

# Lawrence Berkeley National Laboratory

## Lawrence Berkeley National Laboratory

### **Title**

FORECASTING THE ROLE OF RENEWABLES IN HAWAII

### **Permalink**

<https://escholarship.org/uc/item/39v934wn>

### **Author**

Sathaye, Jayant

### **Publication Date**

1980-11-01



# Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

## ENERGY & ENVIRONMENT DIVISION

Presented to the International Association of Energy  
Economists, Washington, D.C., October 5-7, 1980

FORECASTING THE ROLE OF RENEWABLES IN HAWAII

Jayant Sathaye and Henry Ruderman

November 1980

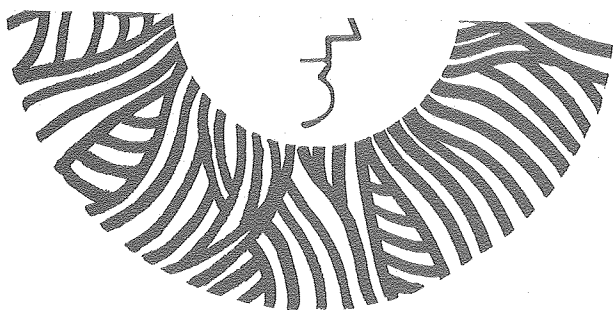
RECEIVED  
LAWRENCE  
BERKELEY LABORATORY

JAN 8 1981

LIBRARY AND  
DOCUMENTS SECTION

### TWO-WEEK LOAN COPY

*This is a Library Circulating Copy  
which may be borrowed for two weeks.  
For a personal retention copy, call  
Tech. Info. Division, Ext. 6782.*



LBL-11903 c.2

## DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

## FORECASTING THE ROLE OF RENEWABLES IN HAWAII \*

by Jayant Sathaye and Henry Ruderman  
Lawrence Berkeley Laboratory  
University of California, Berkeley, CA 94720

1 Introduction

Having no fossil fuel resources of its own, the State of Hawaii is almost totally dependent on external sources of energy. More than ninety percent of the state's energy is imported in the form of crude oil or petroleum products. The rest comes from hydroelectric plants and from burning bagasse at the sugar mills. Hawaii is therefore extremely vulnerable to disruptions in the world oil market. Any decrease in the availability of oil or increase in its price has serious consequences to the state's economy

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. The state's indigenous resources will play a major role in displacing oil as the primary source of energy. To what extent oil can be replaced is the focus of the Hawaii Integrated Energy Assessment, a joint study by the Hawaii Department of Planning and Economic Development (HDPED) and the Lawrence Berkeley Laboratory (LBL). This report describes some of the methodology and results of the study. It concentrates on how we investigated alternative future energy supply systems for Hawaii. Other elements of the study examined future demand for energy, what indigenous resources are available, what technologies will be sufficiently developed to exploit them, and what will be their

---

\*This work was supported by the U.S. Dept. of Energy, Office of Alternative Fuels, Secretary for Resource Application, and by the Office of Strategic Analysis and Integration, Secretary for Conservation and Solar Energy under Contract No. W-7405-ENG-48.

social, economic and environmental consequences. A complete discription of the study and discussion of the results will be found in a forthcoming multi-volume report [1].

As Shupe and Weingart [2] 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 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 higher average insolation than the mainland states, so that solar energy for water heating and electricity generation could become widespread. The large temperature gradients and 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.

Each of the four counties in the state appears to have enough natural resources to supply nearly all its energy needs. The question arises to what extent each of these resources should be developed during the next twenty-five years to provide the state with a reliable and economic energy system. In order to examine the role of renewables in supplying energy, we have constructed an integrated energy supply-demand

model for the state.

Energy demand is intimately related to the levels and types of economic activity pursued by consumers in each county. Projections of energy demand are closely tied to the projected pattern of economic activity. An increase in tourism would have very different consequences than an increase in manufacturing. However, the strongest influence on the future economic activity, and hence energy demand, may well be the world price of oil. World oil prices have been rising rapidly, and at times erratically, over the past several years, with the end to these increases nowhere in sight. It is prudent to examine the consequences of a range of world oil prices for future energy demand and for alternative energy supply options.

To examine the effect of oil prices on energy demand and supply, we have analyzed three potential energy futures for the state of Hawaii. For each future, we analysed both the energy demand and supply projections and their economic consequences. The three futures were based on the same projection of economic and demographic growth. The first two differed in that the second future assumed a more rapid increase in world oil price (10% per year compared to 3% per year). The first and third futures differed in that greater levels of conservation were assumed in the latter. The increased conservation led to significantly lower levels of energy demand. The assumptions that went into constructing the futures are summarized in Table 1.

Energy is currently supplied to Hawaiian consumers in two major forms, electricity and petroleum based liquid fuels (gasoline, aviation fuel, etc.). Liquid fuels may be substituted or at least supplemented

by a single source, biomass derived alcohol or gasoline. Electricity, on the other hand, can be provided by several new renewable technologies: wind, OTEC, geothermal, solar thermal and photovoltaics. Some biomass such as bagasse and wood is also suitable for producing electricity. We considered only energy consumed by civilians in Hawaii; energy for the military and petroleum products refined in the state and then exported were not included in our analysis.

The maximum extent to which each technology can ultimately contribute to the electricity supply will be limited by the availability of natural resources at each site and by the conversion efficiencies of the technologies used to exploit them. Economic and environmental considerations will no doubt constrain the development of these resources to levels below their ultimate availability. Factors affecting the integration of each technology in the existing energy resource base will further reduce the potential utility of the resource.

Electricity generation and supply is a complex activity. Questions of capital costs, reliability of operations, generation and fuel costs, matching load requirements and environmental constraints require an interdependent system of generation technologies, each with its unique characteristics designed to best meet the fluctuations in electricity demands. The renewable technologies will have to mature in this complex environment.

The complexity of the energy futures increases rapidly with each new supply or demand option. The possible use of inter-island submarine transmission cables, for example, is being seriously examined by the utilities as well as private firms in Hawaii. The choice of electricity

generating technologies will be strongly influenced by the technical feasibility, costs and timing of inter-island cables. A computer-based model was developed to evaluate these possibilities for all three energy futures. The model analyzed the least cost supply system that would meet the projected demand for each future. The capital costs and labor requirements, both direct and indirect, were computed for the optimal mix of supply technologies.

In the following sections we first present the analytical methodology and the basic assumptions common to our analyses. At this time we have not completed our analysis of the three futures. For illustrative purposes we will present our preliminary results for one energy supply-demand projection for the County of Honolulu. A complete analysis of the three futures will be published at a later date in Reference 1.

## 2 Methodology

### Overview

The methods and data we used for determining energy futures for Hawaii and their impacts on the state's economy are summarized in Figure 1. The Hawaii Energy Demand Forecasting Model provided energy demand projections for each of the counties by year up to 2005. We made three forecasts which differed in their assumptions about energy prices and the level of energy conservation. The energy prices used in these forecasts were dependent on world oil prices.

Because of the wide variety of technologies that will become available during the next twenty-five years, the projected electricity



demands can 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. To facilitate the electricity supply-demand integration, the Supply Optimization Model was used to find the supply mix that meets the electricity demand and generating capacity demand at the lowest prices. In addition to determining the supply mix, the Supply Optimization Model also calculated the electricity prices for each county. In general, these prices were lower than those projected by the demand forecasting model. The new prices were fed back into the demand forecasting model, and a revised set of demand forecasts was obtained. We repeated this procedure until a consistent set of energy demands and prices was found.

The resulting supply scenarios were analysed 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 brought about by the expenditures on construction of the new facilities. We used the Supply Cost Model and the technology characterizations described below 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.

#### Demand Forecasts

The three energy futures were based on different demand forecasts. All three used the same economic and demographic projections character-

ized by medium growth in population, income and visitor arrivals [3]. They differed in energy prices and the level of conservation. The federally mandated automobile gasoline mileage standards were assumed in each future. In addition, in the third future we incorporated estimates of electricity savings resulting from the implementation of proposed appliance efficiency standards. Initially, we based the energy prices used in forecasting demand on projections of world oil prices. The final prices were determined by balancing supply and demand.

We used the baseline demand forecast for the first energy future. In this forecast we assumed a three percent per year escalation in world oil price and that federally mandated automobile efficiency standards will be implemented. This will lead to a growth in energy consumption in Honolulu of about two percent per year. Electricity sales in the county will nearly double during the next twenty-five years, while gasoline sales will decline by a factor of two. The use of other fuels will increase more slowly than electricity.

The second energy future is the high price case. We assumed that oil prices would increase in real terms by ten percent per year. Such large price increases could occur if there are major disruptions in the world oil market. This scenario exhibited the lowest growth in overall demand. Both diesel fuel and gasoline sales decrease, while electricity sales remain nearly constant, and aviation fuel consumption increases.

The third energy future emphasizes conservation and improved efficiencies. The baseline forecast of demand for electricity was reduced by our estimate of the amount of energy saved due to improved appliance efficiencies. This forecast was intermediate between the baseline and

high price cases. It had the same liquid fuel consumption as in the first future, and electricity sales were greater than in the second.

A complete description of the demand forecasting model and the forecasts for each energy type and county are given in Reference 1.

#### Supply Forecasts

Liquid fuels and electricity are the two major forms of energy currently used in Hawaii. Liquid fuels are used primarily for transportation and electricity generation. For each future we have projected the expected demand for fuels and electricity to the year 2005.

Gasoline used for transportation can be substituted or supplemented by indigenous alcohol production. Apart from using electric vehicles, there are no other easy substitutes for gasoline. Alcohol supplies were assumed to be ten percent of projected gasoline consumption limited only by the forecasted production of alcohol.

Electricity may be generated by several types of power plants. Steam, hydro, gas turbines and internal combustion engines are currently used to generate electricity. Steam generators burn oil and bagasse. On Oahu these may be supplemented by municipal solid waste (MSW) incineration during the next five years. Gas turbines and internal combustion engines use diesel fuel.

Several renewable technologies have the potential to contribute significantly to electricity generation. Wind, geothermal, ocean thermal (OTEC), solar thermal (STEC), and photovoltaics (PV) can all be used to generate electricity. Hydro-electric and pumped storage also have

limited potential in Hawaii.

Due to the nature of their resource, geothermal and ocean thermal energy are available continuously and hence with a higher reliability. These technologies are primarily suited for providing base load electricity generation. We assumed that the solar thermal power plant 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 the base or intermediate loads. No storage was assumed for the photovoltaic system which can be used to meet intermediate electricity loads during the day only. Wind is essentially an unreliable resource; severe fluctuations have been observed at a site from season to season and year to year. From an electricity generation standpoint, the resource can be harnessed only if the generated electricity can be stored or if backup capacity is available. In Hawaii, the oil- and biomass-fired generating capacity can be used as backup if wind generation costs less than burning oil.

In this analysis we chose economic optimality as our major objective in deciding the mix of generating technologies. We have attempted to express all other significant criteria through economic means.

The mix of future technologies was selected with the aid of a linear programming (LP) model. The Supply Optimization Model was run for 5 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.

The objective was to minimize the sum of levelized cost and the operations maintenance and fuel cost. The levelized cost was based on the capital cost and the fixed charge rate allowed for amortizing the capital investment. 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.

Each technology will operate jointly and singly under a set of constraints. The constraints ensured that an adequate amount of energy will be available to meet the base, intermediate and peak components of demand. Base period lasts full 24 hours a day, intermediate varies from 15 to 17 hours a day depending on the county, and peak varies from 2 to 3 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. The constraints ensured that sufficient capacity will be available to meet peak power demand after sunset. The peak demand in each county was derived from the electricity demand and the utilities' projections of peak power to electricity sales.

The amount of energy that can be generated from a power plant depends on the plant availability and on resource availability. Resource availability for wind is limited compared with OTEC or geothermal power plants. We placed limits on the total generation from each type of power plant and on the generating capacity of each type available to meet the base, intermediate, and peak demands. The availability of each type of plant depended upon the number of hours it was required

to be in service each day.

Since wind is an intermittent source of energy, it is necessary to ensure that the system reliability is not affected when wind generation is introduced. Studies have shown that reliability decreases rapidly when wind generation exceeds twenty percent of the installed capacity [4]. A constraint to limit wind generation to this level was incorporated in the model. Furthermore, we did not include wind generation when calculating the capacity available to meet the power demands.

The total capacity of each type of generating unit is limited by constraints other than costs. Most of the renewable technologies are not yet available commercially. A rapid introduction of these technologies will not and should not be attempted under normal circumstances until the technologies are proven. Several time tables have been constructed to show the limits to which each technology may be exploited over the next twenty-five years. From this range of possibilities, we have selected one set to establish the limit to which each technology may be developed in each time period. We 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 Oahu plantations. OTEC plant will be a 40 MWe plant, and the MSW plant is assumed to be rated at 45 MWe.

#### Supply-Demand Integration

The linear program was used to select the optimal mix of technologies for each county required to meet the forecast demand in each energy future. Average electricity costs were determined for each of the six

years 1980, 85, 90, 95, 2000 and 2005. Average electricity costs depended on the capital and operation and maintenance costs assumed for each technology. These costs can be very different from the prices used in the demand model which were related directly to world oil prices. 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 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 were not identical. We modified the prices in the demand model 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. If necessary, the whole process was iterated until the average costs between successive iterations showed no significant difference.

An inter-island transmission cable system is a crucial step in Hawaii's progress towards greater reliance on renewables. It is evident that the major resource for which technology is already commercialized, geothermal energy, is available on the Big Island. This resource may be sufficiently large to meet the entire base load demand on Hawaii, Oahu and Maui in the long run. Development of geothermal energy can be promoted only if transmission cables link it with major demand centers in Oahu and in Maui. Due to its critical nature, we assumed that such a

cable system will be built by the 1990-95 period. 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 cheaper rates, we assumed that geothermal energy would be available first to Hawaii to meet its projected base load demand. The remaining energy was assumed to be allocated to Maui and Oahu in proportion to their base load demands.

#### New Technologies

The technologies included in our analysis and their capital costs are shown in Table 1. Capital costs of conventional technologies were assumed to remain constant over the next twenty-five years, while those of renewables were assumed to decline for reasons mentioned earlier. 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. We used a cost of \$65/KWe for old oil plants based on data in HECO's annual report [5]. An analysis of utility finances would be necessary to get a better estimate of average plant costs for 1980. Costs of geothermal plants were assumed to include cable costs between Hawaii and Oahu and/or Maui. Geothermal plant costs on the Big Island were therefore lower by \$800/KWe after 1990.

The costs that we have assumed for renewables are generally on the conservative side. Photovoltaic costs, for example, exceed the goals set by DOE by a factor of two.

Operating and maintenance costs of fossil fuel plants ranged from 9 mils/KWh for oil to 15 mils/KWh for diesel peaking units. For



renewables, they ranged from 5 mils/KWh for OTEC to 2 mils/KWh for other technologies. Fuel costs for diesel were assumed to be fifteen percent higher than for residual oil. Electricity generated by bagasse-fired generators was assumed to cost 70 percent of oil-fired generation.

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 [6] which estimates the potential resource around the Puna Well at about 250 MWe. We 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 MWe. This figure is smaller than another estimate of 1600 MWe made by HDPED [7].

Wind generation is limited to 20 percent of total installed capacity or to the resource limit of 432 MWe on Oahu, whichever is smaller. The 20 percent figure is based on studies which limit the maximum generation because of a system reliability considerations [4]. The 432 MWe limit is based on choice sites in Oahu [8].

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

### Economic Impacts

The demand and supply models provided for each future 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, we have estimated capital costs and operation and maintenance costs for each technology. We broke these costs down into their manpower, materials and equipment components.

A key assumption in our analysis was that renewable technologies have declining costs. 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 onsite materials as opposed to manufactured equipment will not decline as rapidly as onsite labor and equipment costs since there will be greater scope for improving labor productivity than materials costs. Equipment costs may decline because of improved manufacturing techniques and because of competition from other manufacturers.

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 [9] and the Technology Assessment of Solar Energy Study [10]. The lead time required for construction and the

scheduling of resources during construction was also considered to provide an annual breakdown of capital and labor requirements. This breakdown of capital requirements aggregated over six 5-year periods was used for estimating the indirect impacts.

We estimated indirect impacts using an input-output model of the Hawaiian economy specifically designed for the purpose. The core of the model is an input-output table constructed by HDPED which describes the structure of the state economy during 1977. HDPED developed input-output tables for each of the four counties by updating earlier tables [11]. Special attention was paid to the petroleum importing and refining sectors as well as the electric and gas utilities in order to exhibit the energy flows within the state.

The starting point for calculating indirect impacts was the expenditures 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 plus the annual manpower costs. The latter were also broken down by industry assuming the same proportions as held for household expenditures in 1977. The next step was to estimate what fraction of the purchases in each sector was produced in Hawaii and what fraction was imported. Using the input-output model and our estimates of the purchases of locally produced commodities, we then calculated the increase in industrial activity needed to furnish these commodities. Finally, from the industrial activity we estimated the annual income and employment generated in each industry.

Assumptions and Limitations

The basic assumption we made 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. We therefore assumed that no major technological or structural changes to the economy would occur that would affect energy consumption patterns. In particular, the widespread use of vehicles powered by electricity or synthetic fuels was not envisioned.

This assumption of behavioral constancy means that conservation programs, mandated efficiency standards, and emerging energy use technologies are not endogenous to the model. To remedy this deficiency, in each future we assumed that the currently mandated gasoline mileage standards will be implemented. In addition, in the third energy future we decreased the electricity forecasts by our estimates of the amount of energy saved through improved appliance efficiencies.

Also implicit in our demand forecasts was that fuel and electricity prices are directly related to world oil price. If renewable resources in Hawaii 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, had 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 up.

A second set of assumptions that influenced the supply mix forecast involved the costs and commercialization schedules for the renewable technologies. Since some of these technologies are still in the prototype stage, the figures we used were our best estimates within the range over which experts differ. In addition to costs, we had to make several assumptions regarding utility financing and tax rates over the next quarter century. These assumptions affect each technology equally, so their major effect will be on electricity costs.

It is characteristic of LP's 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 the development of each technology.

The input-output model we used for estimating indirect economic impacts gave us a static picture of the Hawaiian economy. It can 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 twenty-five years if new industries are attracted by the lower prices of electricity generated from renewable resources. It would be in the

direction of greater income and employment in the state than we estimated.

### 3 Results

In this section we discuss our results for the County of Honolulu of which Oahu Island is the principal part. Honolulu has about eighty percent of the state's population and accounts for more than eighty percent of its energy consumption. We present our projections of energy demand, the electricity generation mix, and electricity prices for the first future to illustrate the methods we developed to analyse the supply and demand options for the state. We are presently analysing the three supply-demand cases for the other counties. These results, along with the direct and indirect economic impacts in Honolulu County, will be published in Reference 1.

#### Energy demand

Table 2 shows the energy demand on Oahu for the baseline case. The demand for electricity in Honolulu County will more than double during the next twenty-five years. Demand is heavily influenced by electricity prices, which reach a plateau in 1995 as the fraction of electricity supplied by renewables becomes significant. Since electricity prices will no longer depend on ever increasing oil prices, the demand for electricity will increase as prices decline or increase marginally.

The demand for imported petroleum will also reach a peak in 1995, then it will decline slightly in 2000 before increasing again in 2005. The non-electric portion of this demand will increase steadily; by 2005

it will be forty percent higher than its present level. Oil required for electricity generation, however, will 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 will continue to increase their share after 2000, the use of oil will also increase because the maximum penetration by renewables is limited to a level insufficient to meet the increasing demand. Oil used for generation on Oahu will drop to 37 percent of renewables.

#### Supply mix

Imported petroleum has been the predominant source of electricity in Hawaii for many years. Bagasse combined with oil and hydropower have also contributed to the electricity supply, especially on the Neighbor Islands. Their contribution on Oahu has been relatively small. Figures 2 and 3 show the forecasts of generating capacity and the amount of 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 the figure that shows generating capacity. The capacity demand includes a twenty percent reserve margin. We assumed that all the oil generating capacity available in 1980 will remain on line through 2005 to serve as a backup. The proposed 45 MWe MSW and 40 MWe OTEC plants have been included starting in 1985 and 1990, respectively. Additional generation from OTEC was included if it could compete favorably with the other technologies.

Oahu will continue to use its oil-fired power plants for base load generation until about 1995. As OTEC and geothermal plants come on line

for base load, oil generation will mainly be used for intermediate and peaking loads. At the same time, wind and solar will also make major contributions. About 140 MWe of gas turbines will be built by 1990 to meet peaking loads. The largest capacity increments will occur between 1995 and 2000 when 830 MWe of new wind, solar thermal, OTEC and geothermal plants will be constructed.

#### Electricity prices

Electricity prices are related to the price of oil and to the cost of generating capacity. It is not surprising that as the price of oil increases, so does the price of electricity. Electricity prices will increase rapidly up to 1990. After this date, as lower cost renewables become available, prices will decline or show a slight increase. For Honolulu County, by 1990 the average electricity price will go from 86 to 109 mils/KWh, a 27 percent increase. During the subsequent fifteen years, prices will increase by only five percent. The lower prices result in a larger demand than originally forecast assuming electricity would be generated primarily from oil.

#### Acknowledgments

This report presents some of the results of a collaborative study of Hawaii's energy future by LBL and HDPED under the sponsorship of the Office of Conservation and Solar Energy and the Office of Resource Applications of the U. S. Department of Energy. Data collection for the demand forecasting model and its initial development were carried out by Dr. PingSun Leung at HDPED. Jane Moore, also of HDPED, constructed the county input-output tables. The Supply Optimization Model was developed



at LBL with the help of Ira Starr. Nobie Yagi and Peter Chan did most of the computer programming, while Reid Judd did the computer graphics. Dr. Edward Kahn provided invaluable technical expertise on utility models. We would also like to thank Jerry Weingart and Will Siri for many illuminating discussions of our results.

#### References

1. Hawaii Department of Planning and Economic Development and Lawrence Berkeley Laboratory, "The Hawaii Integrated Energy Assessment," Honolulu, (1980).
2. Shupe, J. W. and Weingart, J. M., "Emerging Technologies in an Island Environment: Hawaii," Ann. Rev. Energy, Volume 5, (1980).
3. Hawaii Department of Planning and Economic Development, "Long-Range Population and Economic Simulations and Projections for the State of Hawaii," Honolulu, (1977).
4. Haslett, J., "On a General Theory of Modelling the Interaction Between Wind Energy and the Electricity Grid," Division of Mathematics and Statistics, CSIRO, Canberra City, Australia, (1980).
5. Hawaiian Electric Company, 1979 Annual Report, Honolulu, (1980).
6. Muffler, L. J. P. (Ed), "Assessment of Geothermal Resources of the United States -- 1978," U.S. Geological Survey Circular 790, Arlington, VA, (1979).
7. Hazard, S. and Dick, Q., "Feasibility and Potential Impact of Man-

- ganese Nodule Processing in Hawaii," HDPED, Honolulu, (1978).
8. Weingart, J. M., "Scenarios for Indigenous Energy Supply," Internal Memorandum dated 25 July 1980.
  9. Bechtel Corporation, "The Energy Supply Planning Model," Vols. I and II, San Francisco, (August, 1975).
  10. U.S. Department of Energy, "Summary of Solar Energy Technology Characterizations," DOE/EV-0099, (September, 1980).
  11. Hawaii Department of Planning and Economic Development, "Interindustry Study of the Hawaiian Economy," Honolulu, (1972).

Figure Captions

- Figure 1 Assessment Methodology
- Figure 2 Generating Capacity in Honolulu County, Future 1
- Figure 3 Electricity Generation in Honolulu County, Future 1

Table 1

## Summary of Hawaii Energy Futures

Future	Demographic Forecast*	World Oil Price Growth	Conservation
1	"Most Likely"	3% per year	Mandated automobile mileage standards
2	"Most Likely"	10% per year	Mandated automobile mileage standards
3	"Most Likely"	3% per year	Improved appliance efficiencies and mandated automobile mileage standards

\* From the Hawaii Macroeconomic Model simulation, 1977. See Reference 3.

TABLE 2

SIGNIFICANT ASSUMPTIONS

	<u>1980</u>	<u>1985</u>	<u>1990</u>	<u>1995</u>	<u>2000</u>	<u>2005</u>
Honolulu Population Projections (10 <sup>3</sup> persons)	805.6	866.0	917.6	965.7	996.2	1031.5
Honolulu Per Capita Personal Income (1967 \$)	4842.3	5469.7	6032.8	6698.3	7384.0	8149.2
State Visitor Arrivals (10 <sup>3</sup> Persons)	4133	5275	6418	7440	7820	8219
Capital Costs (1980 \$/Kwe)						
Wind	2500	1500	1000	700	700	700
Otec	8000	8000	8000	4000	2600	2600
Geothermal	3000	2800	2000	2000	2000	2000
Solar Therm	3000	3000	2500	2500	2000	2000
Photovoltaic	18000	8000	3000	3500	2000	2000
MSW	2222	2222	2222	2222	2222	2222
Oil	65	800	800	800	800	800
Oil Bagasse	65	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
Hydro	50	800	800	800	800	800

Table 3

Energy Demand Projections for Honolulu County  
Baseline Case with Inter-Island Cable  
[Trillions of Btu's]

	<u>1980</u>	<u>1985</u>	<u>1990</u>	<u>1995</u>	<u>2000</u>	<u>2005</u>
Electricity						
Residual	57.1	60.9	65.3	54.6	23.2	37.8
Diesel	0.0	0.8	1.8	0.3	0.0	0.4
Oil Total	57.1	61.7	67.1	54.9	23.2	38.2
Renewables at Oil Equivalent	1.4	4.5	9.9	38.8	91.2	104.1
Generation (10 <sup>6</sup> KWh)	5,230	5,940	6,900	8,410	10,250	12,760
Liquid Fuels						
Gasoline	25.7	17.8	14.0	13.2	12.6	12.5
Residual and Diesel	18.9	21.3	24.2	27.6	30.9	34.7
LPG and Utility Gas	4.3	4.5	4.7	4.9	5.1	5.3
Subtotal	48.9	43.6	42.9	45.7	48.6	52.5
Aviation Fuel	65.8	80.7	94.1	105.7	107.0	108.7
Total	114.7	124.3	137.0	151.4	155.6	161.2
Total Oil Demand	171.8	186.0	204.1	206.3	178.8	199.4
Oil Demand without Renewables	170.6	186.6	210.4	238.5	257.3	280.2
World Oil Price (1980 dollars/barrel)	30	35	40	47	54	63

Notes: The figures for 1980 are estimates of demand, not actual consumption data.

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



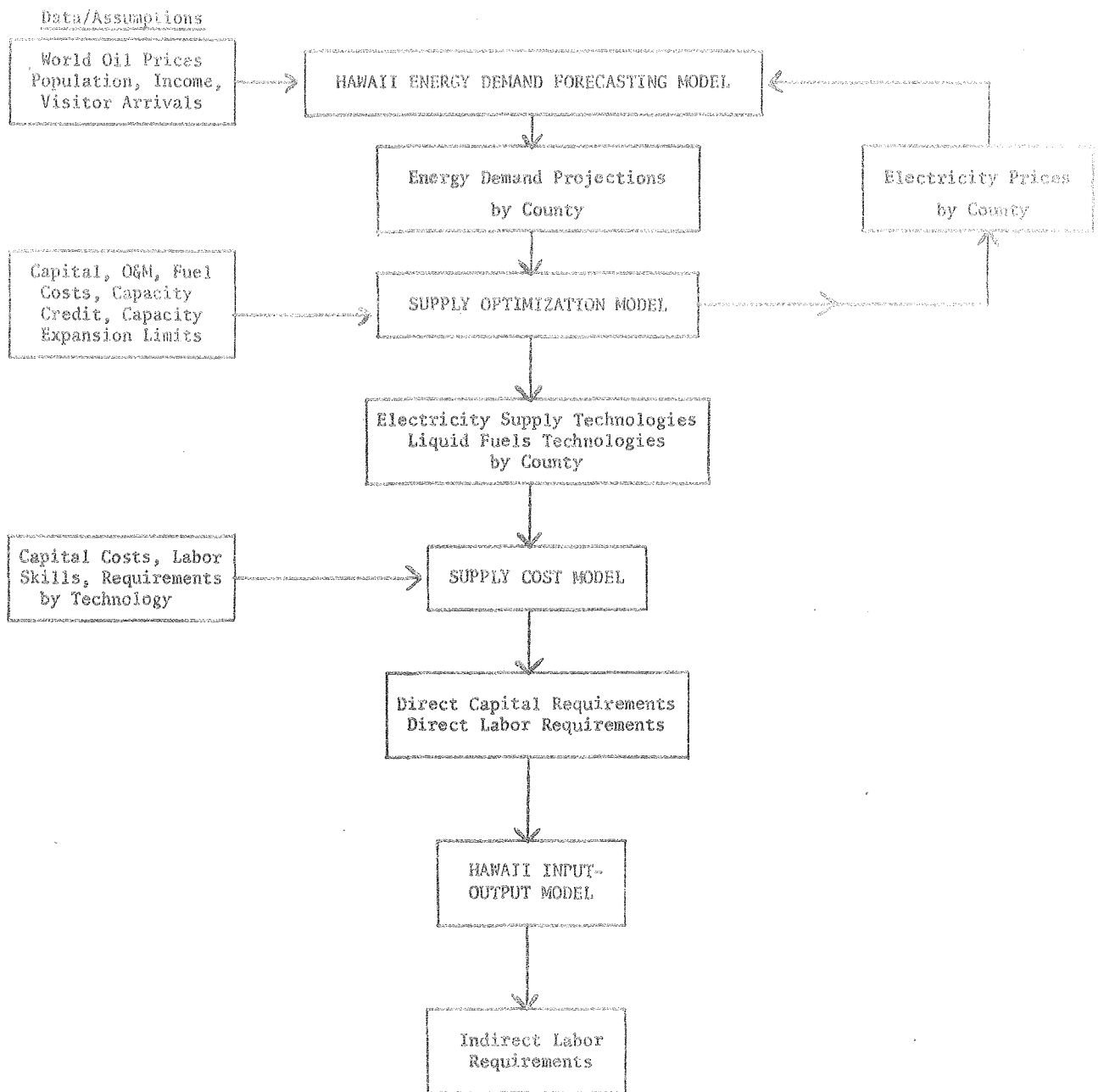


Figure 1



Honolulu Generating Capacity (MWe)  
 Base Oil Price  
 No Coal With Inter-Island Cables

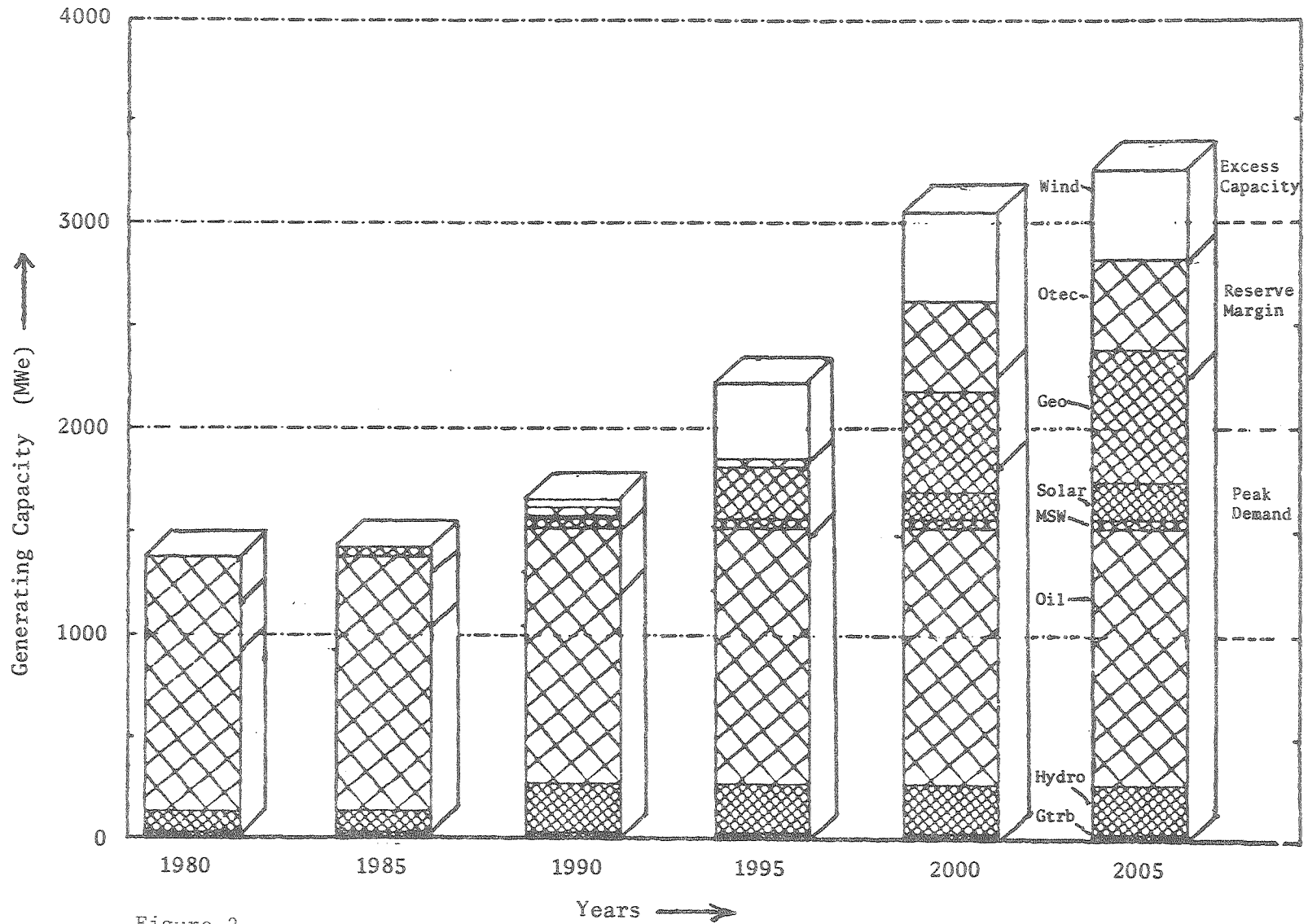


Figure 2

Honolulu Electricity Generation (Million KWh)  
Base Oil Price  
No Coal With Inter-Island Cables

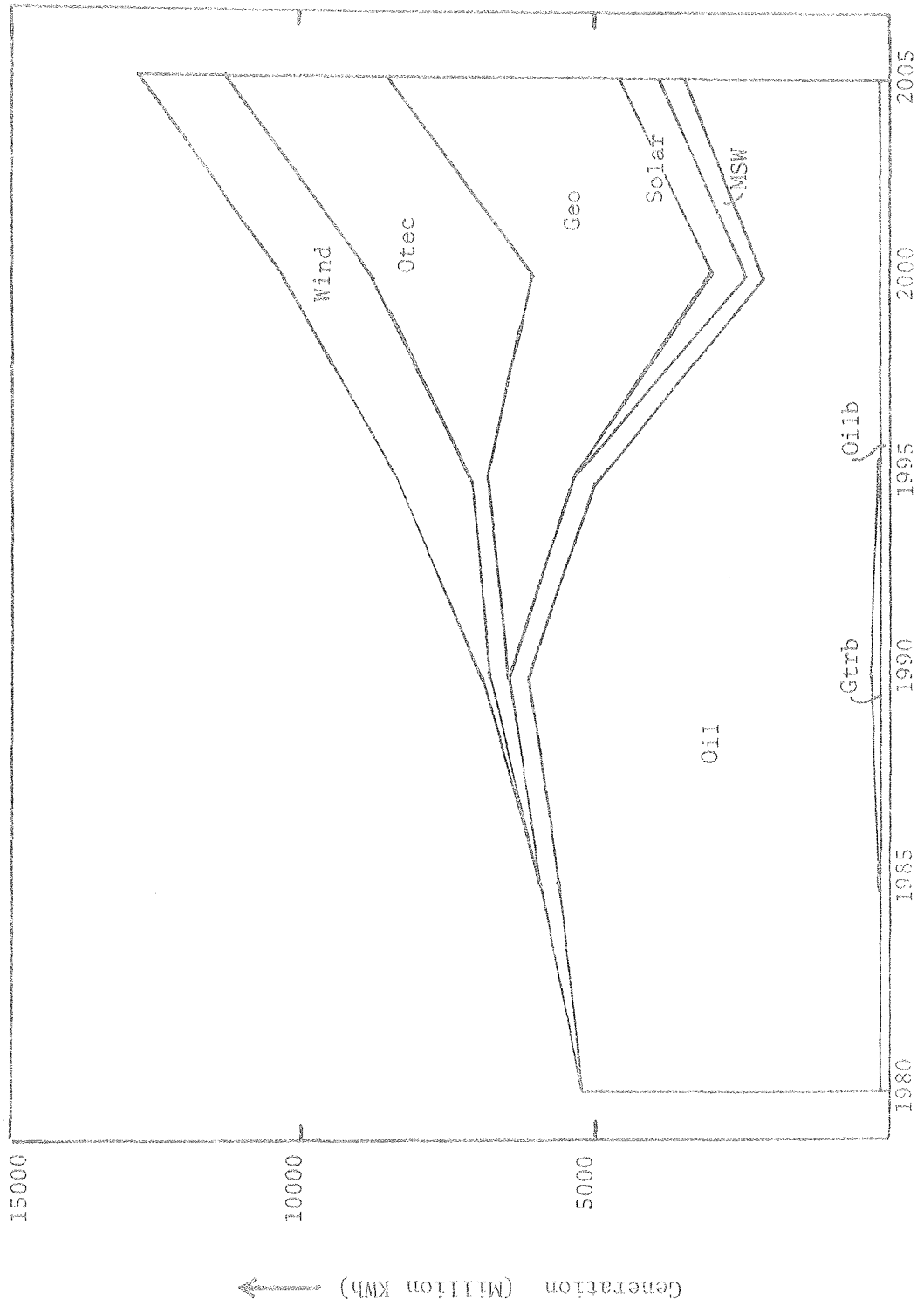


Figure 3

