROWTH TRENDS IN U.S.



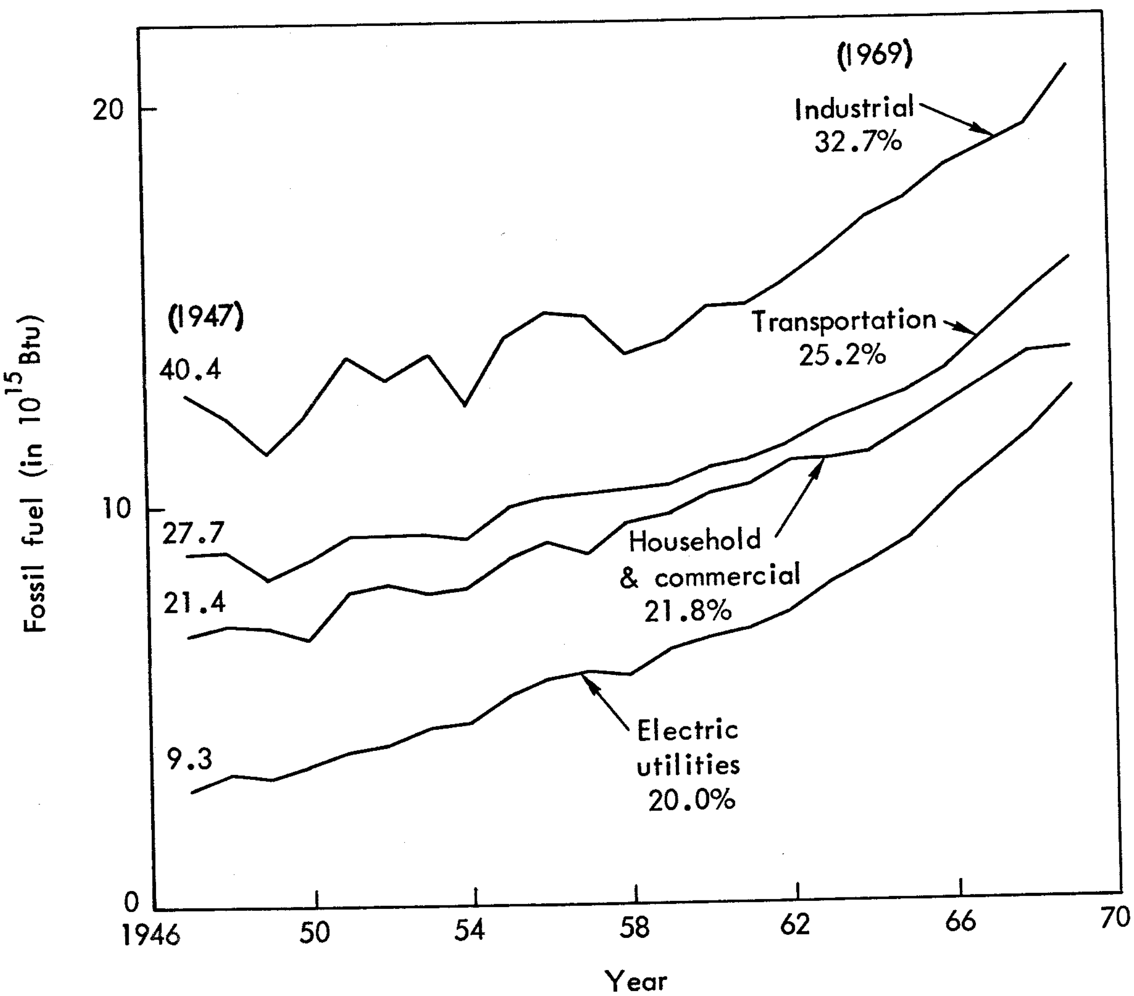



Fig.4 — Direct consumption of fossil fuels versus year-by sector

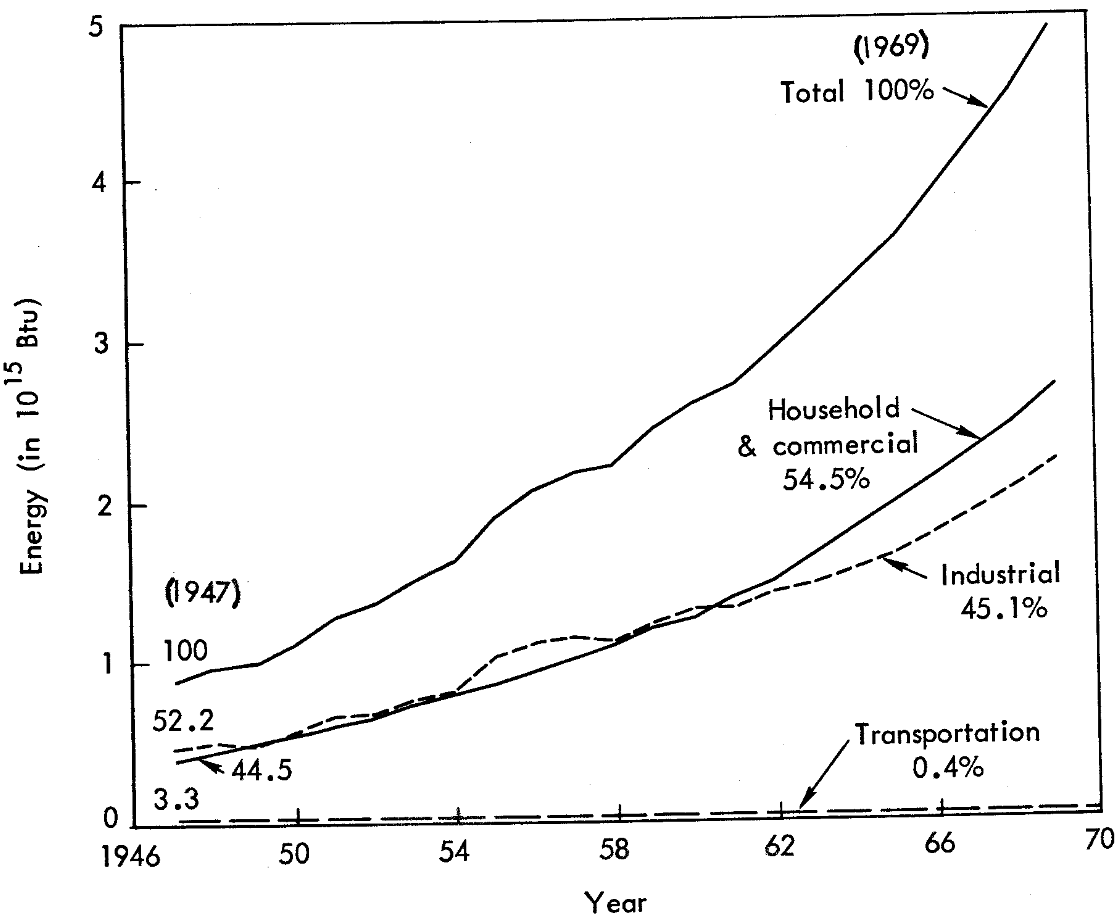



Fig.5 — Utility electricity used by sector versus year

FIG. 6 —
POWER PLANT SITING IN CALIFORNIA

| | AVERAGE SPACING (MI) | |
|---|---|---|
| | 1000 MW | 6000 MW |
| 1980 | 31 | 184 |
| 1990 | 11 | 65 |
| 2000 | 5 | 32 |
| 2010 | 3 | 18 |
| 2020 | 2 | 12 |

FIG. 7—
ENERGY CONSUMPTION IN U.S.

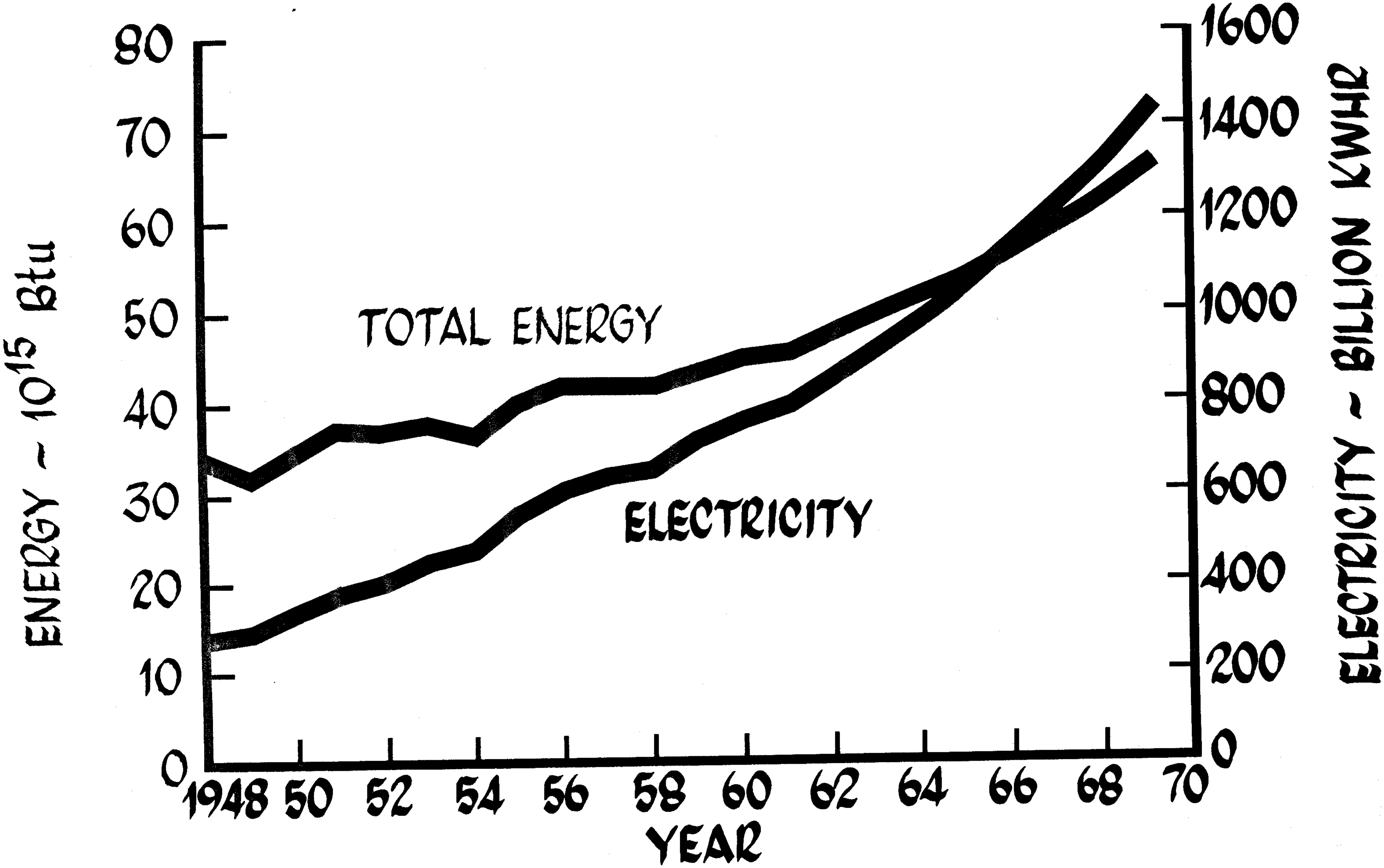


Fig. 8

ELECTRICITY SALES TO INDUSTRY
(Based on Data From 1967
Census of Manufacturers)

| Industry Group | Percent of Total Sales to Industry | Percent of Total National Consumption |
|---|---|---|
| Food and Kindred Products | 5.2 | 2.3 |
| Paper | 5.5 | 2.5 |
| Chemicals | 21.0 | 9.5 |
| Petroleum | 3.9 | 1.8 |
| Stone, Clay and Glass | 4.4 | 2.0 |
| Primary Metals | 24.0 | 10.9 |
| Iron & Steel | (6.7) | (3.0) |
| Aluminum | (9.4) | (4.3) |
| Other Manufacturing | 29.5 | 13.4 |
| Minerals | 6.5 | 2.9 |
| Total Industrial | 100.0 | 45.3 |

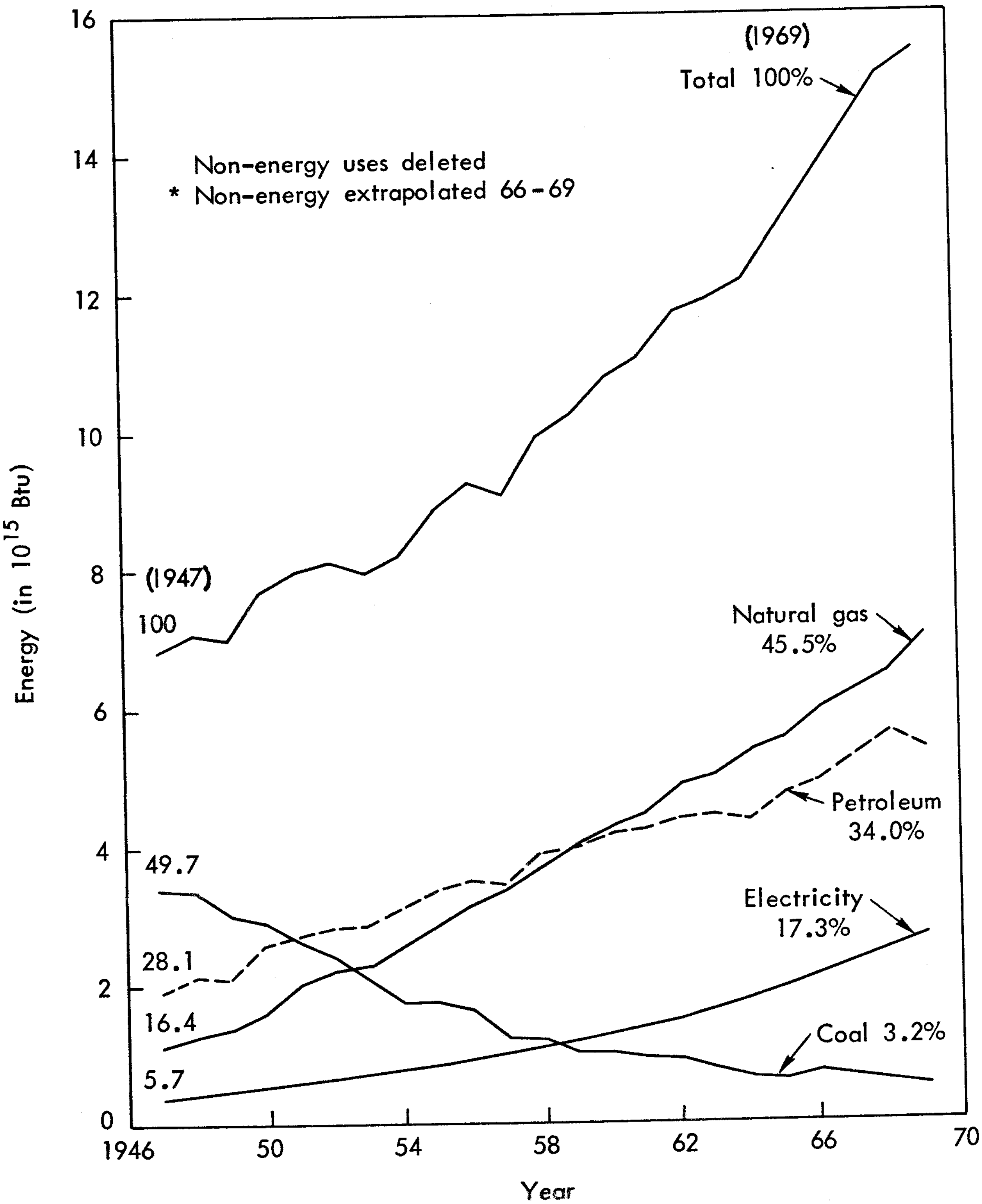



Fig.9 — Energy use in the household and commercial sector

Fig. 10

ELECTRICITY IN THE HOME
(KW-HOURS/YEAR)

| | 1948 | 1969 | | 1948 | 1969 |
|---|---|---|---|---|---|
| Kitchen Group | | | Recreation & Environ. | 1320 | 18,432 |
| Range | 1250 | 1175 | B. & W. TV | 298 | 362 |
| Refrig./Freezer[a] | 350 | 1137 | Color TV | --- | 502 |
| Freezer[b] | 600 | 1195 | Air Cond. (Window) | 935 | 1,389 |
| Dishwasher | 75 | 363 | Heater (Radiant) | 90 | 176 |
| Disposal | 10 | 30 | Heat Pump | --- | 16,003 |
| Misc. | 650 | 914 | Fans - Furnace | 235 | 394 |
| | | | - Rollabout | 30 | 138 |
| Lights, Util., Maint. | | | - Window | 40 | 170 |
| Water Heater | 3400 | 4219 | | | |
| Washing Machine | 45 | 103 | | | |
| Dryer | 365 | 993 | | | |
| Misc. | 680 | 764 | | | |

[a]14 $ft^3$ combined unit (not frost-free).

[b]15 $ft^3$ unit (not frost-free).

SOURCE: Edison Electric Institute.

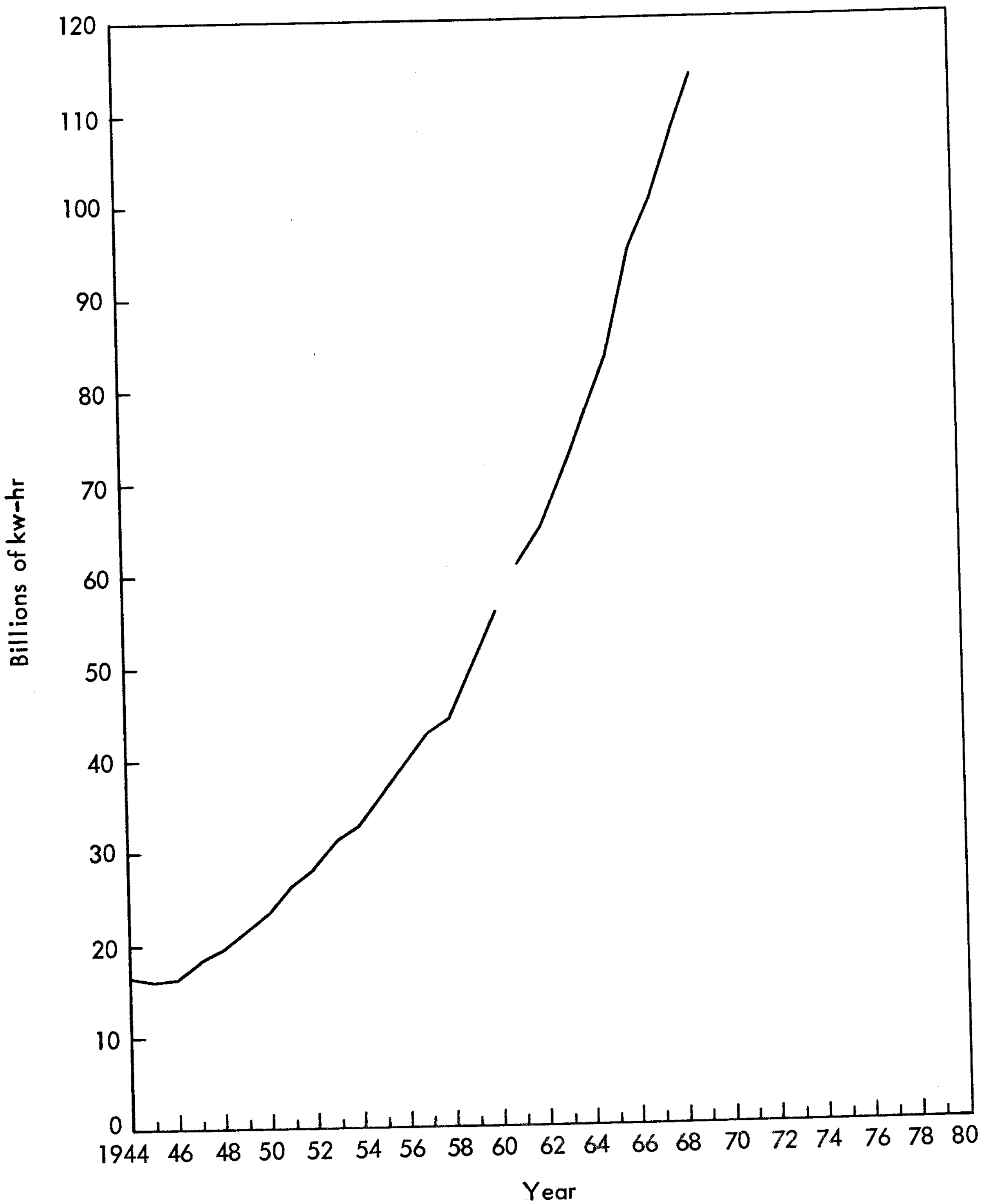



Fig. 11a — Electricity consumption in California

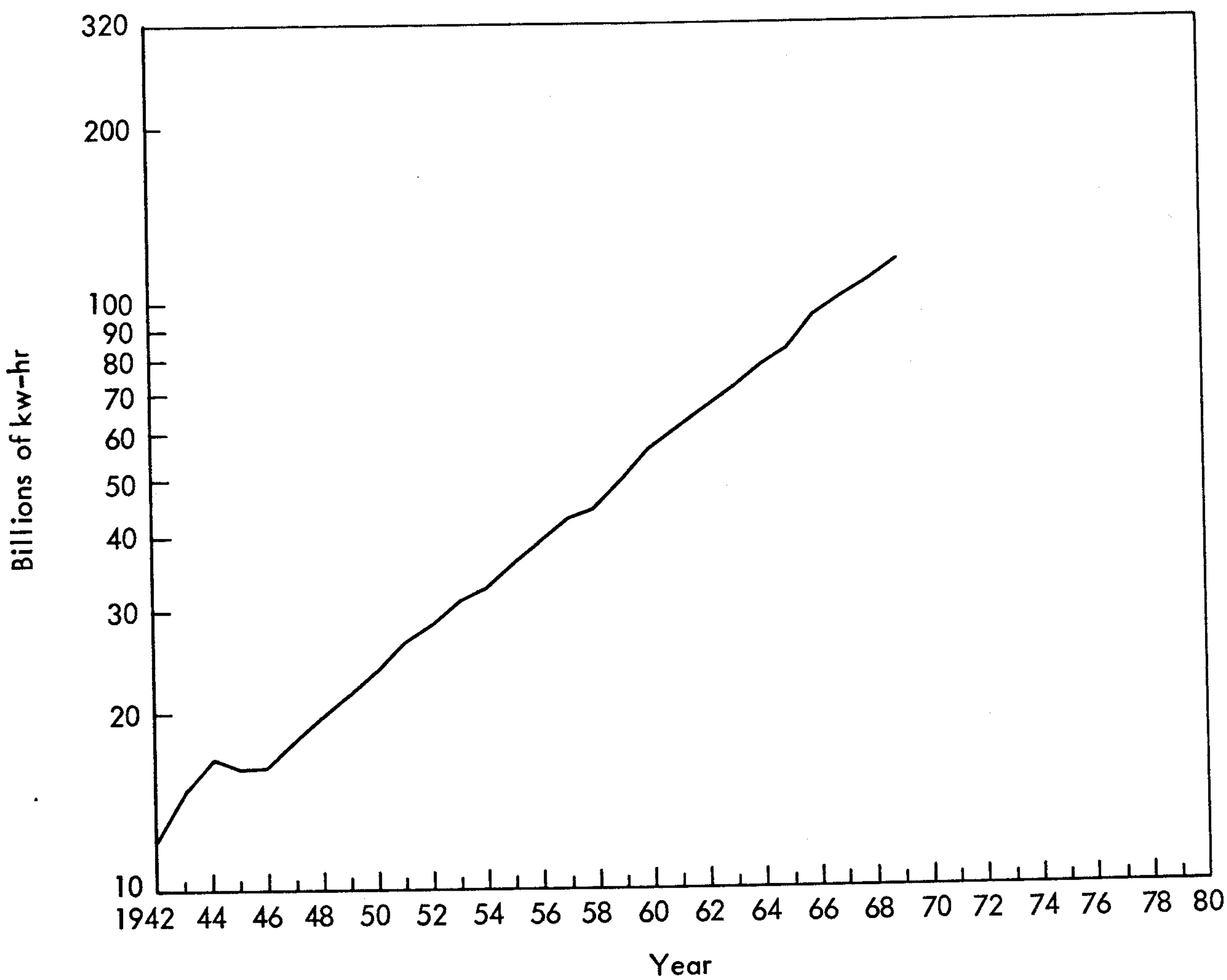



Fig.11b — Electricity consumption in California

Fig. 12

A CORRELATIVE MODEL OF RESIDENTIAL ELECTRICITY USE

[Residential Consumption] = [Consumption per Household] x [Number of Households]

Consumption per Household:

Number and Characteristics of Appliances
Electric or Gas Appliances
Urban versus Rural Household
Income per Household
Electricity and Gas Prices
Appliance Prices
Etc.

Number of Households:

Fertility Rates
Rate of Household Formation
In-Migration and Other Demographic Factors
Etc.

Fig. 13

CALCULATIONS OF HYPOTHETICAL ELECTRICITY DEMAND GROWTH[a]
IN CALIFORNIA BETWEEN 1970 AND 2000

| Sector | Growth of Number of Base Units[b] | Growth of Average Electricity Use Per Base Unit | Growth of Sector Consumption | Sector Share of Consumption in 1970 | Component Contribution to Growth of Total Cons.[c] |
|---|---|---|---|---|---|
| Residential | 1.92 | 1.63-5.05 | 3.12-9.70 | .28 | 0.87-2.72 |
| Manufacturing | 2.27-3.04 | 1.00-1.35 | 2.27-4.10 | .24 | 0.54-0.98 |
| Government | 2.27-3.04 | 1.00-4.32 | 2.27-13.13 | .06 | 0.14-0.79 |
| All other[d] | 2.27-3.04 | 1.00-3.24 | 2.27-9.85 | .42 | 0.95-4.14 |
| Growth of Total Consumption | | | | | 2.50-8.63 |
| Average Annual Rate of Growth of Total Consumption (percent) | | | | | 3.1 -7.4 |

Notes:

[a]Growth is expressed in terms of the ratio of the year 2000 value to the year 1970 value.

[b]Number of customers in the residential sector; "real GSP originating in" for other sectors.

[c]Growth of Sector Consumption X Sector Share of Consumption in 1970.

[d]Includes commercial, all industrial except manufacturing, and other minor categories.

Fig. 14

SATURATION OF ELECTRIC APPLIANCE OWNERSHIP IN THE SERVICE AREA OF SOUTHERN CALIFORNIA EDISON

| Appliance | Saturation Equation* | Coefficients |
|---|---|---|
| Range | S-curve | a = 0.90<br>b = -0.014 |
| Refrigerator | Constant | a = 1 |
| Freezer | S-curve | a = 0.86<br>b = -0.007 |
| Dishwasher | S-curve | a = 1.06<br>b = -0.03 |
| Water Heater | Constant | a = 0.09 |
| Washing Machine | Constant | a = 0.73 |
| Dryer | S-curve | a = 0.96<br>b = -0.01 |
| TV - Black and White | Regression | a = 0.96<br>b = -0.01 |
| TV - Color | S-curve | a = 3.27<br>b = -0.13 |
| Air Conditioner - Room | S-curve | a = 0.94<br>b = -0.006 |
| Air Conditioner - Central | Constant | a = -0.006 |
| Heating | S-curve | a = 1.008<br>b = -0.005 |

*S-curve: $y = 1 - a \cdot \exp[b \cdot x]$
Constant: $y = a$
Linear Regression: $y = a + bx$

$x$ = years since base year (1969)

$y$ = fraction of households having at least one of specified appliance = saturation

Fig. 15

ELECTRICITY CONSUMPTION IN A COMPOSITE HOUSEHOLD
(SOUTHERN CALIFORNIA EDISON SERVICE AREA)

| Appliance | Predicted Values for 1970 From Model | | |
|---|---|---|---|
| | Consumption Per Appliance (kw-hr) | Saturation | Consumption Average Per Appliance (kw-hr) |
| Range | 1200 | 0.27 | 324 |
| Refrigerator | 1150 | 1.00 | 1150 |
| Freezer | 1220 | 0.22 | 268 |
| Dishwasher & Disposal | 400 | 0.33 | 132 |
| Misc. 1 | 715 | 0.43 | 343 |
| Dryer | 1000 | 0.21 | 210 |
| Washing Machine | 110 | 0.73 | 80 |
| Water Heater | 4280 | 0.09 | 385 |
| Lighting | 571 | 1.00 | 571 |
| Misc. 2 | 300 | 0.55 | 165 |
| Room A/C | 1450 | 0.14 | 203 |
| Central A/C | 2000 | 0.06 | 120 |
| B & W TV | 360 | 0.79 | 284 |
| Color TV | 500 | 0.57 | 285 |
| Heating | 5000 | 0.06 | 300 |
| Misc. 3 | 600 | 0.69 | 414 |
| Total consumption for composite household | | | 5235 kw-hr |