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THE ROLE OF RENEWABLES IN HAWAII'S ENERGY FUTURE

Jayant Sathaye and Henry Ruderman

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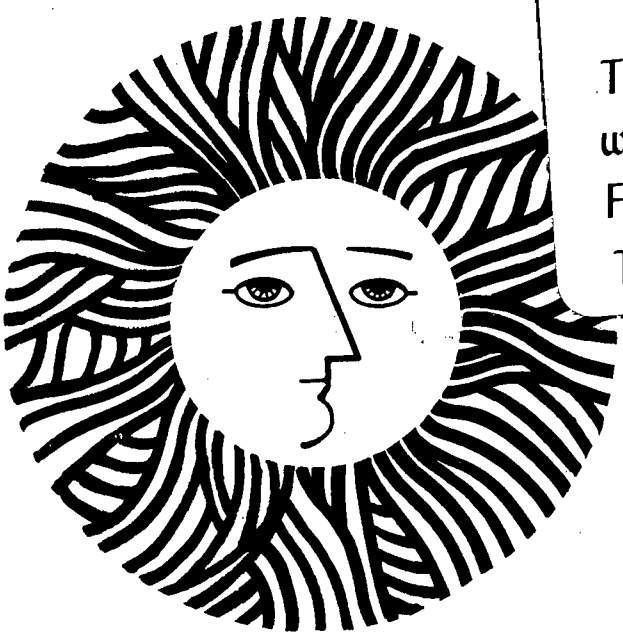

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Jayant Sathaye and Henry Ruderman

Staff Scientists
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
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by Jayant Sathaye and Henry Ruderman

Staff Scientists
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABSTRACT

The Hawaii Integrated Energy Assessment was an investigation of possible energy futures for Hawaii with emphasis on using indigenous sources of energy. The analytic methodology included an interconnected set of models to forecast the demands for various forms of energy, to select an optimal mix of supply technologies, and to estimate the economic impacts of constructing and operating the state's energy system. The analysis indicates that almost all of the petroleum based electricity generation could be replaced by renewable and geothermal sources during the next twenty-five years. Gasoline consumption will show a considerable drop as a result of higher prices, more efficient automobiles, and the use of ethanol to extend gasoline supplies. The major use of petroleum will be for aviation fuel, for which there appears to be no short-term substitute. By 2005, Hawaii's economy will be much less dependent on imported petroleum than it is today.

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Staff Scientists
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
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INTRODUCTION AND SUMMARY

The State of Hawaii is extremely vulnerable to disruptions in the world oil market. Over 90 percent of the state's energy comes from imported petroleum, most of which is from foreign sources. Petroleum also has an indirect impact because of the large role that tourism plays in the Hawaiian economy. During 1978, nearly four million visitors spent over $2 billion in Hawaii. Higher passenger fares and fewer visitors resulting from a rapid rise in petroleum prices would have serious consequences throughout the state.

As Shupe and Weingart [1] point out, Hawaii could play a pioneering role in the development of renewable and geothermal resources. Due to the state's geographic and geological characteristics, it is endowed with a variety of energy sources. The Hawaiian Islands are a series of shield volcanos that rise steeply from the sea floor. They are located in the belt of northeast trade winds that blow for most of the year. This consistent wind pattern, combined with the Island's topographic features, provides the state with many nearly ideal locations for wind

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machines. Extensive high temperature geothermal resources found on the Island of Hawaii can be used to generate electricity, while lower temperature resources on Oahu and Maui can supply hot water for domestic and industrial use. Hawaii also enjoys a high average insolation, so that solar energy for water heating and electricity generation could become widespread. The large temperature gradients and the absence of a continental shelf make Hawaii a prime location for ocean thermal energy conversion (OTEC). The use of crops and trees to supply electricity and possibly liquid fuels can also be expanded.

The state government, recognizing the Island's precarious position, has made one of its prime objectives increasing the level of energy self sufficiency while maintaining a dependable, efficient and economic energy supply system. To what extent oil can be replaced by indigenous resources over the next twenty-five years was the focus of the Hawaii Integrated Energy Assessment (HIEA), a joint study by the Hawaii Department of Planning and Economic Development (HDPED) and the Lawrence Berkeley Laboratory (LBL). The HIEA examined what the future demand for energy might be, which indigenous resources would be available, which technologies would be developed sufficiently to exploit the resources, how the technologies could be combined into an efficient energy supply system, and what would be their social, economic and environmental consequences. A complete description of the study and discussion of the results may be found in a six volume report [2].

This paper discusses the three major analytic portions of the HIEA -- the energy demand forecasts, the energy supply mix, and the economic impacts. The demand forecasts and the supply mix are determined for each county, whereas the economic impacts are determined statewide. The paper begins with a description of the data, methods and models used in the analysis. Then we present the results of applying the models to one of several alternative futures that were examined. In the final section, we summarize the conclusions of the study.

The energy future for Hawaii discussed here is predicated on a set of demographic and economic projections prepared by the state government [3]. Two additional assumptions had a strong influence on the energy

demand forecasts -- that world oil prices would rise at three percent per year, and that the federal gasoline mileage standards would be met. The characterizations of the costs and availability of alternative technologies were common to all cases. A critical factor in these futures is the economic and technical feasibility of an undersea transmission cable to carry electricity from Hawaii to Oahu.

Our results indicate that by 2005 indigenous resources could supply nearly 80 percent of the state's electricity, even though the demand almost triples. The major sources of the additional supply would be geothermal and OTEC plants. Constructing these plants would place a severe financial strain on the state's utilities unless innovative methods of raising capital are found. Gasoline consumption will decline because of higher prices and more efficient automobiles. Alcohol derived from domestic biomass could replace ten percent of the gasoline consumed. The consumption of aviation fuel will continue to increase, however, as tourism continues to grow.

In addition to the scenario discussed above, we considered two alternative cases. In one there is additional energy conservation brought about through improved appliance efficiencies and the use of heat pumps for water heating. In the second, we postulated that world oil prices would increase at a rate of ten percent per year rather than three percent. The major difference in the high price case is that the timetable for introducing alternative technologies is accelerated by five years because they become competitive with oil that much sooner. The higher conservation case requires fewer new facilities, thus reducing the financial burden of the state's utilities.

Several other possibilities were examined. As long as petroleum remains the primary source for electricity, electric vehicles will not reduce the state's dependence on imports. Coal-fired power plants might be the quickest way to reduce oil consumption, but there would be problems with air pollution and solid waste disposal. Furthermore, a large infrastructure would have to be built up to import, distribute, and store coal. Nuclear power plants of the size appropriate for Hawaii (200 MW) are not now being built commercially.

Although complete energy independence for Hawaii does not appear to be possible within the next twenty-five years, indigenous resources could significantly reduce the state's dependence on imported petroleum. Most of its electricity could come from geothermal and renewable plants. Improved vehicle mileage, the use of biomass derived fuels, and eventually electric vehicles could further reduce petroleum demand. Substantial decreases in aviation fuel consumption will have to await improvements in aircraft technology. These changes, along with greater emphasis on conserving energy, would make the state's economy far less vulnerable to disruptions in its petroleum supply than it is now.

METHODOLOGY

The methods and data used to determine energy futures for Hawaii and their impacts on the state's economy are summarized in Figure 1. The Hawaii Energy Demand Forecasting Model (HEDFM) provided energy demand projections by year up to 2005. The HEDFM is a macroeconomic model designed to forecast the annual consumption of seven forms of energy in each of the four counties. It was driven by exogenous projections of demographic and economic variables as well as energy prices. The economic and demographic projections were derived from official state sources. The energy prices used in these forecasts were derived from projections of world oil prices.

Because a wide variety of technologies will become available during the next 25 years, the projected electricity demands could be met in many ways. The technologies will differ in their costs, reliability, the year they first become commercially available, and the amount of electricity they can ultimately supply. The Supply Optimization Model was developed to identify the supply mix that meets the electricity and generating capacity demands at the lowest cost. In addition to determining the supply mix, the model also calculated the electricity prices for each county. In general, these prices were lower than those used in the demand forecasting model. The new prices were fed back into the HEDFM, and a revised set of demand forecasts was obtained. This procedure was repeated until a consistent set of energy demands and prices was found.

The resulting supply scenarios were analyzed for their direct and indirect economic impacts. Direct impacts include the materials, manpower and equipment required to construct, operate and maintain the new energy facilities. Indirect impacts include the income and employment in secondary industries within the state generated by construction expenditures for the new facilities. The Supply Cost Model and the technology characterizations described in Reference 2 were used to calculate the direct impacts in each county. The indirect impacts were estimated for the state as a whole using an input-output model of the state's economy.

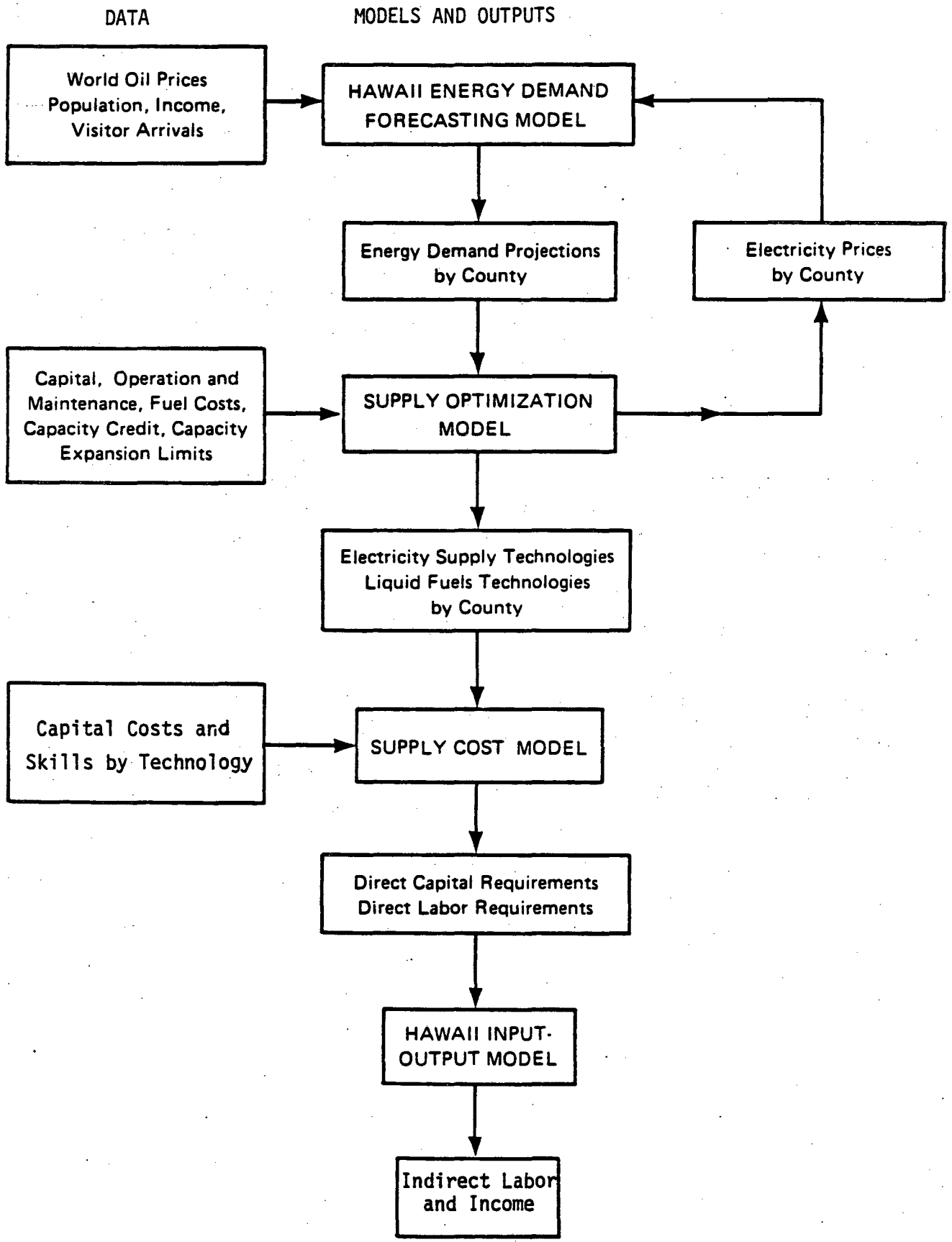

Figure 1. -- Integrated Assesment Methodology

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The Hawaii Demand Forecasting Model*

The HEDFM is an econometric model designed to provide detailed annual consumption forecasts for various fuel types up to the year 2005. The model provided projections of demand for each of the four counties in Hawaii and for the state as a whole. Combining the demand forecasts with supply scenarios furnished by other elements of the integrated assessment permitted quantitative analyses of a range of possible energy futures for Hawaii.

Demand forecasting for the HIEA was performed in two phases. First, a model was constructed to quantify the relationship between the consumption of energy in various forms and the economic and demographic characteristics of the state, such as population, income and prices. The form of the model is based on economic theory, and its structure is determined from historically observed relationships. Once the model was constructed, exogenous projections of the economic and demographic characteristics were used to calculate future energy consumption. During the simulation phase, several forecasts were made to examine the impacts that different economic and demographic futures would have on energy consumption in Hawaii.

Forecasts of consumption were made for seven types of energy use--electricity, gasoline, diesel fuel, residual fuel, aviation fuel, LPG and utility gas--for all four counties. Electricity consumption was broken down into residential and non-residential uses. The forecasts are presented in physical units. Total energy consumption was calculated by converting the physical consumption values of their fossil fuel Btu equivalents and summing. The statewide consumption was calculated by summing the county values.

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*This section is based in part on work performed by Dr. PingSun Leung of the Hawaii Department of Planning and Economic Development.

Structure of the Model

The HEDFM follows a very widely used dynamic flow adjustment model structure [4-8]. Its general form can best be represented by the following two equations:

$$D_t^* = F(X_t) \tag{1}$$

$$D_t - D_{t-1} = k\,(D_t^* - D_{t-1}), \qquad 0 < k < 1 \tag{2}$$

where

D_t^* = desired or equilibrium demand for a given energy product

D_t = actual demand for a given energy product

X_t = vector of variables affecting demand (e.g., prices, income outputs, climate and population)

k = adjustment coefficient

t = current period

The first equation simply defines the desired or equilibrium demand in a static environment. It is assumed here that consumers partially adjust to the equilibrium demand according to equation (2). The adjustment would probably be partial because of some frictions such as inertia or lack of information. In the case of energy demand, this lagged adjustment of actual demand to desired demand could be the result of two factors: 1) the existing stock of energy consuming devices that cannot be replaced immediately; and/or 2) the unwillingness of consumers to view the changes as permanent until they have continued for some time.

The adjustment coefficient k measures the proportion by which the difference between the equilibrium demand D_t^* and the realized value D_{t-1} is reduced during period t. The adjustment is total when k = 1 or $D_t^* = D_t$. The smaller k is, the smaller the adjustment. By replacing X_t in equation (1) with specific variables, equation (1) can be expressed using a log-linear relationship as:

$$\ln D_t = \ln kB_0 + kB_1 \ln Y_t + kB_2 \ln P_t + (1-k) \ln D_{t-1} + k \ln E_t \quad (3)$$

where

D_t = actual per capita demand for a given energy product

Y_t = real per capita personal income

P_t = real energy price

E_t = random disturbance

B_0, B_1, B_2 = constants

The advantage of using the log-linear form is that the coefficients of the independent variables provide direct estimates of elasticities. In equation (3), B_1 and kB_1 are the long-run and short-run income elasticities while B_2 and kB_2 are the long-run and short-run price elasticities. Economic theory also tells us that $kB_2 < 0$ and $kB_1 > 0$ because demand for energy is inversely related to price (hence, $kB_2 < 0$) and directly related to income (hence $kB_1 > 0$). It should be noted that underlying this log-linear form is the assumption of constant elasticity, i.e., the response of energy demand to a small percentage change in each of the independent variables is the same regardless of their levels. The assumption may be invalid when there are very wide variations in the independent variables.

The HEDFM Data Base

The data used in developing the model came from a number of sources. Consumption and prices of electricity and utility gas were obtained from the Public Utility Division of the Hawaii State Department of Regulatory Agencies. Data on liquid fuel use were obtained primarily from the Hawaii State Department of Taxation. There is no readily available source of residual fuel consumption besides that used for utility electricity generation. The detailed historical data are reported in Volume 4 of Reference 2, "Hawaii Energy Data Base".

Consumption data were converted to a common unit, the British Thermal Unit (Btu) for ease of comparison. Figures 2 and 3 present the total energy uses by county from 1963 through 1977. Table 1 shows the energy use by fuel type for each of the four counties and the state as a whole. Aviation fuel includes jet fuel and aviation gasoline. Gas includes utility gas and LPG. Data on diesel and residual fuel in Table 1 exclude that used for generating electricity. Also, the historical figures on residual fuel consumption other than for electricity generation were estimated.

TABLE 1.

Statewide Energy Consumption by Fuel Type: 1963 to 1977
[Trillions of Btus]

Year	Total	Aviation Fuel	Gasoline	Electricity	Gas	Diesel Fuel	Residual Fuel
1963	77.7	16.6	19.0	23.2	3.1	5.3	10.2
1964	86.2	20.5	20.1	25.5	3.2	6.0	10.9
1965	93.2	24.3	21.2	27.3	3.3	6.0	11.0
1966	107.8	34.6	22.2	29.4	3.5	6.2	11.8
1967	123.0	45.4	23.6	31.6	3.7	6.3	12.4
1968	133.2	50.2	24.7	34.7	3.9	6.6	13.1
1969	154.0	62.2	27.9	38.2	4.2	7.8	13.7
1970	159.9	60.2	29.5	41.9	4.5	8.8	14.4
1971	171.9	66.1	31.3	46.5	4.8	8.8	14.4
1972	179.7	65.8	33.2	50.9	5.1	9.8	14.7
1973	190.4	69.1	35.2	54.3	5.4	11.0	15.5
1974	184.4	62.6	33.8	56.1	5.5	10.8	15.6
1975	188.5	62.4	35.6	59.5	5.6	9.8	15.6
1976	193.1	61.7	37.0	62.6	5.6	10.4	15.8
1977	200.4	63.8	39.0	65.0	5.6	10.7	16.2

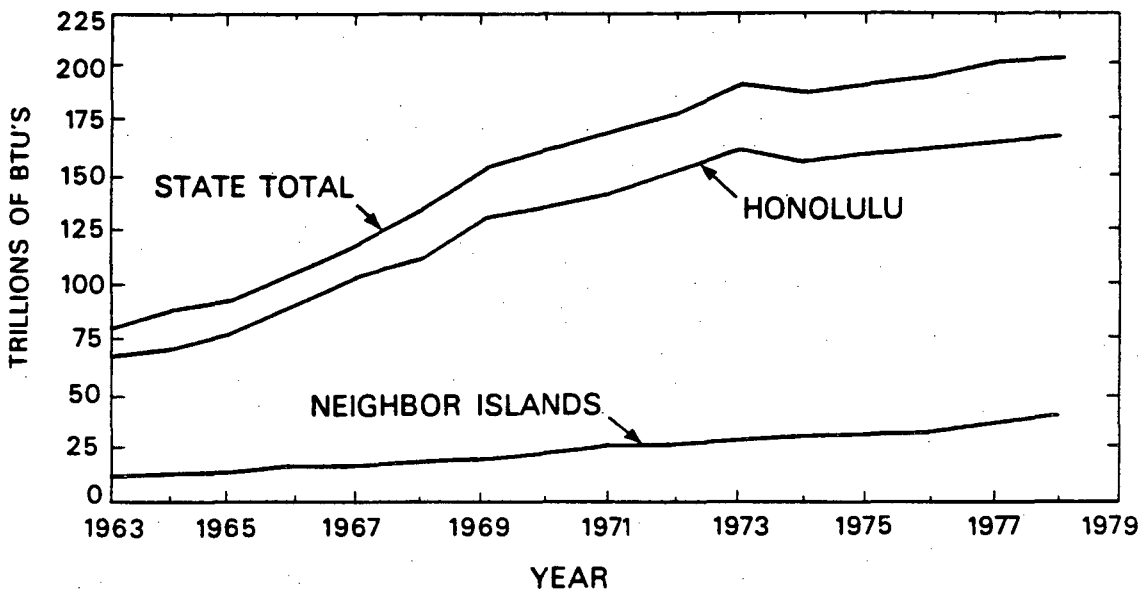


Figure 2. -- Total Energy Consumption, Honolulu vs. Neighbor Islands: 1963 to 1979

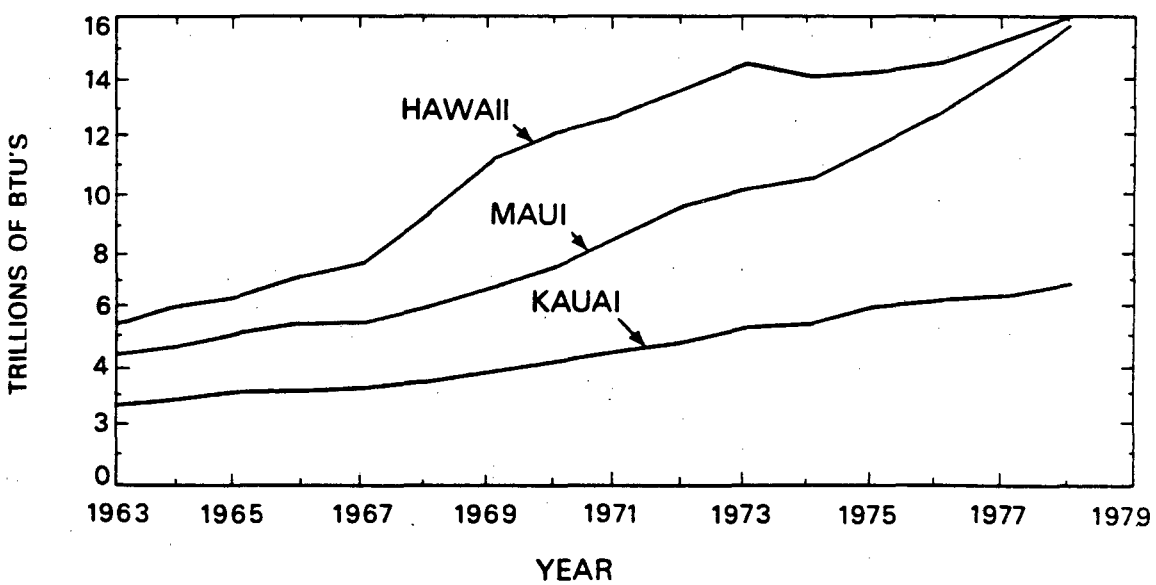


Figure 3. -- Total Energy Consumption, Neighbor Islands: 1963 to 1979

Empirical results of the HEDFM

Two models--an individual county model and a pooled time-series and cross-sectional model--were used to investigate demand for each energy category except for residual and aviation fuels. Consumption data for the fifteen year period 1963 to 1977 (in physical units) were used in estimating the demand equations for the individual fuels. The equations for the county models were estimated using ordinary least squares within the single equation dynamic flow adjustment framework discussed previously. The pooled time-series and cross-sectional models were estimated using ordinary least squares with cross-sectional dummy variables within the same dynamic flow adjustment framework. By using dummy variables, this model assumes the same response for all counties to income and prices, but allows for differences between counties which are not explicitly included in the model.

Most of the estimated demand equations were well fitted with an R^2 of 0.80 or higher. Except for aviation fuel, none of the equations had serial correlation problems as indicated by the Durbin-Watson statistics. Also, most of the elasticity estimates fell within the ranges indicated by other studies [9]. Other than for the aviation fuel demand equations, which depended mainly on visitor arrivals, the equations tell us that price is an important factor in the demand for energy. Forecasting by extrapolating past trends of energy consumption would be misleading without considering this important factor because of the past history of declining prices.

The demand elasticities summarized in Table 2 indicate that the short-term price elasticities for electricity, gasoline and diesel fuel are fairly small. The long-term elasticities are substantially higher as would be expected from the slow turnover in appliances and automobiles. This means that over the long run, price will have an important effect on reducing consumption levels in Hawaii. The long-term price elasticity for residential electricity is larger than for non-residential. Increasing the price, therefore, would be a less useful tool for decreasing non-residential consumption than for residential.

TABLE 2. -- Demand Elasticities

Sector	Short Term Price	Short Term Income	Lagged	Long Term Price	Long Term Income
Residential electricity	-0.103	0.101	0.888	-0.920	0.902
Non-residential electricity	-0.162	.619	.724	-0.587	2.243
Total gasoline sales	-0.155	.230	.642	-0.433	0.642
Total diesel fuel	-0.201	.525	.609	-0.514	1.343

Forecasting Energy Demand

The choice of a particular empirical equation for forecasting depends on three types of criteria: economic, statistical and predictive. The economic criteria require that the signs and magnitudes of the estimates have to be conformable to economic theory (or to the theoretical specification of the model). Whenever this economic criteria was violated, the equation was considered to be misspecified and hence rejected. The statistical criteria pertain primarily to the goodness-of-fit and the significance of the estimates. The goodness-of-fit is measured by the coefficient of determination, R^2, and the significance of an individual estimate is measured by the respective t-statistic. In addition, multi-colinearity and serial correlation problems are also detected in the course of estimation. The economic and statistical criteria provide the base for selecting the appropriate equations. These equations were then put to test for their predictive behavior. Equations with unexpected patterns of predictive behavior were discarded and replaced. This was done entirely in a subjective manner.

The pooled cross-sectional time-series equations were used in forecasting residential and non-residential electricity sales, total gasoline sales and non-electric diesel fuel use. Aviation fuel was forecast with a model that was linear in visitor arrivals and passenger load factor. The demand for utility gas was assumed to remain constant [10]. The data on price and consumption of LPG and non-electric residual oil were not good enough for statistical analysis. For forecasting purposes a simple growth model in proportion to the change in real personal

income was used. The latter three fuels amounted to only about ten percent of the total state energy consumption in 1977.

The projections of economic and demographic variables used in the forecasts were adopted from the Hawaii Macroeconometric Model [3]. This model of the state's economy, constructed by the Hawaii Department of Planning and Economic Development, was run to produce several forecasts based on different assumptions concerning the growth in the economy. It forecasts population, civilian jobs, and personal income for each of the counties and visitor arrivals for the state. Their "most likely" scenario was selected to drive the demand forecasting model. As shown in Table 3, this scenario shows state population increasing from 970,000 in 1977 to 1,475,000 in 2005. Visitor arrivals nearly double over the same period, while per capita income increases by 70 percent, taking inflation into account. The largest percentage increase in population and income in the scenario occurs in Maui County.

TABLE 3. -- Economic and Demographic Forecasts

Year	De Facto Population (Thousands)	Total Personal Income (Millions of 1967 dollars)	Per Capita Personal Income (1967 dollars)	Visitor Arrivals (Thousands)
1977	973	3,975	4,505	3,434
1980	1,032	4,381	4,770	4,133
1985	1,133	5,368	5,386	5,275
1990	1,230	6,304	5,911	6,418
1995	1,325	7,403	6,504	7,440
2000	1,395	8,504	7,088	7,820
2005	1,475	9,768	7,716	8,219

Source: Hawaii Econometric Model Simulation, 1977. See Reference 3.

Fuel and electricity prices for the demand forecasts were derived from projections of world oil prices. Actual oil prices in constant dollars for the period 1977 to 1980 were used. Starting with $30 per barrel in 1980, oil prices were escalated at three percent per year in the Baseline Case. This rate of increase gave prices close to those projected by the Energy Information Administration in its high price forecast [11]

It was assumed that liquid fuel prices would increase at the same rate as the world oil price. Moreover, these prices were assumed to be the same in all four counties. Separate projections of residential and non-residential electricity rates were made for each of the counties. These were based on the historical relationship between electricity rates and world oil price derived from the 1963 to 1977 data. The model also has a provision for using other projections of electricity rates. This is especially important if much of Hawaii's electricity comes from alternative sources in the future, in which case generating costs would be freed from oil prices.

Demand Reduction Through Conservation and Improved Efficiency

The relationships in the HEDFM were derived from historical data for the years 1963 to 1977. Thus any projections based on this model assume that the relationships that were valid during this period will still hold in the future. Because of the recent sharp increases in world oil price as well as mandated and proposed energy efficiency standards for automobiles, buildings and appliances, it is unlikely that historical consumption patterns will continue.

To account for anticipated changes in energy consumption, we have introduced ad hoc demand reduction factors in the forecasting model. These factors represent the percentage reduction in consumption for various end-uses brought about by improved efficiencies and conservation measures. They were applied to the projections of gasoline and electricity consumption to reduce the projected levels of consumption. The factors were based on demographic changes, mandated automobile mileage standards, appliance efficiency improvements, and behavioral changes in response to price increases or exhortations to conserve energy. Some of them differ from island to island. (See Volume I, Chapter 3 of Reference 2, "Issues in Energy Use and Conservation in Hawaii").

The reduction factors for gasoline consumption were derived from estimates of the national average automobile fleet fuel efficiency. These estimates, which were obtained from the Department of Energy, were based on the mandated automobile mileage standards in the Energy Policy

and Conservation Act of 1975. They are shown in Table 4. We assumed that the same percentage improvement in efficiency will prevail for each of the counties. The annual gasoline consumption figures projected by the model were reduced by these factors to give the revised consumption forecast.

TABLE 4. -- National Average Automobile Fleet Fuel Efficiency

Year	Miles per Gallon	Percentage Change from 1978
1978	13.10	
1980	14.26	8.85
1985	17.66	34.81
1990	19.79	51.07
1995	20.49	56.41
2000	20.90	59.54
2005	21.11	61.15

To estimate the reductions in electricity consumption, the econometric forecasts for the residential and non-residential sectors in each county were disaggregated by end-use. The proportions used for disaggregating come from utility data for 1977. Major end-use categories are water heating, cooking, refrigeration, lighting, and clothes drying. For each end-use and year these factors were applied to the projections, and the resulting consumption figures were summed to give the residential and non-residential totals. These savings were assumed to occur only in Future 2; they have not been incorporated in the results for Future 1 presented in this paper.

Supply Optimization Model

In investigating alternative energy futures for Hawaii, we have to consider the two major forms in which energy is consumed -- electricity and liquid fuels for transportation. The HEDFM described in the previous section projected the demand for fuels and electricity to the year 2005. In this section we describe the Supply Optimization Model used to

select from among many competing technologies the mix of energy facilities that would meet the projected demands at the least cost.

The analysis of Hawaii's transportation fuel supply is fairly simple because there are few alternatives. There appears to be no replacement for aviation fuel during the next twenty-five years. Alcohol from indigenous biomass could substitute for or supplement gasoline used for transportation. Apart from electric vehicles, there are no other near-term substitutes for gasoline. We assumed that alcohol would replace up to ten percent of projected gasoline consumption, limited only by the forecast production of alcohol.

Electricity generation is much more complex because of the wide variety of technologies presently available or under development. Steam, hydroelectric, gas turbines and internal combustion engines are currently used in Hawaii. Steam generators burn oil or an oil-bagasse mixture, whereas gas turbines and internal combustion engines burn diesel fuel. On Oahu there are plans to supplement these by municipal solid waste (MSW) incineration within the next five years.

Several renewable technologies have the potential to contribute significantly to electricity generation. Wind, geothermal energy, ocean thermal (OTEC), solar thermal (STEC), and photovoltaics (PV) can all be used to generate electricity. Hydroelectric and pumped storage also have a limited potential in Hawaii.

Due to the nature of their resources, geothermal and ocean thermal energy are available continuously and hence are highly reliable. These technologies are suited primarily for baseload electricity generation. It was assumed that solar thermal power plants would include a thermal storage system. This would permit extended use of stored solar energy for generating electricity at night. The solar thermal plant could then provide electricity to meet either base or intermediate loads. No storage was assumed for the photovoltaic system; it can be used to meet intermediate electric loads during the day only. Wind is essentially an unreliable resource; severe fluctuations have been observed at a given site from season to season and year to year. From a generation standpoint, this resource can be harnessed only if the electricity can be

stored or if backup capacity is available. In Hawaii, oil- and biomass-fired capacity can backup wind generation.

A supply forecast could, to some extent, include all of these technologies. Several criteria may be used to decide on the appropriate mix of technologies for each supply projection. The cost and reliability of the energy supply system are usually major considerations. Other criteria include environmental, health and social impacts.

In this analysis, economic optimality was chosen as the major objective in deciding the mix of generating technologies. The analysis attempts to express all other significant criteria through economic means. Of course, this introduces subjective biases, but it also provides a common measure for evaluating all the technologies that form part of the supply system. Reliability considerations were incorporated by allowing for a reserve margin. During the discussion of the futures, specific assumptions which have strongly influenced the results will be noted.

The mix of future technologies was selected with the aid of a linear programming (LP) model. This technique aided in selecting the optimal mix of technologies subject to several constraints. The Supply Optimization Model was run for five five-year time periods starting with the mix of generating capacity in place in 1980. The optimal mix of technologies was found separately for each county.

Structure of the Model

The objective and the constraints are expressed in a mathematically linear form. The objective was to minimize the sum of the levelized capital costs and the operation, maintenance and fuel costs for each technology. The levelized cost was calculated by averaging the capital cost and the fixed charge rate allowed for amortizing the capital investment over the life of each plant. The fixed charge rate in our formulation was dependent on the taxable life of each plant, the cost of capital, and the tax rate. Since the cost of capital changes with time, it was important that the proper time horizon be used for calculating

the cost of plants coming on-line during different time periods. The following values were used:

Taxable life	20 years
Cost of capital	13 percent
Tax rate	40 percent
Investment tax credit	0 percent
Other taxes	2 percent
Insurance	0.25 percent

The fixed charge rate amounts to 0.226 using these values for the variables. The cost of capital is expressed in constant 1980 dollars.

Each technology will operate jointly and singly under various constraints. The constraints ensure that an adequate amount of energy will be available to meet the base, intermediate and peak components of demand. Base period lasts a full 24 hours a day, intermediate varies from 15 to 17 hours a day, depending on the county, and peak varies from two to three hours a day. Peak demand in Hawaii generally occurs around 7 PM, after the sun has set, so that solar energy is not directly available during the peak hours. Another constraint ensures that sufficient capacity would be available to meet peak power demand during the day. The peak demand in each county was derived from the electricity demand and the utilities' projections of the ratio of peak power to electricity sales. A reserve margin of at least twenty percent was required.

The amount of energy that can be generated from a power plant depends on the plant availability and on the availability of the resource. Resource availability for wind is limited compared with OTEC or geothermal power plants. We limit the total generation from each type of power plant. Since the availability of a power plant depends on the number of hours it is in service per day, we constrain the total capacity of each type of plant available to meet the base, intermediate and peak demand.

The total capacity required to meet base, intermediate and peak loads is also constrained. These constraints ensure that sufficient generating capacity of the right type is available to meet the prescribed demands. Wind, as mentioned earlier, is an unreliable source of energy. It would be prudent to ensure that the system reliability is not affected beyond critical limits when wind generation is introduced. Studies have shown that this limit is reached when wind generation approaches twenty percent of the installed capacity [12], hence we limit wind capacity to at most twenty percent of the peak demand.

The total capacity of each type of generating unit is limited by other factors than costs. The amount of energy that can be generated from a power plant depends on plant and resource availability. For example, resource availability for wind is limited compared to OTEC or geothermal power plants. In addition, most of the renewable technologies are not yet available commercially, and their rapid introduction will not and should not be attempted under normal circumstances until the technologies are proven.

Several timetables were constructed to show the limits to which each technology may be exploited over the next 25 years. From this range of possibilities, one set was selected to establish the limits to which technologies may be developed in each time period. These limits, in turn, constrain the amount of base, intermediate and peak energy that can be generated by each technology.

A utility's ability to raise capital depends to a large extent on its current assets. One frequently noted problem is the high capital burden which utilities will face in introducing alternative technologies. Hence we limit the utilities' ability to borrow net capital to a fixed fraction of its existing assets.

It was assumed that the OTEC plant included in the Matsunaga bill will be built off Oahu, and that there will be an MSW plant using municipal solid waste from Honolulu, along with some bagasse from sugar plantations. We force the model to construct a 40 MW plant OTEC plant and a 45 MW MSW plant.

Supply-Demand Integration

The linear program was used to select the optimal mix of technologies for each county that was required to meet the forecast demand in each energy future. Average electricity costs were determined at five-year intervals from 1980 to 2005. Average electricity costs are a function of the levelized capital costs, the operation and maintenance costs, and the fuel costs assumed for each technology. These costs can be very different from the prices used in the demand model, which were derived from projections of world oil prices. The average electricity costs (a measure of electricity prices) estimated in the Supply Optimization Model were determined by both world oil prices and the costs of renewables. Generally, these were lower than were average electricity prices based on world oil prices alone. When these lower prices were introduced into the demand model, the demand for electricity was higher than originally projected.

Since costs and prices were based on different assumptions, they are not identical. The prices in the HEDFM were modified so that their rate of change corresponded to the cost changes calculated by the supply model. The demand for electricity was estimated again on the basis of these new prices. The Supply Optimization Model was then used to calculate the new supply mix and average costs. When necessary, the whole process was iterated until the average costs between successive iterations showed no significant difference.

Economic Impacts

For each future the demand and supply models provided the mix of generating technologies and the amount of liquid fuels necessary for transportation, heating, and electricity generation. To calculate the direct economic impacts associated with the energy futures, capital costs and operation and maintenance costs were estimated for each technology using the Supply Cost Model. These costs were broken down into manpower, materials, equipment and other components. Labor and capital

costs are given in detail in Volume III of Reference 2.

A key assumption in the analysis was that new energy technologies have declining costs. The first few renewable power plants will be prototypes of commercial plants to come on line later. Prototype plants can cost as much as ten times more than a commercial plant of the same size. Plant costs usually decline because of improved management, more efficient construction practices, competitive bidding on the part of suppliers, mass production of components, and more efficient use of materials. However, costs might increase as a result of unforeseen circumstances, stricter health and safety requirements or environmental regulations, and more expensive on-site resources of land, water and labor. It was assumed that for renewable technologies, since they are relatively benign, unit costs will decline over the next 25 years. The decline was assumed to be fairly rapid during the first 10 to 15 years as the first plants are commercialized, after which it slows down as unit costs stabilize. Costs of conventional generating technologies such as oil- and coal-fired steam generation were assumed to remain constant. All costs were expressed in constant 1980 dollars.

The manpower, materials and equipment components of capital costs will all decline, but probably not at the same rate. The costs of on-site materials, as opposed to manufactured equipment, will not decline as rapidly as on-site labor and equipment costs because there will be greater scope for improving labor productivity than for lowering materials costs. Equipment costs may decline because of improved manufacturing techniques and because of competition from other manufacturers.

Learning curves showing the decline in costs for each component are difficult to estimate. Historical records for similar products provide some clue, but these are usually complicated by other factors whose influence on costs is difficult to isolate. In this analysis, it is assumed that labor and equipment costs will decline at twice the rate at which materials costs change, limited by the assumed decline in total costs.

The direct costs and labor requirements for the technologies in each future were computed on the basis of these assumed unit costs. The materials and equipment costs were disaggregated by industrial sector. The detailed cost breakdown was formulated on the basis of data from the Energy Supply Planning Model [13], and the Technology Assessment of Solar Energy Systems [14]. The lead time required for construction and the scheduling of resource acquisition during construction were also considered to provide an annual breakdown of capital and labor requirements. This breakdown of capital requirements was used for estimating the indirect impacts.

The indirect employment and income were estimated using an input-output (I-O) model of the Hawaiian economy specifically designed for the purpose (see Volume III, Part III of Reference 2). The core of the model is an input-output table constructed by the Hawaii Department of Planning and Economic Development which describes the structure of the state economy during 1977. HDPED developed tables for each of the four counties by updating earlier tables [15]. Special attention was paid to the petroleum importing and refining sectors as well as to electric and gas utilities in order to exhibit the energy flows within the state. HDPED circulated preliminary versions of the I-O tables to the counties for comments. After revision, the county tables were combined to form the state table. HDPED also made estimates of employment in each industry.

The starting point for calculating indirect impacts was the expenditure for the materials, equipment and manpower used in constructing the new power plants and other energy facilities. The Supply Cost Model provided a detailed breakdown of the annual materials and equipment costs by industrial sector, as well as the annual manpower costs. The latter, which represent the income to the construction workers, were assumed to be spent in the same way as household expenditures were during 1977. The next step was to estimate what fraction of the purchases in each sector was produced in Hawaii and what fraction was imported. The input-output model and estimates of the purchases of locally produced commodities were then used to calculate the increase in industrial activity needed to furnish these commodities. Finally, from the

industrial activity an estimate was made of the annual income and employment generated in each industry.

Assumptions and Limitations

The basic assumption in using the Demand Forecasting Model was that energy consumers will respond to future changes in price and income in the same way they did in the past. This does not mean that past consumption trends will continue, only that consumers' behavior will remain constant. It was therefore assumed that no major technological or structural changes in the economy that would affect energy consumption patterns would occur. In particular, the widespread use of vehicles powered by electricity or synthetic fuels was not envisioned.

We have assumed that the shape of the electricity load curve would not change. Utility load management schemes may reduce the peak to base ratio, thus reducing the need for expensive peaking equipment. Cogeneration of electricity, if practiced by local commercial and industrial establishments, could also reduce the demand for new power generation facilities.

Also implicit in our demand forecasts is that fuel and electricity prices are directly related to world oil price. If renewable resources in Hawaii were to furnish a major part of the energy, this would no longer be true. By feeding the electricity prices calculated by the Supply Optimization Model back into the Demand Forecasting Model, we were able to determine a consistent set of prices, demand levels and supply technologies.

The Supply Optimization Model, by using a linear program formulation, contained many of the assumptions and limitations inherent in this method. A major assumption was that costs are proportional to generating capacity or to the amount of electricity generated. For many of the technologies, generating units are built in standard sizes, and unit costs decrease as more units are installed. Unit costs may start increasing when the most favorable sites have been used.

A second set of assumptions that influenced the supply mix forecast involved the costs and commercialization schedules for the renewable technologies. Because most of these technologies are still in the prototype stage, the figures used were the best estimates within the range over which experts differ. In addition, calculating costs required making several assumptions regarding the taxable life of each type of plant, the cost of capital, and the tax rates over the next quarter century.

Building an interisland transmission cable system will be a crucial step in Hawaii's progress towards greater reliance on renewables. The major resource for which technology is already commercialized, geothermal energy, is available on the Big Island. In the long run, this resource may be sufficiently large to meet the entire baseload demand on Hawaii, Oahu and Maui. Development of geothermal energy can be promoted only if transmission cables link it with major demand centers in Oahu and in Maui. Because of the critical nature of the cable, it was assumed that enough resources would birected toward overcoming the technical barriers to enable such a cable system to be built by the mid-1990s. Geothermal energy could then be shared by Hawaii, Maui and Oahu. Since the Big Island can use geothermal energy without the cable system, and hence at presumably cheaper rates, we assumed that geothermal energy would be available first to Hawaii to meet its projected baseload demand. The remaining energy was allocated to Maui and Oahu in proportion to their baseload demands.

It is characteristic of linear programs that they find extreme solutions. If, for example, two technologies differ only in that one is slightly less expensive than the other, then the solution would show the first used to the maximum extent while the second may not be used at all. These limitations were overcome by setting an upper limit on the development of each technology.

The input-output model used for estimating indirect economic impacts presented a static picture of the Hawaiian economy. It could not take into account structural changes in the economy such as new industries moving into the state or existing industries changing their process or

product mix. This effect could be significant during the next 25 years if new industries are attracted by the lower prices of electricity generated from renewable resources. The change would then take the direction of greater income and employment than was estimated.

ANALYSIS OF AN ENERGY FUTURE

We used the models described in the previous section to examine three energy futures for Hawaii. Oil price increased at a rate of three percent per year in Future 1 and Future 2, the base and savings cases, and at a rate of ten percent per year in Future 3 the high oil price case. The second future incorporates energy conservation above and beyond the levels assumed in the base case. Demand for energy in both the high oil price and savings case was, consequently, lower than in the base case. In this paper we will discuss primarily Future 1. At the end of this section there is a brief comparison of the supply mixes for the three futures.

The energy demand and supply alternatives which form the basic description of each future were derived from a large number of factors in addition to the oil price. These describe the characteristics of the Islands and of the technologies which would supply energy in its various end-use forms. Some of these factors, shown in Table 5, were assumed to be the same in all three futures. Others, such as population, income and visitor arrivals, that have a strong influence on energy demand projections were held constant. The capital costs, operation and maintenance costs, and limits on capacity expansion were also the same in all three futures.

The capital costs of all technologies would probably be affected by changes in oil prices. Directly and indirectly, oil forms between five and ten percent of the total inputs in constructing a facility. The costs of construction would increase, albeit at a slower rate than the price of oil. Unfortunately, there was no easy way to estimate this increase since substitution for oil would play a role in keeping the costs down. A reasonable assumption would be that capital costs of all technologies would change in the same proportion, so that the relative advantage enjoyed by any given technology does not change. It was assumed that capital costs do not change because in this analysis the marginal increase in absolute costs was less important than the comparative costs.

The technologies included in our analysis and their capital costs are shown in Table 5. Capital costs of conventional technologies were assumed to remain constant over the next twenty-five years, while those of unconventional technologies were assumed to decline for reasons discussed previously.

The costs shown for 1980 reflect the cost of old power plants already on line, or they reflect the capital cost after depreciation for existing plants. A cost of $65/KW was used for old oil plants based on data in HECO's annual report [16]. An analysis of utility finances would be necessary for a better estimate of average plant costs. The costs of geothermal plants included the cost of a cable from Hawaii to Oahu and Maui, hence they were lower by $800/KW on the Big Island.

The costs assumed for renewables are generally on the conservative side. Photovoltaic costs, for example, are twice as high as the goals set by DOE [17].

For fossil fuel plants, operating and maintenance costs ranged from 9 mills/KWh for oil-fired steam plants to 15 mills/KWh for diesel peaking units. For renewables, they ranged from 5 mills/KWh for OTEC to 2 mills/KWh for other technologies. Costs for diesel fuel were assumed to be 15 percent higher than for residual oil. Coal was assumed to cost 38 percent more than oil per Btu, based on a comparison of the estimated prices of delivered fuel to Hawaii [18].

Under the Public Utility Regulatory Policies Act of 1978 (PURPA), Public Law 95-617, small power producers (less than 80 MW) may sell electricity to a public utility at the avoided cost to the utility. Title II of this act provides small producers certain incentives to generate electricity from biomass, waste and other renewable resources. The utility in turn benefits by not having to bear the risk of developing an unproven technology. Because the utility must pay the avoided costs rather than the production costs, the price of electricity to the consumer may be higher than estimated in out analysis.

TABLE 5. -- Significant Assumptions Common to All Futures

	1980[a]	1985	1990	1995	2000	2005
Population Projections (1000s of Persons)						
Honolulu	805	866	917	965	996	1031
Maui	81	101	121	143	163	184
Hawaii	101	116	132	147	158	170
Kauai	43	49	58	68	77	87
State Total	1031	1033	1229	1325	1395	1474
Per capita personal income (1967 $)						
Honolulu	4842	5469	6032	6698	7384	8149
Maui	5276	6108	6680	7131	7460	7755
Hawaii	3940	4334	4673	5061	5445	5848
Kauai	4301	4785	4979	5168	5284	5383
State Total	4769	5385	5910	6503	7087	7715
State Visitor Arrivals (1000s of Persons)	4133	5275	6418	7440	7820	8219
Capital costs (1980 $/KW)						
Wind	2500	1500	1000	700	700	700
OTEC	8000	8000	8000	4000	2600	2600
Geothermal[b]	3000	2800	2000	2000	2000	2000
Solar Thermal	3000	3000	2500	2500	2000	2000
Photovoltaic	18000	8000	3000	2500	2000	2000
MSW	2222	2222	2222	2222	2222	2222
Oil	65	800	800	800	800	800
Oil-Bagasse	800	800	800	800	800	800
Diesel Base	400	650	650	650	650	650
Diesel Peak	300	500	500	500	500	500
Gas Turbine	200	400	400	400	400	400
Hydropower	50	800	800	800	800	800
Coal	2000	2000	2000	2000	2000	2000

[a]The figures for 1980 are estimates, not actual data

[b]On the Big Island, geothermal plants will cost $800 less per KW. This is the cost assumed for the interisland cable

Our analysis shows that indigenous technologies would not begin to penetrate the state's electricity supply system until the 1990s, by which time they would be considered proven. The increased costs to the utility would primarily affect electricity prices and only secondarily the type of technology used. Higher electricity prices imply lower demand, and therefore slightly less new generating capacity would be required.

The limits to which each resource may be exploited in each year were based on general knowledge of the resource, availability of potential sites, the rate at which each technology may be developed, and general social and political considerations. The limits on geothermal energy were based on a USGS report [19] which estimates the potential resource around the Puna Well at about 250 MW. It was estimated that the area of geothermal activity along the Kilauea Lower East Rift is four times as large and thus could yield up to 900 MW. This figure is smaller than another estimate of 1600 MW made by HDPED [20].

Wind generation was limited to twenty percent of total installed capacity or to the resource limit of 432 MW on Oahu, whichever is smaller. The twenty percent figure was based on studies which limit the maximum generation because of load matching considerations [12]. The 432 MW limit was based on choice sites in Oahu [21].

The limits on OTEC, STEC and photovoltaics (440 MW, 180 MW, and 116 MW, respectively, in 2005) were based on rates at which technologies might be commercialized. There were no limits placed on the addition of conventional fossil-fired generators other than those dictated by the system load configuration.

Energy Supply and Demand in Future 1

This future presents the energy demand and supply forecasts for each county and the state as a whole based on a three percent per year growth in world oil price. This future was regarded as a "baseline" future of which the other energy futures may be considered variants. The discussion of the salient points of this future includes an analysis of the

energy demands and their dependence on world oil price and on electricity prices, the least-cost mix of supply alternatives, and the capital and labor constraints on the development of renewable resources to the required levels. The demands for Future 1 are shown in Table 6.

Energy Demand

In Future 1, the demand for electricity in the state and in Honolulu County would almost triple during the next twenty-five years. Electricity demands in the other counties would increase even more rapidly, reaching four to five times their current values by 2005. In all counties, the demand in this future grows most rapidly during the 1995 to 2005 decade. Demand is influenced by electricity prices, which reach a plateau in 1995 as the fraction of electricity supplied by renewables becomes significant. Since electricity prices would no longer depend on ever increasing oil prices, the demand for electricity would increase as prices decline or increase marginally.

The demand for imported petroleum would also reach a peak in 1995, then would decline slightly in 2000 before increasing again in 2005. The non-electric portion of this demand would increase steadily; by 2005 it would be 40 percent higher than its present level. Oil required for electricity generation, however, would peak in 1990 and then decline to its lowest level by 2000. This decline is due to the rapid penetration of the renewables into the electricity supply mix after 1990. Although renewables would continue to increase their share after 2000, the use of oil would also increase because the maximum penetration by renewables is limited to a level insufficient to meet the increasing demand. Over the next twenty-five years, the use of indigenous resources would save the state $8.5 billion that would otherwise be spent on imported petroleum.

TABLE 6. -- Statewide Energy Demand Projections, Future 1
Baseline Case with Interisland Cable
(Trillions of Btus)

	1980[a]	1985	1990	1995	2000	2005
Electricity						
Residual	64.1	71.4	74.0	63.1	25.5	39.9
Diesel	2.4	4.9	6.9	4.6	0.7	1.3
Oil total	66.5	76.3	80.9	67.7	26.2	41.2
Renewables at oil equivalent	9.1	12.2	25.1	63.1	133.2	155.4
Generation (Millions of KWh)	6,780	7,941	9,503	11,728	14,298	17,631
Liquid Fuels						
Gasoline[b]	35.5	25.3	20.5	19.7	19.2	19.3
Residual and Diesel	28.4	32.3	36.9	42.0	46.7	51.9
LPG and Utility Gas	5.8	6.1	6.4	6.9	6.9	7.2
Subtotal	69.7	63.7	63.8	68.4	72.8	78.4
Aviation fuel	69.2	85.2	99.8	112.5	114.3	116.4
Total	138.9	148.9	163.6	180.9	187.1	194.8
Total oil demand	205.4	225.2	244.5	248.6	213.3	236.0
Oil demand without Renewables	205.4	226.7	258.3	294.7	319.6	350.0
World oil price (1980 dollars/barrel)	30	35	40	47	54	63

[a]The figures for 1980 are estimates of demands not actual consumption data.

[b]Alcohol could substitute for at least ten percent of gasoline consumption beyond 1990.

Gasoline consumption declines due to the combined effects of higher prices and mileage standards. Aviation fuel becomes increasingly dominant, its use rising by 68 percent over the next twenty-five years. If the state's projection of annually increasing visitor arrivals prove correct, there is little hope for entirely eliminating petroleum imports since it is unlikely that there will be any substitute for aviation fuel during this time period.

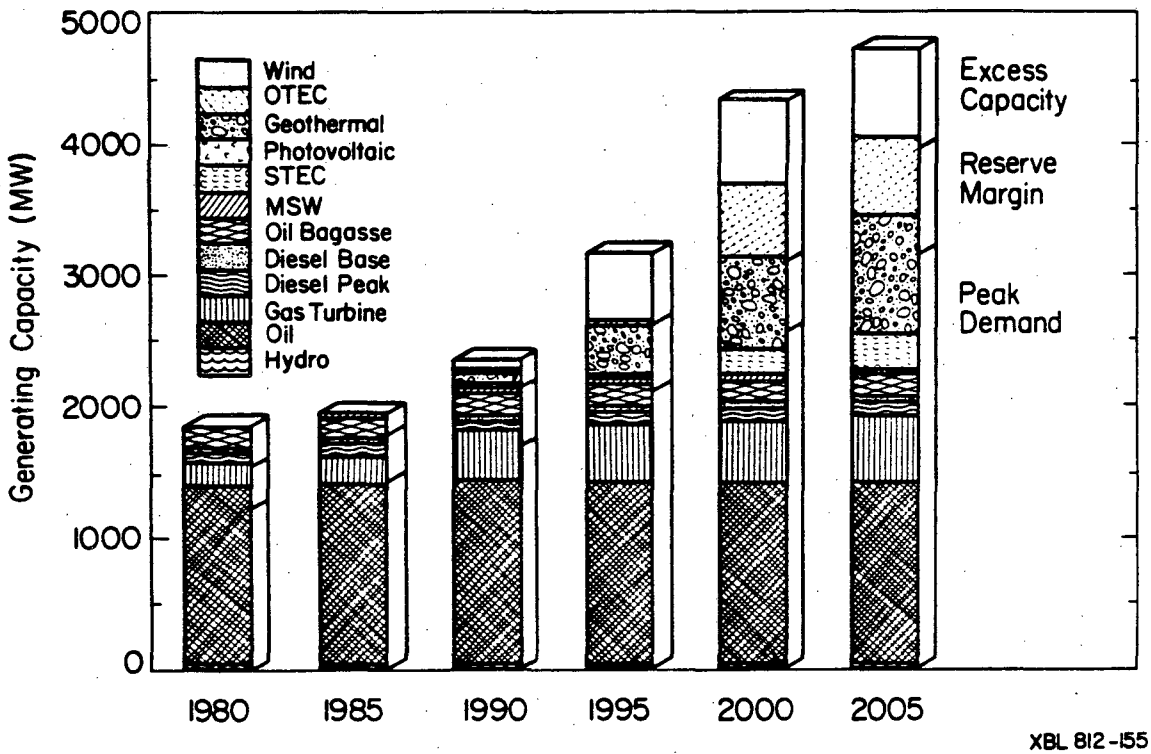
Among the counties, Hawaii County would experience the largest penetration of renewables vis-a-vis oil for electricity generation, followed by Kauai, Mauai and Honolulu in that order. On Kauai and Maui, oil use would be seven percent to nine percent of renewables, while for Honolulu County, oil use would drop to 37 percent of renewables. In absolute terms, the largest use of renewables would be on Oahu, followed by Maui, Hawaii and Kauai. The percentage of renewables that could be used for generating electricity depends on the availability of indigenous resources and the demand on them. Since the Neighbor Islands have a much larger proportion of resources compared to demand, a larger fraction of their electricity would come from renewables.

Figures 4 and 5 show the statewide forecast of generating capacity and electricity generated by each type of power plant for the next twenty-five years. The peak loads and reserve margins are indicated on the bars in Figure 4.

Supply Mix

The capacity demand includes a twenty percent reserve margin. It was assumed that all the oil generating capacity existing in 1980 would remain on-line through 2005 to serve as a backup. The proposed 45 MW MSW and 40 MW OTEC plants were included, starting in 1985 and 1990, respectively. Additional generation from OTEC was included when it could compete favorably with the other technologies.

FIGURE 4. -- Hawaii Generating Capacity, 1980-2005: Future 1



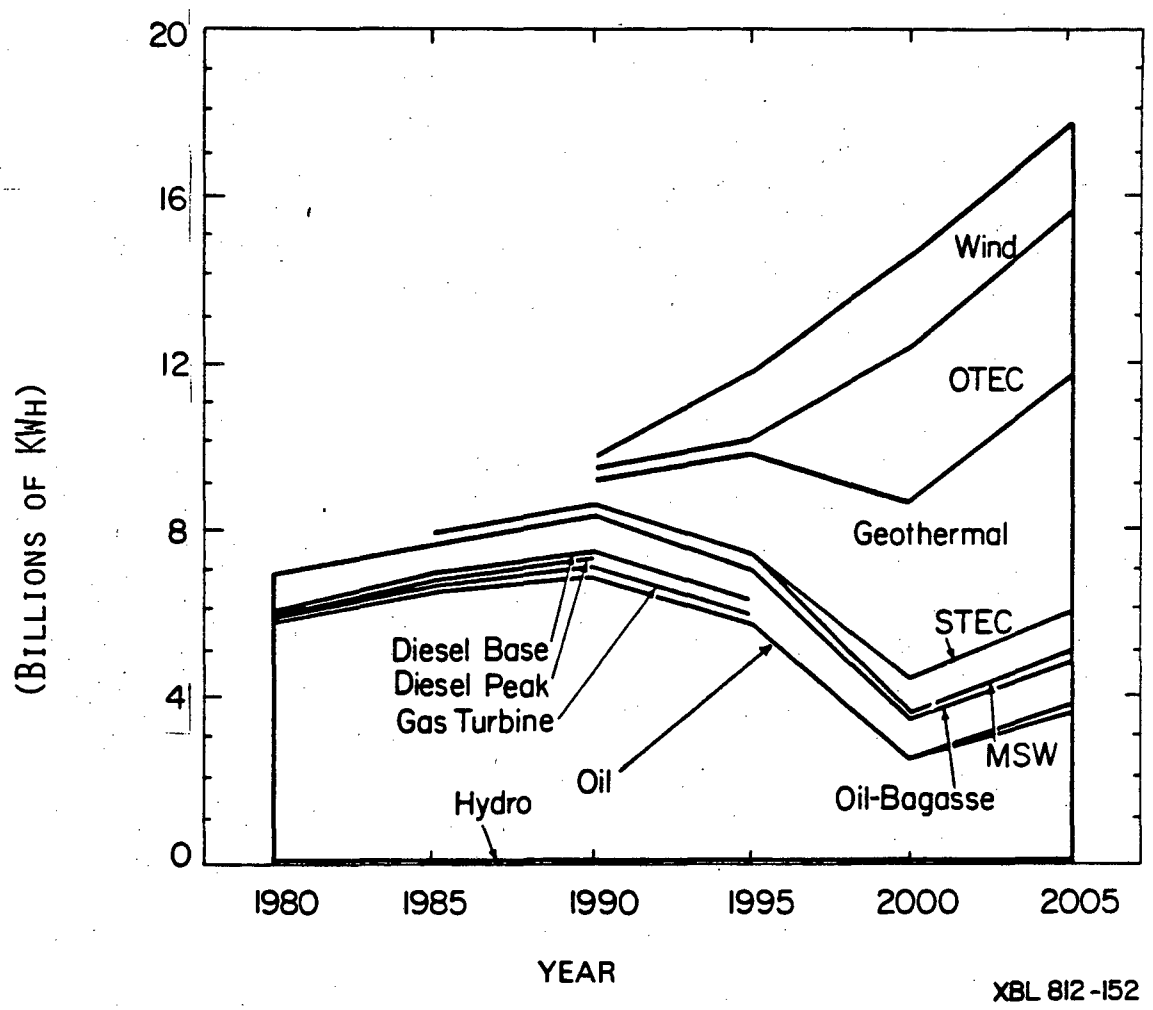


Figure 5. -- Hawaii Electricity Generation, 1980 - 2005: Future 1

Oahu would continue to use its oil-fired power plants for baseload generation until about 1995. As OTEC and geothermal plants come on line via cable for baseload, oil generation would be used mainly for intermediate and peaking loads. At the same time, wind and solar would make major contributions. About 140 MW of gas turbines would be built by 1990 to meet peaking loads. The largest capacity increments would occur between 1995 and 2000, when 830 MW of new wind, solar thermal, OTEC and geothermal (on Hawaii) plants would be constructed.

Because of its rapidly growing electricity demand, Maui County in this future would need additional oil-fired and gas turbine capacity during the next decade. Geothermal and OTEC for baseload, and wind and solar thermal for intermediate load would replace nearly all the oil generation after 1990. By 2005, oil and gas turbines would supply only peaking power, which accounts for less than five percent of the total electricity supply. OTEC and geothermal would supply about 60 percent, while wind and solar thermal would supply about 25 percent. Hydro-power and bagasse would continue at their current levels.

Hawaii County would rely completely on geothermal for baseload electricity. Oil and bagasse would be phased out of base and intermediate load generation and would supply only a small amount of peaking power by 1990. At the same time, wind and solar would be used for intermediate load. A total of 153 MW of geothermal capacity, 80 MW of wind, and 40 MW of solar thermal would be needed by 2005. An additional 774 MW of geothermal capacity would be required to supply the other counties.

Kauai's energy future would be somewhat different from the other counties because the interisland cable would not reach Kauai. Geothermal would therefore not be available, so that OTEC, along with hydroelectric and bagasse, would supply baseload power after 2000. Since Kauai presently has excess capacity, no new power plants would be required before 1995. About 40 MW of OTEC and 30 MW of wind capacity are expected to be constructed between 1995 and 2005.

Electricity Prices

Electricity prices are related to the price of oil and to the cost of generating capacity. As a result, they could be expected to increase rapidly until 1990. As lower cost renewables subsequently become available, prices would decline or show only a slight increase. For Honolulu County, over the next ten years the average electricity price would rise from 86 to 109 mills/KWh, a 27 percent increase. During the following 15 years, prices would increase by only five percent. The lower prices result in a larger demand than originally forecast, assuming that electricity would be generated primarily from oil.

Electricity prices on the Big Island would rise to 91 mills/KWh in 1985, then decline to 77 mills/KWh in 1990, and remain essentially constant thereafter. Rates are lower on the Big Island because a substantial fraction of the electricity would be supplied by geothermal power plants. Since Hawaii would not have to pay for the cost of the interisland cable, electricity would be considerably cheaper there. Kauai and Maui would pay about 25 percent more for electricity than Hawaii.

Economic Impacts

All three futures include renewables to the maximum extent believed feasible, given the economic and technical constraints that are assumed to exist in Hawaii. Because of this, there were no major qualitative differences in the overall economic impacts of the transition to renewables, rather, the differences lay in their timing and magnitude. In terms of the Hawaiian economy as a whole, the direct and indirect income and employment generated by the construction of new facilities would be a few percent of the state totals. The largest impacts would occur on the Big Island because of the anticipated level of geothermal development. Energy development therefore would not be a major direct stimulus to the economy. However, if Hawaii does develop geothermal and renewables to the extent expected, the lower electricity prices could attract new industry and population and thereby generate additional economic

growth. The major obstacle to developing these alternative technologies would be raising the capital needed to construct the required facilities.

Direct Impacts

The direct impacts discussed in this section include the capital and labor required for constructing new power plants. The capacity of each type of power plant in each county was determined by the Supply Optimization Model. The annual capital and labor requirements were estimated by county, using the capital costs of new plants, their construction schedules, and the labor required to construct each type of power plant. Aside from the costs of the interisland transmission cable, no transmission and distribution (T&D) costs were explicitly included. At times, T&D costs can be a substantial fraction of total capital costs. The uncertainty regarding the costs and locations of renewable technologies is extremely large. The cost assumptions shown in Table 2 were on the conservative side, and thus can be viewed as including the T&D costs.

In the first future, capital costs and labor requirements follow the amount of renewables used. They would be especially large during the 1994 to 1998 period, averaging about $550 million annually. Of this, about $400 million per year would be spent for Oahu. HECO's current assets in 1979 were about $650 million [16]. It was estimated that an additional $1800 million worth of capacity would be added by utilities on Oahu, Maui and Hawaii by 1994. Not accounting for depreciation, the total assets by 1994 would amount to roughly $2500 million.

A rule of thumb figure holds that a utility's borrowing is limited to 15 percent of its assets. The results show that the utilities would need to raise 22 percent of their non-depreciated assets and probably 35 percent of their depreciated assets. Obtaining such a large amount of capital may be difficult unless the utility allows its bond rating to go down or some subsidy or tax relief is forthcoming. Several avenues are available for such relief. One would be to allow construction work in progress (CWIP) to be included in the rate base. A second would be to provide the utility a refund for its tax credit.

A third avenue would be to let private entrepreneurs invest in the development of renewable technologies. The public utilities in such a case would contract with the entrepreneur to purchase power at appropriate prices. The utility would not have to raise the capital itself, thus reducing its financial risk. Over the long run, after the reliability of the resource has been proven, the utility may wish to invest in the technology. It would benefit by increasing its asset base at a relatively smaller risk. The increased assets would also help the utility in raising capital for future investments in renewables. A somewhat similar concept is being tried for financing a wind farm that would furnish 80 MW of power to HECO on Oahu. If the concept is successful, it may provide a basis for faster development of renewable resources.

Capital requirements will begin to decline after 2000 because renewables reach their maximum imposed limits. As each technology reaches its limit of development, the additional amount of renewables would decrease thus reducing the need for capital.

Labor requirements would also peak during the 1994 to 1998 period, with the average annual requirement being about 950 man-years, of which Honolulu County would account for 700 man-years. The construction industry in Hawaii had 23,000 employees in 1979 [22], but employment in construction has fluctuated between 20,000 and 28,000 workers during the past ten years. Thus the peak impact of building new energy facilities would amount to three to five percent of the construction labor force.

Since we assumed that geothermal energy would be developed largely on the Big Island, most of the construction labor would be used there. As a result, a much larger fraction of the labor would be situated on the Big Island, whereas the capital investment would be borne mainly by utilities on Oahu and Maui.

Indirect Impacts

The indirect employment associated with the three energy futures are plotted in Figure 6. The secondary impacts of Future 1 would be concentrated in the period from 1994 to 1998, during which, most of geothermal, OTEC and wind facilities would be built throughout the state. At

its maximum, the secondary employment would be 9700 workers, while the income generated would be $235 million. Over the twenty-five years, secondary employment would total 88,600 man-years and income would total $2.1 billion. The sectors that would show the greatest impacts are manufacturing, professional services, and wholesale and retail trade.

Secondary impacts in the other two futures differ mainly in their magnitude and timing. In the high price case, the peak in secondary employment will occur five years earlier. In the savings case, secondary employment will be smaller because fewer new facilities are needed.

To evaluate the significance of these impacts, current and projected levels of employment and income were examined. In 1979, the civilian labor force in Hawaii averaged 399,000 workers, of which 374,000 were employed [23]. Total personal income during 1979 was about $8.3 billion. According to the state's "most likely" projections [3], employment and personal income in 2005 would be nearly 600,000 and $20.5 billion, respectively. Thus the estimates of the secondary impacts are at best a few percent of the state's economic activity.

It should be remembered that these estimates of secondary employment and income were based on the assumption that the structure of the Hawaiian economy would not change significantly. In particular, it was assumed that no new types of industry would move into the state and that the fraction of imported goods would not decrease. Furthermore, there were some respending effects that have been ignored because they are difficult to quantify. As a result, it is likely that the estimates of the indirect effects are too low.

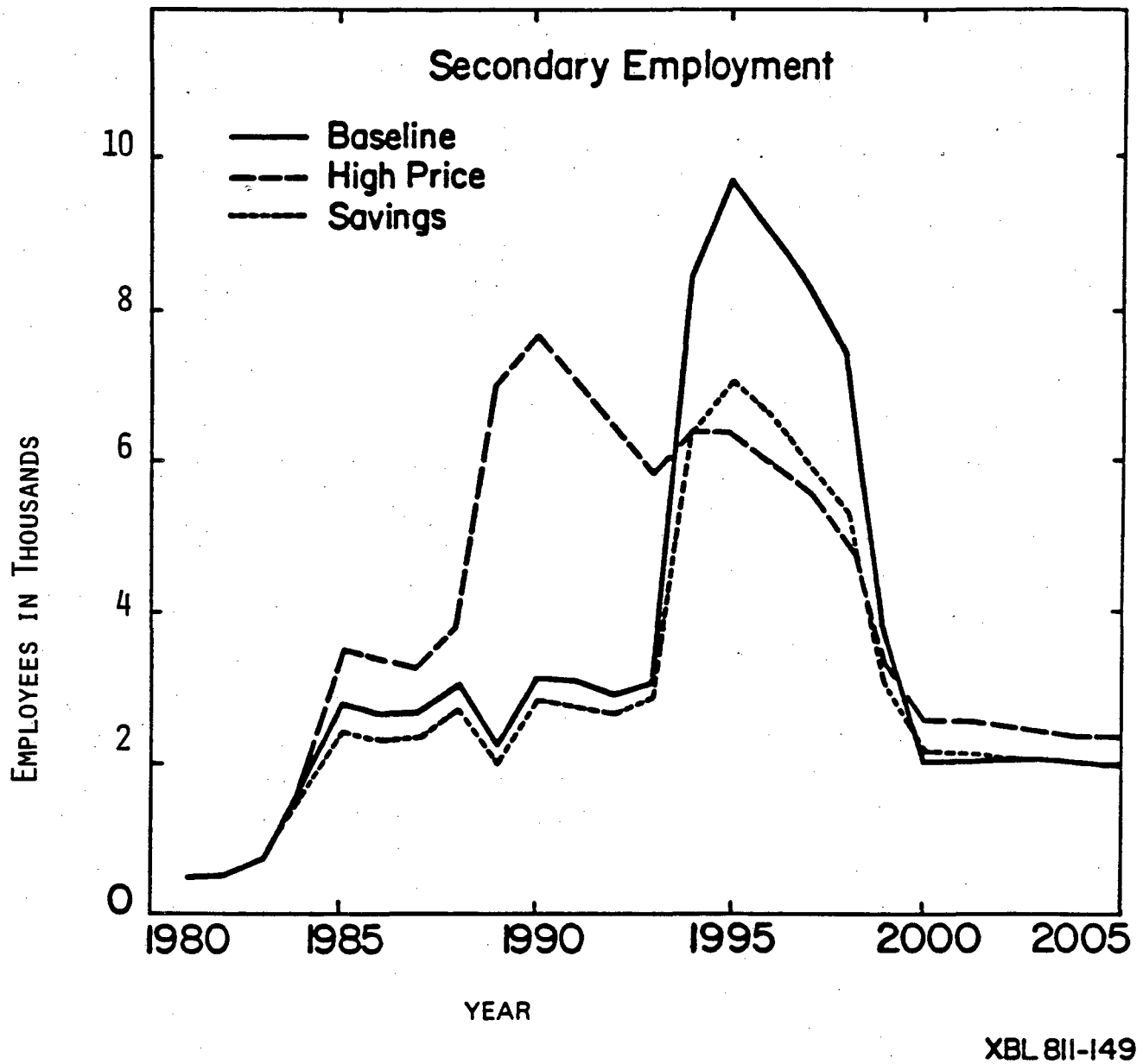


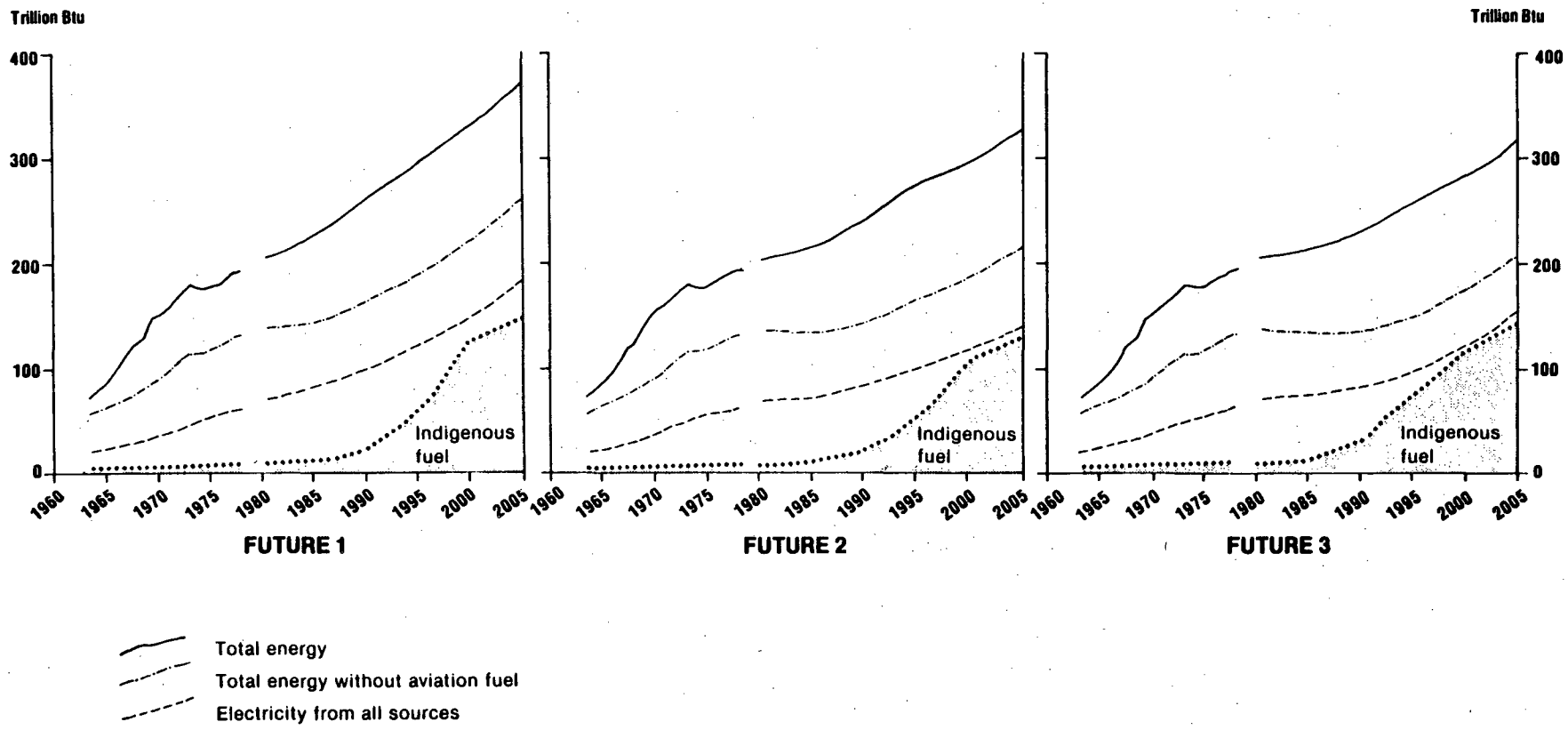
Figure 6. -- Hawaii Secondary Employment, 1980-2005: Futures 1, 2, and 3

Comparison of the Three Futures

The total energy demands for the three futures are shown in Figure 7. Aviation fuel use is the same in all three. Gasoline consumption is lower in Future 3 because of higher prices. Both Future 2 and Future 3 show lower electricity sales than Future 1, but the cause is different. In Future 2 the reduction is due to improved appliance efficiencies and conservation, whereas in Future 3 it is due to higher prices. The net effect is to decrease total energy demand in 2005 in both futures by approximately 50 trillion Btus.

Petroleum will meet all but a small fraction of the energy demand until the mid 1980s when indigenous resources begin to supply most of the electricity. The most rapid introduction of renewables will occur in Future 3 because higher oil prices will make them competitive sooner. In all three futures, indigenous resources are used up to the limits imposed by the constraints in the model. Even so, they could supply up to 90 percent of the state's electricity by the end of the century.

FIGURE 7. -- Energy Demand for the State of Hawaii: Futures 1, 2, and 3



SUMMARY OF MAJOR CONCLUSIONS

In addition to performing the analysis of energy supply and demand and their economic impacts discussed in this paper, the Hawaii Integrated Energy Assessment characterized the supply technologies appropriate to the state, investigated the role conservation could play in decreasing energy consumption, and examined the social and institutional barriers to changing the state's energy supply system. The detailed findings of our analysis of Hawaii's twenty-five year energy future lead to the following major conclusions:

1. Electricity. By the year 2005, Hawaii could produce as much as 90 percent of its electricity with indigenous, renewable resources. Economic analysis shows that these resources could compete favorably in Hawaii under a wide range of oil prices and levels of energy conservation. The rate at which they can be exploited depends more on the rate of technological development and the availability of capital than on oil price. Indigenous resources are expected to make a significant contribution to electricity supply by 1990. If oil prices continue to rise, the use of renewable resources for electricity generation would help stabilize electricity prices.

2. Liquid Fuels. The prospects are less bright for liquid fuels, which represent about 60 percent of all the energy used in Hawaii. This is largely because there is no indigenous substitute for the jet fuel which represents 32 percent of Hawaii's energy use and which is central to Hawaii's economy. At least ten percent of the gasoline consumed could be replaced by liquid fuels produced from biomass, making it possible for all vehicles in the state to run on a 10 percent alcohol/90 percent gasoline mixture. Little liquid fuel should be needed to generate electricity by 2005. Although oil imports may not be reduced by then, they will make up a much smaller fraction of the state's energy supply.

3. Undersea Cable. A submarine transmission cable is critical to Hawaii's energy future. Geothermal energy is the only large scale, indigenous, baseload electricity source that is now commercially mature. The only proven geothermal resources in the state are on the Island of Hawaii. The resource is unlikely to be fully developed unless the

electricity it produces can be exported to Oahu, which consumes 82 percent of the state's electricity.

4. Economic Impacts. Replacing imported petroleum with indigenous energy sources would have a beneficial effect on the Hawaiian economy. Over the next 25 years, the use of renewables could save the state between $7 and $22 billion, depending on the price of oil. Constructing new energy facilities would not have a major economic impact on the state, but Hawaii's utility companies would encounter financing difficulties during the peak construction period unless present financing rules and practices were modified.

5. Conservation. Energy conservation could lead to substantial reductions in electricity and gasoline consumption. Improved appliance and building efficiencies and the use of heat pumps and solar water heaters could cut electricity use by 25 percent. The federally-mandated automobile mileage standard is expected to reduce gasoline consumption by 60 percent.

6. Coal. If the undersea cable and OTEC are long delayed or prove impractical, coal could substitute for oil or for indigenous resources. If plans to use domestic coal were made immediately, Hawaii could be released from its dependence on imported foreign oil sooner than it would if the state waited for renewables to reach maturity. Electricity rates would be somewhat higher with coal than with geothermal power. The use of coal would pose environmental problems, particularly with air pollution and solid waste disposal.

7. Nuclear Energy. Nuclear power plants in the 200 MW range appropriate for Hawaii (Oahu only) are not available, nor is nuclear power presently acceptable to Hawaii. If later developed and if acceptable, such units probably could not be installed and operating in the next twenty years. They are not included in this 25-year projection of Hawaii's energy future.

8. Electric Vehicles. No oil savings can be realized by replacing internal combustion engine vehicles with electric vehicles until a significant part of the electrical supply is generated from indigenous resources or coal after the mid 1990's. For other reasons it is anticipated that not more than about one quarter of the vehicle fleet may be powered by batteries by 2000. Their overall effect on oil demand is small.

9. Public Opinion. A large majority of Hawaiian residents consider energy as serious a social issue as crime, inflation or unemployment, and public awareness of new energy technologies is high. Consumers know less about energy end uses and will not necessarily place energy savings above convenience in purchasing new cars and appliances. Increasing energy costs seem to affect energy use patterns more than a desire to conserve. State strategies for increased public support of self sufficiency programs include strengthening public information programs, providing accurate and timely information on proposed projects, and making energy use data more readily available to consumers.

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LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720